Impact of Experimental Measurements Accuracy on Validation Process of Crimped Connections

Alin-Iulian Dolan* and Constantin-Florin Ocoleanu*

* University of Craiova, Electrical Engineering Faculty, Craiova, Romania, adolan@elth.ucv.ro

* University of Craiova, Electrical Engineering Faculty, Craiova, Romania, focoleanu@elth.ucv.ro

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***Abstract* - In the process of validation of crimped connections, the determination of the connector resistance factor and of the initial scatter coefficient has a decisive role. In this paper is studied the impact of the experimental measurements accuracy on the calculation of initial scatter, cumulating data from various types of crimped connections. This coefficient provides information on the behavior of the crimped connection immediately after installation before any aging effect begins. The standards establish that 6 samples are sufficient to be tested to estimate the identification of a "family" of connectors. The measurements were performed on crimped connections of barrel of terminal lug type for three cross sections of cables and on crimped connections of bimetallic through connector type for two pairs of cross sections. The initial scatter is influenced by 6 representative measured quantities as voltage drops, currents and conductor lengths. First, it was imposed a variation by one unit of hundredths digit of initial scatter and was recorded the variation of each quantity, the others 5 quantities being kept constant. Then simultaneous variations of the 6 quantities caused by device reading errors were imposed, determining the quantities with the greatest influence on initial scatter. Useful recommendations for experimenter are made.**

Cuvinte cheie: *conexiuni sertizate, resistenţă electrică, rezultate experimentale, valori statistice, maşini electrice.*

Keywords: *crimped connectors, electrical resistance, experimental results, statistical values, electrical machines.*

I. Introduction

The crimped connections are permanent electrical contacts widely used in the construction of electrical machines, having a great influence on their reliability [1]. The crimping process is a mechanical one and the crimping quality depends on several factors, from the preparation of the cables and choosing of connectors, to the crimping itself, often made by hydraulic presses.

Much research has been done over time to improve the performances of crimped connections, developing verification methods using ultrasonic inspection [2], [3] and thermography [4], analyzing the behavior at thermal shocks [5] or other factors that affect the contact resistance [6], modeling electric conduction [7] or temperature investigation for different types of crimping [8] with thermal modeling of heat transfer [9], [10]. For a quality pre-control of crimp contact, two solutions were proposed in [11] consisting in experimental determination of specific losses by calculating the initial rate of temperature or checking reaching a critical temperature using on-level thermal indicator. To reduce of contact resistance and increase the reliability of crimped connections, useful solution were proposed in [12] by using two adjacent crimp indents in opposite sides instead of one crimp indents. In a recent work [13] is studied the influence of an improper crimped connection execution on crimping validation, analyzing the limits of variation of parameters so that it will not be compromised.

Checking the quality of a crimped connection is regulated by standards such as [14] and [15], imposing electrical, thermal and mechanical tests.

The electrical test involves measuring the contact resistances of a set of 6 samples, followed by the calculation of connector resistance factors and of a summative coefficient δ called "initial scatter" which must not exceed 0.3. The measurement process is simple but involves high precision measuring devices, necessary for determining resistances of μOhm level.

In [16], a study of the influence of experimental measurements accuracy on this coefficient was performed, cumulating data from 3 sets of crimped connections of barrel of terminal lug type, with different cross sections of cables. From the whole measurement process, 6 independent representative quantities were chosen, with direct influence on the value of δ. First, it was imposed a variation by one unit of hundredths digit of initial scatter and was recorded the variation of each quantity, the others 5 quantities being kept constant. Then simultaneous variations of the 6 quantities caused by device reading errors were imposed, determining the quantities with the greatest influence.

This paper extends the researches on crimped connections of bimetallic through connector type by analyzing two pairs of cross sections.The obtained results are added to those in paper [16] and can help the experimenter to pay more attention to measuring more influential quantities.

II. Connector Resistance Factor And Initial Scatter

The standard [14] establishes formulas for determining the connector resistance factor for different types of crimping: through connector, bimetallic through connector, branch connector, barrel of terminal lug, palm of terminal lug etc. For the experimental determinations are used sets of 6 samples and reference conductors of each type involved in crimping. The measurements are made in direct current.

For barrel of terminal lug type (Fig. 1) the connector resistance factor (k) is obtained by dividing the connector resistance R_{con} adjusted to its length l_{con} (noted r_{con}), by reference conductor resistance R_r adjusted to its length l_r (noted r_r) [14], [16]:

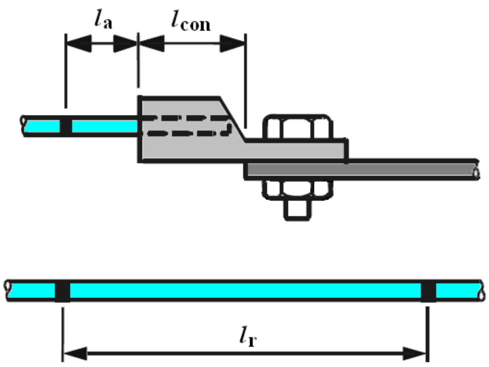

Fig.1. Barrel of terminal lug (a) and reference conductor (b) [16].

