INVESTIGATION OF A NEW 1 MN FORCE CALIBRATION MACHINE OF TWIN CYLINDER DESIGN

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Abstract: *Three new force calibration machines covering the range from 1 kN to 1 MN has been designed and constructed at DM-SIC in Bogotá, Columbia. The 1 MN force calibration machine (fcm) is a reference force calibration machine of new design. A special flexible sealed twin piston cylinder system with rotating cylinders has been used for the generation of hydraulic forces to reduce the friction, oil losses and pressure drops in the hydraulic system. Time optimization and a high accuracy of force control could be achieved by a three-step combination of rapid preliminary positioning, a PI controller algorithm and, finally, a change-over to PID controller characteristics. The relative deviations between the measurements carried out at PTB and the final measurements performed in the 1 MN reference force calibration machine show that the fcm fulfils the predetermined overall specifications limits of relative uncertainty* $< 2 \cdot 10^{-4}$ *in the whole working range from 40 kN to 1 MN.*

Introduction

In the year 2000, an ensemble of three force standard machines was set up at the Force Laboratory at the División de Metrología (the Metrology Division of the Superintendencia de Industria y Comercio in Bogotá) covering the nominal force range from 1 kN to 1 MN. In extensive comparison measurements, the relative deviations of the mean values from those obtained with the force standard machines of the PTB in Braunschweig were determined. Since that time, force transducers can be calibrated with these machines in accordance with DIN EN 10002-3 and/or ISO 376. Two machines operate by the deadweight principle (10 kN and 100 kN), while the third one, with the nominal force range of 1 MN, was conceived as a reference force machine with hydraulically generated force. This machine will be the subject of this contribution.

The 1 MN force standard machine

The working space is enclosed by four columns and bordered at the top and at the bottom by massive closing plates. The upper closing plate carries the twin cylinder system which, via a force distribution piece, takes up the reference force transducer on which a transverse head is rested. Two spindles adjustable by a motor link the transverse head with the crosshead. In this way, a load frame is formed which takes up the force transducer for force in compression or tension. Depending on its direction, the force generated by the twin cylinder system is conducted either to the upper or to the lower closing plate of the machine frame (Fig. 1).

Temperature chamber

Included in the scope of supply is an air-conditioned chamber. It can be mounted into all three machines and allows investigations of load cells within a temperature range from -10 C to +40 °C in accordance with the recommendations of OIML R 60.

Control system

Responsible for the sequential control and the functions relevant to safety is a central unit which is composed of a programmable logic control (PLC) and an industrial PC. The three measuring machines are connected with the central unit via a serial field bus. They can, however, also be run in parallel, independent of each other. Connected with the central unit is also a precision measuring amplifier. It provides the signals for the triggering and

automatic control of the force steps, and also the measurement signal of the force transducer to be calibrated. As a result, the measurement process can take place automatically. The measurement data are transferred to a second PC and stored in a local database. The evaluation is program-controlled, according to DIN EN 10002-3 and/or DIN ISO 376. Furthermore, individual test programs can be developed and at the end, the data can be bound into commercial text processing programs or spreadsheets and processed further.

Force generation

The force is generated hydraulically. An electric motor-driven spindle pump with plunger piston acts on the twin cylinder system. The volume variation caused by the axial stroke of the plunger piston induces a pressure change in the closed hydraulic system which is converted in the twin cylinder system into the required force. Both cylinders are synchronously set in rotation via a belt drive so as to minimize the friction effects. Due to the counterrotations of the cylinder, no rotary pulse whatsoever is generated which could be transmitted to the force transducer via the load frame. Special flexible piston seals reduce the oil leakage rate to infinitely small quantities. As, furthermore, the pistons hardly move any longer in the axial direction as soon as the theoretical force values are reached, friction errors cannot be detected. Due to these design characteristics, only very small quantities of oil are transported during the control process. The pump output and the respective power loss in the hydraulic system can thus be kept very low, which has a positive effect on the stability of the control behaviour.

Fig. 1 The 1 MN force calibration machine

Automatic control

The aim of the automatic control concept was to achieve optimum design of the time response and, at the same time, highest precision in force generation. The force steps should be triggered as fast as possible and without overshoot and be automatically controlled with high precision during the measuring phase to constant values. For solving this problem, the automatic control process was divided into several sections in which the characteristic response of the controller is adjusted to the different requirements. The output signal of the measuring chain (consisting of reference force transducer and precision measuring amplifier) is available in different formats. These are automatically selected and processed by the controller. The switching points are selected by the program after certain threshold values deriving from the theoretical force steps have been exceeded. Via a power stage, the controller acts on the drive motor of the spindle pump so that the loop is closed.

The theoretical values are simulated by the software with a third-degree fitting parabola. The coefficients needed for this purpose were determined at the PTB by calibration of the reference force transducer.
Decisive for the optimization of the automatic control process was the selection of suitable output signals of the measuring chain. In the sections preceding automatic control, the analog signal is used. This is available practically without any delay. The high-precision, digitally filtered measurement signal is not applied until the precision automatic control phase.

