Experience with a New Class of Force Transfer Standards

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Abstract

International force standard machines provide ever increasing accuracy. As a result the requirements for the force transducers used for international comparison measurements are also rising [1]. The development of new force transducers shows that it is possible to reduce their measurement uncertainties.
This paper describes the measuring bodies of these force transducers and the necessary selection method. The results of measurements obtained in force calibration machines and in force standard machines are presented.

1 Introduction

Several measurements taken according to ISO 376 with force transducers of three different types providing nominal forces from 100 N to 500 kN had shown, that the relative measurement uncertainty of some transducers can reach the uncertainty of the deadweight force calibration machine (DW FCM). However, this high precision level cannot be guaranteed for all transducers produced, a selection has to be made. High precision transducers had already been selected for a DKD calibration laboratory within the scope of transfer measurements to the PTB. One goal was to define a procedure which ensures that the capacities of the selected transducers are within the specifications. In the production process the transducers are only measured in one mounting position. Additional tests must be made in different mounting positions to get the reproducibility.
Transducers with different nominal forces have been measured in force standard machines (FSM) to verify the technical specifications according to ISO 376 and for creep measurements. Deadweight force standard machines can be used to measure the properties of the transducer, with relative measurement uncertainties of $2 \cdot 10^{-5}$ (k=2) [2].

2 Force Transducer Types

The measurements have been taken using three different force transducer types. All types enable usage for compressive or tensile forces.
The three types have different measuring body principles. For the type A with nominal forces from 100 N to 1 kN, aluminum double bending beams have been used and complemented with force connections to obtain an S-type force transducer (figure 1). For the nominal forces from 2 kN to 10 kN a newly designed parallel double bending beam is used (type B). The body is made of one piece of stainless steel with integrated force return (figure 2). This

design allows a low body height. One strain-gage full bridge consisting of 8 strain gages with 350 Ohm resistance is applied symmetrically on the top and bottom of the parallel double bending beam. Both types are covered in a case with two connectors (figure 1). One connector is located at the side of the case and the other one is at the bottom; with tensile force measurements, the latter reduces the influence of cable bending moments.

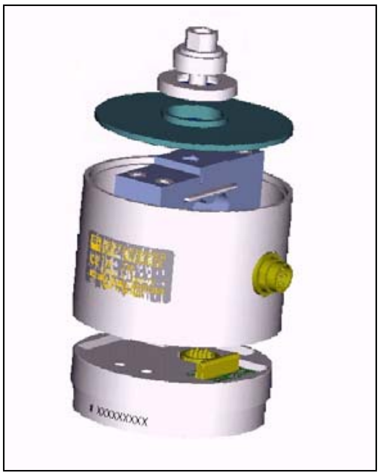


Figure 1: Type A/100N ... 1kN:
S-type force transducer

mounted into the case

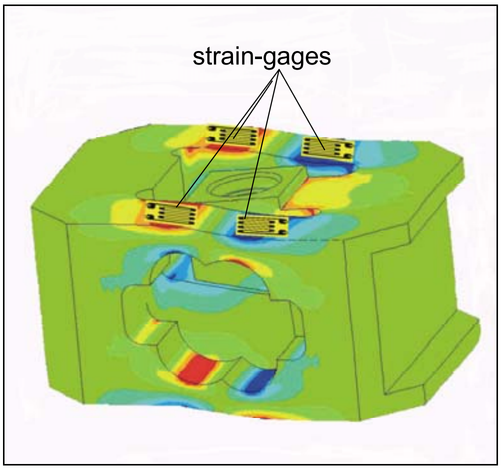
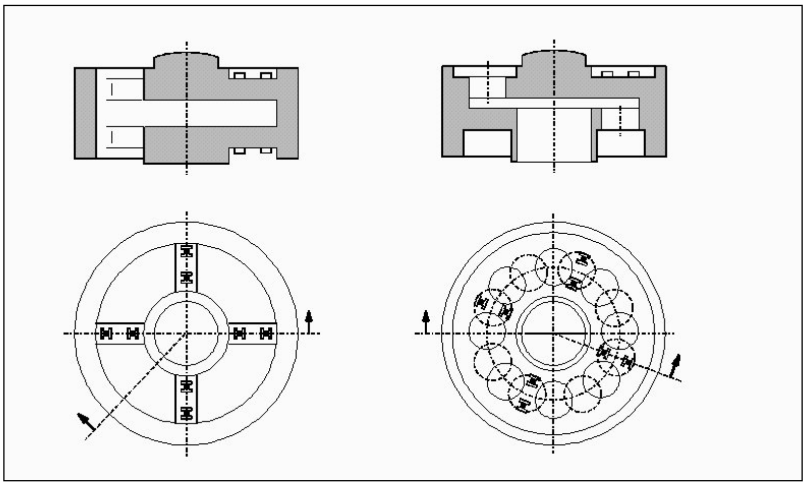


