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ISO 6789:2003 CALIBRATION RESULTS OF HAND TORQUE TOOLS WITH MEASUREMENT UNCERTAINTY – SOME PROPOSALS

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Abstract: The ISO 6789:2003 standard is widely used as technical document for calibrations of hand torque tools, but it does not require any statements about uncertainties of calibration results. Nevertheless, according to GUM it is necessary to report a complete measurement result including its uncertainty. In this paper, a proposal is given on how to estimate measurement uncertainties of ISO 6789 calibration results taking into account various influencing quantities.

Keywords: hand torque tools, torque wrenches, calibration, ISO 6789:2003, uncertainty.

1. INTRODUCTION

The ISO 6789:2003 standard [1] is widely used as guide for the calibration of torque wrenches and other hand-operated torque tools like screwdrivers indicating the applied torque or setting torque tools. Unfortunately, this standard does not contain a method or at least a proposal for the uncertainty calculation of the measurement results obtained in these calibrations. On the other hand, according to GUM [2] it is necessary to report a complete measurement result including its uncertainty. This problem has been subject of an earlier work which was based on the previous issue of the standard [3] and did not take into account some important influences such as the connecting profile (often square drive) and the point of force application (lever length, cross forces and bending moments). This paper describes a proposal on how the standard could be improved in order to become a complete calibration guide. Methods for calculating calibration results and estimating their uncertainties will be presented. The paper will point out influencing quantities which are not taken into account until now and will deal with some specialties of torque tool calibration devices. The topic of this calibration guide is also the subject of discussions within the DKD – the recently (re-)founded German board for the technical cooperation between PTB and torque calibration laboratories. Some conclusions resulting from these discussions are also mentioned in this paper.

2. GENERAL ISO PROCEDURE

The ISO 6789:2003 standard knows two types of hand torque tools: Type I – indicating torque tools and Type II – setting torque tools (see Figure 1). For both of these types various classes are defined, such as torque wrenches or screwdrivers utilizing a scale or gauge or electronic display. Some of these devices have a housing, some have a fixed measuring point, others are adjustable.

Fig.1: Setting torque wrench type 3360, [4]

In general, the calibration procedure consists of one (Type I), respectively five (Type II) pre-loadings with the maximum torque without recording the values and a subsequent series of five (for two classes of Type II: ten) repeated applications of three different torques from the measurement range. The three torque values are defined by the standard as 20%, approximately 60% (depending on the value that can be adjusted on the scale) and 100% of the maximum (nominal) torque of the tool.

A special condition for the loading has to be fulfilled for setting torque tools: An increasing force to approximately 80% of the target value has to be applied first. Then the force has to be constantly and slowly increased up to 100% of the target value within a time window of 0.5 s … 4 s. A calibration facility for setting torque tools must take this requirement into account.

3. CALIBRATION FACILITIES

There are some other important remarks to be made with respect to the calibration facilities. First of all, they are very different. We know facilities that utilize lever-mass-systems and a supported lever with air bearing for generating a pure torque. The torque tool or torque wrench is connected to the measuring axis of the facility and fixed or supported on the opposite side near the handle. These facilities offer the smallest uncertainties.

The majority of the calibration facilities use integrated torque transducers and they are calibrated with torque transfer wrenches. The torque is generated then by either rotating the torque transducer against the fixed or supported tool or by applying a force at the handle of the torque wrench perpendicular to the beam and the torque axis. These systems allow the torque application to be **controlled** by help of the torque transducers used as references. This is often the more accurate and reliable procedure, but it cannot apply to setting torque tools. For these, the torque must be increased until the setting torque is reached. When a calibration facility and the measurement results obtained are to be considered, it must be clear if the calibration procedure was controlled by the facility's **calibration torque** or by the **tool** to be calibrated.

