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Effects due to the misalignment of build-up systems for force measurements in the Meganewton range

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Abstract. Calibration of force transducers in the Meganewton range is typically performed by comparison with reference build-up systems (BUS) under hydraulic presses for high loads. The centring of a BUS is a difficult operation due to its weight and dimension, and possible misalignments and the resulting effects are usually neglected. In this work the effect on force measurements due to a 3 mm misalignment of a 3 MN BUS was evaluated. Measurements were performed at INRiM and at LNE in hydraulic presses. It is shown that the relative measurement errors due to misalignment were lower than the declared CMC uncertainty, thus the shift of the BUS did not influence the measurements.

1. Introduction

The calibration of a force transducer may represent a challenge in the Meganewton range due to the maximum load limits that most of dead weight force standard machines (FSMs) can apply. In this range hydraulic presses are typically used to reach higher forces, but these type of FSMs have the necessity to use a calibrated force transducer as reference. For such purpose, it is possible to use build-up systems (BUS) [1,2]. They are composed of different uniaxial force transducers (UFTs) with a lower capacity in a mechanical parallel arrangement in order to increase the capacity of the complete system. Calibration of BUS is simple and consists in the calibration of each single UFT. When used as reference during calibration procedures, BUS has to be centred with respect to the vertical axis in the hydraulic press. Since a BUS is usually large and heavy [3], such operation can be challenging. In this work, the influence on force measurements, in hydraulic presses, due to a 3 mm misalignment of a BUS is evaluated.

2. Measurement procedure

The BUS under test was a 3 MN BUS, devised and developed at INRiM, consisting of three UFTs with a capacity of 1 MN each [4]. Experimental measurements were performed in hydraulic presses at INRiM (Torino, Italy) and LNE (Paris, France) by comparison with reference force transducers. Reference force transducers used in the hydraulic presses FSMs at INRiM and LNE were a 5 MN UFT and another 3 MN BUS, respectively. Both FSMs has a maximum load of 9 MN and a declared CMC relative expanded uncertainty of $5\cdot10^{-4}$. The aim was to evaluate the force measurement differences

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when the BUS is shifted by 3 mm with respect to the central position. Measurements were performed by the same operators in the respective laboratories. Measurement procedure can be summed as follows:

- The BUS has been aligned and centred with the vertical force load (position A).
- The measurement has been repeated (position Ab).
- The BUS has been shifted with an eccentricity of 3 mm along the x-axis (position B);
- The BUS has been shifted with an eccentricity of 3 mm along the y-axis (position C).

The coordinate system is orientated as shown in figure 1.

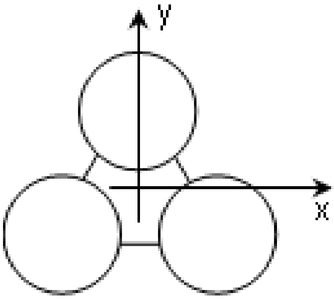

Figure 1. Orientation of the coordinate system.

The first two series of data (positions A and Ab) were needed to calculate the mean values at each level of load (*i*), according to equation (1).

$$m_i = \frac{A_i + Ab_i}{2} \quad (1)$$

Relative expanded uncertainty (at 95% confidence level) of the mean was calculated according to equation (2).

$$U_i = k\,\frac{u_i(m_i)}{m_i} = 4.3 \cdot \frac{|A_i - Ab_i|}{\sqrt{12}m_i} \quad (2)$$

Coverage factor k=4.3 derives from the only two degrees of freedom, while the uncertainty contribution due to resolution is negligible. From data obtained in positions B and C, relative differences with respect to the mean value measured in the central position A, Δx and Δy respectively, were then evaluated according to equations (3).

$$\begin{cases} \Delta x = \frac{|B_i - m_i|}{m_i} \\ \Delta y = \frac{|C_i - m_i|}{m_i} \end{cases} \quad (3)$$

3. Data analysis

Force measurements performed at INRiM in positions A, Ab, B and C and the derived quantities described in Section 2 are shown in table 1. The relative differences, Δx and Δy, with the BUS shifted by 3 mm in positions B and C are depicted in figure 2. Obtained values are within the declared CMC uncertainty.