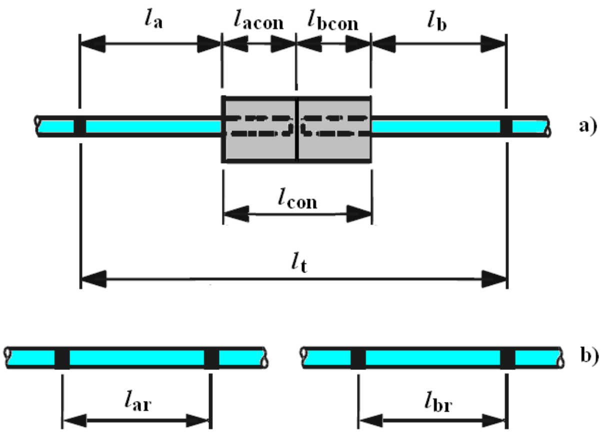

Fig.2. Bimetallic through connector (a) and reference conductors (b).

$$k = \frac{\frac{R_{con}}{l_{con}}}{\frac{R_r}{l_r}} = \frac{r_{con}}{r_r} \tag{1}$$

$$R_{con} = R_1 - R_r \cdot \frac{l_a}{l_r} = R_1 - r_r \cdot l_a \tag{2}$$

$$R_1 = \frac{U_1}{I_1} \cdot \frac{1}{1 + \alpha \cdot (\theta_a - 20°C)} \tag{3}$$

$$R_r = \frac{U_r}{I_r} \cdot \frac{1}{1 + \alpha \cdot (\theta_a - 20°C)} \tag{4}$$

where R_1 and R_r are referred to 20°C from the ambient temperature θ_a with temperature coefficient of resistance α = 0.004 K^{-1}, U_1 and U_r are the voltage drops on the lengths l_a + l_{con}, respectively, l_r , carrying the direct currents I_1 and I_r.

The length l_a is chosen according to the specifications of the standard.

For bimetallic through connector type (Fig. 2) the connector resistance factor (k) is obtained by dividing the connector resistance R_{con} by sum of both conductor resistances (R_{acon} and R_{bcon}) on the lengths l_{acon} and l_{bcon} that make up the connector [14]:

$$k = \frac{R_{con}}{R_{acon} + R_{bcon}} = \frac{R_{con}}{\frac{R_{ar}}{l_{ar}} \cdot l_{acon} + \frac{R_{br}}{l_{br}} \cdot l_{bcon}} = \frac{R_{con}}{r_{ar} \cdot l_{acon} + r_{br} \cdot l_{bcon}} \tag{5}$$

$$R_{con} = R_t - R_{acon} - R_{bcon} = R_t - r_{ar} \cdot l_{acon} - r_{br} \cdot l_{bcon} \tag{6}$$

$$R_t = \frac{U_t}{I_t} \cdot \frac{1}{1 + \alpha \cdot (\theta_a - 20°C)} \tag{7}$$

$$R_{ar} = \frac{U_{ar}}{I_{ar}} \cdot \frac{1}{1 + \alpha \cdot (\theta_a - 20°C)} \tag{8}$$

$$R_{br} = \frac{U_{br}}{I_{br}} \cdot \frac{1}{1 + \alpha \cdot (\theta_a - 20°C)} \tag{9}$$

where R_t , R_{ar} and R_{br} are referred to 20°C , U_t , U_{ar} and U_{br} are the voltage drops on the lengths l_a + l_{con}+ l_b, respectively, l_{ar} and l_{br} carrying the direct currents I_t, I_{ar} and I_{br}. The lengths l_a and l_b are chosen according to the specifications of the standard.

The initial scatter coefficient (δ) provides information on the behavior of the crimped connection immediately after installation before any aging effect begins. It is considered that 6 samples are sufficient to be tested to estimate the identification of a "family" of connectors. If the resistance factors for the type of connector tested are almost equal, it can be assumed that the same design and assembly technology will lead to the same result on a conductor of the same type. The resistance factors calculated above are considered to follow a normal distribution with unknown mean and unknown variance.

The empirical mean of the resistance factors before the standardized heat cycle 1 is an estimator for the unknown statistical mean:

$$\bar{k}_0 = \frac{1}{6} \cdot \sum_{i=1}^{6} k_i \tag{10}$$

The empirical standard deviation of the resistance factors of the six connectors before heat cycle 1 is an estimator for the unknown statistical standard deviation:

$$s_0 = \sqrt{\frac{1}{5} \cdot \sum_{i=1}^{6} \left(k_i - \bar{k}_0\right)^2} \tag{11}$$

The relative initial scatter of the mean of the connector resistance factors of the six connectors before heat cycle 1 standardized by the mean is:

$$\delta = \frac{1}{\sqrt{6}} \cdot \frac{s_0}{\bar{k}_0} \cdot t_s \tag{12}$$

where t_s is 99.5% quantile of Student distribution with 5 degree of freedom (t_s = 4.032).

