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3 MN HYDRAULIC TYPE BUILD-UP FORCE STANDARD MACHINE INSTALLED AT NATIONAL METROLOGY INSTITUTE (UME)

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Abstract − A new hydraulic type build up force standard machine with a 3 MN loading capacity both in tension and compression modes is installed in Force Measurment Laboratory of UME. The machine is designed and manufactured by ÖZMAK Manufacturing Company according to the technical specifications outlined by UME. The performance test results show that relative measurement uncertainty of a new 3 MN build-up machine of UME is better than 4×10^{-4} .

Keywords: Built-up force standard machine, servo hydraulic system, performance test

1. INTRODUCTION

Different type force standard machines are used for calibration of force proving instruments such as force transducers, load cell, proving rings and etc. in many national metrology institutes. Decision about type selection of force standard machines directly depends on the required accuracy of force generation and budget limitation of the institute or country. The most accurate forces can be generated by dead weights with direct application. But direct application of dead weights requires considerable building space, when capacity of forces exceeds 100 kN. Dead weight force standard machines are quite expensive due to their high production cost. Cheaper solutions can be found for establishment of force scale in the country depending on the required accuracy and capacity. Some of these solutions are lever or hydraulic amplification of dead weights and build-up force standard machines, which amplifies the forces by hydraulic ram.

Build-up force standard machine (B-FSM) uses three or power of three (3^n) transducers, which are disposed in parallel. This method called build-up method or force transducers pyramid which makes great advantages and economy for establishment of Force Standard Machines of high capacity. [1-6].

Establishment of force scale in Turkey was realised with dead weight machines in the range between 0.5 N and 100 kN and lever amplification machine with dead weight up to 1 MN at UME in 1995. Requirements of Turkish industries forced UME to extend this range up to 3 MN. Due to height limitation of present UME Force Measurement Laboratory and limited budget of UME, B-FSM system is selected for this range. This machine completely designed and manufactured by OZMAK Engineering Company in Istanbul-Turkey. Reference force transducers, which are used for establishment of the build-up system, were purchased from GTM Company-Germany.

2. DESCRIPTION OF THE 3 MN MACHINE

The UME B-FSM consists of a mechanical construction, a servo-hydraulic system and a control unit. The framework of the machine is designed as three columns principle and composed of loading table and a lower base. A force-generating hydraulic cylinder is located on the loading table and the reference force transducers are mounted on the top of this cylinder giving the signal which is used as the reference value for calibration as well as the system control. The machine generates forces by a piston-cylinder arrangement, which is driven by a servo hydraulic system instead of any hydraulic pump and servo valve combination. This system reduces the noise, vibration, maintenance cost caused by hydraulic pump system. Servo hydraulic system enables to adjust precise pressure control for reducing the pressure fluctuations during force application. As a result, measurement uncertainty of the system is minimized. A general view of the machine is shown in Fig. 1 and Fig. 2.

The overall technical spacifications of the 3 MN Build-up UME Force Standard Machine are given in Table I.

TABLE I. Technical specifications of the 3 MN Build-up UME Force Standard Machine

	3 MN B-FSM
Type of force generation	Hydraulic together with built-up transducer
Rated Capacity	3 MN
Force Ranges	Selectable forces in the range between 50 – 3000 kN
Main frame	3 column
Comp. space (vertical)	100-750 mm
Tension space (vertical)	650- 1300 mm
Operating	PC Controlled and manual

Operating system of the machine is fully computer controlled and a pressure transducer assembled directly to main piston-cylinder getting continuous feedback signal to protect the system. The hydraulic system has been developed to operate the machine for both automatic and manual calibrations. In the automatic mode, calibrations can be performed according to a predetermined procedure by the software and data can be recorded and calibration certificate generated by the same software program. In the manual mode, forces are selected and applied on the transducers and data are recorded by manual operation functions.

Figure 1. 3 MN hydraulic type build-up force standard machine of UME Force Measurement Laboratory

3. REFERENCE FORCE TRANSDUCERS FOR BUILD-UP METHOD

3 MN UME force standard machine uses 3 MN build-up system in which three 1 MN capacity transducers are placed in parallel. The biggest advantage of using 3 MN build-up system shown in Fig. 3 is the supplement of traceability to 1 MN UME force standard machine by calibration of each individual 1 MN reference transducers.