Figure 2: Type B/2kN ... 10kN:
Parallel bending beam with strain gages

applied on the top and bottom

The type C is a rotationally symmetrical multi bending beam made of tempered steel. One strain-gage full bridge consisting of 8 strain gages with 175 Ohm resistance is applied on four fixed links (figure 3).



All force transducer types have a compensation for the bending moment to improve the measurement properties and to obtain the best repeatability for this transducer type, independent of the calibration machine's mechanical properties. All transducers are temperature compensated as to the zero signal and the nominal sensitivity to achieve a constant temperature behavior.

Figure 3: Type C: rotationally symmetrical multi bending beam

3 Selection Method

The selection method has been the same for both force transducer families.

For production quality assurance all transducers are always tested with forces in tension in one mounting position at 10%, 20%, 50%, 100%, 50%, 20% and 10% of the nominal force. The measured values and the calculated best-fit linearity and reversibility error are printed on a production test certificate and stored in a data base.

For the first selection the production certificate has been used as a means to determine the best reversibility.
Force transducers with a reversibility better than 0,02% of 20% of the nominal force have been selected and their TK_0, TK_c and creep have been evaluated. For some transducers these values have been measured in production too but for others an additional measurement proved necessary. The limits for TK_0 and TK_c were 0,01% per 10 Kelvin and the maximum allowed creep was 0,01% in 20 minutes.
The reproducibility for all selected force transducers has been determined by applying a compressive force in the force calibration machines of HBM's DKD calibration laboratory (figure 4). The deadweight machines have a best possible relative measurement uncertainty of 0,005% for compressive forces from 500 N up to 2 kN and for the ranges up to 500 kN a best possible relative measurement uncertainty of 0,01%. The 100 N and 200 N force transducers have been measured on a manual weight construction without a DKD accreditation, the results obtained in the FSM with higher accuracy will have more importance.
The expanded measurement procedure has been carried through by applying compressive forces, in 3 different mounting positions in 0°, 120° and 240° rotation, with increasing and decreasing forces at 10%, 20%, 50%, 100%, 50%, 20% and 10% of the nominal force, for the 1000 N transducer at 20%, 40%, 50%, 60%, 80% and 100% of the nominal force. The transducers have always been complemented with a DMP40 high precision amplifier to get a complete measuring chain [3].

