INTERLABORATORY COMPARISON BETWEEN TUBITAK-UME TURKEY AND INM ROMANIA IN THE FIELD OF FORCE MEASUREMENTS

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Abstract. *Force Laboratory of TUBITAK-UME (Turkey) and INM (Romania) conducted a bilateral comparison of force standard machines between the force range 2 kN and 1000 kN in accordance with EURAMET Project no 838. The main goal of the interlaboratory comparison was to demonstrate the compatibility of the measurements results between the participating laboratories, with the view to support the CMCs declared and accepted in the frame of the CIPM MRA. The paper comprises the conditions of the measurements and summarized the results of the bilateral comparison involving the force standard machines of TUBITAK-UME, Turkey and INM, Romania. The measurement procedure applied and the method to evaluate the interlaboratory comparison results are presented.*

Keywords: *force interlaboratory comparison*

Rezumat. *Laboratoarele Forţe din TUBITAK-UME (Turcia) şi din INM (Romania) au participat la o comparare bilaterală a maşinilor etalon de forţă de 2 kN şi 100 kN, conform Proiectului EURAMET nr. 838. Principalul scop al acestei intercomparări a fost demonstrarea compatibilităţii rezultatelor măsurărilor celor două laboratoare, în vederea susţinerii CMC-urilor declarate şi acceptate în cadrul CIPM MRA. Lucrarea cuprinde condiţiile de măsurare şi recapitulează rezultatele intercomparării bilaterale a maşinilor etalon de forţă ale TUBITAK-UME şi INM. Sunt prezentate metodele de măsurare şi metodele de evaluare ale rezultatelor acestei intercomparări.*

Cuvinte cheie: *comparare interlaboratoare de forţe*

1. INTRODUCTION

The Force Laboratories of TUBITAK-UME (Turkey) and INM (Romania), each administering theirs own national force standards, conducted a bilateral comparison of force standard machines in the range from 2 kN to 1000 kN, in accordance with EURAMET Project No 838.

The Force Laboratory of TUBITAK-UME was selected as pilot laboratory in the view of organizing and progress the comparison measurements. The choice of TUBITAK-UME as pilot laboratory is based on its good results obtained in several participations in bilaterally comparison measurements with PTB Germany and also in CIPM key comparisons.

The following force standard machines were involved in the interlaboratory comparison between TUBITAK-UME and INM:

• Pilot laboratory (TUBITAK-UME):

– Deadweight force standard machine, having maximum capacity of 11 kN, in the range from 100 N to 11 kN;

– Lever-type machine, having capacities up to 110 kN in deadweight side, in the range from 2 kN to 110 kN and lever amplification of the force in the range from 20 kN to 1,1 MN, as shown in **Fig.1**.

• Participating laboratory (INM):

– Deadweight force standard machine, having maximum capacity of 10 kN, in the range from 500 N to 10 kN;

– Deadweight force standard machine, having maximum capacity of 100 kN, in the range from 5 kN to 100 kN, as shown in **Fig. 2**;

– Comparison force standard machine, with reference standards having nominal ranges of 50 kN, 100 kN, 200 kN, 500 kN and 1000 kN, as shown in **Fig. 3.**

The bilateral comparison of the force standard machines of the two participating laboratories in the range from 2 kN to 1000 kN was carried out by using transfer compression force transducers, with the nominal ranges of: 5 kN, 10 kN, 50 kN, 100 kN, 500 kN and 1 000 kN, having a very good proved stability. All the nominated transfer

