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METROLOGY AND METROLOGY ASSURANCE 2019

PROCEEDINGS

September 6-10, 2019, Sozopol, Bulgaria

TECHNICAL UNIVERSITY OF SOFIA

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- **Department of Electrical Measurements**
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Bulgarian Institute of Metrology - activities in the field of scientific metrology

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***Abstract*—Bulgarian Institute of Metrology (BIM) performing its duties as Bulgarian National Metrology Institute and National Legal Metrology Body has a key role in metrology infrastructure. The main activities of BIM support the quality of life and the development of the economy. This is done by providing metrological traceability for national measurements using national standards and certified reference materials that BIM develops and maintains, and also with metrological control activities on measuring instruments related to health, public safety, environmental protection, state and municipal receivables and trade payments.**

Keywords—metrology, BIM, BIPM, EURAMET, EMPIR, calibration and measurement capabilities (CMC).

I. INTRODUCTION

In its activity, Bulgarian Institute of Metrology (BIM) follows the policies, recommendations and strategies of the international metrological organizations in which the Republic of Bulgaria is a member.

The main objectives of BIM are to support the development and reliability of measurements for the benefit of society, science and economy. It is achieved through the following main activities:

- maintaining and developing national standards to ensure their international equivalence;
- producing certified reference materials;
- ensuring traceability to BIPM or to other NMIs for those units for which national primary standards are not supported;
- dissemination of units to accredited laboratories, other industrial and commercial laboratories and costumers;
- ensuring traceability of standards used in legal metrology;
- participation in international comparisons to demonstrate their international equivalence;
- maintaining a quality system (EN ISO/IEC 17025 and ISO Guide 34);
- cooperation with other NMIs, with regional and international organizations and representation of the country in these organizations;
- organization of proficiency testing;
- other activities arising from the responsibilities of BIM as a national metrology institute.

The achievement of strategic goals and the implementation of operational actions in recent years is a solid basis and a guarantee for the realization of the mission and vision of BIM.

These activities lead to:

- development and maintenance of modern reference laboratories in the main measurement areas of BIM;
- participation in international comparisons to demonstrate international equivalence of standards and to support calibration and measurement capabilities (CMCs) [2];
- maintaining, improving and expanding internationally recognized calibration and measurement capabilities;
- capacity building for research projects and participation in the European research program EMPIR [3];
- improving the metrological control activities;
- provision of new and improved services;
- human resources development in BIM;
- strengthening the links with stakeholders.

II. NATIONAL REFERENCE LABORATORIES.

BIM currently maintains reference laboratories at the modern level in the following measurement areas:

- Acoustics and vibrations,
- Time and frequency;
- Length and angle;
- Electroenergy measurements;
- Electromagnetic measurements;
- Chemical measurements;
- Ionizing radiation;
- Mass and volume;
- Pressure, force and hardness;
- Flow;
- Temperature and relative humidity;
- Photometry and radiometry.

III. International comparisons and calibration and measurement capabilities.

Another major activity is participating in international comparisons to support the calibration and measurement capabilities (CMC). At present BIM has over 80 participations in international comparisons. Thanks to the good results of the comparisons, BIM has submitted and published 225 CMS entries in the BIPM database. The results of the last comparisons carried out in 2019 are shown in Fig. 1 and Fig. 2 - respectively in the field of vibration measurement and electric measurements - Josephson voltage standard.

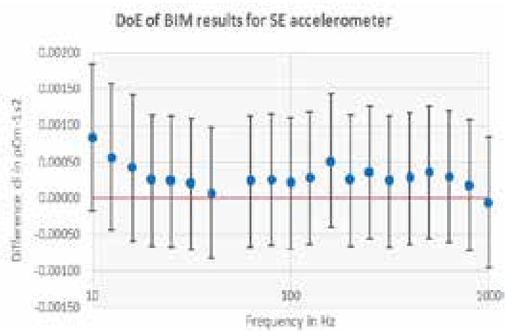


Fig. 1. The unilateral degrees of equivalence for BIM results for SE accelerometer with uncertainty bars corresponding to coverage factor k=2.

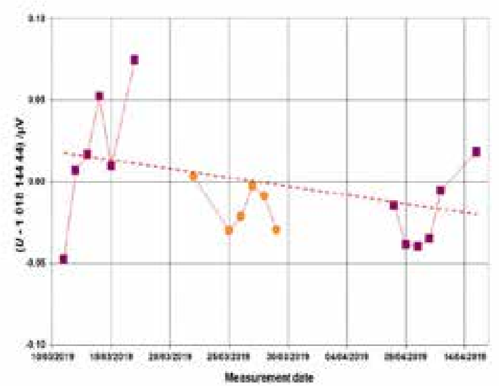


Fig. 2. Voltage evolution of the simple mean of the two standards at 1,018 V.

IV. PT Provider

Since 2012, BIM has been accredited as PT Provider by the Dutch Accreditation Body RvA according to EN ISO 17043 for Mass, Temperature, Electrical and Chemical Measurements. Outside of these measurement areas, BIM also organizes interlaboratory comparisons in line with the requirements of this standard.

V. Project for QMS peer visits and reviews

In 2011, EURAMET project 1208 for peer visit was launched with the participation of BIM and the Serbian NMI - DMDM. Later the NMIs of Montenegro, Bosnia and Herzegovina, North Macedonia and Latvia joined the project.

VI. Quality management system

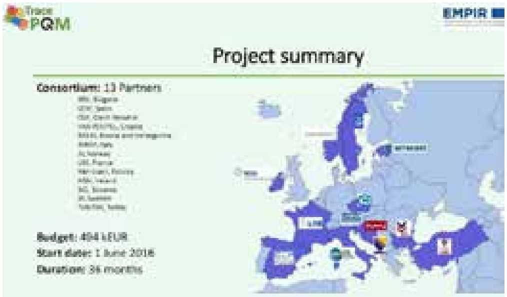
BIM maintains and develops a quality management system (EN ISO / IEC 17025 and ISO Guide 34). According to EURAMET's rules, once every 5 years, the system is presented at the TC – Quality [4]. A change is currently in progress according to the requirements of the new version of the standard.

VII. Participation in projects of the European research program EMPIR

Bulgarian Institute of Metrology joined the European Metrology Program for Innovation and Research EMPIR in 2013. BIM is currently one of the 28 EMPIR participants.

At present, BIM participates in the following projects:

15RPT04 Trace PQM - Traceability Routes for Electrical Power Quality Measurement



- Partners - CMI, Czech Republic; BIM, Bulgaria; CEM, Spain; FER, Croatia; IMBiH, Bosnia and Herzegovina; INRIM, Italy; JV, Norway; LNE, France; Metrosert, Estonia; NSAI, Ireland; RISE, Sweden; SIQ, Slovenia; TUBITAK, Turkey [5].
- Project started in 2016, duration - 36 months, finished in 2019, end of May [5].

With the diversification of electric power generation to include sources with fluctuating output power such as solar and wind, and with the growing number of appliances employing switched-mode power supplies, the measurement of electrical power and power quality (PQ) has become more important. This has led to increased demands for traceable, accurate measurements of power and PQ parameters. Conventional power measurements based on thermal converters only provide information about the root-mean-square (RMS) value which is not sufficient for PQ measurements as this must address complex waveforms.

New measurement setups based on alternative measurement techniques are required and whilst a few national metrology institutes (NMIs) have developed metrology grade power and PQ measurement systems based on sampling techniques, these systems are not generally available and no laboratories can offer calibration services for all the required PQ tests.

This project will help to address this issue by developing and validating a modular metrology grade system for the measurement of power and PQ parameters using digital sampling techniques.

The specific scientific and technical objectives of the project are:

1. To design a modular, metrology grade measurement setup for sampled electrical power and PQ parameters measurements.

2. To develop and validate a modular measurement setup for sampled electrical power and PQ parameters measurements, which can be easily established at NMIs/DIs and at other organizations. The target uncertainties of the modular measurement setup are at least four times smaller than the tolerances specified in documentary standards for PQ meters.

3. To develop an open software tool for instrumentation control, data acquisition and the calculation of electrical power and PQ parameters with full uncertainty estimation.

4. To develop and make available a good practice guide for the assembly and operation of the modular measurement setup including the calibration of all components so as to establish full traceability to the SI of the electrical power and PQ parameters measured.

5. For each partner to develop an individual strategy for the long-term operation of the research capability The individual strategies will ensure that a coordinated and optimized approach to the development of traceability in this field will be implemented for Europe as a whole.

The outputs of the project:

- Validated modular setup for power and PQ measurements;
- Open software tool to allow further modification and extension of the developed setup;
- TracePQMWattMeter tool based on LabVIEW.
- Traceable Power & Power Quality Analyzer tool based on LabWINDOWS/CVI;
- Good practice guide to assist in the design, construction, extension and modification of the developed modular setup;
- First Edition of Guide for Sampling Power and Power quality Measurements is available;
- Individual strategies of all project partners for the long-term development of their research capability in power and PQ metrology;
- Comparison protocol for a future supplementary comparison to support the establishment of new CMCs in power and PQ.

16RPT01 ChemMet-Cap - Development of scientific and technical capabilities in the field of chemical analysis

- Partners - LNE, France, BIM, Bulgaria, BRML, Romania, TUBITAK, Turkey, IAPR, Greece, INRAP, Tunisia [6]
- Project start date and duration: June 2017, 36 months [6]
- Objectives [6]

The general objective of the project is to improve the research capabilities in the field of metrology in chemistry by the development and validation of primary methods. They will be based on isotope dilution mass spectrometry for elemental analyses. A secondary calibration method for pH measurement will be developed. Both methods will be used also for the production of traceable reference values.

This project addresses the following scientific and technical objectives:

1. To develop traceable measurement capabilities for the analysis of heavy metals for concentrations at ppt and ppb levels by developing isotope dilution mass spectrometry methodology as a primary procedure for elemental determination.

2. To develop a secondary method for pH measurement and to apply the method for the production and characterisation of reference pH buffer solutions for the calibration of pH meters and as reference samples for interlaboratory comparisons and proficiency testing.

3. To apply the methods developed to environmental and food samples to determine the heavy metals content in representative matrices, such as potable and natural waters, sediments, and different types of fish/biota samples.

4. To validate the developed methods by participation in suitable international comparisons and hence to underpin the development of appropriate CMCs.

5. To develop individual strategies for the long term operation of the capacity developed, also develop strategies for offering calibration services from the established facilities.

18RPT03 MetForTC - Traceable measurement capabilities for monitoring thermocouple performance

- Project start date and duration: June 2019, 36 months
- Partners - TUBITAK, Turkey, BFKH, Hungary, BIM, Bulgaria, BRML, Romania, CMI, Czech Republic, FSB, Croatia, IMBiH, Bosnia and Herzegovina, JV, Norway, INM, Moldova, MER, Montenegro [7]
- Objectives [7]

The general aim of this project is to develop novel scientific and technical capabilities providing both the dissemination of the International Temperature Scale ITS-90, and accurate low uncertainty temperature measurements by thermocouple, which is the most frequently used temperature sensing instrument.

This objective will be achieved by developing novel practical methods and devices for checking thermocouple drift performance to determine the inhomogeneity of thermocouples for primary and secondary calibration laboratories.

For high precision calibration, primary and secondary calibration laboratories are required to determine the inhomogeneity of thermocouples while performing their calibrations. Unfortunately, standardised, easy-to-use methods and devices are not currently available for the task. At the level of primary laboratories, new and extended traceable measurement methods and devices that will provide confidence in the verification of thermocouple performance are needed.

This project will develop novel methods and techniques, traceable to the ITS-90 that will significantly improve knowledge on drift and homogeneity as well as confidence in the verification of thermocouple performance.

The specific objectives are:

1. To develop and test novel methods and devices for the monitoring of thermocouple drift in-situ in the temperature range up to 1100 °C. These methods have to be suitable for implementation in critical industrial processes in order to assist the users in maintenance and replacement decisions.

2. To develop and test easy-to-operate methods and instruments for the assessment of inhomogeneity of thermocouples for secondary calibration laboratories in the temperature range from 230 °C to 1100 °C.

3. To design and construct novel measurement facilities that can provide confidence in the verification of thermocouple performance and to identify and quantify the range of drift of the thermocouples.

4. for each participant, to develop an individual strategy for the long-term operation of the capacity developed. The individual strategies will lead to an overall strategy document to be presented to the EURAMET TC-T, to ensure that a coordinated and optimised approach to the development of traceability in this field is developed for Europe as a whole.

- Impact

This project will have an impact on a wide range of industries where temperature measurement and control are vitally important, as well as on healthcare, climate change and global warming monitoring. Control of temperature is critical to many industrial processes, yet the relevant sensors require regular calibration.

1. Impact on industrial and other user communities

By organising workshops for accredited laboratories and industry stakeholders, the dissemination of knowledge will be extended to the end user. Ultimately this will facilitate the dissemination of traceable temperature measurements in ranges relevant for high value manufacturing in the participating countries.

Additionally, the NMIs/DIs will have closer relations and strengthen the collaboration with the users' associations, manufacturers, and other stakeholders, and will provide guidance to traceability and good practice in thermometry.

2. Impact on the metrology and scientific communities

The Consultative Committee for Thermometry (CCT) felt the need to establish the Working Group for Secondary Thermometry (WG2) and recommends research at NMIs on novel secondary techniques, monitoring stakeholder needs.

The project will be presented to the accreditation authorities in Europe as well as to end users and manufacturers of thermocouples.

There are a number of smaller NMIs in the consortium and their participation in this project will substantially contribute to capacity building, particularly in the area of thermocouple calibration and the facilities and skills required assessing thermocouple performance.

3. Impact on relevant standards

The project will support active participation and influencing in key European temperature related committees such as the Consultative Committee for Thermometry (CCT) and CCT Task Group for Guides on Thermometry, EURAMET Technical Committee on Thermometry TC-T, EURAMET Technical Committee for Quality TC-Q, and COOMET TC1.10.

4. Longer-term economic, social and environmental impacts

Establishing traceable measurements in the temperature field and collaboration in research (construction of miniature fixed-point cells and new facilities for characterisation of artefacts) will enable important inputs for areas of research, innovation and patenting in this field in future European research.

18RPT01 ProbeTrace - Traceability for contact probe and stylus instrument measurements

- Project start date and duration: June 2019, 36 months
- Partners - TUBITAK, Turkey, BIM, Bulgaria, CEM, Spanish, DMDM, Serbia, FSB, Croatia, GUM Poland INRIM, Italy, IPQ Portugal, NIS, Egypt, SASO-NMCC, Saudi Arabia [8]
- Objectives [8]

The general aim of this project is to develop traceable and cost-effective measurement capabilities for the calibration of form and surface roughness standards with uncertainties in the range 10 nm - 100 nm. Surface finish and form of products are important features to be examined for engineering and scientific purposes. Such characteristics of surfaces include wear resistance, bearing, sliding and lubricating properties, fatigue and corrosion resistance, functionality etc. Form and surface measurement devices with contact probes and stylus are used to characterize such surfaces. This project will improve the scientific knowledge, instruments, methods and research capability in metrology for contact measurement probes and stylus instruments and enable calibration labs to develop new capabilities for self-provision of traceability to the SI unit of length, the meter.

The specific objectives of the project are:

1. To calibrate reference stylus instruments for surface roughness measurements using novel portable displacement generators with uncertainties in the range 10 nm–100 nm and to evaluate the efficacy of displacement generators vs existing methods for calibration of stylus devices. Further, to develop novel software for the calibration of stylus devices using sphere standards.

2. To calibrate reference probes for form measurements in static and dynamic mode using novel portable displacement generators and to evaluate the current state of the art for calibration of flick standards.

3. To investigate the traceable calibration of transducers to be used as portable displacement generators under static (+/- 1000 µm) and dynamic (+/- 100 µm) measurement conditions. Further, to prepare two best practice guides on

their use in the calibration of stylus instruments and form measurement probes.

4. To develop noise reduction software, including the use of numerical methods for random noise bias reduction, that can be used to reduce the uncertainties down to a level of 10 nm in roughness and roundness measurements.

5. For each project partner, to develop an individual strategy for the long-term operation of the capacity developed. The individual strategies will ensure that a coordinated and optimized approach to the establishment of traceability in this field is developed for Europe as a whole.

- Impact

1. Impact on industrial and other user communities

The NMIs will establish new services for calibration of form and surface roughness standards using the traceability route established with the novel methods developed in the project. In addition, newly developed guides will facilitate the application of the new methods for Coordinate Measuring Machines, form and stylus instrument users and manufacturers.

2. Impact on the metrology and scientific communities.

Newly developed methods, which will provide alternatives to the conventional ones, will create an impact on calibration laboratories end users and manufacturers.

Knowledge transfer from experienced NMIs to those less experienced on how to use these new types of standards will be very beneficial. The project will strengthen the collaboration of European NMIs and will increase their competitiveness and consistency by producing a draft calibration guide for the use of portable displacement generators for calibration of stylus instruments and contact measurement probes.

3. Impact on relevant standards

After its end, the project will contribute to a further revision of ISO 12179 [9], use of depth setting standards for calibration of contact stylus instruments. The results will be promoted within the standardization community and will provide input into the standardization process. A contact will be made with the EMPIR project 17NRM03 EUCoM - Standards for the evaluation of the uncertainty of coordinate measurements in industry [10] to share the project outputs.

4. Longer-term economic, social and environmental impacts

Measurement of form and surface finish parameters relate to functionality of manufactured parts. Better achievements for the desired tolerances on automotive parts will provide better engine parts working more efficiently with improved fuel savings, longer life time, reduction in waste and production time, which altogether will have a positive impact on the environment.

The project will provide this for surface roughness and form measurements, which will in turn result in improvements of manufacturing processes. This will increase economic growth in Europe and its neighbouring region(s) and enhance industry competitiveness and will therefore be instrumental for creating jobs particularly in the production of parts in a cost-effective way.

VIII. CONCLUSION

Bulgarian Institute of Metrology performing its activities as a National Metrology Institute has a substantial contribution to the maintenance and development of metrological infrastructure in Bulgaria. Following the policies, recommendations and strategies of the international metrological organizations BIM also has activities in collaboration with other NMIs, including participation in EURAMET projects.

Our participation in EMPIR projects, including RMG and capacity building training programs gives a great benefit to BIM - to increase the competence and confidence of our colleagues in the relevant areas.

These projects are not in the field of fundamental metrology, such as projects relating to the definition of physical constants and new definitions, but nevertheless they have a specific contribution to the development of metrology in Europe.

Also it is important to note that the active and successful participation in EMPIR projects affects the international prestige of BIM and the confidence in the measurements in Bulgaria.

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[10] EURAMET-EMPIR Project: 17NRM03 EUCoM; Standards for the evaluation of the uncertainty of coordinate measurements in industry; Cordinated by INRIM Alessandro Balsamo

Analysis of the state diagram correctness of automatic logic control systems on FPGA Paper

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***Abstract*— The work is dedicated to verification of automatic logic control systems by analyzing the correctness of state diagrams of control finite state machines which are represented in the form of the code in the hardware description language. As a method for state diagram analysis the, it is proposed to use the concept of orthogonality, as a system of incompatible events. Analysis of the correctness is carried out by analysis the results of behavioral modeling and logical synthesis using CAD tools.**

***Keywords*— *finite state machine, state diagram, HDL-model, synthesis,* orthogonal Boolean function.**

I. Introduction (*Heading 1*)

One of the metrological tasks is the quality control of the software. If for traditional programming languages these issues are worked out in sufficient detail, then there are no established approaches for hardware description languages.

Hardware Description Languages (HDL) are characterized by dualism. From one side, this is a code in a formal language with all its characteristics and properties, and from another side, this is a description for digital circuit with all restrictions imposed by the corresponding technological base. In addition, a computer-aided design tool (CAD) has a component called synthesizer which is located between the code in the hardware description language (HDL model) and digital circuit. A subset of HDL, which is correctly converted by a synthesizer into digital circuits, which is called, synthesized HDL subset. In addition to the fact that HDL operators, which correctly describe the circuit, must be included in the synthesized subset, the structure of HDL model must fits to certain rules of optimal synthesis. In case of finite state machine (FSM) model, so-called two-processor FSM's pattern, in which the transition and output functions are calculated in one process, and the assignment of new state is performed in another process associated with synchronization.

During verification of logical control system (LCS) it is advisable to apply the functional approach – check not the software HDL-code and the circuit, which was synthesized on its basis, but the functional model of the state machine – the state diagram. It should be noted that from the point of view of synthesis the FSM's pattern uniquely and correctly reflects the functional model of the finite state machine in the form of the state diagram [1].

The rules for checking the state diagram for correctness are developed in sufficient detail and practically standardized. This is check for completeness, consistency, feasibility and the presence of generating circuits [2]. Proceeding from this, an actual task is to develop verification procedures for HDL models of finite state machines taking into account of the correctness under condition of state diagram from one side, and, rules of synthesizers' operation on technology platform of the CAD FPGA from another hand.

II. Correctness verification of HDL-model, which is represented as state diagram

The syntactical correctness of the state diagram is determined by the fulfillment of the conditions for transition functions: consistency (orthogonality) and completeness. Consistency in the state diagram is provided in the case, if transitions are simultaneously forbidden to any of two or more arcs, which come out from one vertex. The completeness of the state diagram (marks' disjunction of all arcs, which is outgoing from a vertex, is equal to one) is checked after ensuring consistency.

A fragment of the state diagram for vertex a_i with K outgoing arcs is shown in fig. 1.

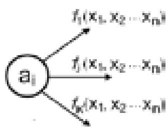

Fig. 1. Mapping of transition function conditions on the graph model

Each arc is associated with logical expression of the transition function conditions $f(x_1,x_2,...x_n)$ in the disjunctive normal form (DNF) also known as sum of products (SOP) form:

$$f(x_1,x_2,...x_n) = f_1(x_1,x_2,...x_n) \vee \ldots$$
$$\vee f_j(x_1,x_2,...x_n) \vee \ldots \vee f_K(x_1,x_2,...x_n).$$

Completeness is checked for each vertex of state diagram by analyzing of transitions' conditions of all arcs, which is outgoing from this vertex, i.e. $\bigvee_{j=1}^{K} f_j(x_1,x_2,\dots x_n)=1$. The completeness of conditions is defined as cover of all 2^n products (terms) of Boolean transitions functions set, where n – quantity of transitions' conditions (input variables which initiate transitions from this vertex), i.e. $f(x_1,x_2,\dots x_n)=1$.

While ensuring the consistency, for each vertex of the state diagram, the orthogonalization of Boolean expressions of transitions' conditions is checked (the absence of common terms in Boolean expressions of conditions for different arcs) for arcs, which is outgoing from the considered vertex, i.e. $\forall(f_g \cdot f_h = 0)$, $g \neq h$ [3].

A normal disjunctive function of the algebra of logic is called orthogonal if all the conjunctive terms are mutually orthogonal. For such function, there is no set of variables' values, which belongs more than to one elementary conjunction, that is, on any set of variables' values, the value of one can be accepted only by one conjunction. If the logical function is presented in the form of a Karnaugh map, the images of conjunctions (products) will not intersect. An example of orthogonal DNF can be its canonical form (CDNF or CSOP), which consists of complete mutually orthogonal conjunctions [4].

Let's consider a method for constructing an orthogonal complete system of transitions functions for the vertex of the state diagram.

Let's use the following definitions: *f* – complete CDNF from *n* variables, that is $f(x_1,x_2,\dots x_n)=1$ – Boolean function that takes the value 1 on all 2^n sets, f^* – complete CDNF from (*n-1*) variables, f^{**} – complete CDNF from (*n-2*) variables, f^{***} – complete CDNF from (*n-3*) variables and so on. Thus, $f = f^* = f^{**} = f^{***} \equiv 1$.

The orthogonality of Boolean function' terms is ensured by decomposing into the corresponding variables, taking into account the completeness of decomposition into all variables [5].

According to the first theorem, the decomposition will be a follows:

$$
\begin{aligned}
f &= \overline{x_1}\cdot f^* \vee x_1\cdot f^* = \overline{x_1}\cdot 1 \vee x_1\cdot f^* = \overline{x_1} \vee x_1\cdot f^* = \overline{x_1} \vee \\
&\vee x_1(\overline{x_2} \vee x_2\cdot f^{**}) = \overline{x_1} \vee x_1(\overline{x_2} \vee x_2(\overline{x_3} \vee x\cdot f^{***})) = \\
&= \overline{x_1} \vee x_1(\overline{x_2} \vee x_2(\overline{x_3} \vee x_3\cdot(\dots\cdot\ (\overline{x_n} \vee x_n)))).
\end{aligned}
$$

Thus, the complete Boolean function of *n* variables decomposes at least to (*n + 1*) conjunctions while preserving the essence of all *n* variables.

As an example, let's consider the complete CDNF $f(x_1,x_2,x_3)=1$. By definition, a CDNF is orthogonal. We write the complete CDNF and perform the decomposition by x_1 with the replacement of the left side of the decomposition inside brackets with 1.

$$
\begin{aligned}
f(x_1,x_2,x_3) &= \overline{x_1}\,\overline{x_2}\,\overline{x_3} \vee \overline{x_1}\,\overline{x_2}x_3 \vee \overline{x_1}x_2\overline{x_3} \vee \\
&\vee \overline{x_1}x_2x_3 \vee x_1\overline{x_2}\,\overline{x_3} \vee x_1\overline{x_2}x_3 \vee x_1x_2\overline{x_3} \vee x_1x_2x_3 = \\
&= \overline{x_1}(\overline{x_2}\,\overline{x_3} \vee \overline{x_2}x_3 \vee x_2\overline{x_3} \vee x_2x_3) \vee x_1(\overline{x_2}\,\overline{x_3} \vee \\
&\vee \overline{x_2}x_3 \vee x_2\overline{x_3} \vee x_2x_3) = \overline{x_1}\cdot 1 \vee x_1\cdot(\overline{x_2}\,\overline{x_3} \vee \overline{x_2}x_3 \vee \\
&\vee x_2\overline{x_3} \vee x_2x_3) = \overline{x_1} \vee x_1(\overline{x_2}\,\overline{x_3} \vee \overline{x_2}x_3 \vee x_2\overline{x_3} \vee x_2x_3).
\end{aligned}
$$

Let's perform similar procedure of decomposition by x_2 for the expression in brackets. Open brackets and get the complete orthogonal function of three variables (1).

Based on this, we can conclude that the complete orthogonal function of *n* variables has at least (*n + 1*) conjunctions. So, from each state of the finite state machine with the function of transitions' conditions from *n* variables $f(x_1,x_2,\dots x_n)$ there must be at least (*n + 1*) transitions.

$$
\begin{aligned}
f(x_1,x_2,x_3) &= \overline{x_1} \vee x_1(\overline{x_2}(x_3 \vee \overline{x_3}) \vee x_2(\overline{x_3} \vee x_3)) = \\
&= \overline{x_1} \vee x_1(\overline{x_2}\cdot 1 \vee x_2(\overline{x_3} \vee x_3)) = \\
&= \overline{x_1} \vee x_1(\overline{x_2} \vee x_2\overline{x_3} \vee x_2x_3) = \\
&= \overline{x_1} \vee x_1\overline{x_2} \vee x_1x_2\overline{x_3} \vee x_1x_2x_3\ .
\end{aligned}
\qquad (1)
$$

One of the ways of visual analysis of the transitions' functions orthogonality is representation of the orthogonal functions using Karnaugh maps. Karnaugh map for the orthogonal function (1) is shown in fig. 2 (a). From this map, it can be seen that for the orthogonal function, groups of ones for the complete CDNF don't intersect, i.e. conjunctions have no common parts.

Karnaugh map for the orthogonal function $f(x_1,x_2,x_3)=\overline{x_1} \vee x_1\overline{x_2} \vee x_1x_2\overline{x_3}$ is shown in fig. 2 (b), but this function is not complete, since there is no group which is corresponds to conjunction $x_1x_2x_3$. This is due to the fact that the construction of this function violated the rule of completeness of the function, i.e. $f^* \neq 1$.

Karnaugh map for the orthogonal function $f(x_1,x_2,x_3)=\overline{x_1} \vee x_1\overline{x_2} \vee x_1x_2$ is shown in fig. 2 (c), but this function is also not complete, since there is no variable x_3. This is due to the fact that construction of this function violated the rule that in complete function supposed to be no less than (*n + 1*) conjunctions.

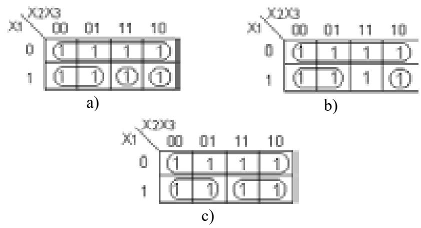

Fig. 2. Karnaugh maps for orthogonal functions

III. Comparison of synthesis results of HDL-codes of correct and incorrect state diagramms

Let's consider an example of the state diagram (fig. 3) with correct conditions for transitions from the a_1 state.

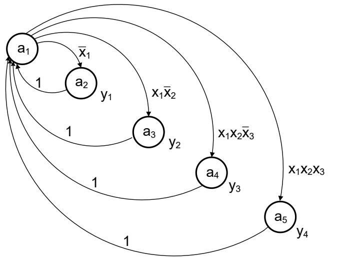

Fig. 3. The state diagram of Moore FSM with the correct conditions of transitions

The transitions' conditions function from the a_1 state is orthogonal, therefore, conditions of transitions are consistent. In addition, the function is complete. VHDL-model of this FSM is shown in fig. 4.

```
library IEEE;
use IEEE.std_logic_1164.all;
entity Fsm_right is
        port (x1, x2, x3, Clk, reset: in STD_LOGIC;
        y1, y2, y3, y4: out STD_LOGIC);
end;
architecture Fsm_right of Fsm_right is
        type State_type is (a1, a2, a3, a4, a5);
        signal State, NextState: State_type;
begin
        Sreg0_CurrentState: process (Clk, reset)
        begin
                if reset='1' then State <= a1;
                elsif Clk'event and Clk = '1'
                then State <= NextState;
                end if;
        end process;
        Sreg0_NextState: process (State, x1, x2, x3)
        begin
        case State is
        when  a1=> if x1='0' then NextState <= a2;
                elsif x2='0' then NextState <= a3;
                elsif x3='0' then NextState <= a4;
                else NextState <= a5;
                end if;
        when  a2=>  NextState <= a1;
        when  a3=>  NextState <= a1;
        when  a4=> NextState <= a1;
        when  a5=> NextState <= a1;
        when others => NextState <= a1;
        end case;
        end process;
        y1 <= '1' when State=a2 else '0';
        y2 <= '1' when State=a3 else '0';
        y3 <= '1' when State=a4 else '0';
        y4 <= '1' when State=a5 else '0';
        end;
```

Fig. 4. VHDL-model of Moore FSM with correct conditions of transitions

Timing diagram of this FSM are shown in fig. 5.

Fig. 5. Timing diagram of Moor FSM with correct conditions of transitions

It reflects the results of simulation in the system ALDEC Active-HDL on all combinations of conditions x_1, x_2, x_3.

The diagram shows that the transitions' conditions function is complete and orthogonal. During the period from 150 ns to 950 ns, the FSM changes to the state a_2 $(y_1 = 1)$ as long as the condition $\bar{x}_1$ is true, i.e. $(x_1 = 0)$, and then returns back to a_1 $(y_1 = 0)$. During the period from 950 ns to 1350 ns, the FSM changes to the state a_3 $(y_2 = 1)$ as long as the condition $x_1\bar{x}_2$ is true, i.e. $(x_1 = 1, x_2 = 0)$, and then returns back to a_1 $(y_2 = 0)$. During the period from 1350 ns to 1550 ns, the FSM changes to the state a_4 $(y_3 = 1)$ as long as the condition $x_1x_2\bar{x}_3$ is true, i.e. $(x_1 = 1, x_2 = 1, x_3 = 0)$, and then returns back to a_1 $(y_3 = 0)$. During the period from 1550 ns to 1750 ns, the FSM changes to the state a_5 $(y_4 = 1)$ as long as the condition $x_1x_2x_3$ is true, i.e. $(x_1 = 1, x_2 = 1, x_3 = 1)$, and then returns back to a_1 $(y_4 = 0)$.

Let's consider the following example of the state diagram (fig. 6). Conditions of transitions from the state a_1 are incorrect from the point of view of transitions' conditions functions orthogonalization; during transition to a_4 and a_5 there is no variable x_1 in the term, but they don't contradict conditions of transitions $x_1x_2\bar{x}_3$ and $x_1x_2x_3$. Transitions' conditions functions are complete.

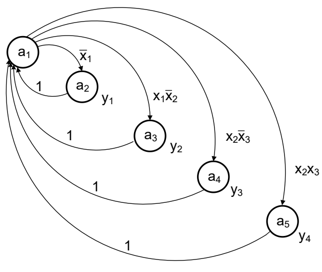

Fig. 6. State diagram of Moore FSM with consistent incomplete conditions of transitions

Transitions from state a_1 can be written in VHDL as follows (fig. 7 (a) or fig. 7 (b)). At the same time, such description is not stylistically correct, but it is not inconsistent and gives the same results during simulation as in fig. 5

```
when  a1=> if x1='0' then NextState <= a2;
        elsif x1='1'and x2='0' then NextState <= a3;
```

```
           elsif x2='1'and x3='0' then NextState <= a4;
           else NextState <= a5;
           end if;
```

а)

```
when  a1=> if x1='0' then NextState <= a2;
           elsif x1='1'and x2='0' then NextState <= a3;
           elsif x2='1'and x3='0' then NextState <= a4;
           elsif x2='1'and x3='1' then NextState <= a5;
           end if;
```

б)

Fig. 7. Fragments of the VHDL-model of Moore FSM with consistent incomplete conditions of transitions

In addition, FSM models which are shown in fig. 3 and 6, give exactly the same correct results during synthesis. Synthesis was performed in the system XILINX ISE.

Next, let's consider an example of the state diagram (fig. 8) with a missing transition (by condition $x_1x_2x_3$) and incomplete condition for the transition from state a_1 to state a_4: $\bar{x}_2 x_3$ instead of $x_1\bar{x}_2 x_3$. The transitions' conditions function in this case is non-orthogonal and incomplete.

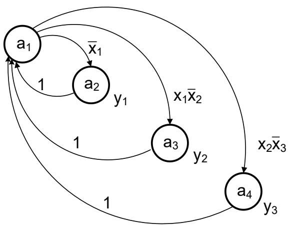

Fig. 8. Moore state diagram with missing transition

A fragment of the VHDL model of this FSM is shown in fig. 9.

```
when  a1=> if x1='0' then NextState <= a2;
           elsif x1='1'and x2='0' then NextState <= a3;
           elsif x2='1'and x3='0' then NextState <= a4;
           end if;
```

Fig. 9. Fragment of the VHDL-model of Moore FSM with missing transition

During simulation of the operation of this FSM (fig. 10), at first glance, everything is fine, but in fact, the variable x_3 is insignificant here, on the set $x_1, x_2, x_3 = 111$ the FSM should not go to any state, but the modeling system put him to the state a_4.

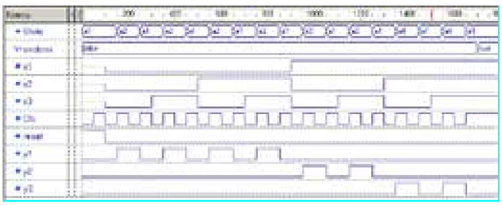

Fig. 10. Timing diagram of Moore FSM with missing transition

Likewise, when conditions $x_1, x_2, x_3 = 010$, the FSM can go into two states a_2 and a_4, which should not be in the case when the FSM works correctly, but the modeling system masks such situation, putting the FSM into the a_2 state. In this example, there is both a lack of completeness and the presence of a contradiction of the transitions' conditions, but this is clearly not manifested at the stages of syntax analysis and simulation.

During synthesis of this FSM can be problems especially in the case of older versions of CAD. For example, when using Xilinx ISE 10.1, a warning appears about four latches in addition to four flip-flops: *Found 4-bit latch for signal <NextState>. Latches may be generated from incomplete case or if statements. We do not recommend the use of latches in FPGA/CPLD designs, as they may lead to timing problems*. That is, instead of two triggers for the four states, 8 triggers of two types are synthesized. This should not be in a correctly synthesized FSM. At the same time, when using the latest version of Xilinx ISE 14.7, this warning will no longer exist.

Thus it is shown that problems associated with incorrect conditions are very difficult to identify during the design process. With equal probability, they can appear both on the timing diagram during behavioral simulation, and in the synthesis process (especially in cases with older versions of CAD). So, the verification of transitions' conditions for consistency and completeness must be carried out at the stage of forming the state diagram of the FSM.

IV. Conclusion

Construction a logical control system based on FPGA is a modern approach to computer-aided design. One of the most common ways to describe logical control systems is the finite state machine model, which description based on the state diagram. The correctness of the future HDL code depends on the correctness of the state diagram.

The concept of orthogonalization, used to decompose logical functions in the synthesis of digital systems [6], can be also used to check the state diagram for correctness [2]. As a result of the research, it was shown that the transitions' conditions function $f(x_1, x_2, \ldots x_n)$ is non contradictory if it is orthogonal. The orthogonal function of transitions' conditions $f(x_1, x_2, \ldots x_n)$, in its turn, is complete if its terms cover all sets $x_1, x_2, \ldots x_n$.

The verification of HDL model is carrying out at all stages of computer-aided design, namely, at the stage of behavioral simulation (by analyzing timing diagrams), at the stage of synthesizing of the RTL circuit (by analyzing the synthesis report) and at the stage of post-synthesis simulation (by analyzing the timing diagrams, taking into account the technological base). Due to the features of the modeling system, missing transitions or contradictory conditions of transitions at the syntax checking stage are not fixed, moreover at the simulation stage and automated synthesis they may go unnoticed (depending on the version of the synthesizer).

Therefore, verification of the state diagram for correctness is an important and integral step in the automated design of automatic logic control systems, the functioning algorithm of which is presented in the hardware description language

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Measurement and analysis of cross-band satellite antenna parameters

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Abstract *— Satellite antennas are constructively shaped like an irradiator and a reflector. Satellite antennas with a single irradiator placed in the focus of one parabola operate at one frequency. Some satellite systems operate at two frequencies of different ranges. Is it possible for two irradiators working on a cross-band to work together on one reflector? In this case, a whole antenna structure is saved.*

The answer to the question is given in this article. Measurements and analysis of the results of three different irradiators were made in real conditions. For the high frequency, a standard low-noise converter is selected. For the low frequency three different beam constructions are selected. Measurements are made on a real Earth - Satellite - Earth track.

Keywords *— measurement, satellite antenna, duobander*

I. Introduction

The standard satellite antennas are constructively shaped like an irradiator and a reflector. Satellite antennas with a single irradiator placed in the focus of one parabola operate at one frequency. Some satellite systems operate at two frequencies of different bands, that is, the cross-band. Two separate antenna structures are needed for two reflectors. Is it possible for two irradiators working on a cross-band to work together on one reflector? In this case, a whole antenna structure is saved.

The answer to the question is given in this article. Measurements and analysis of the results of three different irradiators were made in real conditions. A standard irradiator with a low noise convertor is selected for the high frequency. For the low frequency two different beam irradiator constructions are selected. Measurements are made in the laboratory and on a real Earth - Satellite - Earth track. The system is designed for a geostationary communications satellite. Measurements are made from a point with geographical coordinates: Latitude: 42.676111° and Longitude 23.255227°, Sofia, Bulgaria.

II. Types of Antennas Used for Terrestrial Satellite Communications

Largest distribution has been obtained mirror parabolic antennas.

Other antennas used in terrestrial satellite communications are horns, spiral antennas, and antenna arrays.

A. *According to the type of reflector, the parabolic antennas are:*

- Parabolic antenna with parabolic reflector. It emits a narrow beam along the parabolic axis.
- Closed parabolic antenna. Place a metal cylinder on the edge of the parabola to protect it from electromagnetic fields outside the main axis.
- Cylindrical antenna. The reflector is a curve in one direction and flat in the other.
- Profiled antennas. They are produced from a profile of different shapes.
- "Shaped" antennas. The reflector is formed with a non-circular section and / or with different curves along the horizontal or vertical axis.
- An "orange peel" antenna. This type antennas have a narrow beam in the vertical direction. They are used in scanning radars.

B. *According to the location of the irradiator, the antennas are:*

- An antenna with a centrally positioned irradiator.
- Offset antenna. The reflector is an asymmetric segment of the parabola. The focus and the irradiator are on one side of the reflector (Fig. 1).

Fig. 1. Offset antenna

- Cassegrain antennas. The beam is located on or behind the reflector. A secondary reflector is used.
- Grigorian antennas. Like a cassegrain antenna, but with a concave secondary reflector (ellipsoid) – an opposite of the cassegrain antenna.

III. Selection of Antenna Constructions for Frequencies $F_1 = 10.5$ GHz and $F_2 = 2.4$ GHz

For the experiments, a satellite "Es-Hail-2" (QO-100) of Qatar was used [3].

Es'hail-2 is a joint project by the Qatar Satellite Company (Es'hailSat), the Qatar Amateur Radio Society (QARS) and AMSAT Deutschland (AMSAT-DL).

Together with the European Space Agency (ESA), it is part of the International Space Education Board (ISEB). The ISEB encompasses organizations other than space agencies involved in educational programs to promote the interest in space, science and technology among the student community around the world. The first projects were the creation of satellites of the CubeSat series with polar orbits. The Es'hail-2 project (QO 100) is the first satellite of stationary orbit.

a) Antenna design for frequency f = 10.5 GHz

For an experiment on this topic, we are focusing on an 80 cm offset antenna, which is the most common, simplest construction and widely used in individual satellite access points. We use it for frequency f = 10.5 GHz.

The basic parameter of satellite antennas is the gain (in dB). Depends on the operating frequency and the diameter of the parabola.

b) Antenna constructions for frequency f = 2.4 GHz

To make the antenna system as simple as possible, we use an antenna design for f = 2.4 GHz to accommodate the main antenna. We choose three antenna designs to get more experimental data. We compare them and choose the best one to mount on the antenna system for constant work.

A. First type of antenna

One of the most popular high frequency antennas is the "wave channel" antenna, known as the "Yagi" antenna [1]. They consist of several half-wavelength elements and have unidirectional directed action. In its composition, such an antenna comprises a half-wave active vibrator fed by a feeder line, a reflector and one or more directors. The power gain that is achieved in the direction of the main beam due to the passive elements depends on the distance between the passive elements and the active element.

The first type of antenna (Fig. 2) consists of four pieces of four elemental antennas (4 x 4) of „Yagi" type. The antennas are connected in a single phase to obtain left circular polarization. Coaxial cut λ/4 and coaxial transformer 4:1 were used (Fig. 3).

Fig. 2. „Yagi" type antenna

Fig. 3. Matching unit on 4x4 antennas

B. Second type of antenna

For a second of antenna design, a spiral antenna is selected „Helical" (Fig. 4).

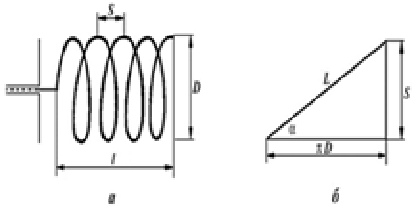

Fig. 4. "Helical" antenna design

The spiral antennas are quite simple in design. Through this type of antennas a circularly polarized electromagnetic wave is obtained. The use of such an electromagnetic wave is necessary when it is undesirable to receive the reflected rays (signal distortions are introduced). For this reason, antennas are designed to react to the field vector polarized in a circle. Such antennas only react to the right or left-field polarized field intensity vectors. In addition to reducing interference, circularly polarized electromagnetic wave is also applicable when separating the transmitted signal from a common antenna, cosmic connections (due to the Faraday effect in the ionosphere) and others. The Gain of the spiral antennas depends on the number of turns in the spiral. These antennas are broadband, making them applicable in many radio systems.

Fig. 5. Antenna type 4 X 1 „Helical"

The second type of antenna consists of four "Helical" antennas with left polarization (Figure 5) and the same matching unit as in the above antennas. Each has an impedance of Z = 50 Ω.

C. Third type of antenna

The third type of antenna is a type of "Helical" that encloses the main antenna irradiator (Fig. 6). The impedance of the antenna is the same as the above antennas. This antenna is directly connected to a coaxial cable with an impedance of Z = 50 Ω.

Fig. 6. Antenna type „Helical“

IV. Antenna parameters comparison for 2.4 GHz

Antennas are designed with free software [2]. The basic parameters for antennas 2 and 3 are given in Table 1. Additional parameters are given in Table 2.

TABLE I. BASIC PARAMETERS

Antennas	F [MHz]	Number of turns	λ [mm]	Turn spacing	D_{ant} [mm]	Gain [dBi]
Antenna 2	2400	5	125	0.25λ	42.4	10.15
Antenna 3	2400	7.5	125	0.25λ	70.0	11.6

TABLE II. ADDITIONAL PARAMETERS

Antennas	Total cond. length [mm]	Total ant. length [mm]	F_{min} [MHz]	F_{max} [MHz]	Beam width (-3 dB)
Antenna 2	684.3	156.2	2150.21	2678.79	46.5°
Antenna 3	1033.3	234.3	2209.62	2606.77	39.9

For the first type of antenna (antenna 1), 4 x 4 elements of ready-made "Yagi" antennas of SG Laboratory Ltd were used [4]. The gain is about 7.3 dBd. The impedance of each antenna is Z = 50 Ω. A system of four such antennas gives an increase of approximately 11-12 dBd.

The parameters of the finished antennas are shown on Fig. 7; 8 and 9.

Measurements are made at the beginning of the coaxial power cable with the "RF vector impedance analyzer" N2201.

Fig. 7. Electrical parameters of antenna 4 X 4 „Yagi“

Fig. 8. Electrical parameters of antenna 4 X 1 „Helical“

Fig. 9. Electrical parameters of antenna „Helical“

V. Measuring the 10.5 GHz frequency cutting for three types antenna

A. First experiment

Measurements are made on the transmitter (P_{out} = 3 W, f = 2.4 GHz), antenna (successively antenna 1; 2 и 3), transponder, 10.5 GHz antenna, LNC converter, SDR receiver (Fig. 10).

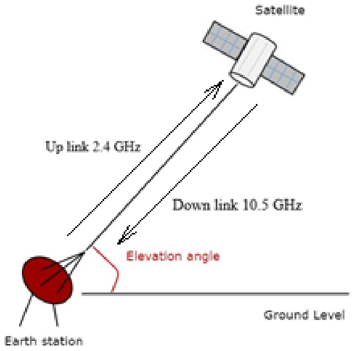

Fig. 10. Схема на измерванията за първия експеримент

The indications are taken from the S-meter of the receiver.

For the fourth attempt, a second offset antenna is used on which a 4 X 4 "Yagi" antenna system is mounted. The results are given in Table 3.

In this way, it is clear how many decibels increase the antenna signal at 10.5 GHz in the absence of another radiation near the primary. The difference is: (-72.3 – (-66.5)) = 5.8 dB.

TABLE III. MEASURED SIGNALS FROM SDR RECEIVER

Antennas	**Ant. 1**	**Ant. 2**	**Ant. 3**	**Ant. only for 10.5 GHz**
S-meter signal [dB]	-72.3	-70.4	-74.4	-66.5

B. Second experiment

The antenna system (from base and auxiliary antenna) is directed to the Sun and the noise level at reception with and without 2.4 GHz antenna is measured.

The measurement is made at the output of the 10.5 GHz converter using a diverter and a receiver off.

When using the antenna 1 X "Helix" mounted around the 10.5 GHz radiator, the result is given in Table 4.

TABLE IV. SUN NOISE LEVEL

Sun noise with Helix antenna	5.6 dB
Sun niose without Helix antenna	7.2 dB

V. CONCLUSION

From the experiments made, it is clear that the "shading" of the antenna placed around the main beam (10.5 GHz) is small. Despite the presence of a closely spaced element, the signal received from the main irradiator is good. This makes it possible to simplify the very construction of a dual-band antenna. The results show that antenna 3 has a larger shade of the main antenna compared to antenna 1 and 2. The difference is not essential for the operation of the whole system. Because of the simpler design than the other antennas, we select antenna 3 (1 X Helix). The cost of the antenna system drops sharply.