Reference force transducer

Special attention was paid to the investigation of the reference force transducer as its characteristic response has an essential influence on the response and the precision of the machine. This is a 1 MN compression force transducer, type KTN-D of GTM make. The measurements were carried out in different force standard machines so as to detect also the different interactions between force transducer and machine. Repeat calibrations in the 1 MN force standard machine at intervals of several weeks supplied information about the time response of the force transducer.

The machine was designed in such a way that the reference force transducer remains permanently in the mounting position and so covers the entire measuring range from approx. 20 kN to 1 MN. In general, characteristic curves of force transducers are more or less non-linear. Close to the zero point, in particular, interpolation deviation can therefore take on such

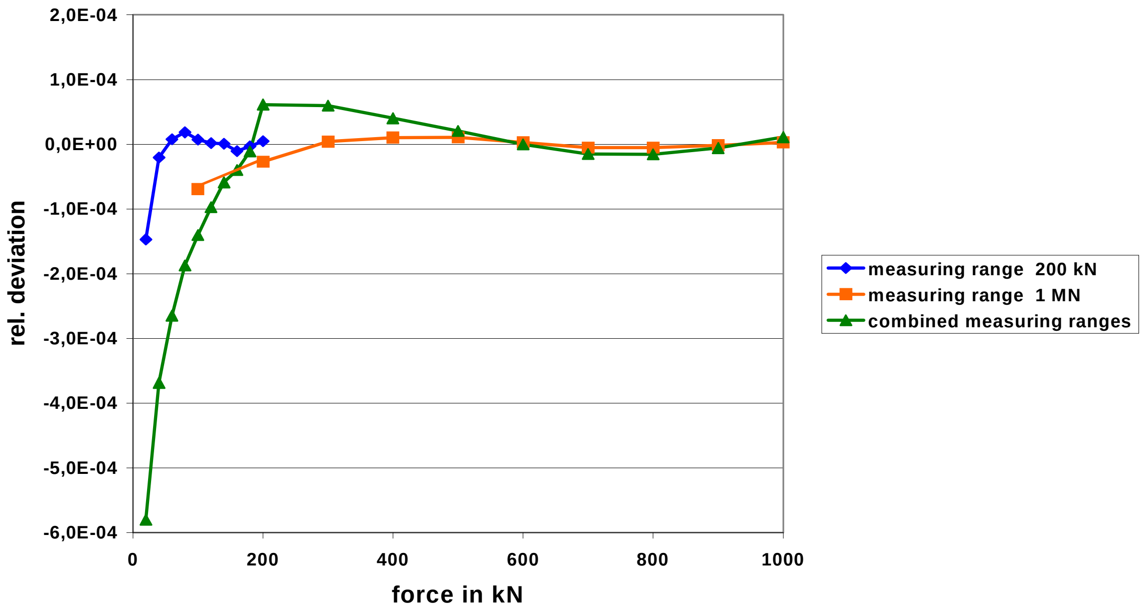

Fig. 2 Influence of the parameters on relative interpolation deviation

high values that the limits of the measurement uncertainty aimed at are exceeded. However, by splitting the total measuring range into several sections, this problem could be solved very well. The reference force transducer was calibrated in the ranges 20 kN to 200 kN and 100 kN to 1000 kN, which allowed the respective coefficients for the computation of the third-degree fitting parabolas to be derived. The interpolation deviations thus remain limited to a metrologically acceptable degree, as shown in Fig. 2.
These parameters were embedded into the software of the control PC. The coefficients are selected automatically in dependence on the measurement value of the measuring amplifier.

The reference force transducer was modified for its mounting into the machine. The force application piece, originally of spherical design, was surface-ground to obtain a defined bearing surface for the transverse head resting on the reference force transducer. This modification led to a change in the sensitivity of approx. $1 \cdot 10^{-3}$, as was found out in the final calibration. Finally, the reference force transducer was thermally insulated. This further improved the stability.

Data collection and evaluation

All measurement data are transmitted to the central control PC, at choice either manually or automatically, and stored. In the case of the 1 MN reference force machine, the signals from the reference force transducer and the test specimen are detected synchronously and stored in a table as so-called raw data. As, for reasons in connection with the automatic control, slight deviations from the theoretical force steps can occur, the software corrects these signals automatically to the exact values.
In addition to the usual calibration schemes according to DIN EN 10002-3 and/or ISO 376, any measuring procedures whatsoever can be programmed in a simple way. At the end of the measurements, the data are saved on the second PC. Here, all measurements are stored in a database and kept available for further evaluations.

Metrological investigations

All measurements were carried out by a method which is used for inter-laboratory comparisons in force laboratories. According to this method, the force transducers are first preloaded three times with nominal force. Then, two measurement series in the 0° position follow with increasing and decreasing force. After rotation by 90° and preloading, two measurement series with increasing force steps are performed. This procedure is repeated at 180° and 270°. After that, the measurement is finished [2], [3].
The transfer transducers are selected in such a way that the entire range of a calibration machine is covered. The transfer transducers were loaded not less than 40% of their nominal force to prevent the resolution of the indicating device from becoming too small and the curvature of the characteristic curve of the force transducer in the lower force range from leading to undesirably high measurement uncertainties. The results for the 1 MN force standard machine are shown in Fig. 3.

