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Difference Between Measured and Real Value in Illuminance Estimation

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Abstract— **When calibration of measuring devices and in particular illuminance meters take place, statistical evidence for the reliability of the procedure must be considered. Calibration process stability should be examined, and control charts should be introduced. The current paper presents three sigma control charts, verifying that the calibration process is under control. They are based on the readings of a precise luxmeter taken in six consecutive years, owned by the Research and Development Laboratory for Lighting Technology in the Technical University of Sofia (R&D Lighting Laboratory). After verification that the calibration process is controlled, X bar R charts for different types of illuminance meters, calibrated within a period of five years are generated. The results obtained show the performance of the measured devices in terms of stability of the sample readings and presence of variations.**

Keywords— illuminance measurement, stability of light meters, luxmeters calibration

I. Introduction

The calibration process includes measurement of a given quantity and verification of the measured value by its comparison with real or true value derived by means of a reference or standard with known and stable parameters. When it comes to illuminance meters calibration, an incandescent standard light source type "A" is used as a reference, which luminous intensity is known and can be reproduced in given conditions and namely – supply voltage and current and ambient conditions [1].

According to [2] statistics is needed to ensure the quality of measurement and calibration procedure and it is the study that gives the best description of data sets, enabling researchers to make significant conclusions, based on the data in a framework, giving recognition of the real values of the measured quantities and their variations.

II. Statistics Used For Stability of the Calibration Process and Measurement Data Estimation

A. Three sigma control charts

The current paper introduces the application of the three sigma control charts for verification of the predictability of the calibration methodology used in the R&D Lighting Laboratory of the Technical University of Sofia. As is well known control charts are used only to show if a procedure or a process is in or out of control. They aim to make a comparison of a group of points, plotted on the same chart with specified warning limits set to two standard deviations above and under the mean value, calculated by means of equation 1.

$$S = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}} \quad (1)$$

When a measurement value falls between the warning and the control limits, this alerts that the process becomes unstable and investigation on the possible cause of instability should be carried out [3].

B. X bar and Range charts for estimation of the consistency of the readings of different types of illuminance meters

Since a representative count of illuminance meters are calibrated annually in the R&D Lighting Laboratory of TU Sofia, they can be easily separated by their type and statistics about the stability of their readings for different range of illuminances – 50, 100, 300, 500, 1000lx can be derived. For these statistics the X bar and Range Charts are chosen in the current paper [4]. In this statistical method the Range chart is used only to state whether a process is in control (the illuminance meters from this type are stable and reliable). Once the process's "in control or predictable" state is verified, the X bar statistics is used for monitoring of the process's performance – whether common or assignable causes of variability appear. When it comes to illuminance meters calibration the control charts exhibit samples that give readings significantly different from the expected value and should not be used for illuminance measurements. The upper control limits and (UCL) and the lower ones for the R range control cards are calculated using equations 2 and 3. The control limits for the X bar control charts are calculated by means of equations 4 and 5.

$$UCL_{\bar{R}} = A_4\bar{R} \quad (2)$$

$$LCL_{\bar{R}} = A_3\bar{R} \quad (3)$$

$$UCL_{\bar{x}} = \bar{\bar{x}} + 3\frac{\hat{\sigma}}{\sqrt{n}} = \bar{\bar{x}} + A_2\bar{R} \quad (4)$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - 3\frac{\hat{\sigma}}{\sqrt{n}} = \bar{\bar{x}} - A_2\bar{R} \quad (5)$$

where n is the number of samples or sample size;

$\bar{\bar{x}}$, the average of the averages of all the samples;

R = $xmax - xmin$ is the range - the difference between the largest and smallest value for each sample;

$\bar{R}$ is evaluated as average of the ranges of all samples;

$\hat{\sigma}$ is the standard deviation.

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The constants used in the equations A2, A3, A4 are dependent on the size of the data – the number of samples and are given in [4].

Previous research of the team, dedicated on the statistical evaluation of calibration data, concerning illuminance meters is also considered [5].

III. Experimental Data and Statistical Observations – Callibration Process Stability

The control charts used for keeping the calibration process under control are the three sigma charts. For the charts the performance of an illuminance meter owned by the R&D Lighting Laboratory type PU 550 is chosen. The control charts are prepared for expected illuminance values of 100, 300 and 500lx. The charts are built on annual consecutive measurements for six years and the first check point is put on the charts. Control measurement is planned after every ten calibrations made in the laboratory. Figures 1, 2 and 3 give the visuals of the results.