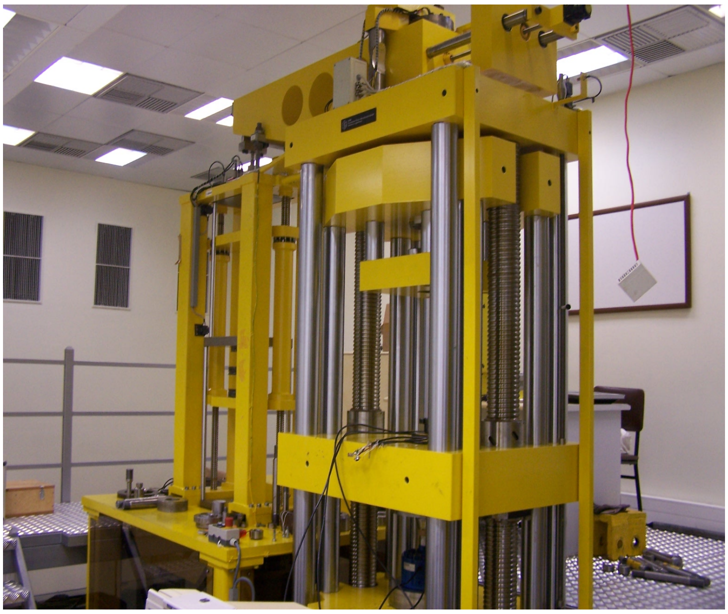

Fig. 1. 110 kN/1.1 MN Lever amplification dead weight force standard machine of TUBITAK-UME.

force standards are belonging to the pilot laboratory (TUBITAK-UME).

Comparison measurements have been realized by TUBITAK-UME and INM in the period September 2008-December 2008.

Prior starting the comparison procedure, the participating laboratories developed together measurement procedures and methods to evaluate uncertainties. The procedure for performing the comparison measurements meets the requirements of the international practices in the field (EURAMET, EA).

Both participants measured the output signal of the same transfer force transducers, connected with their own indicating instrument, in the nominated conditions, using the given measurement procedure, in the existing laboratory ambient conditions.

The values of measurements and the associated uncertainties, estimated in accordance with international standards, norms and procedures, were stated by each laboratory as part of the calibration report.

Fig. 2. 100 kN dead weight force standard machine of INM.

Fig. 3. 1000 kN force standard machine with reference transducers of INM.

The degrees of equivalence of the two laboratories relative to comparison reference values were estimated and presented by the pilot laboratory.

All activities carried out for interlaboratory comparison described in the paper observed the Guidelines on Conducting Comparisons edited by EA.

In the paper the main results obtained during the interlaboratory comparison are discussed, in particular an analysis was applied to evaluate the differences in the reproducibility and accuracy given by the participating calibration laboratories.

2. THE COMPARISON PROCEDURE

The comparison measurements were made to determine the relative deviations between the various forces realized by TUBITAK-UME and INM and the degree of equivalence between the two laboratories.

For this purpose, six force transducers belonging to TUBITAK-UME (used for 12 years in PTB and TUBITAK-UME comparison measurements) were utilized in the interlaboratory comparison. For each force transducer, several force steps were established for interlaboratory comparison.

The measurements were performed only in compression mode, in accordance with international procedures and gudelines utilized for interlaboratory comparisons in the field of force.

The utilized force transducers and the established force steps for comparison are presented in Table 1.

Table 1. **Force transducers used for interlaboratory comparison**

Nominal range	Force steps
5 kN	2 kN, 3 kN, 4 kN, 5 kN
10 kN	4 kN, 6 kN, 8 kN, 10 kN
50 kN	20 kN, 30 kN, 40 kN, 50 kN
100 kN	40 kN, 60 kN, 80 kN, 100 kN
500 kN	200 kN, 300 kN, 400 kN, 500 kN
1000 kN	400 kN, 600 kN, 800 kN, 1000 kN

Since the force transducers are not assumed to have long-term stability, the bilateral comparison between TUBITAK-UME and INM was carried out under a strict time schedule. This enables the participating institutes to make their measurements within a fixed period of time.

Initial measurements of all force transducers were carried out first at TUBITAK-UME in September 2008. These measurements were afterwards performed at INM in October 2009 by a set of similar measurements. To verify the stability of the force transducers used during the comparison, a final set of measurements was obtained at TUBITAK-UME as well.

All activities carried on during interlaboratory comparison followed the Technical Protocol established between TUBITAK-UME and INM.

2.1. Measurement procedure

The measurement procedure for performing the comparison measurements is described in short in below.

Before starting each measurement, the indicating instruments used in comparison, belonging to INM and TUBITAK-UME, both model DMP 40, were calibrated by TUBITAK-UME calibrator, model BN 100.

