Dynamometer calibration

This section only discusses the calibration of a transducer with static forces. The dynamic aspect is not discussed.

When the relationship between the force applied to a dynamometer and the measurement of its output signal cannot be accurately determined during manufacturing or by means of a calculation, it is necessary to calibrate the dynamometer. This operation consists in establishing the exact relationship between the force applied to a dynamometer - input - and the electrical signal it releases - output.

In essence, the operation consists in applying forces that can be accurately measured to a dynamometer and register the values provided by the electronic equipment connected to the transducer. The results obtained are displayed in a value table or a mathematical polynomial allowing the user of the dynamometer to know the value of the force from the indication provided by the linked electronic equipment. The determination of the related inaccuracy is also part of the calibration. This is established according to the guide "Guide to the Expression of Uncertainty in Measurement" established by the International Bureau of Weights and Measures (BIPM).

Calibration is usually performed by applying the protocol established by international standard ISO 376. Standard **ASTM E 74** is also a protocol issued in the US. Other calibration protocols can be defined according to the use of the dynamometer and to the level of inaccuracy sought.

Calibration of a dynamometer must be performed with forces referenced to the force unit - the newton- as defined by the International System of Units (SI). Traceability of this system by units is only formally guaranteed by calibration laboratories applying ISO 17025 Standard and accredited by one of the national accreditation bodies (SMB, COFRAC, DKD, UKAS…).

Application of efforts to the transducer

The calibration bench must be able to apply unidirectional forces to the transducer effort axis. For this purpose, the axis according to which forces are applied by the bench must be materialized and the transducer must be centred on this axis. This is performed by means of a rigorous mechanical assembly of the transducer on the calibration bench.

Regardless of metrological quality, a calibration bench will never generate perfectly unidirectional efforts. Interfering effort and torque components, due to imperfections of the bench are also applied to the transducer. Indications provided by the dynamometer are often affected according to the sensitivity of the transducer to these efforts. The electrical signal increases or decreases according to the direction of these interfering components. Now, the direction of these components is generally constant for a force applied on the calibration bench. The importance of interaction between the calibrated dynamometer and interfering efforts generated by the calibration bench becomes evident by means of a particular proceeding. Several series of efforts are applied, and between each series the transducer turns around its effort axis in an angle representing a whole divided by the number of measurement series, resulting in a 180° angle for 2 series, 120° for three series or 90° for 4 series. Average results obtained at a given load level largely suppress the influence of interfering efforts and their dispersion, or reproduction, and it is a good indicator of this influence.

In fact, a transducer's response to these solicitations depends largely on the way the strains applied are distributed inside the transducer. For this purpose, geometric and functional characteristics of mechanical pieces connected to the calibration bench are essential and condition calibration results. They must therefore be accurately defined and described.

Electric device connected to the transducer

Two cases must be considered, depending on whether the transducer is fitted with a connected electric device or not.

In the first case, adjustment conditions of the measurement chain must be defined. If this chain is fitted with a calibration device, this device must be operated, its results registered and at some point adjusted according to the user's needs. If a calibration adjustment is performed, this will entail a loss of traceability of measurements taken with the dynamometer and calibration values obtained before and after the adjustment must be registered. A modification after calibration renders this operation invalid.

When only the transducer is being calibrated, the calibration laboratory connects it to a measurement device supplying power to the transducer and allowing to measure the output signal. The characteristics and adjustments to these electric supply and measurement devices must be accurately defined in agreement with the user of the transducer. Electrical connections must be specified. Traceability of electrical measurements to the International System of Units (SI) must be guaranteed. Calibration results will only be applicable if the user then connects the transducer to a measurement chain with similar characteristics and settings as those obtained during calibration and with a similar guarantee of electrical traceability.

In all cases the user of the dynamometer must include in the calculation of the uncertainty of forces measured by means of this dynamometer, components taking into account replacement of an electrical device connected to the transducer.

