Measurement uncertainty in torque calibration

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Contents

1. Introduction - Abstract

Calibration of torque measurement instruments (mainly torque wrenches and torque testers), even if widely used in the automotive, aviation and building industry, has received much less attention than other types of instruments (i.e. length measurement instruments). Very few laboratories offer calibrations services for torque measurement instruments, compared to length measurement, pressure, etc. All car manufacturers have developed internal measurement systems to measure torque (i.e. braking systems, frictions, etc), but out of these laboratories the specific situation for torque calibration is still unclear.

Since torque is given in Nm, the usual way to calibrate such instruments is to use a torque balance, set the torque tool at the target value (i.e. 40 Nm) and apply reference weights (N) until the requested KP (click point) is reached. The difference between the nominal KP (on the wrench) and the true KP (measured by the sensor on the torque balance) should be less than 4% or 6%, depending from tool type.

This presentation focus on calibration of torque measurement and the comparison between this traditional method (torque balance) and a new calibration device, also used at the PTB Braunschweig - Germany. Experience shows that the new system applicable to calibration of torque tools is more effective than traditional torque balance systems, since it tests them in the same operating condition (dynamic) and with very small almost continuous increments of forces while torque balance operates almost statically and need discrete mass

increments. The new systems is also much faster (requires about 15 minutes for calibration according to ISO 6789) than the traditional torque balance method.

The new draft of ISO/CD 6789 (not an international standard yet) is also discussed and compared with the previous edition of ISO 6789.

A formula for the determination of measurement uncertainty of a new concept of calibration device is given and briefly discussed.

Some experience of a calibration laboratory in Milano (Italy) will give useful hints at the laboratory level calibration of torque tools (both setting and indicating torque tools) and testers. Slides show that torque tools from different manufacturers do not operate in a similar way, some of them shows a distinct KP (clicking point) while other have a smooth curve with local peaks, in this situation the experience of the laboratory personnel is still important to find out where the correct KP is and some calibration parameters accordingly. This situation is not optimal, since it implies an analysis, and therefore an influence, of the laboratory personnel and risks to affect the independence of the calibration laboratory. Anyway, tolerance at 4% is a close tolerance and will force manufacturers to improve the design and costruction of torque tools components (expecially springs) in order to satisfy these requirements.

2. Standard

The standard documents which refer to calibration of these instruments are, respectively ISO 6789:1992 and DIN 51309, along with DKD guidelines R 3-7 and R 3-8.

ISO 6789:1992 was prepared by ISO TC/29. This Committee is constituted by representatives of torque manufacturers and representatives of research and calibration institutes.
ISO/CD 6789 is a Committee draft and cancels and replaces the second edition ISO 6789:1992, of which it constitutes a technical revision (**slide 10**). New clauses have been added:

3 Terms and definitions
4.1 Design conformance testing
4.2 Quality conformance testing
4.3 Recalibration

Figures 1 and 2 have been revised, figures 3 have been added, the standard has been editorially revised. The document show a strong influence of DIN 51309.

In particular following changes have been introduced with the ISO/CD 6789:

1. the change of tolerance (from 4% to 6% tolerance) also for instruments of type II and classes A and B up to 10 Nm (**slide 15**). This tolerance was, in the previous edition, accepted only for type C, D and E instruments. The internal friction has a greater influence with small torque values, and thus the original tolerance of 4% has been enlarged, as requested by torque wrench manufacturers.

2. A period of validity of a calibration certificate has been introduced (12 months as a maximum). This period should be reduced when the tool is frequently used.

3. Chapter nr. 3 with common terms and definitions has been added. A multilanguage section would be very useful in future editions.

3. Typical torque curve

Slides 2, 3,4,7 and **8** show different shapes of torque vs. time curves for different brands of type II wrenches.
The KP (click point) can sometimes be determined very easily (**slide 3** and **4**), but sometimes the curve has local peaks (**slide 2**), is too smooth (**slide 8**), or shows friction effects (**slide 7**). In this situation the experience of the laboratory personnel is still important to find out where the correct KP is and set certain parameters on the calibration device accordingly. This parameters are be the rotation speed, the trigger used to select a KP (the requested “fall” in % of the torque value after the peak, in order to classify it as a “true” peak, i.e. 80%, 85%, 96%, 99%), the angle of rotation, the point where speed reduces (usually at 80% of the torque target value.