Another topic is related to the signals recorded by the data acquisition. Most of the torque transducers used in the facilities are strain-gauge based and deliver nearly exclusively signals in mV/V or N·m. These can be set to zero (be **tared**) before starting the measurements or not. In addition, when the calibration procedure for measuring tools says that a certain torque has to be applied, then it is not always the best idea to adjust this value as good as **possible**. Especially when the force is applied with a manually operated crank on a spindle, then this can take a long time even for a well-trained person. If the torque is as close to the target value as **necessary** then the value can be recorded. Sometimes it may be useful to calculate the result for the calibration torque using a regression function.

4. CALIBRATION RESULTS ACCORDING TO THE EXISTING STANDARD ISO 6789:2003

According to the current version of the standard (year 2003), the relative deviation A_s in % must be calculated from

$$A_s\ \% = \frac{x_a - x_r}{x_r} \cdot 100\ . \qquad (1)$$

Here x_a is the torque indicated by the tool and x_r is the reference torque, i.e. the calibration torque measured by the calibration facility.

In the special case of Type II classes C and F tools (without scale), the value of x_a is calculated as mean of the ten reference torques x_r measured by the calibration facility. This value is then used in formula (1).

As stated above, no uncertainty of the input or resulting values is given. There is just one requirement to the calibration facility: the maximum uncertainty of the indicated torque must be ± 1%.

The conformity can be declared if the deviations are within the limit set by the standard (± 4%, respectively ± 6% for some classes). Again, there is no measurement uncertainty taken into account in contradiction to the IEC/ISO 17025:2005 standard ("General requirements for the competence of testing and calibration laboratories") which requires that conformity statements must be made including the uncertainty of measurement [5]. This is very important for accredited calibration laboratories.

5. PROPOSED IMPROVEMENTS

There are a number of possible improvements to the ISO 6789:2003 standard. All of them have been discussed within the torque committee of the DKD (Deutscher Kalibrierdienst), the German technical board for the cooperation between PTB and accredited calibration laboratories.

Calibration range: Within the DKD committee it was proposed to choose the starting point of the tool's measurement range as first calibration point instead of 20% of full scale. This would be more useful from the point of view of the tool's application and is especially important for indicating torque tools which are used in a wide measuring range.

Calibration facility's operation mode: Calibration facilities usually utilize torque transducers or sensors of precision torque wrenches as sensing elements. These sensors are calibrated as single devices or as part of the whole facility. It is quite interesting that the ISO 6789 standard does not offer the possibility that the torque is controlled by the calibration facility's sensor but the tool under calibration has to be loaded with increasing force (at the end of the beam) until it indicates the corresponding torque. On the other hand, automated calibration procedures can much easier be realized when the torque is controlled by the facility's sensor and not by the tool. In addition, if the tool shows completely invalid values, then wrong torques can be applied. It is proposed to allow the torque application to be controlled by the calibration facility's indication. This is hereinafter referred to as case A. In the case the torque application is controlled by the tool, we propose to call this case B. Of course, this discussion does not completely apply to Type II torque tools since their reaction (click) is essential for the calibration.

Designations: Calibration certificates are sometimes not very clear with respect to the numbers show in their tables. It would be very helpful to offer some unique designations for the quantities to be measured. Taking into account different possible options, it is important to clearly distinct

- the indications recorded during the calibration: indications of the calibration facility and that of the tool, both can be gross or net (tared) values,
- the calibration facility's operation mode: case A or case B (see above), and
- the calibration procedure, i.e. if the calibration torques are tuned in (by hand or electronic control) or if a subsequent interpolation is necessary.

The designations given in Tables 1 and 2 are proposed.

Calibration result: For the user of a measuring instrument it is sometimes of interest not only to know if the tool is within the specifications (conformity), but also to know the value of the deviation and the uncertainty of this value. Especially with indicating tools the deviation found during the calibration can be compensated when the tools is used in an application. This is, of course, an additional effort, but the reward is a more accurate and reliable measurement. It is now proposed to calculate an additional calibration result for each torque step (and each direction of the torque, if necessary) as the mean of the five or ten single values found for this torque step during the calibration.

