TRACEABILITY IN FORCE MEASUREMENT IN REPUBLIC OF CROATIA

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Abstract: In this study, based on results of the previously performed calibrations and factory specifications, an analysis of force measurement equipment in Republic of Croatia has been done. Transfer force standards of the Laboratory for Testing Mechanical Properties (LIMS) have been calibrated in HBM, Germany. Calibration curves for specific transfer standards were obtained, to be used for estimation of standard uncertainties. Also, expanded measurement uncertainty was calculated at each measuring point, according to the document EA-4/15. This was used for determining the best measuring capability of the Laboratory, as well as for developing of the equipment calibration scheme for force measurement in Croatia. The previous and last calibration results for the same transfer standards were compared and, further to it, certain conclusions were made on how characteristics of the standards are influenced by use during certain period of time.

1. Introduction

Force measurement is the basis for assessment of mechanical properties of material or products. For the continuously assured measurement traceability, calibration of a series of standards, from national standard to the force test equipment, shall be performed in certain periods of time. One of the major parameters of result traceability during force measurement is uncertainty of measurement i.e. measurement capability of the equipment and laboratory that provide the measurement results.

The question is, how to insure traceability in small countries such as Republic of Croatia? These countries, including their economy, are not capable to invest into the first class equipment i.e. to provide the national force standard that should be the base for all other force gauges, all over to the testing laboratories in companies.

2. Analysis of the current state-of-the-art in Croatia

The Laboratory for Testing Mechanical Properties (LIMS) at the Faculty of Mechanical Engineering and Naval Architecture (FSB) is authorized for calibration of the test equipment for force measurement in Croatia; the force gauges data are available. Analyzing these data, it was found that 90% of the force measurement equipment in Croatia meet the criteria of class 1, 2 and 3, according to the norm EN 10002-2 [1]. It was also found that no fixed device can provide values with the best measurement uncertainty according to EA- 4/15 [2] for the force calibration machine types. It is to conclude, that there is no device in Croatia meeting the criteria of the national or reference force standard. This means that Croatia shall rely on other country's metrological infrastructure.

Other parts of the equipment can meet the the highest class criteria. This comprises transfer standards of LIMS. Their factory specifications indicate possibility to meet the highest class specifications for calibration equipment; further to it, calibration has been performed.

3. Calibration of transfer standards

The used transfer standards are made up of measurement amplifier MGC with the read-off device, which serves as the deformation converter (Figure 1) and from dynamometers (type Z4 and C16AC3- Figure 2) serving as deforming body.

C16AC3

Z4

Figure 1: Measurement amplifier MGC   Figure 2: Dynamometers

The transfer standard is made up of two components and the calibration is performed on the whole equipment, but the measurement amplifier MGC was previously calibrated as an electrical device. Four dynamometers were used, therefore four transfer standards were applied:

1. MGC-Z4/20 kN
2. MGC-Z4/100 kN
3. MGC-Z4/200 kN
4. MGC-C16AC3/600 kN

As there is neither national force standard in Croatia nor the laboratory owing reference standard, calibration of these transfer standards was peformed in HBM (Hottinger Baldwin Messtechnik) calibration laboratory in Darmstadt, Germany. HBM is a DKD (Deutscher Kalibrierdienst) approved laboratory with required measurement possibility for calibration of the mentioned equipment. Its best measurement possibility is $\leq 1x10^{-4}$, which allows calibration of the class 00 transfer standards.

Calibration was preformed according to the norm EN 10002-3 [3]. Partial measurement uncertainty was calculated and estimated according to the document EA-4/02 [4]. The composed standard uncertainty of the transfer standard is geometrical sum of the following items:

− best measurement capability of the calibration laboratory (u_{ref})
− standard uncertainty of the dynamometer calibration (u_{din}) and
− standard uncertainty of the amplifier calibration (u_{MP})

The uncertainties, estimated from the results of dynamometer calibration are: uncertainty of zero error (u_{nul}), uncertainty of the result reproducibility in the same installation position (u_{pon}) and in different installation positions (u_{rot}), uncertainty of interpolation deviation (u_{int}), uncertainty of resolution of the read-off device (u_{rez}) and uncertainty of reversibility (u_{his}).

Equation for calculation of the composed standard uncertainty of the transfer standard is as follows:

$$u_{c-PE} = \sqrt{u_{ref}^2 + u_{din}^2 + u_{MP}^2} \qquad (1)$$

For calculating of the expanded uncertainty of the transfer standard calibration, the following equation was used:

$$U_{PE} = k \times u_{c-PE} \qquad (2)$$

The coefficient of coverage k=2 was applied, which refers to the coverage probability of 95%.

