Automation is an Effective Way to Improve Quality of Verification (Calibration) of Measuring Instruments

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Abstract. In order to assess calibration reliability and automate such assessment, procedures for data collection and simulation study of thermal imager calibration procedure have been elaborated. The existing calibration techniques do not always provide high reliability. A new method for analyzing the existing calibration techniques and developing new efficient ones has been suggested and tested. A type of software has been studied that allows generating instrument calibration reports automatically, monitoring their proper configuration, processing measurement results and assessing instrument validity. The use of such software allows reducing man-hours spent on finalization of calibration data 2 to 5 times and eliminating a whole set of typical operator errors.

1. Introduction
Instrument calibration is the key method of governmental control to ensure uniformity of measurements. The purpose of such calibration is to establish whether a specific instrument does or does not comply with a given set of parameters. In order to ensure calibration efficiency and quality, two tasks need to be resolved [1,2].

First, efficient calibration techniques for specific instruments need to be developed that ensure the required level of calibration reliability at a minimal cost. Such task normally comes down to selecting reference templates and fine-tuning the calibration procedure (namely, selecting the metrological characteristics to be monitored during calibration), provided calibration reliability is high. Second, calibration technicians must be highly qualified and productive.

2. Goal setting
Calibration method quality is defined by its reliability, i.e. the probability of false recognition of a defective instrument to be valid (second type calibration error) or false recognition of a valid instrument to be invalid (first type calibration error). However, calibration reliability indicators are unknown for most existing methods. There are methods that vary greatly across groups of instruments with similar properties. For example, calibration of Fluke 572 infrared thermometers is executed in 22 points within the testing range, whereas that of Fluke 572-2 with identical metrological characteristics is executed in 5 points. In a number of cases, the same method is applied to verify instruments with...
different technical characteristics. The goal is to study the possibility to improve the efficiency of instrument calibration by substantiating the number of calibration points, standardizing test conditions and accuracy requirements applied to reference samples. High quality and labor productivity of calibration technicians are provided by automating test result processing.

3. Achievement methods
The goal of assessing calibration reliability can be resolved by simulation modeling of the calibration procedure [1,2]. Calibration reliability criteria include: manufacturer risk \( R_p \), customer risk \( R_z \), likelihood of first \( P_1 \) and second \( P_2 \) type error, likelihood of any incorrect decision \( P_n \). In order to assess reliability, one needs to build a stochastic instrument tolerance model, assess accuracy of measurements taken during calibration, carry out modeling, and analyze the results. Generation of a representative sample requires a few hundred same-type instruments to be available and significant costs to arrange field research. Therefore, using the available instrument calibration data is feasible.

Available EDM systems would not ensure the required level of calibration data processing automation. For this reason, proprietary instrument calibration data processing software has been developed. The software stores data on metrological characteristics of more than 3,500 types of instruments and allows generating reports in accordance with calibration method specifications, selecting reference samples and monitoring their on-schedule calibration. Also allows monitoring compliance of calibration specifications with regulatory standards, making sure reports are filled out completely, performing calculations, assessing compliance of calibration results with established requirements, generating output documents, preparing necessary reports on the tasks completed, storing and recording the results of all the tasks completed.

The software represents a set of 23 OpenOffice.Calc 3.2.1 files developed based on [3,4]. Each file contains data on a specific instrument type and has a universal structure comprising a basic package of work sheets.

‘Catalogue’ sheet stores details on instruments, standard values of influence quantities, the list of control points, and the calibration standards. ‘Modules’ sheet presents data on metrological characteristics of additional measuring channels. ‘OSI’ sheet provides details on the reference samples applied.

‘Report’ sheet is the key work sheet. A report structure is set up as the name of instrument and the type of calibration are selected, all necessary details in ‘Catalogue’ being translated to ‘Report’. Necessary calculations are executed automatically as the report is being filled out. If any fields are left blank or filled out incorrectly or whenever the actual metrological characteristics do not comply with the established standards, a notification window shows up. A conclusion on instrument compliance with the established standards is prepared based on the calibration results.

‘Rep_1’, ‘Rep_2’, ‘Not_1’, ‘Not_2’, ‘Cert_1’ and ‘Cert_2’ sheets are used for printing both sides of calibration report, non-validity report and calibration certificate. The sheets are filled out automatically based on data entered in the ‘Report’ sheet. The other side of the calibration certificate shows calibration data and its uncertainty. As soon as processing is completed, all data is exported to ‘Archive’.

‘Archive’ sheet is used to store data and generate in-house reports: the summary of used calibration marks and output documentation templates and the metrological task record log. ‘Catalogue’ sheet is used for recording available calibration methods.

A uniform data storage format allows analyzing data promptly in order to assess calibration data reliability. Selection of theoretical distributions, verification of their compliance with observations and sorting out of errors are executed using statistical methods.

