XVIII IMEKO WORLD CONGRESS
Metrology for a Sustainable Development
September, 17 – 22, 2006, Rio de Janeiro, Brazil

INVESTIGATION OF FORCE TRANSDUCERS WITH DIFFERENT LOADING PROCEDURES ON JOCKEY-WEIGHT AND DEADWEIGHT MACHINES

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Abstract: Force transducers used as transfer standards are usually calibrated according to ISO 376. Industrially applied force transducers can be calibrated according to more simplified procedures, however with extended measurement uncertainty. The main purpose of this paper is to point out the different values of the characteristic parameters which are due to varied loading procedures.

Keywords: calibration method, continuous load, alternating load, remanence

1. INTRODUCTION

Modern production methods require the improvement of measuring techniques in order to enhance the quality of materials and ensure their economical use. The need for shorter product development times and low costs is in contrast to these requirements. It is therefore necessary to develop new and precise measuring methods to determine the quality and properties of materials and devices within a shorter period of time and at lower costs.

In the field of force, new calibration methods, procedures and calibration machines are being developed to make faster force calibrations possible. A jockey-weight machine for force and torque was developed by the company GTM in Bickenbach, Germany [1]. The machine can be used for both, static and continuous calibration of force transducers in compression, tension and in alternating mode. As it is not necessary to change the force transducer, the measurement can be accomplished without any time delay.

Within the framework of the German Calibration Service (DKD), a guideline was developed which describes methods and procedures for the continuous calibration of force transducers [2]. This procedure is mainly related to force calibration machines with reference force transducers used for continuous loading. In contrast to gradual loading, a so-called "sudden loading and unloading procedure" can be used in deadweight machines to verify the properties of reference force transducers or force transfer standards. "Sudden loading" means that the weights are assembled before the force transducer is loaded.

The measurements reported in this paper are carried out on PTB´s 20 kN deadweight force standard machine (FSM) and on the 25 kN jockey-weight force calibration machine (JW-FCM) of GTM [3,4]. The main purpose of the investigations was to study the behaviour of different force transducers with respect to different loading procedures.

High-quality transducers used as transfer standards as well as low-cost transducers used for industrial applications are investigated on the deadweight and the jockey-weight machine with different loading procedures.

2. MEASUREMENTS

2.1. *Measurements in the 20-kN-FSM of the PTB*

2.1.1 Variation of the measuring time

A more or less random selection of force transducers from different manufacturers with nominal loads from 5 kN to 20 kN was used for the investigations. Three devices can be used for tension and compression. The measuring amplifiers work with a carrier frequency of 225 Hz.

The measurements were carried out according to ISO 376 and according to DKD-R 3-9 with different waiting times until the reading was taken. The time was reduced from 30 s to 2 s. The low-pass filter was always modified in order to make sure that the settling time was over before taking the reading.

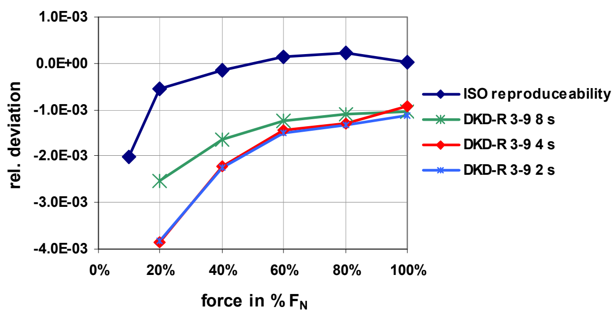

Fig 1. Relative deviation of the mean values due to various calibration procedures

In Fig. 1 it is shown by means of the example of a force transducer for industrial application how the average values differ as a function of the load procedures. While the repeatability in accordance with ISO 376 shows quite good results, the deviations increase in case of the "sudden loading" procedure in accordance with DKD-R 3-9. Furthermore, measurements were performed with different waiting times. It could be noted that below a waiting time of 8 s, the results differ only very little. A reason for this is the time which is needed for the load change. This time is much longer than the measuring time, whereby the total period of the series of measurements changes only insignificantly. The evaluation of the measuring shows that a waiting time of less than 4 seconds is problematic because the transient processes of the measuring facilities have not finished completely.

2.1.2 Fast hysteresis

The load diagram for "fast hysteresis" is shown in Fig. 2. As mentioned under 2.1.1, the time needed for the load change is relevant for the complete duration of the measuring sequence of operations.

