Calibration of a 30 MN Material Testing Machine According to ISO 7500-1 Using a Force-Transducer Build-Up System

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Abstract. New developments in the field of structural engineering and regenerative power engineering require new testing facilities with forces in the two-digit meganewton range. For this purpose, a 30 MN testing machine for tensile and compressive testing was built at MPA Braunschweig and TU Braunschweig. The nominal load of this machine is thus greater than the largest European primary standard for tensile and compressive forces. To enable traceability to this standard up to 30 MN, a parallel connection of force transducers, a so-called build-up system (BU system), was used. For this purpose, the results of a EURAMET-funded research project (EMRP SIB 63) were used and further developed to enable a connection according to Standard ISO 7500-1. The procedure and the results are described in the following.

1. Introduction

New future technologies bring about new challenges for materials research and structural engineering. These challenges present themselves in the form of highly efficient materials for infrastructure projects, ultra-high-strength concretes for high-rise buildings, highly stressable tension members for bridge constructions or for components in the field of renewable energies. All these applications require testing facilities for loads that are notably above the currently available level. In response to these challenges, the Institute for Building Materials, Concrete Construction and Fire Protection of Technical University Braunschweig (IBMB) and the Braunschweig Civil Engineering Materials Testing Institute (MPA BS) have developed a testing facility with a nominal load of 30 MN that is able to generate test forces – both statically and dynamically – up to 30 Hz in the compression and tension direction. To be able to traceably calibrate this facility, the results of a EURAMET research project were used where, among other things, the paralleling of force transducers was scientifically investigated and a corresponding uncertainty model was developed. From this model, a procedure for an ISO 7500-1-compliant calibration was developed. The machine was investigated to be used in the future with a refined reference force transducer system as a calibration facility for ISO 376 calibrations.

2. Construction principle of the 30 MN material testing machine

The IBMB and the MPA BS designed and realized a 30 Mega Newton Test machine in 2011 for testing of structural elements and pre-stressing systems and cables (Figure 1).
The machine is designed for static and dynamic tests under tensile and compression load conditions. The maximum push and pull force under static loading conditions is 30000 kN, under dynamic loading conditions 24000 kN. The test machine has been designed according to the spring principle. Several bladder accumulators are connected to the 30 MN main hydraulic cylinder and act as spring when the dynamic load amplitude is realized by four 1000 kN hydraulic pistons.

The amplitude and the frequency in the dynamic test depend on the stiffness of the specimen. For testing stay cable systems under tension, the maximum achievable frequency is 2.5 to 3.0 Hz. For the installation of samples in the machine, the clearance between the four columns is 1200 mm in both directions.

The reference transducer is designed as a ring transducer and can be mounted in two different positions within the machine for use in compression and tension mode:

- In compression mode, the sample can be installed between the plane bend/buckling plates (1160 mm × 1160 mm, the maximum tilt angle of the plate is 6°). The upper plate has a spherical ball bearing that is compliant with DIN EN 12390-4.
- The maximum length of the test sample in compression mode is 4797 mm.

For testing samples under tensile condition, the specific anchorage of the samples must be fitted to the machine. The diameter of the passage hole in the traverse and the piston of the hydraulic cylinder is 505 mm. Due to the hydraulic piston (l = 2000 mm) and the upper cross head of the machine (d = 1310 mm), some of the samples are inaccessible on their side. The length of the test sample is a maximum of 10311 mm and a minimum of 3580 mm. The position of the upper cross head can be adjusted in steps of 280 mm. In addition, the machine can be used in synchronized axial and transversal fatigue loading mode. The stroke of the piston is 100 mm. The maximum dynamic push load is 285 kN and the max. dynamic pull load is 135 kN.

3. Uncertainty model for the use of BU systems

In the past, it has frequently been assumed that the responsivity of the force transducers is not influenced when force transducers are connected in parallel to form a so-called build-up system (BU system) by means of adaption components that are as rigid as possible. More precise investigations, however, have not confirmed this assumption. Therefore, measurement uncertainty models were developed as square root sums analogous to ISO 376 on individual BU systems [1]. Further research work in this field was conducted by means of a EURAMET-funded project [2; 3]. Derived from this research, a 30 MN material testing machine is now to calibrated accordingly by means of a BU system. To conduct a calibration according to the standard ISO 7500-1 “Tension/compression testing machines - Verification and calibration of the force-measuring system”, the BU system must be calibrated initially as a transfer standard. For conventional transducers, this calibration is performed according to ISO 376. The calibration result and the associated measurement uncertainty obtained are the input quantity for the ISO 7500-1 calibration of the testing machine. If a BU system is used to multiply the available force standard, this transfer standard certainly cannot be calibrated up to its nominal load, which is 30 MN in our case.
Therefore, the single transducers are calibrated up to their nominal load and, thereafter, the entire BU system is calibrated up to the nominal load of the largest available force standard machine (FSM). During this process, the indication deviation $d_L$ [2] of the system behavior is determined. When used as a BU system, the force indication $F_S$ is realized as a function of the load step $F_{LS}$. Here, $F_S$ is the summation force of all single transducers connected in parallel, whose force measurement values are derived from the transducer signals of the individually calibrated transducers. By comparing the summation indication of $F_S$ with the force that is actually applied by the standard $F_{LS}$, the relative deviation $d_L$ between $F_S$ and $F_{LS}$, can be determined. This indication deviation and its measurement uncertainty are determined by the mechanical design; neither of these values may be neglected when working with a BU system. In the previous publications [2], the measurement uncertainty (MU) was calculated according to equation (1). This approach uses the absolute measurement uncertainties calculated from the respective load situation and the ISO 376-recognized determination of the individual typical uncertainty components of the transducers.