This situation is not optimal, since it implies an analysis, and therefore an influence, of the laboratory personnel and risks to affect the independence of the calibration laboratory.
By looking at the torque manufacturer the laboratory personnel can set following parameters: rotation speed and KP sensitivity.
Unfortunately, given the different behaviours of torque wrench brands, it cannot be avoided.

All these curves represent a single measurement acquisition at a certain torque, i.e. 100 Nm. ISO 6789 requires a series of 5 measurement values for each step at 20, 60 and 100%.

4. Actual calibration procedure

A) Torque balance

Having torque dimensions of force X distance, the traditional calibrating device is constituted by a torque balance (**slide 12**) and a set of primary weight reference.

With this system, the necessary force is obtained using a reference mass, keeping in consideration the local gravity constant g, in both directions (right and left).
The torque is transmitted through a double arm, mounted on an aerostatic radial and axial bearing. This guarantees a transmission of radial and axial forces with a minimum level of friction.
A combination of motor and a transmission with high sensitivity is used to compensate the rotation of the reference.
The information for the correction is obtained through non-contact sensors positioned on the arm. Possible force increments with this system are: 20 Nm, 50 Nm, 100 Nm, 200 Nm, 500 Nm and 1000 Nm, each one can be divided in 10 discrete steps.
With this system a typical measurement uncertainty of :

- 0.01% from 5 Nm to 1000 Nm
- 0.02% from 1 Nm to 5 Nm

can be reached.
Torque sensors, torque testers, reference torque tools and torque tools are calibrated with this torque balance.
Calibration with torque balance needs skilled laboratory personnel, requires time and, since we switch from mass to force, can be influenced by vibrations and by changes of the gravitation constant g.
With this system the axis is horizontal and the results contains also the contribution of the weight of the wrench grip (lever effect).
Systems with vertical axis are being also developed, to reduce this problem.

B) Torque tester

After calibrating the sensor or the reference torque with the promary torque balance, we can transfer this result to a torque tester (**slide 16**). These instruments are often used as primary reference in companies or calibration rooms.
The torque tester should then be mounted on a stable support in Aluminium (**slide 13**) and used for calibration of torque tools.
A transmission is needed to reduce the influence of the operator (position of the hand on the grip, local increase and decrease of speed, expecially close to the click point.
Experience shows that measurement values change slightly from user to user when such a transmission is not used.

C) Torque wrench

First of all we should distinguish 2 types of wrenches:

1. setting torque tools (indicated as type II wrenches - **slide 15**)
2. indicating torque tools (indicated as type I torque tools – **slide 14**).

Type II -setting torque tools (Click torque tools)

The release point must be determined at intervals of 20%, 60% and 100% of the maximal nominal torque. For each measurement we take 5 measurement, if **any one** of them (even a single one) is out of the tolerance band of ±4% the wrench is considered out of tolerance.

Experience shows that points have an asymptotic distribution like this, with the first value higher than following points.
This is mainly due to an adaptation of the spring in the guide and an hysteresis effect on the first clicks.

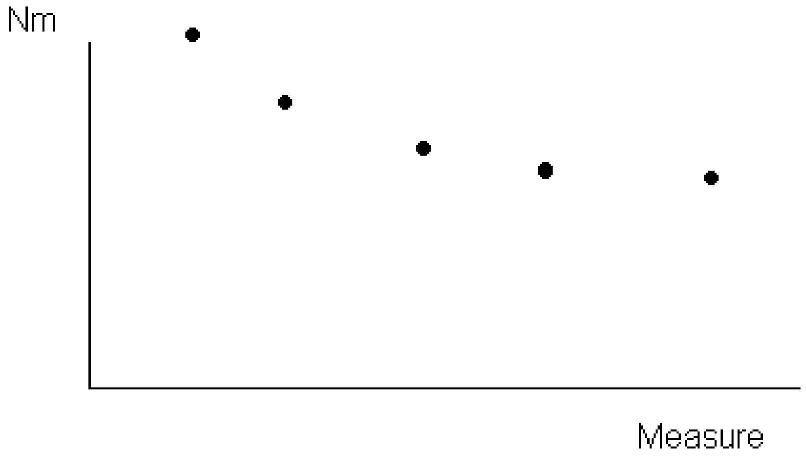

Figure 1: Typical distribution of sequential torque values

This behaviour cannot be considered a random effect, it is due to internal adaptation of the torque wrench. This phenomenon is typical with almost all torque tools even if the tool has been, as requested by the ISO 6789 standard, operated for at least 5 times at full scale a few seconds before the start of the calibration procedure at 20% of full scale torque value.

It is therefore not meaningful to calculate a mean value and to compare this value with the 4% tolerance limits.