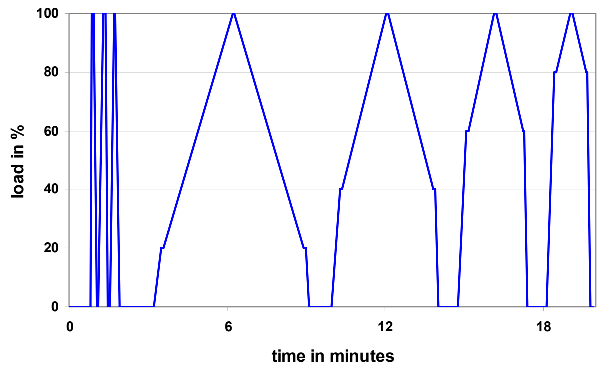

Fig. 2 Real load scheme of the reversibility test in a deadweight machine

As expected, no uniform behaviour of the different force transducer types could be observed. While at the force transducers for industrial applications, considerable differences were observed (s. Fig. 3), equipment of a qualitatively higher order , the so-called transfer standards, showed an almost time-neutral behaviour (s. Fig. 4). However, also for such force transducer types, no generally valid statement can be made.

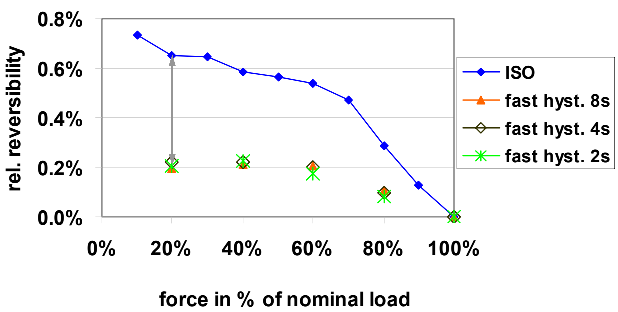

Fig. 3 Reversibility at different load schemes (industrial types)

With regard to the development of simplified calibrating procedures it is often discussed whether it should not be possible to use characteristics of the manufacturers for the analysis of the measuring uncertainty, as an alternative when certain readings are lacking. In view of these results, it can be stated that the data cannot be transferred as they refer to conventional methods only.

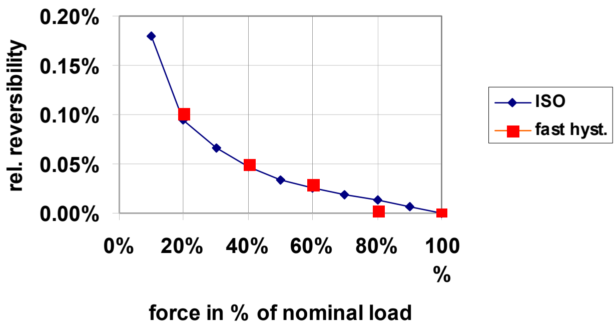

Fig. 4 Reversibility at different load procedures (transfer quality)

2.2 Jockey-weight FCM

The loading device is mounted on a welded base frame which can be levelled precisely. Approximately at the centre of the loading device, a movable crosshead is provided and at the upper end, a fixed crosshead serves as the base plate for the double-sided lever. The jockey weight moves along the lever on roller guides. It is driven by a precision ball screw spindle.

Fig. 5 View of the JW-FCM

2.2.1 Comparison with conventional calibrations

The jockey-weight force calibration machine (JW-FCM) enables stepwise and continuous loading procedures. To get an overview of the properties of the JW-FCM, measurements were first carried out according to ISO 376. The evaluation of the measurements showed that the relative deviations of the average values are in the entire measuring range smaller than $2 \cdot 10^{-4}$.

2.2.2 Continuous calibrations

Within the context of these investigations, the rate of rise was changed within the range of $0.5\% \cdot F_N$/s to $3\% \cdot F_N$/s. Preferably, the speed was between $1\% \cdot F_N$/s and $2\% \cdot F_N$/s. The curves in Fig. 6 show the relative deviations between