This dimensionless parameter represents the percentage deviation from the estimated mean resistance factor and indicates that, for a given probability, a resistance factor is not expected to exceed. It is based on a 99% confidence interval for the unknown true mean. The quantile t_s indicates here that the confidence interval will cover the unknown true mean of the resistance factors with a 99% probability before the heat cycle 1.

III. Experimental Measurements

The measurements were performed on two types of crimped connections:

1) barrel of terminal lug type for three cables with cross sections: S_1 = 95 mm^2, S_2 = 185 mm^2, S_3 = 300 mm^2 [16];

2) bimetallic through connector type for two pairs of cables with cross sections S_{a4} = 70 mm^2, S_{b4} = 56.11 mm^2 and S_{a5} = 60.21 mm^2, S_{b5} = 120 mm^2.

For testing the first type, the samples were made in pairs, two at the ends of the same cable, so that for each cross section we have 3 cables with two crimps, counting 6 samples. In Fig. 3 are shown a pair of crimp connections. In these conditions the reference conductor resistance adjusted to length was deduced by (4) for each cable, identifying $l_{ai} = l_{ri}$ and averaging the results (Fig. 3):

$$r_r = \left(\frac{1}{3} \cdot \sum_{i=1}^{3} \frac{U_{ai}}{I_{ai} \cdot l_{ai}} \right) \cdot \frac{1}{1 + \alpha \cdot (\theta_a - 20°C)} \qquad (13)$$

The connector resistances results by (2) and (3) (Fig. 3):

$$R_{con1i} = R_{1i} - r_r \cdot l_{ai} \qquad (14)$$

For the second type, the samples were independent and the measured quantities are indicated in Fig. 4. The reference conductor resistances were deduced for each cable, identifying l_{ai} = l_{ari} and l_{bi} = l_{bri} and averaging the results (Fig. 4):

$$r_{ar} = \left(\frac{1}{6} \cdot \sum_{i=1}^{6} \frac{U_{ai}}{I_{ai} \cdot l_{ai}} \right) \cdot \frac{1}{1 + \alpha \cdot (\theta_a - 20°C)} \qquad (15)$$

$$r_{br} = \left(\frac{1}{6} \cdot \sum_{i=1}^{6} \frac{U_{bi}}{I_{bi} \cdot l_{bi}} \right) \cdot \frac{1}{1 + \alpha \cdot (\theta_a - 20°C)} \qquad (16)$$

The connector resistances results by (6)-(9) (Fig. 4):

$$R_{coni} = R_{ti} - r_{ar} \cdot l_{aconi} - r_{br} \cdot l_{bconi} \qquad (17)$$

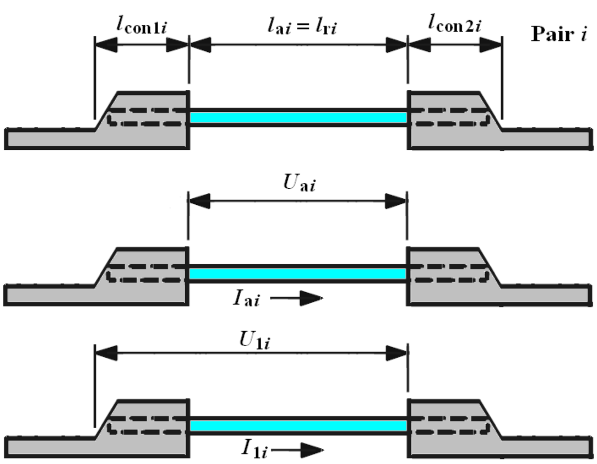

Fig. 3. Pair *i* with 2 samples and quantities taken into account for determining the reference conductor resistance and connector resistance for barrel of terminal lug [16].

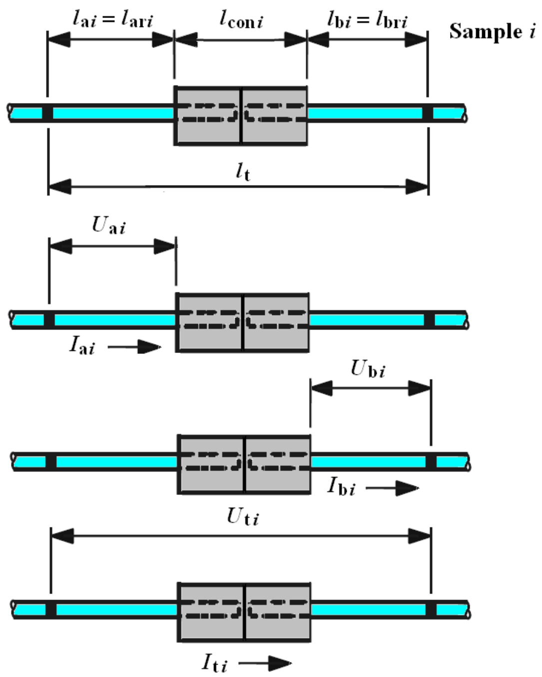

Fig. 4. Sample *i* and quantities taken into account for determining the reference conductor resistances and connector resistance for bimetallic through connector.