For this reason ISO 6789 requests to use at least **5** times the torque tool at the maximum nominal value just before starting the calibration procedure, so that first clicks can be considered outliers and would not affect the automatic calibration procedure.

Type I - Indicating torque tools (Dial torque wrenches)

The calibration intervals are the same as type II wrenches. The calibration cannot be automatically performed, since the operator has to look at the indicator, write manually the value and the systems checks the difference nominal-true torque value.

Considerations on both types of wrenches

As seen before, tolerance limits for small torque tools up to 25 Nm have recently been reduced to ±6% (the same level as torque screwdrivers (see types D, E, F in **slide 16** and types D, E in **slide14**) in the previous edition of the ISO 6789).

5. Considerations on traditional calibration procedure

This system works fine with dial wrenches, but it is not good for KP wrenches, because we can give only finite increments and cannot eventually decide **exactly** find out where the KP point is.
That is the most important issue: KP wrenches should be calibrated dynamically, applying a force increasing **with continuity**, until the release point (KP) is reached and recognised by the sensor. This is the key factor who inspired the construction of a new torque calibration device.

6. New torque calibration device

This device (**slide 11**) is manufactured by a company in Germany, who also manufactures equipment directly for the PTB. The device is equipped with 2 different sensors and motors, one for small torque values up to 30 Nm and another one for torque values up to 1000 Nm. Torque axis is vertical, so that any influence on wrench own weight is excluded.
The wrench is rotated at higher speed until 80% of target torque value or until contact between grip and device, torque is applied until KP is found. 200 measurement are taken every second and can be optionally reported on a graph (**slides 2,3,4**).

The torque wrench to be calibrated has to be stabilised at a temperature of 20% for at least 12 hours, air humidity should be also maintained at 50% ± 5%. It is also very important that the torque wrench spring is kept at the minimum level or less (“spring uncharged”) for all that period. In effect, it is always a good practice to bring the indicator at the minimum level after the wrench has been used and leave the spring ” uncharged” when not in use. All other wrench components (i.e. adapters) must be available. The calibration of type II tools is fully automatic, while type I require laboratory personnel.

7. Calibration of the new device

This device is calibrated using 2 reference torque tools of the PTB (**slide 13**).
In our laboratory we actually use these reference wrenches to calibrate not only the device, but also to calibrate torque testers (both digital and analogic – slide 16).
The calibration is performed dividing the range in at least 5 equidistant step (i.e. up to 100 Nm we shall have steps at 20, 40, 60, 80 and 100 Nm) and performing 4 series of measurements.
See **slide 20** for a matrix with measurement values and a graphical view of these 4 series.
For each series one measurement is taken at every step, in this sequence:

1. going up, maximum arm length
2. going down, maximum arm length
3. going up, maximum arm length
4. going up, minimum arm length

The different contributions to the measurement uncertainty are determined as follows:

- difference between 1 and 2 = contribution of hysteresis (as with i.e. dial gauges)

- difference between 1 and 3 = contribution of repeatability with same arm distance
- difference between 1 and 4 = contribution of repeatability with reduced arm distance

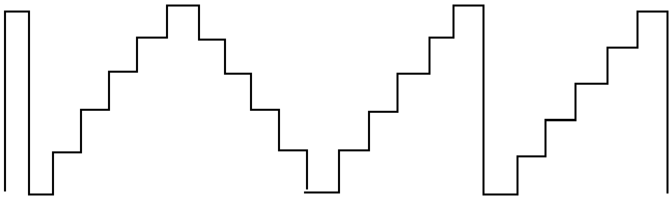

Figure 2. Graphical overview of the calibration procedure

8. Calibration of reference torque tools

The two references torque tools used in our laboratory (up to 100 Nm and from 10 to 1000 Nm) are calibrated every year by using a torque balance (slide 12) with reference weights (PTB primary system) directly at the PTB. The procedure is the same as the one described in the previous paragraph.

9. Calibration certificate

Which information should be given in a calibration certificate?
Standard calibration certificates have a standard format for the front page like this (**slide 9**).
In the front page should always appear the traceability to national standard.
The back page usually contains the measurement values and calculations of parameters like: measurement uncertainty, mean values and standard deviation, Cp and Cpk (or Cm and Cmk) derived from SPC techniques (**slide 5**).

A particular consideration should be given to some calculation which can be found in some certificates like this (**slide 18**): 20 or 25 consecutive measurements are taken and parameters like mean value, standard deviation are calculated.
In our opinion this information is useful only in calibration of torque testers, which are given with a tolerance of ±1%, and could be avoided when calibrating type II torque tools.