Main calibration parameters for a dynamometer

The main parameters necessary for the definition of a calibration are as follows:

- Identification of the transducer and the instruments connected to it, including the connecting cables.
- The direction of the transducer's solicitation: Tension and/or compression
- The nature and characteristics of mechanical interfaces used for the application of forces.
- The calibration domain defined by maximum and minimum forces applied.
- Application of increasing loads only, or increasing and decreasing loads.
- Loading conditions for the transducer: possible pre-loading, waiting times in order to stabilize force, relaxation time between to load series, etc.
- Calibration uncertainty or the precision level sought

Metrologic characteristics

Main metrological characteristics registered during calibration are:

- Dynamometer resolution This corresponds to the smallest increase in the indication reading
- Measurement repetition rate This characterizes the dispersion of indicators along several measurement series for the same load level and performed without changing the position of the transducer on the calibration bench.
- Measurement reproduction rate This characterizes the dispersion of indicators along several measurement series for the same load level and performed changing the angular position of the transducer between measurement series.
- Reversibility or hysteresis It characterizes the difference in the indicators obtained at a given load level by an increasing and then decreasing load.

- Conformity, interpolation or linearity error. Indicators obtained according to applied loads can be modelled by a polynomial allowing to calculate the signal released by the dynamometer for a given value of force in calibration. Registered variations between average values registered for the indicators at each load level and the values given by the polynomial define the conformity or interpolation errors, also called non linearity errors if the model is a line.
- Load creep. This characteristic refers to the fact that the registered indication subject to a constant load evolves slowly due to an imperfectly elastic behaviour of the materials and the detecting elements in the transducer. This generates hesitation as to which indicator readings should be recorded. In order to solve this difficulty, the duration of the constant load as well as the waiting time after suppression for this load should be defined. An evaluation of the importance of this phenomenon can be performed by recording under specific conditions the indication at force zero at the end of each force application series on the transducer. This characteristic is very important, as it largely conditions the quality of calibration.

CALIBRATION RESULT AND UNCERTAINTY

The best way to render the calibration result is to provide the user of the transducer with a 1st, 2nd or 3rd degree polynomial enabling the user to calculate the force according to the indication provided by the dynamometer. For example, in the case of a 2nd degree, the result is expressed as follows:

$$F = a.D^2 + b.D + c$$

Where
F is the force applied to the dynamometer in the unit of force (mN, daN, kN, MN)
a, b and c are constants
$D = I_F - I_0$ is the deformation of the dynamometer by force F
$I_F =$ indication at force F
$I_0 =$ indication at zero force

In the same way, the best way to express calibration uncertainty is:

$$U(F) = A + B.F$$

U = uncertainty expanded on force F with an expansion factor k =2
A = constant expressed by force unit
B = constant without dimension
Calibration uncertainty is calculated taking into account at least the following components:

- uncertainty as to the forces applied to the transducer
- resolution of the indication
- repetition rate for indications
- reproduction rate for indications
- the variation in the indication at force zero before and after the application of a load series
- the temperature and its fluctuations during calibration
- interpolation errors

These different components are evaluated for each force level and the relevant combined uncertainty is calculated. A linear regression according to the force is then applied to these combined uncertainties and the result is expanded with an expansion factor equal to 2.

While the dynamometer provides the results of indications directly in force units, calibration results are generally given in the form of indication errors for each force level, with its associated uncertainty established by taking into account the above mentioned components.

A dynamometer calibration results must be accompanied by all the necessary elements for their understanding, and a proper use of the dynamometer. All calibration parameters must be specified. This includes, in particular, the mechanical assembly for the application of force and the settings of the indicator device connected to the transducer.

Use of the dynamometer

The dynamometer must be used according to the parameters defined during calibration. Any significant change in its conditions will be likely to render calibration results invalid.

Uncertainty as regards the force measured by a calibrate dynamometer must be evaluated taking into account:

- the uncertainty of dynamometer calibration
- the components characterizing the dynamometer and the measurement performed: resolution, measurement repetition and reproduction rate, effect of temperature, creep... etc.
- components resulting in a possible difference regarding calibration conditions: change in the measurement indicator, different loading or force application procedures... etc.
- a component causing the intervention of the evolution of dynamometer sensitiveness since the previous calibration.

Given that dynamometer sensitivity stability through time is not guaranteed, it is necessary to perform a regular recalibration, its regularity depending essentially on the transducer and of the use given to the dynamometer. As a mere indication, ISO 376 Standard recommends recalibration every two years maximum.