NPL
National Physical Laboratory

A NATIONAL MEASUREMENT GOOD PRACTICE GUIDE

No.107

Guide to the calibration and testing of torque transducers

Department for
Innovation,
Universities &
Skills

Measurement Good Practice Guide No.107

Guide to the calibration and testing of torque transducers

Andy Robinson
Industry and Innovation Division

ABSTRACT

This guide describes a collection of methods for the calibration of a torque transducer. It encompasses transducers based on different technologies and transducers that operate in both static and dynamic applications. The user is expected to select the tests suitable for their requirements.

ISSN 1368-6550

National Physical Laboratory
Hampton Road, Teddington, Middlesex, TW11 0LW

Approved on behalf of the Managing Director, NPL
by Susan Evans, Director, *Industry and Innovation Division*

Contents

1. Introduction

This guide is aimed at providing a set of tests for the calibration, testing and evaluation of torque transducers. The guide covers a wide range of applications including transducers used in both static and dynamic environments. Some methods included in this guide will have a relevance that is limited to a particular application. The user is expected to select the tests appropriate to the intended application. The guide allows greater flexibility and covers a wider scope than other existing standards for static torque calibration [1, 2]. Worked examples are included by way of demonstration.

The set of tests described in the guide was designed to provide the data that is typically found in the manufacturer's datasheet for a torque transducer. By documenting a common and practical set of tests, it is hoped to introduce a consistency and understanding that will be of benefit to both the manufacturer and the end user.

During this project a number of UK torque transducer manufacturers were consulted in an attempt to collate a range of tests representative of those currently used in industry and to identify some common best practices. A number of transducers were tested to the methods described in this guide to ensure that the methods were practical and to provide data for the worked examples.

2. General

2.1 Torque machines/rigs

There are many ways of generating torque. A few alternative designs are briefly discussed below:

Lever deadweight – This consists of a set of calibrated masses that act on a calibrated lever arm. The system can be directly applied to the transducer in the case of an unsupported calibration beam (see figure 1). In the ideal case the lever arm will be connected to a bearing to eliminate bending from the weights and masses and to minimise friction [3]. This type of system is used for static torque calibration and offers the best uncertainties.

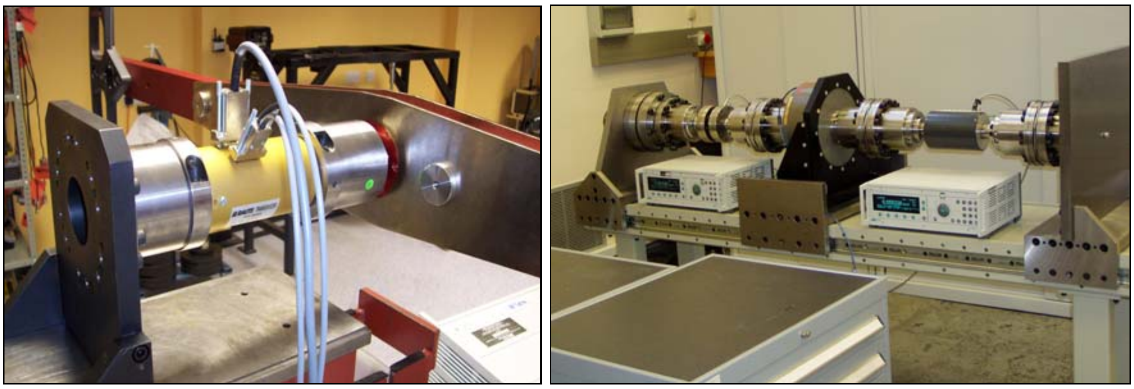


Figure 1. Left; An unsupported calibration beam: right; a motor driven torque machine used for continuous torque calibration

Reference torque transducer – Torque can be applied using a motor or hydraulics and the torque controlled by means of a calibrated reference torque transducer in a feedback loop (see figure 1). This type of system can be used to measure static torque but has the additional advantage of being suitable for continuous torque calibration, whereby the applied torque is applied over a much shorter time. The disadvantage of these systems is that the uncertainty of applied torque will be much higher because the system is dependant on the prior calibration of the reference. Other similar designs may take traceability from calibrated load cells measuring the reaction force at the end of the lever arm.

Regardless of the torque facility to be used, it is important to evaluate the uncertainty of the system [4]. This should include contributions from all influencing parameters (e.g. mass, length, alignment, and environmental factors).

