FEATURES OF EVALUATION DRIFT EFFECT DURING KEY COMPARISON COOMET.EM-K5

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Abstract

Results of pilot laboratory and participating laboratories which are measuring the same travelling standard during Key Comparison must be most similar. However, this may not always be possible, because the travelling standard which is sent in turn to all participating laboratories is not always perfectly stable. So that it is necessary to take into account the drift effect of the travelling standard. The article describes some problems concerning the evaluation drift effect of travelling standard and its further influence on evaluation key comparison reference value during Key Comparison. The procedure for evaluation drift effect when its model can be linear or not linear was presented. Comparative analysis of the proposed procedures for evaluation drift effect is applied to the Key Comparison of Power COOMET.EM-K5 was done.

Keywords: drift effect, key comparison, electric power, key comparison reference value, travelling standard.

1. Introduction

Key comparisons (KC) are the special interlaboratory comparisons for National Metrology Institutes (NMIs) and regional metrology organizations (RMOs) around the world which are carried out within the framework of the International Committee for Weights and Measures (CIPM) Mutual Recognition Arrangement (MRA) [1]. The main purpose of KC is the determination of the equivalence between laboratories of different NMIs.

The unilateral degree of equivalence of a laboratory is obtained as the deviation of its measurement result from the KC reference value (KCRV), together with the uncertainty associated with this deviation according to the MRA [2].

The MRA describes in general how the data of KC should be evaluated but it does not provide enough specifics to define an unambiguous analysis. Consequently many different ways of evaluating KC data have been suggested over the years [3].

Ideally, all laboratories of different NMIs participating in a KC are measuring the same travelling standard (TS), which makes the comparison of reported results most meaningful. However, this may not always be possible, because the TS that is sent in turn to all laboratories common TS is not always stable and may change its value over time in the course of the KC. If in planning the KC the circular scheme will be used or a small number of participating laboratories then for a stable TC, checks can make on the unvarying value in a pilot laboratory at the start and at the end of the KC. In such a way the pilot laboratory makes measurements at least twice [4]. But if in planning the KC the radial scheme will be used the TS is returned to the pilot laboratory after each measurement at a participating laboratory or more often after performing a group of measurements at participating laboratories. During the analysis of the KC data then needs to account for these drift effects.

It should be noted that the accuracy of calculation of KCRV depends on accuracy of determining drift effects during KC [5-7]. Nevertheless since KC are utilized to approve, or disapprove, the calibration and measurement capabilities (CMCs) quoted by NMIs they have received much interest over the years [8].

2. General remark on Key Comparison of Power COOMET.EM-K5

To support the CMCs declared by members of COOMET in the framework of the CIPM-MRA, SE «Ukrmetrteststandart» (UMTS, Ukraine) organized COOMET KC of electric power unit for electrical standards of low-frequency 50/60 Hz power. UMTS was proposed to be the pilot laboratory, which would be responsible for providing the TS, coordinating the schedule, collecting and analyzing the comparison data, and preparing the draft report.

National Institute of Metrology (NIM, China) and D.I. Mendeleyev institute for Metrology (VNIIM, Russia) were proposed to be the linking NMIs for the linking process between CCEM-K5 KC and COOMET.EM-K5 KC [9]. TS of low-frequency 50/60 Hz power will be compared at 11 NMIs from COOMET and EURAMET to establish the relationship between the electrical units of AC power at these laboratories of different NMIs. COOMET.EM-K5 KC will be linked to CCEM-K5 KC.

3. Evaluation of the travelling standard's drift effect

During KC all the participating laboratories should measure the identical TS, which often is not perfectly stable. So that it is necessary to take into account the instabilities arising from the ageing of the TS or by several physical or mechanical changes during the transportation process or from the time. The presence of drift of TS, directly influences the quality of KC.

If preliminary analysis of the KC data indicates the drift in the measured value of the TS, it is necessary to evaluate this drift for subsequent use in establishing the KCRV for the KC and calculating the degrees of equivalence of the NMIs standards.

The pilot laboratory performed repeated measurements over the duration of the KC in order to monitor the stability of the TS and also the correction to compensate the drift can be evaluated. The evaluated correction which depends on both the stability of the TS and the long term stability of the measurements and its standard uncertainty will be included in the model describing the measurement process of the KC [10]. I applied the different approaches for evaluation drift effect to the COOMET.EM-K5 KC [9].

During the COOMET.EM-K5 KC, the TS RD-33-332 (serial number 301308) is measured at the pilot laboratory (UMTS) for each time after i participating laboratory made measurements. Also before the beginning COOMET.EM-K5 KC the pilot laboratory (UMTS) researched the TS for the drift effects. The measurement data, which are measurement results (mean values) by UMTS are listed in Table 1. In this example, I consider only the measurement point 120 V, 5 A, PF 1.0, 50 Hz.