According to the two operation modes, the calibration result is a value calculated from the indications of the tool (case A)

$$Y_i = Y \;\; M_{\mathrm{N},i} \;\; = \frac{1}{n}\sum_{j=1}^{n} Y_{\mathrm{A},i,j} \;\; , \qquad (2)$$

or from the indications of the calibration facility (case B)

$$M_i = \frac{1}{n}\sum_{j=1}^{n} M_{\mathrm{A},i,j} \;\; . \qquad (3)$$

It is important to understand that in both cases the calibration torque is defined by the calibration facility. The deviations $f_{\mathrm{q},i}$ are always calculated as differences between the torque value of the tool and that of the calibration facility, regardless of the facility's operation mode.

designation	description
i	Ordinal number of the torque step (for example, i = 1: 20 N·m, i = 2: 60 N·m, i = 3: 100 N·m, i = 4: -20 N·m and so on)
j	Ordinal number of the single value measured for torque step i (j = 1, 2, … 5, respectively j = 1, 2, … 10)
$J_{0,i,j}$	Zero signal indicated by the calibration facility prior to the measurement of value j for torque step i
$J_{\mathrm{M},i,j}$	Measurement signal indicated by the calibration facility during the measurement of value j for torque step i
$M_{\mathrm{K},i,j}$	Tared calibration torque in the measurement of value j for torque step i
$I_{0,i,j}$	Zero signal indicated by the tool under calibration prior to the measurement of value j for torque step i
I_{M}	Measurement signal indicated by the tool under calibration during the measurement of value j for torque step i
Y_{M}	Tared measuring value in the measurement of value j for torque step i

Table 1: Proposed designations for the indications of the calibration facility and the tool to be calibrated

designation	description
Case A	
$M_{\mathrm{N},i}$	Nominal calibration torque for torque step i (all j)
$Y_{\mathrm{A},i,j}$	The tool's tared and interpolated measuring value for the measurement of the single value j for torque step i
Y_i	The tool's calibration result for torque step i
Case B	
$Y_{\mathrm{N},i}$	Nominal calibration torque of the tool for torque step i (all j)
$M_{\mathrm{A},i,j}$	Tared and interpolated calibration torque for the measurement of the single value j for torque step i
M_i	The facility's Calibration result for torque step i

Table 2: Proposed designations taking into account the facility's operation mode and, if necessary, interpolation

Influencing quantities: It is known that many quantities can influence the calibration result of a torque tool and most of them are not mentioned in the standard. This is normally not a problem when talk is about mechanical torque tools with permissible deviations of 4% or 6%. But in the last years electronic tools with claimed uncertainties of 1% came to market. On the other hand, comparison measurements have shown that connecting parts, such as square drives, can have a significant influence, especially when the results are close to the permissible limits.

These effects are mainly caused by the geometrical dimensions, manufacturing tolerances and material properties (hardness, heat treatment) of the **connecting elements** (often square drives or other types of profiles). Sometimes these parts are worn out but there is no criterion saying that they must be replaced.

The influence of the connecting profile b_{V} can be measured using the following method: for a number of k = 1, 2, … m (for example, $m = 4$ for square drives) equally distributed over 360° positions of the profile, l = 1, 2, … o single measurements (for example, $o = 10$) have to be carried out in each position, i.e. for m = 4 and o = 10, in total 40 measurements. The applied torque should be the starting point of the tool's measurement range with a nominal beam length defined by the middle of the handle.

