A Method to Determine Control Limit and to Monitor the Resistance Value of a Multiproduct Calibrator

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Abstract. Monitoring of the dc resistance value of a multiproduct calibrator had been implemented. This multiproduct calibrator is commonly used as a reference standard to calibrate electrical measurement testers such as insulation tester, earth tester, continuity tester, ground bond resistance tester and many other resistance meters. The monitored value of the multiproduct calibrator can be used to support measurement traceability needs for those electrical measurement testers and meters in a power distribution utility. The monitoring was done by measuring nine data of resistance value within nine respective days to construct a preliminary statistical control limits. The measurement was continued monthly to monitor the dc resistance value that was intended to test the control limits. The monitoring is performed by doing F-test and T-test on the recent measurement data over the all previous measurement data. If a measurement data is found to be outside the control limits, an action should be done to accommodate the information and renew the statistical control limits. The renewal action for the dc resistance value of the observed multiproduct calibrator was performed for several times within a year. It is reported based on the method implementation acquired within a year, that the upper control limit (UCL) and the lower control limit (LCL) for the dc resistance value of 19 kΩ is 18.99964 kΩ and 18.99912 kΩ. Moreover, to verify the performance of the final statistical control limits, the additional measurement is taken and the result lies between the UCL and LCL.

1. Introduction

Based on National Standardization Agency of Indonesia (BSN) website, there are already 246 accredited calibration laboratories, 43 labs of them having electrical calibration scope[1]. These accredited laboratories which have a capability on meters and testers calibration such as a digital multimeter, earth tester, insulation tester represent their standard based on a Multiproduct Calibrator (MPC). Research Center for Metrology of LIPI (RCM-LIPI), as National Metrology Institute, provides the calibration services for the laboratories. One of the calibration services is the MPC calibration. During this year there are already 16 MPCs that have been calibrated by RCM LIPI. Some of them have already been calibrated and the rest are not more than two years recalibration period.

On the ISO/IEC 17025, chapter 5.9 said that the laboratory shall have the quality control procedures for monitoring the validity of calibration undertaken. The resulting data shall be recorded in such a way that trends are detectable and statistical techniques shall be applied to the reviewing of the results [2]. However, to acquire the quality assurance of calibration, the laboratory shall do an
intermediate check within half calibration period, or make the inter-laboratory comparison [3]. Moreover, another method is recommended by National Accreditation Committee (KAN) to acquire the quality assurance for laboratories which is using statistical control process that is widely used to determine measurement result quality to analyze the resulting data [4, 5].

Practically, sometimes the inter-laboratory comparison becomes a more popular option than any options to acquire the quality assurance of the accredited laboratories. However, the comparison should not only become a pilot test to check the quality assurance. Monitoring of calibration validity is more an early stage than the comparison since it is an internal laboratory activity and not depends on other laboratory activity. The monitoring result can be used as the base estimation to support the laboratory’s Calibration and Measurement Capability (CMC).

The quality assurance by the intermediate check mention in [3] does not mean sufficiently enough acquired only one-time monitoring during recalibration period of MPC. The KAN guide as in [3] has already described how to do the monitoring process along a period of time, however, the example to strong for standard mass measurement. By following our study, we propose a method to determine the control limit and to monitor the representing value of MPC. The quality assurance may be set as a recalibration of retained UUC, such a digital multi-meter, that supporting CMC using a standard representation based on MPC acquired more frequent by adapting the KAN guide in term of electrical quantity.