Measurement results on connector resistance factor (k), empirical mean of the resistance factors ($\bar{k}_0$), empirical standard deviation of the resistance factors (s_0) and initial scatter of the mean of the resistance factors (δ) are presented in Tables I-V for the two types of crimped connections. Graphical representations are shown in Figs. 5-9.

TABLE I.
MEASUREMENT RESULTS FOR CRIMPED CONNECTIONS OF BARREL OF TERMINAL LUG TYPE WITH CROSS SECTION S_1 = 95 mm^2 [16]

Sample	**1**	**2**	**3**	**4**	**5**	**6**
k	1,080	1,181	1,171	1,080	1,181	1,193
$\bar{k}_0$	1,147					
s_0	0,053					
δ	0,076					

TABLE II.
MEASUREMENT RESULTS FOR CRIMPED CONNECTIONS OF BARREL OF TERMINAL LUG TYPE WITH CROSS SECTION S_2 = 185 mm^2 [16]

Sample	**1**	**2**	**3**	**4**	**5**	**6**
k	0,923	0,686	0,812	0,797	0,652	0,822
$\bar{k}_0$	0,782					
s_0	0,099					
δ	0,208					

TABLE III.
MEASUREMENT RESULTS FOR CRIMPED CONNECTIONS OF BARREL OF TERMINAL LUG TYPE WITH CROSS SECTION S_2 = 300 mm^2 [16]

Sample	1	2	3	4	5	6
k	1,007	0,987	1,048	1,007	0,904	0,982
$\bar{k}_0$	0,989					
s_0	0,048					
δ	0,080					

TABLE IV.
MEASUREMENT RESULTS FOR CRIMPED CONNECTIONS OF BARREL OF TERMINAL LUG TYPE WITH CROSS SECTIONS S_{a4} = 70 mm^2, S_{b4} = 56.11 mm^2

Sample	1	2	3	4	5	6
k	1,122	1,288	1,473	1,439	1,272	1,151
$\bar{k}_0$	1,291					
s_0	0,144					
δ	0,183					

TABLE V.
MEASUREMENT RESULTS FOR CRIMPED CONNECTIONS OF BARREL OF TERMINAL LUG TYPE WITH CROSS SECTIONS S_{a4} = 60.21 mm^2, S_{b4} = 120 mm^2

Sample	1	2	3	4	5	6
k	0,800	0,594	0,551	0,492	0,596	0,639
$\bar{k}_0$	0,612					
s_0	0,105					
δ	0,282					

IV. ANALYSIS OF THE RESULT VARIATIONS

The used measuring instruments are analog: a voltmeter with a 30 scale-divisions, marked every 0.1 div, used in the 25mV/div range and an ammeter with a 150 scale-divisions, marked every 0.1 div, used in the 100A/150div range. The lengths of the conductors were measured with the measuring tape, marked every 1 mm (1 div).

The measurement process involves reading many quantities (Q) such as voltage drops, currents or conductor lengths, on which the final result depends

For crimped connections of barrel of terminal lug type [16] there are 6 sets of quantities of the same type: U_{ai}, I_{ai}, l_{ai}, U_{1i} and U_{2i}, I_{1i} and I_{2i}, l_{1i} and l_{2i}, $i=\overline{1\div3}$. From each set, only one quantity was chosen to study its influence on the final result. Therefore it can be written:

$$\delta = \delta(U_{aj}, I_{aj}, l_{aj}, U_{kj}, I_{kj}, l_{kj}) \qquad (18)$$

where the chosen indexes k and j correspond to the value farthest from the average of connector resistance factor k:

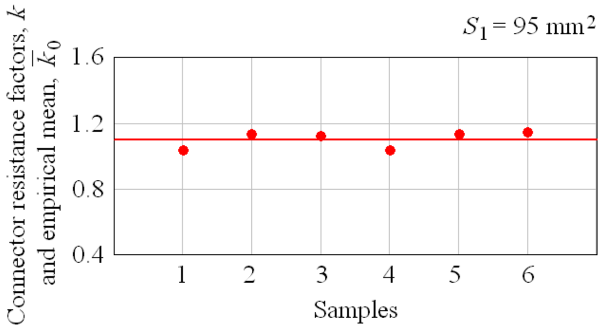

Fig. 5. Connector resistance factors and empirical mean for crimped connection of barrel of terminal lug type, S_1 = 95 mm^2 [16].