The parameter b_{V} can then be calculated

- in case A from

$$b_{\mathrm{V}} = \max_k\left(\frac{1}{o}\sum_{l=1}^{o} Y_{\mathrm{A},k,l}\right) - \min_k\left(\frac{1}{o}\sum_{l=1}^{o} Y_{\mathrm{A},k,l}\right) \;\; , \qquad (4)$$

- in case B from

$$b_{\mathrm{V}} = \max_k\left(\frac{1}{o}\sum_{l=1}^{o} M_{\mathrm{A},k,l}\right) - \min_k\left(\frac{1}{o}\sum_{l=1}^{o} M_{\mathrm{A},k,l}\right) . \qquad (5)$$

Another possible influence is the position of the **force introduction point** of torque wrenches, i.e. the beam length. For constant torque, an increasing beam length corresponds to a decreasing force. This effect is not applicable to screwdrivers.

The influence of the beam length can be measured using the following method: at 60% of the nominal torque, l = 1, 2, … o single measurements (for example, o = 10) have to be carried out with nominal beam length (defined by the middle of the handle), with the beam length increased by 10 mm and with the mean beam length decreased by 10 mm, i.e. for o = 10, in total 30 measurements.

The parameter b_{L} can then be calculated

- in case A from

$$b_{\mathrm{L}} = \max\left(\left|\frac{1}{o}\sum_{l=1}^{o} Y_{\mathrm{A,mean},l} - \frac{1}{o}\sum_{l=1}^{o} Y_{\mathrm{A,long},l}\right|, \left|\frac{1}{o}\sum_{l=1}^{o} Y_{\mathrm{A,mean},l} - \frac{1}{o}\sum_{l=1}^{o} Y_{\mathrm{A,short},l}\right|\right) \qquad (6)$$

- in case B from

$$b_{\mathrm{L}} = \max\left(\left|\frac{1}{o}\sum_{l=1}^{o} M_{\mathrm{A,mean},l} - \frac{1}{o}\sum_{l=1}^{o} M_{\mathrm{A,long}l}\right|,\right.$$
$$\left.\left|\frac{1}{o}\sum_{l=1}^{o} M_{\mathrm{A,mean},l} - \frac{1}{o}\sum_{l=1}^{o} M_{\mathrm{A,short},l}\right|\right) . \qquad (7)$$

Here, “mean” means nominal beam length, “long” – nominal beam length increased by 10 mm, “short” – nominal beam length decreased by 10 mm.

Many setting hand torque tools have a **ratchet** included. So the question arises of how the calibration results change if different positions of this ratchet are used. This effect is partly included in parameter b_{V} if the ratchet is used to change the position of the connecting profile. Otherwise an additional measurement with all possible positions of the ratchet should be considered, but this can be quite time-consuming. The author’s working group has started to collect such values and would be very grateful for any assistance.

Environmental influences play an important role in many calibrations. This is partly appreciated by the standard’s requirement that the temperature should be constant (± 1°C) within an interval of 18°C to 28°C. Ambient humidity must be recorded and be lower than or equal 90% (relative humidity). This value is too high. One problem is that steel parts begin to rust when exposed to very high humidity. Another problem may be the changing viscosity of lubricants inside of mechanical tools thus affecting their mechanical properties. It is expected that changing temperatures have a similar effect.

How can all these influences be treated? Worn square drives or ratchets must be changed. Too extreme temperatures and humidity should be avoided. Thus, it is proposed to include at least the influence of the connecting parts’ geometry b_{V} and the position of the force introduction point (beam length) b_{L}. In order to keep the calibration effort at a justifiable level, it is not necessary to measure the corresponding parameters every time the tool is calibrated and for every single measuring instrument, However, typical values for the given type of tool should be used instead. We think it is sufficient to use an estimate for these parameters for a series of tools with the same design and make. The manufacturers are asked to provide these values. Only in the case of worn out connectors, suspected damage of the tool, or other evidence of deviations, is the complete measurement useful.

