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Approach to Development Metrological Software Test for Verification Intelligent Instrumentation

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Abstract*: There is considered some methods of metrology testing of intelligent measurement systems. Also there is shown the necessity of simulation of components of measurement channel for investigation of the intelligent functions of the intelligent measurement systems in the accelerated time scale. Developed the metrology software test of temperature measurement channel using thermocouple. The results of measurement systems testing by the developed metrology software test are presented in this paper.*

Keywords: - Intelligent Measurement System, Metrology Software Test, Simulation Modeling

1. INTRODUCTION

Modern precision physical quantity measurement systems can be characterized by high accuracy of sensor's signal measurement. This accuracy is many times less than sensor's accuracy [1, 2, 3]. The conversion characteristic (CC) of measurement channel (MC) correction [4] cannot give long time accuracy of MC improvement because of the significant drift of the sensor's CC during exploitation. The methods of sensor error correction based on the drift prediction have low reliability in real measurement conditions. It is connected with individual character of drift and high random component of drift. The guarantied methods of accuracy improvement are based on periodical testing and calibrations have large laboriousness. Topical are methods based on fusion the indicated above methods. This fusion is provided by construction of the individual simulation models (ISM) of sensor error correction using results of testing and calibrations [5]. Systems, which adapt its properties to the operation conditions for providing the defined accuracy of measurement results are named as intelligent measurement systems (IMS). The high accuracy of prediction can significantly decrease the number of testing and calibration. So there are widely used methods of artificial intelligence for improving these methods (neural networks for example).

The precision IMS evaluate the metrology properties of its MC and properties of measurement objects. The purpose of the evaluation is providing the defined accuracy of each MC regardless the error of components of MC. As the result of evaluation IMS goal-seeking adapt the structure of hardware components of MC and change data processing algorithms to the measurement condition [6]. The IMS can significantly improve its adapting properties by self-training [7]. So as opposed to the traditional measurement systems the error of IMS can be decreased during exploitation [8]. The IMS evolution demands the development the adequate methods of metrology support. The goal-seeking adapting the hardware and software components provides analysis of different combination of components and finds the optimal configuration in real measurement condition. Therefore the metrology testing should include the phase, which should confirm the adequacy of decision making system about configuration of IMS functionality in different measurement condition taking into account properties of the components of MC [9].

The existed methods of metrology testing and error setting do not allow accentuating the considered above properties of IMS. It is obvious that experimental evaluation of the full set of metrology characteristics of IMS has very large laboriousness. Besides it the time of such testing is adequate to the life time of the IMS. Therefore it is necessary to make the main path of the metrology investigation by investigation of the simulation models of IMS or change some components of MC by simulation models. So it is necessary to make the great ammount of testing using the testing of the simulate model of the components of measurement channel. So it is necessary to develop the specialized software – the metrology software test (MST) [9, 10], which provide metrology IMS testing taking into consideration its properties. MST is assigned for the estimating of the metrology characteristics of the MC of measurement devices, especially IMS, on all phases of its life cycle: (i) development; (ii) first testing; (iii) periodical testing (on the operating place).

2. STRUCTURE OF THE METROLOGY SOFTWARE TESTS

The metrology testing process consists of two main parts: (i) determination of the MC reaction on the specified measurement and influence quantities; (ii) evaluation of the metrology characteristics of MC. During metrology testing therefore MST should provide fulfillment the following tasks:

- Forming the set of testing codes, which correspond to the output signals of all components of MC. It is necessary to overall simulation of the MC operation or step by step simulation the components of MC.
- Processing of measurement results obtained under the influence of the set of testing codes. The purpose of data processing by MST is evaluation of real metrology characteristics of MC, which should correspond to the defined method error of setting.

It is necessary to provide the fulfillment of indicated tasks in the accelerated time scale for decreasing time of metrology investigation. Therefore, set of testing codes should be made on the basis of physical time, which influence the changing of: (i) measurement and influence quantities; (ii) parameters of the components of MC. The output of testing codes should be done in accelerated time scale. The acceleration of time scale should not correspond the physical quantities, which are lockstep synchronized with physical time (noise for example).