$$u^2(d_L) = \left(\frac{1}{m_{F_{LS}}} \cdot \sum_{j=1}^{m} \sum_{i=1}^{n} F_{i,j}\right)^2 \cdot u^2(F_{LS}) + \left(\frac{1}{m_{F_{LS}}} \cdot \sum_{j=1}^{m} \sum_{i=1}^{n} u^2(F_{i,j})\right)$$

Here, the continuous index $n$ signifies the number of transducers used in the BU system, which can typically also have five or nine transducers. Depending on the calibration methods used, the continuous index $m$ designates the number of the measurement series. The Excel template that was developed during the research activities and can be downloaded free of charge from the homepage of the EMRP SIB 63 project is a suitable tool for processing various measurement procedures and a variety of transducers. The template for the application of BU systems additionally contains all MU calculations according to the results from the EURAMET research project [3].

In the FSM, the indication deviation $d_L$ can, of course, only be determined up to the nominal load of the FSM. To this end, $d_L$ must be extrapolated up to the nominal load of the facility to be calibrated. For this computation, methods were applied that had also been determined in the EMRP SIB 63 project for the regression and extrapolation of calibration results with transducers [3]. For this, a safe extrapolation is used, albeit one that yields comparatively great relative uncertainties. Regarding the extrapolation of $d_L$, however, the absolute uncertainty of this correction is relativized in the overall result by the already small values for $d_L$. With the extrapolated $d'_{L}$, it is possible to realize a calibration force $F'_{cal}$ in the full load range by means of the BU system. This broadened load range is signified by the apostrophe in the formulas. Hence, if $F'_S$ is the indicated signal from the BU system on the amplifier without correction of $d'_{L}$, if $F'_L$ is the real calibration force and if $F'_S$ is the indicated force of the force calibration machine or of the material testing machine, then the indication deviation of the machine to be calibrated can be designated "$q$", like ISO 7500-1:

$$q = \Delta F(F'_S) = F'_L - F'_{cal}(F'_S)$$

This procedure has already been confirmed in a comparison measurement with the 60 MN FSM of the FJIM [2] as well as in a comparison measurement with the 30 MN FSM of the NPL, London [3]. Similar measurements were then performed by means of the machine of the MPA Braunschweig as described in Chapter 2. Analogous to [2], these measurements were used to draw up a result table (Table 1) by means of the free download. Based on the aforementioned Excel template, an integrated program was developed to perform measurements and to issue a calibration certificate according to ISO 7500-1. During this process, several extensions were integrated. In the first version, each of the individual transducers was measured during the calibration only up to its nominal load (in [2] is referred to as “A measurement”). In the example of the comparison measurement with the FJIM using the $5 \times 10$ MN system, however, the problem was that the deviation $d_L$ obtained from the comparison of the 10 MN calibration of an individual transducer was compared only with the summation measurement of the entire BU system up to 16.5 MN – in other words, with merely 3.3 MN per transducer. Thus, a second calibration of the individual transducer up to 3.3 MN was performed.
The polynomial of the transducer sensitivity obtained in the second calibration was then used to determine \( d_L \). This procedure ensures that it is always identical load steps, with the same time schedule and with the same nominal load per transducer, that are compared in the two measurements. For the calibration in the so-called “C-measurement” of the larger material testing machine, the polynomial and the measurement uncertainties are used that are obtained from the 10 MN calibration. The file that can be downloaded from the EMRP SIB 63 page was enhanced by this second “A2 measurement” – as it is referred to on this EMRP SIB 63 page – and it automatically uses the correct polynomials for the determination of \( d_L \) and for the calibration of the machine in the so-called C-measurement in the template. In addition, a further validation of the calibration results was added. In the Excel template, the indication deviation \( q \) of the machine is determined as described in (3). In a second validation calculation, the measurement results of the entire BU system in the testing machine, that were corrected for \( q \), are used to calculate the indication deviation \( d_L \) of the BU system up to the nominal load of the BU system by means of the full load calibrations of the individual transducers in the FSM, and to compare these calculations with the extrapolated results from the FMS. These results obtained from the comparison measurement at the 60 MN FSM at FJIM were lower than 0.002%.

### 4. Planned upgrade of the 30 MN machine for use as a force calibration machine

In the specified force range, the 30 MN testing machine reaches the best possible classification of 0.5 according to ISO 7500-1. Nevertheless, the potentials of the reference transducer system that has been enhanced for special testing purposes are not ideal for using this machine as a calibration facility. Furthermore, when this machine is used as a calibration facility, many load changes may impact the transducer sensitivity during a dynamic stay cable test, even when the necessary measurement uncertainties are taken into consideration. Accordingly, it is planned to complement the machine by a second reference system consisting of four 10 MN transducers that will be used instead of the first one only for calibrations according to ISO 376. For the machine, a relative expanded \( (k = 2) \) measurement uncertainty of 0.05 % is envisaged. The research activities conducted at the MPA BS, at the IBMB and at PTB to develop an economic and precise calibration facility for transducers were synergized to form a “Competence Centre Large Force”. In a further step, the need for an even larger force calibration facility is to be analysed.

### 5. References

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[3] Euramet EMRP SIB 63 project, “Final Publishable JRP Report”, downloadable from the projects homepage: https://www.ptb.de/emrp/sib63-publications.html