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Development of a Virtual System for generating and measuring real signals

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***Abstract*—The generation of signals is important for the troubleshooting and for the development of every electronic device. The generator normally is used to provide known test conditions for the performance evaluation of electronic systems and for replacing signals that are missing in systems during repairing work, it can be used for test some electrical or electronic circuit to generate periodic signals, for computers and control system it can work as a timer. In the present work have been developed a Virtual Functional Generator with output for two real signals. It have been developed inside also a Measurement Tool - Oscilloscope and Spectrum Analyzer. The testing experiments proved that this virtual instrument / VI / works properly. This VI could be used for educational purposes or other purposes.**

Keywords—virtual instruments, generators, spectrum analyzer, oscilloscope

INTRODUCTION

Functional generators create waveforms with analog characteristics and with logic sources generate digital waveforms that are commonly used to test computer buses. In response to a variety of measurement needs, there are more and more types of instruments. LabView launched by the National Instruments is used to integrate the different types of measuring instruments [1,2,3]. It uses the software development way to synchronously control through the common control interface, so as to integrate a variety of instruments. Often the analog and digital signals encounter in electronic circuit design. According to the devices like sensors, the common application is that we can obtain the analog signal and convert it into digital signal to deal with or convert the digital signal into the analog signal to drive control devices[4,5,6]. Now days virtual instrument –in short VI are very popular [7,8,9] because of their flexibility and very wide range of capabilities. We have developed a virtual instrument used for generating function, that has a real output, that can be used in numerous applications, as well another virtual instrument based on the same platform, used to measure the input from the general i.e with a real input.

DEVELOPMENT OF A VIRTUAL SYSTEM FOR GENERATING AND TESTING REAL SIGNALS

LabView has a lots of built-in functions, controls, buttons and more. For generating different type of signals were chosen some built in VI like *sinewave.in*, *squarewave.vi, trianglewave.vi* and *sawtoothwave.vi*. The *Case structure* was chosen, because the simulated signals have been used not all at once. The *Case structure* contains one or more subdiagrams, or cases, exactly one of which executes when the structure executes. The value wired to the case selector determines which case to execute and it can be Boolean, string, integer, or enumerated type. With adding a *graph* block for visual representations this simple structure of this simple VI is almost ready. For measuring the generating signals, was added a measurement block, called *Tone Measurements*. When it is connected to a signal producing output, it will process the data and will output numeric data of known parameters – amplitude, frequency and peak to peak amplitude/ see Fig.1/.

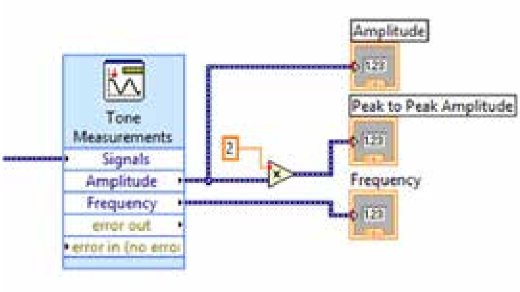


Fig.1.The *Tone Measurements* Virtual Instrument.

To the signal input we had connected the generated waveform output, and for the Amplitude and Frequency outputs, we created two numeric displays, where the measured data can be displayed. The third numeric indicator was added, that goes into a multiplier with a set constant of “2”, that multiply the measured amplitude and will resolve in to us getting the peak to peak amplitude as well. For the processing of the measurements, the spectral measurements tool was chosen /see Fig.2 /. It did fast Fourier transform peaks. The peak represents the most dominant frequency in the investigated periodic signal. The Fourier transform represents the energy at each frequency in the time-domain. The *Spectral Measurement* VI, was then simply connected to a *graph* block so it can be displayed. The option Oscilloscope was added too. For this purpose another case structure was used, a trigger gate, and a Boolean switch control and were connected to the output of the main *graph* display. All the information required to get fed to this measurement system will be coming from the output signal of the signal generation section.

The 3 types of noise was added to the generated signal, *Uniform White Noise*, *Gaussian White Noise* and *Binomial noise*. The sub-menu from the functions VI’s from the signal processing in the block diagram was used. The first case structure vary between the four types of waveforms as we did when we created the simple version of the generators, by switching between its options we will be selecting between Sine, Sawtooth, Square and Triangular waveforms. The second waveform switch between the three kinds of noise that will be applies on the waveforms selected by case one, applying *Uniform White Noise, Gaussian White Noise and Binomial noise.*

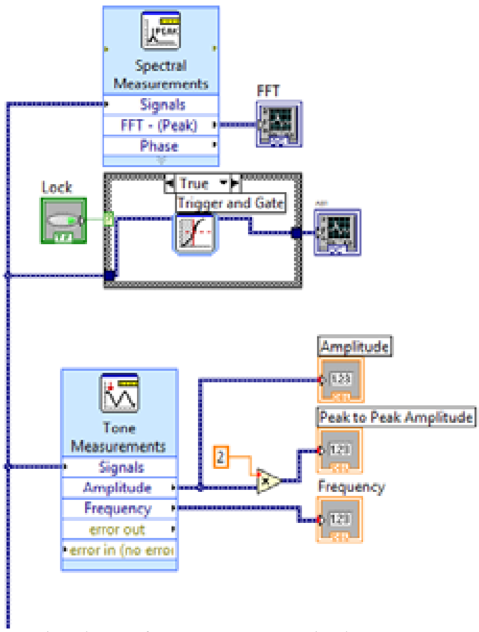


Fig.2.The setup for *Tone Measurements* Virtual Instrument.

And the third case structure act as an on/off switch for when we want to apply noise to the simulated waveform, it will just vary between true and false. We have also added a multiplier to our frequency control with a slider, that would help us reach higher frequencies faster when setting it manually. For the case structure to be fully functional, additional controls to it were added. **1**. A *slider*, labeled offset, that could regulate on a vertical line the visually generated waveform, by connecting it to the offset input of the VI's. **2**. A *knob* selector to be able to switch between the three types of noise of the second structure, with it we can shift trough the options. **3**. Noise On/Off *switch*, that with we will be able to either apply or remove the noise. **4**. A *control knob*, for the duty cycle of the square wave ranging from 1 to 100%, and we have set it to be set as a constant at 50%.

Also were added several property nodes, that when linked to an item in the front panel, can then be hidden or shown, when it's not connected to anything it looks , we have wired it to a simple true or false statement that does not change, so when we shift trough the cases, depending on what noise we are using, we will get the corresponding controls for it, making things a bit more compact. These are simple "led" indicators, that will light up depending on what waveform we are simulating, we have done the same with them, in each case, depending on what waveform we have selected, the corresponding light will turn on. The controls which will regulate the size of the screen like with a oscilloscope for the Voltage and Time divisions were added too. For this was used another property node for a waveform graph, and it was assigned to the graph called "AB1". Was created another case structure, that hold the values of the size of our X and Y dimensions of the graph, for the time division we were used **0.000625**, **0.00125**, **0.0025**, **0.005** and **0.01** and for the amplitude (volts), were used two values one positive and one negative for each side of the cycle, they are +/- **0.25**, **0.5**, **1**, **2.5** and **5** , and they can be spread across 5 divisions for the time and 10 divisions for the amplitude.

With controls can be selected a proper size for the waveform so that it would fit the graph properly and the resulting parameters displayed will be correct. For producing a continues waveform, a while loop was used, it repeats the code within its subdiagram until a specific condition occurs.

For generating a real physical signal, was used a built in soundcard of the personal computer, by using the soundcard, were produced signals in the form of sound, trough the audio jack of the soundcard. On the computer that was used it was a **RealTek ALC269** soundcard. To configure the output of waveform generator into sound we added several VI's additionally to our block diagram and arrange them correctly for it to produce sound properly. Was used: *Sound Output Configure VI* . It configures a sound output device to generate data. Was used and *Sound Output Write VI.* It writes data to a sound output device. Both were used to configure the device if they are writing continuously. For the *polymorphic* VI was createed a control. And for the data not to get stacked and crash the system, at the end we must use a sound output clear VI.*Sound Output Clear VI.* It stops the device from playing sound, clears the buffer, returns the task to the default state, and clears the resources associated with the task. The following configuration as displayed on Fig. 3, was done. The corresponding front panel is given on the figure 4.The samping rate of the sound configure VI must be the same as the simulation block, so they were conected to one source of sampling rate input, for that reason was used a cluster bundle and a to long integer **I32** it converts a number to a 32-bit integer in the range $-(2^{31})$ to $(2^{31})-1$.

For measuring and observing the input sound signals was developed a system – **Measuring Tool** with **Oscilloscope and Spectrum Analyzer** in it**.** Was used function *Sound Input Configure VI.* It configures a sound input device to acquire data and send the data to the buffer. Was used also and *Sound Input Start VI* and *Sound Input Read (DBL)*, and *Sound Input Clear*. Stops acquisition of data, clears the buffer, returns the task to the default unconfigured state, and clears the resources associated with the task. At the Fig 3 is given the block diagram of the Virtual Functional Generator with 2 types outputs for real signals. At the Fig 4 is given the front panel of the Virtual Functional Generator with 2 types outputs for real signals.

For multi-channel sound data, data is an array of waveforms where each element of the array is a single channel. We indexed the channels, with 0 and 1, by this now the resulting image on the other two graphs that we have attached will be different and not distorted, with the parameters we have set from the other device. For the measurements of amplitude, frequency, total harmonic distortion and the signal-to-noise and distortion ratio was added *Distortion Measurement VI*. The final front panel is given at the Fig.5. The experiments were conducted with generating with the developed virtual system some real output signals –with Sine, Triangular, Sawtooth and Square

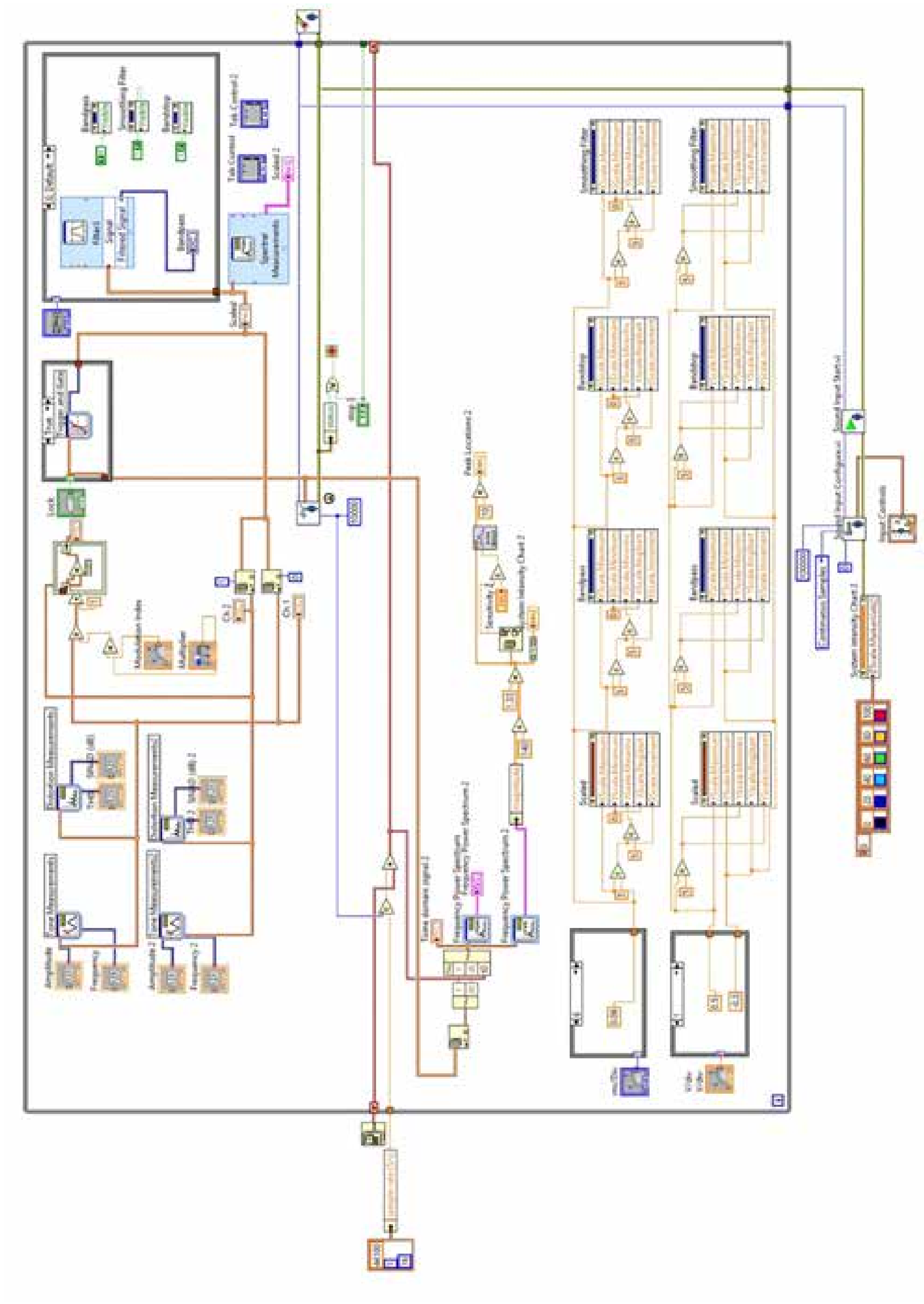


Fig.3. The block diagram of the Virtual Functional Generator with 2 types outputs for real signals

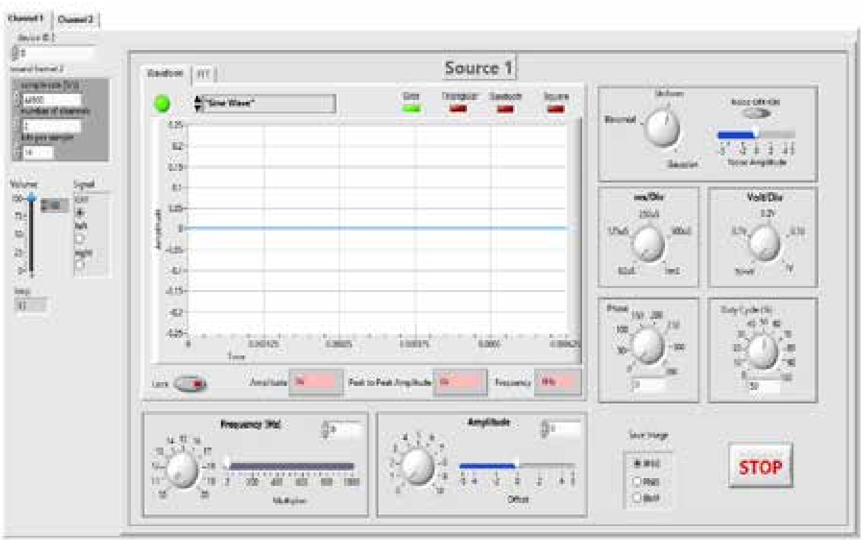


Fig.4. The Front Panel of the Virtual Functional Generator with 2 types outputs for real signals.

waveform, was realized multi-source input/output, were done different types of modulation, were measured properties of of the generated signals and compared with real professional measurement instrument.

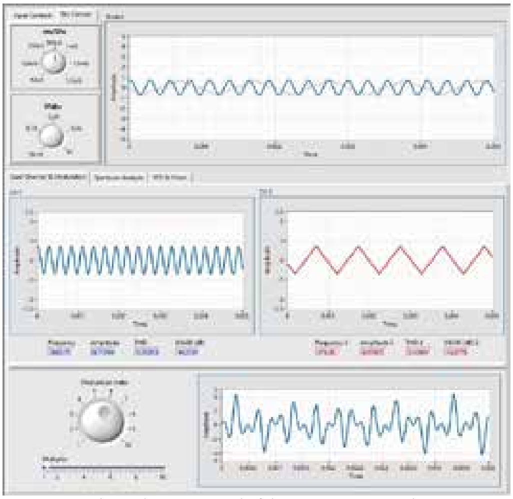


Fig.5. The Front Panel of the Measurement Tool.

At Fig. 5 are shown some results from experiments – usage of the Oscilloscope and Spectrum Analyzer. On the front panel of the Measurement Tool is shown the two-source input and modulation tab open, used for the measuring and observing the two real input signals generated from the same Virtual System but with another front panel.

At Fig. 6 is shown the same Measurement tool with Spectrum Analyzer tab open.

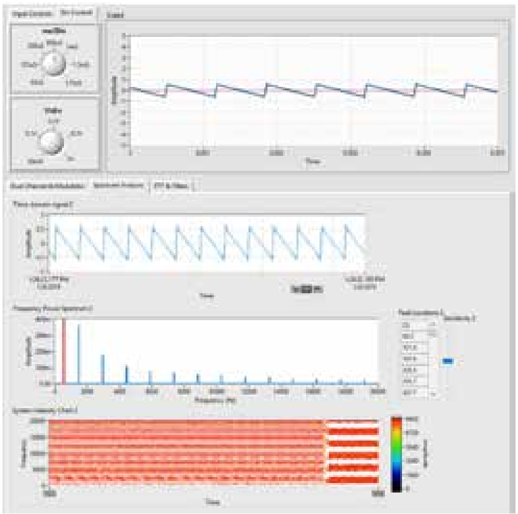
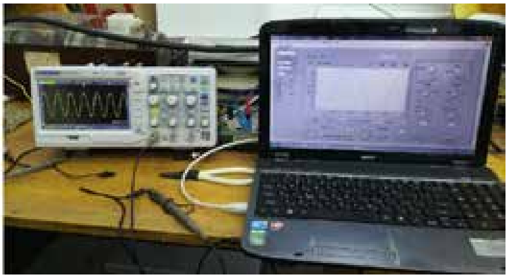


Fig.6. The Front Panel of the Measurement tool

To validate that both Generator and Measurement Tool are working properly, and the generated signals are created with the correct waveform and amplitude, was used a real technical Oscilloscope **Siglent SDS1052DL 50MHz**. First, the signal of the waveform "Sine Wave" was chosen, with frequency 160 Hz and with the amplitude of 1V from the front panel of the developed Virtual System.The measured results done with the Measurement Tool are: measured frequency 159,995Hz, so the absolute error is 0,005Hz and the relative error is 31ppm; measured amplitude is 0,99V, so the absolute error is 0,01V and the relative error is 1%. These error can be attributed to the quality of the cable we are using for the data transfer and differences in production of the two ADC units on the two devices. The validation measurements



were done with real Oscilloscope Siglent and at Fig.7 is given the picture of them, at Fig.8 only the screen of the Oscilloscope Siglent.

Fig.7. The validation experiments with Oscilloscope Siglent.

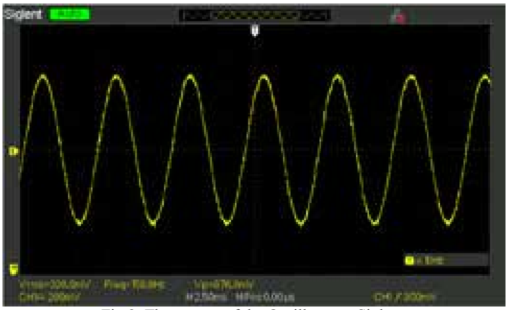


Fig.8. The screen of the Oscilloscope Siglent.

The measured results are: measured frequency 159,9Hz, so the absolute error is 0,1Hz and the relative error is 0,063%; measured amplitude is 0,976V, so the absolute error is 0,024V and the relative error is 2,4%. The same was done for the "triangular wave" generated signal.

The results:

From Virtual Functional Generator of the real signals.

Frequency: 1,1kHz

Amplitude: 1V

Measured Values with developed Measurement Tool.

Frequency: 1,099kHz, abs. er. is 0,001, rel. error is 0,9%

Amplitude: 0,988V, abs. error is 0,012, rel. error is 1,2%

Measured Values with Oscilloscope Siglent.

Frequency: 1,1kHz, abs. error is 0,00, rel. error is 0,0%

Amplitude: 0,952V, abs. error is 0,048, rel. error is 4,8%

A lots of other validation experiments were done, for different type if generated real signals and for combination of the two output real signals. All approved that the developed Virtual System works absolutely correctly.

Conclusion

First - a Virtual Function Generator with two real outputs signals using an ADC-module built in the computer has been developed. Second - a virtual Measurement Tool for the generated real output signals has been developed also. Third - the applicability of the them has been proven. According to the results, we can conclude that the Functional Generator and the Measurement Tool, both based on virtual instrument technology can meet the requirements of high-precision and stable low and medium frequency in many fields. Different type of frequencis, amplitudes and waveforms of the output of the developed Virtual Functional Generator can be set through PC control panel and generated signals through the ADC-modules output, could be measured with developed Measurement Tool. The generation of signals is an important in development and in troubleshootingof electronic devices. The generator is used to provide known test conditions for the performance evaluation of electronic system design and for replacing signals that are missing in systems during repairing work, it can be used test an electrical or electronic circuit to generate periodic signals, for computers and control system it can work as a timer. And as well for the oscilloscope and spectrum analyzer it can be used for a number of applications and in a number of different industries.

Some examples of professionals who use oscilloscopes are automotive mechanics, medical researchers, electronics companies and physicists. Oscilloscopes are an absolutely integral tool for those designing, testing, or repairing electronic equipment. Aside from their applicability in these different industries, they are probably best suited for educational purposes in the fields of electronics, measurement systems and automotive electronics, each school or university in these fields, can take the advantage and teach their students with it, with a progressive method, that doesn't require separate equipment or laboratories, but everything can be thought and done from one room and one device. From an economical point of view, we have developed a tool that is functional, user friendly and relatively cheap compared to the overall market, it can be easily used in the work place or classroom without any additional components, directly with the most common device, the computer.

Acknowledgment

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Measurement System for Engine Cylinder Roundness Assessment – accuracy analysis

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Abstract — **The presented paper is a continuation of research which was conducted and presented in the previous articles. The focus of the paper is to present the metrological limitation of the application of the three-point method in the measurement system dedicated to measuring the roundness of the inner surface. The paper presents simulations showing the influence of mechanics and algorithm on the accuracy of the device. The simulations are made using CAD software. The results and analysis could be used to further investigations and development of systems based on the three-point method as well as help designers who want to design devices to measure roundness based on the three-point method.**

Keywords — precision, measurement, accuracy, roundness, automation

I. INTRODUCTION

The measurement of shape errors in the automotive industry is a crucial problem [1]. The measurement and evaluation of cylindricity errors are essential to ensure proper assembly and excellent performance of the internal combustion engines [2]. Advanced measurement methods are considered the most crucial requirement to produce industrial goods such as the cylinders and pistons [3]. Since the cylinder and piston are the main working couples of the internal combustion engine, the measurement of those details must be fast and accurate. To ensure the best quality of the part, many producers would like to control 100% of produced parts. This kind of control required finding new fast and efficient methods of roundness and cylindricity measurements.

Various methods are applied for the out-of-roundness assessment [4]. One of the used methods is the three-point method [5,6]. The V-block measurement of cylindricity and roundness proved to be accurate and useful [7]. Most of the research concentrate on the measurement of outer cylindrical surfaces [8]. The inner surface measurement principles are the same as the outer surface. Nevertheless, the mechanical setup of the measuring device is more complex, and this makes measurement systems more challenging to design.

Going ahead the industrial need there were designed and built the system to measure the motor cylinder of the truck engine with diameter range 131mm. The prototype device is using three-point symmetrical method and contacts incremental gauges [9]. The design is patented [10], and the prototype was presented on many international exhibitions, among others in Seoul and Brussel. The measurement system was designed for quick and inexpensive measurement and roundness assessment, especially suitable for the combustion engine industry.

The built and checked prototype proved that the main constructional and data processing assumptions were made correctly. The method of measurement based on the modified V-block principle provided good results, even though it is not widely applied in industrial cylindricity and roundness measurement. The reasonable overall expenses indicate that the measurement system may provide quick and accurate measurement for the low price in the dedicated industrial application. The archived accuracy is ±1.5 μm.

The presented paper is a continuation of research which was conducted and presented in the previous papers [9, 11]. The focus of the paper is to present the metrological limitation of the application of the three-point method in the measurement system dedicated to measuring the roundness of the inner surface. There are presented theoretical calculations and simulations. The scope of the conducted simulations is to show the influence of the critical dimensions of the measuring head on the measurement of the roundness. The results and analysis could be used to further investigation and development of systems based on the three-point method as well as help designers of a measuring system.

II. METHODS OF ROUNDNESS MEASUREMENT

A. *Rotational datum method*

The most used roundness measurement machines are using the radial method. They could be divided into two primary groups: rotary sensor and rotary table instruments. These types of measuring devices are characterized by high measuring precision. The roundness could be measured in a scale of nanometers [12]. Radial methods are commonly used in laboratories when measuring conditions are strictly controlled. The price of machines based on this principle is high compared to other methods. This method is the reference method for other methods and was used to collect the reference profile for simulations.

B. *Three points method*

Another way of measuring roundness are V-block methods. These methods could be used in industry, for example, directly on the production line [13]. The requirements of mechanical setup for application of these methods are lower than the radial method, but archived uncertainty is lower, even up to 20% [14]. The type of the method depends on location and number of measuring and base points. [12]. The location of these points is defined by two angles: α and β. These angles are called parameters of the method. In Fig. 1 there is presented two possible setups of measurement using three points: two base points and one measurement point. Fig. 1 a) is presenting the symmetrical method, Fig. 1 b) non-symmetrical method. Both of them found an industrial application. The application of the symmetrical method is more straightforward from the manufacturing point of view but has more metrological limitation connected with the recognition of harmonics of the signal.

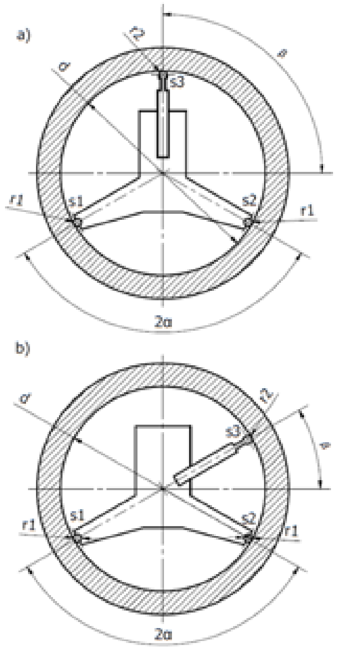

Fig. 1. The geometry of the head for v-block method measurement. s1, s2 – base points, s3 – measurement point, α, β – parameters of the method, r1, r1 - contact measuring tip radius, r2 – measuring probe tip radius, d – diameter of measured detail.

The measurement using three-point methods are not giving the value of roundness and profile of the measured piece directly. During the rotation, the head has to be in contact with the surface through base points s1 and s2. Meanwhile, the profile is collected by a touch probe which is measuring the change of the radius in point s3. Collected data must be processed by an algorithm which transforms measured profile into the reconstructed profile [7]. The transformation is made by presenting the measured profile in the form of complex Fourier series and multiplying the harmonics of the signal by the detectability coefficients, which depends on parameters of method α and β. The algorithm which covers the symmetrical method was presented in the details in previous articles [9,11]. In the case of measuring with the non-symmetrical method, the detectability coefficients have to be calculated by the more complex following formula [7]:

$$\breve{K}_n = e^{in\beta} - \frac{1}{2}e^{ina}\left[\frac{\cos\beta}{\cos a} + \frac{\sin\beta}{\sin\alpha}\right] + \frac{1}{2}(-1)^n e^{-ina}\left[-\frac{\cos\beta}{\cos a} + \frac{\sin\beta}{\sin\alpha}\right], \quad (1)$$

The choice of the parameters of the method is crucial because it defines detectability coefficients. The coefficients should be possibly equal in value and be higher than 0.5. The coefficients with value 0 cause that harmonic corresponding to this coefficient will be not recognized during the measurement, and the profile will be reconstructed without this harmonic. In this case, the reconstructed profile will be not complete and measured roundness value fraught with errors.

In Fig. 2, there are presented detectability coefficients for three widely used groups of parameters used in three-points measurements. There are presented the coefficients for harmonics from 2-15 because they respond for the roundness of the measured profile. The blue color represents the symmetrical method. Using this method, the coefficients of 11th and 13th harmonic have value 0. It means that, if the profile consists of these harmonics, they will be not recognized. A similar situation is observed in a non-symmetrical method with angles: $\alpha=60^0$, $\beta=30^0$. Fig. 2. is showing that from the shown groups of parameters only method with parameters $\alpha=60^0$ and $\beta=33^0$ could ensure proper measurement of roundness. Although the other methods could be applied in case when harmonics are known, and values of the 11th and 13th harmonic do not occur in the profile.

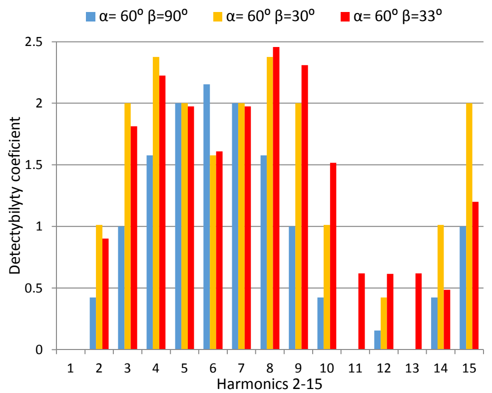

Fig. 2. Values of the detectability coefficients for different values of the angels α and β.

III. Design of Measurement System

The device based on the three-point method is a kind of specialized system. The idea behind this kind of system is to use it on the production line and control all of the produced pieces. Because of these, it is important to mention that the concept of the system is universal and could be applied for many different pieces, but the specific device is designed to measure only the one diameter. In the presented case, it is 131mm. One of the good practice is to know the harmonics which dominated in the profile of the measured piece. Usually, they are typical for all pieces from series because they depend on the technological process of production cylinder. This information helps to choose the proper values of parameters.

From a mechanical point of view, there are possible two solutions to realize measurement. The first is to rotate the cylinder, second to rotate the head of the device. The author's experience with developing both types of devices shows that both of them have some advantages and disadvantages, and there is not possible to decide which solution is better. The decision could depend on many factors like the size and weight of the measured piece, diameter, expected levels of measurement, or value of predicted roundness.

The mechanical design of the measurement system is presented in the schematic drawing (Fig. 3). The operator is locating the cylinder (4) on the table (5), and the measurement process continues automatically. The measuring head (10) is moving up, down, and rotating. The system could measure the roundness on multiple numbers of levels. A supportive beam (22) is connected to the aluminum frame (6). There is a possibility to adjust the angle between the measuring plate (5) and the supportive beam which allows adjusting the angle between the plane of measuring head (10) and measuring plate (5).

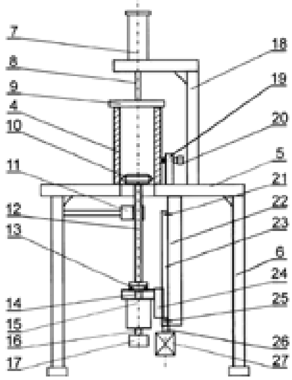

Fig. 3. Schemat of measuring system based on V-base method [10]. The system consists of 4 – Cylinder, 5 – measurement plate, 6 – frame, 7 – pneumatic piston, 8 – rod, 9 – clamping plate, 10 – measuring head, 11 – bearing, 12 – rod, 14 – clutch, 15 – motor, 16 – clutch, 17 – encoder, 18 – top frame, 19 – columns, 20 – screws for positioning, 21 – top position sensor, 22 – supportive beam, 23 – linear module, 24 – adapter, 25 – bottom position sensor, 26 – clutch, 27 – motor [10].

The initial concept of developing a device based on the three-point method was based on the thesis that mechanical setup necessary to apply this method is not so complicated and requirements of the precision of the mechanics are not high. The theory is true but mainly for outer surface measurement, when setup could be simplified. In the inner surface measurements, the mechanical setup is more complicated and has to be more precise. Another limitation is the space inside the measured piece. Because of this three-point method with the presented setup could be applied rather for pieces with a diameter above 100 mm. For smaller diameters possible could be the application of the three-point method based on the pneumatic measurement principle [12].

The constant contact of measuring head during measurement with the measured surface is realized with X-Y rails, four springs, and pneumatic actuator. When the head is idle and is moving to achieve the measuring position, the springs are keeping the head in the middle of the measured piece. During the measurement process, the pneumatic actuator is moving the main part of the head and forcing contact between the base points and measured surface. The same moment the touch probe is starting to touch the measured surface and the head is starting to rotate. After one resolution, the probe and pneumatic actuator is released, and the head could move to another level of measurement. In Fig. 4 there are presented head during the measurement of the reference piece.

Fig. 4. Measuring head during measurement of reference ring. [9]

IV. Results of simulations

A. *Scope of simulation*

The application of the three-point measurement method for measuring the inner surface is more complicated than for measuring the outer surface. The reason is the more complex design of the measuring head. The design of the head and the accuracy of the manufacturing could be critical. Therefore there were performed the simulations which will present the influence of inaccuracy of the manufacturing of the measurement head on the value of the roundness and harmonics 2-15 of the measured profile.

In the simulation, there were taken 3 possible dimensional inaccuracies and its influence: the inaccurate value of angle α, the inaccurate value of angle β, the inaccurate length of arms defining base points s1 and s2. The simulation is presenting a combination of all dimensional inaccuracies. The second simulation shows the influence of the non-perpendicularity between the surface of the measuring head and axis of the measured piece. This is called tilt of the measuring head.

The head used in the simulation is design to measure the diameter 131mm, what is responding to the real cylinders used in the combustion engines for the trucks. The profile used for the simulation is taken from the reference cylinder, which was measured on the high class measuring machine Hommel Roundscan 535.

B. *Methodology of simulation*

The measurement was simulated with parametric CAD software Autodesk Inventor. The prepared model lets to simulate different profiles of roundness, parameters of method α and β, length of measuring arms, the different diameter of the measured part, and accuracy of the measuring probe. There are used iLogic module which is built in CAD software. This module allows automatizing the process of collecting data. The model of the simulation is presented in Fig 5.

Before starting the simulation, the user has to set up all of the parameters of the simulation, like: α, β, D, l1, l2. The value of the p1 is the result of the simulation, and it is stored by CAD software in the text file. The simulated profile is defined directly in CAD software with function, which allows defining the curve based on the equation in the polar coordinate system.

There are stored 1024 points per one resolution. The position of the head is controlled by a program which is incrementing parameter P. The simulation allows changing the angle between the surface of the measurement and axis of the cylinder. This angle is called the tilt of the measuring head. This allows simulating a situation when the head is tilted, and the measuring system is measuring not a circle but an ellipse.

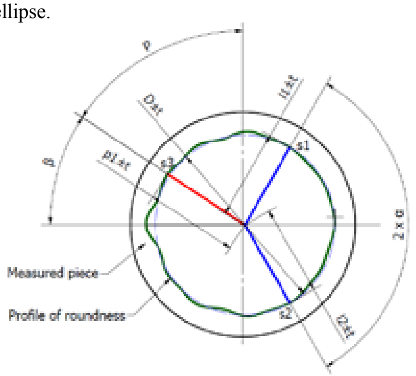

Fig. 5. Schemat of simulation conducted in Autodesk Inventor using parameters: α and β – parameters of the method, D – diameter of measured piece, s1 and s2 – base points, s3 – measurement point, l1,l2 – length of the arm of the head, p1 – measuring probe indication, P – position of the head, t – tolerance (separate for each dimension).

The text file is stored on the hard disc and after this analyze by a separate program wrote in Visual Basic. This program is based on available algorithms presented by other researchers [7]. The result of the calculation is a real profile. After this, there are calculate the roundness and harmonics. This is base to conduct the simulation with different parameter and compare them between each other.

C. *Results of simulation*

There are presented results of two simulations: influence of the measuring head geometrical inaccuracies and influence of the tilt of the measuring head.

Fig. 6 shows the comparison between simulations of measured reference profile with three different head geometry: original, modified 1 and modified 2. Original geometry represents simulation with ideal geometry without any inaccuracies. Modified 1 and modified 2 geometries have changed parameters of measurements. The modified parameters are α, β, l1, and l2. The values are presented in Table 1.

TABLE I. PARAMETERS USED IN SIMULATION

Parameter	Original	Modified 1	Modified 2
2α [°]	120	120,5	119
β [°]	33	33,5	32
l1 [mm]	65.50	65.52	65.55
l2 [mm]	65.50	65.48	65.45

The results of simulation show that even major deviations in the dimensions of the measuring head have not a major influence on the results as harmonics. The bigger influence is visible on, the higher harmonics from 8 to 15, especially in simulation defines as modification 2, where the deviations of the parameters are a big comparison to the accuracy possible to achieve with the machining of the head. The comparison of the roundness values RONt is shown in Fig 8. The comparison regarding simulation 1 shows that values of roundness increased in the worst case 9%.

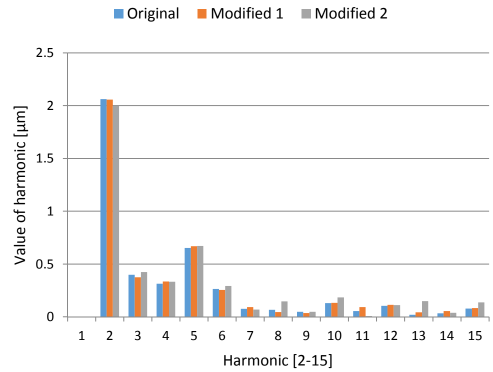

Fig. 6. Values of the detectability coefficients for different values of the angels α and β.

The second simulation shows the influence of the tilting of the measuring head. In this case, the head is measuring the ellipse. Fig. 7 shows the harmonics with different values of the tilt of the head. The simulation was conducted with 4 different values of tilt: 0°, 0.1°, 0.2°, and 0.5°. The biggest influence of the tilt is visible on the second harmonic. The other harmonics are not influenced. Although in the analyze case, this has a big influence on the value of the roundness calculated in simulation (Fig. 8). The reason is that the second harmonic is the main harmonic in the analyze profile. The tilt of the head is causing the increase of the roundness.

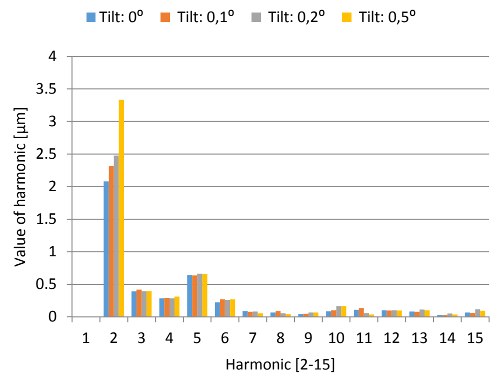

Fig. 7. Values of the detectability coefficients for different values of the angels α and β.

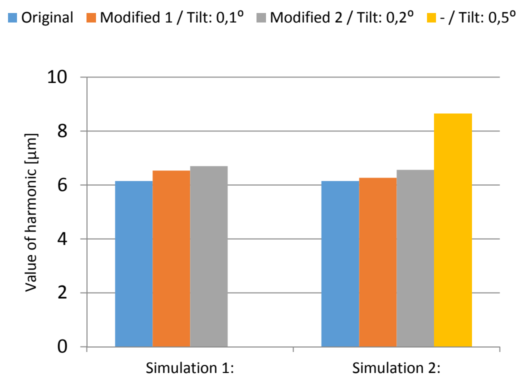

Fig. 8. Values of the detectability coefficients for different values of the angels α and β.

V. Conclusions

The presented results of simulations show only part of the research conducted over the measurement of roundness of the inner surfaces. The two simulations show what influence on results has dimensional precision of manufacturing the head. It is visible that the changes in the dimensions influence the precision of the system. The bigger influence is noticed in the second simulation, but results could depend on the harmonics of a particular profile.

The results of the first simulation show that to increase the accuracy of the system is recommended to measure each of the measuring head and compensate the manufacturing inaccuracies with correcting the values of parameters in the software calculating real profile. The correction will let to minimize the inaccuracies.

The results of the second simulation show that the tilt of the measuring head has an influence on the second harmonic and each system should be equipped with the possibility of the leveling the head to the axis of the measured piece. The leveling should be made for each system separately during the production.

Generally, results show that the simulation of the three-point method measurement is useful and seems to be good practice to simulate the measuring head during the design process. Simulations let to use the profile of the piece collected from the real samples and based on this, adjust the parameters of the method.

The research should go in the direction to improve the model of the simulation to achieve more accurate results and cover more possible cases of inaccuracies.

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MEASUREMENT OF THE CLOSING FORCE AT AUTOMATIC CLOSING BOTTLES WITH SCREW CAPS

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Abstract - **The article explores the influence of the applied torque onto closing the bottles with screw caps on the resulting closing force. By using a specialized stand, an experiment was conducted to measure the force generated at the automated closing. A graphical representation of the experiment's results is proposed.**

Keywords - automation, screw caps, experiment, closing force

I. INTRODUCTION

At present, the multiple opening and closing of the fluid storage vessels is achieved by using screw caps. They were patented in 1904 [1]. For that purpose, thread is made in the cap and the closed hole, which allows the cap to be screwed to the container after it is filled and subsequently repeatedly screwed and unscrewed as well as necessary.

The closing force is realized by screwing the screw cap to the hole of the container. She provides the airtightness necessary to store the product in the container.

The problems here are related to the inadequate closing force, which will result in loss of the stored product or the formation of too much closing force, which will make opening difficult.

The scheme for determining the closing force is shown in Fig. 1 [2].

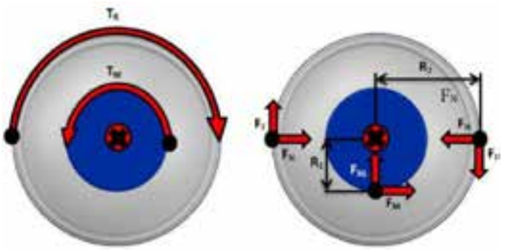

Fig. 1. The scheme for determining the closing force

In this scheme:
T_M – applied torque;
T_R – required torque;
F_M – required radial closing force;
F_N – axial force;
F_F – friction force;
R_1 – radius of the neck of the hole;
R_2 – thread radius.

The required torque for opening a PET bottle with mineral water closed with a plastic screw cap according to [2] is 791 [Nmm]. When the bottle is improperly closed, a problem with opening by the end user is appears.

The purpose of this work is to determine the effect that the application time of applied torque for closing bottles with screw caps has on the resulting closing's moment.

II. TEST-RIG FOR MEASUREMENT OF APPLIED TORQUE

In order to achieve this goal, a test-rig for testing the parameters of the process of automated closure of bottles with screw caps was developed. A 3D model and the general appearance of the test-rig are shown in Fig.2. Its main components are:

- Linear conveyor Fig.2 position 1 - a linear conveyor of the company "SPV" is selected;
- Closing head Fig.2 position 2 - newly designed;;
- Magazine collector Fig.2 position 3 - newly designed, with a slot for the storage of a specific type of caps;
- Module for vertical movement Fig.2 position 4 - newly designed, including pneumatic cylinder Festo DSNU-16-30-P-A;
- Position sensor Fig.2 position 5 - IFM KG5057 position sensor is selected;
- Closing head actuator Fig.2 position 6 - the servomotor MTR-DCI-42 is selected;
- Controller Fig.2 position 7 – Programmable Logical Controller PLC SIMATIC S7-1200 is selected;
- Controlling system Fig.2 position 8 - installed on the PC this newly developed system includes:
  - "NS3" program for controlling the servo motor MTR-DCI-42 and recording the data from the conducted tests;
  - created with the S7 "TIA portal" program, to control the developed test-rig.

The developed test-rig`s control system supports two modes of operation:

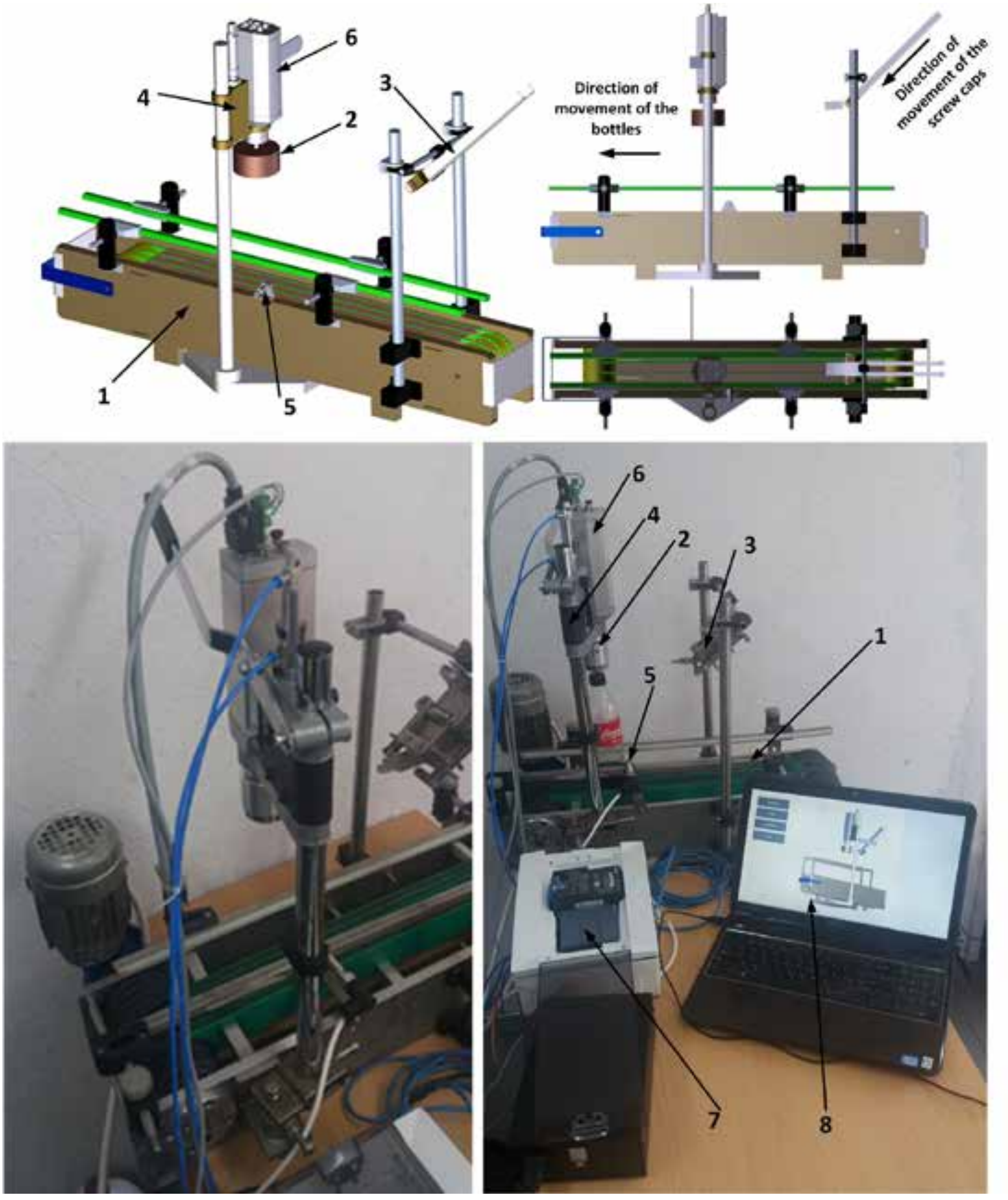

Fig. 2. 3D model and the general appearance of the test-rig

- "Manual" - Used to set up each module on the test-rig. In this mode parameters such as speed, time, capacity, etc. are set. After setting and entering parameters, the program environment has the option to explore each module independently of others.
- "Automatic" - Serves for automatic execution of the closure cycle of bottles with screw caps.

Before starting work in this mode, it is necessary to check all parameters and make their settings in "Manual" mode.