Build-up system uses three 1 MN high quality force trandsducers with high accuracies. These transducers were purchased from GTM (Gassmann Theiss Mectechnik GmbH-Germany). These are KTN type having very low measurement uncertainty and are special VN class force transducers. These are calibrated in PTB at first, then they will be calibrated in 1 MN UME lever amplification dead weight machine.

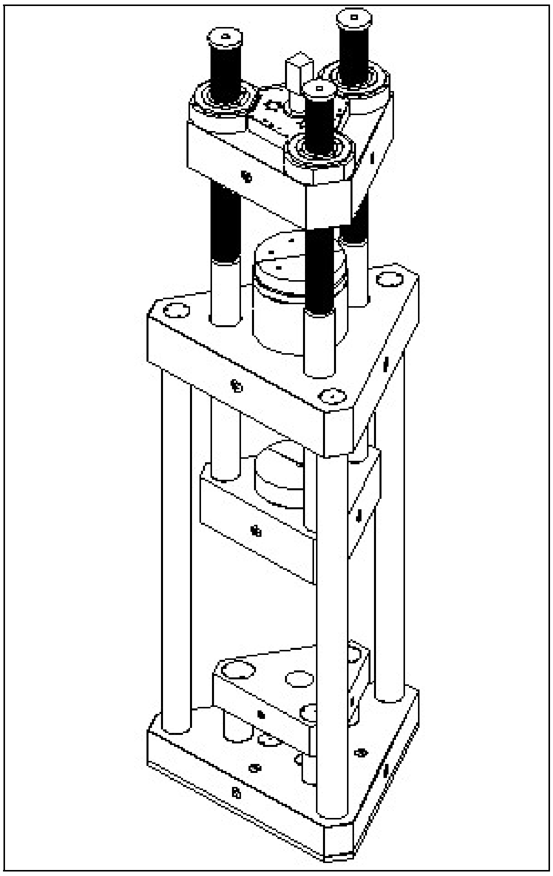

Fig. 2. Schematic wiew of 3 MN UME build-up machine

Fig. 3. 3 MN Build-up force transducer of UME

4. PERFORMANCE TEST

Transfer force transducers with capacities of 200 kN, 500 kN, 1 MN and 3 MN are used in this performance test measurements. The transducer list and used force steps listed in Table II. The performance test procedure is based on the comparison of the measurement results obtained in PTB and UME Force Measurement Laboratories. The measurements were made to determine the relative deviations among the various forces realized by PTB and UME. First measurements of 1 MN and 3 MN transfer force transducers were performed in 1 MN PTB dead weight machine and 16 MN PTB hydraulic amplification machine respectively [7]. At the same time first measurments of 200 kN and 500 kN force transducers were performed in 1 MN UME lever amplfication machine. Then all transfer force transducers are measured in new 3 MN UME hydraulic type build-up force standard machine. Avarage force values were compared to each other similar to international comparison measurement evaluation procedure [7-9]. Evaluation results calculated from equation (1) as relative deviation (RD) betwen reference machine (X_R) 3 M built-up machine (X_{3MN}) and all results are given in Fig. 4, Fig. 5, Fig. 6, Table III and Table IV.

$$RD = \frac{X_{R-PTB,UME} - X_{3MN}}{X_{R-PTB,UME}} \qquad (1)$$

Measurement uncertainty calculation was based on the equation (2) for getting general knowledge about the 3 MN machine. $RU_{R\text{-PTB, UME}}$, $RU_{3\ MN}$, RU_{FTT} are the relative measurement uncertainties of PTB, UME reference force standard machines, 3 MN force standard machine of UME, and force transfer transducers respectively.

$$RD = \sqrt{\left(RU^2_{R-PTB,UME} + RU^2_{3MN} + RU^2_{FTT}\right)} \qquad (2)$$

Measurement uncertainties (RU) in equation (2) are taken as $\pm$ 2.10^{-5} for PTB dead weight machine, $\pm$ 1.10^{-4} for the hydraulic amplification machine of PTB ($RU_{R\text{-PTB}}$), and $\pm$ 1.10^{-4} for UME lever amplification machine ($RU_{R\text{-UME}}$,) and $\pm$ 3.10^{-5} for the transfer force transducers used in comparison measurement (RU_{FTT}).

$$RD = \sqrt{\left((1\cdot 10^{-4})^2_{R-PTB,UME} + (4\cdot 10^{-4})^2_{3MN} + (3\cdot 10^{-5})^2_{FTT}\right)}$$

RD = 4.13 x 10^{-4}

The relative deviation between reference force standards machines of PTB or UME and 3 MN build-up force standard machine of UME can be obtained. If relative deviation is smaller than 4.13 x 10^{-4}, it can be proved that the relative measurement uncertainty of 3 MN machine will be better than 4 x 10^{-4}.