Table 1 provides measuring points of each transfer standard and calculated values of expanded measurement uncertainty using the previously specified calculation, for each measuring point.

Table 1: Values of expanded measurement uncertainty for transfer standards

MGC-Z4/20		MGC-Z4/100		MGC-Z4/200		MGC-C16AC	
F,kN	U,%	F,kN	U,%	F,kN	U,%	F,kN	U,%
2	0,052	10	0,044	20	0,043	60	0,057
4	0,039	20	0,043	40	0,034	120	0,059
6	0,033	30	0,040	60	0,032	180	0,040
8	0,030	40	0,034	80	0,030	240	0,034
10	0,026	50	0,029	100	0,026	300	0,033
12	0,024	60	0,028	120	0,024	360	0,031
14	0,023	70	0,028	140	0,022	420	0,027
16	0,021	80	0,028	160	0,021	480	0,027
18	0,021	90	0,027	180	0,021	540	0,026
20	0,021	100	0,027	200	0,021	600	0,024

4. Analysis of results

In Figure 3, layout of expanded measurement uncertainties within measurement range of each transfer standard is presented. It can be seen at first sight that the highest expanded measurement uncertainty for all standards is placed in the first fifth of their measurement range. If the total measurement range from 0-600 kN is considered, the highest value is 0,059% for the transfer standard MGC-C16AC3/600 kN. All these standards meet the class 00.
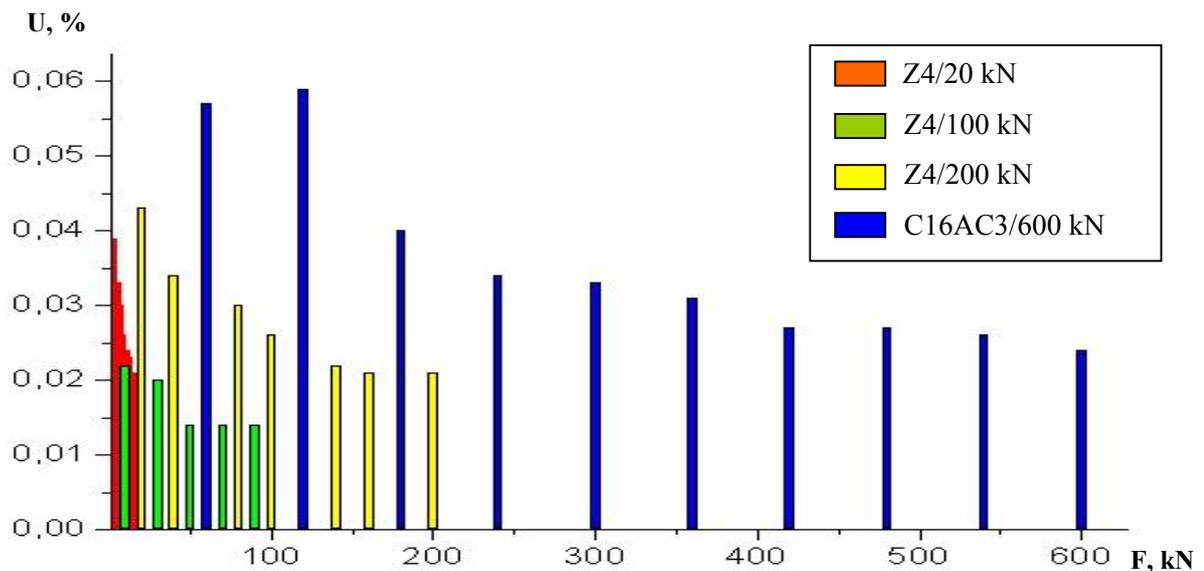

Figure 3: Overlapping of force measurement range for particular transfer standards

The highest values of expanded measurement uncertainty for each transfer standard in the measurement range are:
- MGC - Z4/20 kN → 0,052 %
- MGC - Z4/100 kN → 0,044 %
- MGC - Z4/200 kN → 0,043 %
- MGC - C16AC3/600 kN → 0,059 %

As these values are in the first fifth of the measurement range of each transfer standard, where standards of lower nominal force are used, values of expanded measurement uncertainty under working conditions are lower.

For all four transfer-standards, force increase decreases proportion of uncertainty. Figure 3 also shows that expanded measurement uncertainty of the transfer standard at 40 – 100% of nominal force becomes approximately a constant absolute value. This shows that transfer standards of elastic device type for measurement at 40-100% of nominal force have certain stability. Further to it, these transfer standards should be used in that measurement range during calibration of the force gauges, because that way lesser measurement uncertainty is introduced.

