UNCERTAINTY IN PROJECTING OF CONFIRMATION SYSTEM IN LABORATORY TESTING

Ing. Petr FRANK, Doctoral Degree Programme (2)
Dept. of Power Electrical and Electronic Engineering, FEEC, BUT
E-mail: frank@feec.vutbr.cz

Supervised by: Prof. Karel Hruška

ABSTRACT

This paper handle with reliability of measurement. Accurate and reliable measurement is ensured by implementation of **confirmation system**. There are discussed problems of confirmation system design and applying. In this paper is explained role of uncertainty in confirmation. Practical example of this role is briefly mentioned in closing part of this paper.

1 UP TO DAY SITUATION OF THE USE OF MEASUREMENT EQUIPMENT

Present-day situation in measurement result evaluating is in many cases not sufficient. Quality of measurement is evaluated by measurement error. This measurement error is evaluated by different methods and so final results often aren't unambiguous. Other problem is also that in many cases isn't specified final measurement reliability at all. Measurement error is ordinary obtained from error of equipment without any respect to random error or possibility that equipment characteristic can vary with time.

On one side is the requirement of customer. The Customer can specify goal reliability and accuracy of measurement. There is some risk that laboratory will evaluate wrong measurement result. This is connected not only with financial risk but with safety and reliability too. So it is necessary to evaluate measurement result in proper way with well-estimated measurement error and on set reliability level.

This problem is not easy to solve but there are some guides in international standards. ISO standards give us recipe how to evaluate so called **uncertainty of measurement** and how to apply confirmation system, which should provide unambiguous measurement result.

There is one other reason why to implement calibration system. In before mentioned customer-laboratory relation is often common that one side or both are ISO 9000 certified. In that case is form of testing and measurement result evaluating part of contract. But if it isn't in the contract there is one more important thing. When Czech Republic joins European Union there will come **Community Law** in force. There are some Directions, which are mandatory for every member state. For electrotechnic testing laboratory are most important directives number **73/23/EEC** (low voltage electrical equipment) and **89/336/EEC (**electromagnetic compatibility). Both are harmonized in our law system as Government Decree from year

1997. Result of laboratory testing is valid and lawful only if it meets international standards requirements. That means that measurement result must be evaluated with uncertainty of measurement and all items in chain of measurement must accord to metrological confirmation.

2 CONFIRMATION SYSTEM IN LABORATORY TESTING

Metrological confirmation is a set of operations required to ensure that an item of measuring equipment is in a state of compliance with requirements for its intended use. Metrological confirmation normally includes, for example, calibration, any necessary adjustment or repair and subsequent recalibration, as well as any required sealing and labeling. [1].

Main goals of metrological confirmation are in general:

- The customer's requirement for high performance, accurate and high quality products
- The producer's requirement for high probability of product acceptance
- Minimizing test and testing cost

Basic problem is: how to set **calibration intervals**. Any parameter of **TME** (test and measuring equipment) isn't stable in time. So we must do the calibration time to time. The **calibration** is process, which give us information about TME parameters. Every parameter has its **uncertainty** because any measurement or calibration can't give us a certain result. At figure below is dependence of uncertainty of parameter on time.

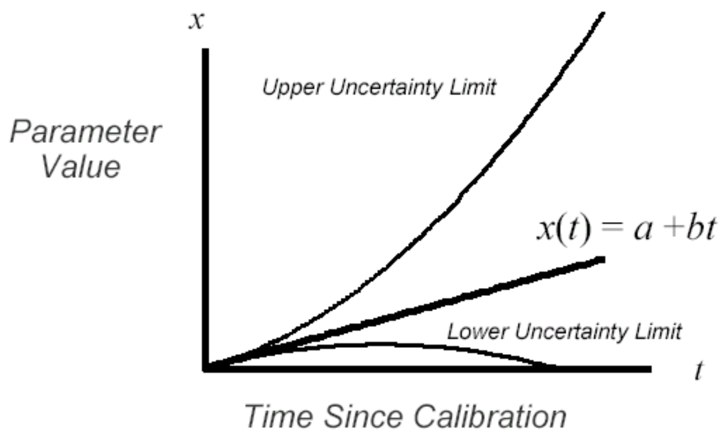

Fig. 1: *Parameter uncertainty growth [2]*

After calibration are uncertainty limits reset to lower value. Key to set correct calibration intervals are in understanding of uncertainty growth process and chiefly in change of parameter itself. If we simplify parameter change to the straight line, we can obtain its tangent from previous calibration history.

Problem how to set correct calibration intervals can be very complicated but can be solved with known guides, **SMPC** (statistical measurement process control) and engineering analysis. But actual **problem is how to describe process of setting calibration intervals** itself. If there is well known routine of setting calibration intervals with minimum human influence, then we can obtain high-quality result with less human, time and economical costs.

