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Calibration Interval Adjustment of a Measuring Instrument in Industries During Long-term Use

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Abstract. Calibration interval adjustment of measuring instruments is one of the urgent tasks in industries. The article represents the calibration interval calculation of the potentiometer PCB-4P according to the verifications for the 4 year period of the Metrological Department in the aviation plant. The calibration interval is shown to be increased according to the calculation of its reliability and stability of metrological characteristics.

1. Introduction

A form of providing and maintaining the appropriate level of metrological reliability of measurements in industries is the calibration. To avoid the problems that inaccurate test equipment can cause, companies must calibrate their equipment regularly. Some companies, however, are so strict about sticking to their calibration schedules that they often calibrate equipment in excess. Although this helps them avoid producing bad parts, unnecessary calibrations also increase costs. The calibration is carried out periodically, at certain time intervals, which are called calibration intervals, established in the certification of measuring instrument evaluation according to the existing system of ensuring uniformity of measurements. Practically, during long-term use in industries it is necessary to make adjustments of the calibration interval of measuring devices. In some types of measuring devices one or even more of the metrological characteristics can go beyond the regulated value, established in the technical documentation, and thus bring the instrument to the disabled state. On the other hand, there are some measuring instruments which rarely demonstrate such kind of failures as metrological property instability of testing equipment, metrological failures and functional failures, so regular verification at certain intervals results in additional financial expense.

The procedure for determining and adjusting the calibration interval of measuring devices is a laborious and complicated task; consequently, nowadays there is hardly a solution for calibration interval adjustments in industries to be easily found.

The purpose of this work is to adjust the period of time between calibration sequences of the potentiometer type PCB-4P during long-term use in industries [1–8].

2. Methods

The process of adjustment of calibration intervals is quite time consuming though several stages can be distinguished such as:

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1. Forming the measurand of measuring instruments for testing. The measurand quantity to be subjected to the test should be a minimum of 30. The same sample may include measuring instruments of various types but close in their purpose, construction, manufacturing technology or application conditions. After checking the uniformity of measuring instruments, the results of their test may be included into the same series of results.

2. The selected sample of measuring instruments is subjected to the test with either normal or accelerated mode (with the definite acceleration ratio). The measurements of the tested parameters are taken with equal periods of service or operation.

3. Considering the simple linear model of predicting, the method of least squares requires a minimum of 3 groups of multiple metering. Thus the test duration is to be not less than 2Δt, where Δt is the initial calibration interval.

4. Covering the results of instability which exceeds the intervals, the sample characteristic of instability distribution of metrological features of measuring instruments is found: the values of the sample mean and sample standard deviation.

5. The values acquired enable to evaluate the time-dependence function of the values of the sample mean and sample standard deviation. Polynomial equation coefficients are selected with the method of least squares. The polynomial order is selected from the options 1…5 according to the minimum error approximation criterion [9–10].

The initial calibration interval for a new piece is important, taking into account the manufacturer's recommendations. This is especially true if there has not been any prior experience with a particular piece of equipment. Though having had any similar equipment already in service, we can use our experience with that equipment to set the calibration interval for the new piece of equipment.

Initial calibration period recommended by the manufacturer for a new piece of equipment is to be taken in consideration in case if the equipment has not been operated before. However, the data gathered in the course of running the same piece of equipment in industries regarding its tests and measurements can also be used for adjusting the calibration interval for the new piece of equipment [11–18].

3. Results

The verification data of thirty devices PCB-4P for four-year period of running are listed in table 1.

According to manufacturer's recommendations, the calibration interval for this type of equipment is twelve months and the accuracy class is 0.5 %.

In order to correct the calibration interval, the results are grouped according to serial numbers of checks, since the manufacture or repair of the measuring devices:

- Group 1 – measuring instruments received in the first verification after manufacture or repair;
- Group 2 - measuring instruments received in the second verification after manufacture or repair;
- other groups according to the serial number of checks, manufacture or repair.

To carry out the statistical processing of the results of the coverage interval for each group enables to find options Fj…j= 1. 2 ... N. of the generalized normal distribution of metrological properties (instability of a measuring instrument), which the results of verification test equipment of this type match with the highest level of significance.