Table 1. Measurement data

№	Measurement points										Period in weeks
	120V, 5 A, PF, 50 Hz					120V, 5 A, PF, 53 Hz					
	1.0	0.5 Lag	0.5 Lead	0.0 Lag	0.0 Lead	1.0	0.5 Lag	0.5 Lead	0.0 Lag	0.0 Lead	
	Measurement results, µW/VA										
UMTS1	1.8	2.5	-4.6	3.8	-4.0	0.9	1.9	-4.3	3.3	-3.9	0
UMTS2	1.8	2.4	-4.6	3.7	-4.1	1.0	1.9	-4.3	3.3	-4.0	2
UMTS3	1.9	2.5	-4.5	3.8	-4.1	0.9	1.8	-4.4	3.2	-4.0	5
UMTS4	1.8	2.3	-4.4	3.9	-3.9	1.1	1.9	-4.2	3.3	-3.9	7
UMTS5	1.9	2.5	-4.5	3.7	-4.1	0.9	1.9	-4.4	3.4	-3.8	12
UMTS6	1.7	2.4	-4.4	3.8	-4.0	1.1	2.0	-4.3	3.3	-4.0	24

3.1 Linear drift

Sometimes the data can show the linear drift, such cases have been considered by different models [4-6].

If there are no regularities that could be the basis of a drift model, one usually is given by a proposed linear model:

$$x - \overline{x} = m_{DRIFT} \cdot (y_i - \overline{y}), \tag{1}$$

where y_i (month) – the given date; $\overline{y}$ (month) – the average date of the NMI measurements on the TS; x (µW/VA) – the measured value given by the linear drift on date y_i; $\overline{x}$ (µW/VA) – the average measured value of NMI measurements on the TS; m_{DRIFT} (µW/VA/month) – the drift of the measured value per month. The proposed procedure of evaluated linear drift is illustrated by its application to recent KC COOMET.EM-K5.

After analyzing measurements were specified that the behavior of TS is the linear drift and can be seen in Figure 1. Also for evaluation of linear drift of TS can be used linear approximations or 1st order polynomial regression.
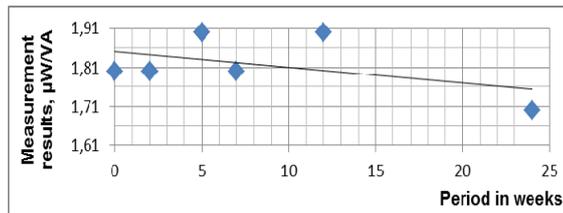
Figure 1. Drift tracked by linear regression

3.2 Non-linear drift

Nevertheless, in most cases the TS shows non-linear drifts, which are probably caused by mechanical changes arising from the transport or from the time.

In such cases the evaluation of the uncertainty due to the instability could be determined from the standard deviation of the measurements of the linking laboratory. And the standard deviation of the measurements of the linking laboratory would be considered in the budget uncertainty of each participating laboratory in KC [9]. To estimate non-linear drifts in the TS during COOMET.EM-K5 KC are proposed to use procedure of evaluation the polynomial regression or piece-wise linear approximations. The polynomial regression model is:

$$y_i = a_0 + a_1 x_1 + a_2 x_2^2 + a_3 x_3^3 + \ldots\ldots + a_n x_n^n + \xi, \tag{2}$$

where ξ = random error with zero mean.

It was assumed that the TS drift in non-linear fashion. Researched non-linear effects are caused probably by mechanical changes during the transportation process.

To estimate non-linear drift in the TS, a polynomial regression was fitted to the six UMTS measurements for each power factor (PF). But the numbers of UMTS measurements will be equal the list of dates of measurements in according to the Technical Protocol [8]. Polynomial regression was selected to track the drift behavior of the TS (Table 2). Also was calculated the determination coefficient (R^2). Applying the Chaddock scale the determination coefficient (R^2) gets quality characteristic which are needed to assess the quality of the selection of the regression equation.

Table 2. Selected polynomial regression to track the drift behavior of the TS

Polynomial regression	Regression equation	Determination coefficient (R^2)	Quality characteristic according Chaddock scale	Conclusion
1st order	$y_{UMTS} = -0.004 \cdot t(UMTS) + 1.8502$	0.2176	Weak level	Don't use
2nd order	$y_{UMTS} = -0.0009 \cdot t(UMTS)^2 + 0.0173 \cdot$ $\cdot t(UMTS) + 1.7878$	0.7161	Salient level	Not good
3rd order	$y_{UMTS} = -0.00005 \cdot t(UMTS)^3 + 0.0007 \cdot$ $\cdot t(UMTS)^2 + 0.0054 \cdot t(UMTS) + 1.8005$	0.7430	High level	Recommended
4th order	$y_{UMTS} = -0.00002 \cdot t(UMTS)^4 + 0.0008 \cdot$ $\cdot t(UMTS)^3 - 0.0089 \cdot t(UMTS)^2 +$ $+0.0381 \cdot t(UMTS) + 1.7885$	0.7783	High level	Good
5th order	$y_{UMTS} = -0.00003 \cdot t(UMTS)^5 + 0.00012 \cdot$ $\cdot t(UMTS)^4 - 0.0165 \cdot t(UMTS)^3 + 0.0806 \cdot$ $\cdot t(UMTS)^2 - 0.1044 \cdot t(UMTS) + 1.8000$	1.0000	Functional dependence between variables	Very well