Modules that can be operated in Manual mode are: Linear Conveyor; a closing head and a vertical movement module.

The developed test-rig allows to examine all separate aspects of the process of automated closure of bottles with screw caps and the process as a whole.

The time for screwing of the caps is set to [ms].

It depends on the design of the cap and the bottle, and can be changed in the range of ***0,5÷15*** [s].

The construction of the test-rig allows it to be used to examine the process of closing bottles of different shapes and sizes with different size screw caps.

III. Implementation of the experiment

The developed test-rig is used to determine the dependence between the application time of applied torque for closing bottles with screw caps has on the resulting closing's moment.

The experiment proceeds in the following order:

1. Adjust the mechanical part of the test-rig for a particular bottle and cap.
2. Initial initialization of the control system on the test-rig.
3. In "Manual" mode, the closing time is set.
4. The bottle is put manually into the closing position.
5. The closing process is started.
6. After the set closing time has elapsed, the closing head automatically returns to the starting position.
7. The maximum torque reached is recorded by the control system.
8. Visual inspection of the closure result is made.

The visual control aims is to determine whether:

- the applied torque is insufficient - the cap is not fully screwed and the bottle is incorrectly closed;
- the applied torque is too great - there are mechanical damage to the cap or the closed bottle.

The experiment was conducted with a ***0,5*** [l] bottle for a soft drink and involved a series of ***100*** attempts with a closure duration:

0,5 [s], ***1*** [s], ***2*** [s], ***3*** [s] и ***4*** [s].

The visual check of the closing result found that on a closing time:

- ***0,5*** [s] in over ***95%*** of attempts, we have incorrect closure of the bottle due to not fully screwed cap;
- from ***1*** [s] to ***3*** [s] we have 100% correct closure of the bottles;
- ***4*** [s] in over 80% of the attempts, we have incorrect closure of the bottles as a result of rewinding the cap due to the too much applied torque.

Some of the experimental results obtained at closure times ***1*** [s], ***2*** [s] and ***3*** [s] are shown in Table I.

TABLE I. Experimental results

Attempt Number	Applied torque [Nm]		
	Time 1 [s]	***Time 2 [s]***	***Time 3 [s]***
1	3,1	8,4	11,1
2	4,3	5,8	11,3
3	1,6	6,8	11,6
4	1,1	6,7	11
5	5,9	6,2	11,9
6	3,1	4,3	11,1
7	2,1	5,1	11,1
…..	…..	…..	…..
50	4,8	5,7	11,8
51	4,4	9,1	11
52	3,5	6,3	11,5
53	3,1	5,7	11,1
54	2,2	5,1	12,3
55	3,1	8,8	11,1
…..	…..	…..	…..
94	9	6,6	11,2
95	4,8	11,5	11,8
96	3,5	8,1	11,5
97	2,1	5,8	11,1
98	3,5	8,1	11,5
99	1,6	5,9	11,6
100	3,2	6,8	11

IV. Processing of obtained results

Statistical processing of the experimental results was performed, assuming hypothesis for a normal distribution [3, 4].

Processing takes place in the following order:

A. Separating data into classes

The results obtained for the applied torque are divided according to (1).

values obtained x_i
i=***1, 2, ……., 100***

number of classes k = ***5***

intervals length:

h=***2*** [Nm] for times *1* [s] и *2* [s]
h=***0,5*** [Nm] for time *3* [s] (1)

Limit values for the determined intervals are given in Table. II.

TABLE II. Limit values for the determined intervals

Class k	Limit values of intervals $x_{i-1}÷x_i$		
	Time 1 [s]	***Time 2 [s]***	***Time 3 [s]***
1	1÷3	4÷6	10÷10,5
2	3÷5	6÷8	10,5÷11
3	5÷7	8÷10	11÷11,5
4	7÷9	10÷12	11,5÷12
5	9÷11	12÷14	12÷12,5

The defined frequencies v_i for each of the specified intervals are given in Table. III.

TABLE III. Frequencies of values in the intervals

Class k	Frequencies of values in intervals v_i		
	Time 1 [s]	***Time 2 [s]***	***Time 3 [s]***
1	50	8	5
2	36	46	18
3	9	38	53
4	3	7	17
5	3	1	7

B. Calculation of the arithmetic average value

For determining the arithmetic average, formula (2) is used.

$$\overline{x}=\frac{\sum_{i=1}^{k}\overline{x_i}v_i}{\sum_{i=1}^{k}v_i} \qquad (2)$$

The determined arithmetic average values for the measured applied torque are given in Table. IV.

TABLE IV. ARITHMETIC AVERAGE VALUES FOR THE MEASURED APPLIED TORQUE

Class k	Arithmetic average value [Nm]		
	Time 1 [s]	***Time 2 [s]***	***Time 3 [s]***
$\overline{x_1}$	2,17	5,14	10,36
$\overline{x_2}$	3,77	6,99	10,89
$\overline{x_3}$	6,18	8,83	11,26
$\overline{x_4}$	7,93	10,97	11,74
x_5	10,03	12,70	12,29
$\overline{x}$	**3,50**	**7,88**	**11,3**

C. Calculation of the average dispersion

For the determination of the average dispersion, formula (3) is used.

$$s^2=\frac{\sum_{i=1}^{k}\overline{x_i}^2v_i}{\sum_{i=1}^{k}v_i}-\overline{x}^2 \qquad (3)$$

The determined average dispersions for the closure times studied are:

- Closure time ***1*** [s] ***3,92***;
- Closure time ***2*** [s] ***2,21***;
- Closure time ***3*** [s] ***0,18***;

D. Calculation of the normalized dispersion

For determination of the normalized dispersion, formula (4) is used.

$$t_i=\frac{|\overline{x_i}-\overline{x}|}{s} \qquad (4)$$

The determined normalized dispersions t_i for each of the specified intervals are given in Table. V.

TABLE V. NORMALIZED DISPERSIONS

Class к	Normalized dispersions t_i		
	Time 1 [s]	***Time 2 [s]***	***Time 3 [s]***
1	0,72	1,84	2,25
2	0,15	0,60	0,97
3	1,15	0,64	0,10
4	2,40	2,08	1,02
5	3,53	3,24	2,34

E. Determination the tabulated values of the normalized dispersions

Determination is done using statistical tables [5]. The determined values are given in Table VI.

TABLE VI. TABULATED NORMALIZED DISPERSIONS

Клас к	Tabulated normalized dispersions $f(t_i)$		
	Time 1 [s]	***Time 2 [s]***	***Time 3 [s]***
1	0,76420	0,96710	0,98780
2	0,55960	0,72580	0,83400
3	0,92650	0,73890	0,53980
4	0,99180	0,98120	0,85310
5	0,99980	0,99939	0,99040

F. Determination of the theoretical frequencies

The determination of the theoretical frequencies is done by formula (5).

$$v_{ti}=\frac{nh}{s}f(t) \qquad (5)$$

The determined theoretical frequencies v_{ti} of the values for each of the specified intervals are given in Table VII.

TABLE VII. THEORETICAL FREQUENCIES OF THE VALUES FOR THE INTERVALSE

Class к	Theoretical frequencies of the values for the intervals v_{ti}		
	Time 1 [s]	***Time 2 [s]***	***Time 3 [s]***
1	41	8	5
2	21	46	18
3	9	38	53
4	3	7	17
5	3	1	7

V. GRAPHIC INTERPRETATION OF THE RECEIVED RESULTS

The graphical representation of the obtained experimental results was made using the data given in Table III and Table VII [6, 7].

Closing duration results:

for duration 1 [s] are shown on Fig. 3;
for duration 2 [s] are shown on Fig. 4;
for duration 3 [s] are shown on Fig. 5.

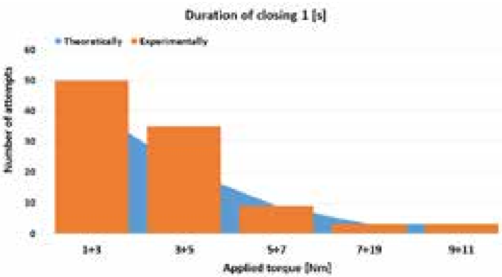

Fig. 3. Applied torques received during the duration ***1*** [s]

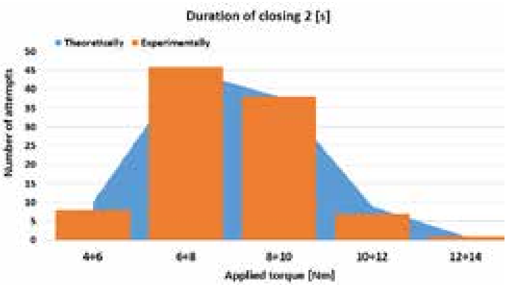

Fig. 4. Applied torques received during the duration ***2*** [s]

The resulting applied torques at closing time ***1*** [s] do not meet the standard normal distribution.

The resulting applied torques at closing times ***2*** [s] and ***3*** [s] correspond to the hypothesis of standard normal distribution.

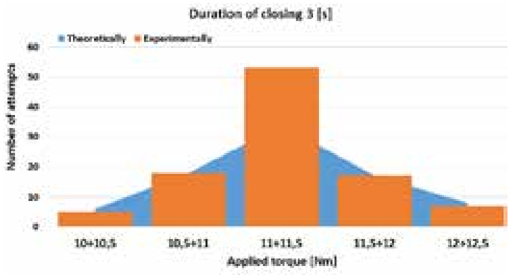

Fig. 5. Applied torques received during the duration***3*** [s]

With a closing time of ***2*** [s] in ***85%*** of cases, the applied torque is between ***6*** [Nm] and ***10*** [Nm].

With a closing time of ***3*** [s] in ***90%***, the applied torque is between ***10,5*** [Nm] and ***12*** [Nm].

VI. CONCLUSIONS

The obtained results allow to make the following conclusions:

With a closing time below ***1*** [s], the applied torques are insufficient, resulting in incomplete screwed of the caps are obtained.

With a closing time of ***1*** [s], the applied torques varies within a wide range of ***1,1*** [Nm] to ***10,5*** [Nm], which creates prerequisites for screwing the caps with difficult predictable forces.

With a closing time of ***2*** [s] or ***3*** [s], the applied torques have normal distribution and average values of ***7,88*** [Nm] and ***11,3*** [Nm] respectively.

With a closing time of more than ***3*** [s], a too large applied torques are produced, resulting in rewinding of the caps.

The best results are obtained at a closing time of ***3*** [s]. In this case, in over ***95%*** of attempts, the applied torques is ***11,3±1*** [Nm], which ensures complete screwing of the caps without the danger of rewinding.

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The problem of the formation of the normalized unbalance when carrying out accounting transactions of petroleum products

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***Abstract*—The problem of the formation of a normalized unbalance during the accounting operations of petroleum products is considered, its relevance and the need for a speedy solution are emphasized. Identified sources of measurement uncertainty, causing the occurrence of unbalance. Recommendations for taking into account unbalance when developing new regulatory documents in the oil sector are given.**

Keywords— Unbalance, mass flow, volume flow, accounting operations of petroleum products, measurement uncertainty

I. THE ACTUALITY OF THE DISCUSSED QUESTION

The most important component of a single technological process of the country's oil industry, which provides uninterrupted supply of petroleum products to consumers in specified volumes, assortment and quality indicators, is petroleum products as the final link of vertically integrated companies in the “extraction – transportation – processing – distribution” chain. The most important role in this process belongs to the measurements of the quantity and quality (accounting) of petroleum products, which are carried out during storage and resource distribution at numerous metering stations, including fuel and lubricant depots, tank farms (NB), gas stations (AZS), etc.

Unbalance (debalance) – the actual amount of discrepancies between the mass of book balances of petroleum products and the measured mass of balances in the tank at the time of the accounting material balance.

The permissible difference is the permissible deviation in the results of determining the mass of the product from the Supplier and Consumer, or the donating and accepting parties, which is calculated taking into account the rate of natural loss, the average relative deviation and the error of the measurement method of both the Supplier and host party according to a consistent algorithm. The permissible amount of discrepancy is used in regulating the relationship between the Supplier and the Consumer, keeping the material balance, determining the mass value of the product to be reflected in the account.

The problem of forming a normalized unbalance during the accounting operations of petroleum products is the problem of metrological support of the whole process of “extraction – transportation – processing – distribution” in the conditions of the movement dynamics of the oil product and working measurement conditions.

The emergence of unbalance of petroleum products is illustrated in Fig. 1; for Fig. 1 marked: WB – waybill.

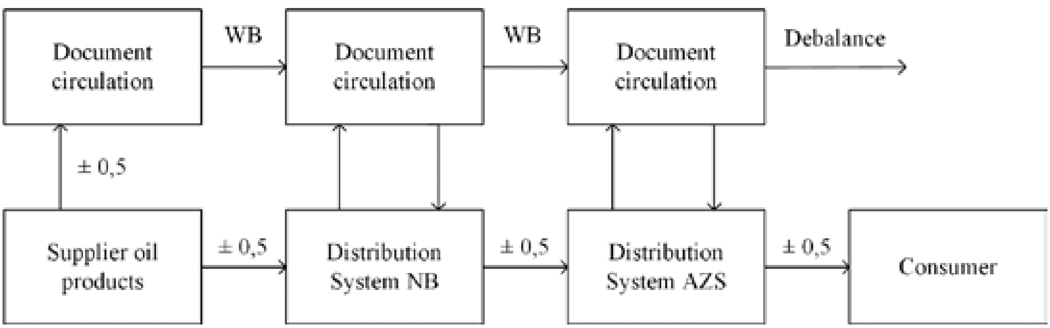

Fig. 1 Structural scheme of oil products supply to consumers of the Russian Federation

The unbalance occurs due to the lack of uniformity of measurements and the traceability of the unit of the petroleum product in the working conditions of the technological process of moving the product. Unbalance is something different as the accumulated (summary) uncertainty of measurements at all stages of resource accounting. The uncertainties of the input quantities in the first stage “extraction” of the chain “extraction – transportation – processing – distribution” contribute to the summary uncertainty at the output of this phase, which, in turn, represents the input uncertainty of the second phase “transportation”, contributing to its total budget output uncertainty. Similarly, for the next third and fourth stages of "processing" and "distribution" the accumulated stage-by-stage summary uncertainty causes the formation of unbalance of the oil product. The unbalance should be minimized by taking into account the action of the totality of the influencing variables that is uniquely formed at any given time and space on the unit of oil product transferred in stages. By correcting for the systematic error due to the effect of the influencing quantities, and the uncompensated part of which is attributed to the discharge of random error, the unbalance is minimized and its value approaches the normalized one.

The current lack of a scientifically based methodological connection between regulatory accounting documents that have the status of “absolute truth” and actual measurement results when moving petroleum products from the Supplier to the Consumer, which are probabilistic in nature, leads to the problem of normalized measurement of uncertainty of measurement results with the accompanying documents when conducting accounting and measurement operations. Going beyond the normalized limits of unbalance during accounting operations leads to significant economic losses both of the economic entities themselves and in the whole country [1]. Therefore, the problem of metrological linking the error of measurement results of the quantity and quality of petroleum products with the normalized accounting error in petroleum products during the technological movement of a resource from the Supplier to the Consumer is relevant, requiring a speedy solution.

II. PRACTICAL SIGNIFICANCE OF THE SOLVED PROBLEM

The solution of the intersectoral problem of accounting for petroleum products and minimizing unbalance eliminates unjustified losses in petroleum products supply, which, with a huge turnover of petroleum products, provides a significant economic effect. For example, at the first category of oil depots with a monthly turnover of 100,000 tons or more (Domodedovo, Pulkovo, Sheremetyevo and other airports) with a normalized relative error of supply of ± 0.5% (i.e. ± 500 tons) and the cost of aviation kerosene 50000 ÷ 60,000 rubles / ton. losses may occur in the range of 25 ÷ 30 million rubles per month, which is equivalent to $ 500,000.

III. SOURCES OF MEASUREMENT UNCERTAINTY THAT CONTRIBUTES TO THE UNBALANCE IN THE CONDUCT OF ACCOUNTING OPERATIONS OF PETROLEUM PRODUCTS

The lack of a unified approach to the problems of technological processes of reception, storage, supply and commercial accounting of petroleum products leads to an excessive variety of technical solutions and the lack of a unified systematic approach to metrological accounting of the resource and unification of measurement principles.

So, speaking of the principles of measurement, in a single technological process "extraction – transportation – processing – distribution" use:

– indirect dynamic mass measurements based on measurements of the density and volumetric flow rate of oil and its products;

– indirect static mass measurements based on measurements of the density and volume of oil and products of its processing in full capacity measures;

– indirect measurements based on the hydrostatic principle of measuring hydrostatic pressure and the level of oil and its products in capacity measures.

The main disadvantages of the existing regulatory documents in the oil sector, violating the RF Law “On ensuring the uniformity of measurements” and causing sources of measurement uncertainty, include:

– accounting operations under conditions of transition from one kind of physical quantity to another kind of physical quantity: accounting operations at gas stations are carried out under conditions of transition from mass - mass flow (when receiving and storing oil products) to volume - volume flow (when releasing resources), which results the incorrectness of the balance of goods;

– unresolved problem of reducing the commodity balance when conducting accounting operations between the results of actual measurements of the mass of petroleum products and the corresponding document flow;

– the lack of making appropriate amendments to the calibration characteristics of tanks to the effect of destabilizing factors, such as: temperature of heating of the walls in the field of oil product; the temperature of the petroleum product itself; oil product viscosity [2]; oil product filling level; the amount of drawdown of the bottom of the tank; overpressure of the gas space; hydraulic pressure value; deformability of steel vertical cylindrical tanks, leading to a change in volume [3]; the weight of the walls of the tank, bending moments arising from the difference in thickness of the shells that make up the tank;

– the absence of periodic calibrations of tanks with the introduction of appropriate amendments to their calibration characteristics on the action of the time factor, which causes: plastic irreversible deformations due to force effects during the operation of tanks; thinning of the walls of tanks, occurring in the process of rusting;

– lack of consideration of the effect of seasonal fluctuations in ambient temperature on the operation of the main pipeline and branches.

Identification of the fullest possible list of sources of measurement uncertainty, leading to unbalance during the accounting operations of petroleum products, will make it possible to justify the development of targeted measures to minimize their impact on the accuracy and reliability of accounting measurements. Revealed sources and budget assessment of measurement uncertainties in the process of “extraction – transportation – processing – distribution” of petroleum products should be taken into account when developing and implementing new regulatory documents in the oil sector.

IV. SYSTEM APPROACH TO THE METROLOGICAL SUPPORT OF THE TECHNOLOGICAL PROCESS "EXTRACTION – TRANSPORTATION – PROCESSING – DISTRIBUTION" OF OIL PRODUCT

A systematic approach to metrological support of the “extraction – transportation – processing – distribution” process and the traceability of an accepted unit of petroleum product by process steps can be considered by analogy with element-by-element calibration of the measuring system under operating conditions of its operation and transferring the unit of magnitude under these conditions [4–7].

To minimize unbalance, a unit of oil product, the nature of which is different at the transfer stages, should be transported, taking into account the values of the influencing quantities at each stage of the “extraction - transportation - processing - distribution” process, and taking into account the change in the nature of the unit of magnitude. Then, at each stage of the process, the unit of oil to be transported should be adjusted by adjusting for the effect of the uniquely established set of influencing quantities at a specific point in time and at a specific point in space, this will ensure the possibility of metrological traceability of the unit and minimize the value of the normalized unbalance when accounting for petroleum [8, 9]. The process of forming the unbalance of petroleum products is presented in table I.

The tremendous capabilities of modern information technologies make it possible to develop and implement automated information-measuring and control systems (AIMCS) for petroleum product accounting, as well as using the data-base and knowledge-base of these systems to improve the accounting methodology itself, which can significantly improve the accuracy of the measurement results. For this it is necessary to solve the following tasks:

– to develop and theoretically substantiate a new principle for constructing an automated information control system for accounting of oil products, eliminating the intersectoral problem of the occurrence of unnormal unbalance during accounting operations;

– to develop scientific and technical solutions for the creation of adaptive automated AIMCS accounting for oil products of a new generation;

– develop a methodology for performing measurements of automated AIMCS, aimed at reducing the total error of the metering station for oil products of the main oil pipeline, consisting of n-parallel connected mass flow meters [10];

– develop and theoretically substantiate the method of statistical evaluation of the effect of destabilizing factors on the accounting technology on the main oil pipeline, which allows to identify systematic and random errors in measuring the mass of oil products automated by the AIMCS of the Depositing and Receiving parties [11];

TABLE I THE FORMATION OF UNBALANCE OF PETROLEUM PRODUCTS

Parameters	**The technological process of "extraction – transportation – processing – distribution»**															
	Extraction				***Transportation***				***Processing***				***Distribution***			
	1				***2***				***3***				***4***			
Values of influencing quantities	X_{11}	X_{12}	…	X_{1f}	X_{21}	X_{22}	…	X_{2k}	X_{31}	X_{32}	…	X_{3q}	X_{41}	X_{42}	…	X_{4m}
The coefficient of the effect of influence quantity	β_{11}	β_{12}	…	β_{1f}	β_{21}	β_{21}	…	β_{2k}	β_{31}	β_{32}	…	β_{3q}	β_{41}	β_{42}	…	β_{4m}
Unit of oil product at the entrance	Y_1				Y_2				Y_3				Y_4			
Unit of oil product at the output	Z_1				Z_2				Z_3				Z_4			
Amendment for the effect of influencing quantities	∇_1				$\boldsymbol{\nabla_2}$				$\boldsymbol{\nabla_3}$				$\boldsymbol{\nabla_4}$			
The summary uncertainty of the amendment (for stage)	$U(\nabla_1)$				$\boldsymbol{U(\nabla_2)}$				$\boldsymbol{U(\nabla_3)}$				$\boldsymbol{U(\nabla_4)}$			
Coverage coefficient (for stage)	k_1				$\boldsymbol{k_2}$				$\boldsymbol{k_3}$				$\boldsymbol{k_4}$			
The expanded uncertainty (unbalance of stage)	$k_1 * U(\nabla_1)$				$\boldsymbol{k_2 * U(\nabla_2)}$				$\boldsymbol{k_3 * U(\nabla_3)}$				$\boldsymbol{k_4 * U(\nabla_4)}$			
The summary uncertainty of the process	$\boldsymbol{U_\Sigma(\nabla) = \sqrt{U(\nabla_1)^2} + U(\nabla_2)^2 + U(\nabla_3)^2 + U(\nabla_4)^2}$															
Coverage coefficient (total)	k															
The expanded uncertainty (process unbalance)	$\boldsymbol{k * U_\Sigma(\nabla)}$															

– develop and theoretically substantiate a methodology for assessing the impact of branches of the main oil pipeline on the unbalance between the Depositing and Receiving parties;

– to develop a design model for the deformation of the structure of vertical cylindrical tanks and to obtain mathematical dependences that allow automatically correcting the calibration characteristics of tanks taking into account the influence of various destabilizing factors [3];

– to develop a new principle of automatic calibration of gas station tanks and tank farms with the help of standard petroleum products metering stations of automated AIMCS [12];

– to develop a new class of wide-range, high-precision, high-speed discrete level sensors [13].

V. CONCLUSION

Noting the relevance of the designated problem of forming a normalized unbalance during the accounting operations of petroleum products and the practical need for its earliest solution, showing the economic importance of the expected decisions, the specific results obtained in this direction are given. The identified sources of measurement uncertainty in a systematic approach to the technological movement of petroleum products, an assessment of the contributions of sources to the budget of uncertainty made it possible to develop targeted measures for their minimization, presented in references to the authors' works.

The presented approach eliminates the intersectoral contradiction between the results of actual measurements and the accompanying document flow, which will allow at any stage of the movement of NP in the process chain Supplier - Distribution system - Consumer to provide a normalized debalance.

The introduction of modern AIMCS (both Russian and foreign ones) in the automatic mode, amendments to the calibration characteristics of tanks depending on the complex impact of destabilizing factors on them, such as temperature, filling level, tank bottom subsidence, excessive gas pressure, will allow to avoid significant errors accounting operations of petroleum products.

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Assessment of Accuracy and Precision of a Complex Polymer Component

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***Abstract*—The work presented is an injection molding filling analysis of a complex polymer component. Assessment of accuracy and precision of the manufacturing process between a virtual prototype and a physical model is achieved by a way of a 3-dimensional laser scanning technology. Defined are basic advantages and potentialities for such an assessment as well as suggestions towards the manufacturing process for achieving the desired quality and accuracy.**

Keywords—CAD modeling, mold tools, scanning, injection molding, polymer

I. Introduction

A. *Injection molding*

Injection molding is a highly effective method of producing plastic components by injecting plastic materials molten by heat into a mold, and then cooling and solidifying them. This technology is widely known for the mass production of products with complex shapes, and takes a large part in the area of plastic processing. [1]

Injection molding is preferred technology due to some crucial advantages and benefits over other methods. The ability to produce complex geometries in various intricate shapes that would consume much less time and costs to produce compared to other technologies. Plastic injection molding process produce details with high dimensional accuracy and yield. [2]

Among the advantages, a typical drawback of technology that prevents full application in the industry where higher accuracy is obligatory, is residual stresses and displacement. [3] Many defects may occur during or after the completion of the process in the products. There are several types of defects like shrinkage, warpage, voids, weld-lines etc. which usually occurs in plastic products. Defects in the products can be occurred at any step of the process. In industry, engineers have tried to minimize these defects by optimization of any of the feature like mold, plastic resin; parameters of the process. [4]

However, since the technological preparation and production of the mold tool equipment is an expensive and time consuming process, it is recommended to model a virtual prototype first. Research stage and virtual analysis of injection molding is shifted before actual production, allowing optimization and corrections of the plastic component, saving time and costs. By this way, defects and displacements could be seen and removed before creating the physical equipment. This additional step saves a lot of correction and work afterwards along with high detail accuracy.

Defects are influenced by parameters such as pressure, temperature, speed, viscosity, type of material, and others. By simulating the injection molding process in CAE software environment, most of defects can be prevented. Solutions to some defects are: [5]

- Sink marks – Melt temperature is too low/Wrong gate location/Cavity pressure is too low/Part ejected is too hot
- Flash – Excessive injection pressure/Excessive melt temperature
- Brittleness – Mold is too cold/Incorrect part design
- Burn marks – Incorrect filling pattern
- Warping – Melt temperature is too low/Incorrect part design/Over packing near gate

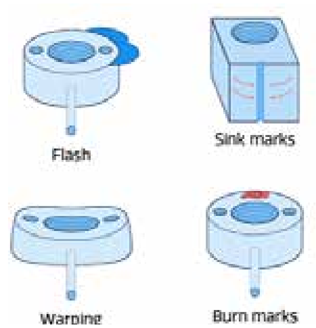

Fig. 1 Common defects in injection molding

The wide range of materials provide a field to engineers to improve some important properties of the injection molded component like toughness, rigidness, tensile strength, abrasion, stiffness, etc. One of the biggest advantages of this technology is the lightweight. In most cases, weight is crucial for a proper exploitation.

B. *3D laser scanners*

3-Dimentional scanners are machines that extract and analyze a real-world object or environment to collect data on its shape and its appearance. The collected data can be used to model virtual 3D model. They provide all purpose of metrology for multitude applications like 3D digitizing, 3D modeling, point cloud inspection, reverse engineering, rapid prototyping and other laser scanner applications. [6]

For this research, a modular high-end laser ROMER Absolute Arm 7329 SI scanning machine is used. It is designed with six rotational axes which provides very accurate and precise measurements on countless work pieces.

Fig. 2 ROMER Absolute Arm 7329 SI

C. *Purpose of the research*

The purpose of this study is to design and simulate the injection molding process of a complex component. Assessment of accuracy and precision between the virtual prototyped component and a physical one is done.

II. METHODOLOGY FOR DESIGN THE PROCESS OF SIMULATING THE FILLING PROCESS OF A COMPLEX GEOMETRY COMPONENT. MATERIAL SELECTION.

The model analyzed in this article is a handle with a complex geometry. The quality of this element is crucial for its mounting parts.

The research represents a comparative analysis between a virtual prototype and a physical model by a way of using a 3D laser scanning technology. The idea is to measure the displacement from the nominal dimensions' model to the real one. Minimizing warpage from the control zones is important.

The working parameters are properly selected after being picked over by multiple of simulations and analysis. By choosing the right material, many defects and distortion from the original form would be avoided. For this specific case, Polyamide 66 with 30% Glass Fiber Reinforced is used because of the stiffness and heat resistance required. CAE software Moldex3D is used for the analysis below.

In TABLE I are given the working parameters of the injection process.

TABLE I WORKING PARAMETERS

Working parameters	Values
Filling Time	5 (sec)
Melt Temperature	270 (°C)
Mold Temperature	80 (°C)
Maximum Injection Pressure	155 MPa
Injection Volume	87.8845 (cc)
Packing Time	15 (sec)
Maximum Packing Pressure	155 MPa
VP Switch by volume (%) filled	98 (%)
Mold Opening Time	5 (sec)
Ejection Temperature	140 (°C)
Air Temperature	25 (°C)

Firstly, the geometry of the handle is checked. In fig. 1 is shown the model thickness.

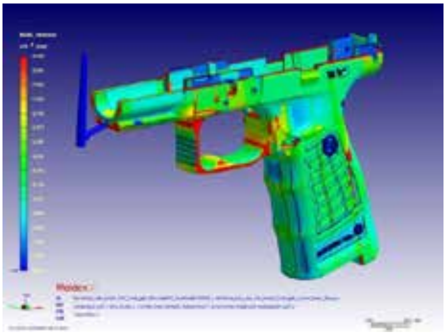

Fig. 3 Model thickness

Thickness of the body is not even. There are zones where the material aggregation is more which can cause sink marks and warpage defects.

In Fig. 4 is shown how the polymer melt is distributed in the mold. Walls have to be filled entirely.

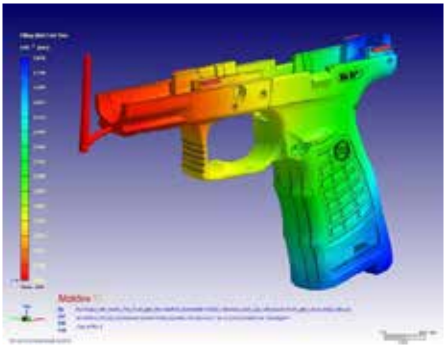

Fig. 4 Filling stage of the body

The cooling stage is the most important step which is crucial for the accuracy and precision of the handle. Temperature distribution is shown in Fig. 3.

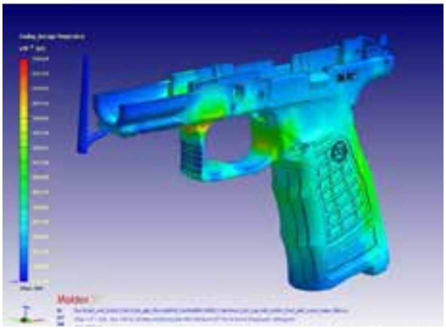

Fig. 5 Average temperature after cooling

There are still hot spots that cause the material to shrink after cooling. This is a prerequisite for a warpage defect that is reflected in displacement of nominal dimensions.

In Fig. 4 is shown the isosurface of plastic melt-zone. Region enclosed by the isosurface has temperature higher than freeze temperature specified in the process condition.

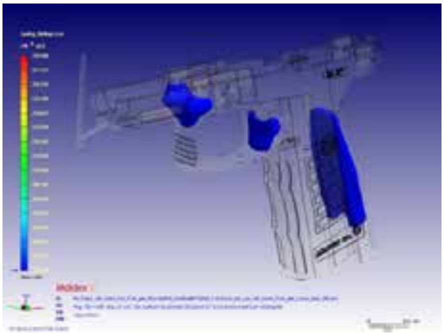

Fig. 6 Melting core

Polymer material in zones above remains partly melted after cooling which is due to the uneven thickness.

Warpage Z-Displacement in Fig. 5 shows total displacement in Z axis direction after the part is ejected and cooled down to room temperature.

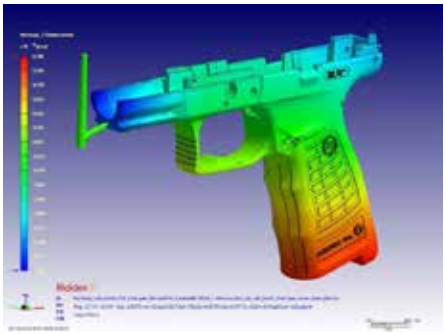

Fig. 7 Warpage Z-Displacement

III. Comperative Analysis Between Virtual Prototyping Model and a Physical Model

Based on simulated results provided by Moldex3D, a verification is made with a physical model.

The comparative analysis between virtual prototyping model and a physical model is done by 3DReshaper software. Meshing is done based on point cloud which is brought by non-contact laser measurement device ROMER Absolute Arm 7329 SI.

In Fig. 8 are shown zones with the biggest deviation based on

Fig. 8 Scanned model Z-Displacement

In Table II is shown displacement in Z-axis in three control zones in percentage.

TABLE II Displacement Difference

	Zone 1	Zone 2	Zone 3
Virtual Prototype	1.01	0.045	0.64
Scanned model	0.9	0.04	0.7
Percentage (%)	11.5%	11.7%	8.9%

IV. Conclusion

There is a high matching between virtual prototype and the physical model.

The result of the study shows that virtual model is highly accurate with the physical model.

Virtual prototypes can be used to predict process issues of newly designed plastic components.

Contemporary 3D scanners allow faster comparison between virtual and physical prototypes.

Acknowledgment

This work was supported by the European Regional Development Fund within the Operational Program “Science and Education for Smart Growth 2014 - 2020” under the Project CoE “National center of mechatronics and clean technologies “BG05M2OP001-1.001-0008- C01.

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Hall effect closed loop current transducers

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***Abstract*— Closed loop current transducers are used in a large number of industrial applications, where they provide the measurement, display and control of currents. Typical applications are represented with their main characteristics.**

Keywords—transducer, closed loop, hall effect

I. INTRODUCTION

The closed loop transducers (also called compensation or zero flux transducers) have an integrated compensation circuit by which the performance of the current transducers using the Hall effect can be markedly improved.

Whereas the open loop current transducers give a V_{OUT} output voltage proportional to the amplified V_H Hall voltage, the closed loop transducers supply a secondary current IS proportional to V_H which acts as counter-reaction signal in order to compensate the induction created by the primary current B_P by an opposed secondary induction B_S. The secondary current I_S, reduced by the turns ratio, is much lower than I_P, because a winding with N_S turns is used to generate the same magnetic flux (ampere-turns). One thus selects:
$N_P \cdot I_P = N_S \cdot I_S$

The B_S induction is thus equivalent to B_P and their respective ampere-turns counter-balance each other (compensate). The system thus operates at zero magnetic flux (fig. 1).

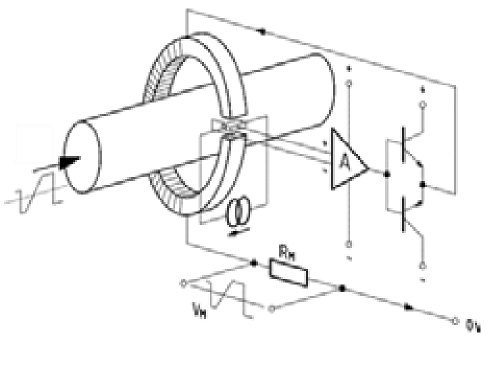


Figure.1. Operating principle of the closed loop transducer

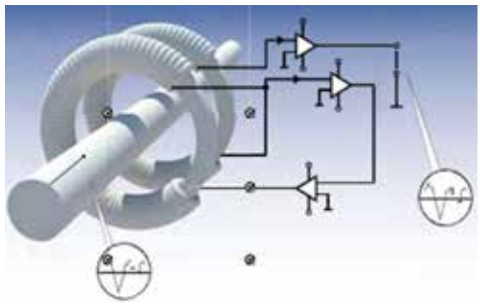
Let us take as an example the measurement of a DC current of 100 A. The number of turns $N_P = 1$, because the conductor leads directly into the magnetic circuit, thereby constituting a single turn. The secondary winding has N_S = 1000 turns. The turns ratio is thus 1:1000.

As soon as I_P takes a positive value a B_P induction appears in the air gap of the magnetic core, producing a V_H voltage in the Hall element. This voltage is transformed into a current by way of a current generator the amplifier stage of which supplies the IS current flowing through the secondary winding. The BS induction is thus created which compensates the BP induction.

The resulting secondary current is thus:

$$Is = \frac{\text{Np.Ip}}{\text{Ns}} = \frac{1.100}{1000} = 100\ mA$$

The range of the closed loop transducers permits measurement of I_{PN} nominal currents from a few amperes to



several tens of kA, with an accuracy of about 1 %. With the devices produced by DynAmp subsidiary, which use the same technology, it is possible to measure very high currents up to 500 000 A. The closed loop transducers are capable of measuring DC, AC and complex waveform currents with galvanic isolation.

This technology uses two toroidal cores and two secondary windings and operates on a fluxgate principle of Ampere-turns compensation. For the voltage type a small (few mA) current is taken from the voltage line to be measured and is driven through the primary coil and the primary resistor.

They stand out by their:
- Excellent accuracy.
- Very good linearity.

- Low temperature drift.
- Very fast response time and wide frequency bandwidth.
- They do not produce any insertion losses in the circuit to be measured.
- Their current output is especially useful for applications in a noisy environment. Furthermore, if necessary it is very easy to convert the signal into a voltage.
- They withstand current overloads without damage.

These transducers are particularly well suited for industrial applications which require high accuracy and wide frequency bandwidth performance. The main limitations of this technology involve mainly the consumption of the power supplies which must provide the compensation current. Furthermore, for the high current ranges, they are more expensive and bulkier than their open loop technology equivalents.

These transducers provide innovative and high quality solutions for measuring electrical parameters. Current and voltage transducers - are used in a broad range of applications including drives & welding, renewable energies & power supplies, traction, high precision, conventional and green vehicle businesses. With higher accuracy and speed, the feedback signal from such transducers enables smoother control and energy consumption reduction of many electrical systems.

Depending on the type of transducer and the magnetic material used, an error could be added to the ones mentioned above. It is due to the residual magnetism (remanence) which induces an offset that we may qualify as magnetic offset, the value of which depends on the magnetization state of the magnetic circuit. This error is maximum when the magnetic circuit has been saturated. This might happen in case of high current overload conditions.

II. Characteristics and Features

A. *Measurable current range*

As they operate with a practically zero flux (in practice low leakage magnetic flux exists), these transducers have an excellent linearity over a wide measuring range. The latter is defined by the capacity of the power supply voltage to provide the secondary current, taking into account the internal voltage drops of the transducer and in the measuring resistor.

Furthermore, this type of transducer can in fact measure a higher current value than the one limited by the parameters indicated above which define the normal measuring range. The high transient currents, which however must (for thermal reasons) be of short duration, can indeed be measured. The transducer operates in this case like a current transformer.

Considerations, such as a good magnetic primary/secondary coupling, must of course be taken into account when mounting the transducer, in order to obtain satisfactory results. This is why the data sheets do not show a value in this respect, because every application must be studied specifically; it is therefore advisable to consult us in order to carry out the necessary tests.

B. *Output signal - Load resistance*

At the output, the transducer supplies a secondary current which is the counter-reaction current. This current can be transformed into a voltage thanks to a load resistance called the measuring resistance. The value of the measuring resistance must be situated within the range shown in the catalogue; meaning: comprised between the RM min resistance (defined in order to respect an adequate power dissipation of the electronic circuit) and the RM max resistance (defined to avoid the electronic saturation of the circuit, taking into account the minimum available supply voltage and which determines the maximum measuring range). It must be noted that in the data sheet we have indicated the RM values corresponding to the permanent nominal rating and a given measuring range.

C. *Measurement accuracy*

Accuracy depends on several factors to be taken into account, depending on the type of measurement to be carried out. Whether they are the electric parameters (AC, DC, industrial frequency or complex waveform with high frequency currents, etc...) or the parameters linked to the environment conditions (ambient temperature, etc...).

Factors determining the accuracy:

At ambient temperature:
- the DC offset current at $I_P = 0$
- the non-linearity.

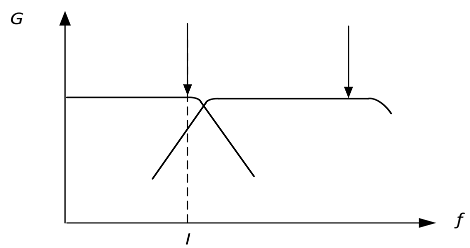
Depending on the operating temperature:
- the offset drift.

D. *Dynamic behaviour*

a) *requency operation*

The measurements carried out on the closed loop transducers show an excellent frequency response.

This bandwidth is due to two phenomena. For the DC current and the low frequencies, the electronics with the Hall-element is determining. In the high frequency regions the transducer operates as a current transformer (Fig. 2). The minimum high frequency limit for most of current transducers



is equal to 100 kHz. Some models even reach a bandwidth of 150 to 200 kHz.

Fig. 2 If the frequency is increased, the closed loop transducer then operates as a current transformer.

Thanks to the combined optimization of the bandwidth of the electronic circuit and the frequency bandwidth of the current transformer it is possible to cover these two frequency regions, providing high accuracy over the product's whole frequency bandwidth. There is a special product range, the principle of which is patented, the LB transducer series. Their frequency bandwidth has been linearized and extended to over 300 kHz.

E. Response time and di/dt behavior

The response time to a current step is defined by several parameters among which are the reaction time, the rise time and the delay time. The response time is comparable to the delay time which also characterizes the correct following of the transducer with the di/dt to be measured.

For the closed loop transducers the reaction time is below 1 ms. The correct following of di/dt depends on the intrinsic construction of each product and of the assembly configuration of the transducer within the circuit to be measured. The closed loop transducers are capable, according to the models, of measuring di/dt's of some 50 A/ms up to several hundreds of A/ms. This is why they are also used for the protection of semiconductors in the case of short-circuits in power equipment.

F. Observation on the magnetic offset

When the I_P current strongly exceeds its nominal value and the ampere-turns can no longer be compensated by the secondary circuit, the magnetic induction B leaves the point 0 and begins a hysteresis cycle. The core is magnetized and the Hall Generator supplies a non-zero V_H voltage for IP = 0. The same effect can occur when one of the two supply voltages is missing. In this case the electronic circuit is unable to supply a sufficient compensation current and the core becomes magnetized. This is remedied by demagnetizing the magnetic core with an AC current progressively decreasing to zero, taking care to previously turn off the transducer's power supply or by opening the measuring output circuit.

III. TYPICAL APPLICATIONS

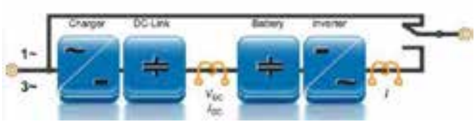
Closed loop current transducers are used in a number of industrial applications, where they provide the measurement, display and control of currents. Among typical applications are the following:

- Frequency converters and three-phase drives for the current control in the phases and in the DC bus, for protection in case of short-circuits.

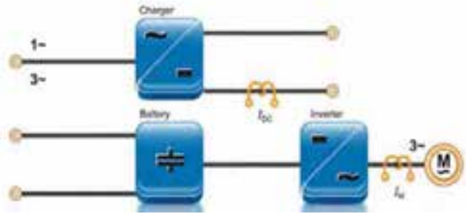
- Converters for servo-motors frequently used in robotics.

- Electric welding equipment for the control of the welding current.

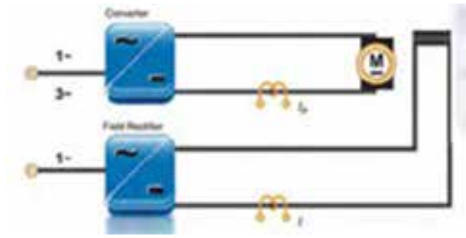
- UPS and other equipment operating with batteries, for the control of charge and discharge currents.



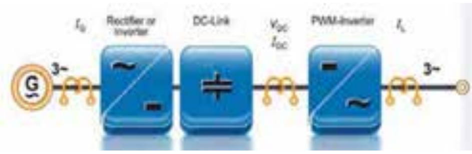
- Electric vehicles, in the traction converters and the control of the battery current.



- Electric traction systems, whether in traction converters and auxiliaries or in the sub-stations.



- Converters for windmills.



- Special power supplies for radars.

Other applications can also be named, such as

- Energy management systems, switching power supplies, lasers, rectifiers for electrolysis.
- There are also many applications for laboratories or for test and control benches.

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BRÜEL & KJAER AND SPECTRI LTD. PRESENTING VIBRATION TEST SYSTEMS

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Abstract - In the recent paper a comparative information about vibration test systems by Brüel & Kjær is presented

Keywords - vibrations, systems, shaker

I. INTRODUCTION

Founded in 1942, Brüel & Kjær Sound & Vibration Measurement A/S has grown to become the world's leading supplier of advanced technology for measuring and managing the quality of sound and vibration. Brüel & Kjær uses core competences and comprehensive range of products and solutions to help customers solve sound and vibration challenges. Since the 1950s, their products have set the standard to which others are compared.

From high-force LDS electrodynamic shakers to palm-sized model and measurement exciters, Brüel & Kjær offers a wide range of vibration test solutions. Brüel & Kjær also have a large selection of dedicated power amplifiers and vibration controllers, as well as matching slip tables, head expanders and thermal barriers, to meet all vibration testing needs – whether it's testing electronic components for mobile phones to complete satellite systems.

Brüel & Kjær's world-renowned experts provide comprehensive staff training onsite and online. And it's all backed up with dedicated service personnel trained at Royston LDS shaker factory in the UK.

Figure 1. LDS shaker factory Royston (UK)

II. VIBRATION TEST

Vibration testing is done so it can be introduced a forcing function, usually with the use of vibration test shaker or vibration testing machine. These induced vibrations, vibration tests, or shaker tests are used in the laboratory or production floor for a variety of things, including qualifying products during design, quality assurance, life test, transport test, prototype evaluation, reduce time-to-market, meeting standards, regulatory qualifications, fatigue testing, screening products, and evaluating performance.

A. Vibration test helps by answering a lot of critical questions like:

- Can 100kg satellite take the excessive vibration level of being launched into space?
- Can HEV battery sustain 250,000 km of road life?
- What is the operational service time for a jet engine turbine blade?
- Can we choose the cheapest mounting principle for this printed circuit card?
- Will this type of package material ensure that a flat screen TV arrives safely at its destination?

Dynamic measurements and vibration testing are necessary, because static measurements of stress/strain properties are not sufficient for the demands of high speed operation and the use of light structures in modern machinery. By doing this we ensure that the products we are using are going to survive real – life conditions. [1]
Brüel & Kjær helps performing the most complex vibration tests to ensure the integrity and reliability of products. The company comprehensive range of LDS electro – dynamic shakers are designed for vibration testing of devices of practically any size from a semiconductor component to a complete satellite system. Combined with world – class

data acquisition systems and analysis software suites, Brüel & Kjær offers the complete vibration testing solution and also provides vital service and staff training to maximize the operation of your vibration test system.

Figure 2. Full measurement chain of vibration test system

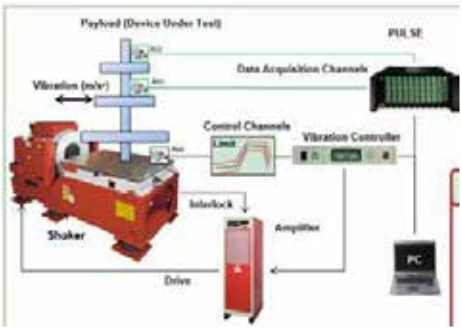

Figure 3. Vibration test system

A. *Durability and fatigue testing:*

- Sine, Random, Shock and SoRRoR;
- Resonance searches;
- Transportation testing;
- HALT testing;
- IEC 60068-2-64.

Brüel & Kjær comprehensive array of exciters and LDS shakers covers applications throughout the entire spectrum of vibration testing and modal and structural analyses. The product range of vibration test systems is split in four sections: small, medium, large and very lager vibration test systems.

