INFLUENCE OF PARASITIC COMPONENTS IN THE STATIC CALIBRATION OF UNIAXIAL FORCE TRANSDUCERS

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INFLUENCE OF PARASITIC COMPONENTS IN THE STATIC CALIBRATION OF UNIAXIAL FORCE TRANSDUCERS

A. Prato[1], E. Giacardi[2], A. Facello[3], F. Mazzoleni[4], A. Germak[5]

INRiM – National Institute of Metrological Research, Turin, Italy
[1] a.prato@inrim.it, [3] a.facello@inrim.it, [4] f.mazzoleni@inrim.it, [5] a.germak@inrim.it
Politecnico di Torino, Turin, Italy, [2] s269924@studenti.polito.it

Abstract:
Static calibration of uniaxial force transducers is performed with force standard machines which ideally generate a downward vertical force. However, these machines can be subjected to parasitic components, such as side forces and bending moments, which are transferred to the transducer under calibration. These components, mainly due to the not perfect verticality or alignment of the applied force, affect the calibration results, thus they should be estimated. In this work, parasitic side forces and bending moments are applied to six transducers by tilting and misaligning them with respect to the vertical gravitational force. Sensitivity coefficients of these parasitic components are obtained to be included in the uncertainty budget.

Keywords: parasitic components; force calibration; side forces; verticality

1. INTRODUCTION

In the force measurement applications, the sensitivity curve of the uniaxial force measuring devices determined during calibration according to ISO 376 [1] gives traceability to national standards. The measurement uncertainty in an application is mainly affected by the sensitivity stability, the influence of temperature and other parasitic components. Therefore, an advanced model which includes these influences, especially with respect to the contribution to the measurement uncertainty shall be developed. This paper focuses on the influence of spurious parasitic components, such as side forces and bending moments that can be generated by force standard machines during the static calibration of uniaxial force transducers and mainly caused by the not perfect verticality or alignment of the applied force [2]. The idea is to generate known side forces and bending moments by tilting and misaligning the trasducer with respect to the vertical gravitational force during the static calibration. Such procedure is applied to six different force transducers and the change of the calibration results is evaluated. In this way, sensitivity coefficients, to be used in the uncertainty assessment, can be derived.

2. MATERIALS AND METHODS

The influence of parasitic components during the static calibration of uniaxial force transducers is evaluated at INRiM with two different deadweight force standard machines (FSMs), with a capacity of 30 kN (MCF30) and 1000 kN (MCF1000), respectively, both with a relative expanded uncertainty of 0.002 %. Six different force transducers are tested as summarised in Table 1.

Table 1: Force transducers under test

Model	Capacity / kN	FSM
HBM Z3H3	5	MCF30
AEP KAL	10	MCF30
HBM Z3H3	20	MCF30
HBM Z4	100	MCF1000
HBM Z4	200	MCF1000
HBM C3H3	500	MCF1000

Known side forces and bending moments are generated by integrating the FSMs with hardened steel tilted plates, between which the transducer under calibration is placed, and by misaligning the trasducer with respect to the center of the machine which coincide with the axis of the applied vertical gravitational force. By modulating the angle of tilt α or by misaligning the transducers by a displacement r with respect to the machine loading axis, it is possible to decompose the applied reference force generated by the FSM, F, with the result of generating vertical, F_v, and side forces, F_s, or a bending moment, M_b [3], [4]. The relevant equations can be easily obtained from elementary trigonometrical laws, as shown in equation (1).

$$\begin{cases} F_\mathrm{s} = F \cdot \sin\alpha \\ F_\mathrm{v} = F \cdot \cos\alpha \\ M_\mathrm{b} = F \cdot r \end{cases} \qquad (1)$$

Three couples of hardened steel (34CrNiMo6) tilted plates with angles of 1°, 2° and 3° are designed and manufactured to be installed in the deadweight FSMs at INRiM to generate the known side forces. Each plate is 200 mm × 200 mm × 70 mm and weighs around 30 kg. The dimensions and tilt angles of the plates are cautiously chosen in order to fit the load platform of the machines and to guarantee the stability of the system under high loads, considering steel-to-steel friction between the tilted plate and a typical transducer. Three misalignments, without tilted plates in order to generate a pure bending moment, of 2 mm, 4 mm and 6 mm are applied to the transducers to generate the bending moments. Only for the 500 kN transducer, no misalignment is applied in order not to compromise the stability of the machine.