Calibration interval analysis can be summarized into few steps:

1. Determine end item performance requirements in terms of acceptance end item attribute values
2. Determine TME parameter tolerances that correspond to acceptable test process uncertainty
3. Determine appropriate measurement reliability targets for TME parameters
4. Collect data on TME parameters to provide visibility of TME uncertainty growth processes
5. Determine reliability models and coefficients using maximum likelihood estimation methods
6. Identify the TME parameter uncertainty growth process. Select the appropriate measurement reliability model
7. Compute calibration intervals which correspondent with appropriate measurement reliability targets

For process of calibration interval setting determination must be every step well known. Calibration intervals process design is impossible without metrology, statistical, engineering qualification.

We want general guide to calibration, but it is clear that differences between various laboratory, measurement methods and TME are great. Therefore **for different laboratory there will be different calibration interval process design**.

If calibration interval process design is made (There is unambiguous guide to calibration intervals evaluating, personnel is knowledgeable and all TME are accord to metrology confirmation) then accuracy and reliability of measurement is ensured and laboratory is ready to fulfill customer requirements.

3 ROLE OF UNCERTAINTY IN DESIGN OF CALIBRATION INTERVAL EVALUATE PROCESS

It is not possible to set calibration limits without uncertainty analysis. Uncertainty importance is obvious from Figure 1. We must take into account uncertainty growth to ensure required accuracy of measurement. Each input uncertainty has another growth rate and so final uncertainty can be obtained only by analysis of each input uncertainty. Calibration helps us to keep uncertainty in required limits. At Figure 2 is shown how length of calibration interval and uncertainty growth affects final reliability of measurement.

Figure 2 represents three calibrations. In the time of a calibration is evaluated uncertainty U_0. Dashed line represent presumption of change of observed parameter. Real change is found out in next calibration. Calibration history helps us predict next parameter. The growth of uncertainty is essential for quality of measurement. The fact that we don’t know anything about parameter change after calibration is the reason for uncertainty growth. Progression of uncertainty vary case to case and can be linear, parabolic or another.

Main purpose of repeated calibration is to keep resulting uncertainty in customer defined limits. There is upper control limit (UCL) and lower control limit (LCL). At Figure 2 is pointed out $U(t_x)$ - uncertainty in time t_x. It is obvious that for example two times longer interval will violate the requirement. It doesn’t mean the measurement is not accurate but it mean the measurement isn’t reliable.