2.2 Setup

The transducer, lead, and readout unit should be considered as a complete system for the calibration. Part numbers and serial numbers should be recorded. The temperature at which the measurements are to take place should also be recorded.

Stabilisation - the equipment should be allowed to thermally stabilise for at least one hour before measurements begin. In cases where the equipment is subjected to a significant temperature change, a longer time period should be allowed for acclimatisation.

The readout unit should be chosen carefully so that there is adequate resolution over the whole of the torque range of interest, otherwise a lack of resolution may limit the analysis of the parameter to be measured. Resolution is given by the last active unit of the indicator, or in the case of a fluctuating reading, half the magnitude of the largest fluctuation.

The cable should be handled carefully so that it has negligible influence on the transducer under test. Particularly with small torques and good resolutions, the handling of the cable can have a significant effect on the output.

In the ideal case a pure torque is applied to the transducer under test. In practice the transducer will also be subject to additional bending and parasitic forces and torques, which may affect the transducer to varying degrees [5-8]. It should always be the aim to keep these additional forces to a minimum. When using unsupported calibration beams bending forces are unavoidable. In this case it is important to be aware of the influence that bending can have on the measurement result and, where possible, to be able to quantify this. The mounting of the transducer is very important. The transducer should be held as rigidly as possible on the mounting plate. The fit of the squares should be as good as possible to minimise any slack (see figure 2).

Figure 2. Transducer clamped in a mounting bench for an unsupported beam calibration. The fit of the squares and rigidity of the mounting plate are important factors

Bearings are often used to eliminate bending effects due to the weight of the lever beam and weights. However depending on its quality the bearing itself may introduce errors such as friction and the performance of the bearing still requires evaluation.

Alignment - practically it is very difficult to perfectly align a transducer in a torque machine. Usually there will be some misalignment due to the mismatch of the two axes that will give a radial, angular, or axial misalignment or any combination of the three. One way to minimise this is through the use of flexible coupling elements.

The influence of bending and parasitic effects on a transducer will be dependant on the particular design of that transducer. However the reproducibility of the device, when calibrated in different orientations, can often be a good indicator of the influences of bending.

2.3 Calibration

It is good practice to record all data from the measurement process. This includes the preloads and untared zero values. This data can give important information, particularly in cases where the transducer doesn’t behave as expected.

Following the application of the torque, a short time should be allowed before taking a reading to allow the system to settle. Often this will be between 30 to 60 seconds but the operator should allow longer if necessary. Depending on the loading mechanism the system may be subject to inertial effects or swinging weightstacks. Some systems have damping mechanisms to limit this. A consistent wait time should be used across the entire measurement range to minimise time-dependant effects such as creep.

2.4 Traceability

One effective method of gaining confidence in a system’s performance is to compare it to another system by means of a reference torque transducer. The second system should have an uncertainty similar to, if not better than, the system being evaluated. The reference transducer should be of the best possible quality so as to have a negligible influence on the measurement result. In addition to the reproducibility of the transducer, something should be known about its long-term stability (or drift) and its sensitivity to temperature and humidity effects.

3. Basic calibration

Preload – *the preload is applied to bed in the mechanical setup of the transducer and adapters, and to exercise the gauges. When the transducer is first put in the calibration rig it should be preloaded 3 times to maximum torque before any measurements are made. If the transducer is disturbed and moved to a new mounting position a further preload is required to bed in the transducer.*

a. Preload the transducer.
b. Record the zero torque output.
c. Apply at least 5 equally spaced torques, increasing torque from zero torque up to and including the maximum torque.
d. At each torque, record the output after a period of at least 30 seconds.
e. If decreasing torques are to be applied, then apply a decreasing series back down to zero torque.
f. Record the final zero torque output.
g. The transducer should be disconnected and rotated in a clockwise direction. After each rotation the transducer should be preloaded once.
h. Repeat the steps so that the transducer is calibrated symmetrically (3 orientations for flange and shaft style transducers, 4 orientations for square drive transducers).