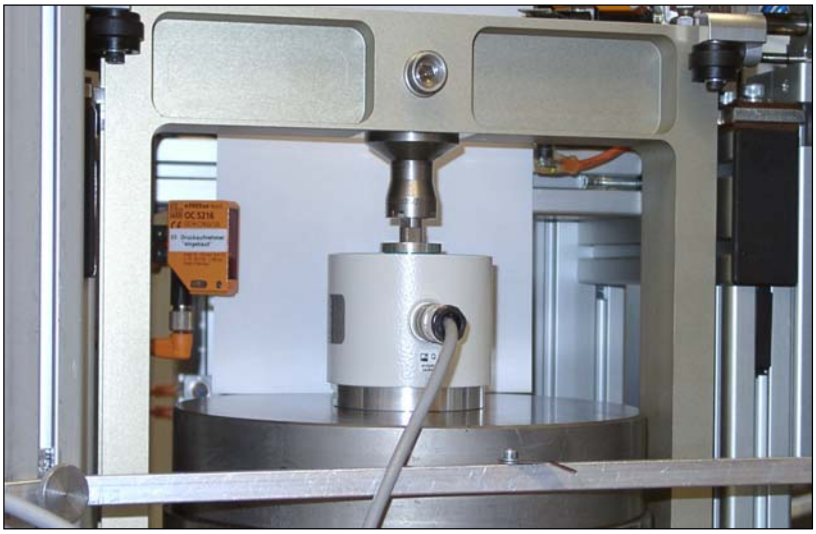


Figure 4: Type B/5kN in a 25 kN DW FCM

Table 1: Results of the production test certificate compared with the expanded test certificate

Nominal force	Percent of nominal force	Relative reversibility in % Production test certificate Tension	Relative reversibility in % Expanded test certificate Compression
200 N	20	-0,005	-0,002
	50	-0,001	-0,001
1000 N	20	-0,006	-0,004
	50	-0,004	0
5 kN	20	0,004	0,006
	50	0,002	0,004
20 kN	20	-0,007	-0,002
	50	-0,002	0
500 kN	20	-0,07	-0,012
	50	-0,05	0

The comparison between the production certificate and the expanded measurement shows that, typically, the expanded procedure with forces in compression verifies the results of the relative reversibility in the standard production certificate with forces in tension (table 1).

Nevertheless the expanded production certificate is important for measuring the reproducibility of the force transducer in three different mounting positions.
For the 500 kN transducers the values of the reversibility in tension of the production test certificates are always higher than in compression, because the calibration machine has a measurement uncertainty of $6 \cdot 10^{-4}$ in tension at 500 kN compared to $1 \cdot 10^{-4}$ in compression.

4 Measurement Results

For additional measurements in deadweigt force standard machines at the PTB at least one type of each measuring body had been chosen. The measurements at the force standard machines were performed according to ISO 376 with ten force steps in compression (figure 5). Creep measurements were carried out too. The transducers were always connected to a DMP40. The force standard machines with capacities of 200 N, 2 kN, 20 kN and 1 MN have been used for the measurements, all of them with a relative measurement uncertainty of $2 \cdot 10^{-5}$ (k=2).

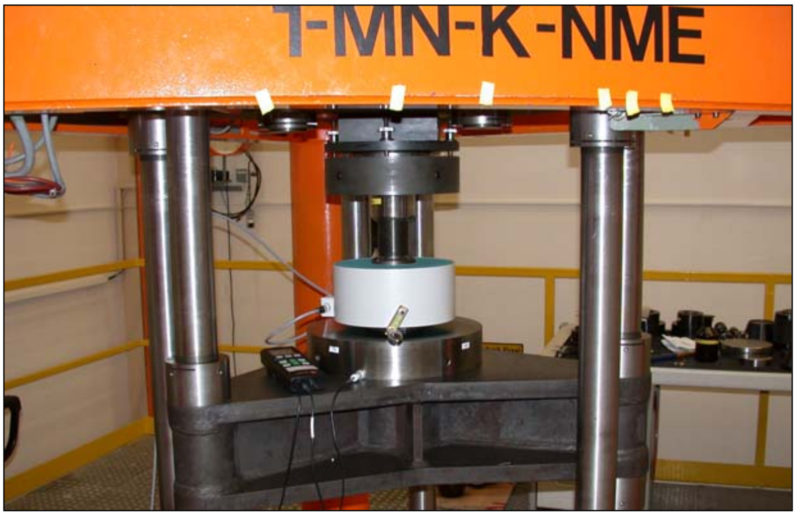


Figure 5: Type C/500kN at a 1 MN Force Standard Machine

Achievable results for the different measuring bodies are summarized in table 2. The specific values obtained in force standard machines are calculated according to ISO 376. The measurement uncertainty is calculated according EA-10/04 which takes all significant effects like repeatability, reproducibility, reversibility, interpolation error, and the resolution of the indicator into account. The measurement uncertainty of the mean value of the increasing forces which is important for intercomparison measurements is less because it is related to the reproducibility of the measurement rows in three different positions with increasing force values. Some transducers reached the best possible measurement uncertainty of the force standard machine.

