HÄUSSERMANN

Calibration of diaphragm spring testing machine to DIN EN ISO 7500-1

International standard ISO 7500-1 "Metallic materials - Verification of static uniaxial testing machines - Part 1: Tension/compression testing machines" has been adopted as a European standard and published in November 1999 as the German version under DIN EN ISO 7500-1 "Prüfung von Prüfmaschinen für statische einachsige Beanspruchung, Teil 1: Zug- und Druckprüfmaschinen – Prüfung und Kalibrierung der Kraftmesseeinrichtung".

As the rules governing European standardisation (CEN rules; CEN = Comité Européen de Normalisation), do not permit national standards to be in contradiction with European standards, nor may they have the same content, the following German standards have, among others, been withdrawn:

- DIN 51 232 "Federprüfmaschinen zur statischen Prüfung von Federn (July 93)",
- DIN 51 302-1 "Prüfung von Zug-, Druck- und Biegeprüfmaschinen (July 93)" and
- DIN EN 10002-2 "Metallische Werkstoffe – Zugversuch, Teil 2: Prüfung der Kraftmesseinrichtung von Zugprüfmaschinen (version published July 1993)".

To prevent the loss of important national interests which have not (yet) been taken into account in this "new" standard, the following national addenda have been included in the German version:

- Addendum 1: "Allgemeines zu Anforderungen und zur Prüfung und Kalibrierung von Zug-, Druck- und Biegeprüfmaschinen" ('General matters regarding the requirements, verification and calibration of tension, compression and flexion testing machines')
- Addendum 2: "Allgemeines zu Anforderungen und zur Prüfung und Kalibrierung von Federprüfmaschinen" ('General matters regarding the requirements, verification and calibration of spring testing machines')
- Addendum 3: "Allgemeines zu Anforderungen und zur Prüfung und Kalibrierung von Schwingprüfmaschinen" ('General matters regarding the requirements, verification and calibration of vibration testing machines')

These addenda contain useful information about the requirements, verification and calibration of various testing machines which is not contained in European standard EN ISO 7500-1, but which has proven its usefulness in many years of practical application in Germany. They should also make it easier for their content to be integrated in the standard when future revisions are made.

The following applies with regard to the particular requirements of diaphragm spring testing machines:

there have been no fundamental changes for the calibration of force measuring systems. Essentially, changes take into account developments in technology from mechanical and hydraulic pendular force measuring systems to electro-mechanical and electronic force measuring systems with digital measured data processing.
As modern force measuring systems make it possible to measure both tension and compression forces, some of the standards for tension, compression and flexion testing machines are no longer relevant.
Depending on the type of springs to be verified, spring testing machines are assigned to one of these machine types.
As far as DIN standards for testing machines are concerned, Class 0.5 for force measuring systems existed only in standard DIN 51232 for spring testing machines. In International Standard ISO 7500-1 it exists for all testing machines.

This standard and its German addenda are based on the principle that they should be as generally applicable as possible and independent of the manufactured form of the specimens and test objects, and that design solutions should only be shown as examples and should not form the subject of the standard. This is to prevent technical progress from being impeded. Product-specific requirements such as thrust collars for diaphragm springs or roller carriages for leaf springs, are therefore not mentioned in Addendum 2 or they are only dealt with in general terms (they should be included in product-specific standards as far as possible).

Specific requirements made of the calibration of spring testing machines

Dynamic measurement error

Semi-static tension and compression verifications are also dynamic tests as far as force measurement is concerned. Even if the specimen is drawn or compressed at a low (= semi-static) speed, where rigid (hard) specimens are concerned this produces a large rate of change in the force signal. This applies in particular to the verification of rigid diaphragm springs. Here, continuous "dynamic" verification is aimed for, i.e. without pausing at the measuring point, the reasons being

- short verification times make for greater economy and
- each spring must be set at least once before verification (with an additional setting cycle before the verification cycle).

The springs are not destroyed by the verification process – in contrast to tension verification. Consequently, 100% verifications can be carried out for special applications; these must be performed in the shortest possible production cycles.

However, under this standard force calibration is static only. Although Addendum 1 does point out that dynamic as well as static measurement errors occur during semi-static verification, it only mentions possible causes for this.