Therefore using the functions of MST it is possible to form its structure. So MST should consist of three main parts:

1. Testing set forming routine. The formed testing set should correspond to the output signals of the components of MC; The purpose of this routine is building the full set of the test signals, which simulate the nominal CC of the components of MC as well as their error in measurement conditions and influence the influence quantities and noise on the CC of these elements. Later this test set as analog signal or digital code should go to the input of appropriate input of hardware module of the tested MC [9, 10]. In this case it is necessary to make the testing of the metrology characteristics of MC in simulation of the different measurement conditions of all components of MC. Therefore the testing set forming routine should correspond to the following criteria:
   - The structure of this program should correspond to the structure of tested MC;
   - The testing set forming routine should provide functions for simulating the nominal CC of all components of MC;
   - The testing set forming routine should provide functions for simulation of the influence of influence quantity on the nominal CC of each component of MC;
   - The testing set forming routine should have the user friendly interface for setting the measurement condition of IMS;

   It is logical to make the set of testing codes (including nominal values of physical quantity and time marks) as records of database.
2. Routine, which provide connection with measurement device. This routine should provide the following: (i) transmitting the testing codes of the set generated by the first routine on the input of the appropriate components of MC in the appropriate instant time; (ii) receiving of the measurement results obtained by the influence of testing codes. Obtained measurement results added to the database of testing codes to the appropriate records.
3. Data processing routine for the results of the IMS under influence the testing set (result of the testing set forming routine fulfillment) on the components of MC. These testing codes were formed by the first routine and are in the database of testing codes. The results of influence of testing codes on the MC are in the same database. The deviation of the measurement results of the nominal value determines the error of MC. Nominal values of the influence quantities determine the condition of error appearance. The purpose of data processing is evaluation the real value of metrology characteristic of IMS.

The testing set forming routine should combine the set of the simulation models of all components of MC into the simulation model of MC. In the same time the simulation models of each component of MC should adequately imitate the metrology properties of this components as well as provide their complex or selective simulation in all allowable measurement conditions under the influence of all combinations of influence factors. It means that simulation model of MC should correspond to the requirements [11]. The simulation model of MC provides the investigation of the influence of the error of each components of MC on the general error. There should be considered the MST using with the simulation model of MC as well as the communication with the hardware components of measurement channel [9, 10].

The general structure of the first routine of the MST of temperature MC using thermocouple is presented on fig. 1. It consist of the simulation models of: thermocouple [11], connection line CL, cold junction compensation circuit CJCS, analog measurement converter (amplifier) AMC, multiplexer MUX, analog to digital converter ADC and computing component CC. The structure fig. 1 corresponds to the multichannel measurement system (each thermocouple is connected to the own signal condition amplifier). Adapting of this structure to the multipoint measurement system (multiplexer of the low voltage signals connect thermocouples to the input of the amplifier or to the low level ADC) demands changing the modules AMC and MUX between each others.

All simulation models in this MST are developed according to the simulation model of thermocouple, which is described in [11] using methodology described in [15]. MST includes the simulation models which form:

- Nominal CC of all components of MC (the CC of multiplexer is equivalent 1 therefore fig. 1 does not include it).
- Instrumentation errors Δ_{INSTR} in normal operation conditions (the components of this error for all components of MC are presented below the appropriate module);
- Input impedance, current and noise error $\Delta_{R\ IN}$, $\Delta_{I\ IN}$, Δ_{NOISE} ;
- Additional error of the influence the operating temperature deviation of the normal operation conditions $\Delta_{INSTR}\ t^o$ and exploitation time $\Delta_{INSTR}\ \tau$;
- Methodology errors of CJCS, which are caused by the cold junction temperature inequality to the temperature of the sensor of CJCS $\Delta_{MET}\ t^o$. And inequality of the CC of the thermocouple to the CC of CJCS $\Delta_{MET\ CC}$;
- Error of the leakage current of multiplexer $\Delta_{U\ ALLOW}$ [16].