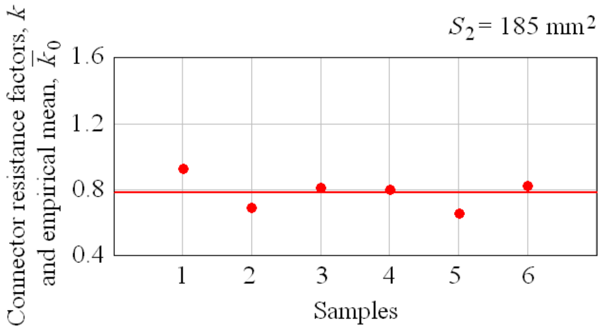

Fig. 6. Connector resistance factors and empirical mean for crimped connection of barrel of terminal lug type, S_2 = 185 mm^2 [16].

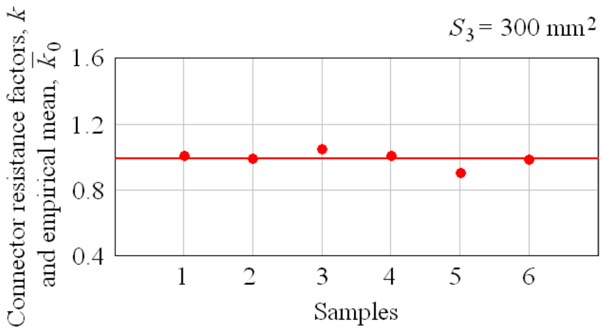

Fig. 7. Connector resistance factors and empirical mean for crimped connection of barrel of terminal lug type, S_3 = 300 mm^2 [16].

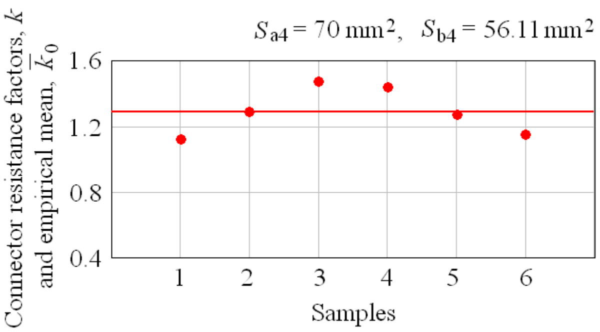

Fig. 8. Connector resistance factors and empirical mean for crimped connection of bimetallic through connector type, S_{a4} = 70 mm^2, S_{b4} = 56.11 mm^2.

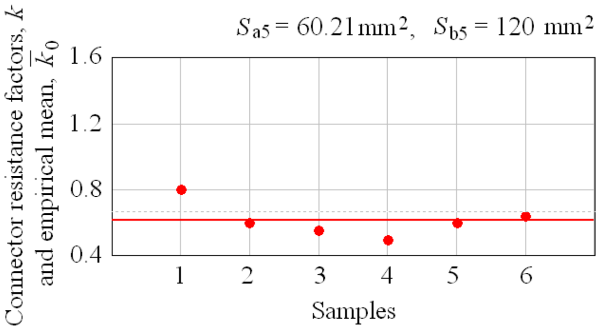

Fig. 9. Connector resistance factors and empirical mean for crimped connection of bimetallic through connector type, $S_{a5} = 60.21$ mm^2, $S_{b5} = 120$ mm^2.

$$\delta_{S1} = \delta_{S1}(U_{a1}, I_{a1}, l_{a1}, U_{11}, I_{11}, l_{11}) \quad (19)$$

$$\delta_{S2} = \delta_{S1}(U_{a1}, I_{a1}, l_{a1}, U_{11}, I_{11}, l_{11}) \quad (20)$$

$$\delta_{S3} = \delta_{S3}(U_{a2}, I_{a2}, l_{a2}, U_{22}, I_{22}, l_{22}) \quad (21)$$

For crimped connection of bimetallic through connector type the read quantities form also 6 sets of quantities of the same type: U_{ai} and U_{bi}, I_{ai} and I_{bi}, l_{ai} and l_{bi}, U_{ti}, I_{ti}, l_{ti}, $i = \overline{1 \div 6}$. As the same, from each set, only one quantity was chosen to study its influence on the final result. Therefore it can be written:

$$\delta = \delta(U_{aj}, I_{aj}, l_{aj}, U_{tj}, I_{tj}, l_{tj}) \quad (22)$$

where the chosen index j correspond to the value farthest from the average of the connector resistance factor k:

$$\delta_{S4} = \delta_{S4}(U_{a3}, I_{a3}, l_{a3}, U_{t3}, I_{t3}, l_{t3}) \quad (23)$$

$$\delta_{S5} = \delta_{S5}(U_{a1}, I_{a1}, l_{a1}, U_{t1}, I_{t1}, l_{t1}) \quad (24)$$

Based on this information, a study of the impact of the variations of these quantities on the initial scatter coefficient was performed.