Table 1. Measurements performed at INRiM

Ref / kN	A / kN	Ab / kN	B / kN	C / kN	m_i / kN	U_i	Δx	Δy
300	300.36	300.48	300.49	300.57	300.42	$4.96\cdot10^{-4}$	$2.33\cdot10^{-4}$	$4.99\cdot10^{-4}$
600	600.61	600.55	600.58	600.64	600.58	$1.24\cdot10^{-4}$	$1.89\cdot10^{-16}$	$9.99\cdot10^{-5}$
900	900.45	900.63	900.69	900.73	900.54	$2.48\cdot10^{-4}$	$1.67\cdot10^{-4}$	$2.11\cdot10^{-4}$
1200	1200.71	1200.71	1200.77	1200.85	1200.71	$3.30\cdot10^{-7}$	$5.00\cdot10^{-5}$	$1.17\cdot10^{-4}$
1500	1500.88	1500.76	1500.87	1500.85	1500.82	$9.92\cdot10^{-5}$	$3.33\cdot10^{-5}$	$2.00\cdot10^{-5}$
1800	1800.80	1800.83	1801.12	1801.21	1800.82	$2.07\cdot10^{-5}$	$1.69\cdot10^{-4}$	$2.19\cdot10^{-4}$
2100	2101.08	2101.07	2101.24	2101.41	2101.08	$5.91\cdot10^{-6}$	$7.85\cdot10^{-5}$	$1.59\cdot10^{-4}$
2400	2401.34	2401.27	2401.58	2401.51	2401.31	$3.62\cdot10^{-5}$	$1.15\cdot10^{-4}$	$8.54\cdot10^{-5}$
2700	2701.32	2701.53	2701.58	2701.62	2701.43	$9.65\cdot10^{-5}$	$5.74\cdot10^{-5}$	$7.22\cdot10^{-5}$
3000	3001.50	3001.61	3001.83	3002.11	3001.56	$4.55\cdot10^{-5}$	$9.16\cdot10^{-5}$	$1.85\cdot10^{-4}$

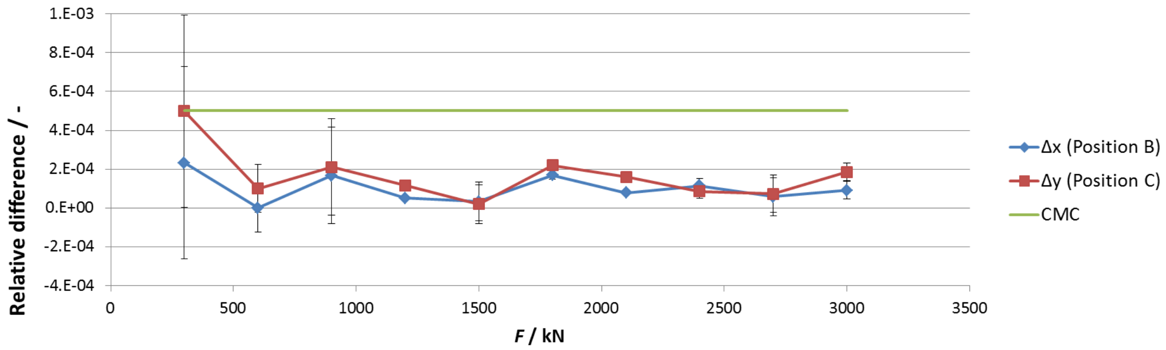

Figure 2. Relative differences due to BUS misalignment at INRiM compared to the declared CMC.

The same measurements were performed at LNE. Measurement results are shown in table 2, while the relative differences are depicted in figure 3. The relative differences are within the declared CMC uncertainty.