TABLE II. Transfer force transducer used in performance test

Force transducer	Force steps (kN)
200 kN	50, 100, 150, 200
500 kN	150, 200, 250, 300, 350, 400, 450, 500
1 MN	400, 500, 600, 700, 800, 900, 1000
3 MN	300, 600, 900, 1200, 1500, 1800, 2100, 2400, 2700, 3000

TABLE III. Performance test results for 200 kN, 500 kN, 1000 kN and 3000 kN transfer force transducers

Force Transducer KN	Force Steps kN	PTB or UME Ref. Machine mV/V	3 MN Built-up Machine mV/V	Relative Deviation
200 kN	50	0.500906	0.500981	-1.49E-04
	100	1.001653	1.001770	-1.17E-04
	150	1.502342	1.502546	-1.36E-04
	200	2.002969	2.003277	-1.54E-04
500 kN	150	0.600100	0.600230	-2.16E-04
	200	0.800080	0.800257	-2.21E-04
	250	1.000069	1.000288	-2.19E-04
	300	1.200097	1.200305	-1.73E-04
	350	1.400107	1.400333	-1.61E-04
	400	1.600081	1.600383	-1.89E-04
	450	1.800079	1.800391	-1.73E-04
	500	2.000098	2.000425	-1.63E-04
1000 kN	400	0.800636	0.800810	-2.17E-04
	500	1.000801	1.001025	-2.24E-04
	600	1.200969	1.201210	-2.01E-04
	700	1.401141	1.401409	-1.91E-04
	800	1.601302	1.601595	-1.83E-04
	900	1.801461	1.801796	-1.86E-04
	1000	2.001615	2.001989	-1.87E-04
3000 kN	300	0.200206	0.200204	9.99E-06
	600	0.400364	0.400365	-1.87E-06
	900	0.600526	0.600512	2.33E-05
	1200	0.800664	0.800611	6.59E-05
	1500	1.000830	1.000726	1.04E-04
	1800	1.200979	1.200809	1.42E-04
	2100	1.401175	1.400894	2.01E-04
	2400	1.601318	1.600994	2.02E-04
	2700	1.801491	1.801108	2.13E-04
	3000	2.001600	2.001272	1.64E-04

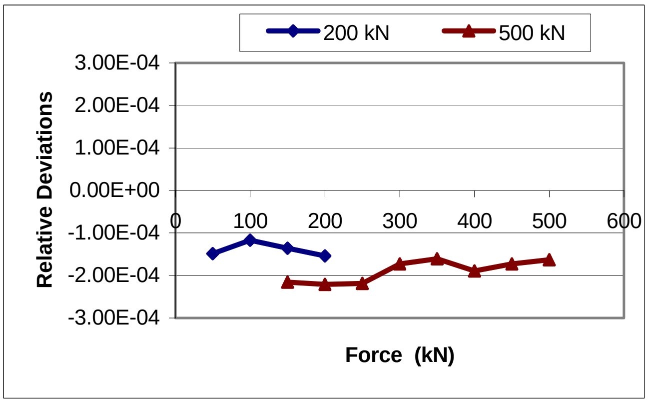

Fig. 4. Performance test results for 200 and 500 kN transfer force transducer

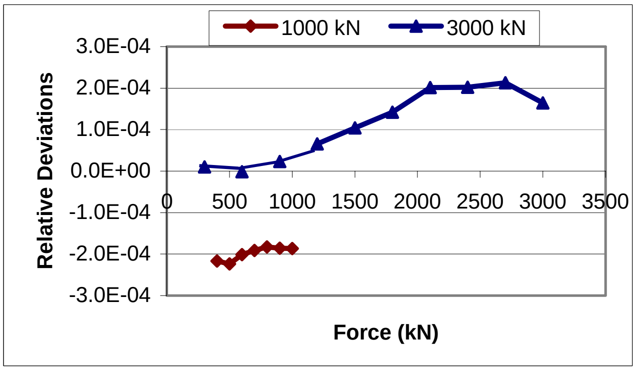

Fig. 5. Performance test results for 1000 kN and 3000 kN transfer force transducer