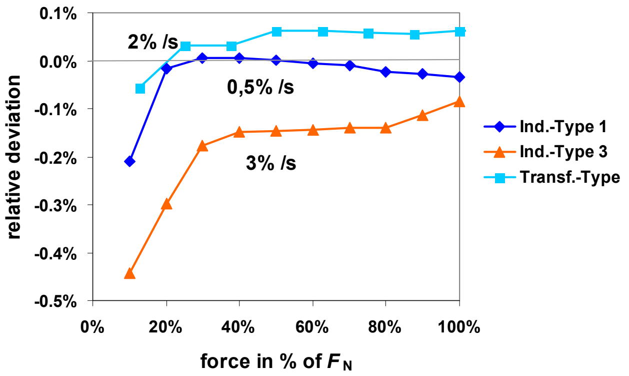

Fig. 6 Relative deviation of the mean values between PTB and the continuous calibration at the JW-FCM, GTM

the continuous calibrations in the JW-FCM and the calibrations according to ISO 376 in the FSM of the PTB. The influence of the rate of rise can be seen very clearly.

2.2.3 Alternating load

With such calibration facilities, new possibilities of force calibration arise. Tension and compression forces can be applied to a force transducer in one mounting position without having to unmount the transducer and without any time delay from one force direction to the other.

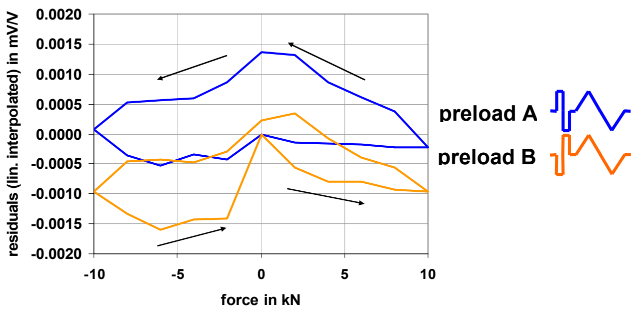

Fig. 7 Remanence as a function of the preload direction

The result can, however, depend on the direction of the preload and on the loading sequence that follows. These effects do not appear in the case of conventional measuring methods.. While the prehistory of the force transducers is deleted when the preloadings are carried out according to the conventional method, certain traces remain during the alternating loading. These can be called “remanence”. This remanence affects the characteristic of the force transducer (s. Fig.7).

2.2.4 Variation of the integration time

The data of the continuous measurement series were recorded using the system-specific LWL-DMS measuring amplifier. Control measurements with the DMP 40, which is normally used, showed a very good correspondence between the two amplifier systems.

An important parameter is the averaging time. This is the

Fig. 8 Influence of the averaging time as a function of the rate of load application

time in which the measuring system stores and averages the detailed signals. A digital filter downstream works as a low-pass, in order to suppress to a large extent any external influences of noise. To the extent in which the rate of load application is increased, the averaging time of the measuring amplifier must be shortened. Without this adaptation, faulty measurements would occur, especially at the return points and at the zero crossover. The measuring signal thereby becomes slightly more scattered. This can be seen in Fig. 8. However, the average values can be compared very well. The relatively large peaks in the proximity of the zero crossover are due to the limited resolution of the measuring system. A fair area is grasped here which usually lies outside the range that can be calibrated.

2.3 Alternating load in the 20-kN-FSM of the PTB

After the measurements in the JW-FCM were finished, the interest in reproducing these procedures as similarly as possible in the deadweight machine increased. For this, the same force transducer as before was used. A KTN-type of GTM with a nominal force of 16 kN was used. First the force transducer was preloaded with the nominal load as usual. Hereafter, a series of measurements with increasing and decreasing force steps in compression direction was applied to the force transducer. After that, it was re-mounted for the tensile direction. A series of measurements like the first sequence followed without preloading. Finally the force transducer was changed again for the load in compression direction and a sequence of increasing and decreasing force steps without preloading was repeated.

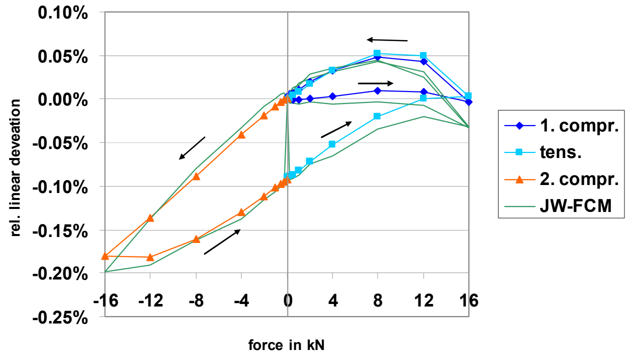

Fig. 9 Comparison of the loading procedures in the JW-FCM and the deadweight - FSM PTB

Although the time management is different in the two calibration facilities, the re-arrangement for the other force direction requires some time and the force transducer could not remain in the same position, the results show a remarkably good correspondence with the JW-FCM (s. Fig. 9). All effects, such as remanence and the increased linearity error, could be observed here, too.