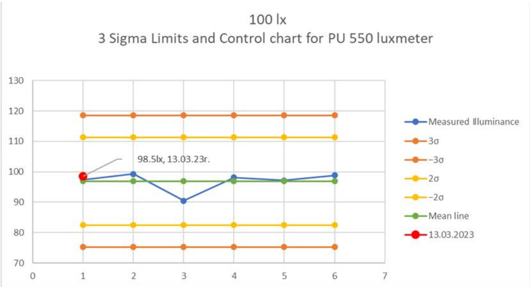

Fig. 1. Control chart for expected reading of 100lx of the illuminance meter

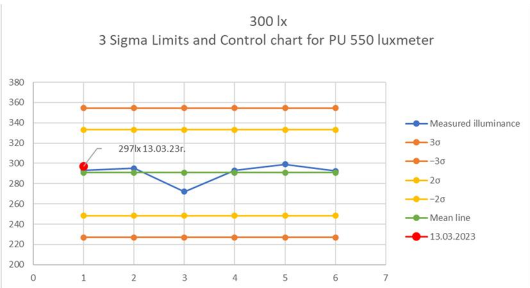

Fig. 2. Control chart for expected reading of 300lx of the illuminance meter

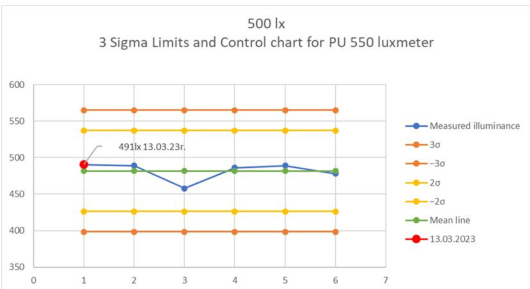

Fig. 3. Control chart for expected reading of 500lx of the illuminance meter

IV. Experimental Data and Statistical Observations – Unreliable Equipment

After the verification that the calibration methodology used in the R&D Lighting Laboratory of TU Sofia is a process statistically under control, the X bar and range control charts are obtained for the same illuminance values – 100, 300, 500lx for the different types of illuminance meters, calibrated in the laboratory. The range charts show that all the illuminance meters considered in the investigation are reliable. After this verification the X bar statistics is made, and the outliers are shown. The visuals of the results are only given for illuminance value 500 lx (measured for most experimental samples) - figures 4 to 13, because of the significant volume of the visual data. The rest of the results are given as tables, showing the percent of the measured illuminance values which fall within the control limits and the outliers that appear

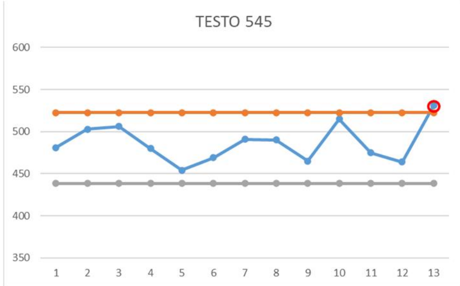

Fig. 4. X bar chart for expected reading of 500lx of Testo 545 illuminance meters

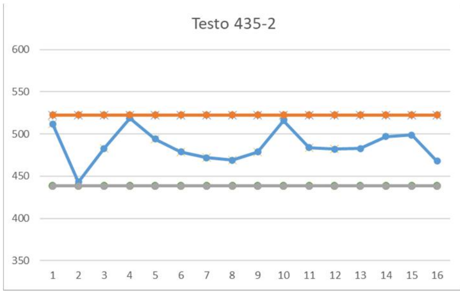

Fig. 5. X bar chart for expected reading of 500lx of Testo 435-2 illuminance meters

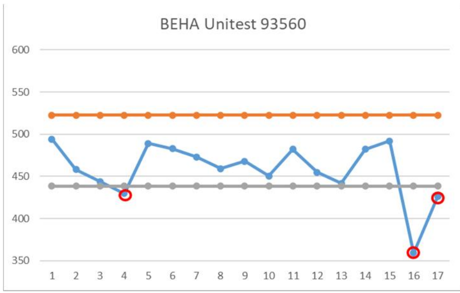

Fig. 6. X bar chart for expected reading of 500lx of BEHA Unitest 93560 illuminance meters