Verification under load and when free of load

With usual tension, compression and flexion verification procedures, a load is applied to the specimens until they break. However, with diaphragm springs a load is applied and then removed from the specimen up to a maximum value – and verification values must be determined in both load directions. That is why for diaphragm spring testing machines, relative reversibility (parameter for the hysteresis of the force measuring system) is important. Under the new standard, reversibility will only be determined if so requested.

Measuring spring travel

The most frequently measured parameter during tension, compression and flexion verification is the maximum force reached. This can be determined without measuring travel or deformation. However, when carrying out spring verification, spring force must always be determined independently of spring travel – and vice versa.

Unlike "old" standard DIN 51232, Addendum 2 refers to these specific requirements for spring testing machines. This concerns the mutual dependence of spring force and spring travel defined via spring stiffness (spring rate) and the possible effect of eccentric loading and force patterns on force measurement.

Unfortunately the spring manufacturers and users have not supplied information to make it possible to determine error limits for the measurement of spring travel, e.g. for different types of springs, stiffness and application areas – (the DIN standardization committee does not contain a representative of the spring manufacturing industry!). However, the remark has been included that the change in force resulting from spring travel measurement error should not exceed 0.5 % of the relevant measured value so that the overall test force error does not exceed the 1% error limit (error limit 0.5% for "pure" force measuring system).

Spring travel is usually measured indirectly as the change in travel or displacement of the cross-arm (electro-mechanical spindle drive) or of the piston (hydraulic drive). The inherent deformation of the testing machine must be taken into account here; usually this is significantly greater than the relevant permitted measurement error. It is the sum of the deformations of all the machine components lying within the force flow – e.g. force sensors, cross-arms, columns, spindles or pistons, etc. and is normally in the range between 0.5 and 1 mm, referred to the rated load of the testing machine. Deformations are purely elastic; yet because local deformations (Fig. 2) occur at the contact points between the components at the beginning of loading, as do displacements due to friction (Fig. 3), the force deformation curve of the machine components is progressively inclined in the initial range and forms a hysteresis when the load is removed. These effects can be largely eliminated by the use of sufficient pre-tensioning and special design measures. The contact surface between the contact parts (spring fixture seats) of the diaphragm spring testing machine and the exchangeable fixtures specific to the type of spring (thrust collars, etc.) makes a significant contribution to this effect. A further effect is that when verifying the diaphragm spring, the force flow does not pass centrally through the spring (as with tension verification through the tensile specimen); instead, it is directed via the fixtures and the diaphragm springs concentrically apart and then together again (see force flow in Fig. 1). Fixtures and fixture seats are thus subject to flexion. The corresponding deformations are therefore also dependent on the dimensions of the diaphragm springs being verified. For this reason, if highly accurate measurement of spring travel is required, the force deformation curve for each test arrangement must be measured, saved and taken into account when determining spring travel. If, for small and particularly stiff springs, the uncertainty of measurement of spring travel measurement has to be < 0.02 mm (the typical value, as mentioned in Addendum 2), spring travel measurements must be made using an additional, highly accurate measuring system (e.g. laser interferometer), arranged centrally along the test axis, and the change in travel must be evident as close as possible to those points where the force is transferred to the diaphragm spring.

For the calibration and verification of a diaphragm spring testing machine, taking into account the dependence of spring force and spring travel decisive for spring verification, two different methods are available:

1. component verification
2. comparison of spring stiffness standards

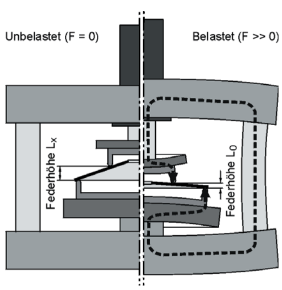

Fig. 1: Deformation of a diaphragm spring testing machine (greatly simplified). The dotted line shows the flow of the force (vertical: under tension or compression load; horizontal: under flexion load)

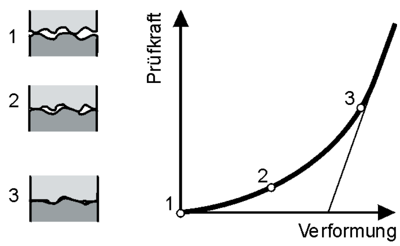

Fig. 2: Development of contact surfaces between 2 compressed components (greatly simplified) and the progressive inclination of the force deformation curve