B. *Small systems characteristics:*

Type: Permanent magnet vibration test system:

- Permanent magnet construction;
- Low mass, high performance armature construction;
- Well – proven armature suspension system;
- 9 N to 489 N force;
- V101 to V455;
- Modal and structural analysis;
- Electronics assembly test;
- Calibration systems.

Figure 4. Permanent magnet – small vibration test system

C. *Medium systems characteristics*: *Type:*

Air – cooled vibration test systems:

- Air – cooled vibration test system;
- V555 – V780;
- 940 N to 5.1 kN force;
- Lightweight, high – performance armature design;
- Choice of amplifiers – linear or switching
- Easy self – installation design;
- Automotive component testing;
- Aerospace component testing;
- Electronic assembly testing;
- Vibration stress testing under varied environmental conditions

Figure 5. Air – cooled vibration test system – medium

D. *Large systems characteristics:*

Type: Air – cooled vibration test systems:

- High strength, low mass armature, Up to 76mm continuous displacement;
- High force, long duration testing;
- 8.9kN to 60kN force
- V830 – V8
- Automotive parts and systems – qualification testing
- Avionics and military hardware testing
- Satellite components testing
- Electronic assembly computer
- Product and package testing

Figure 5. Type: Air – cooled vibration test system – large

E. Very large system characteristics:

Type: Water – cooled vibration test systems:

- High force, long duration testing;
- Space, avionics and military hardware testing;
- Product and package testing;
- 3 – axis testing of complete satellite systems;
- Multi – shaker, multi – axis application
- Suitable for clean room environments
- V9 – V994
- 89kN to 289kN force

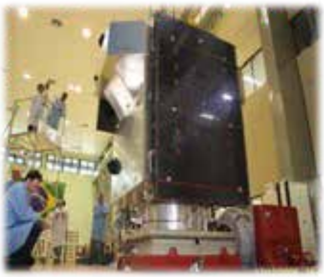

Figure 7. Water – cooled vibration test system – very large

F. Testing with respect to gravity

Typically a fixture will support the product for all 3 axes and thus a test can be applied using a vertical shaker only. However if the UUT has a requirement to be tested with respect to gravity (e.g. filled water tank), a slip table shall be used. A slip table can be designed in many sizes and their overturning moment specifications are depending of the used bearing technology and number. There are two main slip bearing technologies:

- Low Pressure Table

Low pressure table (LPT) uses standard low pressure journal bearing, magnesium alloy plate floating on an oil film above a granite block.

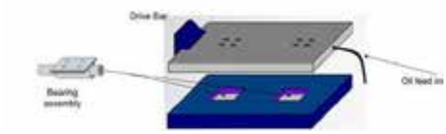

Figure 8. Low Pressure Table (LPT)

- Hydrostatic Bearing Tables

Hydrostatic bearing tables (HBT) uses special high pressure journal bearing, magnesium alloy plate floating on an oil film above a granite block. Using high pressure oil (172bar) though the bearing, and a clever multi – bearing arrangement on an HBT slip plate, the all specifications are improved.

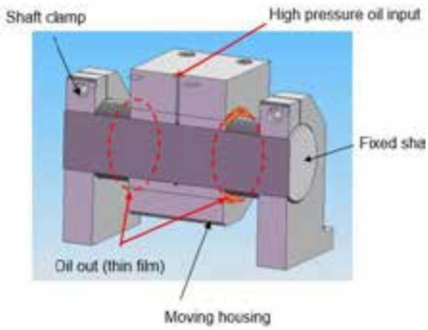

Figure 9. Hydrostatic Bearing Tables (HBT)

	LPT600	HBT600
Slip plate working area, mm	600 x 660	600 x 660
Slip plate thickness, mm (nominal)	37	37
Slip plate mass, kg (nominal)	29.7	28.9
Number of bearings	2	2
Moving mass of each bearing, kg	1.0	4.5
Maximum stroke (metal to metal), mm	91	91
Table pitch moment, kN m	6.1	23.7
Table roll moment, kN m	5.1	21.3
Table yaw moment, kN m	0.45	19.0
Maximum table load, kg	500	4250

Figure 10. Comparison of overturning moment restrains (V875LS)

III. VIBRATION TEST SYSTEMS ISOLATION, SUPPORT, BARRIER

A. Lin – E – Air isolation:

The Lin-E-Air air isolation system by Brüel & Kær VTS provides excellent isolation between the shaker and the mounting platform (and hence the building floor), allowing tests to be conducted at frequencies as low as 5 Hz. The additional air isolation between the platform and the building floor further reduces the requirements and costs of seismic bases for simple tests. However, systems used for high-force shock testing and low frequency applications requiring maximum displacement can be isolated from the building by removing the Lin- E-Air suspension, and rigidly fixing the trunnion- mounted shaker to a seismic mass which itself is isolated from the building. This allows tests to be conducted below the 5 Hz limit imposed by the air suspension.

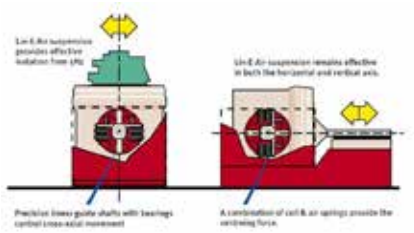

Figure 11. Lin-E-Air body isolation

B. Air isolation mounts:

To isolate the combo from the floor, the base assembly is supported as standard on air isolation mounts. Two manual regulators control the air supply to the isolation mounts. One regulator supplies the mounts located under the vibrator while the other supplies the mounts located under the slip table.

The two regulators should be adjusted to raise the combo by approximately 12 mm (½ in) at each mount. Before operating the slip table, an engineer's level should be used to check that the table is perfectly level; minor adjustment of the regulators may be required.

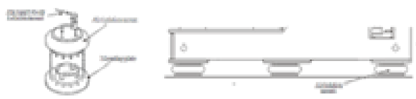

Figure 12. Air isolation mounts

Each isolation mount here above incorporates a safety stop which prevents the base fabrication being lowered when the air isolation mounts are deflated to such an extent that a human foot could be crushed between the combo and the floor.

C. Internal load support:

Available displacement is a major limitation on what shock pulses can be achieved, and therefore long stroke exciters have a clear performance edge. The exciters have an Internal Load Support System (ILS) which adds no unnecessary mass, and does not limit maximum acceleration levels or frequency range. Apart from supporting heavy test loads without external aid, these ILS systems allow the armature datum to be positioned at one extreme of the available travel, to get maximum performance with controllers that use pre- and post-pulse conditioning.

D. Thermal barrier:

When operating a slip table in conjunction with a climatic chamber it is normal practice to fit a thermal barrier to the slip plate in order to reduce thermal transfer from the chamber to the slip plate. This reduction, combined with the heat sink effect of the slip table granite block, allows short duration tests (up to approximately 90 minutes) to be performed without any control of oil temperature. At higher temperature, or if the test time is to exceed 90 minutes, it will be necessary to maintain the temperature of the slip plate within acceptable limits. This is achieved by the use of a special hot/cold oil supply combined with special 'gundrilled' holes in the slip plate as described further.

IV. VIBRATION TEST CONTROLLERS

Brüel & Kær has wide range portfolio of controllers and some of them are:

a) COMET USB

- 2 channels;
- Sine, Random and Shock.

b) LASER USB

- 4 – 16 channels;
- Mixed mode, kurtosis, SRS and Resonance search;

- Amplifier control and chamber interface.

c) VC – LAN

- Scalable (64-ch.): combine smaller controllers to one large one;
- Waveform recording and replication;
- Built – in charge support.

V.CASE STUDIES

A. Case study number: 1

- For satellite production testing – vibration sine testing, shock response and modal analysis.

- For company INPER – a research unit of the Brazilian Ministry of Science and Technology and the civilian research center for aerospace activities.

- Case studying a 160kN shaker combined with a very large PULSE system (320 – channels)

B. Case study number: 2

- Doing it for pre – production qualification and functional test for electric and hybrid vehicles, also heavy – duty, durability, testing and simulating the whole lifetime of the car which means continuous testing for several days at very high vibration levels and extreme temperature conditions
- For company named General Motors – one of the world's largest automakers, with roots going back to 1908
- Case studying a LDS V8 – based system, test capacity 60kN Random and Sine and Payload ~ 250 kg.

C. Case study number: 3

- For electronics transportation testing by simulating the journey of products from manufacture to a customer's home.

- Doing the case study for the company Foxconn – one of the world's principal contract manufacturers of electronic products and equipment.

- Case studying a load bearing platform and V8 shakers.

VI. CONCLUSIONS

Brüel & Kjær's mission is to find long – term solutions for their customers sound and vibration challenges. The company also provides vibration test systems solutions that are ready to run. They are designed to be ease – of – use and they come with specialized training for the customers that are going to use the system, so they can become real experts in less time.

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DEVELOPMENT, NEWS AND PRODUCTS IN THE FIELD OF NOISE AND VIBRATIONS BY SPECTRI LTD

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Abstract - Since 1998 SPECTRI LTD focus has been sound and vibration till today. With the development of new technologies in that field, we are trying to adapt, learn, evolve so we can do our work better, accurate and correct to our customers. By becoming partners with world leading companies in the last year we are able to achieve that. In the recent paper a comparative information for the progress, development, news and products in the field of noise and vibrations by SPECTRI Ltd. is presented.

Key words - noise, vibrations, spectri, measurements, news, development

I. WHO WE ARE:

The company SPECTRI was founded in 1998 with manager Eng. Boris Mihaylov. Specialists in the company are leading experts in the field of noise and vibration with a wide practical experience of successfully implemented projects.

In 2006, Dipl. Eng. Boris Mihaylov took leading role as founder and later on Member of the Management Body, and Co-President of BAPNCM ("Bulgarian Association for Public Noise Control and Management").

Since the founding, an exclusive agency contract has been in force (technical, engineering, service, commercial) of the company - leader in the field of noise and vibrations, Bruel & Kjaer – Denmark.

SPECTRI is partnering with world leading manufacturers of measurement equipment. SPECTRI carries out service activities, deliveries of spare parts and equipment for measurements, monitoring and analysis of vibrations, noise, pressure, power, offset and others., also and engineering and installation on the territory of the Republic of Bulgaria.

SPECTRI organizes different events (courses, symposium, seminars) for training and acquaintance with the latest developments in the field of noise and vibration.

II. MISSION AND VISION:

A. Mission

Our mission is to help our clients and partners to improve their working conditions, safety, competitiveness and efficiency. In this way, we strive to influence the environment, the quality and the joy of life.

B. Vision

Our vision is to be the preferred partner and provider for leading companies and institutions, which are thinking and carrying about their business and human comfort, development and prosperity and also to be the national centre for competence and knowledge in the field of vibrations and noise.

III. CERTIFICATES:

A. SPECTRI with certification ISO 9001:2015

SPECTRI successfully implemented system for managing the quality with compliance with the requirements of international standard ISO 9001:2015 including: Designing, manufacturing, engineering, maintenance, service, trading and delivery of solution, expertise, measurement equipment and software for noise and vibrations, process-parameters. Installations and settings, training and consultations. Measurement, diagnostic analysis, control and assessment of the condition. Test of noise-vibration parameters, calibration of noise and vibrations measuring equipment. The certificate is valid until 25.11.2019.

Fig. 1: Certificate on ISO 9001:2015

B. SPECTRI with certification on BDS EN ISO / IEC 17020:2012 – ACS „SPECTRI – MEASUREMENTS”

Authority body control of type C at "Spectri" Ltd. Sofia is accredited in accordance with BS EN ISO / IEC 17020:2005 by EA "BAS" with a unique certificate number № 122 ACS. This certificate is valid until11.30.2016


СЕРТИФИКАТ
ЗА АКРЕДИТАЦИЯ

Fig. 2: Certificate on BDS EN ISO / IEC 17020:2012

C. *OKC SPECTRI SCOPE OF ACCREDITATION*

CONTROL OF NOISE ENVIRONMENT AND / OR DOMESTIC ENVIRONMENT - range of the control parameter - equivalent noise level, day, night, evening noise

- **Control of noise environment** - range of the control parameter - equivalent noise level, peak sound pressure level, noise level, daily level of exposure to noise, average weekly level of exposure to noise
- **Vibration control conveying system " hand-arm 'and' body**- range of the control parameter - the daily value of exposure
- **Vibration control machinery**- range of the control parameter - Vibration acceleration, velocity
- **Vibration control in residential areas** - range of the control parameter - Vibration acceleration

D. *SPECTRI with certification on BDS EN ISO / IEC 17025 – ACS „SPECTRI – LAB"*

Laboratory for testing and calibration at SPECTRI LTD. is acreditated according to BDS EN ISO / IEC 17025:2006 by EA "BAS" with unique number № 1. The certificate is valid until 30.04.2023.


СЕРТИФИКАТ
ЗА АКРЕДИТАЦИЯ

Fig. 3 Certificate BDS EN ISO / IEC 17025

E. *SPECTRI – LAB SCOPE OF ACCREDITATION*

MEASUREMENT:

- **ENVIRONMENTAL NOISE** - range of the control parameter - equivalent noise level, Maximum A – weighted noise level, noise level at the place of exposure, level of total sound power

CALIBRATION:

- **Acoustic (sound) calibrators** – sound level pressure, dB for nominal frequencies 250 Hz and 1 kHz. Measurement range – 94, 114, 124 dB (according to 20 µPa). CMC – 0,15 dB.
- **Acoustic (sound) multifunctional calibrators** – sound level pressure, dB for nominal frequencies 250 Hz and 1 kHz. Measurement range – 94, 114, 124 dB (according to 20 µPa) from 31,5 Hz to 4 kHz and from 8 kHz to 16 kHz. CMC – 0,2 and 0,4 dB
- **Sound level meters** – sound level pressure measured in dB for nominal frequencies 31,5 Hz to 12,5 kHz (acoustic calibration). Measurement range – from 94 to 114 dB (according to 20 µPa) from 31,5 Hz to 2 kHz and from 4 kHz to 12,5 kHz. CMC – 0,3 and 0,6 dB.
- **Sound level meters** – sound level pressure measured in dB for nominal frequencies 20 Hz to 16 kHz (electrical calibration). Measurement range – from 20 to 140 dB (according to 20 µPa). CMC – 0,4 dB.
- **Personal sound dosimeters** – sound level pressure for nominal frequencies from 63 Hz to 8 kHz

(acoustical calibration). From 60 dB to 120 dB (according to 20 µPa). From 63 Hz to 2kHz, for 4 kHz and for 8 kHz. CMC – 0,4; 0,8; 1,3 dB

IV. PARTNERS AND SHORT INFORMATION ABOUT THEM

We are proud to present our new partners as it follows:

Brüel & Kjaer Vibro
Internet: www.bkvibro.com

Ensuring high availability of rotating machinery with intelligent monitoring solutions, Brüel & Kjær Vibro has been a global forerunner in this field for decades. Whether for wind or hydro power, the HPI or thermal power industries, numerous leading companies rely on our innovative solutions, high level of expertise and dedicated service.

Brüel & Kjær Vibro is independent of machine manufacturers and suppliers of process control systems. This allows us to develop solutions that are tailored to the interests of our customers.

Connection Technology Center
Internet: https://www.ctconline.com

Connection Technology Center, Inc. - CTC - offers the widest variety of high quality accelerometers, vibration sensors cables and connectors for industrial use in condition monitoring and predictive maintenance applications. It's an industry leading product portfolio supported by an unconditional lifetime warranty on all CTC Industrial accelerometers and vibration analysis.

SoundEar A/S
Internet: https://soundear.com/

SoundEar helps companies worldwide reduce noise at work. We do this through our 20 years of experience in the noise monitoring industry, and through our unique offer of not only measuring noise, but also visualizing noise.

Creating awareness about noise is the first step towards making a change, and we believe the best way to create awareness about noise, is to visualize it.

EMS Brüel & Kjaer
Internet: https://www.emsbk.com

EMS Brüel & Kjær is a global provider of continuous, unattended environmental monitoring solutions. Our managed services and products deliver environmental intelligence to help clients achieve business outcomes and growth.

And our old ones which we are continuing our partnership with:

Brüel & Kjær Sound & Vibration A/S
Internet: www.bksv.com

The company Bruel & Kjaer – Denmark was founded in 1942 by Per Bruel and Viggo Kjaer. From 1994 the company becomes a part from Spectris Group – United Kingdom (See http://www.spectris.com). Turnover for the past years is more than € 150 million a year.

The company is world leader in the field of noise and vibrations, with over 65% of world market share. The main ISO and EN standards in the field of noise and vibration have been created by and in collaboration with Bruel & Kjaer specialists.

Instantel
Internet: www.instantel.com

Founded in 1982, Instantel specializes in the production of vibration and explosive modules. The company is part of Stanley Black & Decker, Inc.
Instantel's equipment for "regulated" vibrations and overpressure control over the years has earned the reputation of the most reliable similar equipment (used in over 110 countries around the world) – for various applications in the mining, construction and geotechnical research.

Bulgarian Association for Public Control and Management of (BAOKUSH)
Internet: www.nonoise-bg.com

BAOKUSH is a non-agricultural public organization that has formed itself as an expert national center of competence in noise and vibration and whose main objective is to promote and defend the expertise in the preparation of opinions, consultations, national and international strategy papers in the field of acoustics.

V. PROJECTS

A. In 2018-2019, successful updates of Strategic Noise Maps and action plans of:

- Agglomeration Sofia
- Agglomeration Plovdiv
- Agglomeration Burgas
- Agglomeration Varna
- Agglomeration Ruse
- Agglomeration Pleven
- RIA

B. Realization of acoustic audits

Realization of acoustic audits of large industrial sites as well as of large infrastructure projects:

- Monitoring and noise
- Sound level measurements
- Research
- Noise maps

C. System for noise monitoring. Sofia Airport.

Annual maintenance contract, acoustic expertise, diagnostics and calibration.

D. Opening of a modern hydro-acoustic laboratory at the Technical University – Varna

The main objective of the project is to build a sustainable national competence center where the three sides of the knowledge triangle - education, research and business are in effective and dynamic interaction based on shared strategies, strong and specific engagements and joint research projects and partnerships, explain the beneficiaries of the project.

The laboratory is built in the building of the Faculty of Electrical Engineering. The equipment so far is 3 pcs. hydrophones type 8104 manufactured by the Danish company Brüel & Kjær, 4-channel hydro-acoustic signal amplifier (from hydrophones) Bruel & Kjaer model 2692-A "NEXUS" and Testo 890-2 thermographic camera.

6. News

A. New product from Brüel & Kjaer – Sound level meter 2245

The new sound level meter from B&K is developed to be easy to use, intuitive developed collaboratively with applications for specific surveys (environmental noise measurement, work noise measurements). It has measurement range from 15,2 to 140 dB, A – weighted. The sound level meter provides effortless usability with a rubberized body for a more secure grip and seven buttons you can comfortably reach with your thumb. The clear, bright display shows the most important information you need for noise measurement surveys at a glance, and with a 14-hour battery life, you can be sure it won't let you down.

Fig.4 Sound level meter 2245

B. "SPECTRI – LAB" Test and Calibration Laboratory has received an accreditation certificate under BDS EN ISO / IEC 17025 by BAS

The accredited Bulgarian company in the field of measurement and management of noise and vibrations Spectri Ltf. with manager Boris Mihaylov received an accreditation certificate for its new field - Laboratory for calibration of sound level meters, calibrators, multifunctional calibrators and noise dosimeters.

Our new business is a natural continuation of our 18 years of experience in this field. The accreditation certificate of the laboratory is in accordance with BDS EN ISO / IEC 17025 and gives us the right to perform environmental noise measurements and calibration of acoustic calibrators, acoustic multifunctional calibrators, sound level meters and personal sound dosimeters.

With our accredited laboratory we aim to expand its portfolio of services in the field of measurement, evaluation and calibration of noise and vibrations and to increase its expertise potential. Last but not least, we strive to provide our customers with additional facilities and support in their metrological and quality control tasks on the equipment they use.

spectri Lab
Testing and calibration laboratory

Fig. 5 – "SPECTRI – LAB" logo

C. New upgraded own products - by SPECTRI LTD

Expanding the capabilities of hardware Spectri Data Logger and integration software at http://webnoise.eu.

D. Spectri Ltd. is representative of Brüel & Kjaer Vibro for Bulgaria

B & K Vibro's products cover the whole range of vibration monitoring systems, ranging from vibrometers, modular fixed vibrocontrol systems with indication and protection functions to computer integrated video surveillance systems. With them, we can now offer our customers even more reliable and effective vibration analysis. The B & K Vibro equipment allows effective control over compliance with the set parameters, and the product portfolio of the company also includes proximeters.

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SPECTRI – LAB NEW ACCREDITED LABORATORY FOR TESTING AND CALIBRATION OF CALIBRATORS, SOUND LEVEL METERS, MULTIFUNCTIONAL CALIBRATORS AND NOISE DOSIMETERS. METHODS OF APPLYING METHODOLOGIES, INTERNATIONAL STANDARDS.

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***Abstract* - This paper presents the used concept, technical support and metrological reference regarding the unique accredited laboratory for calibration of sound level meters, calibrators, multifunctional calibrators, noise dosimeters - SPECTRI - LAB in the Republic of Bulgaria. Presenting SPECTRI – LAB calibration system and methods of applying methodologies and international standards.**

***Keywords* - calibration, sound level meters, calibrators, dosimeters, laboratory, SPECTRI, testing**

I. INTRODUCTION

As a natural continuation of more than 18 years of successful commitment in the field of measurement and management of noise and vibrations, SPECTRI Ltd. has succefuly accredited laboratory for testing and calibration of acoustical calibrators, sound level meters, multifunctional calibrators and noise dosimeters according to 17025 “SPECTRI – LAB”.

The company is investing in the latest generation of measuring and software equipment from the world's highest class (Brūel & Kjær) to provide its Bulgarian partners and customers with a reliable, fast and flexible service to support their ambition to work accurately and deliver quality business.

Calibration is a fundamental step in the measurement process. It ensures that the instrument used for testing shows exactly the required parameter and that the instrument meets its specification.

A. . SPECTRI-LAB is using the following calibration system (main plan):

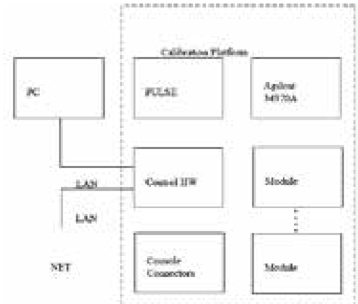

Fig.1 *Elements of the calibration system*

B. SPECTRI-LAB is using the international standards for the calibration of sound level meters as it follows:

- BDS EN 60651;
- BDS EN 60804;
- BDS EN 61672-1, 2, 3

C. SPECTRI-LAB is using the international standards for the calibration of acoustic calibrators as it follows:

- BDS EN 60942

D. SPECTRI-LAB is using the international standards for the calibration of personal noise dosimeters as it follows:

- BDS EN 61252

E. SPECTRI-LAB is calibrating in the following range:

- *Acoustic Calibrator* - sound pressure level: 94, 114, 124 dB (resolution 20 µPa), rated frequency 250Hz, 1 kHz. CMC: 0.15 dB
- *Acoustic multifunction calibrator* - sound pressure level: 94, 104, 114 dB (resolution 20 µPa), nominal frequencies 31.55 Hz ÷ 4 kHz, 8 kHz ÷ 16 kHz. CMC: 0.2 dB, 0.4 dB
- *Sound level meter* - response from an acoustic calibrator signal: 94 ÷ 114 dB (20 µPa), nominal frequencies 31.55 Hz ÷ 2 kHz, 4 kHz ÷ 12.5 kHz. CMC: 0.3 dB ; 0.6 dB
- *Sound level meter* - Response to electrical measuring signals: 20 ÷ 140 dB (20 µPa) nominal frequencies 20 Hz ÷ 16 kHz. CMC: 0.4 dB
- *Personal noise dosimeters* - response of acoustic calibrator signal: sound pressure level of the calibrator 60 ÷ 120 dB, nominal frequencies 63 Hz ÷ 2 kHz, for 4 kHz and 8 kHz; Measuring time 60 s ÷ 120 s. CMC: 0.4; 0.8; 1.3 dB
- *Personal noise dosimeters* - Response to Electrical Measurement Signals: 60 dB ÷ 140 dB CMC: 0.4

F. SPECTRI-LAB is using the international standards for measuring environmental noise as it follows:

- *Equivalent noise level, dBA – BDS ISO 1996 -2; BDS 15471, BDS ISO 8297, Methodology of the Ministry of environment and water.*
- *Maximal A – weighted noise level, dBA – BDS 15471, BDS ISO 1996 – 2;*
- *Noise level at the impact site, dBA - Methodology of the Ministry of environment and water.*
- *Total sound power level, dBA – BDS ISO 8297, Methodology of the Ministry of environment and water.*

The model we use to determine the uncertainty budget is as follows (items to be included):

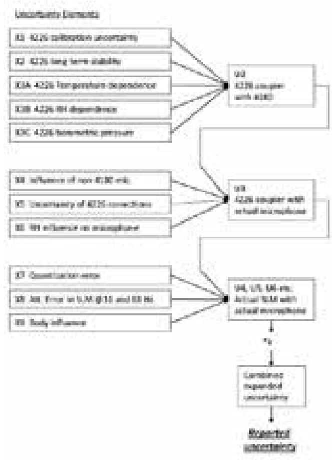

***Figure 2** Uncertainty model*

II. CALIBRATION PRINCIPLE USED - NOISE METERS

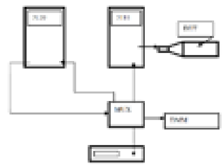

***Fig.3** Check analogue signal*

***Fig. 4** Automatic acoustic calibration - sound level meter 2238*

III. CALIBRATION ACOUSTIC MEASUREMENT MODEL - USING THE DIRECT MEASUREMENT METHOD WITH STANDARD MULTIFUNCTIONAL SOUND CALIBRATOR:

The deviation from the actual sound level "ΔLsp", dB of 20 µPa is derived from the equation:

ΔLsp = ΔLspm + δLspe + δLe,
Such as ΔLspm = Lspm - Lspe (2)

Where:

- ΔLspm - the difference between the readings of the measured sound level meter and the set level of the reference multifunctional sound calibrator dB;
- Lspm - Measurement sounder reading, dB about 20 μPa;
- Lspe - set level of reference multifunctional sound calibrator, dB about 20 μPa;
- δLspe - deviations from the actual sound level value, dB (From the Calibration Certificate of the Reference Sound Calibrator);
- δLe - correction of the measured value due to the sound meter resolution. The reference multifunctional sound calibrator type 4226 - Brüel & Kjær has feedback for equalizing atmospheric pressure. Therefore, the correction of the change in atmospheric pressure in the specified calibration conditions is negligible. This is reflected in the calibrator's technical documentation.

IV. ACOUSTIC CALIBRATORS PRINCIPLE USED

Calibration principle

The devices and auxiliaries are connected according to fig.6

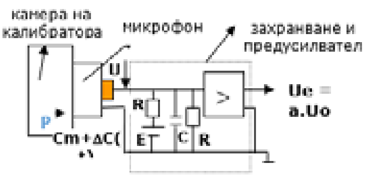

Fig.6 *Automatic acoustic calibration*

P = *Uo* / *So*;
Lp = 20.lg (P / Po);

Where:

P - sound pressure (Pa);

Po - Rated value 20μPa (2.10 Pa);

So - sensitivity of the open microphone reference (V / Pa) expressed in calibration cards as *Mo*, dB for 1v / Pa.

Determination of *Uo* by measuring the effective value of the output voltage "*Ue*" and reading the coefficient "a", which depends on the degree of loading of the microphone output (Figure 6)

Ue = *a.Uo* or *Uo* = *Ue* / *a, a* = *b.Cm*/(*Cm*+*C*);

Where:

Ue - voltage at the output of the preamplifier;

Cm - the capacity of the microphone capsule;

C - input preamplifier capacity;

b - voltage factor for the pre-amplifier kit with power supply unit.

Determination of *Uo* by direct measurement by the substitution voltage method (Fig.2)

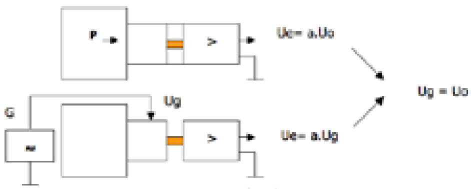

Fig.6 *Determination of Uo*

Ug - a sinusoidal substitution voltage fed by a generator in series to the microphone capsule

Measurement model for determining Lp by a reference microphone with a normalized sound pressure transducer in an electrical signal:

The sound pressure level "Lp" in the chamber of the measured sound calibrator is derived from the equation:
Lp = Lo - Mo - Lpo - δLpa + δLv + δLa + δLe + δLs + δLt (1)
Where:

Lo - value of the measured open-circuit level at the output of the reference microphone, dB vs. 1v;

Lpo - reference level corresponding to 20 μPa, Lpo = 20.lg (2.10), dB;

- *Mo* - open loop sensitivity of the reference microphone, dB relative to 1v / Pa;

- *δLpa* - correction of the atmospheric pressure barometer;

- *δLv* - correction, depending on the equivalent volume of the microphone used;

- *δLa* - correction of the coefficient "a". When measured by the replacement voltage method, this correction is not counted;

- *δLe* - correction of the measured value due to the resolution of the sound metering system;

- *δLs* - correction of the measured value, depending on the polarization voltage tolerance for the microphone;
- *δLt* - change the sensitivity of the reference microphone from a change in temperature.

V. VALUES XJ OF INPUT QUANTITIES:

A. *Measured value (Lo)*

For repeated measurements, Lo is calculated by the formula:

$$Lo = \frac{\sum_{i=1}^{n} Lio}{n} \quad (3)$$

Where: Lio - the value of the level recorded in the i-th measurement;
N - number of measurements.
Lone level (Lpo) - Constant value
Lpo = 20.lg (2.10) = -93.98 dB (4)
The evaluation of the open circuit sensitivity level of the reference microphone under point 3.1 is "Mo" dB. 1v / Pa of the certificate of its last calibration for the relevant frequency.
The assessment of the barometric correction (*δLp*) depends on the atmospheric pressure at the moment of measurement and is read by the corresponding barometer. In some types of sound calibrators, there is a pressure equalization feedback input, and the estimate of this correction is zero and the contribution to uncertainty is increased. This is detailed in the technical documentation of the respective calibrator.

Correction depending on the equivalent volume of the used microphone (*δLv*). There are advanced sound calibrators with volume feedback, so it is important that the fixation (*δLv*) be in accordance with the technical documentation.

Resolution of resolution (*δLe*)
This input parameter has a zero expectancy and an error equal to half the value of the smallest significant digit of the voltmeter.
Since all input quantities are uncorrelated, the *Lp* level equation is equal to the square root of the sum of the dispersions (squares of the uncertainty inputs) of the input quantities

$$u(Lp) = \sqrt{\sum u^2(Xi)}$$

B. *Extended uncertainty, U (Lp)*

The expanded uncertainty of the U measurements is obtained by multiplying the quadratic uncertainty of the estimate *u(Lp)* by the confidence interval *k*, *U=k.u(Lp)*
For normal (Gaussian) distribution of the measured magnitude and probability of the confidence interval, approximately 95%, k = 2.

VI. PRESENTATION OF SPECTRI-LAB CALIBRATION SYSTEM

The Calibration Platform of the Brüel & Kjær 3630 is a universal platform for the calibration of instruments and transducers in the field of noise and vibration.

The applications used by SPECTRI are as follows:

Calibration of noise meters (SLM) - calibration software Type 7763
Calibration of noise meters is extremely governed by legislation. As the number of instruments requiring calibration increases, the need for an efficient calibration system is present.
Sound level meters calibration complies with all relevant international standards and recommendations and is equally well suited for use in national calibration laboratories and calibration centers.

The system combines state-of-the-art information technology with Brüel & Kjær's proven expertise in calibration of noise and vibration tools.
Calibration of sound meters (SLM) with Type 7763 Calibration Software is not just an effective tool, it is actually a globally-supported, easy-to-read system with uncertainty budgets needed for accreditation purposes.

Used for acoustic and electrical calibration of noise meters, calibrators, dosimeters, octave filters - according to international standards.

The Calibration Platform of the Brüel & Kjær 3630 uses the portable 100 kHz PULSE ™ multi-analyzer as the core element of the system. Portable PULSE ™ is an extremely versatile multi-analyzer that can analyze signal level, FFT, 1 / n-octave filters and the overall range of measurement parameters. PULSE ™ also generates the test signals needed to meet the requirements of international standards.

The Type 3630 Calibration System is designed to calibrate Brüel & Kjær instruments as well as other manufacturers' sound level meters in accordance with IEC 60651, IEC 60804, IEC 61672 as well as all other relevant standards. The system comes with Genuine Type 7762 Sound Level Measurement Software and Type 7763 Test Option, performing different tests manually, semi-automatically or in automatic modes. Tests are performed both acoustically and electrically.

Here is a functionality for tracking and controlling calibration intervals by standard and the tools used by the system are facilitated by the calibration manager software, including client and tool database. The measurement circuit is guaranteed by an integrated digital voltmeter DMM Agilent 34970 and Brüel & Kjær Type. Used as a 4226 multi-frequency calibrator (a), as well as the 4180 microphone laboratory standard.

Fig.7 *Calibration system Type 3630.*

A. Calibration platform Type 3630 with calibration software Type 7792 for noise dosimeters

Noise Dose Meter Calibration Type Type 7792 for Type 3630 Calibration platform is an automated tool designed to perform periodic noise dosimeter tests in accordance with IEC 61252. The software automatically starts a variety of predetermined tests according to selected references. The system includes a database of the current Brüel & Kjær types of noise meters, including sound level measurement and noise exposure. New types of dosimeters are entered with a range of parameters required for their definition. Uncertainty budgets are provided to facilitate laboratory accreditation (ISO 17025) and calibration reports are automatically generated to reduce the risk of human error.

B. Calibration platform Type 3630 with calibration software Type 7794 for calibrators.

Platform Type 3630 with Calibration Software Type 7794 is a tool for performing automated periodic calibrator tests in accordance with IEC 60942. The system performs calibration of acoustic calibrators and speech recorders with one frequency (250 Hz / 1000 Hz) as well as multifunction calibrators with different calibration frequencies and amplitudes). Calibration procedures for Brüel & Kjær Acoustic Calibrators Types 4220, 4228, 4230 and 4231 are pre-defined in the software, which also allows the addition of new types of calibration tools and procedures. Uncertainty budgets are provided to facilitate laboratory accreditation (ISO 17025) and calibration reports are generated automatically.

Used calibration system for calibrators, noise meters, noise dosimeters: Type 3630-Brūel & Kjær

Fig.8 *Real working visualization*

From 30.04.2019, SPECTRI, through its testing and calibration laboratory, SPECTRI-LAB provides a new type of services on the Bulgarian market, namely:

- Testing and monitoring of noise in industrial locations
- Calibration of acoustic calibrators
- Calibration of noise meters
- Calibration of noise dosimeters

With this initiative, SPECTRI Ltd. aims to strengthen its portfolio of services in the field of measurement, evaluation and calibration of noise and vibrations, to increase its expertise potential and, last but not least, to provide its clients with additional services and support in their

Metrological assurance tasks and quality control of the equipment used by them.

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[6] BDS EN 60804: 2003 Integral instrument for measuring the average sound level;

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SPECTRI LTD. AND THE LEADERS IN THE FIELD OF ROTARY AND RECIPROCATING INDUSTRIAL MACHINES VIBRATIONS BRÜEL & KJAER VIBRO. INNOVATIVE PROJECT DELIVERY, CONDITION MONITORING SOLUTIONS, MACHINE DIAGNOSIS AND SERVICES.

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Abstract - In the recent paper a general information about the new partnership from Brüel & Kjaer Vibro with Spectri is presented. Brüel & Kjær Vibro is the world's leading independent supplier of protective/safety monitoring, and knowledge-based condition and performance monitoring solutions forrotating machinery. Their solutions, incorporating a wide product range and global service organisation, are tailored to maximize safety, plant utilization and operational effectiveness, while minimizing unplanned outages and maintenance costs. By becoming partners with them, we can provide the Bulgarian industry with new online/offline solutions for machine protection, condition monitoring, diagnosis, vibration measuring equipment, sensors, accessories.

Keywords – Vibration, Sensors, Spectri, Monitoring, Solutions

I. INTRODUCTION

In the past, machines and machine components were over-designed and operated at constant loads. Life cycle times were easily predictable and a time based maintenance strategy was sufficient to remedy most faults. Additionally, a team of well-qualified operators and maintenance crew were always at hand. Today's situation is a far contrast to that of the past. Lean computerdesigned machines are operating ever closer to their limits, and the need for production flexibility leads to widely variable operating conditions and machine loads. The result is an increase in the number of potential
failure modes and a very broad mean time to failure of the machine components. These elements combine to make a condition and performance monitoring strategy not only viable, but indispensible. Brüel & Kjær Vibro is the world's leading independent supplier of protective/safety monitoring, and knowledge-based condition and performance monitoring solutions for rotating machinery. The solutions that Spectri Ltd. provides in collaboration with Brüel & Kjaer Vibro are a wide product range, innovative project delivery, condition monitoring solutions, machine diagnosis and services, all of them are tailored to maximize safety, plant utilization and operational effectiveness, while minimizing unplanned outages and maintenance costs.

Figure 1 – https://www.bkvibro.com/en.html

Spectri Ltd. recently became a representative of Brüel & Kjær Vibro,- one of the world's largest independent suppliers of systems for monitoring and control of rotary and reversing industrial machines, including pumps, turbines, compressors, motors, generators and transmissions for Bulgaria.

II. MAINTENANCE OF ROTARY MACHINES

Why do we need to do annual maintenance of rotary machines? This is the main question the customers ask. The answer lies in that everything is wearing out with time so is the machines. This is the reason vibration diagnostics experts exists or called “machine doctors” that through diagnosis they aim to resolve issue with the machine before even they’ve happened. “What kind of issues may occur through the life of the machine?”, the issues in this field correspond to louder machines than usual, downwards bicycle swing of a valve or other phenomens which lead to the effect of unbalance.

The term unbalance and balance comes mostly from the so called scales. The reason of its origin is because when the same weight exists on both sides of the scale beam the system is in equilibrium (balance). The same goes for rotary machines, when you distribute correctly the mass across a rotational axis of a rotor you are balancing it. If you don’t do an even distribution of the mass it leads to an unbalance of the rotor which increases the vibration, causes centrifugal force, noise during rotation. This can lead to safety risks, because the vibrations that are created by the unbalance of the machine reduce the frictional grip of screwed and clamped connections, until components loosen. Forces caused by unbalance, disruptive vibration and noise are removed by balancing. This involves improving the mass distribution of a rotor so that a smaller centrifugal force act in its bearings. In addition, the type of unbalance also has to be taken into account during balancing. There are different types of unbalance which divide depending ot their effect:

- Static unbalance
- Couple unbalance
- Dynamic unbalance

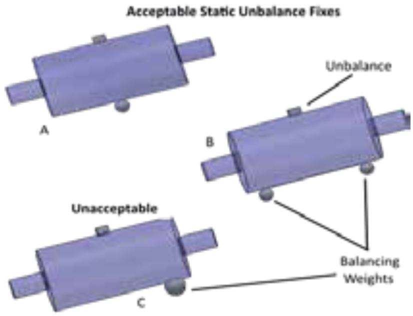

Figure 2 – Balance / unbalance schematic representation

To avoid the issues mentioned above big range of solutions are provided from Brüel & Kjaer Vibro designed specifically for every customer needs, and as well from Spectri Ltd as their representative for Republic of Bulgaria.

A. Types of Condition Monitoring

- Online Condition Monitoring is the continuous monitoring of machines or production processes. The Online Condition Monitoring analysis system will generate data on the most critical moments of the machine. During startup and shutdown of the installation, data is collected on critical speeds and changing spindle positions.

- Periodic Condition Monitoring gives insight into changing vibration behavior of installations. A trend analysis is drawn by performing vibration measurements with a fixed interval. The trend analysis shows the cause of the changing vibrations, followed by specialist advice on predictive measures.

- Remote Condition Monitoring gives the opportunity to analyse data at a distance. The remote reading of measurement data enables measurements and analyses to be performed without bothering your organisation and without unnecessary travel time.

III. SOLUTIONS

A. Brüel & Kjaer Vibro solutions:

Brüel & Kjær Vibro offers a full range of monitoring solutions ranging from sensors and accessories to plantwide monitoring systems. Their equipment is designed to the highest industrial standards of quality and integrity. With a name for reliability, many of our systems are still in service more than 20 years after initial commissioning.

- First to include profile type alarm limits on FFT and envelope spectrum measurements
- World's first balancing machine
- Design and development of the first commercially available piezoelectric accelerometers
- Development of advanced techniques required for rolling element bearing and gearbox fault detection and analysis including: Constant Percentage Bandwidth (CPB), Selective Envelope Detection (SED) and cepstra measurements.
- Setpoint condition monitoring system using OSIsoft PI system

One of the interesting products that Brüel & Kjaer Vibro can provide lately is the condition monitoring system Setpoint. With the acquisition of the US Setpoint® vibration monitoring platform in May 2017, the company expanded its product portfolio by adding state-of-the-art technology to machine monitoring with machine protection. The system fully complies with the API 670 standard. Its universally programmable hardware eliminates the cost and complexity of competing systems. In addition, no stand-alone status monitoring software is needed as the system uses the existing OSIsoft® PI system.

Fig. 3 – Setpoint with OSIsoft System

Full API 670 compliance. Integral touchscreen display. 56 channels in just 19" of rack space. Refreshingly competitive pricing. Ultra-reliable architecture. Dual- and even triple-redundant power. SIL-ready. Industry-first full (including waveforms) connectivity to your PI Server. Embedded ultra-high resolution flight recorder to capture up to one full year of condition monitoring data even without a CM server. And of course, globally available service via our worldwide B&K Vibro network of partners and factory-direct personnel. Discover why customers all over the world are turning to the SETPOINT® machinery protection system.

B. Spectri solutions:

Spectri Ltd. offers new services as it follows:

- Balancing of turbines, pumps, compressors, engines, generators
- One or two-plane field balancing (static/dynamic)
- Two-plane balancing with one vibration sensor
- Diagnosis of rotary and reciprocating industrial machines (FFT analysis)
- Equipment and services for condition monitoring
- Accelerometers, vibration meters, accesoaries
- Offline condition monitoring

All the services are done by using high end equipment provided by Brüel & Kjaer. All of this can be tailored to meet specific customer requirements or combined in a long-term service agreement.

Fig. 4 – Field balancing using Vibroport 80

IV. CONCLUSION

Being able to deliver good business value to our customers is based on several important blocks; our team, experience, long-term partnership with world leading companies, what are we focused on, equipment and technology, quality and our own business. All of this qualities combined gives us the way to be successful.

Spectri Ltd. is maintaining a culture of customer focus. This requires intimate knowledge not only of our customers monitoring requirements, but also of their machines and operating processes.

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Approach in the Analysis of Complex Objects

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Abstract — **The article shows the need for a systematic approach in the analysis and evaluation of the state of complex objects of various types. A systematic approach to the analysis of complex date objects the opportunity to find new ways to optimize the resources of these projects.**

The main goal of the system approach is physically implemented by a number of software tools. In the proposed work, as a tool for the implementation of the systems approach, it was proposed to use the methodology of functional modeling IDEF0. This approach allowed us to create a functional model of the object to determine the function of each element and at the same time visualize its structural features. Methodology IDEF0 is actively used for the analysis and design of technological processes. In this paper, the authors proposed using technology IDEF0 to describe and analyze the interaction of resources for such a complex object as the human body.

There is a decomposition of several levels in this work. In the form of blocks presents the main functions of the simulated object. These functions are broken down (decomposed) into composite parts and presented in the form of more detailed diagrams. The situation continues until the object is described at the level of detail necessary to achieve the objectives of a particular study. The top level diagram provides the most general or abstract description of the functioning of the human body. This chart is followed by a series of diagrams that give a more detailed picture of the main subsystems of the body.

Using decomposition, the human body was divided into main subsystems. A mathematical model is proposed for one of the subsystems of the organism. This model is tested for adequacy. And it can be used to describe the output of this subsystem from the state of homeostasis.

Keywords—functional modeling, decomposition, systems approach, body subsystems, model component.

I. Introduction

In recent decades, more and more technical methods and tools for the analysis and evaluation of complex objects are being implemented in the fields of economics, biology, medicine, ecology and others. The necessity of constructing functional models for describing structures of complex objects is an actual problem, which allows solving questions of evaluation of both the current state of these systems and predicting their state when changing factors of influence. The proposed work uses the methods of functional modeling of IDEF0 and the principles of decomposition for assessing the current state of biological systems[1,2].

II. Problem resolution

ICAM (Integrated Computer-Aided Manufacturing) methodology is used to solve complex computer systems modeling problems, which allows to display and analyze models of the activities of a wide range of complex systems in various sections. They allow you to analyze in detail all the connections in the system, develop and analyze problem solving models, and use these models to make specific decisions. Therefore, the male to her approach was obnaya for assessing the functional state of the organism.

This methodology is widely used in solving problems of design analysis and operation of complex systems. It is based on the IDEF0 (Integrated DEFinition) methodology.

The basic conceptual principle of the IDEF methodology is the representation of any investigated system as a set of interacting and interconnected blocks, which represent the processes, operations, actions occurring in the investigated system. Functions in IDEF0 - all that occurs in the system and its elements, for this example, are processes that are transformed in each subsystem of an organism. Each function performed by an organism is placed in a matching block [1].

The model is an artificial object, representing the reflection of the system and its components. The body model is developed to understand, analyze and make decisions about the functional state of the organism and its homeostasis. The system of the organism is a set of interconnected and interacting parts that perform some useful work. The state of the organism is considered as a system having an effect of destabilizing external factors that have both positive and negative effects. Such factors can be external influences such as stress, sleep disturbance, climatic influences, emotional overload and others. And also mechanisms of regulation as external: the reception of medicines, physical activity, relaxation procedures, rest and other; both internal and internal: biological feedback, compensatory effects of individual systems, and others.

So, with the help of IDEF0 technology, the organism can be presented as a system, as shown in Fig. The decomposition of the diagram given in Figure 1 can be carried out as subsystems of the organism, where all systems are in close interconnection, and the nervous and endocrine system in turn is performed by a control function. As can be seen from Figure 2, each of the subsystems has its own decomposition. So the subsystem describing the urinary subsystem has a decomposition A5 and is shown in Figure 3.

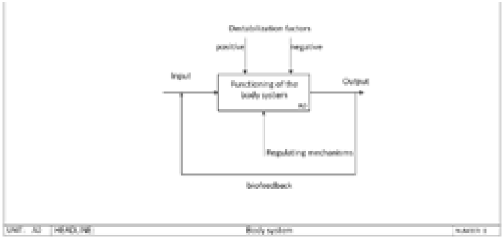

Figure 1. Top Level Context Chart

The decomposition of the diagram given in Figure 1 can be carried out as subsystems of the organism, where all systems are in close interconnection, and the nervous and endocrine system in turn is performed by a control function. As can be seen from Figure 2, each of the subsystems has its own decomposition.

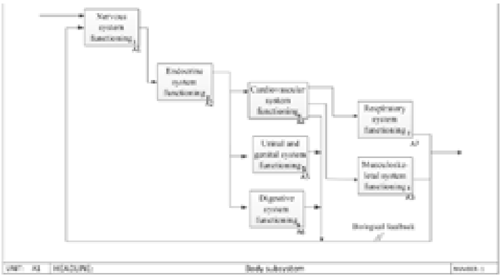

Figure 2. Child top-level diagram

According to the IDEF technology, the most important properties of an object are usually detected on the upper levels of the hierarchy; As the function of the upper level decomposes and splits it into subfunctions, these properties are specified. So after breaking down the system of the organism into the subsystem, the urinary system was selected to determine its main components. Each subfunction, in turn, is decomposed into elements of the next level, and this is so until a relevant structure is obtained that allows us to distinguish the factors that influence the process of functioning of the subsystem [1].