For each tilt angle α (0° included) or misalignment r, transducers are rotated around their axis with steps of 45° and three loads F (10 %, 50 % and 100 % of the transducers' capacity F_c) are applied. In total, 168 deflection measurements (4 tilt angles × 8 rotations × 3 loads + 3 misalignments × 8 rotations × 3 loads) are carried out for each transducer with the same amplifier HBM DMP40. An example of the 20 kN transducer placed between the 3° tilted plates integrated into the MCF30 FSM is shown in Figure 1.

Figure 1: The 20 kN transducer placed between the 3° tilted plates integrated into the MCF30 FSM

For each condition, the sensitivity S in (mV/V)/kN is evaluated according to equation (2), where d is the force transducer output

$$S = \frac{d}{F \cdot \cos \alpha} \tag{2}$$

It is worth noting that, taking into account the tilt angle in the denominator of equation (2), its influence should be ideally compensated. However, a spurious side force F_s is still acting on the transducer and its influence is the one of the aims of the work.

Then, taking as a reference the mean sensitivity S_i (in (mV/V)/kN), at a specific load condition ($i = 1 \ldots 3$), from the eight rotations measured without any tilted plate nor misalignment according to ISO 376:2011 [1], reported in Table 1, the relative differences $\delta_{ij,\text{sf}}$ and $\delta_{ij,\text{bm}}$, as function of the spurious side force F_s or bending moment M_b, respectively, both in three different conditions $j = 1 \ldots 3$, are then computed according to equation (3).

$$\delta_{ij} = \frac{S_{ij}}{S_i} - 1 \tag{3}$$

where S_{ij} (in (mV/V)/kN) is the mean sensitivity evaluated from the eight rotations at a particular i^{th} load and j^{th} side force F_s or bending moment M_b.

Table 2: Transducers' mean sensitivity $\bar{S}$ at different loads

Transducer capacity F_c / kN	**Mean sensitivity $\bar{S}$ / (mV/V)/kN**
5	$4.084\,8 \times 10^{-1}$
10	$2.000\,5 \times 10^{-1}$
20	$1.019\,9 \times 10^{-1}$
100	$1.998\,9 \times 10^{-2}$
200	$9.992\,1 \times 10^{-3}$
500	$4.084\,4 \times 10^{-3}$

3. RESULTS

As an example, results, in terms of sensitivities evaluated with and without tilted plates or misalignments as function of the rotation angle at a specific load of 50 % of the transducer's capacity F_c, are shown in Figure 2 and Figure 3 for the 5 kN transducer. Results with different tilted plates (Figure 2) generating spurious side forces F_s mainly follow a sinusoidal trend and the amplitude increases at increasing tilt angle α (or increasing side force F_s), so standard deviation does.

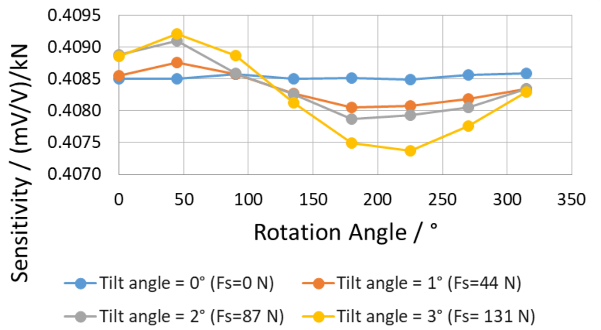

Figure 2: Sensitivity of the 5 kN transducer as function of the rotation angle with different spurious side force (or tilt angles) at an applied vertical force of 2.5 kN

With different misalignments r generating spurious bending moments M_b (Figure 3), standard deviations of the sensitivities are quite constant for different rotations. Similar behaviours are found for the other transducers.