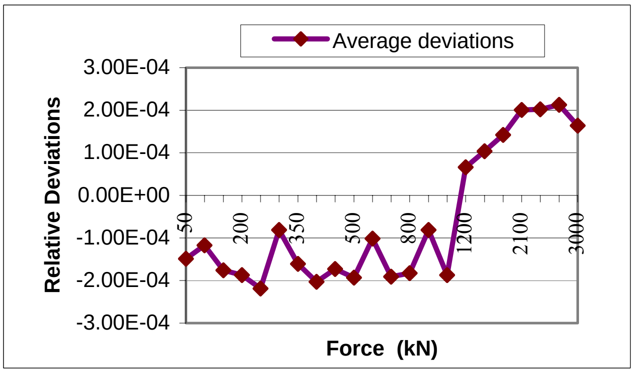

Fig.6. Performance test results of 3 MN UME Built-up machine

TABLE IV. Relative deviations between PTB, UME force standard machines and UME 3 MN built-up force standard machine

Force Step kN	Transfer Force Transducers				Average Relative Deviation
	200 kN	500 kN	1000 kN	3000 kN	
50	-1.49E-4				-1.49E-4
100	-1.17E-4				-1.17E-4
150	-1.36E-4	-2.16E-4			-1.76E-4
200	-1.54E-4	-2.21E-4			-1.88E-4
250		-2.19E-4			-2.19E-4
300		-1.73E-4		9.99E-6	-8.15E-5
350		-1.61E-4			-1.61E-4
400		-1.89E-4	-2.17E-4		-2.03E-4
450		-1.73E-4			-1.73E-4
500		-1.63E-4	-2.24E-4		-1.94E-4
600			-2.01E-4	-1.87E-6	-1.01E-4
700			-1.91E-4		-1.91E-4
800			-1.83E-4		-1.83E-4
900			-1.86E-4	2.33E-5	-8.14E-5
1000			-1.87E-4		-1.87E-4
1200				6.59E-5	6.59E-5
1500				1.04E-4	1.04E-4
1800				1.42E-4	1.42E-4
2100				2.01E-4	2.01E-4
2400				2.02E-4	2.02E-4
2700				2.13E-04	2.13E-04
3000				1.64E-04	1.64E-04

5. CONCLUSIONS

The performance test results according to intercomparison measurements show that the agreement between PTB, UME force standard machines and 3 MN build-up machine is better than 2.3×10^{-4} over the range of 50 kN to 3000 kN. This study show that relative measurement uncertainty of a new 3 MN build-up machine of UME is better than 4×10^{-4}. Further international comparison measurements between UME and other metrology institutes are planned.

REFERENCES

[1] Bray, A., Barbato, G., Levı, R., 1990. Theory And Practice of Force Measurement, Academic Press, London.

[2] S. Fank, Report of UME 3 MN Hydraulic type built-up force standard machine, 2002, UME, Gebze, Turkey

[3] J.Cruz, V. Prodonoff, J. Guerhard, Research, Development and Characterization of a Build-up System Prototype up to 600 kN, 17th International IMEKO TC3 Conference, 17-21 Sept. 2001, Istanbul, Turkey.

[4] Dae-Im Kang, Chang-Sun Hong, 1994, Rotation effect of force transducers on the output of a build-up system, Measurement 14(1994), 147-156.

[5] Wieringa, H., 1984, Design of 1.65 and 4.95 MN Transfer Standard based on Build-up System, 10th International IMEKO TC3 Conference, September 1984, Kobe, Japan.

[6] S. Fank, Li, Qingzhong, 1999, Build-up force standard machines, UME Kuvvet Lab. Gebze, Kocaeli,Turkey

[7] S.L.Yaniv, A. Sawla and M. Peters, Summary of the Intercomparsion of the Force Standard Machines of the National Institute of Standards and Technology, USA, and the Physikalisch-Technische Bundesanstalt, Germany, Journal of Res. Natl. Inst. Stand. Technol., 96, 529 (1991),529-540.

[8] S. Fank, A. Sawla, H.Ö. Özbay, H. Gassmann, "Establishment of National Force Scale at UME and Results of Intercomparison Measurements between UME and PTB, IMEKO TC3 Proceesdings, 1996, Madrid, Spain

[9] S. Fank, Dr. A. Sawla, H. Ö. Özbay, "Long term observation of newly developed 110 kN/ 1.1 MN lever amplification dead weight force standard machine at UME", IMEKO World Congress Proceedings, 1997, Tampere- Finland

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