Blocks are joined by arrows that are in or out of it. The input arrows indicate which conditions must be temporarily executed so that the urinary function, which is described by the block, is in a state of homeostasis.

So the diagram describing the urinary subsystem has a decomposition A5 and is shown in Figure 3

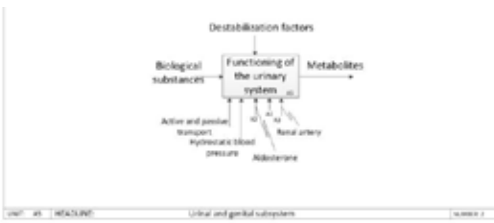

Fig. 3. Child top-level diagram A5

On the IDEF0-diagram, the block represents a rectangle characterizing the functioning of the urinary system. The decomposition of the subsystem of the urinary system is given in Figure 4.

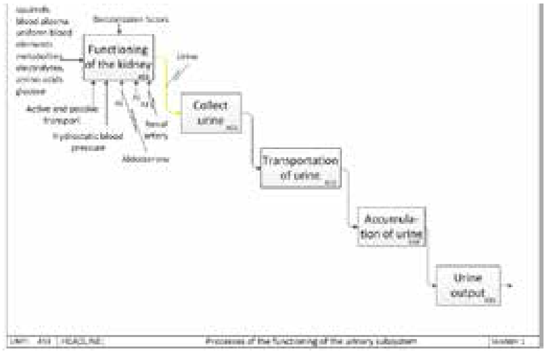

Figure 4. Decomposition of unitA5

In this diagram, the input is biological substances (proteins, blood plasma, uniform blood elements, metabolites, electrolytes, amino acids, glucose, water), which are converted by various functions and mechanisms. The indicated biological substances are converted into the products of vital activity by the urinary tract system using the mechanisms presented in Figure 4. The process of functioning of the system can be influenced by destabilizing factors, which are more detailed at the following levels of decomposition.

Next, the block A5 is decomposed and describes in more detail the process of functioning of the urinary system in diagram A5, which has five blocks (see Figure 4):

- functioning of the kidney (A51);
- collection of urine (A52);
- transportation of urine (A53);
- accumulation of urine (A54);
- urine output (A55).

Diagram A51 begins with the block of blood supply A511 (Figure. 5), the mechanism of which is block A1 (functioning of the nervous system) and block A4 (functioning of the cardiovascular system, namely, the renal artery).

The path of blood with all biological elements, within the block A511, begins with the renal artery and ends with the afferent artery, which continues to enter the glomeruli (Figure 5).

The blood filter unit A512 includes six arrows. The red arrow is responsible for the transport of purified blood, and the blue arrow is responsible for the delivery of reabsorbed amino acids, glucose and electrolytes. The input arrow of black reflects the delivery of metabolites, proteins, plasma blood.

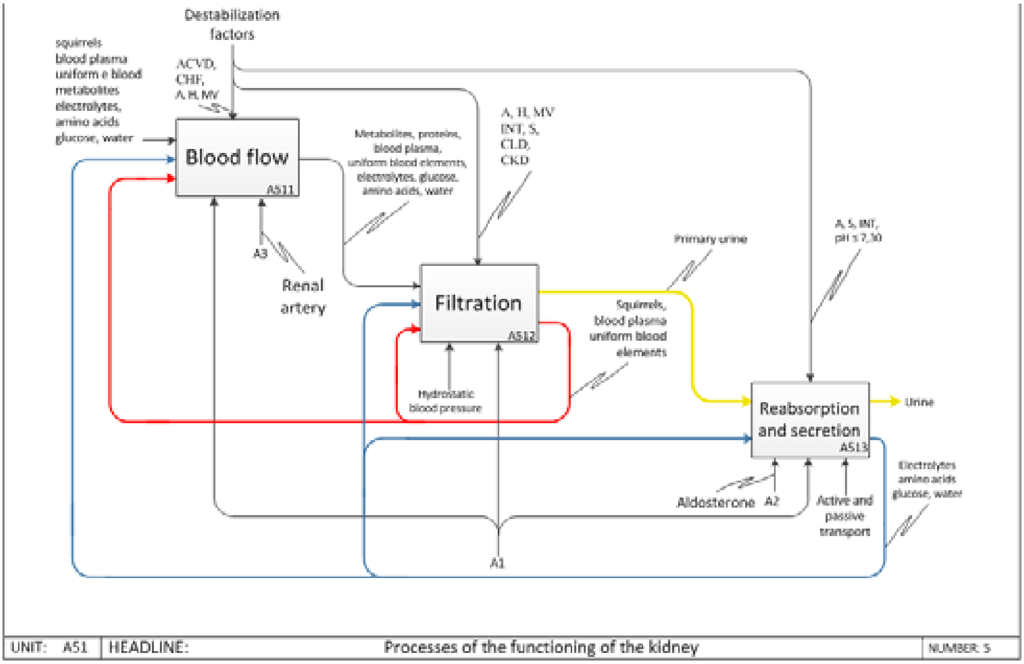

Figure 4. Decomposition of unitA51: processes of the functioning of the kidney

Thus, the filtrate is converted into urine, which then, according to the diagram A5, is collected (A52), transported (A53), accumulates (A54) and outputs (A55).

This functional block has the beginning of a biological feedback, which is responsible for the transport of electrolytes, amino acids, glucose and water to the total blood flow.

The functionality of the kidneys is affected by destabilizing factors, which were selected by the results of a prospective observational study conducted in two major university clinics, USCD and Mayo Clinic. The regression model (1-2) developed by them demonstrated good prognostic properties regarding the probability of acute renal failure. Thus, in one cohort, the AUC ROC was 0.79 and in the other 0.81 [2].

Destabilizing factors were selected using the formula of linear regression of the species (1):

$$P = \frac{e^a}{1 + e^a} \qquad (1)$$

where:

$$a = 0{,}059 + [0{,}860 \cdot x_1] + [0{,}778 \cdot x_2] + [0{,}720 \cdot x_3] +$$
$$+ [0{,}563 \cdot x_4] + [0{,}490 \cdot x_5] + [0{,}977 \cdot x_6] + [0{,}929 \cdot x_7] +$$
$$+ [0{,}743 \cdot x_8] + [0{,}447 \cdot x_9] + [0{,}390 \cdot x_{10}] \qquad (2)$$

In formula (2) x_i-destabilizing factors that can affect the development of acute kidney damage.

The model used the following factors of influence:x_1: chronic kidney disease (CKD);

- x_2: chronic liver disease (CLD);
- x_3: chronic heart failure (CHF);
- x_4: hypertension (H);
- x_5: atherosclerotic coronary vascular disease (ACVD);
- x_6: pH $\leq$ 7,30;
- x_7: the influence of nephrotoxins (INT);
- x_8: sepsis (S);
- x_9: mechanical ventilation (MV);
- x_{10}: anemia (A).

Anemia and pH $\leqslant$ 7.30 are potentially corrected states [2].

The effect of destabilizing factors is presented in detail in Diagram A51, which begins with the block of blood supply A511 (Figure 5). The following factors are affected by blood transfusions: atherosclerotic heart disease, chronic heart failure, anemia, hypertension and mechanical ventilation. According to the regression model, chronic heart failure most influences the transport of blood vessels of the body. The least affects anemia.

Blood filtration occurs under certain hydrostatic pressure, therefore factors such as hypertension can cause dysfunction, which in turn will affect the quality of the filtration. Also, the glomerular filtration is influenced by:

- influence of nephrooxides;
- chronic kidney disease;
- chronic liver disease;
- sepsis;
- mechanical ventilation;
- anemia.

The following factors influence the functioning of the block A513: reabsorption and secretion: pH ⩽ 7,30, the effect of nephrotoxins, sepsis and anemia.

Thus, the presented factors may serve as predictors of the development of acute kidney damage, that is, the appearance of such factors is the cause of acute kidney damage. The proposed (2) [2] regression model for determining the factors influencing the development of acute kidney damage has been tested on the statistical results of two Ukrainian medical institutions specializing in patients with acute kidney damage and chronic kidney disease. The research was carried out at the following medical institutions: Kyiv City Clinical Hospital №5, and Kyiv City Hospital №3, which is the association "Kyiv City Center for Nephrology and Dialysis". The collected statistical data made it possible to check the regression model (2) for adequacy for use in these institutions with the specifics of their patients.

The adequacy of the proposed model (2) is verified using the determination coefficient [4]:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Y_{1i} - y_{1i})^2}{\sum_{i=1}^{n}(y_{1i} - \bar{y})^2}.$$

According to statistical data, the determination coefficient was calculated. Determination Coefficient for the processed data of 105 patients: R2 = 0.6356, which indicates a satisfactory degree of approximation [5,6].

After processing the statistical data, it was found that destabilization of the factors of influence x_8, x_9 and x_{10} was not characteristic of the investigated group. Therefore, a regression model was proposed without taking into account these factors:

$$a = 0{,}059 + [0{,}860 \cdot x_1] + [0{,}778 \cdot x_2] + [0{,}720 \cdot x_3] + \\ + [0{,}563 \cdot x_4] + [0{,}490 \cdot x_5] + [0{,}977 \cdot x_6] + [0{,}929 \cdot x_7] \quad (3)$$

The calculated value for this mathematical model is $R^2 = 0{,}9804$. That is, the dependence of the functioning of the kidneys on the variation of the variables x_1 ... x_7. That is, the model (3) confirms the observation obtained from data from 105 patients in the center of nephrology and dialysis.

To verify the mathematical model (3), the Fisher's F-criterion [4,7] is used for adequacy by comparing its calculated value with the table for a given confidence level. For this we put forward the hypothesis H_1 that the regression model is adequate and H_0 is not adequate. To test the hypothesis H_1 for the adequacy of the regression model (3), the following calculations were made by statistical data. Calculated Fischer coefficient value:

$$F = \frac{(p-3)\sum_{i=1}^{p}(Y_{1i} - \bar{y})^2}{(p-1)\sum_{i=1}^{p}(Y_{1i} - y_{1i})^2}$$

$$\sum_{i=1}^{p}(\hat{y}_i - \bar{y})^2 = (0{,}4923 - 0{,}5)^2 + (0{,}4905 - 0{,}5)^2 + \dots$$
$$+ (0{,}4941 - 0{,}5)^2 + (0{,}4917 - 0{,}5)^2 =$$
$$= 0{,}000059299 + 0{,}00009025 +$$
$$+ \dots + 0{,}00006889 = 0{,}000512459;$$

$$\sum_{i=1}^{p}(\hat{y}_i - y_i)^2 = 0{,}00024964 + 0{,}00000081 +$$
$$\dots + 0{,}00009216 = 0{,}00038591;$$

$$F = \frac{(p-3)\sum_{i=1}^{p}(Y_{1i} - \bar{y})^2}{(p-1)\sum_{i=1}^{p}(Y_{1i} - y_{1i})^2} = \frac{\frac{1}{5-1} \cdot 0{,}000512459}{\frac{1}{5-3} \cdot 0{,}00038591} =$$
$$6{,}06113.$$

$$F = \frac{\frac{1}{105-1} \cdot 0{,}000512459}{\frac{1}{105-3} \cdot 0{,}00038591} \approx 1{,}3023.$$

Since for a given number of degrees of freedom the critical value is Fqr = 3.94, then F <Fkr, that is, the given regression model (3) to determine the probability of acute kidney damage is adequate [7]. And it can be used to investigate the probability of acute kidney damage

Conclusion

. In this work the modeling of the IDEF0 technology for the analysis and determination of the peculiarities of the functioning of the body, namely, one of its subsystems, was performed. Different levels of decomposition have been performed to determine the factors influencing the risk of developing renal diseases. Calculations have been carried out to check the adequacy of the proposed model. Determination of the factors influencing the development of acute kidney damage was carried out using the functional modeling of the standard IDEF0, since this graphical representation of this modeling is concise and does not overload the amount of information. Such qualities can be useful in studying the functioning of different subsystems of the organism, analysis of their destabilizing factors and in direct work with functional models for physicians of different specialties, engineers and specialists in IT technologies for the coordination of their actions in the development of decision-making systems in medicine.

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Software simulation system for the solution of the reverse problem of volume scattering of natural gas bubbles. Architecture optimization subsystem

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***Abstract—The simulation and optimization of the software simulation system for solving the inverse problem of* volume scattering of gas bubbles are investigated. The developed software enables to automatically simulate the situation of the process, calculate the physical model with the given input data and visualize the result for development. The software development method is based on the C ++ programming language, the Boost library, the Qt framework and the Qt Creator integrated development environment.**

Keywords — C ++, BOOST, Qt, GUI, CHARTS, HISTOHRAM, DESKTOP, THREADS LIBRARY, LIBTEST, BDD, UNIT-TESTS

INTRODUCTION

The main problem of the power complex of Ukraine is the need to import natural gas. Ukraine’s domestic gas is now extracted only on land, there is no offshore production.

Gas fields on land have been depleted or are difficult for accessing, with high cost of production, which already exceeds the design cost of gas from offshore fields.

The State Service of Geology and Subsoil of Ukraine estimates the balance reserves of natural gas, which can be produced on the shelf of the Black and Azov Seas, at the level of 48 billion cubic meters.

The product consumption market is the Ukrainian gas market with a recent volume of about 35 billion m3 per year; at the same time, this country annually consumes at least 50 billion m3 of gas and 10 million tons of oil products. At present, the market is supplied by Ukraine’s domestic gas at about 40%. Ukraine pays a high price for importing the remaining 60% of gas. In the depths of the Black Sea there are gas reserves that could provide Ukraine with its own gas for decades.

The implementation of this project will make it possible to carry out and automate natural gas prospecting and take an important step towards the energy independence of Ukraine.

I. SCOPE AND OBJECTIVES

Currently, about 400 groups of underwater gas flares have been found in the northwestern part of the Black Sea. Underwater gas flares are the result of gas reaching the surface; it is mainly methane coming from the deep layers of the Earth. According to estimates, the specific volumetric gas yield (the volume of gas supplied from 1 square meter of the bottom per unit time) from individual boreholes can reach 0.4 l/sq. m. With average borehole diameters of 10 - 40 m, it is equivalent to the release of methane from a single borehole located at a depth of 70 m in a volume of 810 liters - 130 106 cubic meters per year. According to the results of systematic monitoring gas emissions are stable. The gas flare deposits can be of industrial significance, and the task of evaluating its gas recovery is urgent.

The objective of the paper is to develop an architecture optimization subsystem for combining all the components of the system. The software development method is based on the C ++ programming language, the Boost library, the Qt framework and the Qt Creator integrated development environment. The result is a desktop application that visualizes the user experiment outcome.

II. THE OBJECT OF STUDY

To solve the inverse problem of volumetric dispersion in intense gas flares (i.e., under conditions where the flares are formed by clusters of bubbles of various sizes, and individual pop-up bubbles are not “traced” by the acoustic system) there is a set of values of back volume scattering at different frequencies fk of probing signals:

$$m_\gamma(f_k) = \int_{r_{min}}^{r_{max}} \sigma(r,f)n(r)dr \qquad f_k = f_1, f_2 \dots f_k \tag{1}$$

where $\sigma(r,f)$ − is the single-bubble backscattering cross section

$$n(r)dr = \frac{\text{the number of bubbles in the range of radii between } r \text{ and } r+dr}{volume}$$

In other words, $n(r)dr$ is the number of bubbles per unit volume in the range of radii $[r \leftrightarrow r + dr]$.

Number of dimensions:

$$[m_\gamma] = 1/\text{м} \ ,[\sigma(r, f)] = \text{м}^2 \ ,[n(r)dr] = 1/\text{м}^3$$

$n(r)$ is a size bubble distribution function (SBD)

$n(r) = n_0\, p(r)$, where $p(r)$ is the probability density function of SBD

n_0 is bubble concentration per unit volume

Number of dimensions $[p(r)] = \text{м}^{-1}$, normalization $\int_{all\ r} p(r)dr = 1, [n_0] = 1/\text{м}^3$

Thus, the task of creating an input data interface comes down to the following steps:

– To represent $\sigma(r, f)$ adequately;

– To set $p(r)$ based on the real data (obtained in natural experiments);

– To determine the concept of n_0 using the experimental values of the m_γ coefficient at the frequency of 38 kHz in the intensive flares of the Black Sea

The formation of the gas flare contour is influenced by the following main parameters: gas volume concentration in a borehole, bubble ascent rate, mass transfer coefficient from a gas bubble to the environment, bubble surface area, depth of borehole location and its diameter. The first four parameters depend on the dispersed composition of gas bubbles.

The dispersed composition of bubbles can be obtained by means of gas flare sonar sounding. This raises the problem of transition from the dispersed composition of gas bubbles to the four specified formative parameters. The dispersed composition of gas bubbles is mainly represented in the form of histograms characterizing the proportion of bubbles of a given size group in the total composition of bubbles.

In the mathematical description of a flare, the medium inside the contour of the flare is considered as homogeneous with a change in individual parameters from layer to layer. In this connection, the parameters determined by the dispersed bubble composition must be averaged.

The requirement is to develop a graphical user interface for visualizing and analyzing the direct and inverse problems, as well as the system architecture.

The interface is supposed to support input data entry and visualization of the algorithm, namely, build a diagram of input data, a graph of input data change before solving the inverse problem, and graphs of direct and inverse problem behavior.

Besides, the program is supposed to lobby all the calculations to a file in order to visualize the problem in such mathematical modeling systems as OriginLab and MATLAB, if necessary.

The system architecture is supposed to be multi-layered and distinctly subdivided into a model, visualizations and a controller. Due to this, the support and expansion of the system will not cause any difficulties henceforth. It is necessary to take care of the optimization of the algorithms, because the program makes a lot of calculations and this may affect its performance.

III. Purpose of Software Development

The software being developed is designated to verify the suggested recommendations. The software implements the method developed on the basis of scientific research. In this case, the algorithm that implements this method is intended for experimental determination of its main indicators.

A. Requirements for Functionality

To test the efficiency of the method and the proposed recommendations, it is necessary to implement the following functional mechanisms:

- Physical model;
- Graphical user interface;
- Logging system;
- Table and graph representation of input data;
- Visualization of the analysis of echo signals and the residual error of alpha;
- Graphic representation of the solution of the direct and inverse problems.

The program is supposed to enable the user to simulate the process situation, calculate a physical model with the given input data and visualize the result.

B. Interface Requirements

The test program is launched by means of the exe file, where the user specifies the following parameters:

– Path to the statistics file;

– Integral decomposition;

– Number of system dimensions;

– Minimum bubble radius;

– Maximum bubble radius;

– Production depth;

– Damping coefficient;

– Alpha counting number;

– Accuracy of calculations;

– Sensing frequencies;

– Value for regulating alpha

The program visualizes calculations by means of graphs; a log of calculations is conducted for more detailed visualizations in mathematical packages as well.

To develop the software, it is necessary to use QtCreator which is considered to be a modern tool and allows implementing all the requirements.

IV. Software Simulation

The simulation process is used for the design, development, analysis and optimization of technological processes, such as: chemical plants, chemical processes, environmental systems, power plants, complex production operations, biological processes and similar technical functions.

The simulation process is a model based on the presentation of chemical, physical, biological and other technical processes and individual operations in the software. The basic prerequisites are in-depth knowledge of chemical and physical properties of pure components and mixtures, reactions, and mathematical models which, in combination, allow calculating processes by using computers.

When modeling a system by means of a use case diagram, a systemanalyst aims to:

- Clearly separate the system from its environment;

- Determine the actors, their interaction with the systemand the expected functionality of the system;

- Define the concepts in the glossary of the subject area related to the detailed description of the system functionality (i.e., use cases).

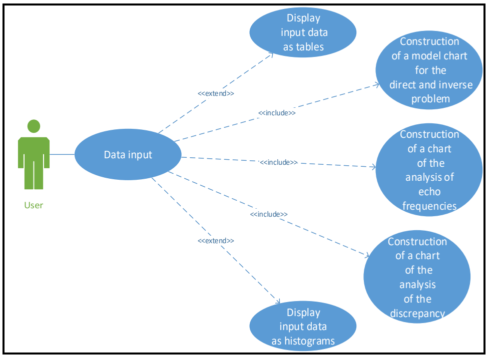

Fig. 1. Chart of use case options

From the results of the analysis carried out by the variant network method, it follows that the best software tool for developing the software product is the C ++ language, the Qt framework and the Boost library

V. CONCLUSION

The objective of the paper was to develop an architecture optimization subsystem for the software of the simulation system intended for solving the inverse problem of volumetric dispersion of natural gas bubbles; its significance was confirmed on a national scale and the main operation algorithms were obtained. The work was carried out by solving the inverse problem of volume scattering in intense gas flares (i.e., under conditions where the flares are formed by accumulation of bubbles of various sizes, and individual pop-up bubbles are not "traced" by the acoustic system).

As a result, the task was completed and the prototype of the systemwas created.

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Measurement in Psychophysiology: Analysis of Current Challenges and Achievements by the Example of EEG-studies of Acute Stress

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***Abstract*—Measurement issue is one of the core problems in modern neuroscience due to continuous improvement in spatial and temporal resolution of techniques for brain investigation. This paper presents main challenges and up-to-date achievements regarding the registration, analysis of EEG signals, as well as the current trends in search for new biomarkers of acute and chronic stress based on the processing of electrophysiological data obtained by non-invasive way**

Keywords— psychophysiology, EEG, acute stress, biomarkers

I. Introduction

Modern psychophysiology is, on the one hand, a biological science subject area (as a branch of physiology) that studies the neuronal mechanisms for emergence and functioning of cognition, on the other hand, a discipline of human sciences, one of psychological science areas with its own theoretical and methodological foundations and categorical-conceptual framework.

Accordingly, it is not considered surprising that the measurement problem in psychophysiology is a double-edged sword. Being originally an interdisciplinary field, psychophysiology tries to solve so-called «brain-mind problem" based on the use of measuring tools developed over many decades, both in psychology and neurophysiology. The researcher in this case is faced with the need to take into account the nature of studied phenomena (objects of measurement), the features of measurement methods themselves, the scales of measured values, as well as problems associated with measurement errors and inaccuracies.

In this paper metrological aspects of the problem of recording, analyzing and interpreting data in psychophysiology will be shown by the example of searching for electrophysiological biomarkers reflecting characteristics of system organization and functioning of neural ensembles when an organism responds to stress.

II. EEG-studies of Acute Stress

Investigation of stress issue in science is one of the priority areas of research, primarily because of its high social significance. Chronic stress is considered as one of the main contributing factors for etiology and pathogenesis of a number of mental disorders, such as depression, anxiety disorders, panic attacks, post-traumatic stress disorder (PTSD), adjustment disorder, and psychosomatic diseases, in particular, disorders of the cardiovascular system diabetes, obesity, etc. In this regard, a necessary step is to develop appropriate tools for diagnostics of chronic stress and the prevention of its adverse effects.

In the era of emergence and active growth of evidence-based and personalized medicine, the search for objectively recorded biomarkers of stress. A significant proportion of modern studies of acute stress in laboratory settings, as well as experiments involving patients suffering from stress-induced disorders, are conducted by using neuroimaging techniques (fMRI, PET, EEG, and functional near-infrared spectroscopy). Electroencephalography (EEG) as a non-invasive method for recording summated activity of postsynaptic potentials generated primarily in the neocortex is currently perhaps one of the most commonly used neuroimaging methods in applied clinical and fundamental scientific studies of brain activity [4]. It is also considered to be one of the most easy-to-use, but at the same time, reliable and informative diagnostic tools in neuroscience. Scientific and technical progress in recent decades has significantly improved the recording technology and methods of EEG analysis. A significant breakthrough was achieved in the field of solving EEG inverse problem — source localization methods implemented in a raw of available to date particular data-processing software, for example, LORETA (low resolution electromagnetic tomography), BESA, Brainstorm, Fieldtrip, BrainLoc which were verified by using joint EEG-fMRI registration, as well as invasive method called electrocorticography (ECoG) in patients undergoing brain surgeries.

The main advantage of EEG is its high temporal resolution, which makes it possible to study the electrical brain activity in a millisecond range. It should be noted that magnetoencephalography (MEG) has the same advantage, but it is significantly inferior to EEG in terms of compactness and mobility of equipment, making it highly unlikely to record MEG outside laboratory conditions (however, nowadays, the MEG has a good opportunity to take advantage of using a novel type of sensors for this purpose) [2]. Thus, the combination of abovementioned characteristics of EEG, in particular: • high temporal resolution; • low cost compared to other neuroimaging techniques; • compactness / mobility allowing recording outside of lab settings; • the absence limitations typical for other methods (claustrophobia as a relative contraindication for PET, MRI scanners; invasiveness associated with the need to introduce radioligands during PET scanning) determines the current position of electroencephalography as one of the leading methods among all available tools designed for studies of living brain functioning.

A number of current studies show that electrophysiological markers of stress can be considered effective, reliable and objective indicators of activation of body and brain stress systems , and can also be considered as targets of therapy, for example, through transcranial magnetic stimulation or neurofeedback paradigm.

A huge amount of research in neuroscience over the past decades has demonstrated a close relationship between perceptual, cognitive, motor, emotional and motivational processes and specific oscillatory patterns. It is emphasized that neuronal rhythmic activity is not just an epiphenomenon of brain functioning, but plays a key role in the organization of local and global information processing modes in nervous system (for example, synchronization through coherence theory).

Recent progress in signal analysis has enabled electroencephalography to become a full-fledged neuroimaging method, capable of providing detailed spatial and temporal information about brain function in health and disease. Due to ever-increasing interest among professional scientific community to the prospects for improving temporal resolution when analyzing brain networks, EEG is gradually becoming the object of choice for researchers. An additional factor for this kind of preference is the possibility of comparability of EEG results with results obtained by using other neuroimaging techniques such as MEG, fMRI, fNIRS.

Unfortunately, a significant proportion of modern cognitive and clinical EEG studies still focus on analysis of graphoelements analyzed in specific scalp leads. Such an approach to data analysis using electroencephalography presents considerable difficulties in interpreting research results. One of the trends of modern neuroimaging studies is the shift of focus from space of EEG sensors to source space. This approach is justified for several reasons. The first of these is that an electrode (sensor) does not record information directly from the source beneath this electrode, due to the fact that EEG signal taken from a specific lead, actually is the sum of activities of many brain sources. Often this problem is referred to as "volume conduction," reflecting the fact of isotropy of the electric field propagation from a brain source lying in cortical and subcortical areas. The second significant drawback of working in the sensor space is a problem of reference electrode. Measuring the voltage difference between electrically neutral and active electrodes is a fundamental principle of recording electrical brain activity using EEG. However, it is worth noting that there is no electrically neutral point ("true zero" point) on the surface of human body, which should be used as a reference when registering an EEG signal. Fluctuations of the voltage on the reference electrode lead to changes in potentials picked up from active electrodes, even if these electrodes do not actually detect any changes in electrical activity of the brain. In order to minimize this effect, a number of different placement options for the referent were proposed, including vertex, nose, ears, and the averaging over all electrodes as possible solutions. Lack of universal and generally accepted standard for placement of the referent among laboratories is a significant problem for comparability of research results. Theoretically, the ideal referent is the point positioned as far as possible from the active electrodes (extreme case is infinity). This idea was implemented in REST (reference electrode standardization technique) software. The third problem associated with the sensor space is a small number of electrodes used to record the signal. In today`s research practice, number of studies which use so-called high-density EEG, having 64 and more electrodes, is constantly growing, that allows one to achieve a significant increase in accuracy in the source localization of neuronal activity.

The problem of acute and chronic stress is one of the most pressing problems of modern psychology and neuroscience. Non-invasive neuroimaging methods are best suited for studying these phenomena in both laboratory and natural conditions. At present, the existing types of research stress protocols are represented by several main variants, differing from each other mainly by nature of stressors affecting a person. Depending on the nature of stimuli used in the experiment, stressor can be defined as cognitive, social, emotional or physiological. Each of these types of stressors is assigned a specific format of experimental protocol and design of experiment. The use of such experimental protocols and designs made it possible to identify a number of electrophysiological activity patterns specific to stress states.

A recent study by M. Gertner et al. convincingly demonstrated a decrease in power of theta rhythm in prefrontal cortex in situation of stress during a performance of work memory task. One of the proposed interpretations for role of theta rhythm during cognitive tasks is that brain activity at frequencies of 4–7.5 Hz is a mechanism by which working memory information is "protected" from influence of irrelevant stimuli. Some authors consider frontal theta rhythm as a biomarker of intact executive functions implemented by the prefrontal cortex.

Strengthening of left hemispheric activity in scientific literature is considered to be associated with emotions, reflecting the activity of approach system. On the contrary, increased right-hemispheric activity is associated with negative emotions, reflecting the work of avoidance system. Thus, hypoactivation of the left frontal lobe may be a factor of individual predisposition for increased reactivity against aversive stimuli, which, in turn, may be related to an increased risk of anxiety disorders and depression [6].

Another possible stress biomarker in the same alpha range is an individual alpha rhythm frequency, which can be an indicator of cognitive functioning in a stress situation.

N. Hamid et al. found that high scores on subjective stress assessment scales correlate positively with a lower ratio of left to right hemisphere activity in the range of alpha and beta rhythms. The results of experiments by P. Putman and his colleagues revealed a strong positive correlation between the power ratio in theta and beta rhythms (theta / beta ratio) and vulnerability to more pronounced manifestations of anxiety in tasks with cognitive load [7]

Thus, today there are several dozens of empirically validated electrophysiological indices - candidates for the role of stress biomarkers, several of which were presented in this article. Further unification of registration procedures and stages of analysis of EEG data (for example, in BIDS format), as well as verification of diagnostic value of the identified biomarkers in future studies, will speed up the transition from bench to bedside.

A few decades ago, electroencephalography was considered as a non-invasive method for diagnosing only fairly gross disturbances of structure and activity patterns of human brain, or identifying pronounced differences between electrophysiological patterns of various functional states, such as sleep and wakefulness. However, in the process of continuous improvement of instrumental methods in neuroscience, there have been significant changes in both signal recording technology and methods for analyzing the data obtained. This made it possible to consider electroencephalography as one of the leading and retaining their informative value methods of neuroimaging.

In this paper, the main problems associated with EEG data analysis were emphasized. Unfortunately, page restrictions do not allow addressing the complex issue of sources localization, where we face a need to take into account the difficulties arising in regard to the formulation of direct and inverse EEG problems. However, the current position and further improvement of the methods for studying brain activity in neuroscience allows us to address, among other issues, the problems of related disciplines, one of which is the problem of stress. In addition, a number of issues are still open and of particular importance for experimental studies, for example, the problem of manual or automatic search and removal of artifacts in a recorded EEG signal.

Nevertheless, the problems presented in the publication related to measurement procedures in psychophysiology, and a brief review of the experimental characteristics of the electrophysiological activity of the brain and their correspondence with the activity of specific brain structures, makes it possible to develop new algorithms and protocols for investigation of experimentally induced stress.

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Key Metrological Issues of Medical Psychological Diagnostics

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***Abstract*—Medical psychological diagnostics is a relatively new interdisciplinary branch of clinical psychology that has developed in recent years. It combines problems and objectives of at least two areas of knowledge and practice: psychological diagnostics and medicine. Measurement (as finding of measure, that is, the ratio of quantity and quality of an object) involves the use of different scales, at least, quantitative and qualitative, and the result is, as a rule, a quantitatively expressed value, even though the value is measured on the basis of qualitative ordinary scales. But it should be noted that in medicine, primarily in psychiatry and clinical psychology, there are no scales of their own, and classical metrological scales are borrowed. Thus, the question arises about the correctness and permissibility of transformations of results obtained by indirect measurements using such scales. The problems and questions raised in this publication reflect only part of the difficulties that arise in medical psychodiagnostics as an industry that deals with measurement of non-physical quantities, alienated products of brain activity and do not cover even deeper phenomena.**

Keywords— medical psychological diagnostics, measurement in medicine and clinical psychology

I. INTRODUCTION (*HEADING 1*)

Medical psychological diagnostics is a relatively new interdisciplinary branch of clinical psychology that has developed in recent years. It combines problems and objectives of at least two areas of knowledge and practice: psychological diagnostics and medicine [1]. Nowadays, the issues of measurement and procedures similar to it, such as assessment, qualimetry and so on, come to the fore. Moreover, the main problems are related both to the characteristics of the object of measurement in medicine (which mostly are non-physical phenomena), as well as the measurement problem itself.

In the first case, medicine has taken as an object of its study not only the symptoms of the disease, but also categories gravitating toward abstract constructs, for example, quality of life, the internal picture of the disease, problems of altered states of consciousness, etc. At the same time, the differences in measurement issues in somatic medicine and in domain of neuropsychiatric disorders are obvious. In the latter case, the objects of measurement are not only non-physical phenomena, but often do not have a direct material substrate, being alienated products or functions of the nervous system. Besides, it is of huge importance to obtain informative data for further making, among others, management decisions: for example, World Health Organization suggested that in the 21st century the effectiveness of medical interventions should be evaluated according to patient's quality of life. By using the example of studying the phenomenon of quality of life, we can ask the question: What is the metrological procedure for determining the characteristics of quality of life: measurement, assessment or qualimetry? It is obvious that these 3 procedures are different among themselves, just as the data obtained with their help will be different.

II. PREPARE YOUR PAPER BEFORE STYLING

Measurement (as finding of measure, that is, the ratio of quantity and quality of an object) involves the use of different scales, at least, quantitative and qualitative, and the result is, as a rule, a quantitatively expressed value, even though the value is measured on the basis of qualitative ordinary scales. But it should be noted that in medicine, primarily in psychiatry and clinical psychology, there are no scales of their own, and classical metrological scales are borrowed. Thus, the question arises about the correctness and permissibility of transformations of results obtained by indirect measurements using such scales.

The evaluation and assessment procedure that is common in practice can be viewed as a reduced version of the measurement, in which the measuring metrics are made up of the evaluator's own psychological tools. At the same time, the estimates obtained in this way can be both affective and cognitive in nature [2]; can be expressed qualitatively or quantitatively, etc. It is obvious that the accuracy of assessment is largely dependent on characteristics of the evaluating subject, for example, his/her level of insight, competence, tendency to make / not make marginal judgments, as well as metrics of the subjective scale, which the expert is guided by. Thus, the scales used in psychological diagnostics for registering the answers of subjects externally look like equal interval scales, but in essence they are not more powerful than ordinal ones.

Qualimetry (from lat. Qualis), on the one hand, is an example of measurement procedures, but, on the other hand, it relies on methods for quantifying qualitative phenomena and phenomena. As a consequence, it has the same aforementioned problems of measurement and evaluation in medicine. At the same time, there is a need to develop novel descriptions of qualities of the phenomenon being measured. For instance, addressing the latter case, in psychodiagnostics the procedure of the so-called construct operationalization is often used.

In addition, in relation to the object of study in medicine and psychology, several other problems should be noted: firstly, until now there are no data confirming that the distribution of the phenomena studied in medicine and psychology (incidence levels, intensity of symptoms, manifestations of diseases and disorders, and so forth) are subject to the law of normal distribution. Moreover, clinical evidence suggests that this distribution does not have a form of a well-known bell-shaped curve (Fletcher). At least, in the moment, it is theoretically difficult to substantiate what kind of known distributions the characteristics of medical and psychological phenomena approach to. In any case, the solution to this problem seems to be necessary in order to obtain so-called psychometric norms for psychodiagnostic tests. In metrological terms, this means that it is necessary to establish an unambiguous mutual correspondence between the results of an individual testing of a patient, obtaining so-called population norms and determining the location of the subject in the continuum of norms.

In addition, the question of the distribution of healthy, non-pathological and painful clinical manifestations is also not resolved: are they tails of a single distribution of manifestations in the continuum of health-disease manifestations or whether non-pathological / pathological phenomena are two independent distributions, possibly having an area of overlap.

A special challenge is an appropriateness of results (which are indirect measurements of non-physical phenomena) extrapolation on criteria of diseases, malfunctions, etc., set by regulations. For example, in the international classification of functioning, a graduated scale (the percentage range in increments of 10–20%) of the degree of mental functions impairment is established. At the same time, in practice of medical psychodiagnostics (pato- and neuropsychological assessment), the research results are expressed, as a rule, in terms of dichotomy – whether there is any pathology or not. In the latter case, the interval is sometimes divided into several gradations (slight, moderate, strong degree of violation from the normal pattern of functioning). Moreover, these grades are frequently converted into quantitative indicators (1, 2 or 3 points, respectively). Processing of the results, in this case, is mostly carried out according to criteria common to interval scales, while the power of such scales is not higher than the ordinary one. At the same time, the probability of obtaining normally distributed data poses a separate problem. Existing procedures for transforming the distribution of such estimates into approximately normal (for example, percentile normalization, lognormalization, etc.) are not statistically apparent, despite the possibility of constructing a Gaussian curve on this basis. In this case, it is challenging not only to obtain z-statistics, but also to display the results on the percentile axis for normally distributed data. Without solving this problem, it seems to be metrologically incorrect to ensure the adequacy of qualitatively characterized abnormalities of the higher psychological functions according to World Health Organization criteria.

In addition to consideration of the metrological aspects in medicine and clinical psychology, the features specific to psychometrics as a branch of psychological diagnostics should also be emphasized. Basic psychometric criteria for psychodiagnostic methods, including methods of medical psychodiagnostics, are to ensure the characteristics of representativity, reliability, validity. Obviously, the absence of a metrologically correct understanding of the nature of clinical phenomena distribution in population makes it almost impossible to statistically substantiate the general representativity of the technique. Moreover, the methods of medical psychodiagnostics, created on the basis of research data taken from cohorts of patients, can be assessed only for groups of patients with the same type of disorder. The clinical criteria for disorder diagnostics are laid down in various disease classifiers, the most prominent among which are ICD-10 and DSM-5. In addition to the differences between these classifiers, there are differences related to national clinical schools, the variability of manifestations of diseases across different groups of people, which limits the identification of representativity characteristics. Characterization of the validity and reliability of medical psychodiagnostic methods is based on correlation procedures, including external criterion (whose role is commonly played with another psychodiagnoctic techniques, studying the same construct). In this case, there is also an issue of extrapolating the data obtained in one group of participants or patients to another one by using metrologically different instruments.

One of the mandatory requirements in the development of psychodiagnostic techniques is their re-standardization (first of all, the revision of the tests norms, at least once every 5-10 years). As a rule, during this period, psychological and mental phenomena measured by such methods are transformed both by themselves and as a result of various subjective and objective processes (age acceleration or retardation in childhood, sociocultural changes, psychological changes in the personality against the background of digitalization and widespread use of IT-technologies, advances in medicine, etc.). At the same time, most of the known techniques do not undergo such re-standardization. For example, in the Russian population there is no information about the re-standardization of the MMPI test for a period later than 1980. The data from a survey of patients who lived at the end of the 2nd decade of the 21st century are compared with the norms obtained from a sample of people who lived at the end of the 3rd quarter of the 20th century or, in fact, even with the population of USA of the late 40s. At the same time, the restoration of standardization (clarification of norms of the psychometric tests) in metrological terms is a fairly rigorous and time-consuming procedure, carried out according to specific algorithms and in accordance with specific requirements.

The problems and questions raised in this publication reflect only part of the difficulties that arise in medical psychodiagnostics as an industry that deals with measurement of non-physical quantities, alienated products of brain activity and do not cover even deeper phenomena. For example, disorders of consciousness, perception (hallucinations) and other mental or psychological products. At the same time, it seems necessary to develop a special methodology for psychodiagnostics (measurement, psychological assessment, qualimetry) of such clinical phenomena and mental disorders.

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Expert Assessment and Expert Judgments as a Metrological Problem in the Field of Non-Physical Quantities Measurement

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«Man is the measure of all things: of the things that are, that they are, of the things that are not, that they are not»

Protagoras (c 490 BC – c 420 BC).

The choice of the statement by Ancient Greek sophist, skeptic and materialist Pritagoras as an epigraph to this paper predetermines the need for adhering to the principles of competence, consistency, being open to doubts and criticism, and materialism in its strict and applied sense.

In this regard, it seems appropriate to start considering the issue within the framework of so-called "terminological problem".

So, let us outline the definitions of basic concepts and terms:

Metrology is a science of methods and means of providing measurements and ways to achieve their accuracy in order to obtain information about properties of the measured objects and quantities;

Measurement is a set of actions for determining the ratio of measured value to another value taken per unit, fixed by means of specific measuring instrument (in the particular case - on the scale of measurements);

Measure is not only a unit of measurement of quantities by assigning them a standardized numerical value based on the establishment of the ratio of measured and standard quantity, but also a philosophical category reflecting a dialectical unity of the quality and quantity of an object, beyond which a change in quantity entails a change in the quality of the object and vice versa;

Assessment (in the metrological context; as a process) is a specific sequence of procedures used to obtain estimates, which are a special case of establishing the ratio of the measured and reference values, and the latter is not always the standard itself; and the assessment process itself has the nature of so-called evaluative comparison by using one or another evaluation basis;

Assessment (in a psychological context) is a mental process of reflecting the relations of superiority and preferences in various types of subject-object interactions, implemented during the comparison (matching) of the subject of assessment and the evaluation basis. [1]

Evaluation basis is an aggregate of ideas about a certain class of homogeneous objects or heterogeneous objects ordered by the criterion of superiority or preference, based on a predominantly emotional or rational approach to their perception (affective or cognitive evaluation bases, respectively) [1];

Estimates as “... opinions, judgments about the quality, character of something” [5];

Estimates (grades) as "... marks set by a teacher"

Components of estimate include an expert (a person or group of persons who assign value to a certain object); a subject of the assessment (the object to which the value is attributed, or the objects whose values are compared); the very nature of the assessment (absolute and comparative); basis of the assessment (taking into account the position based on which the evaluation is made). The absence of at least one of these components does not allow such a judgment to be referred to as an estimate [6].

Evaluation statement - a statement that establishes the absolute or comparative value of an object, giving it an estimate; at the same time, the logical structure and logical connections of such a statement are determined in accordance with the logic of assessments (evaluations) - a section of logic that is composed of the logic of absolute estimates and preferences of logic (там же);

Expert (in a legal context) is a person who has special knowledge and who is involved in conducting an examination and, ultimately, making a judgment on matters requiring the use of the special knowledge, and who is responsible for this judgment as well.

Expert (in a psychological context) is a person competent for making an expert assessment, having a special experience in a particular field and participating in the research as a source of information about the subject of expert assessment;

Expert assessment (as a process) is a procedure for obtaining expert evaluation of particular issue based on opinions of specialists (experts) for the purpose of subsequent decision making (selection) [7].

Expert evaluation (as an ultimate result) is a result of method application, obtained on the basis of using personal or collective expert opinions (e.g., expert groups) in form of specific expert opinions (judgments, statements), as well as direct estimates (grades), presented in the form of certain characteristics and values of measured quantities, expressed in the metrics of qualitative, quantitative and other (including subjective) scales.

Definition of the key concepts. The foregoing, in accordance with the stated principles of competence, consistency and anti-dogmatism, allows us to suggest the following definition of concepts and (as a result) of the terms “expert assessment”, “expert” and “expert evaluation” from the standpoint of a metrological approach:

Expert assessment (in the metrological context) is a specific kind of measurement aimed at obtaining information about properties of measured quantities established by way of finding the correspondence between the object being studied and another value acting as a subjective metrically non-rigorous standard, the ideas about which are formed by the subject of evaluation (expert) on the basis of affective or rational way of perceiving information about this standard (reference) value (evaluation base). The results of expert assessment are expert opinions, expert judgments and expert statements.

An expert (in a metrological context) is a person with special knowledge who performs the function of a tool (or toolkit) to obtain relevant information about the properties of measured objects based on his/her experience of interacting with these kinds of objects reflected in the established system of expert evaluation bases (subjective analogues of measurement scales) and who is able to make expert judgments.

Expert evaluations are personal or collective opinions of experts (or expert groups) obtained by using certain methods for mining information in form of specific expert evaluative opinions (judgments, statements), as well as direct assessments (grades) presented in the form of certain characteristics and values of the estimated (measured) objects (quantities) expressed in qualitative, quantitative and other (including subjective) scales.

On the main controversy of both metrology and expert assessment methodologies (in terms of methods and means of measurement provision).

The implementation of the metrology postulates (at least, in terms of the principles of ensuring the validity and reliability of measurements, as well as the achievement of the required accuracy) with regard to justification of the need to use these methods and technologies of expert assessment for this purpose needs some clarification and explanation.

One of the aims of ensuring the accuracy of measurements (the degree of closeness of its results to the true value of the measured quantity) is to obtain objective results with a minimum error of measurement. In terms of application of the expert assessment method, one should initially recognize the impossibility of obtaining “objective” data in the case of quasi-measurement (that is, how expert evaluation can be defined), performed on the basis of subjective evaluation bases and a metrologically weak procedure for making expert opinions in the form of assessments grades and scores. The subjective nature of an expert as a specific analogue of “measuring instruments” excludes, by definition, the possibility of being guided by the criterion “objectivity of expert assessments”. At the same time, the need to exclude measurement “arbitrariness” (in the sense of off-metric freedom) does not allow us to remove the issue of statistical correctness of expert opinions arrays.

It seems that this kind of problem can be solved by providing so-called “objectification of expert assessments” (we recall that they are subjective in their nature). In this understanding, it is about finding (choosing) such statistical approaches and procedures that allows one to alleviate the factor of the expert's subjectivity. It also appers that among such principles is technology for obtaining and analyzing expert assessments, implemented in the form of a computer version of Expan-2 (EXPert ANalysis) proposed by A.G. Shmelev. By using this system, one can obtain and statistically process an array of expert judgments or statements from a group of experts of up to 50 people. These assessments are received during estimating an array of items (quantities) up to 50 units, each of which gets estimates of the assessment parameters of up to 50 criteria (the total maximum cube of data according to expert estimates is 50 * 50 * 50 = 125000 values). The objectification of such expert scores (judgments) is ensured by a number of generally standard statistical procedures (calculation of indicators of total consistency between experts, coefficients of expert consistency on individual objects and on individual criteria, integral evaluations of each object based on a set of criteria, and rating of each object on each criterion). Subsequently, the system provides the possibility of achieving a higher objectification of expert assessments, for example, for a set of deleting experts who are rejected on a particular basis from the data cube.

It should be noted that the use of such technology requires a lot of work with teams of experts (so-called expert meetings), the purpose of which is to ensure a uniform understanding of the objects and criteria for expert assessment (while maintaining the possibility of variability in their subjectively based expert estimates).

The issue of expert assessment of non-physical quantities. Based on the understanding of non-physical quantities as phenomena of the subject area of non-physical phenomena and processes (which, at the same time, can be expressed using quantitative indicators), it should be emphasized that such subject areas are often defined as “fuzzy” structures. Firstly, as a result, in such areas the probability of measurement defects has a tendency to increase (from its errors to errors of its accuracy, etc.). Secondly, the results of measurements in such areas often represent quite diverse data arrays (including expert ones), which complicates their correct processing. Thirdly, it is often the case that the analysis of received expert assessments requires the use of procedures of not so-called “formal” (classical) logic, but another kind of procedures (from evaluating Bayesian probabilities to applying the rules of the so-called fuzzy logic).

At the same time, it seems that such methods are more suitable for processing arrays of expert assessments than the classical procedures for obtaining, registering and processing them. Moreover, a combination of both such approaches seems dialectically more appropriate.

The author of the publication has experience in various options for collecting, processing, and analyzing expert assessments, based on models for developing methods of medical psychodiagnostics, references to which are given in a relatively recent publication on this issue. Besides, new approaches to the measurement of non-physical quantities (which, undoubtedly, normal and pathological psychological phenomena belong to), require critical rethinking of the abovementioned statements.