Uncertainties: It is proposed to calculate the parameter repeatability b_i from the five (or ten) single measurement values for each torque step as span maximum – minimum:
- in case A from

$$b_i = b\ Y_i\ = \max_j\ Y_{\mathrm{A},i,j}\ - \min_j\ Y_{\mathrm{A},i,j}\ , \qquad (8)$$

- in case B from

$$b_i = b\ M_i\ = \max_j\ M_{\mathrm{A},i,j}\ - \min_j\ M_{\mathrm{A},i,j}\ . \qquad (9)$$

Together with b_{V} and b_{L}, another parameter must be taken into account: the resolution r of the tool, as defined in the standard. The influence of the interpolation f_{a} can often be kept small enough to be neglected. From all these parameters, relative standard uncertainties are calculated according to Table 3.

parameter and distribution	relative standard uncertainty w in % case A	case B
r type B, rectangular	$w_r = \frac{\left(\frac{r}{2}\right)}{\sqrt{3}} \frac{100}{M_{\mathrm{N},i}}$	$w_r = \frac{\left(\frac{r}{2}\right)}{\sqrt{3}} \frac{100}{Y_{\mathrm{N},i}}$
b_i type B, rectangular	$w_{b,i} = \frac{\left(\frac{b_i}{2}\right)}{\sqrt{3}} \frac{100}{M_{\mathrm{N},i}}$	$w_{b,i} = \frac{\left(\frac{b_i}{2}\right)}{\sqrt{3}} \frac{100}{Y_{\mathrm{N},i}}$
b_{V} type B, rectangular	$w_{\mathrm{V}} = \frac{\left(\frac{b_{\mathrm{V}}}{2}\right)}{\sqrt{3}} \frac{100}{M_{\mathrm{N},i}}$	$w_{\mathrm{V}} = \frac{\left(\frac{b_{\mathrm{V}}}{2}\right)}{\sqrt{3}} \frac{100}{Y_{\mathrm{N},i}}$
b_{L} type B, rectangular	$w_{\mathrm{L}} = \frac{\left(\frac{b_{\mathrm{L}}}{2}\right)}{\sqrt{3}} \frac{100}{M_{\mathrm{N},i}}$	$w_{\mathrm{L}} = \frac{\left(\frac{b_{\mathrm{L}}}{2}\right)}{\sqrt{3}} \frac{100}{Y_{\mathrm{N},i}}$

Table 3: Proposed distributions and corresponding standard uncertainties for important parameters

Together with the standard uncertainty of the calibration torque $w_{\mathrm{M},i}$, the standard uncertainties $w_{\mathrm{SV},i}$ of the single measurement values can be determined from

$$w_{\mathrm{SV},i} = \sqrt{{w_{\mathrm{M},i}}^2 + 2\cdot {w_r}^2 + {w_{\mathrm{V}}}^2 + {w_{\mathrm{L}}}^2}\ . \qquad (10)$$

The standard uncertainties $w_{\mathrm{MV},i}$ of the mean values calculated from (2) or (3) can be determined from

$$w_{\mathrm{MV},i} = \sqrt{{w_{\mathrm{M},i}}^2 + 2\cdot {w_r}^2 + {w_{b,i}}^2 + {w_{\mathrm{V}}}^2 + {w_{\mathrm{L}}}^2}\ . \qquad (11)$$

In (10) and (11) it was taken into account, that the measurement value is often the result of two readings, one at zero and one at the load point. It was assumed that both readings are affected by the resolution of the tool’s setting or indication in the same manner. The resolution of the calibration device was not used in this formula directly since it had to be considered when the uncertainty of the calibration torques $w_{\mathrm{M},i}$ was calculated.

As usual, the expanded relative uncertainties can be found by multiplying standard uncertainties with the corresponding coverage factor k = 2.