2. Measurement process

The parameter tested in this paper is a dc resistance which is generated by the standard of Multiproduct Calibrator (MPC). It is usually used to calibrate industrial and laboratory ohm meter. In this method, the preliminary data need to be taken to obtain the preliminary control limits, and then the acquired control limits will be tested using a monthly measurement process. To maintain good reproducibility along the process, the personnel, the mean equipment and the method are the same. The environment condition shall be maintained at a temperature of (23 ± 2) °C and relative humidity of less than 75%

The example measurement point used is 19 kΩ, where it is one of a verification point of MPC Fluke 5520A corresponding to the standard resistor of RCM-LIPI. In monitoring calibration value of a DC resistance of MPC can be done through several steps. The steps are determining control limits, taking data of a monthly measurement process, and renewing control limits based on F-test and T-test analysis

2.1. Determining control analysis

Preliminary statistical control limits are constructed from a set of measurement consisting of nine data taken within nine respective days. The measurement is a calibration of retained digital multi-meter which is operated following a direct comparison method as our work instruction. The statistical control limits are determined based on twice standard deviations and the mean of nine preliminary data. The statistical control limits that determined in this paper can be expressed as follow

$$\text{CL} = \bar{x} \pm 2 \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2}$$

(1)

The statistical control limits consist of both upper and lower limits, for obtaining upper control limit (UCL), add twice standard deviation to the mean of preliminary data and for obtaining lower control limit (LCL), subtract the mean of preliminary data by twice standard deviation.

2.2. Monthly measurement

The measurement is continued monthly to monitor the dc resistance value that was intended to test the control limits. This measurement process is performed to obtain the ten data observed.
2.3. Monitoring of control limit

Monitoring of control limits is performed by doing F-test and T-test on the recent measurement data over the all previous measurement data.

2.3.1. F-Test. F-test is used to test the equality of variances of two populations. The two populations mentioned are the all previous measurement data and the recent measurement data. F-test is performed by obtaining the test statistic of $F_{\text{test}}$ and the critical region of $F_{\text{critical}}$. $F_{\text{test}}$ and $F_{\text{critical}}$ can be obtained by equation (2) and (3), respectively:

$$F_{\text{test}} = \frac{s_1^2}{s_2^2}$$  \hspace{1cm} (2)

$$F_{\text{critical}} = \begin{cases} F_{(1-\alpha/2, N_1-1, N_2-1)} \\ F_{(\alpha/2, N_1-1, N_2-1)} \end{cases}$$  \hspace{1cm} (3)

Then indicate the equality of two variances by comparing $F_{\text{test}}$ and $F_{\text{critical}}$ with two conditions. The hypothesis that the two population variances are equal will be rejected if:

$$F(\alpha/2, N_1-1, N_2-1) < F_{\text{test}} < F(1-\alpha/2, N_1-1, N_2-1)$$  \hspace{1cm} (4)

T-Test. T-test is used to know the equality of means of two populations. T-test is performed by obtaining the test statistic of $T_{\text{test}}$. $T_{\text{test}}$ can be obtained by Eq. 5 and Eq. 6, where the Eq. 5 is used for unequal in means and the Eq. 6 is used for equal in means.

$$T_{\text{test}} = \frac{\bar{Y_1} - \bar{Y_2}}{\sqrt{s_1^2/N_1 + s_2^2/N_2}}$$  \hspace{1cm} (5)

$$T_{\text{test}} = \frac{\bar{Y_1} - \bar{Y_2}}{s_p \sqrt{1/N_1 + 1/N_2}}$$  \hspace{1cm} (6)

Where

$$s_p^2 = \frac{(N_1-1)s_1^2 + (N_2-1)s_2^2}{N_1 + N_2 - 2}$$  \hspace{1cm} (7)

The hypothesis that the two population means are equal will be rejected if:

$$T_{\text{test}} > T_{1-\alpha/2,\nu}$$  \hspace{1cm} (8)

Where $T_{1-\alpha/2,\nu}$ is the critical value of the t-distribution at $\alpha$ significant level (we use 0.05) with $\nu$ degrees of freedom for unequal in mean can be seen in Eq. 9, and equal in mean can be seen in Eq. 10.

$$\nu = \frac{(s_1^2/N_1 + s_2^2/N_2)}{(s_1^2/N_1)^2/(N_1-1) + (s_2^2/N_2)^2/(N_2-1)}$$  \hspace{1cm} (9)

$$\nu = N_1 + N_2 - 2$$  \hspace{1cm} (10)

The results obtained by using F-test and T-test are used to determine the renewing of control limit.

