

# Features of Evaluation Drift Effect During Key Comparison COOMET.EM-K5

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**Abstract** –The paper describes some problems concerning the evaluation of travelling standard drift effect and its further influence on evaluation key comparison reference value during a key comparison. The authors have demonstrated the evaluation procedure for drift effect when its model can be linear or not linear. Comparative analysis of the proposed procedure with other different approaches was done applying the electric power data of COOMET.EM-K5 key comparison. All the calculations were done in MATLAB.

**Keywords** –drift effect, key comparison, electric power, key comparison reference value, travelling standard, MATLAB.

## I. INTRODUCTION

Key comparisons (KC) are the special inter-laboratory 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, 2]. 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 [3].

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 [4].

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 NMI these laboratories of different NMIs. COOMET.EM-K5

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 [5]. 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 [6-9]. 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 [10].

## II. 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 "UKRMETRTESTSTANDARD" (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 analysing the comparison data, and preparing the draft report.

National Institute of Metrology of China (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 [11-13]. TS of low-frequency 50/60 Hz power will be compared at 12 NMIs from COOMET, EURAMET and APMP to establish the relationship between the electrical units of AC power at KC will be linked to CCEM-K5 KC.

### III. 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 points out the presence of TS drift, it is necessary to evaluate this one. This evaluation has significance for a final assessment KCRV and 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 [14]. We applied the different approaches for evaluation drift effect to the COOMET.EM-K5 KC [13].

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  $i$ -th participating laboratory made measurements. Also before the beginning COOMET.EM-K5 KC the pilot laboratory researched the TS for the drift effects. The measurement data for used measurement points, which are measurement results (mean values) by UMTS are listed in Table 1. In this example, we consider only the measurement point 120 V, 5 A, 50 Hz, PF (1.0).

Table 1. Measurement data in  $\mu\text{W/VA}$  for measurement points 120V, 5 A, PF.

Number of measurement	50 Hz					53 Hz					Period in weeks
	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	
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
UMTS7	1.8	2.4	-4.6	3.8	-4.0	0.9	1.9	-4.2	3.3	-3.9	32
UMTS8	1.9	2.3	-4.4	3.9	-4.0	1.1	1.9	-4.4	3.4	-3.9	40

#### A. Linear drift

Sometimes the data can show the linear drift, such cases have been considered by different models [5-7].

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

$$x - \bar{x} = TS_{DRIFT} \cdot (y_i - \bar{y}), \quad (1)$$

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

After analysing measurements were specified that the behaviour of TS is the linear drift and can be seen in Fig. 1. Also for evaluation of linear drift of TS can be used linear approximations or 1-st order polynomial

regression.

#### B. 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 [10]. 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:

$$y_{UMTSi} = a_0 + a_1 \cdot t_1(UMTS) + a_2 \cdot t_2^2(UMTS) + a_3 \cdot t_3^3(UMTS) + \dots + a_n \cdot t_n^n(UMTS) + \quad (2)$$

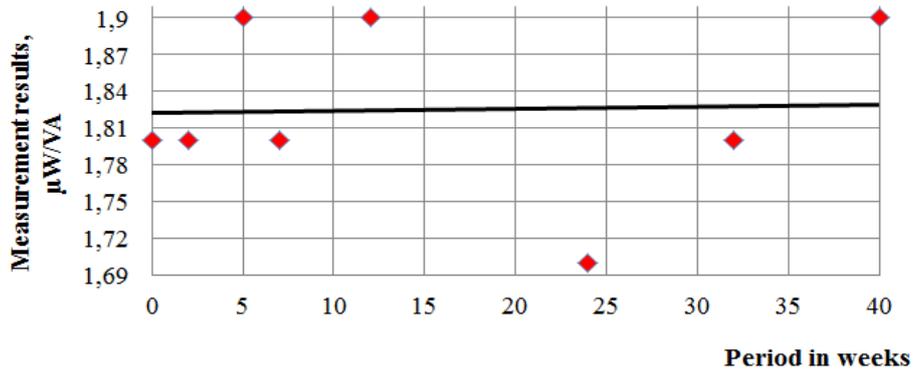


Fig. 1. Drift tracked by linear regression

where:  $a_i$  – selective estimates of the drift model parameters;  $t_i^i(UMTS)$  – measurement results ( $\mu W/VA$ ) in the period of weeks;  $\xi$  = random error with zero mean;  $i = (1, 2 \dots n)$ .

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 [12]. Polynomial regression was selected to track the drift behaviour of the TS (Table 2). Also, was calculated the determination coefficient ( $R^2$ ) [15]. 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 travelling standard.