In the first stage, it was imposed a variation $\Delta\delta_{lim}$ of initial scatter coefficient δ corresponding to the change by one unit of its hundredths digit:

$$\Delta\delta_{lim} = \frac{0.01}{\delta} \quad (25)$$

and the range of variation of each of the 6 quantities was exclusively determined (ΔQ_{lim}) and compared with the measuring instruments reading errors:

$$\Delta U = \frac{0.05 \cdot \text{div}}{U_{read}[\text{div}]}, \quad \Delta I = \frac{0.05 \cdot \text{div}}{I_{read}[\text{div}]}, \quad \Delta l = \frac{0.5 \cdot \text{div}}{l_{read}[\text{div}]} \quad (26)$$

This means that the variation limits of initial scatter for the five cases are $\Delta\delta_1$ = 12.790%, $\Delta\delta_2$ = 4.809%, $\Delta\delta_3$ = = 12.488% [16], $\Delta\delta_4$ = 5.457%, $\Delta\delta_5$ = 3.543%. The results are presented in Table VI.

It is observed that for crimped connections of barrel of terminal lug type the variations allowed for each voltage drops U_{kj} for the modification by one unit of the

TABLE VI. EXCLUSIVE VARIATION OF EACH QUANTITY THAT LEADS TO CHANGE BY ONE UNIT OF THE HUNDREDTHS DIGIT OF INITIAL SCATTER

Cross sections, S / Initial scatter, δ / $\Delta\delta_{lim}$	**ΔU_{aj_lim} / ΔU_{aj} [%]**	**ΔI_{aj_lim} / ΔI_{aj} [%]**	**ΔL_{aj_lim} / ΔL_{aj} [%]**	**ΔU_{kj_lim} / ΔU_{kj} [%]**	**ΔI_{kj_lim} / ΔI_{kj} [%]**	**ΔL_{kj_lim} / ΔL_{kj} [%]**
S_1 = 95 mm^2 δ_1 = 0.078 $\Delta\delta_{lim1}$ = 12.79%	ΔU_{a1_lim} 0.289 ΔU_{a1} 0.230	ΔI_{a1_lim} 0.289 ΔI_{a1} 0.062	ΔL_{a1_lim} 0.263 ΔL_{a1} 0.103	ΔU_{11_lim} 0.185 ΔU_{11} **0.213**	ΔI_{11_lim} 0.185 ΔI_{11} 0.062	ΔL_{11_lim} 0.178 ΔL_{11} 0.095
S_2 = 185 mm^2 δ_2 = 0.208 $\Delta\delta_{lim2}$ = 4.809%	ΔU_{a1_lim} 0.675 ΔU_{a1} 0.450	ΔI_{a1_lim} 0.675 ΔI_{a1} 0.060	ΔL_{a1_lim} 0.896 ΔL_{a1} 0.119	ΔU_{11_lim} 0.208 ΔU_{11} **0.403**	ΔI_{11_lim} 0.208 ΔI_{11} 0.060	ΔL_{11_lim} 0.223 ΔL_{11} 0.105
S_3 = 300 mm^2 δ_3 = 0.080 $\Delta\delta_{lim3}$ = 12.488%	ΔU_{a2_lim} 0.561 ΔU_{a2} 0.317	ΔI_{a2_lim} 0.562 ΔI_{a2} 0.033	ΔL_{a2_lim} 0.790 ΔL_{a2} 0.091	ΔU_{22_lim} 0.175 ΔU_{22} **0.287**	ΔI_{22_lim} 0.175 ΔI_{22} 0.033	ΔL_{22_lim} 0.192 ΔL_{22} 0.082
S_{a4} = 70 mm^2 S_{b4} = 56.11 mm^2 δ_4 = 0.183 $\Delta\delta_{lim4}$ = 5.457%	ΔU_{a3_lim} 9.765 ΔU_{a3} 0.455	ΔI_{a3_lim} 9.958 ΔI_{a3} 0.082	ΔL_{a3_lim} 1.929 ΔL_{a3} 0.325	ΔU_{t3_lim} 0.334 ΔU_{t3} 0.180	ΔI_{t3_lim} 0.334 ΔI_{t3} 0.083	ΔL_{t3_lim} 0.239 ΔL_{t3} 0.140
S_{a5} = 60.21 mm^2 S_{b5} = 120 mm^2 δ_5 = 0.080 $\Delta\delta_{lim5}$ = 3.543%	ΔU_{a1_lim} 5.13 ΔU_{a1} 0.440	ΔI_{a1_lim} 5.163 ΔI_{a1} 0.038	ΔL_{a1_lim} 0.943 ΔL_{a1} 0.347	ΔU_{t1_lim} 0.229 ΔU_{t1} 0.207	ΔI_{t1_lim} 0.229 ΔI_{t1} 0.034	ΔL_{t1_lim} 0.273 ΔL_{t1} 0.137

hundredths digit of initial scatter are lower than reading error of the voltmeter. Therefore an increased attention is indicated to these measurements, which are more sensitive. There is a general increase in the sensitivity of measurements ($\Delta Q/\Delta Q_{lim}$) to smaller sections of conductors.

For crimped connection of bimetallic through connector type a greater sensitivity of measurements can be associated to the greater rate of cross sections (S_{max}/S_{min}).

In the second stage, a variation identical to the reading errors of the measuring instruments was imposed exclusively for each quantity and the effect on the initial scatter variation was recorded. The results are presented in Table VII.