The foregoing makes it possible, on the basis of the principle of skepticism and anti-dogmatism declared above, to propose a clarification or rephrasing of the Protagoras quote «Expert is the measure of all things: of the things that are, that they are, of the things that are not, that they are not»

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Measurements of Non-Physical Quantities and Data Analysis in Clinical and Psychological Practice: Issue of Metrological Correlation in the Process of Development of Mathematical Models of Psychological Phenomena

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JUSTIFICATION OF THE TOPIC RELEVANCE

In recent years science needs to embrace digitization as one of the methods of reproduction of scientific knowledge. Thus emerges the question about the possibility of using non-physical quantities and related psychological phenomena. Methods of mathematical modelling are at the basis of digitization, they are employed to describe certain phenomena, to analyze and forecast the changes within them. The success and priority of the creation of mathematical models is additionally justified by the inherent strict elegance, which also makes it possible to obtain completely unexpected solutions based on statistics processed with specified algorithms.

“Research conducted by mathematicians represents beautiful and elegant abstract mathematical systems. It is art, which way of expression is using ideas.”

However, the problem of data mining in measurement of psychological phenomena, as well as principles and rules of their analysis (for developing adequate mathematical models) are under-represented in the most of scientific researches.

INTERDISCIPLINARY ASPECTS OF THE MEASUREMENT PROBLEM IN RESEARCH OF PSYCHOLOGICAL PHENOMENA

Fundamentally metrological (including metric and diagnostic) research of psychological phenomena has postulates of mathematical theory of measurements.

At the same time some specific aspects of receiving results of measurement require specifications.

A. Methodological problem

As measurements of phenomena in psychology are indirect, identification of phenomenon with result of its measurements is impossible, therefore the necessity of differentiation between property and result of its measurement appears. Those measurements in psychology are indirect and their external indications are the subject to the signs of measurements. As a result, variable contains the result of phenomenon sign measurement. This is the main problem of measurement in psychology - correspondence of variable with measured phenomenon. Distinctions between the amount and quality of measured phenomenon influence the accuracy of developed model.

B. Metrological problem

In psychology purely measurement is only a part of “measuring” procedures. More specifically, the theory of measurement postulates corresponds only to the methods used in psychophysics. Among others kinds of such procedures there are many variants of expert evaluations, descriptive (qualimetric) methods and whole system of secondary measurement methods that are used in psychometrics (as a section of psychodiagnostics). Mathematically presented data of research object (mostly - of different psychological features, processes, conditions and properties of the person) is based on results of their self-evaluation tests. The tool of such self-evaluation (of subjective measurement) is organized psychodiagnostic technique that is a special image (test), which structure inevitably consists of various scales of subjective evaluations (quasi-measurements). The data received this way undergoes accepted in psychometrics methods of processing, enabling reception of so-called psychometric data both of measurement toolkit properties (representativity, validity, reliability) and interpretation of results algorithms (so-called methodology norms). Usage of such algorithms allows reception of the final version of “psychological measurement” (psychological diagnostics) results representation of psychological specifications of the person as the object of measurement in psychology.

Another big cluster of quasi-measuring ways of data recording is presented by various methods of receiving expert evaluations. Distinctions between information value of data received purely by methods of measurement and methods of expert evaluation are evident. Metrological and mathematical approaches exist, which increase accuracy of “measurement” by method of expert evaluations (for example, definition of the “weights” system for such evaluations exists; calculation of coherence - incoherence measures of expert evaluations, selection of procedures to exclude incompetent and marginal experts, etc.). At the same time, method of expert evaluations is represented along with purely measurement method.

To complete the discussion of some metrological problems, it should be emphasized that in clinic-psychological practice one of the traditional methods of data acquisition is execution of diagnostics procedures (including psychological and psychological phenomena diagnostics). In a strict sense, diagnostics in this are presented by the procedures of informative signs revealing (in medicine - symptoms), their evaluation (by degree of expressiveness, referring to one or another group in determined illnesses qualifier) and their separation from similar indications. In this perception diagnostics as method of receiving informative data, is represented by an adequate analogue of measurement in the area of nonphysical phenomena.

Above mentioned examples of three approaches to receiving the determined structured data ("marked" - in the terminology of thesaurus and the language of machine training procedures) illustrate by no means all problems of metrology application in the area of physical quantities research (in the context of the clinic-psychological researches area).

C. Terminological problem

Distinctions are evident not only in the content of thesaurus of metrological terms or in the systems of terms used solving measurement, evaluation, diagnostics and some other issues in clinic-psychological area. For example, terms "size", "value", "specification", "sign", "variable", "factor" and so forth have a various value in these (sometimes - substantially different) areas. At least, in case of mathematical models development not only partitioned libraries of such terms, but also integrated thesaurus with direction of various indicators of terms usage in a contexts are required.

D. The problem of objective limitations in the process of collection and analysis of metric data

Not going into details, we will note a few problems that can limit methods application of mathematical analysis of data in the process of psychological phenomena simulation. Among them:

- Absence of own indicators in the area of clinic-psychological researches (first of all - measuring scales) and primary use of borrowed toolkit). As psychological phenomena are latent constructs, directly beyond the reach of measurement, then use of the primary standard with regard to these phenomena practically is impossible. That is why absolute measurements in psychology are not practically used.
- Prevalence of indirect measurements and plural chain transformations of initial data with unknown values of the lost information.
- Absence of information about true nature of considered sizes distribution in general totality and samples, depriving application opportunities of necessary statistical measures, algorithms of the conclusion and the quality estimation metrics of produced model.
- Presence of basic distinctions in methods of mathematical simulation for the cases of received data usage based on methodologically different grounds (for example, not only its measurements, expert evaluation and psychological diagnostics, but their combination as well).
- The practice of representing variables in the form of parameters of a mathematical equation or statistical expression allows to simulate far from all the phenomena and processes described quantitatively. Phenomena accessible directly or closely to it are quantifiable, while phenomena accessible indirectly or those requiring transformations of measurement, moreover, depend on many unobservable factors, that are difficult to undergo mathematical modeling.
- Basic differences between clinic-psychological phenomena in a series of other physical quantities displayed by their essentially non-material nature (at least those phenomena excluded by the intellect); by nonstep-type behavior of the nature and the form of their indications; by necessity of the accounting while modelling their involvement into structure, so-called "open systems"

Accuracy Factors of Mathematical Model of Clinic-Psychological Phenomena and the Criteria of Its Evaluation

Development of mathematical model includes a few phases, from the wording of task and requirements of the model, to the evaluation of its accuracy, validity and reliability.

In modern clinical psychology various methods of mathematical simulation are widely used to describe the phenomenon, to reveal laws of process under study, as well as to draw conclusion or to generate the forecast of its further development. When statistical verification of conclusions became compulsory, questions of priority of qualitative or quantitative approaches in simulation arose.

At the same time necessity to increase model accuracy appeared, and expectations of simultaneous performance of the requirements of quantitative and quality indicators increased. However, this criteria is difficult to implement, especially in application of methods of mathematical simulation of mental processes and phenomena.

There are some methods of data statistical analysis, which assume qualitative interpretation and allow to describe the structure of the phenomena or to reveal different quality types. At the same time, each of designated purposes is reached with the aid of the whole system of mathematical models, each of these models is adequate only in determined conditions. In modern science there is a plenty of known alternative methods, in particular, machine training methods are common, they are based data processing by means of other mathematical methods. As a result, the decision of performing similar task with smaller limitations but with bigger requirements appears. However, with the problem of processing and simulation of data it is necessary to solve another important problem of similar research - data acquisition.

First of all, there is a problem with volume of initial data and the type of distribution of analyzed sizes. To use the methods of statistical analysis it is necessary to determine given types of distribution. But with increase of specifications and growth of various signs order measured by means of modern tools, not always and more and more often it is not possible to execute this requirement. To use other approaches minimum number of supervision is extremely important, because accuracy of produced model depends on it. This criteria is difficult to perform in case of psychological research as well. Firstly, specifications of objects are unique because objects possess individual distinctions. In addition, result, which is necessary to receive to prove the work of mathematical model, should not possess value judgment, but at the same time, result of work is expected to be used in experts' report. Moreover, some may ask about the requirements to the amount of expert evaluations of initial data with regard to current problem for their subsequent accounting in the working model of data analysis.

Therefore, the question to answer is how many supervision, specifications, expert evaluations and reference given is necessary and enough? Researchers have to specify each above mentioned aspect, that have to be sufficient for reproductive, interpretative or reliable conclusions. Therefore, “average” opinion of a series of the authors conclude the following: for reproduced - the more, the better; for interpretative - required minimum to the format of their representation is enough; regarding importance, it is dependent not so much on the psychological phenomena, but on many factors which have nothing to do with the phenomena itself.

At the same time, it is essential to recall the main requirement applicable to mathematical model under development of conducted research. The simulation of mental processes task assignment is of significant importance here. At the current stage of scientific development one should take into consideration the variety of methods and approaches to physical phenomena simulation, as well as remember about the expectations placed on the mathematical model of the most complex processes dynamic system of human behavior. Solving such problems, first of all, it is necessary to start with the idea pursued in mathematical simulation, as well as with the source of the original wording of the stated modeling of mental phenomena problem. This affects methods of receiving and processing data, the choice of applied approach to data analysis and methods for developing predictive mathematical models.

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Research of colorimetric characteristics of reference materials for reflection in various measurement geometries

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***Abstract:* The results of measuring the spectral diffuse reflectance and spectral radiance factor of white, gray, black and color reference materials in various geometries of measurement are presented. Their colorimetric characteristics are defined. Their color differences are rated. The study was conducted with three different spectrophotometers in the visible range of the optical spectrum.**

***Keywords:* reference material, diffuse reflectance, radiance factor, geometry for reflection measurements**

I. INTRODUCTION

Spectrophotometers with Reflectance Accessories are used to quality control of production in many industries. Depending on the measurement geometry realized, a spectral diffuse reflectance and spectral radiance factor is measured. To ensure accurate results, it is necessary to calibrate these measuring devices (MD). This is done using reference materials (RM)[1], which are black standards made of ceramics, fabric (velvet), metal substrate with composite coatings, etc. White standards are used as well and they are made of opal glass, ceramics, polytetrafluoroethylene, barium sulphate and other materials.

II. EXPERIMENTAL

The spectral diffuse reflectance ρ(λ) is the ratio of the reflected radiant flux or luminous flux to the incident flux in the given conditions [2]. Unit 1.

$$\rho(\lambda) = \frac{\Phi_{e\rho}(\lambda)}{\Phi_e(\lambda)} \quad (1)$$

Where:

Φ_e - incident radiant flux;

$\Phi_{e\rho}$ - reflected radiant flux.

The spectral radiance factor β(λ) (at a surface element of a non-self-radiating medium, in a given direction, under specified conditions of irradiation) is the ratio of the radiance of the surface element in the given direction to that of a perfect reflecting diffuser identically illuminated and viewed [2]. Unit 1.

Measurements were made for the spectral diffuse reflectance and spectral radiance factor of set No 2-78, consisting of 7 standard RM, produced in Russia. The set consists of a white, MC-20 (opal glass), three gray, ONG (Optical Neutral Glass) type, which serves to calibrate and test the linearity of the photometric scale and three color RM (green, red and blue) for the colorimetric measurements. The white and gray RM are 9 mm thick and 60 mm in diameter, and the color RM is 8 mm thick and 50 mm x 50 mm. One of the working surfaces of all RM is matte and the other glance makes them suitable for radiance measurements in d/0 and 45/0 geometries. A white RM W1 was also measured, a white ceramic tile developed at the Bulgarian Institute of Metrology (BIM). Two black RM are also measured, the first RM 773145 is a reflection standard of the LEUKOMETER reflectometer [3] and is made of black glass in Carl Zeiss - Jena. The second RM B1 is a metal substrate on which a composite black coating, has been applied, developed in BIM.

Set No 2-78 was calibrated in Germany's Metrological Institute (PTB - Physikalisch-Technische Bundesanstalt) in 2016 for β (λ) in the measurement geometry d/0. The expanded measurement uncertainty for RM in the PTB calibration certificates is U = ± 0.004 in the spectral range from 380 nm to 390 nm and U ≥ ± 0.002 in the spectral range from 400 nm to 780 nm. With these RM, are calibrated a Cary 5000 spectrophotometer with a external accessory for diffuse reflection DRA 2500 and a Color-Eye 2180 spectrophotometer with an expanded measurement uncertainty U = ± 0.005 in the spectral range from 380 nm to 390 nm and U = ± 0.003 in the spectral range from 400 nm to 780 nm. These spectrophotometers measure reference materials with an expanded uncertainty of U = ± 0.006 in the spectral range from 380 nm to 390 nm and U = ± 0.004 in the spectral range from 400 nm to 780 nm.

The study is conducted in various geometries of measurement - 0/d, d/0 and 45/0 recommended by the CIE (Commission internationale de l'éclairage) [4]. While both diffuse geometry measurement 0/d and d/0 are important primarily for colorimetry, directed geometry 45/0 is interesting for photometry as an opportunity for reproducing and transmitting the unit of luminance.

A comparison was made between the spectral diffuse reflectance and spectral radiance factor results obtained, the colorimetric characteristics and the color differences for all RM.

III. Equipment

The following equipment is used to conduct measurements:

- A measurement standard system of spectral diffuse reflectance [5], consisting of a spectrophotometer UV-Vis-NIR Cary 5000 and external accessory for diffuse reflection DRA 2500 (External Diffuse Reflectance Accessory) - fig. 1, made of Spectralon - thermoplastic material extruded from polytetrafluorethylene (PTFE). Spectral diffuse reflectance ρ(λ) in geometry 0/d (8°/d) is measured [4];

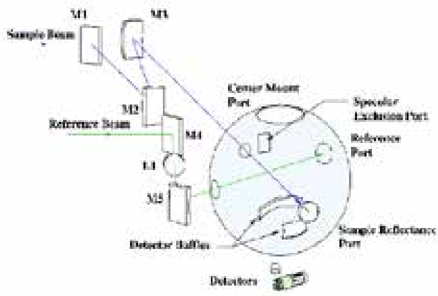

Fig. 1. Optical design of DRA 2500

- Spectrophotometer "Color-Eye 2180" [6] - a compact stationary device for measuring spectral radiance factor and color in the spectral range from 360 nm to 750 nm with spectral interval of 10 nm and geometry d/0 (d/8°)) - fig. 2. Internal coating of the sphere is $BaSO_4$ (barium sulfate). Spectral radiance factor β(λ) in geometry d/0 is measured;

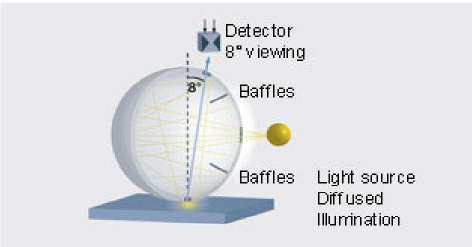

Fig. 2. Optical design of Color-Eye

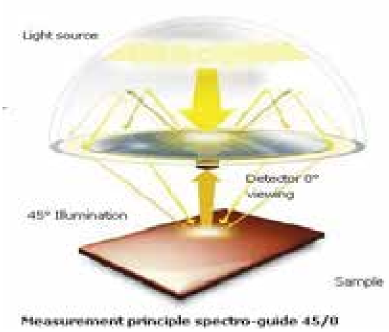

Fig. 3. Optical design of spectro-guide 45/0 gloss

- Spectrophotometer "spectro-guide 45/0 gloss" [7] - a compact stationary device for measuring spectral radiance factor and color - fig. 3 in the spectral range from 400 nm to 700 nm with spectral interval of 10 nm and geometry 45/0 [4].

IV. Results

Multiple independent measurements for all reference materials are made in the visible spectral range from 380 nm to 780 nm under the following environmental conditions: temperature from 20 °C up to 25 °C and a relative humidity from 20% up to 65%rh.

A comparison between RM measured in three geometries 0/d, d/0 and 45/0 is presented on fig. 4 - fig. 9.

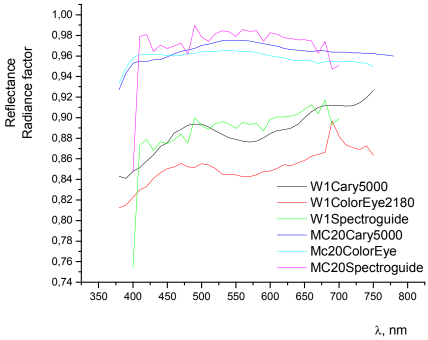

Fig. 4. Spectral reflectance and spectral radiance factor for white RM

Each curve is obtained using the arithmetic mean of repeated measurements ρ(λ) and β(λ).

$$\bar{\rho}\,(\lambda) = \frac{1}{n}\sum_{i=1}^{n}\rho_i(\lambda),\ n=10 \tag{2}$$

Where:

$\bar{\rho}(\lambda)$ - arithmetic mean or the average of the individual observed values ρ_i (i = 1, 2, …, n) of the spectral reflectance

n - number of measurements.

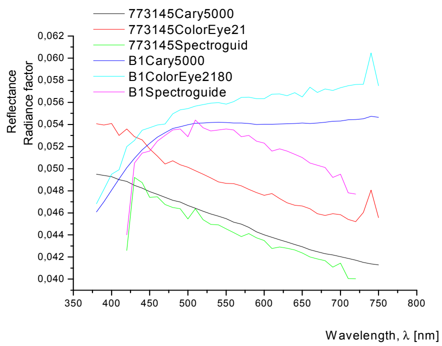

Fig. 5. Spectral reflectance and spectral radiance factor for black RM

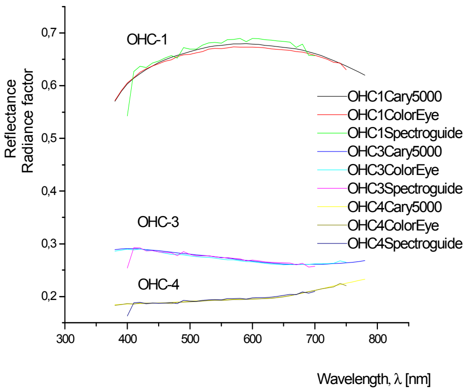

Fig. 6. Spectral reflectance and spectral radiance factor for grey RM

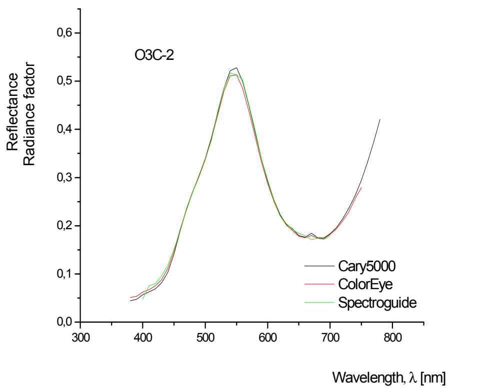

Fig. 7. Spectral reflectance and spectral radiance factor for green RM

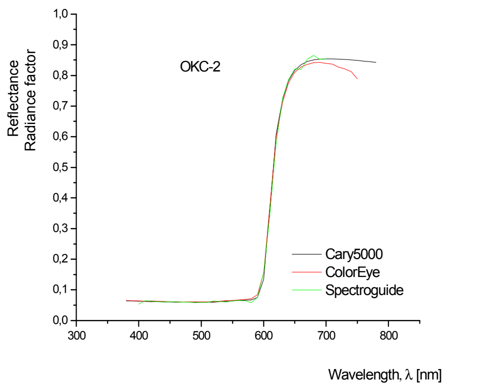

Fig. 8. Spectral reflectance and spectral radiance factor for red RM

Also interesting is the almost overlapping of the white RM curves for the two diffuse geometries 0/d and d/0, which is the affirmation of the statement in [8,9] that roughly matt surfaces are in effect approximately equal ρ(0/d)= β(d/0).This refers to these RM to the group of homogeneous materials with near-lambberic reflection, for which the spectral diffuse reflectance ρ(λ) in geometry 0/d and the spectral radiance factor β(λ) in the geometry d/0 are identical within the expanded measurement uncertainty[8, 9].

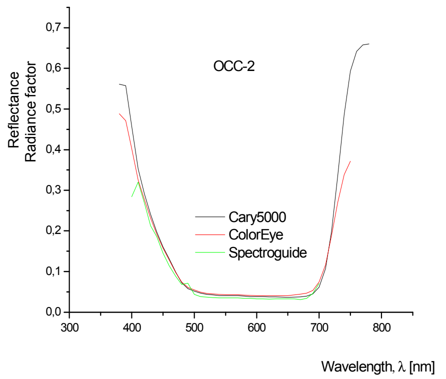

Fig. 9. Spectral reflectance and spectral radiance factor for blue RM

The colorimetric characteristics of the studied RM are defined by the measured values of ρ(λ) and β(λ).For their calculation, the software Color iQC Basic is used, which manages the computer of the spectrophotometer "Color-Eye 2180", as just as the software BYKWARE easy-link of the spectrophotometer "spectro-guide 45/0 gloss".

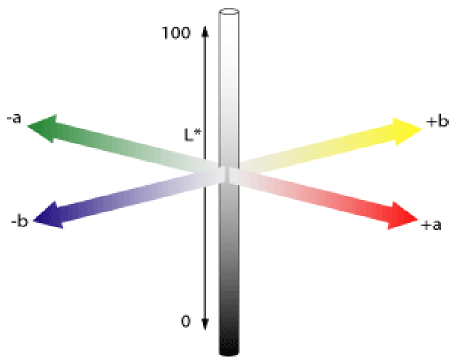

Fig. 10. CIE 1976 (L*a*b*) color space

The color difference ΔE*[4] between a standard color and a sample color is given by:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (3)$$

For the CIE 1976 (L*a*b*) space the value ΔE*of around 2,3 corresponds to a JND (just noticeable difference) [10].

Color space values L*a*b* of each RM for supplementary standard colorimetric 10^0 – observer CIE 1964, for CIE standard illuminant D65[4] are given at table1.

TABLE I. COLOR SPACE VALUES L*A*B* OF RM FOR SUPPLEMENTARY STANDARD COLORIMETRIC 10^0 – OBSERVER CIE 1964, ILLUMINANT D65

RM	L*a*b*	Cary 5000, DRA 2500 External 0/d	Color Eye 2180 d/0	Spectro guide 45/0
MC-20	*L**	98.90	98.55	99.23
	*a**	-0.48	-0.31	-0.36
	*b**	0.78	0.13	0.70
OHC-1	*L**	85.66	85.40	86.01
	*a**	-0.59	-0.50	-0.40
	*b**	2.62	2.31	2.86
OHC-3	*L**	59.32	59.09	59.34
	*a**	-0.65	-0.46	-0.57
	*b**	-1.98	-2.02	-1.67
OHC-4	*L**	51.06	51.01	51.19
	*a**	0.22	0.35	0.33
	*b**	1.18	1.06	1.34
OKC-2	*L**	42.76	43.15	42.63
	*a**	48.88	48.46	48.58
	*b**	22.83	23.02	22.58
O3C-2	*L**	68.86	68.34	68.77
	*a**	-28.10	-27.66	-27.15
	*b**	39.94	35.41	35.15
OCC-2	*L**	26.18	26.83	24.45
	*a**	20.79	19.11	20.14
	*b**	-37.00	-34.71	-36.53
W1	*L**	95.32	93.39	95.00
	*a**	-0.32	-0.11	-0.30
	*b**	0.48	-0.33	0.88
773145	*L**	25.37	26.26	24.99
	*a**	-0.42	-0.17	-0.29
	*b**	-1.30	-1.38	-1.44
B1	*L**	27.85	28.44	27.51
	*a**	-0.39	-0.10	-0.81
	*b**	0.85	1.13	-0.01

The color difference ΔE* is calculated from the measurement of β(λ) and ρ(λ) in the PTB, Germany and BIM. For example, for RM MC-20 ΔE * = 0.12 (d/0 (PTB) - 0 d) means that this is the color difference for the same RM obtained with the measurement with two different spectrophotometers. The first is in PTB, Germany, geometry d/0, and the second one is the UV-Vis-NIR Cary 5000 spectrophotometer with External Diffuse Reflectance Accessory DRA 2500, geometry 0/d - table 2.

TABLE II. COLOR DIFFERENCE ΔE* PTB-BIM

RM	d/0(PTB) - 0/d	d/0(PTB) - d/0	d/0(PTB) - 45/0
MC-20	0.12	0.75	0.47
OHC-1	0.22	0.53	0.51
OHC-3	0.21	0.28	0.19
OHC-4	0.09	0.13	0.27
OKC-2	7.41	7.39	7.01
O3C-2	2.26	2.00	2.02
OCC-2	1.40	1.60	2.40

The color difference ΔE* is calculated from the measurement of ρ (λ) and β (λ) with two different spectrophotometers. For example, for PM MC-20 ΔE* = 0.76 (0 / d - d / 0) means that this is the color difference for the same RM obtained with the measurement with two different spectrophotometers. The first is the UV-Vis-NIR Cary 5000 with External Diffuse Reflectance Accessory DRA 2500, geometry 0/d, and the second is the Color-Eye 2180 spectrophotometer, d/0 geometry. Color differences ΔE* of each RM are given at table 3.

TABLE III. COLOR DIFFERENCE ΔE*

RM	0/d – d/0	0/d – 45/0	d/0 – 45/0
MC-20	0.76	0.36	0.89
OHC-1	0.41	0.46	0.83
OHC-3	0.30	0.32	0.44
OHC-4	0.18	0.23	0.33
OKC-2	0.60	0.41	0.69
O3C-2	1.67	2.03	0.72
OCC-2	2.91	1.91	3.17
W1	2.10	2.02	0.51
773145	0.93	1.28	0.43
B1	0.71	1.02	1.63

V. CONCLUSION

From the investigations carried out one could conclude that there close results are obtained for the colorimetric characteristics for spectral diffuse reflectance ρ(λ) and spectral radiance factor β(λ) in different geometries of measurement - 0/d, d/0 and 45/0 for white, gray and black RM. The condition for just noticeable colour difference is fulfilled. But for color RM the differences are bigger. Therefore one should not compare results obtained with different measurement geometries.

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Traceability of the National vibration measurement standard via comparison with previous PTB calibration report

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***Abstract*— The traceability of National vibration measurement standard is achieved through periodic calibration check by determination of the magnitude of the complex sensitivity S_q of a standard accelerometer type B&K 8305(BB) via the Initial calibration method based on Laser Interferometry. Harmonic sinusoidal vibration is applied to the accelerometer and its amplitude is measured with laser interferometer according to ISO 16063-11(Method#3: Sine wave-approximation). The obtained results are compared with their previously measured values from past PTB calibration report, in order to assure its stability and quality of operation.**

Keywords—Vibrations, Laser Interferometry, Accelerometer, ISO16063-11, Relative Expanded Uncertainty

I. INTRODUCTION

The development of Bulgarian national standards for mechanical vibration measurements has more than 30-year history within the Bulgarian Institute of Metrology (BIM). The Initial method is used for reproducing of a unit length and currently serves for measuring of vibro-displacement *d* by its comparison with the exactly known wavelength λ of a He-Ne laser via Michelson interferometer. The derivatives, such a velocity *v* and acceleration *a* are obtained through the etalon units of frequency *f* and period *T*. The methods for the Initial vibration calibration by laser interferometry are specified in the international standard ISO16063-11[1]. The traceability of the units is accomplished via comparison with the readings of standard calibration equipment, according to accepted international standards and calibration methods. Periodic check and calibration of vibration etalon transducers is of great importance for variety of fields in industry, where precise measurements of vibrations are taken into account for safety and proper work of machinery and vehicles. The last calibration of the National vibration measurement standard was carried out in 2015 at PTB (Physikalisch-Technische Bundesanstalt) Germany.

II. CALIBRATION METHOD USED

The Initial calibration methods with laser interferometry are based on the theory of the Michelson interferometer. The light beam is split on two parts, as one of them is reflecting from fixed mirror and the other one from the reflecting surface of the accelerometer. The interference between the two beams is causing shift in the light intensity maxima and minima every time when the optical path difference between those two beams is equal to half of the wavelength $\lambda/2$ or any integer multiple of $\lambda/2$. When the optical path is changing periodically by the vibration displacement *d* the resulting light interference maxima are seen by the detector as a periodic signal with cos^2 function behavior [2]. Respectively, the minima will be seen when those beams are out of phase at 180^0. The number of maxima/minima changes per one vibration period is directly proportional to the amplitude of the vibration displacement *d*, which can be used for determination of the velocity *v* and the acceleration *a*. Determination of the vibration parameters at the Initial calibration is conducted through precise interferometric measurements with computer controlled dynamic calibrator. The wavelength of the He-Ne Laser is accepted as etalon. The computer software determines the parameters of the mechanical vibration *d*, *v* and *a*, as function of time, taking into account correction of the wavelength of the He-Ne laser in vacuum (λ=632.991354 nm) with respect to the ambient conditions. The principle of the method used complies with the International Standard for Initial Vibration Calibration measurements with Laser Interferometry, described in ISO 16063-11, Method#3: Sine wave-approximation [1]. The laser interferometer is measuring *d*. For harmonic vibration at frequency *f*, the parameters *d*, *v* and *a* are related according to[3] through the following equations:

$$v = 2\pi f d \tag{1}$$

$$a = 2\pi f v = 4\pi^2 f^2 d \tag{2}$$

The Initial calibration of vibration transducer includes the following steps: harmonic vibration is applied to the transducer via electro-vibrating table, determination of *d* through the interferometer system, measuring of the output signal (electrical charge or voltage) of the transducer to be calibrated and calculation of its conversion coefficient or the absolute value of the so called charge sensitivity S_q. The charge sensitivity coefficient S_q is calculated through the equation:

$$S_q = \frac{q}{a} \tag{3}$$

The values of a u q can be amplitude and or RMS, and they are related through,

$$q = \frac{u}{S_{qA}} \quad (4)$$

where S_{qA} is the amplification factor of the charge amplifier and u is its output voltage, measured with voltmeter. Finally, the charge sensitivity coefficient S_q is given by:

$$S_q = \frac{u}{(2\pi f)^2 . d . S_{qA}} \quad (5)$$

Evaluation of the input parameters, mean-square uncertainty , sensitivity coefficients at different frequencies and the contribution of the uncertainty factors are accomplished according to the requirements of ISO 16063-11 [1] and JCGM100:2008[13].

The measurements are conducted at fixed acceleration amplitudes from 5 m/s^2 to 70 m/s^2 for different frequencies within the range 10 Hz-1000 Hz.

III. CALIBRATION EQUIPMENT

The calibration system used is based on modified Michelson Laser Heterodyne Interferometer type HP5529A, with folded beam and double resolution set up. The schematic diagram of the interferometer is shown in Figure 1.

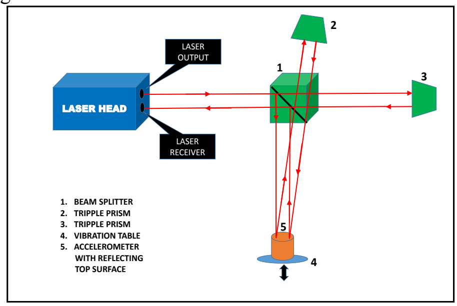

Figure 1. Michelson Laser Heterodyne Interferometer type HP5529A, with folded beam and double resolution configuration.

The block diagram of the overall measurement system is shown in Figure 2 and contains the following equipment:

1. Sine wave voltage generator.
2. Frequency counter.
3. Power amplifier.
4. Laser head.
5. Interferometer system.
6. Accelerometer.
7. Electromagnetic vibrating table.
8. Interferometer electronics controlled by a computer.
9. Charge amplifier.
10. Digital multimeter.
11. Oscilloscope.

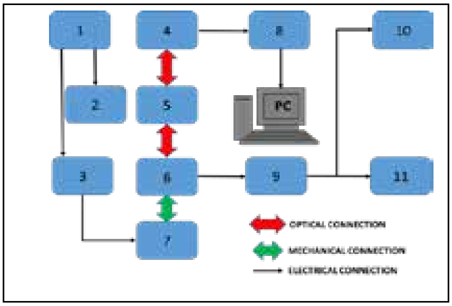

Figure 2. Block diagram of the overall measurement system.

The harmonic vibration is produced by sine wave generator, power amplifier and electro-vibrating table. The vibration frequency is measured with etalon frequency meter. The vibration parameters are obtained through the computer controlled laser interferometer system HP 5529A. The output signal of the calibrated accelerometer is supplied first to the input of the charge amplifier and then is measured (the RMS value) with digital voltmeter. The oscilloscope is used for monitoring the signal only.

The models and brands of the all equipment used are given in Table 1.

TABLE I.

#	Description	Brand
1	Sine wave voltage generator	Agilent,USA, Model:33220A,Serial#MY44059449
2	Frequency counter	Model Ch.Z-38(ЧЗ-38), Russia, Serial #610565
3	Power amplifier	B&K,Denmark, Model:2707, Serial#1173261
4	Laser head(part of Laser Interferometer system)	Hewlett Packard ,USA, Model:HP5529A, Serial#3617A00253
5	Interferometer system	Hewlett Packard ,USA, Model:HP5529A System 2
6	Accelerometer	Standard accelerometer (back-to-back, BB) B&K type 8305 SN 1655958
7	Electromagnetic vibrating table	B&K,Denmark, Model:4805, Serial#1176109(Model:4815, #1235980)
8	Interferometer control electronics	Docking station connected to HP-OmniBook 900 PC
9	Charge amplifier	B&K,Denmark, Model:2635,Serial#1156183
10	Digital multimeter	Fluke, USA, Model:8506A, Serial#AS3585033, and #AS3435022
11	Oscilloscope	Tektronix,USA, 2 Channel,Model:DPO2012B,Serial #C010738

a. Table 1. Models and brands of the equipment used.

The block diagram of the control electronics of the Laser Heterodyne Interferometer system HP5529A is shown in Figure 3 with the following description:

- (1) Laser electronics.
- (2) Measurements data collection PCB, HP 10887A of the interferometer.
- (3) Compensation PCB, HP 10886A.
- (4) Sensor for air absolute pressure and relative humidity.
- (5) Temperature sensor.
- (6) HP OmniBook computer.
- (7) Docking station with ISA/PCI interfaces for the interferometer's PCBs
- (8) Color printer.
- (9) Remote control.

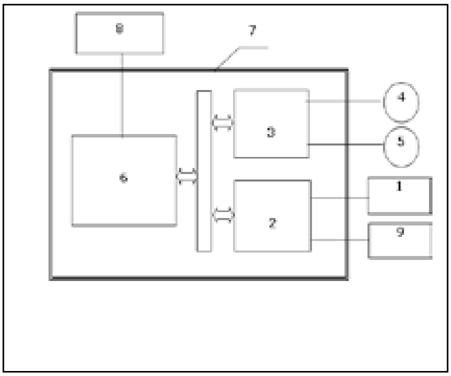

Figure 3. Block diagram of the control electronics of HP5529A.

The advantage of the interferometer type HP 5529A is the automated measurement permitting to obtain the vibration quantities, displacement, velocity and acceleration as time functions presented in table and graphics formats. The sampling frequency range for this system is 33 to 50 kHz.

A. Auxiliary equipment

The auxiliary equipment for measurements of the ambientconditions is listed below:

- Air thermometer with measuring range from 0°C to +50°C and expanded uncertainty 0.2°C.
- Thermometer for temperature monitoring of the vibration-measuring circuits, with measuring range from 0°C to +50°C and uncertainty 0.5°C.
- Humidity meter with measuring range up to 90 % and expanded uncertainty of 2%
- Barometer with measuring range from 90 kPa to 104 kPa and expanded uncertainty 0.17 kPa.

The auxiliary equipment for mounting of the accelerometer:

- Dynamometric key with measuring range from 1 to 20 N.m and uncertainty of 10%.

B. Ambient conditions

- Ambient temperature (in the room): (23 ± 1) °C
- Temperature of the accelerometer: (23 ± 1) °C
- Atmospheric pressure: (95.2 ± 1) kPa
- Relative humidity: (45 ± 5) %rh

IV. MOUNTING TECHNIQUE

In Fugure 4 is shown the primary mounting configuration used in the current calibration measurement: Back-to-Back(BB). The laser beam is reflected from the polished top surface of the accelerometer.

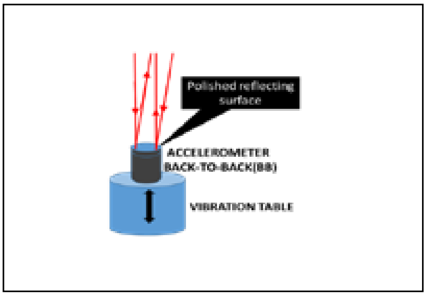

Figure 4. Schematic of the reflecting beams paths from the reflecting surface for Back-to-Back(BB) mouting configuration of the accelerometer(B&K type 8305.

The cables of the accelerometers are fixed with tape to the stationary mounting setup of the vibration table, in order to avoid the effect of accumulation of parasitic electrical capacitance. This is shown in Figure 5.

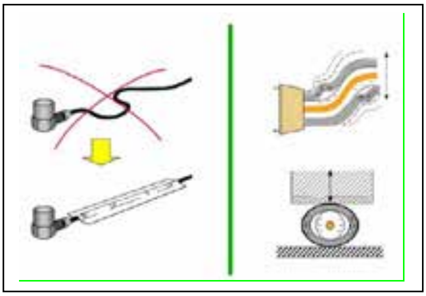

Figure 4. Parasitic electrical capacitance formation in bending non-fixed cables.

Eliminating consequences of this effect is of great importance, especially at low frequencies, for precise measurements, since the output signal of the accelerometer is equivalent to a variable electrical potential of a charged capacitor. Another important factor for obtaining good quality of measurements is the mounting foundation where the whole experimental setup is placed. The solid reinforced concrete foundation of the vibration standard is 8 m deep having a mass of the order of 50 tons on a sand cushion and residual vibration RMS level is less than 10-12 m at frequency above 50 Hz, 10-9 m at 10 Hz and 10-7 m at 1 Hz.

V. Calibration results including the relative expanded uncertainty

In Table 2 are given the final results for the magnitude of the complex charge sensitivity S_q currently obtained from BIM for the National measurement standard (B&K 8305 (BB) accelerometer), and compared with S_q calibration data for the same measurement standard at PTB in 2015(with reported relative expanded uncertainty 0.2% at coverage factor K=2). In Figure 5 the same data are compared graphically along with their uncertainty bars for the relative expanded uncertainty of the magnitude at coverage factor K=2.

TABLE II.

Nominal Freq. [Hz]	Magnitude of complex charge sensitivity PTB [pC/(m/s²)]	Magnitude of complex charge sensitivity BIM [pC/(m/s²)]	Rel. Exp. uncertainty of magnitude PTB [%] (K=2)	Rel. Exp. uncertainty of magnitude BIM [%](K=2)
10	0.1253	0.1256	< 0.2 %	< 0.5 %
12.5	0.1254	0.1252	< 0.2 %	< 0.5 %
16	0.1255	0.1253	< 0.2 %	< 0.5 %
20	0.1255	0.1254	< 0.2 %	< 0.5 %
25	0.1254	0.1254	< 0.2 %	< 0.5 %
31.5	0.1254	0.1254	< 0.2 %	< 0.5 %
40	0.1254	0.1253	< 0.2 %	< 0.5 %
50	0.1254	0.1255	< 0.2 %	< 0.5 %
63	0.1254	0.1254	< 0.2 %	< 0.5 %
80	0.1254	0.1254	< 0.2 %	< 0.5 %
100	0.1253	0.1254	< 0.2 %	< 0.5 %
125	0.1253	0.1254	< 0.2 %	< 0.5 %
160	0.1254	0.1254	< 0.2 %	< 0.5 %
200	0.1254	0.1254	< 0.2 %	< 0.5 %
250	0.1254	0.1254	< 0.2 %	< 0.5 %
315	0.1254	0.1254	< 0.2 %	< 0.5 %
400	0.1254	0.1254	< 0.2 %	< 0.5 %
500	0.1254	0.1256	< 0.2 %	< 0.5 %
630	0.1255	0.1256	< 0.2 %	< 0.5 %
800	0.1255	0.1258	< 0.2 %	< 0.5 %
1000	0.1255	0.1254	< 0.2 %	< 0.5 %

b. Table 2.Comparison of experimental results between PTB and BIM for B&K type 8305 accelerometer (BB).

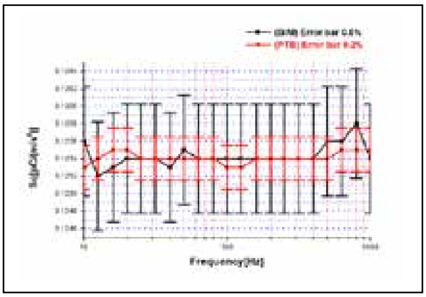

Figure 5. Sencitivity of the accelerometer S_q as a function of the frequency on logarithmic scale.

Looking at the data one can see that the condition of the National measurement standard is pretty stable in time (within last 3 years) within the frequency range 10-1000 Hz and can serve successfully for calibration of other vibration measurement devices. The relative expanded uncertainty at coverage factor K=2 of the magnitude of S_q is used according to the values from the last CMC reports of BIM (2005).

VI. Conclusion and future work

The current comparison demonstrates that the BIM results are consistent with the PTB results within the range of the relative expanded uncertainty at coverage factor K=2 of the magnitude of S_q.
Although, the results express good consistency within the whole frequency range 10-1000Hz (Figure 5), higher precision can be achieved with better equipment. According to the "Strategy of the Bulgarian Institute of Metrology for the period 2017-2025" new computer controlled equipment for vibration measurements is expected to be purchased, which will increase the precision of the obtained results.
This national vibration measurement standard accelerometer has participated recently in bilateral key comparison with National Metrology Institute of Poland (GUM, CCAUV.V-K2) and the obtained results are in support of CMCs of BIM into the database of BIPM.

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Impact of the new definition of the kilogram on the BIM (DG NCM) work

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With the introduction of the new definition of the kilogram, the last definition of a base unit based on a physical artefact is sent to history. This change will not affect directly the life of ordinary citizens, but it will have a huge impact on the work of the National Metrological Institutes (NMI) in the long term, and on the Bulgarian Institute of Metrology (BIM) including.

Keywords—kilogram, definition, Kibble balance, BIM

I. INTRODUCTION

The definition of the kilogram changed fundamentally. The previous definition defined the kilogram as the mass of the international prototype kilogram, which is an artefact rather than a constant of nature.The new definition relates the kilogram to, amongst things, the equivalent mass of the energy of a photon given its frequency, via the Planck constant. This leads to a change in the traceability of a unit, as well as in the work of NMI. The paper discusses the main aspects of the work on the introduction of the new definition by NMI.

II. KILOGRAM IN BULGARIA

The end of the 19th century is marked by many memorable events for Bulgarian history, yet some of them remain hidden for the wide audience. Along with the heroic deeds of the Bulgarian army for the protection of the fragile freedom and the diplomatic efforts to gain independence, there are also other not less important dates for strengthening the Bulgarian state. The third law implemented in the newly established Bulgarian state was The Law on Weights and Measures of 15-th November 1888. From June 1st, 1889, the Law on Food Measures entered into force and for the rest of the measures and weights, it came into force from January 1st, 1892. The introduction of the new measures and weights in the governmental institutions was mandatory from 1st January 1889. Since 1911 Bulgaria is a member of the Meter Convention. The same year the state acquired its two national standards – one of the unit of mass and one of the length unit. The Bulgarian Law on Measures was one of the first metrological laws in the world and wasrecognized by the world's scientific circles as one of the most sophisticated in this field.

III. NEW DEFINITION

Over the past decades of the 19th century, science and technology have marked an outstanding upsurge. From the dream of mankind to fly into space, to the nowadays plans for the colonization of new planets. Naturally, metrology can not remain unchanged by this upsurge, and even more so, it is one of its engines. For this reason, the standards adopted in 1875 are hardly able to meet the requirements of the contemporary scientists. The first major "sacrifice" of this progress - the meter - fells in 1960. Almost a century and a half after the adoption of the International Prototype of the Kilogram, a new definition of the mass unit enters into force.

Although the International Prototype of the Kilogram is made of a wear-resistant alloy with good stability and it is stored in a strictly controlled environment, the comparisons between it and its copies show that the kilogram is altering .

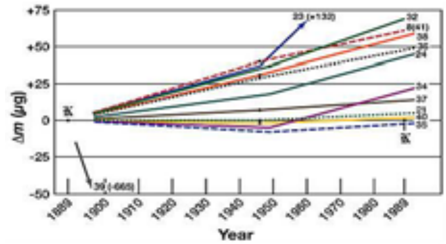

Fig. 1. Mass drift over time of national prototypes K21–K40, plus two of the International Prototype Kilogram's (IPK's) sister copies: K32 and K8(41). All mass changes are relative to the IPK[4].

To meet the ever-growing accuracy demands from the NMIs, the International Bureau of Weights and Measures (French: Bureau International des Poids et Mesures (BIPM)) regularly makes adjustments to the masses of the national standards, with the last one referring to BIM in 2015. After multiple experiments of the two competing and at the same time complementary projects and, naturally, with international consent, the new kilogram definition based on the Planck's constant has come into force on 20th May, 2019.

"The kilogram, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant h to be 6.62607015×10−34 when expressed in the unit J·s, which is equal to kg·m2·s−1, where the metre and the second are defined in terms of c and ΔνCs."

The kilogram may be expressed directly in terms of the defining constants: [5]

$$1kg = \frac{299792458^2}{9192631770(6.2607015 \times 10^{-34}} \frac{h\Delta v_{C_s}}{c^2} \qquad (1)$$

IV. THE TRANSITION

The transition from an artefact-based definition to a definition based on a fundamental constant will be performed according to the following rules[2][3]:

- The BIPM will continue to provide traceability. In practice, even if a particular NMI has a working experiment (under working experiment is meant a prototype reproducing the unit kg), it can not disseminate the unit to the lower-grade standards alone. As pointed out earlier, the new definition is possible due to international consensus.

- This consensus, apart from purely declaratory, has its scientific and practical application in terms of accepting a fixed value of the Planck constant on the one hand and, on the other hand, defining the so-called "consensus value." This consensus value will be determined by the BIPM on the basis of the last 3 key comparisons between successful experiments for realization of the mass unit. These comparisons will be initiated and conducted by the BIPM every 2 years. The continuity between the new and the old definition is ensured in two stages. The first stage is already a reality – the fixed value of Planck's constant relative to the current prototype of the kilogram is determined. During the second stage, the International Prototype of the Kilogram will participate in the determination of the consensus value up to the accumulation of the defined number of key comparisons;
- In regard to the measurement uncertainty determination – in practice the methodology remains unaffected. The change is in the uncertainty that BIPM gives in its Certificates of Calibration of National Standards. In a BIPM note, all NMIs are notified of the need to increase the standard uncertainty cited in their BIPM calibration certificates by adding 10μg in quadrature at (k = 1). NMIs are also advised to update their uncertainty budgets with the new uncertainties for the standards. This is due to the fact of transition from a definition based on material artefact with zero uncertainty to a definition based on physical measurement (the fixed value of Planck's constant determined by comparisons), which inevitably leads to uncertainty from the measurements;
- Change of NMI CMC entries - Over the years, the BIPM has significaltly improved its calibration capabilities and has reduced the uncertainty in its certificates. By introducing the additional contribution (Planck's constant) to the uncertainty, it naturally increases. Preliminary analyzes made by the BIM's experts show that the same level of uncertainty as about 20-25 years ago are reached. This necessitates the revision of the NMIs CMC entries and, in particular, those published during the last 20 years. The review does not necessarily mean that these entries will be roughened. Preliminary analyzes indicate that NMIs with a CMC of about 0,050 mg or larger for 1kg should not expect substantial roughening of the their CMCs. Guidance on adjusting of the CMCs published in the BIPM KCDB will be issued after the meeting of the Consultative Committee for Mass and Related Quantities on 16-17 May 2019.