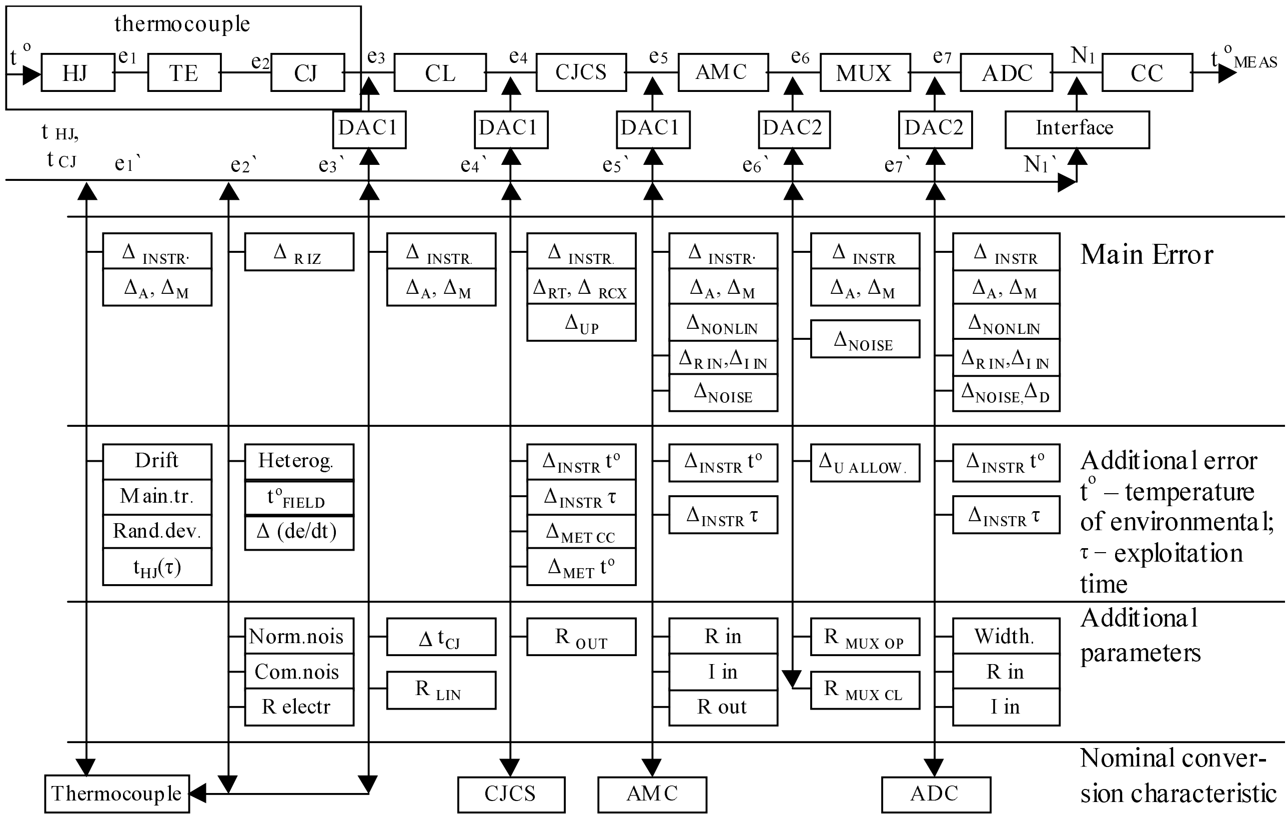

Fig. 1 – Structure of the metrology software test of the temperature measurement channel using thermocouple.

Besides it MST includes simulation models, which form the auxiliary parameters of the components of MC, which are necessary for error evaluation. For example input impedance error of AMC can be evaluated as $\Delta_{\text{R IN AMC}} = U_{OUTCJCS} * R_{OUTCJCS} / (R_{INAMC} + R_{OUTCJCS})$, input current error can be evaluated as $\Delta_{\text{I IN AMC}} = I_{INAMC} * R_{OUTCJCS}$.