Dynamometer has the greatest influence to the total expanded measurement uncertainty in all four standards, while the least influence has measurement uncertainty of the amplifier. In Figure 4 (a, b, c, and d) are the values of particular standard uncertainties at each measuring point, as well as the composed standard uncertainty of dynamometer. These values are expressed in mV/V.
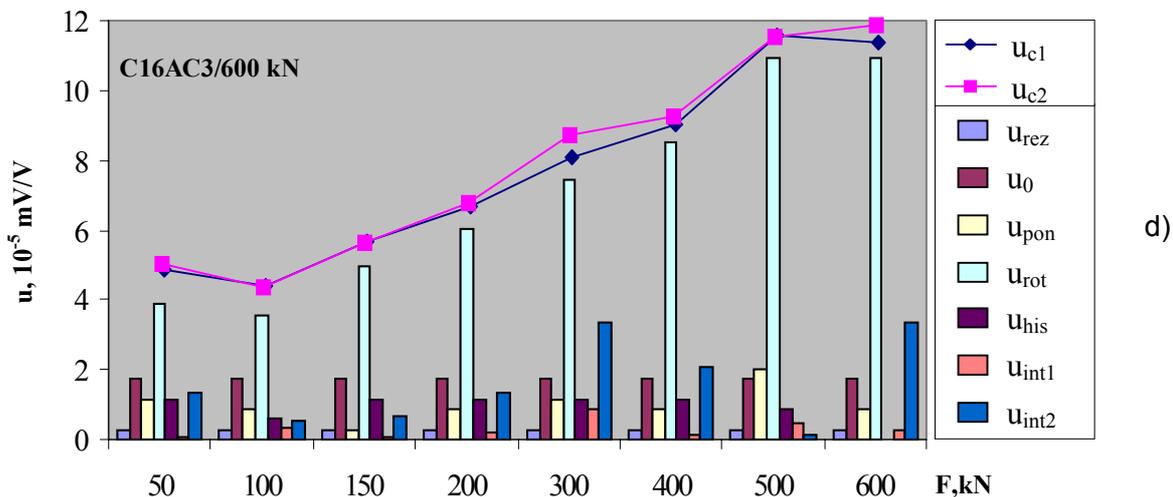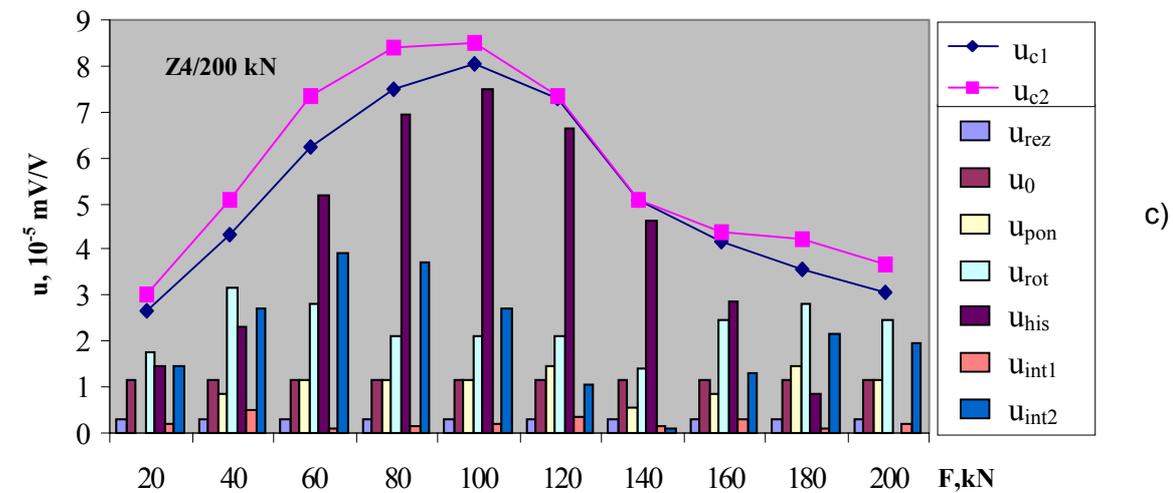

a)