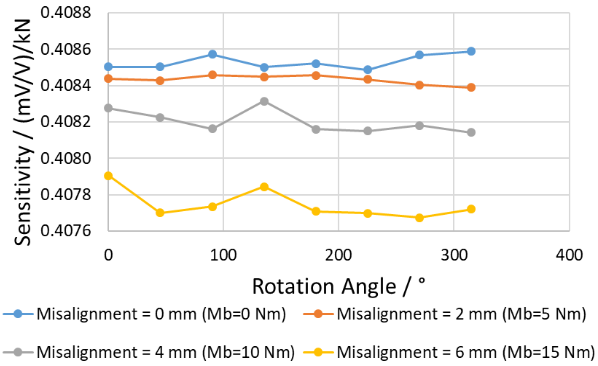

Figure 3: Sensitivity of the 5 kN transducer as function of the rotation angle with different spurious bending moments (or misalignments) at an applied vertical force of 2.5 kN

Performing the mean sensitivity value from the eight rotations at different load conditions and the relative differences according to equation (3), and plotting them as function of the side force F_s (Figure 4) or bending moment M_b (Figure 5), it is found that the sensitivity decreases at increasing spurious side forces or bending moments for each load condition for this specific transducer. This behaviour, however, varies from transducer to transducer. This means that the parasitic components influence the output of the transducers in a non-linear way, depending on their elastic sensitive element, the applied load, its direction and alignment. In general, relative sensitivity differences are in the order of 10^{-5} to 10^{-3}.

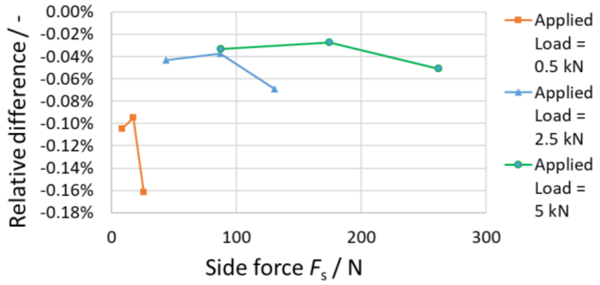

Figure 4: Relative differences of the 5 kN transducer as function of the side force F_s at different applied loads F

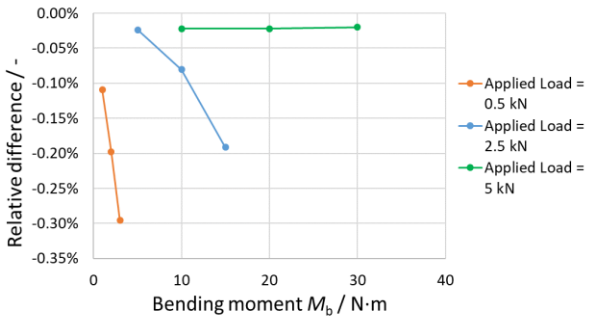

Figure 5: Relative differences of the 5 kN transducer as function of the bending moment M_b at different applied loads F

4. SENSITIVITY COEFFICIENTS

By performing a linear regression of the relative differences $\delta_{ij,\text{sf}}$ and $\delta_{ij,\text{bm}}$, for each i^{th} load condition (i.e. 10 %, 50 % and 100 % of the transducer's capacity) and for each transducer, as function of the j^{th} spurious side force F_s or bending moment M_b, the regression coefficients c_1 or c_2 associated with side forces or bending moments, respectively, are found according to equation (4) and equation (5)

$$\delta_{i,\text{sf}} = c_1 \cdot F_s \quad (4)$$

$$\delta_{i,\text{bm}} = c_2 \cdot M_b \quad (5)$$

Results are shown in Table 3 to Table 8.

In addition, it is also possible to perform the linear regression of the above-mentioned coefficients (c_1 or c_2) associated with the side force F_s or the bending moment M_b as function of the applied load F for each transducer, according to the linear equation

$$c = a \cdot F + b \quad (6)$$

Results are reported in Table 9.

Table 3: Regression coefficients of the relative differences, at each load condition, as function of the side force or bending moment for the 5 kN transducer

Applied force F / N	**Regression coefficient for side forces c_1 / N^{-1}**	**Regression coefficient for bending moments c_2 / (N·m)$^{-1}$**
500	-6.38×10^{-5}	-9.95×10^{-4}
2 500	-5.33×10^{-6}	-1.08×10^{-4}
5 000	-1.97×10^{-6}	-9.02×10^{-6}

Table 4: Regression coefficients of the relative differences, at each load condition, as function of the side force or bending moment for the 10 kN transducer