Table 1. Verification results of PCB-3P for 4 year period.

Number of Measuring Instrument	Values of metrological properties per year				Number of Measuring Instrument	Values of metrological properties per year			
	1	2	3	4		1	2	2	3
1	0.22	0.22	0.23	-0.2	16	0.35	0.11	0.15	0.16
2	0.22	0.21	-0.53	-0.13	17	0.37	-0.08	-0.06	0.11
3	0.23	0.2	-0.14	-0.2	18	0.11	0.1	-0.11	0.08
4	0.2	0.11	-0.17	0.53	19	0.11	0.06	0.14	0.09
5	-0.22	0.13	0.18	-0.13	20	0.26	0.12	0.51	0.12

6	0.22	-0.14	-0.15	-0.12	21	0.11	0.1	0.11	0.12
7	0.2	0.15	0.2	0.18	22	0.29	0.04	0.06	0.12
8	0.2	-0.2	-0.14	-0.2	23	0.35	-0.09	0.24	0.1
9	0.14	0.13	0.12	-0.15	24	0.12	0.19	-0.2	0.18
10	0.38	0.14	-0.09	-0.18	25	0.45	0.14	0.06	0.24
11	0.23	0.06	0.07	0.06	26	0.24	0.17	-0.11	-0.19
12	0.15	0.14	0.16	-0.07	27	0.21	-0.09	0.2	0.2
13	0.16	-0.08	0.11	0.16	28	0.3	0.22	-0.11	0.56
14	0.16	-0.12	0.1	-0.11	29	0.32	0.2	-0.13	0.18
15	0.26	-0.51	0.1	0.06	30	0.24	0.23	-0.11	0.1

To calculate this parameter the matrix of F values from 0 to 4 in 0.1 is defined.

For each value of the matrix we find:

Value X^F_i =sign $(x_i|x_i|)$ = 1 ... N;

where sign(x_i), $\begin{cases} X_i < 0, \text{sign}(x_i) = -1 \\ X_i = 0, \text{sign}(x_i) = 0 \\ X_i > 0, \text{sign}(x_i) = 1 \end{cases}$.

The calculation results are shown in table 2.

Table 2. The parameter values of the generalized normal distribution of PCB-3P metrological properties.

Number of parameter	x_i \ F	0	0.1	0.2	0.3	…	2.9
1	2	3	4	5	6	7	8
1	0.22	1	0.8595	0.7387	0.6349	…	0.0124
2	0.22	1	0.8595	0.7387	0.6349	…	0.0124
3	0.23	1	0.8633	0.7453	0.6435	…	0.0141
4	0.2	1	0.8513	0.7248	0.6170	…	0.0094
5	-0.22	1	-0.8595	-0.7387	-0.6349	…	-0.0124
6	0.22	1	0.8595	0.7387	0.6349	…	0.0124
…							
29	0.32	1	0.8923	0.7962	0.7105	…	0.0367
30	0.24	1	0.8670	0.7517	0.6517	…	0.0159

According to Table 2, the values of the sample mean and sample standard deviation obtained due to of the equations (2) and (3). The results are shown in table 3.

Table 3. Values of the sample mean and sample standard deviation.

F	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
m	1	0.8022	0.6905	0.5953	0.5139	0.4443	0.3847	0.3336
σ	0	0.3156	0.2758	0.2435	0.2168	0.1945	0.1755	0.1590
F	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
m	0.2897	0.2519	0.2193	0.1912	0.1670	0.1459	0.1277	0.1119
σ	0.1446	0.1318	0.1203	0.1100	0.1007	0.0922	0.0845	0.0774
F	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3
m	0.0982	0.0863	0.0759	0.0668	0.0589	0.0520	0.0459	0.0406
σ	0.0709	0.0650	0.0596	0.0546	0.0500	0.0459	0.0420	0.0385
F	2.4	2.5	2.6	2.7	2.8	2.9		
m	0.0359	0.0318	0.0282	0.0250	0.0223	0.0198		
σ	0.0353	0.0324	0.0297	0.0272	0.0249	0.0229		

The value of the likelihood function is calculated according to the equation:

$$\ln[L(F)] = N \ln\left[\frac{|F|}{\sqrt{2\pi}\sigma_i}\right] + (F-1)\sum_{i=1}^{N}\ln(|x_{i|}|) - 0{,}5(N-1), \tag{1}$$

where F – distribution exponent.