All the more is the hysteresis affected by the alternating load procedure. In this case, relative values up to 4 % were measured (s. Fig. 10), which is almost 20 times more than the normal values which are observed in accordance with ISO 376. It must be pointed out that these effects were determined by means of a force transducer of higher quality which normally meets the requirements of class 00 without any problems.

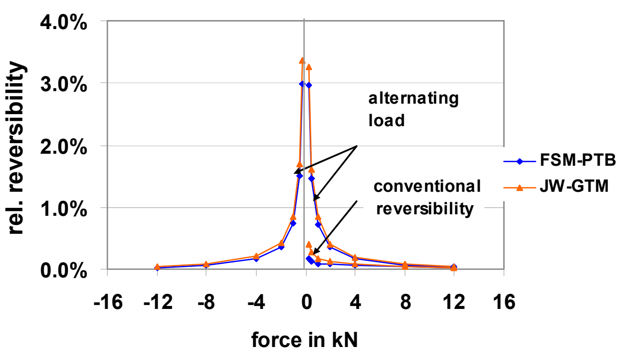

Fig. 10 Relative reversibility due to different loading procedures

In many cases, force transducers are not only used in the nominal but also in the partial load range. Therefore the force transducer was measured by means of the same procedure also within the ranges of 50 % and 25 % of the nominal load. The results are shown in Fig 11.

Each measuring sequence started with a preloading of the corresponding load of 100%, 50% as well as 25% of the nominal load of the force transducer. Parallel to the reduction of the load, the values for remanence and reversibility decrease more and more but are still recognizable. For the evaluation of a measurement with alternating load it is especially important to know in which sequence the load occurred.

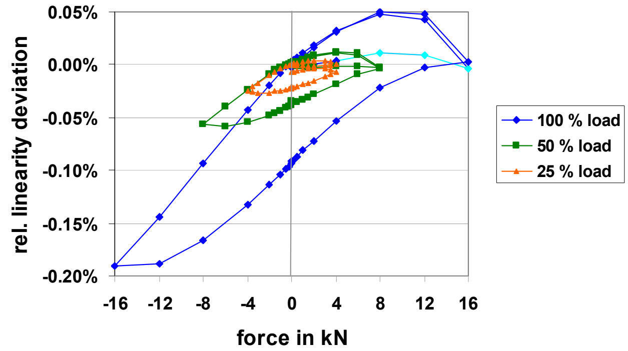

Fig. 11 Characteristic of the force transducer due to partial load

3. CONCLUSION

When simplified measuring procedures are used, larger values – as had already been expected - have to be accepted for the measurement uncertainty. With the shortened methods, not all effects are measured. For measuring methods which are a shortened procedure of ISO 376, this is not problematic. In that case, the lacking measuring data can be derived from empirical values or from data sheets of the manufacturers.

For a reliable determination of the force transducer characteristics, at least the force transducer type should be investigated in detail to determine typical parameters. This is all the more important when new methods, e.g. the alternating load, are used.

So far, the effects described in this paper are not contained in any data sheet, as the measuring method is new and has not been treated normatively so far. No suitable calibration facility existed. From industry, however, an interest in such load processes has been signalized.

Due to the results of this investigation, the development of a standard for such measuring is highly recommended as otherwise the results differ to such an extent that a comparison would only be possible with difficulties.

ACKNOWLEDGMENTS

The authors would like to thank all colleagues from PTB's Force Group and from GTM for their support in this work.

REFERENCES

[1] Th. Allgeier; U. Kolwinski,and D. Schwind "Jockey-Weight Lever Machines For Force And Torque" , VDI-BERICHTE Nr. 1685; 2002, pp. 393-402

[2] DKD-R 3-9 "Kontinuierliche Kalibrierung von Messgrößenaufnehmern für Mechanische Größen nach dem Vergleichsverfahren, Blatt 1: Messgrösse Kraft"

[3] A. Sawla, H. Gassmann; W. Kuhn "The Design Concept of a 20 kN-Force Standard Machine", XIV. IMEKO World Congress, 1997, Tampere Finland

[4] GTM Product Information; www.gtm-gmbh.com/news/jwf_p_e.pdf