Compared to the results of the expanded measurement procedure in the DW FCM, the repeatability at 200 N is much better. As mentioned before the lower ranges have been measured by deadweights with a hand-procedure, not DKD accredited; the results obtained in force standard machines are relevant in this case. For the 1000 N, 5 kN and 500 kN transducers the results received in force calibration machines have been confirmed.

Table 2: Results for different transducers achieved in Force Standard Machines (FSM) compared with the results of the expanded measurement procedure in Force Calibration Machines (FCM)

Nominal Force	F_{nom}	200 N		1000 N		5 kN		500 kN	
Machine type		FSM	FCM	FSM	FCM	FSM	FCM	FSM	FCM
Rel. repeatability in %[1)]	b'	0,001		0		0,001		0,002	
Rel. reproducibility in %[1)]	b	0,002	0,015	0,001	0,002	0,005	0,005	0,003	0,015
Rel. reversibility in %[1)]	u	0,001	0,002	0,001	-0,004	0,008	0,006	0,008	-0,012
Rel. zero error in %	f_0	0,001	0	0,001	0	0,003	0,001	0,002	0,003
Rel. interpolation error 2nd-degree in %[1)]	f_c	0,001		0,001		0,001		0,002	
Rel. measurement uncertainty according EA-10/04 in %[1)]		0,002		0,002		0,006		0,006	
Relative measurement uncertainty of mean value for increasing forces in %[1)]		0,0022		0,0021		0,0036		0,0022	

[1)] for the range 0,2 F_{nom} to F_{nom} according ISO376

As an example the results of the 1000 N force transducer are plotted in figure 6. The relative deviation between the measurements in a FSM and a FCM is included, as well as the repeatability measured in the FSM and a comparison of the reproducibility in the FCM and in the FSM. Similar results for the reproducibility are obtained in the entire force range.

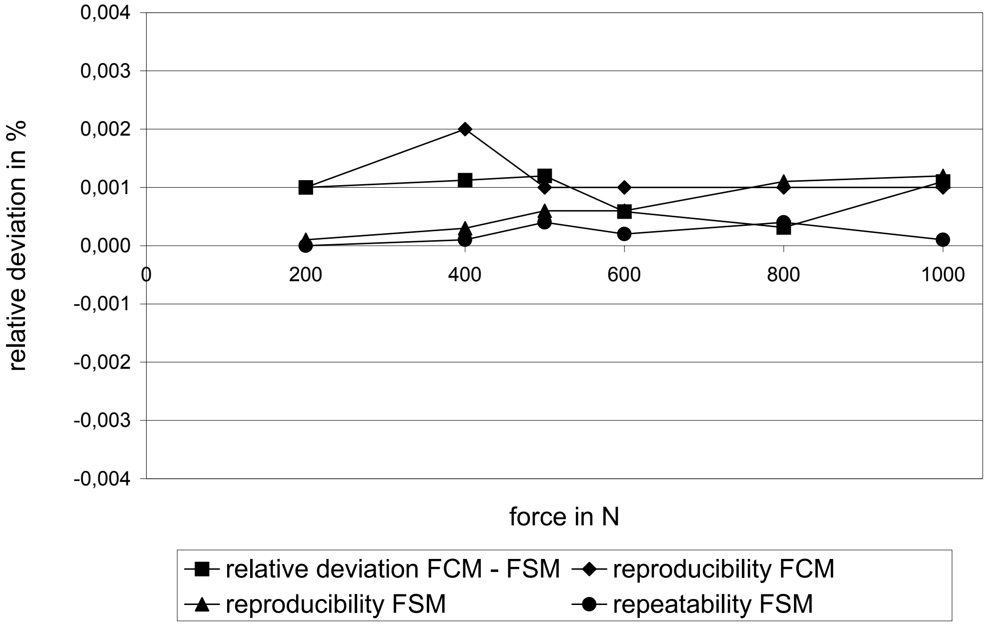


Figure 6: Results obtained with the 1000 N force transducer

Figure 7 indicates some typical creep measurements, loading and unloading, each 20 minutes for the three transducer designs. The results show, that the influence of creep on the