To minimize the effect of creep, for each force transducer included in the comparison, the time required to achieving a stable response following loading and unloading was determined prior to start the comparison.

In most instances it was found that a 3 minutes time delay between the initiation of the loading (or unloading) and the actual reading is adequate. However, after the force transducer is loaded or unloaded, some drifts due to mechanical, thermal and electrical effects may occur in the output of the transducer for longer time.

Many measurements and experience of the participating laboratories show that this effect on force transducer output stabilizes within about 3 minutes. For these reasons 4 minutes time delay was selected as a time interval between measurements.

Machine-transducer interactions can significantly influence measurement accuracy. To minimize the errors due to these non-axial components of deformation, the response of each force transducer was obtained at five symmetrically distributed positions relative to the axis of the machine (0º, 90º, 180º, 270º, 360º). In order to get better results, prior to start of a measurement cycle, the force transducer was loaded with maximum test load three times at the 0º position.

Each first series of measurements was used as preloading series for 0º, 90º, 180º, 270º, 360º positions of the transfer force transducers.

For deadweight machines, three sets of measurements at 0º, two sets of measurements at 90º, 180º, 270º rotational positions were applied in increasing loadings. A set of measurements at 360º was applied increasing and decreasing loadings, using 5 kN, 10 kN, 50 kN and 100 kN transfer force transducers.

For comparator machine of INM, due to hysteresis effect of the reference transducers, three sets of measurements at 0º, two sets of measurements at 90º, 180º, 270º and 360º rotational positions were applied in increasing and decreasing loadings, using 500 kN and 1000 kN transfer force transducers.

All measurements were carried out at a temperature range of (21±1) ºC and relative humidity (45±10) %, the usual laboratory conditions at TUBITAK-UME and INM.

2.2. Evaluation method of comparison results

The evaluation of the comparison results and the drawing up of the comparison Report were performed by TUBITAK-UME collecting all measurement data by the contribution of INM.

Analytical measurement results obtained during the comparison are presented in the Tables from 2 to 7.

The values x_{UME} were calculated on the basis of average deflections obtained by TUBITAK-UME at initial measurements and final measurements respectively, taking into account a linear drift of the utilized transfer force transducers.

The values x_{INM} represent the averages of the measurement deflections, at corresponding force steps with increasing force, obtained by INM.

W_{UME} and W_{INM} are the expanded relative uncertainties obtained by TUBITAK-UME and INM respectively, associated with the measurement results.

Table 2. **TUBITAK-UME and INM 10 kN deadweight machine comparison using 5 kN load cell GTM-SN:01275**

Force steps, kN	x_{UME}, mV/V	W_{UME}	x_{INM}, mV/V	W_{INM},
2	0,799652	2,92E-05	0,799692	3,66E-05
3	1,199566	3,18E-05	1,199635	3,38E-05
4	1,599423	3,25E-05	1,599512	3,62E-05
5	1,999129	3,35E-05	1,999243	4,42E-05

Table 3. **TUBITAK-UME and INM 10 kN deadweight machine comparison using 10 kN load cell GTM-SN:00117**

Force steps, kN	x_{UME}, mV/V	W_{UME}	x_{INM}, mV/V	W_{INM}
4	0,802629	2,85E-05	0,802592	4,21E-05
6	1,204013	2,38E-05	1,203957	2,83E-05
8	1,605339	2,21E-05	1,605266	2,61E-05
10	2,006545	2,26E-05	2,006475	2,53E-05

Table 4. **TUBITAK-UME and INM 100 kN deadweight machine comparison using 50 kN load cell GTM-SN:00367**

Force steps, kN	x_{UME}, mV/V	W_{UME},	x_{INM}, mV/V	W_{INM}
20	0,800350	3,05E-05	0,800338	3,46E-05
30	1,200672	2,63E-05	1,200623	3,00E-05
40	1,601050	2,56E-05	1,600973	2,70E-05
50	2,001499	2,53E-05	2,001395	2,62E-05

Table 5. TUBITAK-UME and INM 10 kN deadweight machine comparison using 100 kN load cell GTM-SN:00539