The relative deviation A_{s} defined in (1) now reads with the new designations introduced above in Table 2

- in case A as

$$\frac{f_q\ M_{N,i}}{M_{N,i}} = \frac{f_{q,i}}{M_{N,i}} = \frac{Y_i - M_{N,i}}{M_{N,i}}\ , \qquad (12)$$

- in case B as

$$\frac{f_q\ Y_{N,i}}{M_i} = \frac{f_{q,i}}{M_i} = \frac{Y_{N,i} - M_i}{M_i}\ . \qquad (13)$$

Due to the fact that this deviation is not a stochastic quantity but shows a rather deterministic behaviour, it was not treated like an uncertainty. Therefore it cannot be combined with the other uncertainties under the square root sign in (10) or (11). For the calibration results, uncertainty intervals W'_i will be calculated instead as the sum of the absolute value of the relative deviations and the expanded relative uncertainties.

The result for case (A) is

$$W'_i = \left| \frac{f_q\ M_{N,i}}{M_{N,i}} \right| \cdot 100\% + k \cdot w_{MV,i} \qquad (14)$$

and for case B

$$W'_i = \left| \frac{f_q\ Y_{N,i}}{M_i} \right| \cdot 100\% + k \cdot w_{MV,i}\ . \qquad (15)$$

Numerical examples

Case A – calibration controlled by the calibration facility's indication (not applicable to Type II tools).

$M_{N,i}$ N·m		$Y_{A,i,j}$ in N·m				
		j = 1	2	3	4	5
i = 1	20	20.2	20.1	20.3	20.3	20.1
2	60	60.4	60.5	60.6	60.4	60.6
3	100	101.0	101.5	102.0	102.5	103.0

Table 4: Sample calibration data for case A

$M_{N,i}$ N·m	in N·m					
	Y_i	$f_{q,i}$	b_i	b_V	b_L	r
20	20.2	0.20	0.20	0.20	0.10	0.10
60	60.5	0.50	0.20	0.20	0.10	0.10
100	102.0	2.00	2.00	0.20	0.10	0.10

Table 5: Calculated calibration results for case A

$M_{N,i}$ N·m	in %						
	$w_{M,i}$	$w_{b,i}$	$w_{V,i}$	$w_{L,i}$	$w_{r,i}$	$w_{MV,i}$	W'_i
20	0.05	0.289	0.289	0.144	0.144	0.481	1.963
60	0.05	0.096	0.096	0.048	0.048	0.167	1.168
100	0.05	0.577	0.058	0.029	0.029	0.585	3.169

Table 6: Calculated uncertainties for case A

Case B – calibration controlled by the torque tool

$Y_{N,i}$ N·m		$M_{A,i,j}$ in N·m				
		j = 1	2	3	4	5
i = 1	20	19.8	19.9	19.7	19.7	19.9
2	60	59.6	59.5	59.4	59.6	59.4
3	100	99.0	98.5	98.0	97.5	97.0

Table 7: Sample calibration data for case B

$Y_{N,i}$ N·m	in N·m					
	M_i	$f_{q,i}$	b_i	b_V	b_L	r
20	19.8	0.20	0.20	0.20	0.10	0.10
60	59.5	0.50	0.20	0.20	0.10	0.10
100	98.0	2.00	2.00	0.20	0.10	0.10

Table 8: Calculated calibration results for case B

$M_{N,i}$ N·m	in %						
	$w_{M,i}$	$w_{b,i}$	$w_{V,i}$	$w_{L,i}$	$w_{r,i}$	$w_{MV,i}$	W'_i
20	0.05	0.289	0.289	0.144	0.144	0.481	1.963
60	0.05	0.096	0.096	0.048	0.048	0.167	1.168
100	0.05	0.577	0.058	0.029	0.029	0.585	3.169

Table 9: Calculated uncertainties for case B

The values and results given in Tables 4 to 9 can be taken as reference data sets for the validation of calculations.

6. CONCLUSIONS

The improvements of the ISO 6789 standard discussed here would allow this document to become a full calibration guide which is in accordance to the GUM. The methods proposed in this paper take into account the most important and relevant influencing quantities which are known until now.

7. REFERENCES

References: All ISO standards are available from the ISO website at http://www.iso.org.

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