measuring result is less $7 \cdot 10^{-5}$ in the first 20 min and can be taken into account in high precision measurements.

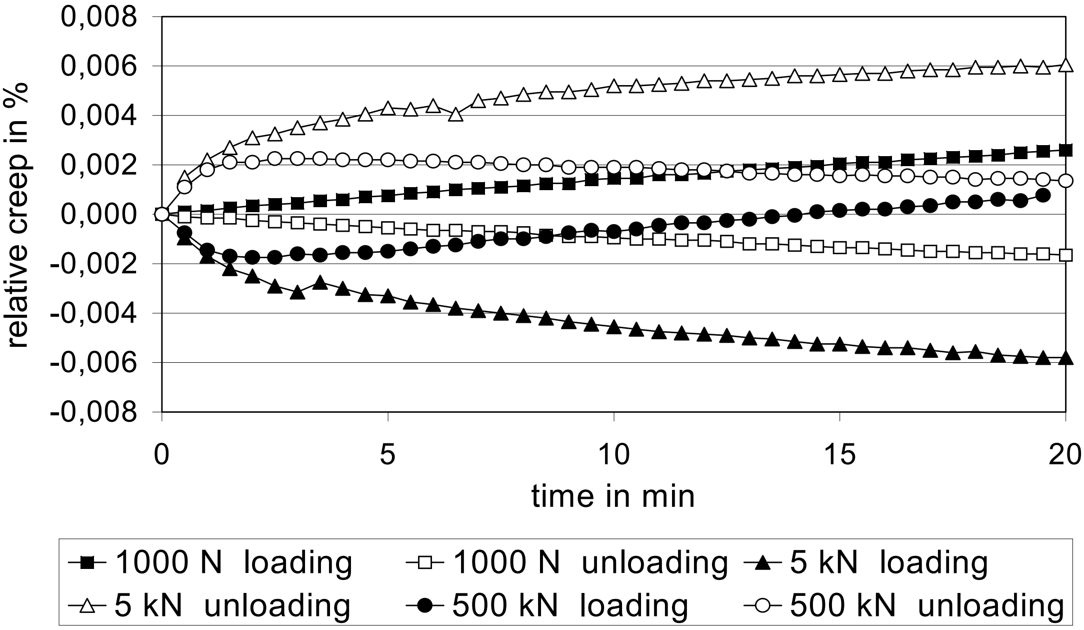


Figure 7: Typical results for the creep measurements, for different force transducer types

5 Conclusion

Measurements carried out with different force transducer types have shown, that a short measurement procedure with only four force steps in three different mounting positions, enables high precision force transducers to be selected from the standard production. Some typical results show, that it is possible with these selected transducers to reach the measurement uncertainty of the force standard machines. An additional calibration is always necessary to verify the excellent specifications, the best results will be obtained at National Metology Institutes.
The ambient influence of temperature for the high precision measurements is reduced by small TK_c and TK_0. The creep curves show, that the stability of the force signal is guaranteed.

Measured reproducibilities over 2 years with the transducers of type A with nominal loads from 100 N up to 1000 N in a deadweight force calibration machine (DW FCM) showed a typical change of the sensitivities of 0,002%. Under consideration of the relative measurement uncertainty of the calibration machine of 0,005% (k=2) the expected long-term stability will be less than 0,005% per year. Additional measurements will be taken during the next years to check the excellent long-term stability over a longer time period.

References

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