Force steps, kN	x_{UME}, mV/V	W_{UME}	x_{INM}, mV/V	W_{INM}
40	0,799475	2,23E-05	0,799438	6,42E-05
60	1,199246	2,19E-05	1,199208	3,71E-05
80	1,598994	2,59E-05	1,598934	3,08E-05
100	1,998694	2,63E-05	1,998622	2,94E-05

Table 6. **TUBITAK-UME and INM 1000 kN force standard machine comparison using 500 kN load cell GTM-SN:43018**

Force steps, kN	x_{UME}, mV/V	W_{UME}	x_{INM}, mV/V	W_{INM}
200	0,800102	3,66E-05	0,800106	2,74E-05
300	1,200279	1,65E-05	1,200255	2,00E-05
400	1,600468	0,66E-05	1,600415	1,26E-05
500	2,000632	1,86E-05	2,000633	0,81E-05

Table 7. **TUBITAK-UME and INM 1000 kN standard machine comparison using 1000 kN load cell GTM-SN:45084**

Force steps, kN	x_{UME}, mV/V	W_{UME}	x_{INM}, mV/V	W_{INM}
400	0,800699	1,57E-05	0,800737	10,90E-05
600	1,201052	3,65E-05	1,201101	5,53E-05
800	1,601479	1,04E-05	1,601520	3,44E-05
1000	2,001851	0,94E-05	2,001852	3,00E-05

The uncertainties were estimated in respect of principles laid out in the Document "Expression of Uncertainty of the Measurement in Calibration", published by EA (EA 4/02). The principal components of the uncertainty budget to be evaluated were estimated in accordance with the document EAL G22 "Uncertainty of Calibration Results in Force Measurements" published by EURAMET and in accordance with consensus document.

The general budget of uncertainties and statistical distributions are presented in Table 8.

Table 8. **Uncertainty contributions and statistical distribution**

Uncertainty arising from	Approximate equation, *Q*	Distribution	Relative uncertainty contribution (a= half width of *Q*)
Reproducibility [a]	$b_{RP} = \frac{\lvert X_{\max} - X_{\min} \rvert}{X_{AVE}}$ $X_{AVE} = \frac{X_1 + \ldots + X_5}{5}$	U shape	$w^2_{(b_{PR})} = \frac{a^2_{b_{RP}}}{2}$
Repeatability [b]	$b_R = \frac{\lvert X_2 - X_1 \rvert}{X_R}$ $X_R = \frac{X_1 + X_2}{2}$	rectangular	$w^2_{(b_R)} = \frac{a^2_{b_R}}{3}$
Temperature effect of the sensitivity [c]	$S_{td} = \alpha \cdot (t_P - t_L)$ $\alpha \approx 5x10^{-6}$ / °C	rectangular	$w^2_{(S_{td})} = \frac{a^2_{S_{td}}}{3}$
Standard uncertainty of applied force [d]	w_{FSM}	normal	w^2_{FSM}
Hysteresis [e]	$v = \frac{i' - i}{i}$	rectangular	$w^2_{(v)} = \frac{a^2_v}{3}$
Resolution [f]	$e = \frac{r}{X_{AVE}}$	rectangular	$w^2_{(e)} = \frac{a^2_e}{3}$
Relative expanded uncertainty (*k*=2)	$W = k\sqrt{a^2 + b^2 + c^2 + d^2 + e^2 + f^2}$		

The results of the interlaboratory comparison were evaluated using the E_n number, which represent the figure of merit of the INM laboratory, calculated for each measuring point, expressing the degree of equivalence between TUBITAK-UME as reference laboratory and INM.

The E_n number was calculated using the equation (1):

$$E_n = \frac{x_{INM} - x_{UME}}{\sqrt{W^2_{INM} + W^2_{UME}}} \tag{1}$$

W_{UME} and W_{INM} are the expanded relative uncertainties, associated with the measurement results x_{UME} and x_{INM} obtained by TUBITAK-UME and INM respectively.

The compatibility of the calibration measurements provided by INM with the reference laboratory TUBITAK-UME is testified by the setting of the figures of merit in the specified range [-1, 1].

The relative deviations between the measurements performed by INM and TUBITAK-UME, associated expanded relative uncertainties and figures of merit ascribed for each range of forces and for each force standard machine utilized in the interlaboratory comparison are presented in Tables from 9 to 11.