According to „CCM detailed note on the dissemination process after the redefinition of the kilogram", Calibration and Measurement Capabilities (CMCs) published by NMIs in the KCDB (where expanded uncertainties, U, are listed) will need to be revised to reflect the increase in the uncertainty in the IPK (u_{mIPK}=10 μg). It is the responsibility of individual NMIs to revise their CMCs to this effect. The revised expanded uncertainty$U_{20-05-2019}$, can be calculated from equation.

$$U_{20-05-2019} = 2\sqrt{\left(\frac{U}{2}\right)^2 + \left(\frac{M}{1\,kg}u_{mIPK}\right)^2} \qquad (2)$$

Where M is the nominal mass value of the CMC. After rounding to two significant digits, many CMC values will remain unchanged[1].

Phase	Time scale	Description	Source of traceability	Uncertainty of BIPM mass calibrations	Role of realization experiments	Dissemination of mass from NMIs with realization experiments
0	Until 20 May 19[1]	Traceability to the IPK	$m_{IPK} \equiv 1$ kg $u_{mIPK} \equiv 0$	$u_{stab}(t)$	Measurement of h	Dissemination from national prototype traceable to IPK
1	20 May 19 - date 1[2]	Traceability to the Planck constant via the IPK, with additional uncertainty from the (new) definition	$m_{IPK} = 1$ kg $u_{mIPK} = 10\ \mu g$	$\approx \sqrt{u^2_{mIPK} + u^2_{stab}(t)}$	Contribute to Key Comparison (KC), improve and resolve discrepancies	Dissemination from national prototype traceable to IPK, with 10 μg added uncertainty
2	date 1 – date 2[3]	Traceability to the Planck constant, dissemination from a consensus value[4] (CV)	Consensus value (CV)	$\approx \sqrt{u^2_{CV} + u^2_{stab}(t)}$	contribute to CV (via KC), improve experiments and resolve discrepancies	Dissemination from consensus value with uncertainty $\approx \sqrt{u^2_{CV} + u^2_{stab,NMI}(t)}$
3	from date 2	Traceability to the Planck constant, dissemination by individual realizations	Fixed value of h $u(h) \equiv 0$	(Uncertainty of BIPM realization experiment)	Realization of the unit of mass, Participation in KCs to demonstrate equivalence	Dissemination from validated realization experiments with the uncertainty of the experiment. The terms of the CIPM MRA are applicable.

Fig. 2. The four phases necessary for the reliable transition from the IPK to independent NMI realizations of the unit mass[1].

Impression in „CCM detailed note on the dissemination process after the redefinition of the kilogram", makes reference to "date 2". In fact, "date2" is a non-fixed date. This is the date until the above traceability mode will work.

„date 2 = CCM decision that dissemination from consensus value no longer necessary, because dispersion of calibration results from validated primary realization experiments is compatible with their individual uncertainties.“[1] After this date, NMIs, which have their own successful experiments on the realization of the unit proved by key comparisons, will be able to ensure their own traceability both to themselves and to other NMIs. BIPM will maintain its role as the initiator of key comparisons and will provide traceability to those NMIs that do not have a successful experiment. Expectations are at the time of "date 2", the fixed value of the Planck constant being defined with an uncertainty equivalent to 0.

V. NEW DEFINITION IN BULGARIA

All this raises the question of how the new definition will affect Metrology in Bulgaria. Here a key role is played by BIM and in particular the Mechanical Measurements Department of the Directorate General of National Centre of Metrology (DG NCM). In 1911 Bulgaria acquired its own kilogram. Unfortunately, this artefact is not one of the prototype copies, but it is a cilynder of steel type baros. Although the standard is not of platinum-iridium alloy, it has served us well until 1994 when, due to the increased requirements to the reference standards and a BIPM recommendation, the 80-year-old artefact is retired. The lack of platinum-iridium copy of the kilogram brings both negatives and positives for Bulgaria. The negatives are more than obvious - because our standard is not a platinum-iridium copy, the uncertainties given by the BIPM are approximately 2-3 times greater than those of the NMIs with platinum-iridium standards. This significantly aggravates the laboratory's capabilities. On the other hand, the storage of a platinum-iridium standard is quite expensive and complicated, which combined with the limited funding in the recent years is a risk for the standard itself. All this leads to the decision of buying a new standard in stainless steel of accuracy class E1, as a stainless steel standard is considerably easier to maintain and inexpensive to store with the purchase of modern equipment respectively. For financial reasons, the new equipment only covers the limited range of 10 g - 1 kg. This new equipment allows BIM to confirm better CMCs by participation in comparisons in this range. With taking part in a key comparison at 1kg, the BIM has confirmed having the best CMC among the Central and Eastern European countries, including Turkey (with its platinum-iridium standard comparable to that of Russia (44 μg for BIM versus 40 μg for Russia). Despite the limited funding, the laboratory's capacity has increased significantly during the recent years. This is due to the following factors:

- High accuracy standards have been purchased;
- New auxiliary equipment;
- New calibration procedures have been developed and employed;
- The matrices used for dissemination of the unit of mass have been optimized;
- Analyses of the influencing factors on the measurement process are performed on regular basis;
- Systems for preliminary analysis of the measurement results are developed and implemented.
- An automatic system for calibration management is developed and implemented.

All of this undoubtedly should be proved by taking part in international comparisons in order to improve current CMCs. Steps have already been taken. The laboratory successfully completed a key comparison at 1kg, which confirmed an uncertainty of 35μg. Early next year is scheduled a participation in a key comparison at 500 kg for BIM, along with taking part in other comparisons for the remaining points in the range. It should be noted, unfortunately, that the perfect result of the comparison of 1 kg cannot be applied directly to the BIM CMC entries because the result was achieved before the introduction of the new definition. This does not mean that the comparison failed because the result proves the high capabilities of the laboratory and allows the upcoming revision of the CMCs to be done on the basis of this comparison result, which, according to the preliminary analyzes, allows us to keep for the future a value within the current CMC entry of 44 μg for 1 kg. All this shows that in the future review of the CMC entries, the BIM is in a favorable position and has the opportunity to confirm the good results of its internal research.

From what has been said, it is clear that the consensus value of the mass is determined on the basis of key comparisons of successful experiments for unit realization. Such projects have been launched in most major metrology institutes in the world, of course at a different level of realization. It is also possible for BIM to try to successfully realize such an experiment. The funding for such experiment is of critical importance, although it is not the only issue. Regardless of that how simple the scheme of the Kibble balance might seem,

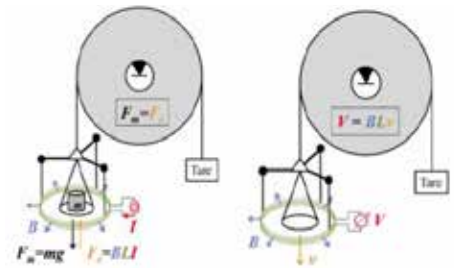

Fig. 3. Scheme of the Kibble balance[6].

its practical realization is in fact a pile of engineering, technical and metrological challenges. Modern metrology is an aggregation of combined solutions for different measurement fields. Nowadays, if an expert has to work on the development of his field of measurement, he needs a comprehensive training in other metrology areas as well. This of course also applies to the mass measurements and, in particular, the activities related to the development of a functioning unit for the realization of the new definition of the kilogram. Work on this project has already started. Informal training programs have been set up by experts in different departments in order to improve their qualification in other measurement fields apart from their own measurement area. These programs are aimed at familiarizing the metrologists in the field of mass measurements with the measurement capabilities of electrical measurements laboratory in particular. But cooperation with experts from Length and Optical measurements is also needed. The availability of the Josephson voltage standard at BIM is a prerequisite for the realization of such project and facilitates launching of our own experiment for the realization of the kilogram. The experiment itself requires measurements with voltmeters to be done, so these voltmeters have to be calibrated with the quantum Josephson standard. The Electrical Measurements Department within BIM is currently taking part in a an international comparison of quantum Josephson standard.

VI. CONCLUSION

The introduction of the new definition per kilogram puts NMI on a number of challenges. On a global scale, the institutes that have managed to divide their own experiments on the re-establishment of the unit are extremely small and the results achieved are still significantly distracted. Traceability will remain a priority for BIPM, while encouraging the NMI to develop its own experiments. Realizing our own successful experiments on the implementation of the definition requires:

- a team of experts in various fields of metrology;
- In-depth knowledge of experts in different areas;
- solid financing;
- • a very good material base needed to produce the individual elements of the experiment;

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Metrology assurance of differential pressure transmitter with square roof function

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Summary: **The report addresses the method and tools to perform verification of differential pressure transmitters with DC output signal, Metran 22, DD-2440 model, with square root function and computation of the functional relationship between input and output signal.**

The aim is to detect the compliance between the normalized and measured characteristics in the process of verification of the characteristics.

***Key words**: differential pressure transmitter, Metran-22 DD-2440, square root, metrological verification.*

I. Introduction

In the process diagrams of Kozloduy NPP for certain cases of measurements of fluid flow rate, a measurement method is used based on the relationship of pressure difference upstream and downstream the fixed throttle device, an orifice plate placed in the pipeline from the flow rate of the measured medium. The pressure difference of the fluid upstream and downstream the restriction is measured with differential pressure transmitters. Since remote transmission of the indication is required, pressure transmitters are used. It has been scientifically proven that the relationship between the measured flow rate and pressure drop is root square, which requires the use of other measuring pressure transmitters to convert the output signal into linear. This weakness of the method has been avoided through the application a new generation of differential pressure transmitters fulfilling also the root square function.

The report reviews the method, tools for performance of metrological verification and calculation of the relationship between the input and output signal of the differential pressure transmitters used for the needs of the Kozloduy NPP.

The differential pressure transmitters with the root square function, Metran 22, DD 2440 model, identification number 69409, measuring range 0 to 0.630 kg/cm^2, range of the output signal 0 to 5 mA and accuracy class 0.25 has been verified.

The metrological verification checks the compliance between the normalized characteristics and those obtained in the process of verification after a measurements in six points according [1].

II. Verification conditions:

– Ambient temperature – 22.4 °C to 23.1°C
– Atmospheric pressure – 1009 hPa
– Relative air humidity - 49.8 %RH
– Power supply voltage – 30V.

III. Used standards and technical resources

- Digital pressure calibrator Beamex PC106, accuracy 0.04, having pressure measuring modules whose range covers the input signal of the verified measuring instrument

- Digital multimeter Fluke 45, No. 5940038, accuracy 0.025, measuring range 0 to 1000 mV.

- Magnetic resistor P4831, No. 23089, accuracy 0.021. The resistance used in the measuring diagram is 200Ω.

- Calibration pressure pump Beamex PGM.

Each of the used standards causes an error in the measurement. The total error of the standards is calculated according to (1)

$$\gamma_e = \pm\sqrt{\gamma_1{}^2 + \gamma_2{}^2 + \gamma_3{}^2} \quad (1)$$

where:

γ_e – total error of the standards

γ_1 – error of the *1st* standard

γ_2 – error of the *2nd* standard

γ_3 – error of the *3rd* standard

After replacement the total error of the used working standards equal to 0.051 is received, this is approximately 5 times less than the pressure transmitter error and meets the requirements for the relationship of accuracy between the standards and the measuring instrument.

IV. Sequence of operations and calculation of the output signal during verification

The metrological verification applies the direct comparison method – Fig. 1

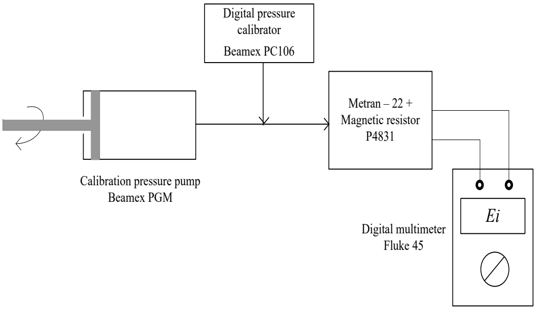

Fig.1 metrological verification scheme

Pressure is applied P_i at the input of the verified measuring instrument. The values of the electric output signal are measured E_i for several different values of pressure P_i. Using the conversion function (2), the theoretic values of the output signal are calculated Et_i for the values of the applied pressure P_i,

$$Et_i = E_{\min} + (E_{\max} - E_{\min})\sqrt{\frac{P_i}{P_{\max}}} \tag{2}$$

where:

Et_i – calculated (theoretic) value of the output signal

$E_{\min}$ – lower limit of the output signal

$E_{\max}$ – upper of the output signal

$P_{\max}$ – upper limit of the input signal.

An example for calculation of one of the values of Et_i:

pressure P_i equal to 0.150 kg/cm^2 is created.
Using the (2), is calculated.

$$Et_i = 0 + (5 - 0)\sqrt{\frac{0.150}{0.630}} = 2.4397 \text{ mA}$$

The obtained result is in milliamperes. When checking the output signal, voltage V and reference resistance of 200 Ω is connected.

The calculated values of voltage at the measuring points are given in TABLE 1.

TABLE 1 CALCULATED VALUES OF VOLTAGE

Pi	**Eti**	**Eti**
kg/cm^2	mA	V
0.000	0.000	0.0000
0.150	2.439	0.4880
0.300	3.450	0.6901
0.450	4.225	0.8452
0.600	4.879	0.9759
0.630	5.000	1.0000

The pressure generating device creates pressure whose values are, equally distributed within the measuring range It is obligatory to include the two limits of the measuring range..

Upon request of the owner, additional measurements at specific points within the range of the measuring instrument are performed.

For each pressure value, the values of the electric output signal are measured.

The pressure values are ranging from 0 to 0.630 kg/cm^2, creating pressure P_i with the values indicated in TABLE 1. For each value of P_i, the electric output signal is recorded E_i.

Then the pressure is decreased to initial position, as the values of P_i are the same as for pressure increase. Thus, two series of measurements are obtained. Therefore, for one pressure value two values of the output signal will be obtained, when the pressure $E_i \uparrow$ is increased and when the pressure $E_i \downarrow$ is decreased, TABLE 2.

TABLE 2 THE READINGS OF THE WORKING STANDARD

The readings of the working standard at:		
Pi	$E_i \uparrow$	$E_i \downarrow$
kg/cm^2	V	V
0.000	0.0005	0.0005
0.150	0.4888	0.4886
0.300	0.6908	0.6909
0.450	0.8460	0.8460
0.600	0.9765	0.9764
0.630	1.0007	1.0007

The difference between these two values is an evidence for hysteresis in the indications of the checked measuring instrument as a result of the approach applied to the measuring value.

The error of the verified measuring instrument is calculated on the basis of the values of Et_i and E_i.

V. Processing of the check results

- For every measured value of the output signal E_i, for pressure increase and decrease respectively, the absolute error of the measurement is calculated, TABLE 3:

$$\Delta_i = E_i - Et_i \quad (3)$$

TABLE 3 ABSOLUTE ERROR

Absolute error at		
Pi	$\Delta i_{,\uparrow}$	$\Delta i_{,\downarrow}$
kg/cm^2	V	V
0.000	0.0005	0.0005
0.150	0.0008	0.0006
0.300	0.0007	0.0008
0.450	0.0008	0.0008
0.600	0.0006	0.0005
0.630	0.0007	0.0007

Absolute error at

- The maximum absolute value for all obtained errors Δi is assigned as the error of the verified measuring instrument:

$$\Delta = \max|\Delta_i| \quad (4)$$

- For each value of the measured pressure, without two limit values, the hysteresis H_i in the indications of the verified measuring instrument is calculated.

$$H_i = E_i^{\uparrow} - E_i^{\downarrow} \quad (5)$$

- The maximum value of all obtained values is assigned to the hysteresis of the verified measuring pressure transmitter H, TABLE 4:

$$H = \max|H_i| \quad (6)$$

TABLE 4 HYSTERESIS OF THE INDICATIONS

Hysteresis of the indications	
Pi	H_i
kg/cm^2	V
0.000	-
0.150	0.0002
0.300	0.0001
0.450	-
0.600	0.0001
0.630	-

- Conditions to validate the metrological fitness of the verified measuring pressure transmitter:

$$\Delta \le \Delta_{\partial on} \quad (7)$$

$$H \le H_{\partial on} \quad (8)$$

where:

Δ - maximum absolute error of the verified measuring instrument

$\Delta_{additional}$ - maximum allowable absolute error indicated in the technical documentation of the verified measuring instrument

H - hysteresis of the indications

$H_{additional}$ - allowable hysteresis equal to the maximum allowable error $\Delta_{\partial on}$.

From TABLE 3 $\max|\Delta_i|$ = 0.0008 V is defined and compared to $\Delta_{\partial on}$ = 0.0025 V.

The condition of (7) is fulfilled.

From TABLE 4 $\max|H_i|$ = 0.0002 V is defined and compared to $H_{\partial on}$ = 0.0025 V.

The condition of (8) is fulfilled.

VI. Conclusion

When the conditions for the verification of metrological fitness of the verified measuring instrument are fulfilled, the related label will be placed.

The measuring instruments which do not meet the conditions are labelled with a unsuitable sign.

Based on the calculations made, a conclusion is made that the verified measuring instrument is fit in terms of metrology and is allowed to operation for the period indicated in the label.

The use of this type of pressure transmitters Metran-22 in the process diagrams at Kozloduy NPP EA improves the accuracy of measurements. The number of measuring pressure transmitters in one measuring circuit is reduced, which, in turn, leads to error reduction in the data transfer to the end user. Thus, the end user will obtain information about the measured quantity, which is closer to the real value.

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Metrology assurance of dosemeters/radiometers, UIM 2-2 type

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Abstract - The report describes the main tasks for metrology assurance of dosemeter/radiometer, UIM 2-2 type, at Kozloduy NPP, the activities to provide for the anticipated high performance in this field and compliance with the national and international requirements. The report is based on the developed and approved documents according to the process established by Ionizing Radiation Measurement Laboratory in Metrology Assurance Department at Kozloduy NPP EAD, and which are based on the long-term experience and meet the regulatory and legal requirements.

Keywords - Metrology assurance, metrology, calibration, verification

1. Introduction

Measurement of ionizing radiation is carried out in many areas of the industrial and monitoring activities performed at Kozloduy NPP EAD and these measurements are particularly important in the field of radiation protection.

The dosemeter/radiometer, UIM 2-2 type, is a device broadly used for measurement of radiation contamination. The measuring instruments of this type are part of the radiation monitoring equipment at Kozloduy NPP EAD and departments of SE RAO: Specialised Division for Units 1-4 Decommissioning, and Specialized Department RAW.

Depending on the detection unit installed, they are used for:

– measurement of the particle flow density in the event of surface beta contamination of the items in the rooms and equipment in the controlled area

– measurement of the equivalent dose rate of gamma radiation in the CA rooms.

2. Metrology assurance objective

In order to provide for the anticipated high performance and reliability of measurement results, metrology assurance activities are carried out for metrology assurance of the measuring equipment at Kozloduy EAD in compliance with the national and international requirements.

Ionizing Radiation Measuring Laboratory provides for metrology assurance of the instruments for measurement of ionizing radiation in three different areas:

– maintenance and development of reference sources

– arrangement and performance of metrology control of measuring equipment

– implementation of the international codes and standards for verification and calibration

– training and qualification of the personnel.

3. Range

Metrology assurance of dosemeter/radiometer, UIM 2-2 type, includes the following main activities:

– metrological verification of measuring equipment

– calibration of measuring equipment.

4. Technical characteristics

Dosemeter/radiometer, UIM 2-2 type, is a portable device for measurement of equivalent dose rate of gamma radiation and beta particle flux density of surface contamination with beta radionuclides. It measures counting rate of the pulses recorded by detection units at the input of the device.

Several detection units are used to record the beta particle flux density, the most used is detection unit, БДБ 2-02 type, with measuring range 4.0 to 4000 $\beta/(cm^2.min)$

For recording of the dose exposure rate of gamma radiation, the following detection units are used:

Detection unit type	Measuring range
БДМГ-41	100 µR/h ÷ 100 mR/h
БДМГ-41–01	1 mR/h ÷ 1R/h
БДМГ-41–03	10 mR/h ÷ 50 R/h
БДМГ– 02Р	10 µR/h ÷ 10 mR/h

5. METROLOGICAL VERIFICATION OF DOSEMETER/RADIOMETER, UIM 2-2 TYPE

The verification provides for proper measurement with given measuring equipment in compliance with design requirements for a certain period of time.

5.1. The metrological verification of UIM 2-2 with detection unit for surface beta contamination

5.1.1. Verification of the own background

The detection unit is positioned so that the distance from the input window to the closest clean surface is higher than 30 cm. The air kerma rates at the point where the radiometer is places should not less than 0.2 μGy /h. A number of measurements are carried out, and than their average value is calculated $\overline{n_b}$

Operability requirement $\overline{n_b} \leq 8$ s^{-1}

5.1.2. Verification of recording efficiency

The efficiency verification is performed by reference radioactive source, C0 type with nuclides $^{90}Sr+^{90}Y$ compared to the manufacturer's efficiency.

The detection unit is above the emitting area of a reference source in contact position.

A series of counting rate measurements are carried out and the average value of $\overline{n}$ s^{-1} is calculated. The efficiency is evaluated as

$$\varepsilon_{\varphi} = \frac{n_0}{q_{2\pi}\dfrac{60}{S}}$$

where

$$n_0 = \overline{n} - \overline{n}_b$$

is the measured absolute counting rate , s^{-1}

$$q_{2\pi} = q_{2\pi,0} \cdot \exp(-\ln 2 \frac{\Delta t}{T_{1/2}})$$

$q_{2\pi}$ – surface particle emission rate of reference source at the moment of measurement, s^{-1}

$q_{2\pi,0}$ – surface particle emission rate of reference source as of a reference date according to the certificate of the source, s^{-1}

$T_{1/2}$ – half-life period of radionuclide used for calibration

Δt – time interval between the reference date and the moment of measurement

S – active area of the reference source, cm^2.

Operability requirement

$\varepsilon_{\varphi} > 0.39$ s^{-1}/[β/(cm^2.min)]

5.1.3. Verification of the relation between sensitivity and position of the source of ionizing radiation

The objective of verification is to verify the operability of the two Geiger -Mueller counters, which are part of the detection units.

The verification is performed with reference radioactive sources, 1CO type, having the area of 1 cm^2, and particle emission rate is ≈ 500 ÷ 700 s^{-1}.

The source is placed at 4 different points of the working surface of detection unit (2 points per counter) and the counting rate is measured.

Operability requirement $\frac{M_{\min}}{M_{\max}} \geq 0{,}5$

5.1.4. Verification of the linearity of measuring range

The verification is performed with a set of reference radioactive sources, C0 type.

At least one point within every subrange of the working range is verified.

The verification points are chosen from 40 to 80% of the maximum value of subranges, and for the smallest subrange from 50 to 80%. The recorded values are used to verify the efficiency within every subrange εi and their average value is calculated $\overline{\varepsilon}_i$

Operability requirement

$$\xi = \frac{\varepsilon_i - \overline{\varepsilon_i}}{\overline{\varepsilon_i}}.100 \leq 20\%$$
,

5.1.5. Verification of the basic error

When verifying the basic error, reference sources with the same geometry and nuclide similar to those used for the calibration are applied.

The detection unit is positioned above the emitting area of the reference source upon the measuring conditions (geometry) indicated in the calibration certificate. Measurements and determination of the recorded particle flow density φtest are carried out.

The basic error is calculated as

$$\Delta = \frac{\varphi_{test} - \varphi_e}{\varphi_e}.100\%$$
,

where

$\varphi_{test} = K.n_0$,

$\varphi_e = q_{2\pi}.\frac{60}{S}$ - frequency flow density of the reference radioactive source

K, [β/(cm^2.min)]/s^{-1} is the calibration factor defined during calibration.

Operability requirement $\Delta \leq 30\%$

5.1.6. Verification of the relation between efficiency and energy

The verification is carried out with broad-area sources with different radionuclides but with the same design and active area.

The radionuclides used for verification should be with maximum energies of the beta spectra providing for monitoring at the points of three energy ranges.

The suitable nuclides are:

1) $E_{max} \leq 0.2$ MeV - ^{14}C

2) $E_{max} = 0.2 \div 0.5$ MeV - ^{60}Co and ^{137}Cs

3) $E_{max} > 0.5$ MeV - ^{36}Cl, ^{204}Tl and $^{90}Sr/^{90}Y$

The detection unit is positioned above the emitting surface of the reference source according to the measurement (geometry) conditions indicated in the calibration certificate.

For each of the sources, measurements and result processing are carried out according to the procedure described in item 5.1.2.

$$\Delta = \frac{\varepsilon_{test} - \varepsilon_{klb}}{\varepsilon_{klb}}.100\%$$

Operability requirement

5.2. Metrological verification of UIM 2-2 with detection unit for surface beta contamination

5.2.1. Verification of the basic error

The verification is carried out with radioactive sources with nuclide ^{137}Cs of the reference gamma radiation lines, IM1/P and IM6/M type

The verification is performed at least at one point within all subranges of measuring range, and the point is selected from 30 to 80 % of the maximum value of subrange.

The verification is carried out in the following sequence:

- The source of gamma radiation is selected.
- The verification point ($H_x ref$) is defined by a radiation monitoring calculator *EasyCalc.mdb.*
- The detection unit is positioned at the point for verification as indicated in the technical documentation.
- A series of measurements of background are carried out and the average value of $\overline{N}_b$, s^{-1} is evaluated.
- A series of measurements of counting rate are carried out and the average value of $\overline{N}$ s^{-1} is evaluated.
- The absolute counting rate is evaluated as:

$$N_0 = \overline{N} - \overline{N}_b$$

- The equivalent dose rate $H_x test$, μSv/h, is calculated as:

$$H_x test = K.N_0,$$

where K (μSv/h)/s^{-1} is calibration factor defined during calibration.

The basic error is calculated such as

$$\Delta = \frac{H_x test - H_x ref}{H_x ref}.100,\%$$

where

$H_x test$ - measured value

$H_x ref$ - actual value of the quantity Hx, reproduced from the reference source

Operability requirement $\Delta \leq 20\%$

5.2.2. Verification of the relation between indication and energy

The verification is performed with reference radioactive source from the reference source basis with nuclides

^{137}Cs (E = 662 keV)

^{60}Co (E = 1.25 MeV).

The verification point is defined so that the values of the quantity H_x of the two nuclides (H_{xCo} *and* H_{xCs}) will coincide or differ from each other by up to ± 10 %.

- The relations are calculated.

$$N_{Cs} = \frac{H_{Cs}}{\overline{N}_{Cs}}; \qquad N_{Co} = \frac{H_{Co}}{\overline{N}_{Co}}$$

where

$H_{Co} = H_{Cs}$ are real values of Hx, μSv/h, (mSv/h);

$\overline{N}_{Cs}$ and $\overline{N}_{Co}$ are average values measured by the corresponding radiation sources, s^{-1}.

Operability requirement $\frac{N_{Co}}{N_{Cs}} = 0.80 \div 1.25$

5.2.3. Verification of the relation between indication and radiation direction

The verification is carried out with radioactive sources with radionuclide ^{137}Cs of the reference source equipment.

The measurements are carried out in the following sequence:

- The detection unit is positioned at the point of verification and is rotated to both direction at ±45°around the horizontal axis of the cross section. When rotating, the verification point will keep its coordinates.

- The average values are calculated.
- The relations are calculated:

$$N_{Cs}(+45^o) = \frac{\overline{N}_{Cs}(+45^o)}{\overline{N}_{Cs}(0^o)}$$

$$N_{Cs}(-45^o) = \frac{\overline{N}_{Cs}(-45^o)}{\overline{N}_{Cs}(0^o)}$$

where

$\overline{N}_{Cs}(+45^o)$, $\overline{N}_{Cs}(-45^o)$ и $\overline{N}_{Cs}(0^o)$,

are the average values measured when the detection unit is positioned at the angle of (+45°), (0°) and (+ 45°), s^{-1}.

Operability requirement $N_{Cs}(\pm 45^o)$ = 0.6 ÷ 1.4

The metrological verifications are carried out in compliance with the documents developed by the IRM Laboratory according to the established process and which documents comply with the regulatory and legal requirements.

The results of this activity are recorded according to the requirements of the internal procedures which establish this activity.

In the event of non-conformity of the obtained results to the operability requirements, measure for repair and /or recalibration of the equipment will be taken.

6. CALIBRATION OF UIM 2-2

The calibration is an important activity in terms of metrology assurance. For calibration solid knowledge about the specifics of the measurement, its performance and result evaluation is required. Compared to the verification, the calibration provides for qualitative assessment, which show to what extend a certain objective is feasible with given equipment when applying a specific measuring method.

The calibration is carried out:

– upon delivery of new equipment

– after repair of the equipment

– regularly in compliance with the working documents of the relevant organizational structure

– upon unsatisfactory result from the verification of basic error.

The main operations performed during calibration are:

– identification of the recording efficiency

– calculation of the calibration factor

– evaluation of the expanded uncertainty of recording efficiency.

The used reference sources and measuring instruments should be traceable to the national or international reference sources and have characteristics complying with the requirements set in ISO 8769:2016, ISO 4037-1:2019 and ISO 4037-3:2017

6.1. Calibration of UIM 2-2 with detection unit for surface beta contamination

The calibration is carried out by thin broad-area reference sources with active area of 150 cm^2.

Nuclides ^{90}Sr, ^{60}Co and ^{137}Cs are used for the needs of the radiation monitoring at Kozloduy NPP EAD.

The distance from the active surface of the source to the protective grille of the input window of detection units is h = 10 ± 1 mm.

Depending on the requirements of the user, the calibration may be performed according to the external radiation $q_{2\pi}$ and/or particle flow density, φ_e of the reference radiation source.

The efficiency according to the external radiation is evaluated as:

$$\varepsilon_{2\pi} = \frac{n_0}{q_{2\pi}}, \quad s^{-1}/s^{-1}$$

The efficiency according to the particle flow density is evaluated as:

$$\varepsilon_{\varphi} = \frac{n_0}{\varphi_e}, \quad s^{-1}/[\beta/(cm^2.min)]$$

The calibration coefficient is defined as:

$$K_{\varphi} = \frac{\varphi_e}{n_0}, \quad \beta/(cm^2.min)/s^{-1}$$

The expanded uncertainty of efficiency ε of the detection unit is calculated according to the formula

$$U(\varepsilon) = k \cdot \varepsilon \cdot u(\varepsilon)$$

where

$$u(\varepsilon) = \sqrt{u^2(n_0) + u^2(q_{2\pi}) + u^2(h) + u^2(\xi)}$$

is a combined uncertainty of the measurement

k = 2 is the coverage factor corresponding to a certain confidence probability - for normal distribution of the measure quantity and probability of the confidence interval is approximately 95 %.

6.2. The calibration of UIM 2-2 with detection unit for gamma contamination

The calibration is carried out with radioactive sources with nuclide ^{137}Cs of the reference gamma equipment, IM1/P and IM6/M type.

The equivalent dose rate $H_x ref$, µSv/h, and distance from source to detection unit *d, mm* are defined by radiation monitoring calculator *EasyCalc.mdb*, The efficiency is evaluated as:

$$\varepsilon = \frac{N_0}{H_x ref}, \quad s^{-1}/(\mu Sv/h)$$

The calibration factor is defined as:

$$K = \frac{H_x ref}{N_0} \cdot \frac{1}{f_{nu} \cdot f_{room} \cdot f_d \cdot f_r}, \quad (\mu Sv/h)/s^{-1}$$

Where f_i id is correlation factors taking into account the influence of the characteristics of the filed and positioning of the detection unit.

The expanded uncertainty of calibration factor *K* of the detection unit is calculated according to the formula

$$U(K) = k \cdot K \cdot u(K)$$

where

$$u(K) = \sqrt{u^2(N_0) + u^2(H_x ref) + u^2(d)}$$

The calibration activities are performed in compliance with the calibration techniques prepared by the Ionization Radiation Measurement Laboratory in compliance with the instructions provided by the equipment manufacturer and in compliance with the regulatory requirements.

The calibration results are given in the calibration certificate and calibration report in compliance with the procedure requirements.

7. CONCLUSION

Ionizing Radiation Measurement Laboratory at Kozloduy NPP plc is responsible for metrology assurance of a large number of measurements and measuring instruments in the industrial and legal metrology. The principles and methods for metrology assurance, which are applied by the laboratory, comply with the modern international and national trends for development of metrology assurance.

The laboratory has focused its efforts on the the harmonization of the metrology assurance of process measurements with the regulations of the Republic of Bulgaria and the European Union through development of programmes for quality assurance of different measurements, calibration of the measuring instruments, improvement and development of the reference sources, improvement of the quality of metrological verifications, preparation of the measurement methods, receiving inspection, etc.

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REALIZATION OF THE RELATIVE HUMIDITY AND DEW POINT TEMPERATURES AT NATIONAL CENTER OF METROLOGY (NCM), BIM, BULGARIA

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Abstract—***At Temperature Measurements Department of the National Center of Metrology, BIM the standard in the field of calibration of relative humidity is a Precision Dew Point Hygrometer, which is included in an Automatic Relative Humidity Calibration System with temperature camera and flow type generation of the moisture gas.***

Review of relative humidity (RH) measurements requires:

- Traceability of reference standards
- The inputs with known contribution to uncertainty
- Validated procedures
- Uniformity of the chamber environment
- Multiple RH and temperature calibration points

Calibration and Measurement Capabilities (CMC's) for Relative Humidity of Temperature Measurements Department, National Center of Metrology (NCM), BIM were adopted in 2016 and in 2017 they were published in Appendix C of the KCDB.

A brief review and description of the measurement techniques, apparatus used and important points of uncertainty budget are given in this paper.

Keywords— NMIs – National Metrology Institutes, RH – Relative Humidity, %rh - Relative Humidity measurement unit, DP – Dew Point , WVP – water vapor pressure, temperature gradients, CMC – Calibration and Measurement Capabilities

I. INTRODUCTION

Relative Humidity (RH) is a critical environmental factor in thousands of processes and materials. The accurate measurement of RH is concern in many applications like product shipping and storage, food, pharmaceutical and electronic manufacturing. RH is included in many processes of control and monitoring procedures. These requirements have led the industry to produce instruments with different levels of RH accuracy. Many secondary RH sensors today have technical specifications of accuracies ranging from ± 1 to 5 %rh. In this time horse hair hygrometers at ±10 %rh accuracy don't lose their application in the fields, where the sparks and any electrical currents are undesirable. All secondary RH sensors are absolutely dependent on accurate calibration.

II. PRINCILAS AND IMPORTANT OBSERVATIONS

Relative humidity at all temperatures and pressures is defined as the ratio of the water vapor pressure (P_w) to the saturation water vapor pressure (P_{ws}) (over water) at the gas temperature:

$$RH = P_w / P_{ws} \cdot 100\% \qquad (1)$$

Vapor pressure is dependent of temperature. The dew point is the temperature to which air must be cooled to become saturated with water vapor. Thus value of RH at atmospheric pressure is calculated from values of two temperatures – the dew point temperature and the ambient temperature. Measurement of RH includes broad range of moisture contents, that one sensor must measure. For example sensor with measurement range 10 %rh to 90 %rh at temperatures from -20 °C to 70 °C must perform in humidity conditions ranging from 100 ppm to 400 000 ppm. The dynamic range is 4000:1 that would challenge the linearity of the measuring devices. RH is temperature-dependent; the value can change significantly with variations in ambient temperature and without any change in moisture content. For example, at 90 %rh a ±1 °C change in ambient temperature will result in ± 6 %rh uncertainty.

The most significant calibration challenge is that RH testing must be carried out in air. RH sensors measure only the water vapor in the layer of gas contacting the surface of the sensor. Air is a poor thermal conductor and the temperature at any point can be affected by temperature gradients, heat conductance, thermal radiation and other temporal variations. This means that the homogenous environmental conditions are very important, but time-consuming, even when a primary standard system is used. All secondary RH sensors are working by changing their electrical properties with variations in humidity. Linearity of sensors is a problem and validation is a necessity.

III. EQUIPMENT AND APPARATUS

Temperature Measurements Department has Michell Automatic RH Calibration System provided for calibrating relative humidity probes. It is capable of repeatable generation of humidity levels over the range 5 %rh to 98 %rh (-50 °C to 50 °C dew point) at -20 °C to 50 °C ambient temperature with good stability. Accuracy for complete system is ±0.1 °C for dew point measurements and ±1.0 %rh for humidity. Gas temperature accuracy is ±0.2 °C.

Michell Automatic RH Calibration System consists of following parts:

- S4000 Precision Dew Point Meter
- Automatic Relative Humidity Generator, which includes PSD-2 Pressure Swing Drier and Durr Technik Oil Free Compressor Station
- CTS Temperature Test Chamber
- Software RH Generator V3.exe

Clean dry compressed air is produced via the Compressor Station and Pressure Swing Dryer and this conditions the air simply to a dew point of around -75 °C. This dry gas is then passed into the Auto RH Generator which divides the gas into two streams each of which flow through a water saturator and is mixed by volumetric ratios with the other stream to produce different humidity levels over a full operating range of the instrument.

The output from the Auto RH Generator is fed into a Temperature Test Chamber via a heat traced sample line where it is then divided into two controllable gas streams. One of these streams passes through the S4000 Precision Dew Point Hygrometer measuring the generated humidity (dew point). The other stream passes through a calibration manifold used to calibrate humidity probes and finally both flows venting to atmosphere (in camera).

Fig. 1 illustrates the flows.

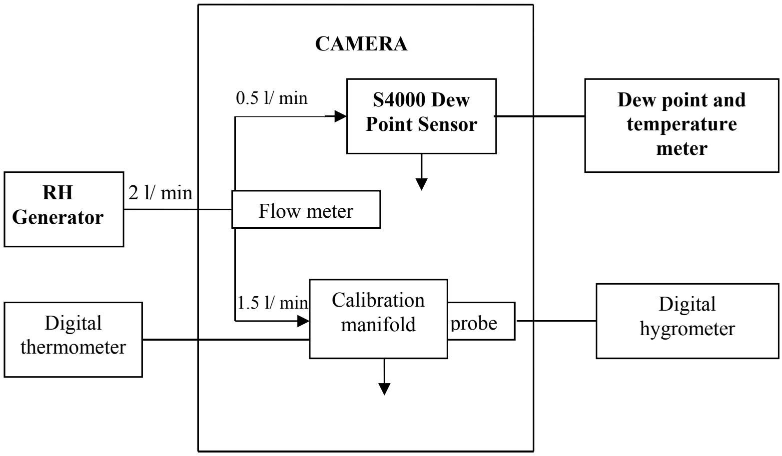

Fig. 1

On the fig. 2 ,3 and 4 can be seen how the calibration system looks like.

Fig. 2

Fig. 3

Fig. 4

Within the S4000 DP sensor a Peltier thermoelectric device cools the plated copper mirror (chilled mirror). At a temperature, determined by the moisture content of the sample gas, dew or ice forms on the mirror surface. This formation of dew causes a reduction in reflected light intensity from the red L.E.D. light source and causes an increase in scattered light from the mirror surface. This signal change is perceived by a differential optical detection system which in turn regulates power to the Peltier via control circuit. The control loop maintains the mirror surface exactly at the dew point temperature (the equilibrium, where the rate of condensation and evaporation are equal), which is then measured by an embedded four-wire platinum resistance thermometer. The monitoring performs displaying the results in other engineering units than °C and %rh and includes optical balance – either manually or automatically.

As can be seen from description, the system works with flows, what means the control of the gas pressure is absent. The pressure can be measured, but not controlled at desirable value. This is the reason the dew point meter is calibrated – the generation of the gas with known dew point isn’t exactly controlled as this is made in 2 - pressures/ 2 - temperatures primary standard generators. At this moment the dew point meter has four calibrations – three in NPL, UK and the last calibration is from PTB, Germany. The last calibration certificates are: 30473 PTB 2019/ 13.05.2019 for chilled mirror sensor and 30474 PTB 2019/ 13.05.2019 for remote temperature control PRT. An example for measuring point: RH = 10 %rh; DP = - 8 °C; ambient temperature = 25 °C can be seen on figures 5, 6 and 7:

Results for drift of PRT for ambient temperature 25 °C:

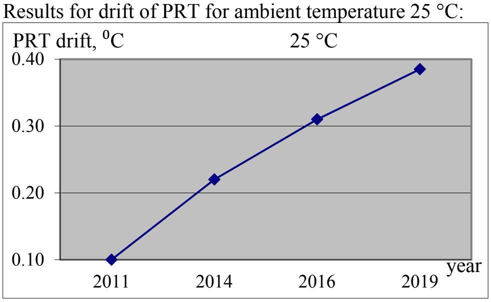

Fig.5

Results for drift of DP temperature = -8 °C:

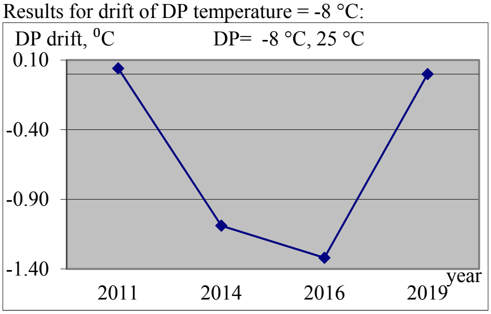

Fig. 6

On fig. 7 can be seen that the calculated relative humidity is with a profile of the dew point temperature. That is because at 10 %rh and 25 °C the sensitivity coefficients for DP and ambient temperatures are close to 1.

Results for drift of calculated RH = 10 %rh:

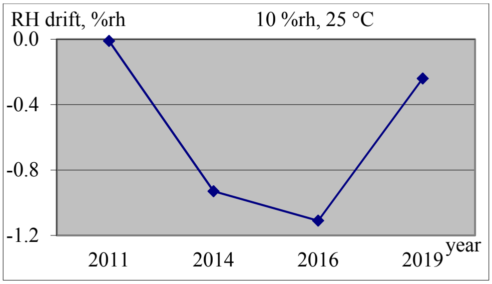

Fig. 7

When the DP temperature increases the relative humidity also increases. When the moisture content remains constant, dew point remains constant. If ambient temperature increases, relative humidity decreases. On fig. 9 can be seen how the drift of temperature probe for ambient temperature at 25 °C (fig. 5) and the drift of the dew point temperature at 23 °C (fig. 8) influence the results for calculated RH = 90 %rh. The positive drift for ambient temperature lowers the results for RH, because at levels of RH, higher than 10 %rh the sensitivity coefficients are over 1.

Results for drift of DP temperature = 23 °C:

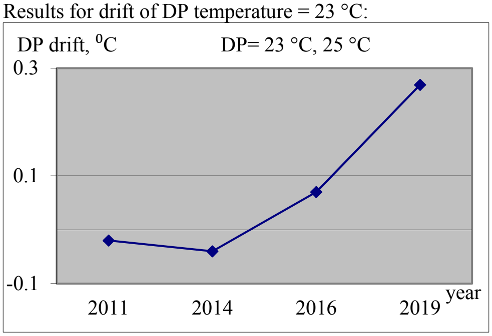

Fig. 8

Results for drift of calculated RH = 90 %rh:

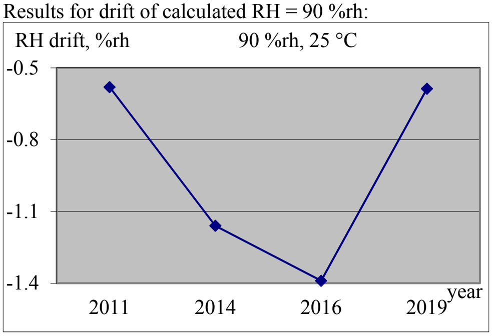

Fig. 9

IV. METHOD OF REALIZATION

The realization of the levels of humidity in dew point calibration with the system, presenting in this paper, is time consuming, slow and sensitive process. Important part before starting is drying of the gas (air). It takes four hours and if it isn't done correctly, the flows are not stable. It's necessary to make optical balance of the system manually before measurement. First level of humidity needs at least one hour for stabilization, for others – 40 minutes as minimum. All components of the system (with some exceptions) are automatically controlled and programmable. Data downloading can be done manually or from the data storing files of the program RH Generator.exe. Then these files are processed via budget, which will be presented in section V.

The following points are important in carrying out the review of RH measurement:

- Traceability of reference standards

- The inputs of the reference standards with known contribution to uncertainty

- Reliable formulas for calculating relative humidity with known contribution to uncertainty

- Validated and verified procedures

- Uniformity of the chamber environment

- Multiple RH and temperature calibration points

According the specific acceptance criteria, for intra-laboratory evaluation of the uncertainty in RH calibration, in 2016 were submitted, accepted without questions and in 2017 were published in the Appendix C of the KCDB the following Calibration and Measurement Capabilities (CMC) for relative humidity sensors and other hygrometers:

For ambient temperature (1 ÷ 20) °C:

for (10 ÷ 30) %rh – U = 1.4 %rh

for (30 ÷ 50) %rh – U = 1.8 %rh

for (50 ÷ 90) %rh – U = 2.2 %rh

For ambient temperature (20 ÷ 50) °C:

for (10 ÷ 30) %rh – U = 1.4 %rh

for (30 ÷ 50) %rh – U = 1.6 %rh

for (50 ÷ 90) %rh – U = 2.0 %rh

V. UNCERTAINTY BUDGET

The methods used for evaluation and calculation in the calibration and measurement procedures follows the uncertainty document presented in 2008, Evaluation of measurement data - Guide to the expression of uncertainty in measurement [1]. Additional document specifically for uncertainty in humidity measurements is Review Protocol for Relative Humidity CMC's [2]. The estimation of the components of uncertainty in budget is based on the multiple measurements or evaluation on the base of the other observed or measured components in the calibration system. The pressure drop in the system is accepted at highest real level for the presented calibration system and the laboratory conditions. Important notes to this budget:

1. Mathematical model is:

$$RH_{app} = \left[\frac{e(t_d)\ f(P, t_d)}{e(t_g)\ f(P, t_g)} .100 + \delta RH_{corr., ind} \right], \%rh \qquad (2)$$

Where:

$e(t_d)$ - Water vapor pressure at DP temperature, Pa

$e(t_g)$ - Saturation vapor pressure at camera temperature, Pa;

t_d - Dew point or frost point, °C;

t_g - Camera temperature, °C;

P - Pressure in the system, Pa;

$\delta RH_{corr.,ind}$ - Correction of the applied RH in this point of calibration, %rh

2. $f(P,\ t_d)$ and $f(P,\ t_g)$ are enhancement factors, from Greenspan's approximation formula [3]. They are for real gases and in case of measurement have contribution only to uncertainty. This uncertainty is estimated as 0.02 % of the value of the water vapor pressure [4].

3. Water vapor pressure $e(t_d)$ is calculated from the approximations of Sontag-Wexler [5]:

$$\ln e_w(T_d) = -6096.9385\ T_d^{-1} + 21.240964 - 2.711193\times10^{-2}\ T_d + 1.673952\times10^{-5}\ T_d^{2} + 2.433502 \ln T_d \qquad (3)$$

$$\ln e_i(T_d) = -6024.5282\ T_d^{-1} + 29.32707 + 1.0613868\times10^{-2}\ T_d - 1.3198825\times10^{-5}\ T_d^{2} - 0.49382577 \ln T_d \qquad (4)$$

Where:

$T_d = (t_d + 273.15)$ K - dew or frost point temperature (K)

$e_w(T_d)$ - WVP at DP temperature, Pa

$e_i(T_d)$ - WVP at frost point temperature, Pa

Real WVP is strongly influenced of the phase of the water on the mirror of the dew point sensor - dew or ice, when DP is close to -10 °C. Contribution to uncertainty from Sontag's approximations is accepted as 0.5 % of the result for the water vapor pressure $e(T_d)$.