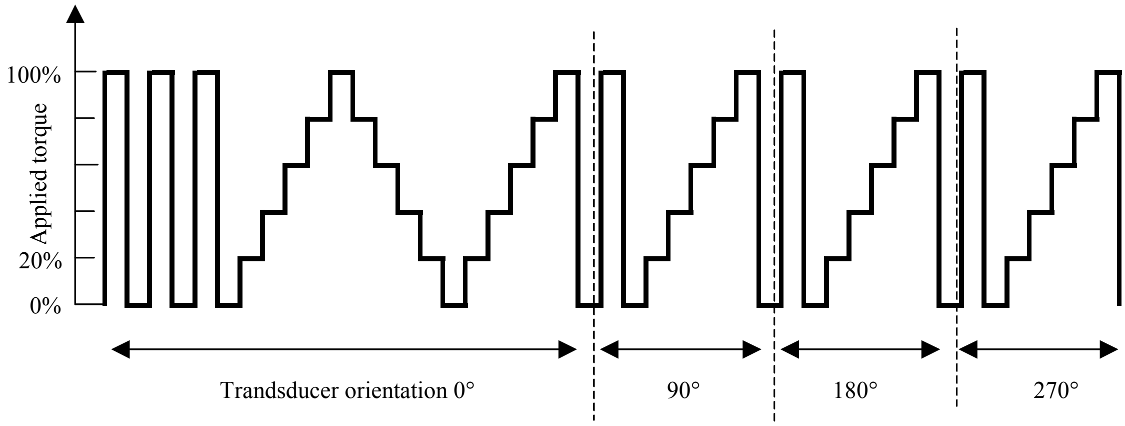


Figure 3. Loading diagram for a square drive transducer

3.1 Departure from curve fit / Non-linearity ~ *maximum difference between the deflection and polynomial curve fit.*

a. For many applications, polynomial curve fits can be programmed into the instrumentation. Using this method a first order curve fit can be used to calculate the deviation from a straight line if required.
b. Calculate the mean deflection for each increasing calibration torque.
c. Using the method of least squares, compute the coefficients of a polynomial equation giving deflection as a function of applied torque.
d. For each calibration torque, calculate the difference between the mean measured transducer deflection and the value computed from the equation.
e. The non-linearity shall be taken as the maximum of these differences, when expressed as a percentage of the mean deflection.

$$\mathrm{Max}\left[\frac{\bar{d}-d_{comp}}{d_{comp}}\times 100\right]$$

where:
$\bar{d}$ is the mean deflection;
d_{comp} is deflection value calculated from the curve fit.

Worked example

Calibration data $\quad \bar{d} \quad \bar{d}_{comp}$

N·m	0°	90°	180°	270°	Mean Value	Curve fit	non linearity
0	0.0000	0.0000	0.0000	0.0000	0.0000		
40	0.3986	0.3984	0.3985	0.3987	0.3986	0.3985	0.0004%
80	0.7970	0.7970	0.7970	0.7971	0.7970	0.7972	-0.0235%
120	1.1963	1.1963	1.1962	1.1965	1.1963	1.1960	**0.0311%**
160	1.5944	1.5944	1.5944	1.5946	1.5945	1.5947	-0.0175%
200	1.9935	1.9937	1.9935	1.9936	1.9936	1.9935	0.0037%

Cubic Curve Fit
Deflection in terms of torque

$D = b_1\,T + b_2\,T^2 + b_3\,T^3$
$b_1 =$ **9.961 94 E-03**
$b_2 =$ **4.855 E-08**
$b_3 =$ **-1.036 E-10**

$$\left[\frac{\bar{\boldsymbol{d}}-\boldsymbol{d}_{comp}}{\boldsymbol{d}_{comp}}\,x100\right]$$

hence deviation from curve fit/non linearity = **-0.0311%**

3.2 Reproducibility ~ *maximum change in deflection from changed mounting positions.*

a. Calculate the maximum difference between the deflections at each increasing calibration torque across the measurement series at different orientations.
b. The reproducibility shall be taken as the maximum of these differences, when expressed as a percentage of the mean deflection at each calibration torque.

$$\mathrm{Max}\left[\frac{d_{\max}-d_{\min}}{\bar{d}}\times 100\right]$$

where:
$\bar{d}$ is the mean deflection;
d_{max} is the maximum deflection across the measurement series;
d_{min} is the minimum deflection across the measurement series.