Table 2. Measurements performed at LNE

Ref / kN	A / kN	Ab / kN	B / kN	C / kN	m_i / kN	U_i	Δx	Δy
300	299.98	300.01	300.01	299.99	300.00	$1.24\cdot10^{-4}$	$5.00\cdot10^{-5}$	$1.67\cdot10^{-5}$
600	599.98	600.01	600.01	600.00	600.00	$6.21\cdot10^{-5}$	$2.50\cdot10^{-5}$	$8.33\cdot10^{-6}$
900	899.98	900.02	900.02	900.00	900.00	$5.52\cdot10^{-5}$	$2.22\cdot10^{-5}$	$1.89\cdot10^{-16}$
1200	1199.97	1200.02	1200.02	1200.00	1200.00	$5.17\cdot10^{-5}$	$2.08\cdot10^{-5}$	$4.17\cdot10^{-6}$
1500	1499.97	1500.02	1500.02	1500.00	1500.00	$4.14\cdot10^{-5}$	$1.67\cdot10^{-5}$	$3.33\cdot10^{-6}$
1800	1799.98	1800.02	1800.02	1799.99	1800.00	$2.76\cdot10^{-5}$	$1.11\cdot10^{-5}$	$5.56\cdot10^{-6}$
2100	2099.97	2100.01	2100.01	2100.00	2099.99	$2.36\cdot10^{-5}$	$9.52\cdot10^{-6}$	$4.76\cdot10^{-6}$
2400	2399.97	2400.02	2400.02	2400.00	2400.00	$2.59\cdot10^{-5}$	$1.04\cdot10^{-5}$	$2.08\cdot10^{-6}$
2700	2699.97	2700.02	2700.02	2700.04	2700.00	$2.30\cdot10^{-5}$	$9.26\cdot10^{-6}$	$1.67\cdot10^{-5}$
3000	2999.97	3000.02	3000.02	3000.00	3000.00	$2.07\cdot10^{-5}$	$8.33\cdot10^{-6}$	$1.67\cdot10^{-6}$

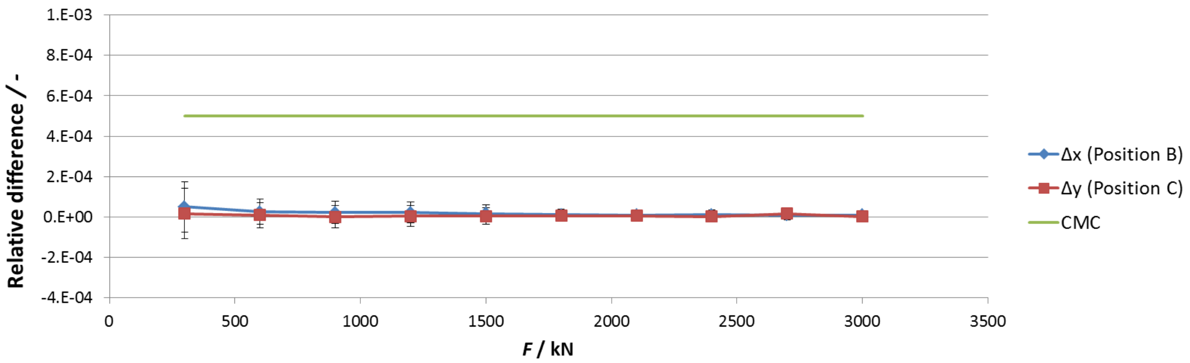

Figure 3. Relative differences due to BUS misalignment at LNE compared to the declared CMC.

4. Conclusions

In this work, the influence on force measurements due to a 3 mm misalignment of a 3 MN BUS in hydraulic presses was evaluated at INRiM and LNE laboratories. Relative errors due to misalignment with respect to the central position were less than the CMC uncertainty declared for each hydraulic press and, in addition, differences due to misalignments along the two horizontal axis are comparable. We can conclude that a misalignment with an eccentricity of less than 3 mm does not influence the measurements.

5. Acknowledgments

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