F in kN	$\boldsymbol{u}$ (RefTransd) for increasing forces	Rel. deviation between SIC and PTB	$\boldsymbol{U}_{SIC}$
20	1,1E-04	1,2E-04	2,4E-04
30	9,9E-05	4,2E-05	2,0E-04
40	9,8E-05	8,9E-05	1,5E-04
50	6,6E-05	1,0E-04	1,5E-04
80	4,1E-05	7,6E-05	1,2E-04
100	3,3E-05	1,2E-04	1,1E-04
120	2,1E-05	7,0E-05	9,4E-05
160	1,8E-05	-1,2E-05	8,5E-05
200	1,7E-05	7,2E-06	8,5E-05
300	3,7E-05	1,5E-05	1,4E-04
400	2,7E-05	1,6E-05	1,4E-04
500	2,5E-05	1,9E-05	1,3E-04
600	2,0E-05	2,0E-05	1,3E-04
800	1,4E-05	9,5E-05	8,5E-05
1000	1,6E-05	1,3E-04	9,4E-05

Table 1 Relative uncertainty of the 1 MN FCM

The measurements were carried out with force transducers belonging to the force laboratory of SIC. Only the 1 MN transfer transducer is property of PTB. Table 1 shows an extraction from the investigations on the 1 MN reference force calibration machine [4]. The second column contains the values for the combined relative uncertainty of the reference transducer for increasing forces. The third column shows the relative deviations of the mean values between PTB and SIC. Finally the values for the relative uncertainty of investigation with a coverage factor of *k*=2 are listed in the fourth column.

With the comparison measurements it was found that the relative deviations of the mean values of PTB from those of SIC are smaller than $1{,}4 \cdot 10^{-4}$ in the range from 20 kN to 1 MN as it is shown in Fig. 3. The relative uncertainty of investigation (*k*=2) is noticeable smaller than $2 \cdot 10^{-4}$ in the range from 80 kN to 1 MN and appreciable in the range between 40 kN to 80 kN.

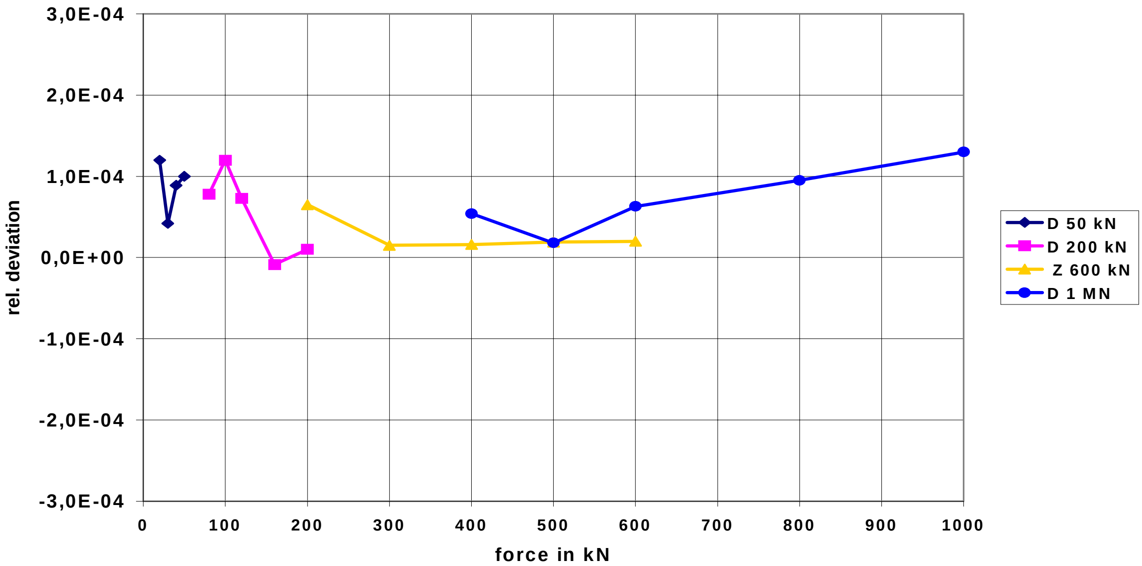

Fig. 3 Relative mean value deviation between DM-SIC and PTB

Summary

With these force standard machines, the Force Laboratory of the Metrology Division of the Superintendencia de Industria y Control in Bogotá, Colombia, is in a position to carry out calibrations of high precision in the nominal force ranges from 1 kN up to 1 MN. On the 1 MN reference force calibration machine, which was decribed in this contribution, it is possible to calibrate force transducers of class 0,5 in compliance with DIN 10002-3 and/or ISO 376 in the working range between 40 kN and 1 MN.

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