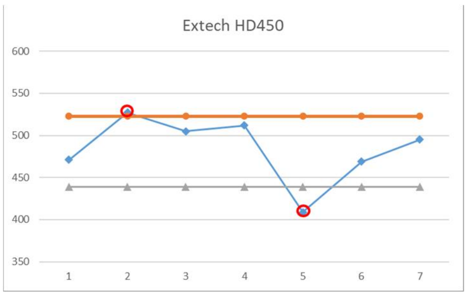

Fig. 7. X bar chart for expected reading of 500lx of Extech HD450 illuminance meters

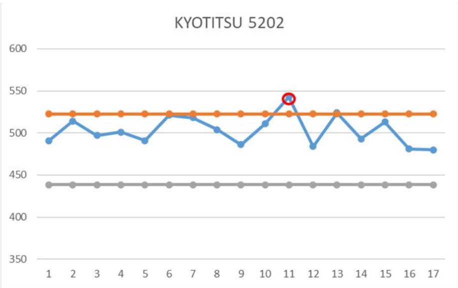

Fig. 8. X bar chart for expected reading of 500lx of KYORITSU 5202 illuminance meters

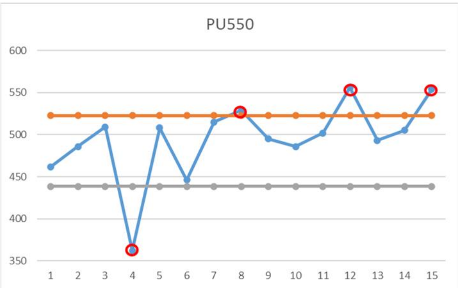

Fig. 9. X bar chart for expected reading of 500lx of PU 550 illuminance meters

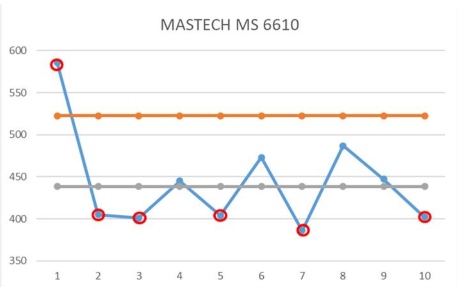

Fig. 10. X bar chart for expected reading of 500lx of MASTECH MS 6610 illuminance meters

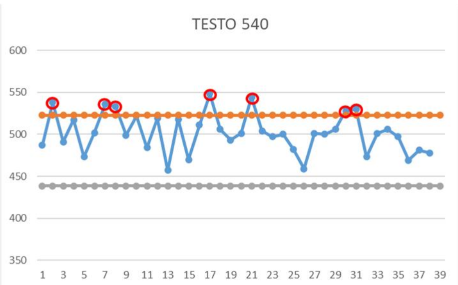

Fig. 11. X bar chart for expected reading of 500lx of Testo 540 illuminance meters

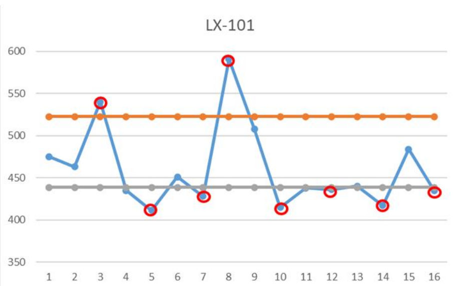

Fig. 12. X bar chart for expected reading of 500lx of LX-101 illuminance meters

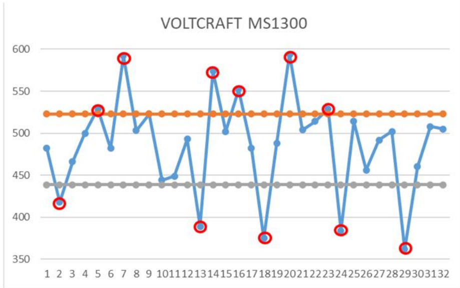

Fig. 13. X bar chart for expected reading of 500lx of Voltcraft MS1300 illuminance meters

TABLE I. GENERALIZED RESULTS IN PERCENT FOR THE ILLUMINANCE VALUES, OBTAINED IN THE CALIBRATION PROCESS FOR EXPECTED ILLUMINANCE OF 100LX. OUTLIERS.

Illuminance meter type	Number of smples	Within the control limits, %	Under the LCL, %	Above the HCL, %
EXTECH HD450	8	87.5	12.5	0.0
TESTO 545	12	91.7	0.0	8.3
TESTO 435-2	15	93.3	0.0	6.7
TESTO 540	33	69.7	6.1	24.2
KYOTITSU 5202	15	80.0	0.0	20.0
PU 550	17	82.4	5.9	11.8
BEHA Unitest 93560	19	84.2	15.8	0.0
MASTECH MS 6610	9	22.2	66.7	11.1
LX-101	14	64.3	28.6	7.1
VOLTCRAFT MS1300	20	60.0	5.0	35.0

TABLE II. GENERALIZED RESULTS IN PERCENT FOR THE ILLUMINANCE VALUES, OBTAINED IN THE CALIBRATION PROCESS FOR EXPECTED ILLUMINANCE OF 300LX. OUTLIERS.