Table 9. **TUBITAK-UME and INM 10 kN deadweight machine comparison**

Force steps, kN	Relative deviation between INM and UME	Expanded relative uncertainty associated with deviation	E_n
2	5,01E-05	5,75E-05	0,87 1)
3	5,79E-05	5,91E-05	0,98 1)
4	5,59E-05	5,95E-05	0,94 1)
5	5,70E-05	6,00E-05	0,95 1)
6	-4,63E-05	5,51E-05	-0,84 1)
8	-4,49E-05	5,48E-05	-0,82 1)
10	-3,48E-05	5,52E-05	-0,63 1)

Table 10. **TUBITAK-UME and INM 100 kN deadweight machine comparison**

Force steps, kN	Relative deviation between INM and UME	Expanded relative uncertainty associated with deviation	E_n
20	-1,61E-05	4,24E-05	-0,38
30	-4,08E-05	5,67E-05	-0,72 1)
40	-4,60E-05	6,87E-05	-0,67
50	-5,21E-05	5,60E-05	-0,93 1)
60	-3,19E-05	4,31E-05	-0,74
80	-3,76E-05	4,04E-05	-0,93
100	-3,61E-05	3,92E-05	-0,92

Table 11. **TUBITAK-UME and INM 1000 kN force machine comparison**

Force steps, kN	Relative deviation between INM and UME	Expanded relative uncertainty associated with deviation	E_n
200	-0,51E-05	4,64E-05	-0,11
300	2,02E-05	2,56E-05	0,79
400	-4,71E-05	10,95E-05	-0,43
500	-0,03E-05	2,02E-05	-0,02
600	-4,10E-05	6,61E-05	-0,62
800	-2,54E-05	3,58E-05	-0,71
1000	-0,03E-05	3,92E-05	-0,01

Note 1): The E_n number was calculated taking into account the stated CMC of INM laboratory.

3. CONCLUSIONS

The main aims of the comparison were to confirm the stated measurement capabilities of the participant laboratories, use the achieved information to validate the calibration methods and ascertain the quality of the measurement results and to check the adequate dissemination of force unit in Turkey and Romania.

Further, the obtained results in the interlaboratory comparison may be utilized to assess the proficiency of the calibration laboratories in the denominated field.

The analysis of the interlaboratory comparison results is mainly based on reading the figures of merit E_n calculated for each measuring point. To base on these figures were established: the compatibility degree of the INM force laboratory, relative to reference laboratory - TUBITAK-UME, the compatibility ranges and the measurement capabilities.

Generally, INM force laboratory demonstrated the compatibility of the force measurements with the reference laboratory- TUBITAK-UME in the mentioned ranges.

The performance interlaboratory comparison results show that relative measurement uncertainty of TUBITAK-UME and INM deadweight standard machines is compatible within 5×10^{-5}. In the same time, it was demonstrate that 1.1 MN TUBITAK-UME lever amplification standard machine and INM 1 MN comparator type force standard machine are compatible within 1×10^{-4}.

The bilateral interlaboratory results demonstrate the compatibility of the measurements of the participating laboratories, with the view to support the CMC's declared and accepted in the frame of CIPM MRA.

ACKNOWLEDGMENTS

One of the most important activities of the metrological organizations at European as well as international level is the organization of a series of interlaboratory comparisons, to verify the measurement capabilities of the calibration laboratories, in the view to mutual and general recognition of the calibration results.

In this frame, the organization of a bilateral comparison involving the force standard machines of TUBITAK-UME, Turkey and INM, Romania was very useful.

The experience obtained during the entire process of interlaboratory comparison developed the scientific knowledge in the field of the participating

laboratories. In the same time, this experience conduced to a better grasp of the activities and general approach of the participating laboratories.

We are pleased to acknowledge to the technical director of TUBITAK-UME and director of INM who are Dr. Sakir Baytaroglu and Dr. Dragos Boiciuc, respectively and to all members of TUBITAK-UME Force Laboratory and INM Force Laboratory for considerable help in the organization and accomplishment of this interlaboratory comparison.

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