4. According to Review Protocol for Relative Humidity CMC's [2], point 3.2 1b) the laboratory should provide evidence that the uncertainties dew to water vapor pressure gradients in the measurement chamber is not larger than the uncertainty component included in uncertainty budget (u_{ewG}). The difference between the maximum and minimum dew point temperature in the measurement chamber (T_{dMax} and T_{dMin}, respectively) must fulfil the requirement:

$$u_{ewG} \geq \frac{e_w(T_{dMax}) - e_w(T_{dMin})}{2\sqrt{3}} \qquad (5)$$

Where:

T_{dMax} – maximum dew point temperature (K)

T_{dMin} – minimum dew point temperature (K)

$e_w(T_{dMax})$ – WVP at maximum dew point temperature, Pa

$e_w(T_{dMin})$ - WVP at minimum dew point temperature, Pa

u_{ewG} - uncertainty dew to water vapor pressure gradient, Pa

For fulfilling these requirements, tests for water vapor pressure gradients are done. In table 1:

$e_{wMax} = e_w(T_{dMax})$, Pa

$e_{wMin} = e_w(T_{dMin})$, Pa

Table 1: Test results for water vapor pressure gradients:

RH	Camera temp. t_g	e_{wMax}	e_{wMin}	Δe_w	u_{ewG}	Clamed u_{ewG}
%rh	°C	Pa	Pa	Pa	Pa	Pa
10.6	1.02	69.8	68.1	1.78	0.51	0.51
94.2	1.02	620.0	610.6	9.38	2.71	2.7
10.0	50.02	1239	1220	18.9	5.47	5.5
90.0	50.02	11051	11034	16.7	4.82	4.8

Where:

t_g – test temperature in the camera, °C

Δe_w – water vapor pressure gradient, Pa

5. Traceability of t_g (camera temperature) is provided from CMC entries of the Temperature Measurements Department of National Centre of Metrology, BIM. Tests for temperature gradients in camera and calibration manifold are done with five PRTs – four at corners of the camera or calibration manifold and one in the center of the experimental area. Measurements with five PRTs are done and recorded simultaneously. Results for tests and clamed uncertainty u_{tG} are in Table 2.

Δt_g – temperature gradient, °C

u_{tG} - uncertainty dew to temperature gradient, °C

Table 2: Uncertainties for temperature gradients:

Temperature, t_g	Δt_g	u_{tG}	Claimed u_{tG}
Sub fold, 0.001 m3	°C	°C	°C
0 °C	-0.045	0.013	0.01
25 °C	0.135	0.039	0.04
50 °C	0.209	0.060	0.06
Camera, 0.05 m3	°C	°C	°C
0 °C	0.210	0.060	0.06
50 °C	0.508	0.147	0.15

VI. CONCLUSIONS

Temperature Measurements Department, NCM, BIM has proven ability to perform reliable and traceable calibrations of humidity sensors, probes and other hygrometers in the range of (-26 ÷ 48) °C dew point temperatures (relative humidity in the range from 10 %rh to 90 %rh) and (1 ÷ 50) °C range for ambient temperatures. The uncertainties are supported by intra-laboratory investigations like in [6] and published CMC's. Future participation in international comparisons is planned for submission new or corrected CMC entries with lower uncertainties. Data for such corrections are present now, but they need support from international comparison results.

ACKNOWLEDGMENT

I would like to express my special thanks to my colleagues from the Temperature Measurements Department for help and patience in making some measurements that were needed to evaluate some of the budget contributions. I also thank the management of NCM and BIM for the training they provided with such a brilliant lecturer like Dr. Vito Fernicola.

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Exploring the need for FMEA analysis in the choice of the Photogrammetric method for control and measurement in heavy machinery.

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***Abstract*—The article examines the feasibility of the application and the acute practical need to develop the FMEA (the analysis of the failures and their consequences), the choice of the photogrammetric method for technical control of the quality indicators, tolerances of the form, the position and the dimensions in the heavy machine building, dependence.**

Keywords—FMEA method, photogrammetric method of measurement, heavy machinery, risk assessment method.

I. INTRODUCTION

In the process of manufacturing, storing, transporting and installing machines, elements and welded structures, their qualitative features and properties of structural purpose and /or/ aesthetic appearance (visual discrepancies) are altered. Each property of a particular machine or element is characterized by one or more basic quantitative indicators, which are called product parameters. The object of our research will be the constructive and visual parameters concerning the quality of production. When changing one or several technical parameters of the product, the quality indicators of the machine product are also changed. Thus, at different points in time, the product may fall into different states - corresponding, inadequate, inadequate repair, inappropriate, inaccurate, according to the technical documentation. The reasons behind the disruption of the physical performance of the production produced during its technological routes is called a mismatch in the quality of the product. The reasons for inconsistencies are due to a large number of objective and subjective factors. Any discrepancy with the technical documentation is removed at different stages of the manufacturing process and location of the product. Depending on when it is registered in the production process, and the location refers to whom the discrepancy is registered - from the final customer or even on the production base. The first option is extremely undesirable, on which depends the burden on the consumer S, which is very important for the production costs and the final cost of the product. With the increase in the burden on the consumer, the added value of the product should also increase. If the technological reasons giving rise to inappropriate output are not remedied in due course, they may be the cause of a customer claim. One method for controlling and analyzing failures and failures in machinery and equipment as a consequence of a non-compliant product is the application of the Failure Mode and Effect Analysis (FMEA) method [1]. The purpose of this article is to demonstrate the need to apply the FMEA methodology in modern quality control and management in machine building companies to create a database based on which to apply a rational strategy when choosing the photogrammetric method of control and measurement in the heavy machine-building according to their constructive features.

II. EXPLANATION

A. Types of FMEA

Development / product (DFMEA);
Process (PFMEA);
Human error (EMEA);

B. B. Creating the FMEA Method

The FMEA method was developed in 1949 for the US Armed Forces. In the early 1960s, it developed as a method to ensure the quality of APOLO's NASA and Nuclear Power Plant projects. Later in 1970 FORD MOTOR COMPANY introduced the method in the automotive industry. The FMEA is a methodology for analyzing potential failures and failures, depending on their complexity and likelihood of occurrence when using machines as intended. By its nature, it is a preventive method for maintaining the performance of nodes and aggregates. The FMEA makes it possible to localize potential failures based on existing databases for similar nodes and aggregates, with its application minimizing the cost of maintaining the quality of the production company. At present, it is increasingly used in the field of service for products of different uses. For ease of reference below in the analysis of the term refusal, we should understand a client's claim or a discrepancy in the quality indicators found in the manufacturing process [1].

The FMEA method has 3 main tasks to solve:

- To identify and evaluate potential failures and the reason for their occurrence.
- To regulate the impacts on the basis of which to minimize or prevent the occurrence of failures.
- Based on the results of the application of the FMEA methodology, a database should be created and maintained.

The localization of failures can be of varying labor intensity, depending on the construction characteristics of the machines and the possibility of adapting the diagnostic (metrological) apparatus to them. The second task is related to the application of the FMEA methodology related to the impact on objects. The third task of creating the database allows for the choice of a rational strategy for improving the quality of the produced machines and machine components and for forecasting deviations in the quality indicators of the machines.

It is known that the denial is an event, which is a violation of the working condition of the machines. It is known that the denial is an event, which is a violation of the working condition of the machines. It is important to note that a failure means not only the complete disruption of the device but also the deterioration of its basic parameters to a level lower than the established limits and in our specific case may be the impossibility of mounting a particular node or element. An analysis of the effect of failures deals with the consequences that have arisen after its occurrence. Refusals are ranked by priority, depending on their complexity of detection and control; of the consequences that will occur after their discovery or appearance over time; of how easily they can be localized, ie. how laborious it will be to make control and measurement with a suitable method with satisfactory accuracy. By applying the FMEA methodology, it is possible to classify refusals, starting with those that have serious consequences in their actual appearance not only for the non-conforming elements but also for the elements that are in close kinematic relation with them, especially when it comes to lifting machines as our object of research and analysis [1]. When a denial occurs in the machine, certain features are violated. The latter can be divided into primary and secondary. The primary function is that in which the machine can not be used for its intended purpose. If the secondary is damaged, the machine retains its working condition but does not meet certain requirements related to the ecological, ergonomic, economic and directly related to our research object - the structural and technological requirements defined in the NTD (normative technical documentation) of the machine. The FMEA responds to the question whether it is appropriate for the machine to be used as intended or not due to a malfunction. It is advisable to use:

- When designing new products.
- Developing a strategy to maintain or absorb the production of new or modified products.
- To improve an existing system of service or quality control and management of machine-building products.
- to analyze causal links for the occurrence of failures or inconsistencies in certain systems, subsystems or products.
- Periodic aggregation of the results of the analysis for the occurrence of failures (inconsistencies) throughout the life cycle of the machine or the product cycle of the product and decision making to improve their reliability and quality.

III. METHOD AND SURVEY

To use the FMEA analysis, it is necessary to go through the following 10 steps:

1. Determining the function of the machine (the device).
2. Determine potential models of refusal.
3. Drawing up a list of likely consequences of the refusal.
4. Determining the significance (severity) of the consequences of the refusal (the claim).
5. Determine the intensity of failures (inconsistencies) over time.
6. Determination of the controllability and accessibility of the measurement and control methods related to localization of the non-compliance (refusal).
7. Calculation of RPN - risk priority number for consequences of non-compliance (refusal).
8. Determine the financial burden on the consumer after a claim (may include the manufacturer's financial burden of return for refinancing by the supplier, customization at the expense of the supplier or only administrative financial penalty for the manufacturer.
9. Take action to prevent or reduce the risk of the refusal.
10. Calculation of RPN after actions taken [1].

It is essential to note that any refusal can have different consequences and with a different level of severity. Based on this, an individual assessment should be given - Table №1, depending on the extent of the consequences of the respective refusal.

Based on the database, the intensity of occurrence of failures is determined. When these are not available or are extremely insufficient, the probability of occurrence of failures based on the methods and means used in the theory should be predicted - №2.

TABLE I

The meaning of the refusal S	
Evaluation	Significance
1	No functional and visual effect
2	Very small (visual effect determined by measuring the thickness of the paint)
3	Small (visual effect visible on the naked eye)
4;5;6;	Medium (Impossibility to install the product)
7;8	High (failure can lead to injuries)
9;10	Very high (failure can lead to fatal outcome)

TABLE II

Intensity of occurrence O	
Evaluation	Significance
1	There is no evidence of such failures
2;3	Weak (new refusals / complaints)
4;5;6;	Average (rarely recurring claims)
7;8	High (repeat refusal)
9;10	Very high (the claim is almost inevitable)

The assessment of determining causality links for occurrence and localization of rejection is largely determined by the availability, availability and availability of the relevant metrological equipment - Table №3.

TABLE III

Detection rate D	
Evaluation	Significance
1	Almost unknown
2	Easily discoverable (no fitting)
3	Moderate difficulty (with conventional SI)
4;5;6	Increased difficulty (with nonstandard metrological equipment)
7;8;9	Hardly detectable (No required method available
10	It is necessary to implement an innovative method of mod. and control

The determination of RPN (risk priority number) is calculated:

$$RPN = S*O*D \tag{1}$$

Where there are estimates of the importance of the refusal (the burden on the consumer);
O - Intensity for the occurrence of the rejection (probability or frequency of the refusal);
D - Detection of the reason for the refusal (The degree of detection of the non-compliance), it is essential, each FMEA method is different.

That is why we will use a specific item of the customer with a detailed data collection in the years of manufacture of the product shown in Fig. 1 common type, namely the "Arrow telescopic inner" for a corporate client.

The analysis of the attached tables shows that the highest intensity of the complaints is observed in the control of the qualitative indicators, which can not be done with the available or conventional metrological support.

FIGURE I

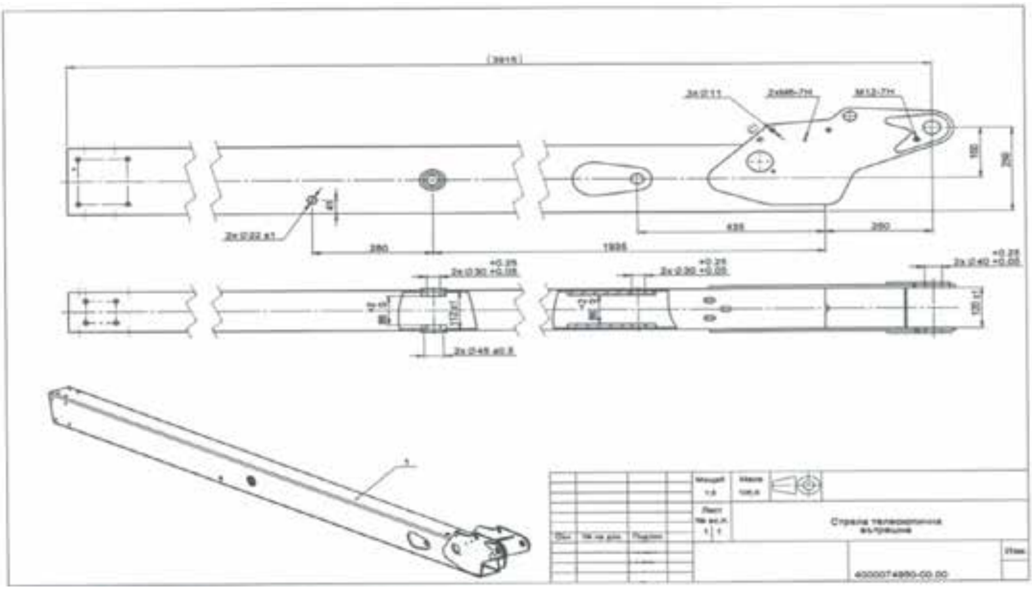

TABLE IV

List of product deviations from the customer's design documentation. Arrow Telescopic Inner (Atlantis Inner) Drawing № 4000074951.														
Inconsistencies in details, in sub-assemblies or in whole article:														
№	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	*Detail / Product*	*Clearance number*	*Size, requirement*	*Under Construction Documentation*	*S*	*Filled*	*Tolerance*	*O*	*Consequence of non-compliance*	*D*	*RPN*	*Corrective measure / corrective technology (action)*	*Execution process*	*Date of appearance*
2	Page set right	4000074951-01.00	Flatness requirement	0,5	6	1,3	0,5	4	Unable to mount.	3	72	Correction technology. Included upright operation.	LAG / MAG welding	24.2.2016
3	Page set right	4000074951-04.00	Flatness requirement	0,5	6	1,5	0,5	4	Unable to mount.	3	72	Correction technology. Included upright operation.	LAG / MAG welding	3.3.2016
4	Arrow	4000074951	Size 395 of the CS	395	6	415	(-2/+2)	5	Unable to install a power double acting hydraulic cylinder.	6	180	Designed and implemented a linear size control template.	LAG / MAG welding	14.7.2016
5	Arrow	4000074951	Size 40 of a common type of CS	40	7	20	(-2/+2)	5	Strength in the cross section of the opening	4	140	Recalculated control size entered 435	LAG / MAG welding	25.10.2016
6	Arrow	4000074951	Size 86 of the general appearance of the CS	86	6	82	(-0/+2)	5	Unable to install a power double acting hydraulic cylinder.	6	180	A linear calibration line is developed and implemented.	LAG / MAG welding	27.2.2017
7	Arrow	4000074951	Size 120 of the general appearance of CS	120	6	110	(-/+1)	2	Installation impossibility.	3	36	To be guaranteed by a snap and welding device.	LAG / MAG welding	26.5.2017
8	Arrow	4000074951	Size 74 of a common type of CS	74	9	76	ϕ2 from positional tolerance to bases A and C (- / + 1).	4	Unable to install the switch.	6	216	Change of technology.	mechanical processing	13.7.2017
9	Arrow	4000074951	Size 112 of the common type of CS	112	9	114	(-/+1)	3	Unable to mount the safety rings in the spindle of the spindle.	3	81	Self-control by the operator.	mechanical processing	30.10.2017
10	Arrow	4000074951	Size 60 of a common type of CS	60	6	64	(-2/+2)	7	Unable to mount in the outer boom.	3	126	Designed and implemented template to control the size of the weld.	LAG / MAG welding	6.11.2017
11	Arrow	4000074951	Visual evaluation.		5	Следи по повърхността на материала на поз. 1 от ЧС	From standard BDS EN 9013-231	4	Defects of the material on the surface of sheet steel.	5	100	Scheduled maintenance.	Thermal nesting (gas cutter)	14.5.2018
12	Arrow	4000074951	M6-7H	Max ϕ5,153	4	ϕ5,62	min ϕ4,917; max ϕ5,153	5	Poor appearance of the screw line.	3	60	Self-control by the operator through threaded caliber control.	mechanical processing	
13	Arrow	4000074951	Visual evaluation.		10	С подрези на ЗШ	From standard BDS EN 13920 BF	5	Reduced strength characteristics of the welding joint.	3	150	Check the power of the welding current according to the thickness of the sheet material.	LAG / MAG welding	
14	Plane inside	4000074951-00.07	Visual evaluation.	a 3,5	10	С несплавяване на ЗШ	From standard BDS EN 13920 BF. Non-alloying of the additive to the base material is not allowed.	5	Reduced strength characteristics of the welding joint.	3	150	Refresher course of the welder.	LAG / MAG welding	
15	Arrow	4000074951	Size 30 of the common type of CS	ϕ30	6	ϕ31,0	ϕ30 (+0,05/+0,25)	2	Inability to mount the poly-graphite sleeve.	3	36	Replacing the fine cutting head.	mechanical processing	
16	Arrow	4000074951	Size 112 of the common type of CS	112	4	105	(-/+1)	2	Axial oscillation (clearance) when installing the safety rings in the spindle of the spindle.	3	24	Self-control by the operator.	mechanical processing	
17	Arrow	4000074951	Size 60 of a common type of CS	ϕ60	6	ϕ70,80	(-/+1)	6	Unable to mount in the outer boom.	3	108	Included in the MD's Prototype technology.	mechanical processing	
18	Arrow	4000074951	Visual evaluation.	Satisfactory appearance .	4	Следи по повърхността на материала на поз. 6 от ЧС	BDS EN 10025	8	Defects of the material on the surface of sheet steel.	5	160	Precipitation of lead materials. Notified Deliveries department.	Input control	

IV. CONCLUSIONS

The above requires a differentiated approach to selecting a quality improvement strategy, a strategy to stabilize production processes and introducing a new effective metrological method with the necessary tools for quality control. From the risk number (RPN) it can be concluded that the large-dimensional discrepancies, which require sufficient measurement accuracy, are the most risky. Secondly, there are the inconsistencies concerning the shape of the tube for the article and its functional suitability. It is recommended to introduce the Photogrammetric method for control and measurement in heavy machinery. By means of which, a large part of the metrological difficulties, having a high potential value for customer complaints, will be solved. For this purpose it is necessary to carry out further studies on the required budget and others.

The use of the FMEA methodology in improving the quality of production produces a reduction in the occurrence of complaints, which improves the company's performance in the implementation of the QMS.

V. LITERATURE REVIEW

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The manifestation of synergy in management and social sciences, and methods for measuring it

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***Abstract*— The article suggests the use of a systematic approach in management by using well-known management schools and areas of achievement at the same time. The article touches on the essence of the concept of synergy, and that synergy exists only in such a system that performs its functions. On its basis, a hypothesis has been proposed for identifying synergy, and in the processes themselves a systematic approach has been proposed to identify phenomena such as synergy. It is proposed that the source of synergy might be "entropy". The author of the article indicates that processes take place in any activity of a human beings and society, such as the humanities, social and economic sciences, which implies the existence of entropy, which is very similar to the theory of transactions and transaction costs. This approach is necessary for the application of budgeting and financial relations for individual entities and as well as the whole state.**

Keywords—schools of management systematic approach, synergy, synergy effect, entropy, process, transactions, transaction costs

I. INTRODUCTION

At the present stage of management development, in most scientific literature on economics and management, it is defined as an effective way to achieve the set goal for the organization through the rational use of all available resources. In purpose of this, various methods have been developed and proposed in order to increase the "efficiency" of the organization in the conditions of a market form of management. So, the founders of the school of scientific management, F. Taylor, spouses F. and L. Gilbert and others believe that the use of such activities as measurements, observation, logic and analysis, using appropriate people appropriate to a particular situation, allows to improve a fairly wide range of operations manual labor, allowing you to use it more efficiently.

The first phase of the scientific management methodology was the analysis of the content of the work and the determination of its basic elements (1), which was based on obtaining more detailed information about the work operation that allows eliminating unproductive movements on standard procedures and equipment that increase the efficiency of work at a particular workplace.

The great achievement of this school was the establishment of real production standards, in which it was possible to assess the intensity of the workload of workers. In this case, the employee overfulfillment of these norms provided for additional payment. Thus, this school made the main emphasis in its research on production management. This allowed F. Taylor to formulate well-known principles of labor organization.

Administrative or classical schools of management were seen as a source of increasing efficiency in managing the whole organization. The founder of this school is A. Fayol, who saw the source of increasing the effectiveness of the organization in determining the characteristics and patterns of development of the organization. Representatives of the classical school of management suggested that the creation of universal management principles could lead to success.

These principles affect two aspects: the development of a rational organization management system, which suggests an optimal way of dividing into work groups, such as: production, marketing, finance, etc .; and the construction of an optimal organizational structure for the organization and management of employees, in which A. Fayol formulated 14 management principles that are relevant at the present stage of the development of management science.

The objective reasons for the emergence of the school of the psychology of human relations and social systems were the inability to fully recognize the human factor as the main element of the organization's effectiveness (2). Thus, this school was based on the achievements of such sciences, the study of which is man and society: psychology and sociology.

All this served the start of the new school of "human relations." The founder of this school is E. Mayo, who discovered that the developed clear operations and high wages do not always lead to higher labor productivity, the employee is not more responsive to pressure from the direct supervisor, but to his colleagues in the group.

The school of human relations emphasized the importance of informal ties between the individual in production. This allowed us to consider such areas as the motives of human activity in the labor process. All this made it possible to develop recommendations for collective decision-making, for the participation of workers in management, and for the ways and methods of continuing education for workers. Also in the field of view of this school were the problems of relations between people in the production process, the delegation of authority of leaders and a number of administrative issues.

The main achievement of this school was the discovery that behind the motives of certain actions of people are not economic incentives, but various needs that cannot be fully or partially satisfied with the help of high wages.

Thus, representatives of the psychological school suggested that if, managers show great concern to their employees, this will lead to the fact that the level of employee satisfaction will also begin to increase, which, in turn, will lead to increased productivity. All this served the use of such techniques in the management of human relations as: consulting with employees, providing them with more opportunities at work, etc.

II.

The introduction of computer technologies, communications, etc. in the sphere of management, highlighted quantitative approaches to solving managerial problems. There was an increased need for accurate answers to production and economic questions: how to rationally distribute the enterprise's resources (equipment, raw materials, labor, time, finances) in order to achieve the organization's goals. This situation required accurate estimates, which led to the need for mathematical methods for their calculation.

This situation required the development by scientists from different countries of a new area of applied mathematics, the so-called "Methods of research operations." This contributed to the emergence of such a problem as the quantitative justification of managerial decisions made in various sectors of social activity. Such a problem in relation to economic activity was called as economic-mathematical methods.

Economic and mathematical methods have found their practical application in inventory management; resource allocation; mass service; network planning and the search for optimal solutions using linear, nonlinear and dynamic programming methods.

The management schools proposed above substantiate the importance of applying each aspect of the impact on the employee in management, but, in our opinion, they cannot give an objective assessment or measure how the use of any so-called "tools" proposed by various management schools can lead to any systematic the end result. Since objective reality seems to be the existence of the proposed various management theories in aggregate, all concepts of management schools cannot exist separately. We assume that for the further development of management theory, it is necessary to combine all the achievements of the above schools of management and consider their actions together, since all the management tools of the schools presented cannot exist separately in reality.

The organization of all the proposed methods and tools for influencing an employee of different management schools is used in conjunction; each method of influence cannot exist separately. Thus, we can say that it will be much more convenient to apply a systematic approach to management in determining synergy in it.

The word synergy is Greek (sinergeia - cooperation, commonwealth) and denotes a specific variant of the body's response to the action of two or more medicinal substances, characterized by the fact that such an action exceeds the action exerted by each component individually (3).

The word "synergy" and "synergistic effect" (from the Greek. Sinergos - together acting) in scientific works on economics means as a principle provision for increasing the economic effect as a result of the joint use of individual elements of the system, which may imply connections or merging within the system in practice, such a phenomenon in the economic literature is called emergence.

The discoverer of the phenomenon of synergy as a phenomenon manifesting itself in the system itself is generally accepted by I. Ansoff in the 60s. XX c. The above term for explaining "the phenomenon when income from own use of resources exceeds the sum of income from using the same resources separately, is often called the effect of "2 + 2 = 5", taking from the natural sciences as biology called it as "synergism" (4).

Synergy is the effect of the interaction of interconnected elements in the system. Hence, synergy is obtained in the form of a synergistic effect within the system itself. This means that the effect obtained by simply expanding the economies of scale at the concentration of production (due to reductions in fixed costs) is incorrectly attributed to synergy. I. Ansoff, explaining the synergy, divided it into two components: cost optimization and productivity improvement.

By objective necessity, we can talk about synergy only if the system performs its own functions designed for it. In the scientific literature, the concept of a system is classified as: simple, open, closed, conservative, dissipative, linear, non-linear, etc. (5).

As we know, there are dozens of different definitions of the concept of "system" in the world. Thus, L. von Bertalanffy defines a system as a complex of interacting components (6).

He also writes that the system is a set of elements that are in certain relations with each other and with the environment (7). A system is a set of interconnected elements, separated from the environment and interacting with it as a whole (8).

Synergy can be represented as a property of a system that arises as a result of the interaction of system elements. This leads to the fact that we can only say that synergy is not characteristic of any system, but takes place in the very processes of interaction of elements within the system. Accordingly, we can say that synergy is due to the existence in the system itself, which arises in the process of interaction of system elements. Therefore, systems do not need to be associated with synergy at all.

The process determines the practical embodiment of the theory into practical applications, which characterizes the phenomenon during the interaction of system elements, without which it seems impossible to quantify the synergy, respectively the synergistic effect.

The process itself can be scientifically explained in detail by the methodology proposed by IDEF0 (Integrated Definition Function Modeling), authored by Douglas Ross, which was developed in 1973. This methodology was designed to cover the emerging needs for the analysis of heterogeneous methods of interactions of individual processes. This technique describes in more detail and explains the essence of the constituent elements of any process that has received public recognition and is accepted in the United States as federal. Such a methodology revealing the essence and content, as well as clearly explaining the process, can be a source of successful application in various humanitarian and social sciences, such as: political science, psychology, sociology, economics, jurisprudence, etc. Currently, the IDEF0 methodology is widely used by researchers not only in the United States, but throughout the world (9).

We will try to demonstrate the very essence of the IDEF0 methodology, in it the process is presented as: the process of transition of the trends of the "Input" to "Output" transition, with the influence of the "Management" tool using the tools that are presented as the "Mechanism". Graphic notation of the process in the modeling (10) system is presented in Fig. 1. (11)

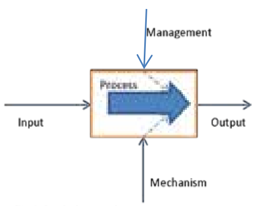
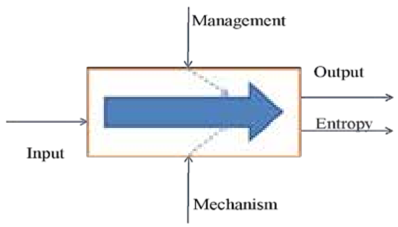


Fig. 1. Standard process diagram

As can be seen in Fig. 1, the process can be represented as a rectangle, the beginning of which is the "Input" arrow from the left, the top is represented by the "Management" arrow, the bottom is represented by the "Mechanism" arrow, the process ends with the "Output" arrow presented to the right. In the presented model, the arrow "Input" means all the initial data in the aggregate included in the process for changing them in it, therefore, "Input" is the initial state of the system itself. Under the arrow called "Output", you can imagine the converted product, through the interaction of a heterogeneous process leaving. "Management" can be presented as a component of the process, representing the human impact on the very interaction of the elements of the system. And finally, under the "Mechanism" arrow, we can mean an instrument of influence by influencing process controls. Mechanisms are those resources that cannot be transferred to the "Output", but create the necessary conditions for the process of transformation (like a catalyst in chemistry). The most important element of the process can be considered the life cycle of the process, which is shown by an arrow in the rectangle. It is in the process of the

life cycle that is an algorithm or sequence of effects of process elements with other components and how the transition of the input to the output itself, through the impact of "Management" as a person, and using resources - the "Mechanism".
The transformation of "Input" into the total desired "Output" in society and the economy can be called a process.
Development in the context of the totality of the desired changes in the economy and society, began to be seen as a process (12).
The special model of the process approach given in our article makes it possible to demonstrate the differentiation of the process itself into its components - subprocesses.The whole set of classified systems can be characterized by the description of one or several processes existing in any system. Objectively, it can be argued that when converting "input" to "output" during the course of the processes that transform them, we can say that there are always any losses in the form of energy or matter in the life cycle and the elements themselves involved in the process. Thus, let us dwell on the losses, which we tried to clearly show as "entropy", which is an objective indicator that, in our opinion, will help to measure such losses, which are presented in Fig. 2. (13)



Like "synergy", the term "entropy" has a Greek origin (en, tropē - rotation, transformation). In 1865, the German physicist first introduced it into scientific circulation, who was subsequently one of the founders of thermodynamics and the molecular-kinetic theory of heat, Rudalf Klausius (14). He discovered that all matter has the property of losing energy, i.e. the process of energy absorption by matter is proportional to the state of the "internal property" of the system under study.
Consequently, "entropy" means the objective depreciation of energy as a measure of its loss, "dispersion" into the environment, etc. In our opinion, the "internal property" can be understood as the processes themselves in the tendencies of the interaction of elements in the process of a system. Therefore, it can be stated that "entropy" exists in every component element of the process (input, output, management, mechanism), as well as in the process life cycle itself. For simplicity, we cited it as a parallel exit from the process.
Therefore, it can be asserted with certainty that in objective reality there cannot be processes with a 100% useful action. "Entropy" can be characterized as an additional result of the action of individual elements of the system or a parallel process, which cannot be determined by individual elements of each system.
Thus, "entropy" can exist both on "input", "management", "mechanism" and on the life cycle of the process itself. The appearance of a synergistic effect can be explained by the fact that the "entropy" decreases, i.e. individual elements in the system, in the process of interaction and its life cycle, tend to zero. This, in turn, leads to an increase in an additional useful output - synergy.
So, the objective reality of the law of conservation of energy and mass, says that synergy cannot come from nowhere, which means, in our opinion, it is formed together with "entropy" in the very processes occurring in systems.
Therefore, synergy arises from the utilization of "entropy" by absorbed system elements during their interaction and by the process itself, the elements of which can be "input", "management", "mechanism" and "output". We can conclude that synergy can occur only when utilization of the entropy of jointly acting processes simultaneously and alternately in the system itself. So, we were able to clearly identify the existence of such a phenomenon as synergy. The problems of synergy manifestations also exist in the so-called humanitarian and social sciences. If we assume that all of the above sciences are related to human activity, which means that society as a whole consists of an individual person, then any human activity is accompanied by economic categories, such as the costs of carrying out activities and income, characterizing the receipt of benefits.
O.V. Rybakova uses the following approach to determining costs: Costs are a cost expression of the value of economic resources when a corporation takes any actions (15), which science itself is also pursuing management. She also refers to costs as losses, defining it as the costs of the organization that did not generate income or led to losses (16).
So entropy in the humanities and social sciences, we believe, can be equated with economic categories as costs, presented in the form of cost reduction, while increasing the result, presented in the form of an economic category - income. Since entropy is the absorption of energies by individual elements of the system in the process of their interaction with each other, we can assume this as economic losses in the form of the costs of interaction of the elements of the system, and synergy as the benefits received from such interaction in the form of additional income.
A certain difficulty is presented in the classification of so-called "entropy" costs. For this, we believe that it is necessary to go over to the theory of "transactional" costs proposed by the American economist, Nobel Prize laureate R. Coase, to explain these types of costs. This concept refers to the process of transfer or reproduction of property rights. The term "transaction" is close to this, in which the ownership right is changed or transferred to one or another business entity. In this case, the transaction covers more social and economic phenomena, which should be given using the classification of the transaction proposed by J. Commons, who defined it in three possible forms:
1. bargaining transaction: the transfer of ownership takes place on the basis of a voluntary agreement of the parties, here there is a coincidence of the concepts of "transaction" with a negotiated transaction;
2. managerial transaction: the transfer of ownership occurs in the case of directives of one person and subordination to another, for example, the manager's attitude to the executor;
3. rationing transaction: the transfer of ownership is transferred by a team that is given by a collective body, and submission comes from individuals, a similar relationship is observed between the state and the population;
Transactional costs can be understood, in the aggregate of definitions, as costs in defense of property rights. Also in the scientific literature we can find a definition of transaction costs, as the costs of using the market mechanism or as the costs associated with the conclusion of transactions.
In classical physics, it was believed that when moving objects, the friction force does not significantly affect the result of the movement, but the use of friction force with an increase in the physical effect on the result has not been invented in science. Thus, we can say that "entropy" has the same meaning as the force of friction, which did not come under the scrutiny of economists. The same assumption is made in non-classical theory, where the movement of economic objects, i.e. ownership rights occurs with zero friction, i.e. free of charge. Thus, we can see that the theory of transaction costs, as it tells of the existence of entropy in social, political and economic relations. But due to the fact that it is not possible to measure these costs, it does not find the popularity of their practical application. On the basis of our hypothesis, entropy occurs during the functioning of the system, both during the interaction of the processes of the system and the course of economic activity itself.

Consider system processes in management. Human economic activity ensures survival in the natural environment, mainly acquires an economic nature, which is the basis and creates the conditions for political, legal, social and managerial human activity.
So using the process of rationalization of available resources in management, the organization achieves an increase in labor productivity, as a result, the number of manufactured products increases at constant production costs. This leads to an increase in income, and subsequently, in profit, all other things being equal. By creating a rational organization management system, the so-called "control costs" are reduced, which also reduces economic losses, which can manifest themselves as production costs, which suggests increasing the company's profitability in the country's financial market. Increasing the atmosphere of an organization's "cosiness" in a individual's work can also increase the organization's "corporate spirit", leading to an increase in the economies of scale from available resources, which also leads to an increase in profitability and company's reputation, etc. The use of mathematical methods in inventory management; resource allocation; mass service; network planning and the search for optimal solutions by using linear, non-linear and dynamic programming methods, the organization also eliminates downtime, unjustified losses manifesting in additional unforeseen expenses of the organization, which also lead to increased profitability of the organization.
There is a cascade of synergy, in the management concepts above. First, the instruments of the schools of scientific management are used, then the instruments of the classical school, after applying the concepts of the school of human relations. And finally, the application of the achievements of the quantitative school increases all social, political indicators, and the most important they are confirmed by economic indicators.
In nature, such a combination of processes is practically not feasible, it is only possible when managing individual processes by a human based on synergy. For example, managing an orchestra with the help of a person who is a conductor. Achieving consistency in the sound of a huge number of instruments in the form of an orchestra involves reducing the entropy (inaccuracy, inconsistency, errors) of each participant. It can also include coordination of all functional departments of the corporation, which will lead to the above described effect. For this, a synergy process is used, the producer of which is the manager, and according to the established system of plans, he addresses each functional structure, or even each employee, leading to a decrease in entropy in production systems and processes, the result of which is to obtain a synergistic effect - synchronous interaction of all processes production and system elements at the same time.
Thus, all the practical activities of a human being, such as social, political, legal and economic, are associated with obtaining and using synergy, which in any case provides a positive effect and improvements in living conditions. Therefore, we can say that the skillful coordination of all social, political, legal and economic areas of human activity combines, embraces, and can synchronize industrial management. We believe that the synergistic effect is clearly manifested in their joint and joint participation of the individual elements of the system among themselves, which can be estimated by economic categories as costs and profitability.
All economic activities of society are associated with the formation, production and rational use of available resources. Economists equate or see resources in terms of commodity-money relations as money. The transfer of ownership rights, in these conditions, is associated with financial flows, i.e. cash payments are directed to owners of property rights, while owners receive financial responsibility to fulfill their obligations. In this case, the disclosure of synergy issues in the field of budget formation and execution as separate economic entities and the whole state becomes especially relevant.

Conclusion
Based on the research, the following conclusions were obtained:
1. A hypothesis is proposed, which is based on the concept of a process in management, acting in the system and applying all the concepts of management schools at the same time, because in our opinion, each school is useful and the world is developing not one-sidedly, but comprehensively, and it is necessary to use the achievements of all management schools simultaneously to obtain a synergistic effect.
2. A process approach hypothesis was formed to explain the description as a source of the synergistic effect obtained within the system.
3. All practical human activity is based on certain processes, which means that the process approach introduces a new system of concepts that describes the movement of matter, as well as an explanation of the "postulate" theory of transaction costs based on the latter.
4. Using the developed functional model of processes in nature and the social, political and economic sciences, since processes exist in all of the listed sciences, it allows us to identify synergy and synergistic effect.
5. It is necessary to carry out additional checks of this hypothesis in the budgeting of business entities and a separate state, since the basis of human economic activity at the present stage is commodity-money relations involving financial flows and settlements between them.

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Exploration of the advantages and an algorithm for the implementation of the digital twin concept

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The paper presents a research into the concept of digital twins based on a virtual prototype and the advantages it has. Also presented are the inner workings of the digital twin method and the possible algorithms for implementing it in the manufacturing workflow. Additionally, software products that take care of that process by guiding the user and helping them to implement the vast quantities of data and the sensor data acquisition the needed components from the Internet of Things methodology.

Presented are the summarized advantages and reasons for implementing the digital twin methodology.

Keywords: Digital Twins, CAE, IoT, Industry 4.0

I. INTRODUCTION

With the massive integration of intelligent systems and the industrialization of Internet of Things (IoT), a conceptual model has emerged that has become an intersection between them and the concept of Digital twin.

In essence, the Digital twin is informationally linked to a specific physical object and is built based on systems for modeling and simulation technologies which are essential for supporting the engineering cycle into a loop enclosed into an interconnected cyber-physical system.

There are many definitions mentioned in the literature for the Digital twin concept. Some of them include the following:

- The Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin. [1]
- Coupled model of the real machine that operates in the cloud platform and simulates the health condition with an integrated knowledge from both data driven analytical algorithms as well as other available physical knowledge [2]
- The digital twin is a real mapping of all components in the product life cycle using physical data, virtual data and interaction data between them. [3]
- The digital twin is a dynamic virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning and reasoning. [4]
- Using a digital copy of the physical system to perform real-time optimization [5]
- A digital twin is a digital replica of a living or non-living physical entity. By bridging the physical and the virtual world, data is transmitted seamlessly allowing the virtual entity to exist simultaneously with the physical entity. [6]

It is easy to see that there are many and very different definitions of the Digital Twin concept, which can lead to confusion towards the concept as a whole. This in turn demonstrates the novelty and the relatively early stage of the concept development which is currently in a stage of strong innovation. These innovations are expected to continue between 5 and 10 years before the expected slowdown in development. [7]

The development concerns the presentation of the advantages and an exemplary algorithm for the implementation of the concept of Digital Twins.

II. NATURE AND APPLICATION OF THE DIGITAL TWINS CONCEPT

The concept of a digital twin finds its application in situations where a physically working product can bring more useful information than existing virtual prototypes while using the Internet of Things as a communication medium between the twin and the real object. This is a very valuable feature of the digital twin, especially when it comes to complexity in determining the load on the construction in an analytical way. [8]

The transfer of traditional mechanical products to a new generation of products with built-in connectivity and intelligence is new and therefore unknown to the industry. Solving problems through physical prototyping is a classic solution for mechanical system issues and has its place. In turn, virtual prototyping by product modeling and simulation is faster in reaching a good result in the prototyping process compared to physical prototyping [9]. This approach has an even greater advantage in the use of Intelligent Systems and IoT platforms.

Based on the study, it is necessary to precisely define the differences between the virtual prototype and the digital twin because of the apparent similarities between them. The main differences are described as follows:

- **The virtual prototype is an information and simulation "duplicate" but for a nominal physical object, thus not taking into account the specific features of the specific physical object. In addition, the virtual prototype is used and generates information for the product in an abstract rather than real time.**
- **The digital twin is not an abstract information and simulation "duplicate" of a nominal physical object, but is specific and individual to the physical**

object in question. In this way, it takes into account its specific features and is specific to it.

- **The digital twin also includes the real time parameter – that is, it collects data about the behavior of the physical object with respect to time in an informational database that is an integral part of the twin. These data are obtained through a built-in sensor system by feedback to the digital twin, measuring the values for important parameters. These measurements are not only under certain conditions, but also a function of time.**

III. An approach to building a Digital Twin on the basis of a physical prototype

An intelligent integrated digital twin product development approach that is linked to the Internet of Things (IoT) platform can be addressed by building a partial or full physical prototype. Once it is built, a sensor system is integrated on it and that system needs to be connected to an IoT platform that is responsible for collecting and processing the measured data. The processed data should be translated into a usable format for the digital twin, thus generating large amounts of data on the behavior of the physical prototype and being compared to a virtual prototype in order to improve it.

In the case of digital twins based on a physical prototype, there are limitations on the experiments due to the possibility of destruction of the physical prototype, limitation of the sensor's positioning due to lack of space or impossibility of attachment, electromagnetic, vibrational or other disturbances. Particular attention should be paid to electromagnetic fields due to the possibility of interfering the communication between the sensor and the Digital Twin. This determines the careful determination of these parameters.

An example of a cycle of building a Digital Twin is proposed by ANSYS for their ANSYS TwinBuilder package and is shown in Fig. 1.

Fig. 1. Cycle for Creating and Integrating the Digital Twins Concept proposed by ANSYS

IV. Practical interpretation of a Digital Twin

Digital twins are widely used in connected and intelligent products and IoT platforms. They also further develop the functions of the virtual prototype.

This is done through the following approaches:

- **Implementation of the virtual prototype to predict the behavior of physical devices.** This option uses expert systems and artificial intelligence in combination with logical and mathematical algorithms to process and evaluate the data collected and their degree of influence on the investigated product by correlating against data from existing events. In such a way, it is possible to predict future behavior based on statistical data.
- **0D simulation** – the model may have no geometric dimension and is only functional. For these simulations, the only variable that is important for it is time. These simulation models are only used for functional verification of a system.
- **1D simulation** – these models are a combination of separate validated blocks that simulate the operation of multidisciplinary engineering systems in a certain one-dimensional direction (tracking and predicting the change of a given parameter). They can provide a deeper insight into the current work of the physical object by analyzing the possible changes to the product.
- **3D simulation** – these models are used to predict the structural and dynamic indicators of the studied products. [10] They have the opportunity to gain in-depth knowledge of the current operation of the product as well as to study the behavior of the product in difficult reproducible and unfavorable working modes of the product in order to improve or prevent failure of the product.
- For digital twins based on engineering simulations with a virtual prototype and in the absence of a physical one, there is an opportunity to accumulate knowledge about the abstract behavior of the virtual prototype in different conditions. In the absence of a physical prototype that feeds the virtual one with data and transforms it into a complete digital twin, it remains at the virtual prototype level.
- With "historical" data derived from such products, virtual prototypes can be transformed into digital twins as there is information to feed the integrated digital twin database.

V. An algorithm for the integration of the concept of Digital Twins with the help of ANSYS TwinBuilder

Based on the capabilities provided by ANSYS TwinBuilder, a methodology has been developed for their implementation. ANSYS TwinBuilder is a special module designed to facilitate the implementation and use of digital twins by providing different languages and development domains. This way, a very high level of abstraction can be achieved to precisely build the digital twin. Some of these languages and domains are as follows:

- Multi-Domain Systems
- Co-Simulation
- Block Diagrams
- Circuits
- Test Data
- Reduced-Order Models – Example from 3D to 1D simulation
- Digital/Mixed-Signal
- C-Code, FMU, VHDL-AMS, Modelica, etc.

In addition, ANSYS Twin Builder allows the use of 0D simulation models as part of the digital twin with the help of built-in dedicated libraries for modeling control, hydraulic, mechanical, digital, electrical, power, manufacturing, automotive, aerospace and other systems that are interconnected.

Based on the rich toolset of the software, an algorithm for digital twinning is proposed. This algorithm is shown in Fig. 2 and is explained in detail below.

- **Stage 1: Creating a Virtual Computing Model of the Product.** At this stage, a multiphysical or a physical model of the product may be created depending on the digital twin's desire for detail.
- **Stage 2: Creation of a Reduced-Order Model** At this stage, a simplified model is created based on created functional surfaces describing its behavior. The goal of this reduced-order model is to reduce the occupied computing space, as well as speeding up the computing process. Of course, this is achieved as an optimum between the calculation time and satisfactory data accuracy.
- **Stage 3: Defining the input parameters for the Reduced-Order Model.** At this stage it is selected which input parameters are important to the model. An example of such data may be the magnitude of the current for an electric asynchronous motor.
- **Stage 4: Defining the input parameters for the Reduced-Order Model.** Similar to Stage 3, the output parameters relevant to the digital twin are selected here. Continuing with the example for an electric asynchronous motor such data can be the magnitude of the torque and the maximum engine operating temperature.
- **Stage 5: Using test data for the input parameters.** At this stage, input parameters from pre-collected real-time data are used to duplicate its behavior and are fed to the input parameters of the Reduced-Order model.
- **Stage 6: Executing a system simulation of the product.** In this stage, the input parameters are calculated based on the values of the output parameters for the digital twin. These calculations are based on the approximate values of the calculated response surfaces.
- **Stage 7: Processing the calculated output data.** At this stage, based on the output parameters, an overall assessment of the monitored product data is made – in the case of an asynchronous electric motor this can be the calculated life of the product.
- **Stage 8: Generating of the digital twin.** After the results are obtained, ANSYS TwinBuilder provides the opportunity to create a digital twin model based on the performed system simulations.

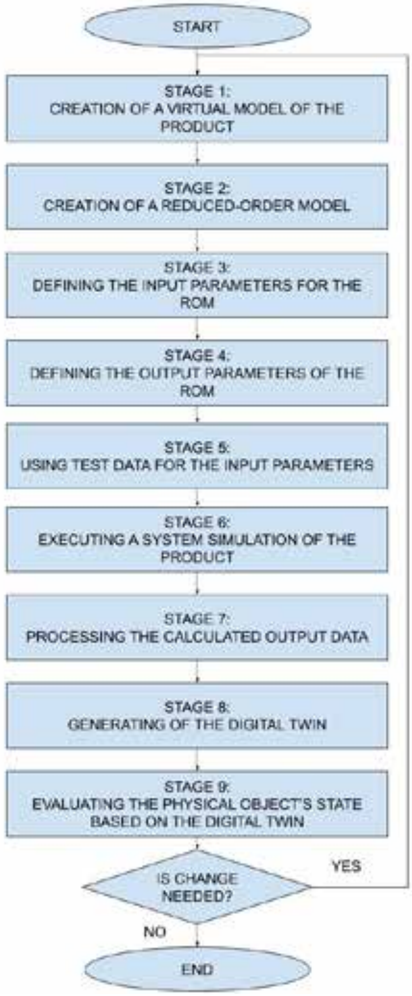

Fig. 2. Suggested algorithm for implementation of the Digital Twin concept using ANSYS Twin Builder

- **Stage 9: Evaluating the physical object's state based on the digital twin.** At this stage, an actual product can be evaluated, even if it is remotely placed. In this way, the operating modes and the wear of hard-to-reach objects can be assessed. An example of such an object is an electric wind turbine in the ocean.

If an adjustment to the operating modes or the product itself for future items is needed, it is necessary to repeat the evaluation stage. However, if the results from the taken steps are satisfactory, the cycle is closed.

VI. CONCLUSIONS

The advantages and application of digital twins are presented in the modern conditions of a highly modernized industry, which uses technologies from Internet of Things to achieve intelligent connected systems.

The set of previous definitions of a Digital Twins is outlined and a new one is proposed that differentiates it from virtual prototypes. An algorithm for the implementation of a digital twin is also proposed using the ANSYS TwinBuilder software module. The result of the study is the determination of Digital Twins and their place in terms of Industry 4.0.

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