Illuminance meter type	Number of smples	Within the control limits, %	Under the LCL, %	Above the HCL, %
EXTECH HD450	9	100.0	0	0
TESTO 545	14	100.0	0	0
TESTO 435-2	16	93.8	6.2	0.0
TESTO 540	34	91.2	2.9	5.9
KYOTITSU 5202	26	96.2	0.0	3.8
PU 550	18	83.3	5.6	11.1
BEHA Unitest 93560	20	65.0	35.0	0.0
MASTECH MS 6610	7	42.8	28.6	28.6
LX-101	6	66.7	16.7	16.7
VOLTCRAFT MS1300	24	75.0	8.3	16.7

TABLE III. GENERALIZED RESULTS IN PERCENT FOR THE ILLUMINANCE VALUES, OBTAINED IN THE CALIBRATION PROCESS FOR EXPECTED ILLUMINANCE OF 500LX. OUTLIERS.

Illuminance meter type	Number of smples	Within the control limits, %	Under the LCL, %	Above the HCL, %
EXTECH HD450	7	71.4	14.3	14.3
TESTO 545	13	92.3	0	7.7
TESTO 435-2	16	100.0	0.0	0.0
TESTO 540	38	81.6	0.0	18.4
KYOTITSU 5202	17	94.1	0.0	5.9
PU 550	15	73.3	6.7	20.0
BEHA Unitest 93560	17	82.4	17.6	0.0
MASTECH MS 6610	10	40.0	50.0	10.0
LX-101	16	50.0	37.5	12.5
VOLTCRAFT MS1300	32	65.6	15.6	18.8

Generalized information about all the calibrated devices is given in table 4. Table five gives generalization of the results as percent reliable measuring devices, for illuminance range 100 to 500lx.

TABLE IV. GENERALIZED RESULTS IN PERCENT FOR ALL THE ILLUMINANCE METERS AND ALL THE REFERENT ILLUMINANCE VALUES.

Expected illuminance value, lx	Number of samples	Within the control limits, %	Under the LCL, %	Above the UCL, %
100	162	74.07	11.11	14.81
300	174	84.48	8.62	6.90
500	181	76.80	11.60	11.60

TABLE V. GENERALIZED RESULTS IN PERCENT FOR EVERY TYPE OF ILLUMINANCE METER REGARDLESS OF THE REFERENT ILLUMINANCE VALUES.

Illuminance meter type	Number of samples	Within the control limits, %	Under the LCL, %	Above the HCL, %
Extech HD450	24	87.50	8.33	4.17
TESTO 545	39	94.87	0.00	5.13
TESTO 435-2	47	95.74	2.13	2.13
TESTO 540	105	80.95	2.86	16.19
KYOTITSU 5202	58	91.38	0.00	8.62
PU550	50	80.00	4.00	16.00
BEHA Unitest 93560	56	76.79	23.21	0.00
MASTECH MS 6610	26	34.62	50.00	15.38
LX-101	36	58.33	30.56	11.11
VOLTCRAFT MS1300	76	67.11	10.53	22.37

V. ANALYSIS OF THE RESULTS AND CONCLUSIONS

The current paper reviews the stability of the illuminance meters calibration process at the R&D Laboratory of Lighting Technology at the Technical University of Sofia and the consistency of the readings of equipment of different types, used in practical applications. As can be observed from the results, the calibration process is stable, but not all the calibrated illuminance meters are good for measurements, because their readings are far from the expected values and are thus unreliable.

The generalized information shows that for the devices that are statistically not reliable at expected value of 100lx, more illuminance meters measure greater value, for expected value of 300lx, more devices exhibit lower illuminance than expected and for real value of 500lx, equal percent of the devices give lower and higher values, that are outside the confidence intervals. Also, some of the devices can be considered statistically reliable for one illuminance range and unreliable for another. The greatest percentage of the measuring devices show reliability for expected value of 300lx. The biggest percentage of reliable devices according to their type is obtained for TESTO 435-2 and the lowest percent – for MASTECH MS 6610 illuminance meters.

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