The requirements to the data processing routines can be formed on the basis of the analysis of the defined method of metrology characteristic of MC setting. But the ordinary methods of metrology characteristic setting do not indicate the properties of IMS. In particular the ordinary methods do not provide the opportunity of measurement accuracy improvement during exploitation by self adapting and self training. So let consider the influence of self adapting and self training on the error of MC during its exploitation.

3. INFLUENCE OF SELF ADAPTING AND SELF TRAINING ON THE ERROR OF MC

The self adapting and self training of IMS is directed on improvement its parameters, in particular on accuracy improvement by error of different components of MC correction. This correction is based on the simulation model of correction factor. The simulation models of correction factor can be general for some type of component or be individual for each component of MC. The structure and parameters of the general simulation model for some type of component is a priori defined and cannot indicate the individual properties of each component of the same type. Therefore the precision IMS should use the individual simulate models constructed during exploitation of IMS. But the construction of the individual simulate model demands some results of testing or calibration these component. The acquisition of these results demands some time interval t1, which can be named as the preliminary information acquisition (fig. 2). The error of measurement channel is high during this interval. It is defined by the initial error of the components of MC or the error of their simulation models. After t1 finishing IMS construct the first iteration of individual simulate model of correction factor and use it for error correction. This simulate model can have the significant uncertainty and low reliability for long time using. So during the further exploitation IMS corrects the first simulation model by the results of the further testing or calibration. During this step by step improving of the individual simulation model the general accuracy of MC is increased. This process is indicated on the fig. 3 by decreasing the error on the time step t2. This time step can be named as the improvement of the simulation model of correction factor. Later comes the significant decreasing of the speed of “error decreasing” process. This speed decreasing is connected with the limitation of the selected method of individual simulation model construction. However the further exploitation of IMS with the precision simulation models demands making the periodic testing or calibration with larger period than in the first phase.

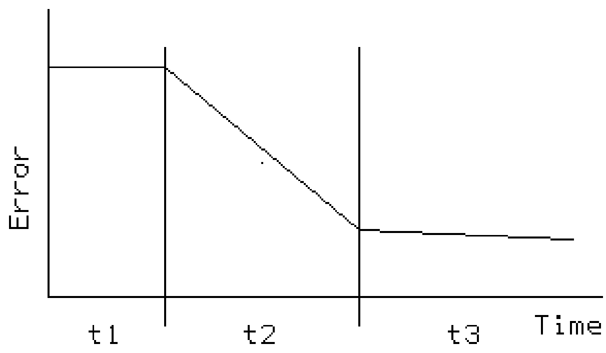

Fig. 2 – Error of IMS dependence of the exploitation time for beginning of exploitation.

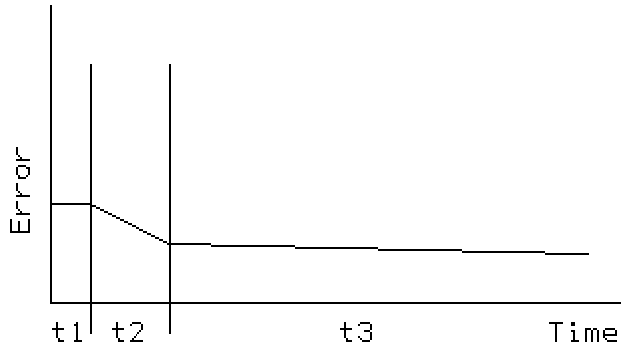

Fig. 3 – Error of IMS dependence of the exploitation time in the presence of historical data about sensor drift.

It is connected with the providing the specific reliability of error correction. The results of the testing or calibration give the opportunity of the gradual accuracy improvement during exploitation. This process is indicated on the t3 interval (fig.2). This period can be named as more precise definition of the simulation models.