b)
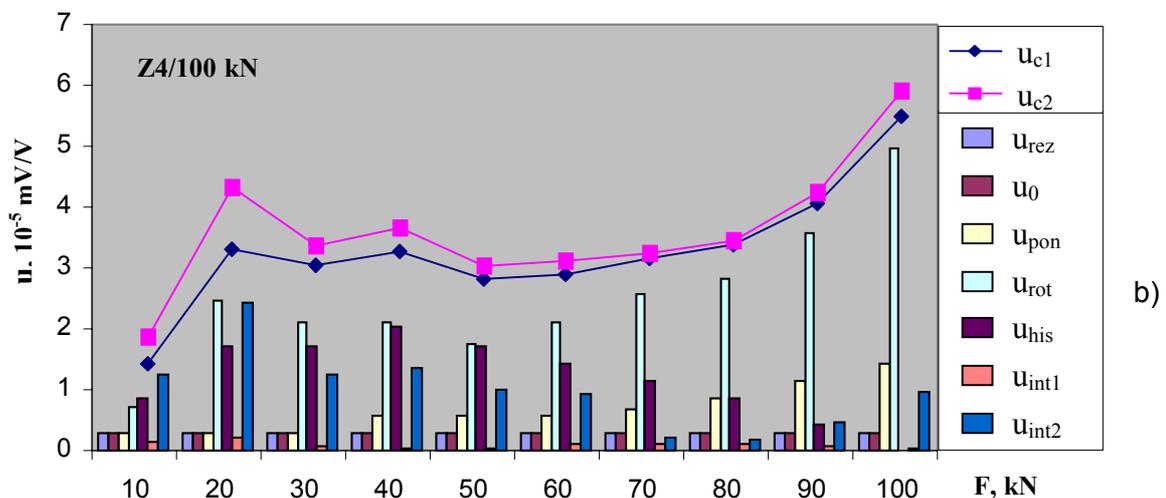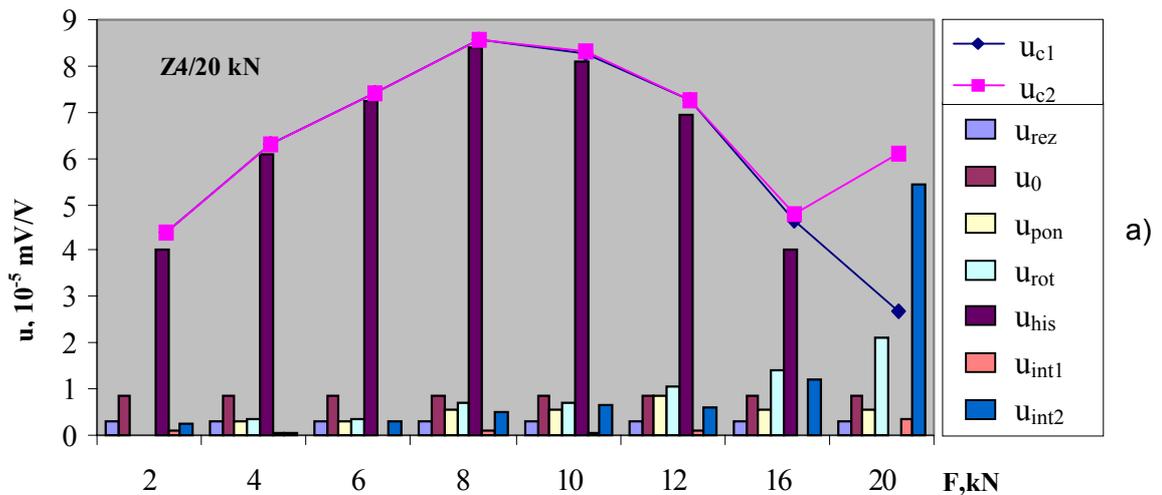
Figure 4: Distribution of standard uncertainties for dynamometer
    a) Z4/20 kN
    b) Z4/100 kN
    c) Z4/200 kN
    d) C16AC3/600 kN

These figures also show the composed standard uncertainties of dynamometer with applied polynomial interpolation (u_{c1}) and composed standard uncertainties of dynamometer with applied linear interpolation (u_{c2}). It is to mention that polynomial interpolation is performed by the third degree polynomial. Analysis of the results of calibration of dynamometers has shown that following errors have influence to estimation of measurement uncertainty.

    − reproducibility during change of the dynamometer position *(Z4/ 100kN; C16AC3/600 kN)*
    − errors due to the reversibility measurement *(Z4/20 kN; Z4/200 kN)*,
    − linearization of the calibration curves *(Z4/100 kN; Z4/200 kN; C16AC3/600 kN)*.

Difference between standards that were used for one calibration period (Z4/20, C16AC3/600) only and the standards which were used for two calibration periods (Z4/100, Z4/200) is obvious. There is increase of measurement uncertainty of the transfer standards, which were more used during linearization of their calibration curve – see Figures 4 b and c. The transfer standard Z4/200 has a significant difference between polynomial and linear

interpolation (Figure 4c). The same effect appears at Z4/100 (Figure 4b). In contrast to them, Z4/20 and C16AC3/600 have a small difference between these interpolations. While applying a certain kind of interpolation for calibration results, caution must be taken.