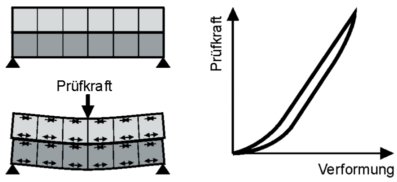

Fig. 3: Displacements due to friction between 2 superimposed components subject to flexion (e.g. spring fixture and seat of spring fixture; greatly simplified) with the resulting hysteresis of the force deformation curve for the testing machine

1. Note concerning component verification

The software is nowadays an essential part of almost all new testing machines; not only for the evaluation of measured values and the monitoring of the verification procedure, but also - and especially - for the conversion and transmission of measuring signals. This comprises the following functions:

- Correction of zero-point and sensitivity deviations (with analogue sensors)
- Correction of weight force (with force sensors)
- Linearization of the sensitivity curve (with analogue sensors)
- Monitoring and control of analogue-digital conversion (with analogue sensors)
- Interpolation of measuring signals (with incremental sensors)
- Measured value filtering
- Standardization of measured signals (conversion to SI basic units, taking into account valuation factors such as measurement range, conversion ratio, etc.)
- Temporal synchronization of force and travel/deformation measured values (for more than one mutually assigned measured signal)

Only since the introduction of this "intelligent" technology has it been possible to significantly increase the size of the measurement ranges, as systematic measurement errors can even in part be determined automatically and then eliminated by calibrating.

The software forming a part of this measuring system is verified during the calibration of the measuring system. As it needs to react very fast and in real time, the process usually takes place in special processors.

The evaluation and further processing of the "finished" measured values, on the other hand, is usually carried out on a PC. Here, it is also possible to determine (e.g.) spring travel and spring height measured values (by subtracting the stored machine deformation due to force from the measured cross-arm travel or piston travel).

Annex A of the most recent edition of standard DIN EN 10002-1 for the tension testing of metals, published in Nov. 2001, contains discussion of the verification of software for automatic tension verification (section A5). Annex J contains discussion of the precision of tension verification and of the estimation of uncertainty of measurement (both annexes are attached as a PDF file).

2. Notes on the comparison with spring stiffness standards

The advantages of this type of standard are that force and spring travel can both be determined at the same time, and a functional check can be carried out relatively swiftly and without too much effort.

The control/examination of dynamic force measurement errors should be carried out with this type of standard; it is assumed that the force-travel curve within the envisaged range is independent of speed (non-friction springs). For this application, the maximum test speed is selected in such a way that the force alteration speed occurring in dependence of the spring stiffness of the standard, is as big as the biggest value occurring during testing. It is sufficient here to carry out the test in the lower range of the force sensor as the signal run-times of the measuring system are independent of the measured values.

The following problems occur when carrying out force and spring travel calibration:

A relatively large number of these standards is required in order to calibrate the force-travel measurements with the necessary precision.

Measurement in the main axis (centre) of the testing machine does not take into account measurement errors:

- resulting from the concentric transfer of force to the diaphragm spring (flexion of the fixtures and of the fixture seats, depending on the test force and spring dimensions) and

- resulting from the transfer of force between the machine component contact surfaces, especially between spring fixtures and compression plates (force-travel curve which is non-linear and due to hysteresis; depending on the test force, pre-tensioning and the design version)

The following steps should therefore be taken:

a) Direct spring travel measurement
Spring travel is measured as the distance between two articulated "measurement stars". These are positioned with constant spring force at three points a short distance apart directly in the force line exerted on the spring fixtures. A laser interferometer can be used as the travel measurement system, generating an incremental measurement signal. Referencing is derived from the measuring signal transmitted by the piston travel sensor which performs absolute measurements at rest before every setting and verification operation. The resolution of these two sensors should be at least 0.1 µm.

b) Indirect spring travel measurement
A curve of measurements for the machine both loaded and unloaded is recorded in a single calibration operation for every spring-fixture combination, and the results are stored (takes into account non-linear curve and curve due to hysteresis).
To this end, a thick, virtually deformation-free plate is positioned on the edge of the lower fixture.

The measurement of machine deformation is carried out using the direct travel measuring system with the "measurement stars". If initial tests show it is possible to do without direct measurement using the very expensive laser interferometer, an inexpensive digital measuring sensor is used, e.g. MT 5 or 25, made by Heidenhain.

Special design features (narrow, circular seats, measuring directly at thefixtures) should make non-linearities and hystereses so small that reproducibility within the required uncertainty of measurement range of ±0.01 mm is achieved. However, in the absence of previous practical experience, this should first be confirmed by making measurements.