Applied force F / N	**Regression coefficient for side forces c_1 / N^{-1}**	**Regression coefficient for bending moments c_2 / $(N·m)^{-1}$**
1 000	-3.86×10^{-6}	-2.60×10^{-4}
5 000	-1.07×10^{-7}	-4.56×10^{-5}
10 000	-5.36×10^{-8}	3.35×10^{-7}

Table 5: Regression coefficients of the relative differences, at each load condition, as function of the side force or bending moment for the 20 kN transducer

Applied force F / N	**Regression coefficient for side forces c_1 / N^{-1}**	**Regression coefficient for bending moments c_2 / $(N·m)^{-1}$**
2 000	-3.59×10^{-7}	-1.38×10^{-4}
10 000	-3.70×10^{-8}	-4.40×10^{-7}
20 000	-9.56×10^{-9}	-8.71×10^{-9}

Table 6: Regression coefficients of the relative differences, at each load condition, as function of the side force or bending moment for the 100 kN transducer

Applied force F / N	**Regression coefficient for side forces c_1 / N^{-1}**	**Regression coefficient for bending moments c_2 / $(N·m)^{-1}$**
10 000	-6.06×10^{-7}	5.85×10^{-7}
50 000	2.62×10^{-8}	3.38×10^{-7}
100 000	2.82×10^{-8}	1.68×10^{-7}

Table 7: Regression coefficients of the relative differences, at each load condition, as function of the side force or bending moment for the 200 kN transducer

Applied force F / N	**Regression coefficient for side forces c_1 / N^{-1}**	**Regression coefficient for bending moments c_2 / $(N·m)^{-1}$**
20 000	-3.07×10^{-7}	-4.13×10^{-7}
100 000	2.59×10^{-8}	6.17×10^{-9}
200 000	1.54×10^{-8}	-1.95×10^{-8}

Table 8: Regression coefficients of the relative differences, at each load condition, as function of the side force or bending moment for the 500 kN transducer

Applied force F / N	**Regression coefficient for side forces c_1 / N^{-1}**
50 000	1.21×10^{-7}
250 000	5.78×10^{-8}
500 000	-1.53×10^{-8}

Table 9: Regression coefficients of the previous regression coefficients as function of the applied load F for each transducer with a capacity F_c

F_c / kN	**Regression coefficients of the coefficients of side forces**		**Regression coefficients of the coefficients of bending moments**	
	a / N^{-2}	**b / N^{-1}**	**a / $(N·m)^{-2}$**	**b / $(N·m)^{-1}$**
5	1.32×10^{-8}	-5.90×10^{-5}	2.12×10^{-7}	-9.35×10^{-4}
10	4.06×10^{-10}	-3.51×10^{-6}	2.82×10^{-8}	-2.52×10^{-4}
20	1.87×10^{-11}	-3.35×10^{-7}	7.34×10^{-9}	-1.24×10^{-4}
100	6.76×10^{-12}	-5.44×10^{-7}	-4.59×10^{-12}	6.08×10^{-7}
200	1.71×10^{-12}	-2.71×10^{-7}	2.09×10^{-12}	-3.65×10^{-7}
500	-3.02×10^{-13}	1.35×10^{-7}	-	-

In this way, starting from the transducer's capacity F_c and the applied load F, one can obtain the relevant regression coefficients c_1 or c_2 and can correct the systematic effect due to these spurious components or propagate the relative uncertainty of the transducer sensitivity S associated with the side forces $u_{sf}(S)$ and the one associated with the bending moments $u_{bm}(S)$, when they are nominally equal to zero. Both can be written according to equations (7) and (8).

$$\frac{u_{sf}^2(S)}{S^2} = c_1^2 \cdot u^2(F_s) \tag{7}$$

$$\frac{u_{bm}^2(S)}{S^2} = c_2^2 \cdot u^2(M_b) \tag{8}$$

5. SUMMARY

In this paper, the influence of spurious parasitic components, such as side forces and bending moments, on the static calibration results of six different force transducers is evaluated. Spurious side forces and bending moments are generated by means of tilted plates and known misalignments. Relative sensitivity differences with respect to reference calibration results without spurious components, in the order of 10^{-5} to 10^{-3} are found. Sensitivity coefficients to be used to compensate for the systematic effects or to propagate the uncertainty related to these spurious components are also evaluated.

6. ACKNOWLEDGEMENTS

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