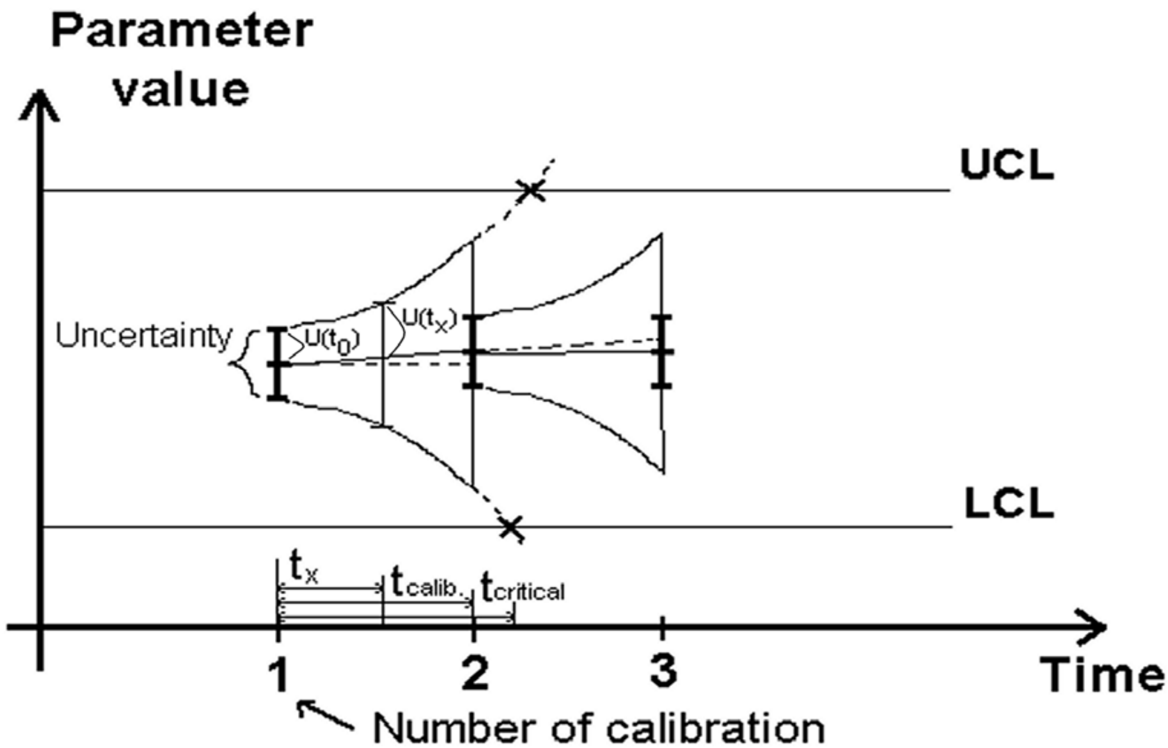

Fig. 2: *Relationship between uncertainty of measurement and length of calibration interval*

4 CALIBRATION INTERVAL CALCULATION WITH UNCERTAINTY CONSIDERATION

If we take parameter change and uncertainty growth as linear, then we can evaluate its tangents k_p and. k_u. Equation (1) must be satisfied to provide result in tolerance limits.

$$[x + U(t) < UCL] \wedge [x - U(t) > LCL] \qquad (1)$$

$$\lfloor x + U(t_0) + t \cdot k_p + t \cdot k_u < UCL \rfloor \wedge \lfloor x - U(t_0) + t \cdot k_p - t \cdot k_u > LCL \rfloor \qquad (2)$$

Where *x* is observed parameter. Meaning of other symbols is obvious Figure 2.

Equations (1) and (2) assume symmetrical growth of lower and upper uncertainty limit.

$t_{critical}$ is time when equations (1) and (2) become to false state. It is cleat that $t_{calib.}$ must be lesser than $t_{critical.}$

$$t_{calib.} < t_{critical} \qquad (3)$$

5 EXAMPLE: EVALUATING OF CALIBRATION INTERVAL OF DIGITAL VOLTMETER

Calibration of digital voltmeter with accuracy 1% of measured value + 3digits on 5V standard. Uncertainty of 5V standard is $u_{standard} = 1.10^{-4}$ V. Result of repeated measurement is 5,001 V. Type A uncertainty is evaluated from measured values as $u_A = 1{,}6.^{10\text{-}3}$V. From voltmeter accuracy a uncertainty of standard is Type B of uncertainty $u_B = 3.10^{-2}$ V. That means that combined uncertainty will be $u_c = 3{,}1.10^{-2}$ V. Because of high degree of freedom and required confidence level 95% is coverage factor k = 2. This coverage factor implicate expanded uncertainty $U = 6{,}1.10^{-2}$ V.

For evaluation of combined uncertainty was used this standard equation:

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) + 2 \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{\partial f}{\partial x_i^{(k)}} \frac{\partial f}{\partial x_j^{(k)}} u(x_i^{(k)}, x_j^{(k)}) \qquad (4)$$

From previous measurement is likely that systematic error change in time is minimal and so $k_p = 0$. From foregoing theoretical analysis of this type of voltmeter is known that uncertainty after calibration doubles in eight months.

If time unit is one month then $k_u = 0{,}25.U(t_0)$. It doesn't matter if we use equation for UCL or DCL because of $k_p = 0$.

$$x + U(t_0) + t_{critical} \cdot k_u = UCL \qquad (5)$$

If required relative accuracy is ±1,6% on 95% level of confidence then

$$5{,}001V + 6{,}1.10^{-2} V + t_{kritický} \cdot 0{,}25 \cdot 6{,}1.10^{-2} V = 5{,}08V \qquad (6)$$

=> $t_{critical} = 1{,}18$ month

How much is $t_{calib.}$ lesser than $t_{critical}$ depends on several parameters. Important parameters are time of calibration and cost of calibration. The more smaller $t_{calib.}$ the more greater reliability of measurement. In general we must solve minimization of cost equation (cost of time, money, human resources). Logistics is also important because we must adjust calibration interval with other equipment in laboratory. Because in our example isn't calibration expensive it is appropriate do the calibration twice in month.

6 CONCLUSION

The paper shows that correct evaluated uncertainty is fundamental for confirmation system. At the beginning mentioned process of calibration intervals design is very important in today mass production of consumer electronics because we can't manage quality without correct data. Sometimes it is very difficult to set right calibration intervals but we must try to evaluate measurement reliability in every case because without it the result isn't utilizable.

REFERENCES

[1] ISO 10012:2003(E), Measurement management systems, Requirements for measurement processes and measuring equipment, First edition , Switzerland, 2003

[2] Waytt, D. W., Castrup, H. T.: Managing Calibration Intervals, Proc. NCSL Workshop&Symposium, Albuquerque, NM, August 1991

[3] Hruška, K., Frank, P.: Řízení jakosti a metrologie, Brno, 2003