The 2nd - 5th order polynomial regressions can be seen in Figures 2–5. The drift of the TS is calculated according to the formula:

$$DRIFT(TS) = \frac{1}{n}\sum_{i=1}^{n} x_{icorr.pol} - \frac{1}{m}\sum_{j=1}^{m} x_{jmeas.val} = \overline{x}_{corr.pol} - \overline{x}_{meas.val}, \tag{3}$$

where $x_{icorr.pol}$ – i corrected measurement made by pilot laboratory; $x_{jmeas.val}$ – j measurement made by pilot laboratory; $\overline{x}_{corr.pol}$ – average corrected measurement result; $\overline{x}_{meas.val}$ – average measurement value made by pilot laboratory.
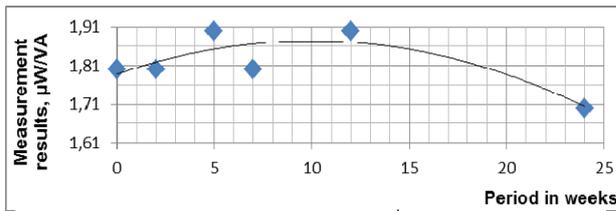
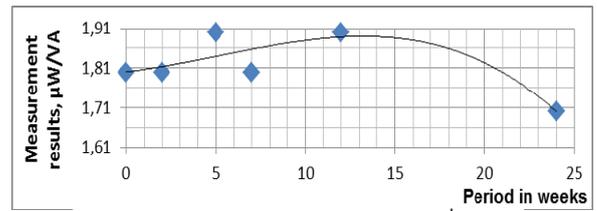Figure 2. The drift tracked by 2nd order polynomial regression

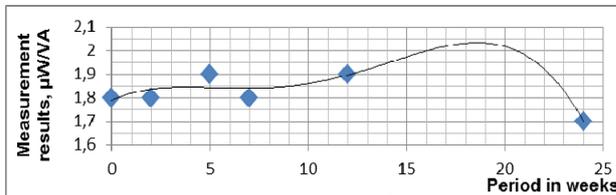Figure 3. The drift tracked by 3rd order polynomial regression

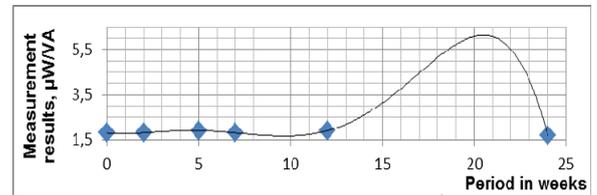Figure 4. The drift tracked by 4th order polynomial regression

Figure 5. The drift tracked by 5th order polynomial regression

Ideally, I consider the drift of the TS have to be evaluated for each measurement of pilot laboratory in a KC individually for each participating laboratory and sum of them. For evaluation drift of the TS was proposed the next formula:

$$DRIFT(TS) = \frac{\sum_{i=2}^{n} \frac{x_{UMTS\ i} - x_{UMTS\ i-1}}{2}}{m}, \qquad (4)$$

where $x_{UMTS\ i} - i$ measurement made by pilot; $x_{UMTS\ i-1} - i$-1 measurement made by pilot; m – the total measurement period of pilot laboratory.

Comparative analysis of the proposed procedures for evaluation drift when the model is linear or not-linear which is applied to the KC of Power COOMET.EM-K5 was done (Table 3).

Table 3. Evaluated drift of the TS

Evaluated drift of the travelling standard, µW/VA	Model of drift of the travelling standard						
	Linear	Non-linear					
		Polynomial regression					Proposed method
		1st order	2nd order	3rd order	4th order	5th order	
	0.026267	0.026267	-0.000413	0.000156	0.016231	-0.026713	0.002083

Conclusion

The procedures for revealing and evaluating of the linear or non-linear drift effect of the TS when making KC of Power COOMET.EM-K5 was proposed. If the TS which is sent in turn to all participating laboratories is perfectly stable it is enough to apply linear drift model (linear approximations or 1st order polynomial regression). However the TS is not perfectly stable than must be used non-linear drift model. Proposed procedure for evaluation non-linear drift is easier in calculation part but may lose in accuracy in some cases.

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