Worked example

$$\left[\frac{d_{max} - d_{min}}{\bar{d}} \times 100\right]$$

Calibration data

$\bar{d}$

↓

N·m	0°	90°	180°	270°	Mean Value	Reproducibility
0	0.0000	0.0000	0.0000	0.0000	0.0000	
40	0.3986	0.3984	0.3985	0.3987	0.3986	**0.075%**
80	0.7970	0.7970	0.7970	0.7971	0.7970	0.013%
120	1.1963	1.1963	1.1962	1.1965	1.1963	0.025%
160	1.5944	1.5944	1.5944	1.5946	1.5945	0.013%
200	1.9935	1.9937	1.9935	1.9936	1.9936	0.010%

hence reproducibility = **0.075%**

----

4. Additional tests

4.1 Repeatability ~ *maximum change in deflection from unchanged mounting positions.*

a. Following the basic calibration procedure (see Section 3), add a second series of increasing torques with the transducer in the zero orientation.
b. Calculate the differences between the two series of deflections.
c. The repeatability shall be taken as the maximum of these differences, when expressed as a percentage of the mean deflection at each calibration torque.

$$\text{Max}\left[\frac{d_1 - d_2}{\bar{d}} \times 100\right]$$

where:
$\bar{d}$ is the mean deflection;
d_1 is the deflection from first series in the 0° mounting position;
d_2 is the deflection from second series in the 0° mounting position.

Worked example

$$\left[\frac{d_1 - d_2}{\bar{d}} \times 100\right]$$

Calibration data

$\overline{d}$

N·m	0° (1)	0° (2)	……	Mean Value
0	0.0000	0.0000		0.0000
40	0.3986	0.3983		0.3992
80	0.7970	0.7966		0.7991
120	1.1963	1.1960		1.1987
160	1.5944	1.5942		1.5985
200	1.9935	1.9931		1.9978

Repeatability
0.075%
0.050%
0.025%
0.013%
0.020%

hence repeatability = **0.075%**

4.2 Hysteresis ~ *difference between measurements of transducer deflection for the same applied torque, one measurement being obtained by increasing the torque from zero, the other by decreasing the torque from the maximum calibration torque.*

a. Follow the basic calibration procedure in section 3, but in addition apply a single decreasing series of torques with the transducer in the zero degree orientation.
b. Calculate the difference between the increasing and decreasing deflections for each applied torque.
c. The hysteresis shall be taken as the maximum of these differences, when expressed as a percentage of the increasing deflection.

$$\mathrm{Max}\left[\frac{d_i - d'_i}{d_i} \times 100\right]$$

where:
d_i is the deflection for the incremental series;
d_i' is the deflection for the decremental series.

Worked example

$$\left[\frac{d_i - d'_i}{d_i} \times 100\right]$$

Calibration data

$\overline{d}$

N·m	0° inc	0° dec	……	Mean Value
0	0.0000	-0.0004		0.0000
40	0.3986	0.3995		0.3992
80	0.7970	0.7985		0.7991
120	1.1963	1.1981		1.1987
160	1.5944	1.5958		1.5985
200	1.9935	1.9935		1.9978

Hysteresis
0.226%
0.188%
0.150%
0.088%

hence hysteresis = **0.226%**

4.3 Creep ~ *change in output which occurs with time while a torque transducer is subjected to a constant torque and with all environmental conditions and other variables remaining constant [9] &* ***Creep recovery*** ~ *change in output which occurs with time after the torque applied to the torque transducer has been removed, with all environmental conditions and other variables remaining constant.*

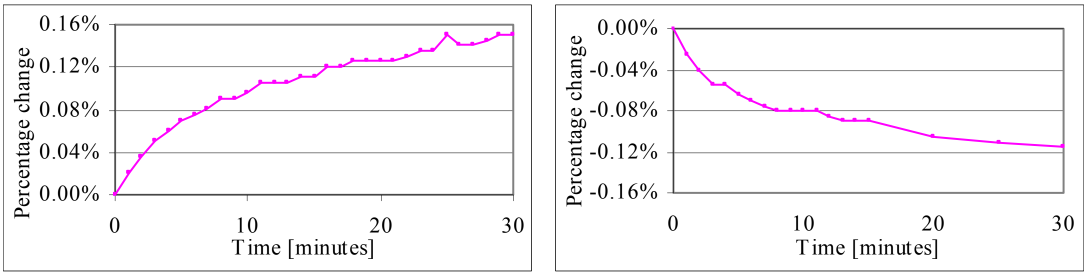


Figure 4. Graphs showing creep and creep recovery curves for a typical transducer

a. Preload the device.
b. With zero applied torque, wait for between 30 and 60 minutes. Record the zero torque output.
c. Apply the maximum calibration torque. Immediately record the initial torque output and record the reading thereafter at intervals not exceeding 5 minutes, over a period not less than 30 minutes.
d. Subtract the initial torque output from each subsequent output. Express these differences as a percentage of the maximum deflection. The creep shall be taken as the maximum difference obtained in the first 30 minutes.
e. Remove the applied torque, immediately record the initial zero torque output and record the reading thereafter at intervals not exceeding 5 minutes, over a period not less that 30 minutes.
f. Subtract the initial zero output from each subsequent output. Express these differences as a percentage of maximum deflection. The creep recovery shall be taken as the maximum difference obtained in the first 30 minutes.