3. Results and discussion

The value of preliminary control limits (UCL and LCL) consisting 9 data taken in 9 respective days can be seen in table 1. The values of these control limits can be obtained by using Eq. 1.
Table 1. Value of preliminary control limits.

| Nominal | UCL          | LCL          |
|---------|--------------|--------------|
| 19 kΩ   | 18.99923 kΩ | 18.99944 kΩ |

These control limits can be renewed based on the monthly measurement process. The values of monthly measurement are analyzed by using F-test and T-test where it can be done by using Eq. 2 and Eq. 5. In addition, the value of UCL and LCL are not more than CMC of F5520A in 19 kΩ, where the CMC value is ± 0.00043 kΩ. The illustrations of UCL, LCL and CMC values can be seen in figure 1.

![Image](image.png)

Figure 1. UCL, LCL and CMC.

The values of $F_{\text{test}}$, $F_{\text{critical}} (1-\alpha/2, N_1-1, N_2-1)$ and $F_{\text{critical}} (\alpha/2, N_1-1, N_2-1)$ on the first month measurement respectively are 2.65 and 0.23 and 4.10. These values show that the dispersion of recent data is equal to the previous data as mentioned in Eq. 4. The values of $T_{\text{test}}$ and $T_{\text{critical}}$ on the first month measurement respectively are 1.32 and 2.11. These values show that based on T-Test, the mean of the recent data is equal to the previous data because based on the criteria, if $T_{\text{test}} < T_{\text{critical}}$, the two population means are equal. So the conclusion is the result based on either T-Test or F-Test for first month measurements are lie inside the control limits. So the control limits do not need to be renewed.

For the second month, the standard deviation value for the recent data is 0. It means denominator value for $F_{\text{test}}$ is 0, because of this the value of $F_{\text{test}}$ is infinity ($\infty$). Meanwhile, the value of $T_{\text{test}}$ bigger than $T_{\text{critical}}$. The values of $T_{\text{critical}}$ and $T_{\text{Test}}$ respectively are 1.72 and 2.03. So the conclusion is the recent data taken lies between the control limits and these control limits do not need to be renewed.

Table 2. Value of control limits in the second month.

| Nominal | UCL          | LCL          |
|---------|--------------|--------------|
| 19 kΩ   | 18.99945 kΩ | 18.99925 kΩ |

For the third month, the value of $F_{\text{test}}$ lies between the value of $F_{\text{critical}} (1-\alpha/2, N_1-1, N_2-1)$ and value of $F_{\text{critical}} (\alpha/2, N_1-1, N_2-1)$. The value of $F_{\text{test}}$ is 1.47, and the value of $F_{\text{critical}} (1-\alpha/2, N_1-1, N_2-1)$ and $F_{\text{critical}}$ values (\alpha/2, N_1-1, N_2-1) are 0.38 and 3.58. Meanwhile for the T-Test, $T_{\text{critical}}$ is bigger than $T_{\text{Test}}$. The values of $T_{\text{Critical}}$ and $T_{\text{Test}}$ respectively are 1.72 and 2.03. So the conclusion is the recent data taken lies between the control limits and these control limits do not need to be renewed.
The fourth month has a similar type of data if it is compared with the second month because the standard deviation is 0. So it makes the data lies outside the control limits and needs to renewing the control limits. The new control limits can be seen in table 3.

**Table 3.** Value of control limits in the fourth month.

| Nominal | UCL       | LCL       |
|---------|-----------|-----------|
| 19 kΩ   | 18.99946 kΩ | 18.99927 kΩ |

For the fifth month and sixth month, the recent data are out of control. So the control limits need to be renewed. The new control limit for the fifth month and sixth month can be seen in table 4.