To find the maximum of likelihood function such steps are to be made. As F_j the value corresponding to ln[L(F)] the equation (1) is taken. According to the principle of maximum likelihood function, it will be the best approximation of the sampling distribution of metrological properties (instability of a measuring instrument) due to the normal distribution law.

The maximum value of the function ln [L (F)] in the first group reaches F = 1.1.

Next, the distribution of values of optional features X^F_i (jT) for every group of measuring potentiometer PCB-4P are to be found:

– the value of the sample mean is accounted according to the equation:

$$\overline{m}_i(T_j) = \frac{1}{N}\sum_{i=1}^{N} X_i^F(T_j),\ j = 1{,}2...; \tag{2}$$

where T_J - the order of calibration interval;

– the value of the sample standard deviation is calculated according to the equation:

$$\sigma_i(T_j) = \sqrt{\frac{\sum_{i=1}^{N}(x_i^F(T_j) - m_i(T_j))^2}{N-1}},\ j = 1,\ 2...N \tag{3}$$

The results of data processing for the four PCB-4P Verifications are shown in Table 4.

Table 4. Sample characteristics of the values distribution of X^F_i (jT).

	Sample mean	Sample standard deviation	Maximum of ln [L(F)]	F
Group 1	0.0084	0.1122	18,13	1.1
Group 2	0.0404	0.1256	13,53	1.2
Group 3	0.0166	0.1536	7,7	1.2
Group 4	0.0445	0.1564	7,46	1.2

According to the obtained values of the distribution of sample characteristics X^F_i (jT), approximating polynomial for the functions due to the method of least squares is selected.

To calculate the m_i coefficients, the system of equations with four unknowns are used (eq. 5):

$$\begin{cases} 0{,}0084 = m_0 + 12m_1 + 12^2 m_2 + 12^3 m_3 \\ 0{,}0404 = m_0 + 24m_1 + 24^2 m_2 + 24^3 m \\ 0{,}0166 = m_0 + 36m_1 + 36^2 m_2 + 36^3 m \\ 0{,}0446 = m_0 + 48m_1 + 48^2 m_2 + 48^3 m \end{cases} \tag{5}$$

Solving this system of equations, the values of coefficients are obtained: m_0= - 0.1905; m_1= 0.027; m_2= 0.001; m_3= 0.00005.

In such a way the calibration interval of measuring potentiometer PCB-4P is obtained which is equal to 60 months.

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4. Conclusion

The calculation provided in the paper confirms that calibration interval adjustment of measuring instruments is a worthy process and is economically profitable for the company as the calculated period of time between verifications exceeds 5 times the interval which is recommended by the manufacture.

Despite the economic benefits of the adjustment of the calibration interval there is some critical information that cannot be ignored. The critical approach refers to setting initial calibration intervals and such criteria are to be considered before the adjustment process starts: stability of the equipment; the complexity and critically level of the measurements to be made; the frequency of the use of the measurement and test; the environmental conditions (such as dust, vibration, and temperature) in which the equipment is operated; the risk of damage or misuse; the qualification of the equipment operators and technicians; the mode of the measurement: automated or manual one; the possession of the equipment: company-owned or employee-owned one; any customer contract obligations in regard to calibration intervals; any regulatory agency obligations regarding calibration intervals; the risks associated with the improper use of the calibrated equipment.

So the calibration interval is considered the most important parameter of the metrological service of measuring instruments directly affect the level of uniformity of measurements. The smaller the calibration interval is, the higher the level of measurement trueness is. On the other hand, the smaller the calibration interval is, the greater the financial costs of the calibration of measuring instruments are, as well as the production costs associated with the withdrawal of funds from the measurement site. Thus, determining optimal value for the calibration interval is found quite important.

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