Creep

$$\mathrm{Max}\left[\frac{d_i - d_{init}}{d_{max}} \times 100\right]$$

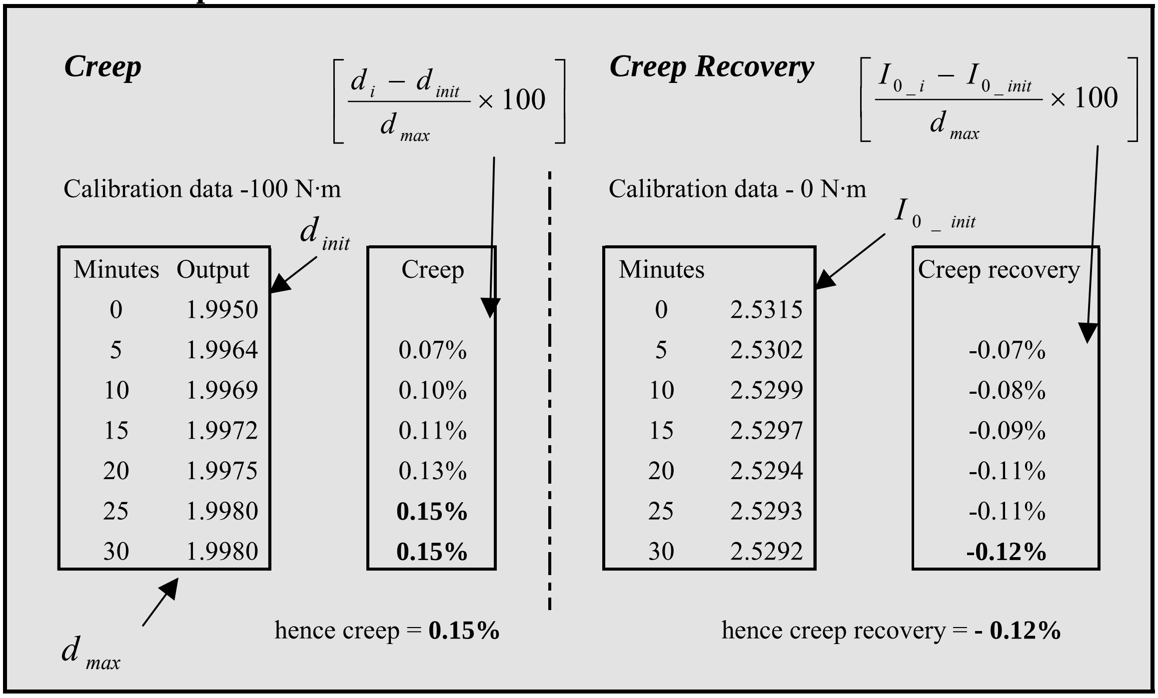
Creep recovery

$$\mathrm{Max}\left[\frac{I_{0\_i} - I_{0\_init}}{d_{\max}} \times 100\right]$$

where:
d_i is the ith deflection at maximum applied torque;
d_{init} is the initial deflection at maximum applied torque;
d_{max} is the maximum deflection at maximum applied torque;
I_{0_i} is the ith indicator output at zero applied torque;

I_{0_init} is the initial indicator output at zero applied torque.

Worked example



Creep

$$\left[\frac{d_i - d_{init}}{d_{max}} \times 100\right]$$

Calibration data -100 N·m

Minutes	Output	Creep
0	1.9950	
5	1.9964	0.07%
10	1.9969	0.10%
15	1.9972	0.11%
20	1.9975	0.13%
25	1.9980	**0.15%**
30	1.9980	**0.15%**

hence creep = **0.15%**

Creep Recovery

$$\left[\frac{I_{0\_i} - I_{0\_init}}{d_{max}} \times 100\right]$$

Calibration data - 0 N·m

Minutes		Creep recovery
0	2.5315	
5	2.5302	-0.07%
10	2.5299	-0.08%
15	2.5297	-0.09%
20	2.5294	-0.11%
25	2.5293	-0.11%
30	2.5292	**-0.12%**