It is necessary to mark that dependence of the MC of IMS error of the exploitation time (fig.2) is considered for the starting exploitation time. Than in the process of individual simulation model construction the self training properties of IMS can not significantly influence on the process of individual simulation construction. The long term exploitation of the self training allow improving the process of simulation models of correction factor construction. For example for upgrading some component of the MC (particularly sensor). Than self training methods allow: (i) using the previous results about the error of the same type components in the same measurement condition as the “historical data” for speeding-up the construction of the individual simulation model of the correction factor for the new component [5, 13]; (ii) decreasing the time interval for selection the type of the simulation model; (iii) decreasing the control risk of the intertesting or intercalibration time interval. Therefore the curve, which indicates the error dependence of exploitation time for the long term working IMS is presented on fig.3. This curve will look like the fig.2 with the same stages. The time interval t1 (fig.3) in the condition of “historical data” consideration and appropriate methods of prediction [5, 13] can be decreased in many times. Application during t1 interval the simulation model constructed in this exploitation place should increase the accuracy of correction. The interval t2 (fig.3) should be decreased in comparison with t2 interval of fig.2. So the t3 interval will start earlier and will be longer. As it is show on the fig.2 and fig.3 the IMS provides high accuracy of measurement after beginning the stage of improvement of the simulation model of correction factor t3. This time is the best time for starting the active exploitation of IMS. So one of the main tasks for MST is construction of the curves of error variation during exploitation and founding the defined time intervals.

4. THE EXPERIMENTAL RESEARCHES OF MST

There were made the experimental researches of the metrology characteristics of temperature measurement channels of ISIS using MST. ISIS was developed according to the INTAS-OPEN 97-0606 grant. The main objectives of these metrology researches was definition of the time dependence variation of the overall error of MC for IMS and evaluation of the t1 and t2 time (see fig.2,3) using the developed MST in the condition of different combination of individual properties of the components of MC, operating conditions and influence quantities.

The purpose of this metrology testing was evaluation the t1 and t2 time intervals using MST for simulation different combination of: individual properties of components of MC, measurement condition and influence factor. The experimental way of t1 and t2 evaluation in real measurement condition demand the long term testing in special measurement condition. The MST using gives the opportunity of time intervals evaluation in accelerated time scale. The MST was combined with the experimental researches of ISIS [9, 10].

The temperature MC of ISIS consists of the K thermocouple, cold junction sensor (couple RTD), low voltage multiplexer (based on the hermetically sealed rely with the thermo-shunt for decreasing thermo-emf), precision low-level ADC [14], controller with remote reprogramming [15] for current data processing (including correction) and PC for construction the individual simulation models [7].

During testing MST simulated K type thermocouple according to its simulation model [11]. This simulation model includes:

- Nominal CC [16];
- Random starting deviation of nominal CC [16];
- Drift of the CC [11]. This component includes: (i) systematic individual trend of the drift; (ii) random component. The drift speed vas take according to [17];
- Temperature of could junction influence (for simplification the investigation the compensation of could junction was not simulate);

As a method of accuracy of ISIS improvement there was chosen the periodic testing of working sensor by reference S-type thermocouple simulated by MST. The inter testing interval vas automatically chosen by ISIS.

The results of experimental researches of the overall error of MC dependence of the exploitation time are presented on fig. 4. There are presented curves of real error variation (curves a, b, c, d) and their envelope curves. The envelope curves can characterize the allowable error of MC. Curve a corresponds to the error of the MC of the nonintelligent measurement system, which provide changing of the sensor after each 1000 hours of exploitation. Curve b corresponds to the error of the MC of the nonintelligent measurement system, which provides periodic (each 1000 hours) calibration of the sensor. Curve c corresponds to the error of the MC of the IMS which provides the periodic (each 1000 hours) calibration of the sensor and drift of its CC correction. The prediction error is step-by-step decreasing proportionally to the increasing the calibration numbers. Curve d corresponds to the error of the MC of the IMS which provides sensor's drift correction by using artificial neural networks. There is used method of prediction using additional approximate neural network, which forms training set for the prediction neural network [18]. The decision-making subsystem of ISIS implements the constant costs strategy, which is appeared by the constant inter calibration time interval.

As it can be seen from the fig. 4 time t1 and t2 for the curve c are not obviously. Curve d has obviously indicated these times and t1 = 5000, t2 = 6000 hours of exploitation.

As it can be seen using the results of experimental researches the constant costs strategy is not optimal for cost minimization. MST gives opportunity of different strategies analysis and comparison.