Once again, there is a greater sensitivity in measuring U_{kj} voltage drops ($\Delta\delta / \Delta\delta_{lim}$) compared to other quantities in the case of barrel of terminal lug. The same trend can be found in measuring U_{ti} voltage drops for bimetallic through connector, especially for greater rate of cross sections (S_{max}/S_{min}).

In the last stage, the impact of the simultaneous variations of the 6 quantities on the initial scatter coefficient was evaluated, using the theory of experimental design [17], [18], [19]. For this, the matrix of experiments X in normalized form having $2^6 \times 2^6$ elements was used, in which the variation limits of quantities were replaced by – 1 and +1 and the vector of the response function Y carries the corresponding initial scatter values.

TABLE VII. EFFECT OF EXCLUSIVE VARIATION IDENTICAL TO READING ERROR OF EACH QUANTITY ON INITIAL SCATTER

Cross section, S / Initial scatter, δ / $\Delta\delta_{lim}$	**ΔU_{aj} / $\Delta\delta$ [%]**	**ΔI_{aj} / $\Delta\delta$ [%]**	**ΔL_{aj} / $\Delta\delta$ [%]**	**ΔU_{kj} / $\Delta\delta$ [%]**	**ΔI_{kj} / $\Delta\delta$ [%]**	**ΔL_{kj} / $\Delta\delta$ [%]**
S_1 = 95 mm^2	ΔU_{a1}	ΔI_{a1}	ΔL_{a1}	ΔU_{11}	ΔI_{11}	ΔL_{11}
δ_1 = 0.078	0.230	0.062	0.103	0.213	0.062	0.095
$\Delta\delta_{lim1}$ = 12.79%	10.190	2.743	5.002	**15.008**	4.418	7.015
S_2 = 185 mm^2	ΔU_{a1}	ΔI_{a1}	ΔL_{a1}	ΔU_{11}	ΔI_{11}	ΔL_{11}
δ_2 = 0.208	0.450	0.060	0.119	0.403	0.060	0.105
$\Delta\delta_{lim2}$ = 4.809%	3.231	0.432	0.646	**9.307**	1.396	0.280
S_3 = 300 mm^2	ΔU_{a2}	ΔI_{a2}	ΔL_{a2}	ΔU_{22}	ΔI_{22}	ΔL_{22}
δ_3 = 0.080	0.317	0.033	0.091	0.287	0.033	0.082
$\Delta\delta_{lim3}$ = 12.488%	7.167	0.752	1.494	**20.357**	2.375	5.337
S_{a4} = 70 mm^2 S_{b4} = 56.11 mm^2	ΔU_{a3}	ΔI_{a3}	ΔL_{a3}	ΔU_{t3}	ΔI_{t3}	ΔL_{t3}
δ_4 = 0.183	0.455	0.082	0.325	0.180	0.083	0.140
$\Delta\delta_{lim4}$ = 5.457%	0.255	0.046	0.977	2.958	1.366	3.243
S_{a5} = 60.21 mm^2 S_{b5} = 120 mm^2	ΔU_{a1}	ΔI_{a1}	ΔL_{a1}	ΔU_{t1}	ΔI_{t1}	ΔL_{t1}
δ_5 = 0.080	0.440	0.038	0.347	0.207	0.034	0.137
$\Delta\delta_{lim5}$ = 3.543%	0.304	0.026	1.305	3.214	0.520	1.777

$$X=\begin{pmatrix} 1 & -1 & -1 & -1 & -1 & \dots & 1 \\ 1 & 1 & -1 & -1 & -1 & \dots & -1 \\ 1 & -1 & 1 & -1 & -1 & \dots & -1 \\ 1 & 1 & 1 & -1 & -1 & \dots & 1 \\ 1 & -1 & -1 & 1 & -1 & \dots & -1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix},\quad Y=\begin{pmatrix} Y_1 \\ Y_2 \\ Y_3 \\ Y_4 \\ Y_5 \\ \\ Y_{64} \end{pmatrix} \qquad (27)$$

The effect of the variation of the quantity Q_m on the initial scatter is obtained with the formula:

$$E(Q_m)=\frac{1}{64}\cdot\sum_{s=1}^{64}\left(Y_s\cdot X_{s,m+1}\right),\quad m=\overline{1\div 6} \qquad (28)$$

Based on this study were drawn the histograms of effects shown in Figs. 10-14.

As expected, for barrel of terminal lug the most influential quantities are U_{kj} voltage drops on connector + conductor, all the more so as the quality of the crimps is worse (case of S_2).

The least influence has I_{aj} currents measured in order to calculate the resistance of the reference conductor.

For bimetallic through connector the most influential quantities are the total lengths l_{ti} of assembly conductor a + connector + conductor b, but quite influential is also the total voltage drops U_{ti}.

However, the sensitivities for bimetallic through connector type are lower than for barrel of terminal lug type.