hence creep recovery = **- 0.12%**

4.4 Overload effect *~ effect of 110% overload on zero output and maximum calibration torque.*

a. Apply the maximum calibration torque 3 times, recording the zero torque output and the maximum calibration torque output for each torque application. Calculate the mean zero torque output and the mean deflection.
b. Apply an overload of approximately 110% of the maximum calibration torque three times, recording the zero torque output and the overload torque output for each application.
c. Repeat step a.
d. Calculate the difference between the mean zero torque output obtained in step a and the mean zero torque obtained in step c. Express this as a percentage of the maximum deflection.
e. Calculate the difference between the mean deflection obtained in step a and the mean deflection obtained in step c. Express this as a percentage of the maximum deflection.

$$\mathrm{Max}\left[\frac{\bar{I}'_0 - \bar{I}''_0}{\bar{d}'} \times 100\right] \text{ - zero output}$$

$$\mathrm{Max}\left[\frac{\bar{d}' - \bar{d}''}{\bar{d}'} \times 100\right] \text{ - maximum calibration torque}$$

where:

$\bar{I}'_0$ is the mean zero torque output before the overload;

$\bar{I}''_0$ is the mean zero torque output after the overload;

$\bar{d}'$ is the mean deflection before the overload;

$\bar{d}''$ is the mean deflection after the overload.

Worked example

zero output

$$Max\left[\frac{\bar{I}'_0-\bar{I}''_0}{d'}\times 100\right]$$

maximum calibration torque

$$Max\left[\frac{\bar{d}'-\bar{d}''}{\bar{d}'}\times 100\right]$$

Calibration data

0 N·m	*100 N·m*
-0.010133	-1.345833
-0.010146	-1.345846
-0.010153	-1.345846
0 N·m	*110 N·m*
-0.010156	-1.479461
-0.010175	-1.479478
-0.010184	-1.479482
0 N·m	*100 N·m*
-0.010192	-1.345897
-0.010188	-1.345888
-0.010194	-1.345900

$\bar{I}'_0$ -0.010144

$\bar{d}'$ -1.345842

$\bar{I}''_0$ -0.010191

$\bar{d}''$ -1.345895

-0.0035%

-0.0040%

hence overload effect on zero output = **0.0035 %**
overload effect on maximum output = **0.0040 %**

4.5 Bending effects ~ *effects of side loads on the calibration result [10].*

This test is to be carried out on a symmetrical unsupported calibration beam.

a. Calibrate to the basic calibration method in Section 3.
b. At each calibration torque record the deflection then apply an additional 50% of the load on each side of the beam, so that 150% of the applied load is in the direction the direction the torque is to be applied and 50% of the load is in the opposite direction. Record the deflection. Remove the additional load and then apply the next increasing torque.
c. Calculate the maximum difference between the single and double loading deflections at each increasing calibration torque across the measurement series and at different orientations, expressing this as a percentage of the single load deflection.
d. The bending parameter shall be taken as the maximum of these differences, when expressed as a percentage of the deflection.

$$\mathrm{Max}\left[\frac{d_{doub}-d_{\sin g}}{d_{\sin g}}\times 100\right]$$

where:
d_{sing} is the deflection for the single loading series;

d_{doub} is the deflection for the double loading series.

Worked example

$$\left[\frac{d_{doub} - d_{\sin g}}{d_{\sin g}} \times 100\right]$$

d_{sing} d_{doub}

0°			
N·m	single	double	bending
200	0.129842	0.129872	0.023%
400	0.264157	0.264214	0.022%
600	0.398471	0.398559	0.022%
800	0.532792	0.532930	0.026%
1000	0.667134	0.667284	0.022%

90°			
N·m	single	double	bending
200	0.129754	0.129744	-0.008%
400	0.264035	0.263999	-0.014%
600	0.398298	0.398260	-0.010%
800	0.532587	0.532526	-0.011%
1000	0.666868	0.666845	-0.003%

180°			
N·m	single	double	bending
200	0.129717	0.129702	-0.012%
400	0.263983	0.263949	-0.013%
600	0.398262	0.398210	-0.013%
800	0.532540	0.532464	-0.014%
1000	0.666830	0.666806	-0.004%