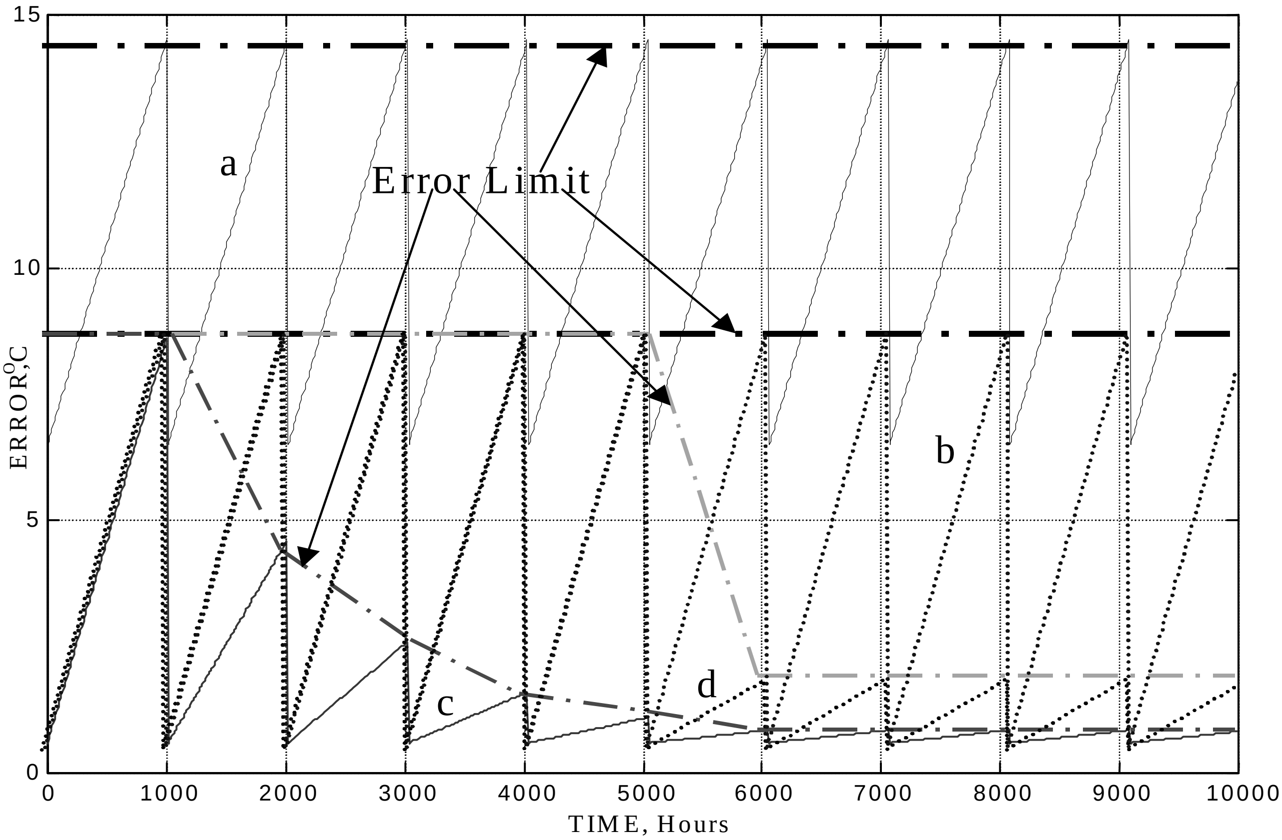

Fig. 4 – Temperature measurement channel error dependence of the exploitation time.

5. CONCLUSIONS

The proposed approach to development of MST allows investigating the metrology characteristics of IMS in accelerated time scale. MST application allows evaluating the curve of IMS error variation during exploitation and evaluating the optimal time of starting IMS exploitation and evaluates the error of IMS in real measurement conditions. Besides it MST allows evaluating of the affectivity of decision-making system, which makes goal-seeking behavior in defined measurement condition and evaluates costs for realization of this strategy. The comparison of the metrology and economy characteristics allows estimating the advantages and disadvantages of different types of IMS.

6. ACKNOWLEDGEMENTS

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