Polynomial regression	Regression equation	Determination coefficient ( $R^2$ )	Quality characteristic according Chaddock scale	Conclusion
1-st order	$y_{UMTS_1} = 0.0002 \cdot t(UMTS) + 1.8226$	0.0011	Weak level	Don't use
2-nd order	$y_{UMTS_2} = 0.0002 \cdot t(UMTS)^2 - 0.0062 \cdot t(UMTS) + 1.8493$	0.1130	Salient level	Not good
3-rd order	$y_{UMTS_3} = -0.00005 \cdot t(UMTS)^3 - 0.0016 \cdot t(UMTS)^2 + 0.0192 \cdot t(UMTS) + 1.7918$	0.5933	High level	Recommended
4-th order	$y_{UMTS_4} = -0.0000009 \cdot t(UMTS)^4 + 0.0001 \cdot t(UMTS)^3 - 0.0031 \cdot t(UMTS)^2 + 0.0303 \cdot t(UMTS) + 1.7798$	0.6256	High level	Good
5-th order	$y_{UMTS_5} = -0.0000002 \cdot t(UMTS)^5 + 0.00002 \cdot t(UMTS)^4 - 0.0005 \cdot t(UMTS)^3 + 0.0051 \cdot t(UMTS)^2 - 0.0067 \cdot t(UMTS) + 1.8027$	0.7603	Functional dependence between variables	Very well
6-th order	$y_{UMTS_6} = -0.00000003 \cdot t(UMTS)^6 + 0.000003 \cdot t(UMTS)^5 - 0.00009 \cdot t(UMTS)^4 + 0.0015 \cdot t(UMTS)^3 - 0.0108 \cdot t(UMTS)^2 + 0.036 \cdot t(UMTS) + 1.7911$	0.8000	Functional dependence between variables	Very well

Additional criteria for selected polynomial regression to track the drift behavior of the travelling standard were calculated. The multiple correlation coefficient ( $R$ ) [16-17] also was calculated (Table 3) which generalizes the standard coefficient of correlation. It is used in multiple regression analysis to assess the quality of the prediction of the dependent variable. It corresponds to the squared

correlation between the predicted and the actual values of the dependent variable. It can also be interpreted as the proportion of the variance of the dependent variable explained by the independent variables.

The adjusted determination coefficient ( $R^2_{ADJ}$ ) [16-17] indicates as ( $R^2$ ) assumes that in the model the variation of the dependent variable is explained by every

independent one. It gives the percentage of explained variation as if all independent variables in the model affect the dependent variable. When the adjusted determination coefficient ( $R^2_{ADJ}$ ) offers to consider the percentage of variation, which can be explained by only those independent variables that in reality affect the

dependent one. Applying the Chaddock scale the multiple correlation coefficient ( $R$ ) and adjusted determination coefficient ( $R^2_{ADJ}$ ) gets quality characteristic which are needed to assess the quality of the selection of the regression equation.

Table 3. Additional criteria for selected polynomial regression to track the drift behavior of the travelling standard.

Polynomial regression	Multiple correlation coefficient ( $R$ )	Adjusted correlation coefficient ( $R^2_{ADJ}$ )	Quality characteristic according Chaddock scale	Conclusion
1-st order	0.0338	-0.1653	Weak level	Don't use
2-nd order	0.3361	-0.2418	Salient level	Not good
3-rd order	0.7703	0.2884	High level	Recommended
4-th order	0.7909	0.1264	High level	Good
5-th order	0.8720	0.1611	Functional dependence between variables	Very well
6-th order	0.8944	0.4001	Functional dependence between variables	Good

The 2-nd –6-th order polynomial regressions can be seen in Fig. 2. The drift of the TS is calculated according to the formula:

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

where  $x_{icorr.pol}$  –  $i$ -th corrected measurement made by pilot laboratory;  $x_{jmeas.val}$  –  $j$ -th measurement made by pilot laboratory;  $\bar{x}_{corr.pol}$  – average corrected measurement result;  $\bar{x}_{meas.val}$  – average measurement value made by pilot laboratory. Ideally, we 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:

$$TS_{DRIFT} = \left( \sum_{i=2}^n \frac{x_{UMTS_i} - x_{UMTS_{i-1}}}{2} \right) / m, \quad (4)$$

where  $x_{UMTS_i}$  –  $i$ -th measurement made by pilot;  $x_{UMTS_{i-1}}$  – ( $i-1$ )-th 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 non-linear which is applied to the KC of Power COOMET.EM-K5 was done (Table 4).

Table 4. Evaluated drift of the travelling standard,  $\mu W/VA$ .