The best measurement capability of LIMS has been defined according to these testing results, according to the reference [5] and to the Laboratory policy in exposition of the best measurement capability.

3. Conclusion

Republic of Croatia has neither national nor reference standard in the force measurement field. The model of measurement traceability is a link to such standards in other countries, i.e. in Germany. LIMS calibrates its transfer standards in HBM calibration laboratory. In Croatia, it is the calibration laboratoy for force test equipment with the best measurement capability $U_{LIMS} \leq 0,06\%$. Further to it, a measurement traceability scheme for force measurement equipment in Republic of Croatia has been developed, as shown in Figure 5.
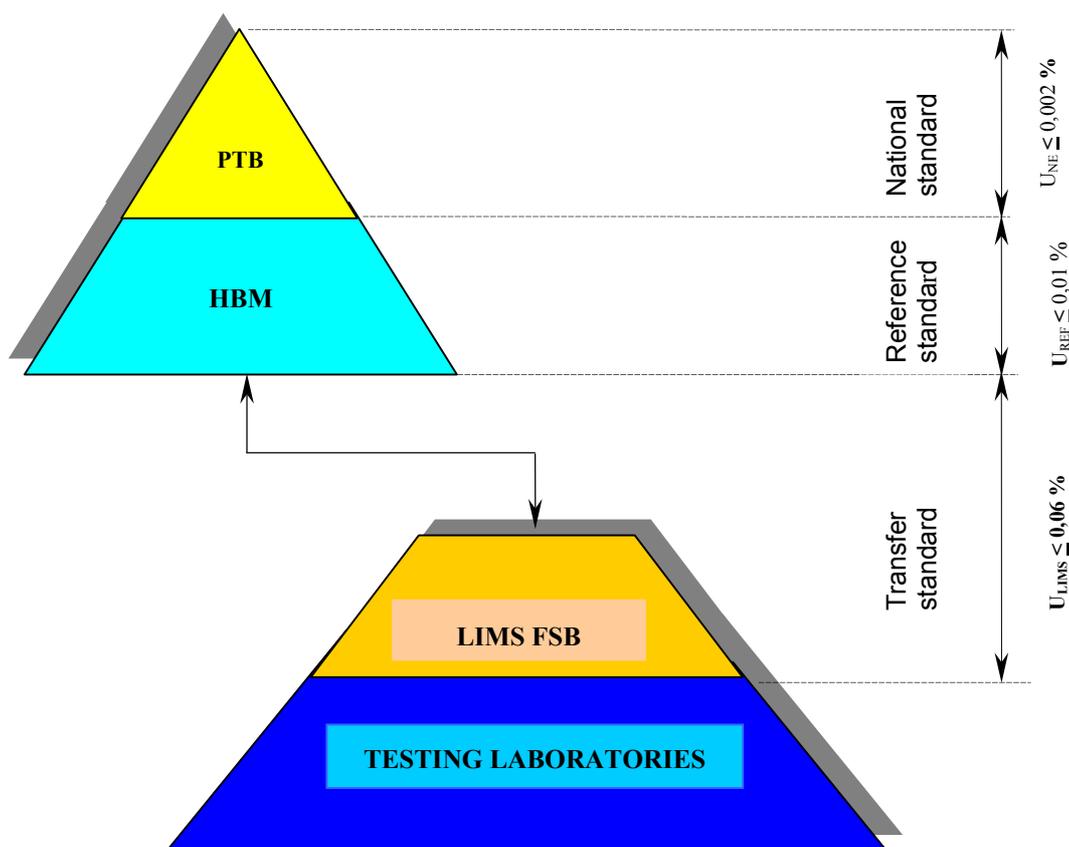

Figure 5: Schematic review of measurement traceability for force gauges in Croatia

REFERENCE:
[1]   EA-4/15 (EAL-G22):Uncertainty of Calibration Results in Force Measurement, 1996.
[2]   EN 10002-2: Metallische Werkstoffe – Zugversuch – Teil 2: Prüfung der Kraftmessseinrichtungen von Zugprüfmaschinen, 1994.
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[4]   EA-4/02: Expression of Uncertainties of Measurement in Calibration, 1999.
[5]   A. Sawla: Guidance for the determination of the best measurement capability of force calibration machines and uncertainty of calibration results of force measuring devices, PTB-Mitteilungen 104 4/94, pp.237-242.

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