**Table 4.** Value of control limits in the fifth and sixth month.

| Nominal | UCL       | LCL       |
|---------|-----------|-----------|
| 19 kΩ (5<sup>th</sup>) | 18.99952 kΩ | 18.99917 kΩ |
| 19 kΩ (6<sup>th</sup>) | 18.99956 kΩ | 18.99918 kΩ |

For the seventh month, the value of F<sub>test</sub> lies outside the F<sub>critical</sub> values it means that the dispersion of previous and recent data are unequal. Even though the F-Test shows that the dispersion of two populations is different, the T-Test shows that the mean of previous and recent data are equal as the value of T<sub>test</sub> is 2.25 and the value of T<sub>critical</sub> is 1.99. Although the dispersion is different, the control limits do not need to be renewed because the mean is equal.

For the tenth and eleventh month, the result of F-Test shows that the dispersions of previous and recent data are equal. But based on the T-Test, the mean of previous and recent data are unequal. Although the dispersion two populations are equal, the control limits needed to be renewed because of the T-Test result. If the result of T-Test is unequal, it means the value of recent data is out of control. The new value of tenth and eleventh control limits can be seen in table 5.

**Table 5.** Value of control limits in the tenth and eleventh month.

| Nominal | UCL       | LCL       |
|---------|-----------|-----------|
| 19 kΩ (10<sup>th</sup>) | 18.99955 kΩ | 18.99917 kΩ |
| 19 kΩ (11<sup>th</sup>) | 18.99954 kΩ | 18.99917 kΩ |

For twelve months, the dispersion and the mean of recent and previous data are equal. So the control limits do not need to be renewed. Based on the F-Test and T-Test, the dispersions of previous and recent data are equal but the mean of two data are unequal. So the control limits need to be renewed. The last control limit can be seen in table 6.

**Table 6.** Value of control limits in last month.

| Nominal | UCL       | LCL       |
|---------|-----------|-----------|
| 19 kΩ   | 18.99964 kΩ | 18.99912 kΩ |

The last value of UCL and LCL verified for the following year. The verification is done by measuring the nominal in the following year and analyzing based on F-Test and T-Test. The values of F<sub>test</sub>, F<sub>critical</sub> (1-α/2, N<sub>1</sub>-1, N<sub>2</sub>-1) and F<sub>critical</sub> (α/2, N<sub>1</sub>-1, N<sub>2</sub>-1) of verification respectively are 1.87, 0.45 and 3.39. The values of T<sub>test</sub> and T<sub>critical</sub> respectively are 0.31 and 1.98. Based on the Eq. 4 and Eq. 8, the dispersion and the mean are equal to the previous data. So the control limits do not need to be renewed and it means that the last control limits (based on one year observation) verified and can be used for the following year. In addition, the value of verified UCL and LCL are bigger than the preliminary UCL and LCL but still not more than CMC of F5520A. The illustration of UCL, LCL, uncertainty and all measurement data can be seen in figure 2.
During the monitoring period, there are several measurement data that lie outside the CMC, this data can be caused by several factors such as measurement configuration and environmental condition. Since the measurement configuration for this paper using 4 terminal dc resistance measurement is the same from the first month until now based on the work instruction, the remainder is assumed that the measurement configuration is not the main cause for the several data that lie outside the CMC. Otherwise, the environmental condition such as drastic changes in humidity, temperature and atmospheric pressure can affect the resistor and make the dc resistance value fluctuate although it is not more than its floor value [6]. The possibility data that lie outside the CMC for the following time is still in observation.

4. Conclusion
The quality assurance has been set as a recalibration of retained digital multi-meter that supporting Calibration and Measurement Capability (CMC) using the Multiproduct Calibrator (MPC). The quality assurance has been acquired more frequent by adapting KAN guide in term of electrical quantity. A typical calibration point of 19 kΩ using the MPC, both of LCL and LCL limits have been renewed for seven times. However, it is verified that the limits are still under the CMC estimation and do not change up to September 2017. The contributing factors include in measurement process such as a standard used, a digital-multimeter used, the implemented method and staff performance are observed to be consistent; however, the occurred variability is still in observation.

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