Calibration method research findings
Integration of the software allowed automating instrument calibration data processing, namely the measurement uncertainty calculation process. It allowed ensuring uniformity of how output documentation is finalized, storing calibration results in a space effective manner, and generating in-house reports. Application of the software allowed assessing reliability of pyrometer and thermal imager calibration data and developing recommendations on improving how the calibration methods.
The derived stochastic pyrometer and thermal imager error models have shown a strong positive correlation for two groups of calibration points (below and above ambient temperature). The results correlate with the non-contact temperature measurement principle and provide justification for revising the common rule that calibration points are distributed evenly within the test range. It appears feasible to calibrate these instruments at temperatures near the bottom measurement limit, close to ambient temperature, at the point of range relevant to a modified method of tolerance standardization (100 °C) and at temperatures close to the upper measurement limit.

Table 1 shows calibration data reliability indicators obtained by calibration procedure simulation modeling [2]. These have been calculated for the calibration of Testo 875 – 882 thermal imagers in six and four points of the test range. A first-category blackbody model was used as a reference template. The number of realizations during calculations was 4.8 x 10^6.

| Reliability indicator | Six calibration points (minus 20, plus 30, 100, 200, 280 and 350°C) | Four calibration points (minus 20, plus 30, 100 and 350°C) |
|------------------------|---------------------------------------------------------------------|-------------------------------------------------|
| Rp [%]                 | 6.3                                                                | 6.1                                             |
| Rz [%]                 | 4.1                                                                | 3.9                                             |
| P1 [%]                 | 8.3                                                                | 7.9                                             |
| P2 [%]                 | 12.1                                                               | 12.8                                            |
| Pn [%]                 | 9.3                                                                | 9.0                                             |

Table 1 reveals that the likelihood of false decisions during calibration Pn drops insignificantly (by 0.3%) as the number of calibration points decreases from 6 to 4. The results obtained prove that the number of calibration points can be reduced with negligible effect on calibration data reliability.

In order to eliminate the size-of-source effect impact, its distance to radiator and its aperture in calibration methods need to be standardized.

The impact of atmospheric transmission is dramatic for devices which spectral range includes strong water vapor absorption bands. During calibration of AKIP 9301 – 9303 infrared thermometers with spectral range of 5 to 14 µm, calibration data reliability indicators show the following values: Rp = 11.5%, Rz = 4.6%, P1 = 13.8%; P2 = 22%, Pn = 15.1%. Reduction of calibration outcome to nominal values of temperature and relative air humidity provides for the following values: Rp = 5.4%, Rz = 2.9%, P1 = 6.5%, P2 = 14.6%, Pn = 7.8%, which basically match the reliability indicators obtained using first-category reference samples. The suggested algorithm of bringing the measuring outcome to nominal values of influence quantities has been integrated in the software described.

The likelihood of any false decision for various types of infrared thermometers and thermal imagers varies from 8% to 24% [2]. Such values can hardly be accepted as satisfactory although they are formally not standardized in any of the calibration methods.

Expanded uncertainty of temperature reproduction by a first-category blackbody within the range from minus 50 to plus 200°C varies from 0.6°C to 0.9°C. Correlation of maximum permissible error...
limits and reference blackbody uncertainty within the specified range is from 1/1.3 to 1/2.2 for various types of verified instruments. This results in a high likelihood of control errors. Details on liquid thermostat blackbody models with temperature reproduction uncertainty within the specified range of 0.13°C to 0.34°C are provided in [6].

Inserts in the form of a blackbody model have been fabricated for fluid thermostats available at Novosibirsky CSM. The inside of the inserts is covered with paint of high emissivity (over 0.9). Effective emissivity has been calculated based on the diffuse interreflection theory [7, 8] using a trial version of SHEET 321 software [9]. The temperature difference of the coolant and the insert inside have been determined experimentally and considered in the temperature reproduction uncertainty budget.

Pre-trial outcome allows assessing the temperature reproduction uncertainty within the range from minus 50°C to 200°C with a value from 0.05°C to 0.36°C, which is 2.5 to 12 times lower than the first-category reference template uncertainty. In this case, Testo thermal imager calibration data reliability indicators will be $R_9 = 1.9\%$, $R_c = 1.4\%$, $P_1 = 2.5\%$, $P_2 = 4.3\%$, $P_n = 2.9\%$ (calibration in six points). It is 2.8 to 3.3 times less than the first-category reference template reliability indicators.

4. Conclusion
Integration of the software has allowed collecting research materials and reducing man-hours required to finalize the calibration data 2 to 5 times. In total, over 50 thousand of calibration reports have been prepared from 2010 through 2017, with over 8 thousand man-hours saved. The software cost efficiency has been evaluated at RUB 4.8 mln.

The research completed has allowed assessing calibration data reliability based on the existing methods. The possibility of reducing the number of calibration points within the test range has been justified for a few types of infrared thermometers and thermal imagers with hardly any higher risk of false calibration decisions. The impact of the size-of-source effect and atmospheric transmission on reliability indicators has been studied.

Liquid thermostat blackbody reference templates have been designed and fabricated. Recommendations have been provided to improve calibration methods for some types of heating instruments.

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