Unfortunately norms do not indicate a standard format for the technical information of a torque calibration certificate, apart from the front page (**slide 9**). Some work still has to be done in order to reach a common standard like i.e. in calibration of dial gauges or block gauges.

10. Measurement uncertainty

The formula used to determine measurement uncertainty is shown in **slide 19**. This discussion refers to the calibration of a digital torque tester (DIN ISO 51309) (**slide 16**) using a PTB reference torque wrench (**slide 13**).

The expanded uncertainty is given by U, where U_{MG} is the measurement uncertainty of the measuring instrument and U_{TN} is the measurement uncertainty of the reference torque wrench (given by PTB):

$$U = \sqrt{(U_{MG})^2 + (U_{TN})^2}$$

$$U_{MG} = \left|f_q\right| + k\sqrt{\frac{1}{12}f_0^2 + \frac{1}{8}b_l^2 + \frac{1}{8}b'^2 + \frac{1}{12}\left(\frac{r \cdot 100}{M_i}\right)^2 + \frac{1}{12}h^2}$$

Where:

U_{TN}	uncertainty of the transfer normal (reference wrench)	
U_{MG}	uncertainty of the measurement instrument (calibration equipment)	
fq	Contribution of the digital display (error is known)	(7) DIN 51309
f0	Contribution of initial zero position (error is unknown)	(4) DIN 51309
bl	Contribution of the distance (error is unknown)	DKD R 3-8
b’	Repeatability (error is unknown)	DKD R 3-8
r	Resolution of the display	DKD R 3-8
Mi	Nominal torque	DKD R 3-8
h	Contributions of hysteresis	(6) DKD R 3-8
k	Coverage factor, standard is k=2 (95,45%)	

Standard U_{TN} values are as follows:

Torque M	**Measurement uncertainty U_{TN}**
M ≤ 5 Nm	0,2 %
5 Nm < M ≤ 150 Nm	0,1 %
150 Nm < M ≤ 1000 Nm	0,05 %

In particular following contributions are taken in account for the determination of measurement uncertainty:

- hysteresis (h) (only with both right and left direction)
- display (fq) – it can be corrected and therefore is does not enter in the square
- first set to zero (f_0)
- torque reference (U_{TN})
- arm distance (bl)
- repeatability (b’)
- digital display resolution (r)

Remarks
Environmental factors as temperature and air humidity are NOT taken into account, given their minimal influence on measurement results. All electrical equipment must have been switched on at least 15 minutes before starting the calibration procedure

Distribution
A rectangular distribution is assumed for all uncertainty contributes.
This explains the 1/12 coefficient in the given formula (**slide 19**).
The conventional coverage factor is k = 2. This value is reported on the calibration certificate, together with the indication that the given uncertainty refers to „expanded" uncertainty.

11. Acknowledgements

Dieter Kenzler	SCHATZ – Remscheid
DIN	Deutsches Institut für Normung e.V.
Salvatore Merlo	IMGC CNR Torino

12. References

1. ISO 6789:1992
2. ISO/CD 6789 (Draft) Assembly tools for screws and nuts – Requirements and test methods for design conformance testing, quality conformance testing and recalibration procedure
3. DIN 51309
4. DKD Richtlinien R 3-7 and R 3-8
5. ISO GUM - Guide for determination of measurement uncertainty - 1995

13. Acronyms

DKD	Deutscher Kalibrierdienst
IMGC	Istituto Metrologico Gustavo Colonnetti
PTB	Physikalisch Technische Bundenanstalt
SIT	Sistema Italiano di taratura

14. Slides

1. Example of 3 different curves torque/time
2. Example of a curve with local torque peaks
3. Example of a “good” torque curve (KP easily determined)
4. Example of a “good” torque curve
5. Example of a calibration certificate (back page)
6. Typical distribution graph on a single torque wrench
7. Example of a torque curve with friction
8. Example of torque curve with indistinct KP and local peak
9. Example of front page of a calibration certificate
10. ISO 6789 draft (english)
11. Calibrating device (new concept)
12. Typical torque balance
13. Reference torque wrench
14. Typical torque tools – class I (dial)
15. Typical torque tools – class II (click)
16. Typical torque tester
17. Calibration laboratory
18. Alternative certificate (measurement on 25 consecutive values)
19. Formula for torque measurement uncertainty
20. Calibration certificate (page nr.3) of a digital torque tester