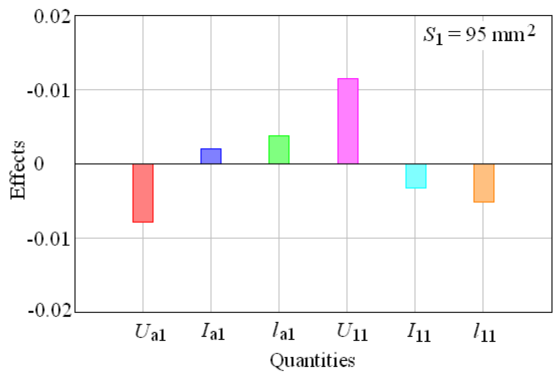

Fig. 10. Histogram of effects for S_1 = 95 mm^2 [16].

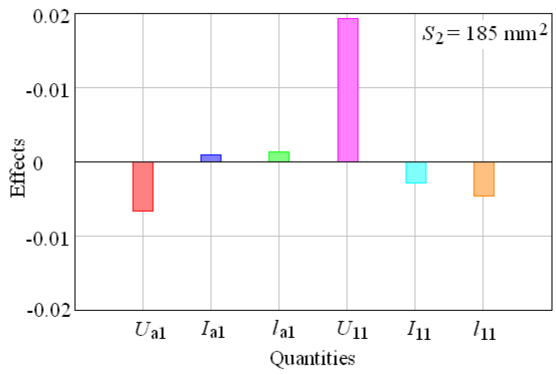

Fig. 11. Histogram of effects for S_2 = 185 mm^2 [16].

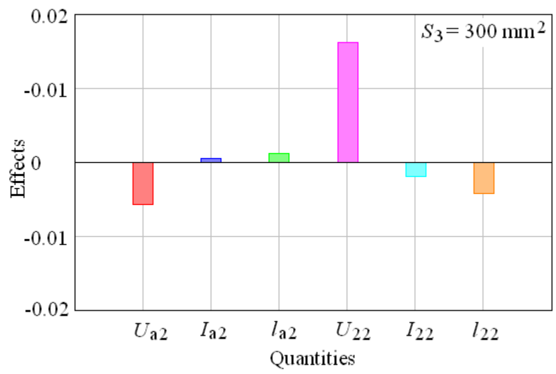

Fig. 12. Histogram of effects for S_3 = 300 mm^2 [16].

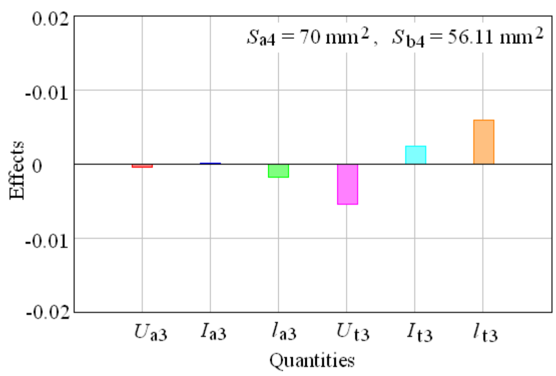

Fig. 13. Histogram of effects for S_{a4} = 70 mm^2, S_{b4} = 56.11 mm^2.

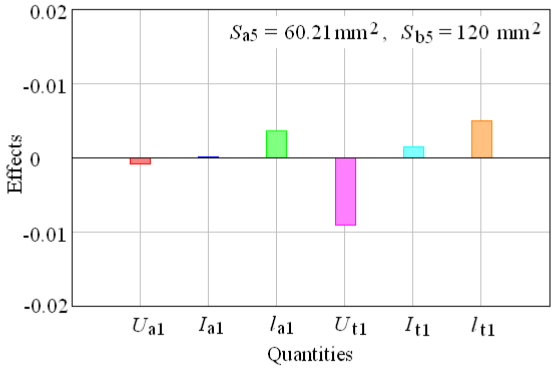

Fig. 14. Histogram of effects for S_{a5} = 60.21 mm^2, S_{b5} = 120 mm^2.

V. Conclusions

The impact of the experimental measurements accuracy on validation process of crimped connections was studied, cumulating data for two constructive types: barrel of terminal lug and bimetallic through connector. For this study, three sets of samples of the first type and two sets of the second type were used, for which the connector resistance factor and the summative coefficient initial scatter were determined.

Choosing 6 independent representative quantities with direct influence on the initial scatter it was found that for crimped connections of the first type, the measurement of voltage drops on both conductor + connector is very sensitive, being able to induce errors that affect the hundredths digit of this coefficient by more than one unit. As a result, the entire validation process can be compromised if initial scatter exceed to 0.3. It was also observed a general increase in the sensitivity of measurements to smaller sections of cables.

For the second type, a greater sensitivity can be associated to the greater rate of cross sections of cables involved in crimping.

Cumulating the variations of the quantities caused by the reading errors of the measuring instruments, the same conclusions are reached, which recommends an increased attention of the experimenter to measuring of voltage drops on both conductor + connector, for barrel of terminal lug type and to measuring the total lengths of assembly conductor a + connector + conductor b and also the total voltage drops, for bimetallic through connector type.

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