270°			
N·m	single	double	bending
200	0.129852	0.129887	0.027%
400	0.264166	0.264218	0.020%
600	0.398485	0.398578	0.023%
800	0.532809	0.532913	0.020%
1000	0.667133	0.667318	**0.028%**

hence bending parameter = **0.028%**……between 20% & 100% of applied torque

4.6 Output stability at zero torque *~ drift in zero value.*

Through regular use, knowledge of a transducer's long-term stability can be built up. For a new transducer, or one with little history the following tests (4.7 & 4.8) can give some indication of the stability of the transducer. The longer the stability test the better although this has to be balanced against practicalities.

a. Mount the transducer in the calibration rig and allow at least 30 minutes to settle.
b. With zero applied torque take a series of 15 readings at regular time intervals over a period of at least 48 hours simultaneously recording temperature.
c. Record the spread and express as a percentage of maximum deflection.

$$\frac{I_0 max - I_0 min}{dmax} \times 100$$

where:

I_0 max is the maximum output with zero applied torque;
I_0 min is the minimum output with zero applied torque;
d max is the deflection at the maximum calibration torque.

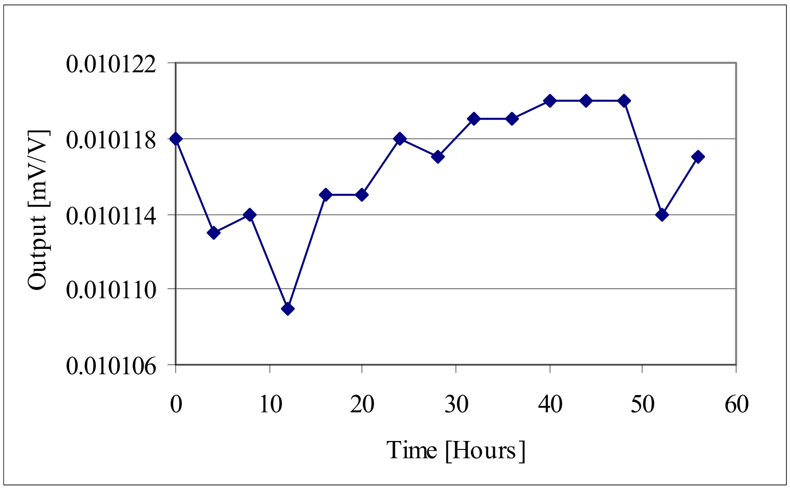


Figure 5. Output stability at zero torque over a 56 hour period

4.7 Output stability at maximum torque *~ drift at maximum calibration torque.*

a. Preload the transducer according to the procedure in Section 3.
b. Apply the maximum calibration torque.
c. While maintaining the maximum calibration torque take a series of 15 readings at regular time intervals over a period of at least 48 hours simultaneously recording temperature.
d. Record the spread and express as a percentage of maximum deflection.

$$\text{Max}\left[\frac{dmax - dmin}{dmax} \times 100\right]$$

where:
dmax is the maximum deflection recorded over the measurement period;
dmin is the minimum deflection recorded over the measurement period.

Worked example

Output stability at zero torque

Calibration data

Time	Output
0	0.010118
4	0.010113
8	0.010114
12	**0.010109**
16	0.010115
20	0.010115
24	0.010118
28	0.010117
32	0.010119
36	0.010119
40	**0.010120**
44	0.010120
48	0.010120
52	0.010114
56	0.010117
60	0.010118

$I_0 min$

$I_0 max$

$$\mathrm{Max}\left[\frac{I_0max-I_0min}{dmax}\times 100\right]$$

0.00082%

hence stability at zero torque = **0.00082%**

Output stability at maximum torque

Calibration data

Time	Output
0	**1.345911**
4	1.345933
8	1.345929
12	1.345946
16	1.345957
20	1.345958
24	1.345983
28	1.345994
32	1.345998
36	1.346003
40	1.346009
44	1.346023
48	1.346024
52	1.346026
56	1.346014
60	**1.346027**

dmin

d max

$$\mathrm{Max}\left[\frac{dmax-dmin}{dmax}\times 100\right]$$

0.0086%

hence stability at maximum torque = **0.0086%**

4.8 Alternating torque *~ zero shift when applying a clockwise torque followed by an anticlockwise torque. The toggle effect occurs when a full alternating load cycle takes place or when the directions of preloading and loading differ [11-12].*