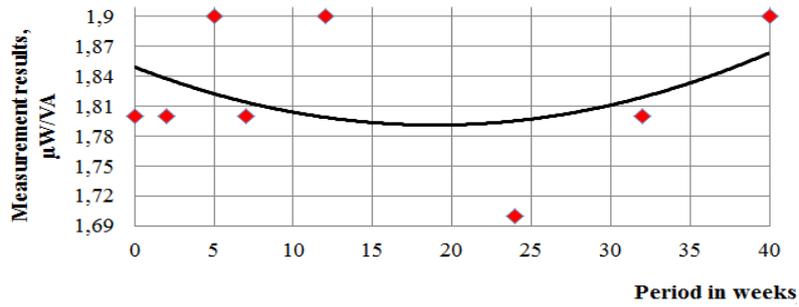
Linear		Non-linear					Proposed procedure
Proposed procedure	1-st order polynomial regression	Polynomial regression					
		2-nd order	3-rd order	4-th order	5-th order	6-th order	
0.026267	0.026267	-0.000413	0.000156	0.016231	-0.026713	0.001255	0.002083

#### IV. CONCLUSIONS

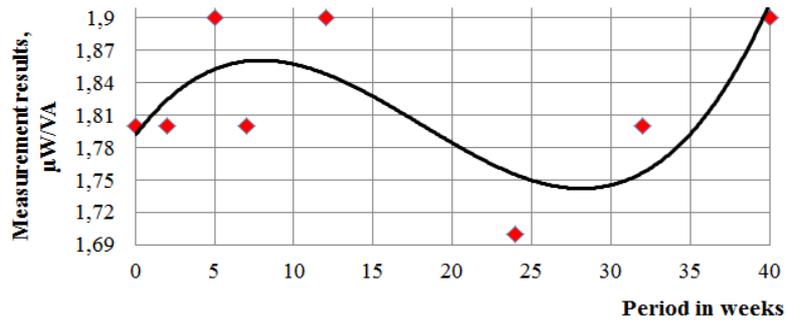
The procedures for revealing and evaluating of the linear or non-linear drift effect of the TS when making KC of Power COOMET.EM-K5 was proposed. If the TS which is sent in turn to all participating laboratories is perfectly stable it is enough to apply linear drift model

(linear approximations or 1-st order polynomial regression).

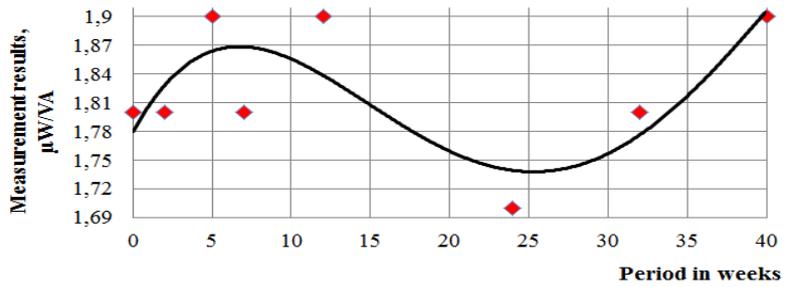
However, the TS is not perfectly stable than must be used non-linear drift model. Proposed procedure for evaluation non-linear drift is easier in calculation part but may lose in accuracy in some cases.



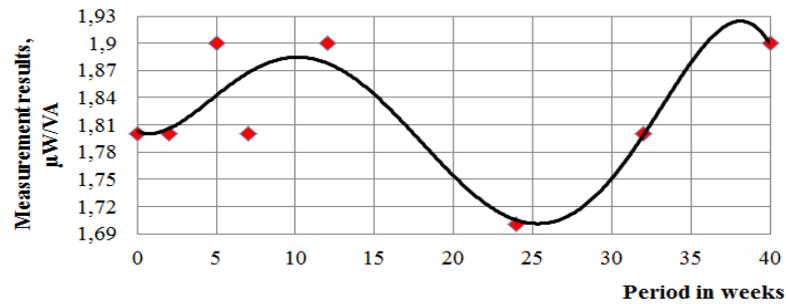
a) 2-nd order polynomial regression



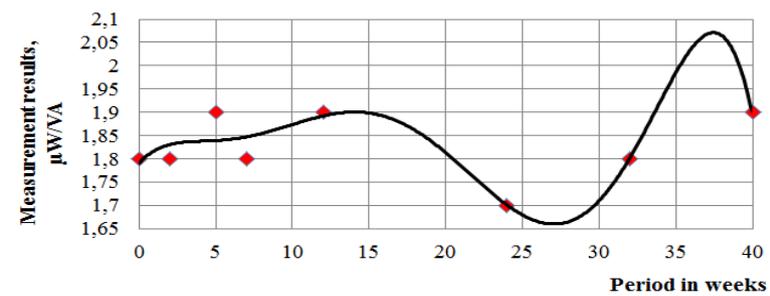
b) 3-rd order polynomial regression



c) 4-th order polynomial regression



d) 5-th order polynomial regression



e) 6-th order polynomial regression

Fig. 2. The drift tracked by 2-6-th order polynomial regression.

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