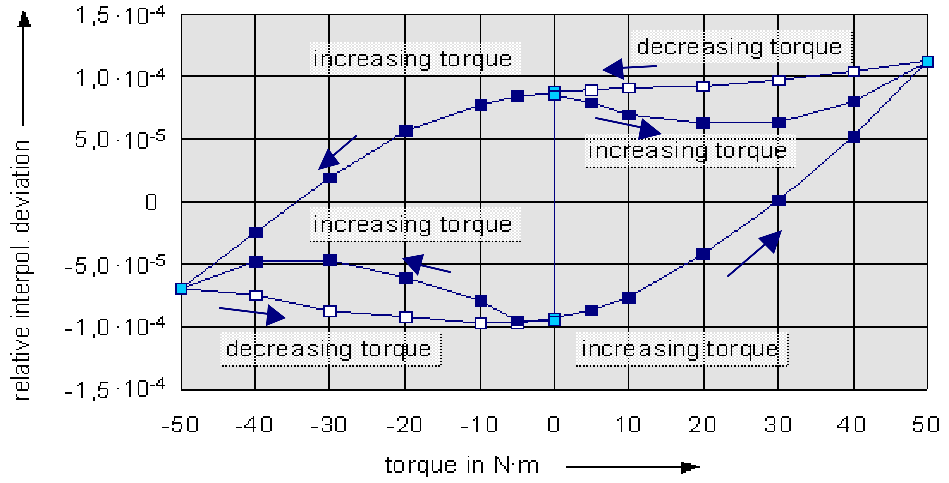


Figure 6. The graph shows the effect of alternating torque - plotted as a relative deviation from a straight line fit

a. Calibrate to the basic calibration procedure in section 3 in both clockwise and anticlockwise directions.
b. Calculate the mean zero output for the clockwise calibration. Calculate the mean zero output for the anticlockwise calibration. The toggle value shall be taken as the difference between these two values expressed as a percentage of the mean of the magnitude of the two maximum deflections for the clockwise and anticlockwise calibrations.

$$\frac{\overline{I}_0 clock - \overline{I}_0 anti}{[|\overline{d}_{max} clock| + |\overline{d}_{max} anti|]/2} \times 100$$

where:

$\overline{I}_0 clock$ is the mean zero output in the clockwise direction;

$\overline{I}_0 anti$ is the mean zero output in the anti-clockwise direction;

$\overline{d}_{max} clock$ is the mean maximum deflection in the clockwise direction;

$\overline{d}_{max} anti$ is the mean maximum deflection in the anti-clockwise direction.

Worked example

	Output mV/V
I_0 clock	0.00138
I_0 anti	0.00222

Maximum Deflection	
Clockwise	1.50128
Anticlockwise	1.50146

$$\frac{\overline{I}_0 clock - \overline{I}_0 anti}{[|\overline{d}_{max} clock| + |\overline{d}_{max} anti|]/2} \times 100$$

0.13%

hence alternating torque parameter = **0.13%**

4.9 Torque versus angle (flexural stiffness).

a. Preload the transducer according to the procedure in Section 3.
b. Record the angle at zero torque.
c. Apply at least 5 equally spaced, increasing torques from zero torque up to and including the maximum torque.
d. At each torque, record the angle after a period of at least 30 seconds.
e. If decreasing torques are to be applied, then apply a decreasing series of torques back down to zero torque.
f. Fit a straight line to a plot of angle versus torque. Calculate the gradient and express in units of °/N·m.
g. Note: Care should be taken to ensure that the angle is measured is specific to the transducer and doesn’t incorporate flexing in other parts of the system.

Worked example

N·m	Angle °
0	0.00000
1	0.10125
2	0.20225
5	0.50725
10	1.01625
15	1.52575

From the graph the
angle y in terms of torque x [N·m]
is given by

$y = 0.10173x - 0.00074$

4.10 Excitation voltage effects ~ *change in output caused by a change in the excitation voltage for a mV/V measurement system.*

a. Preload the transducer according to the procedure in Section 3.
b. Using the recommended excitation voltage apply the maximum calibration torque three times, each time taking a reading after at least 30 seconds. Calculate the mean deflection for the three readings.
c. Using the maximum excitation voltage apply the maximum calibration torque three times, each time taking a reading after at least 30 seconds. Calculate the mean deflection for the three readings.
d. Calculate difference between the two mean readings and express as a percentage of maximum deflection.

$$\frac{\overline{d}max - \overline{d}rec}{\overline{d}max}\times 100$$

where:

$\overline{d}$ max is the mean deflection at maximum calibration torque using the maximum excitation voltage;

$\overline{d}rec$ is the mean deflection at maximum calibration torque using the recommended excitation voltage.

Worked example

Recommended excitation voltage
8 V

0	2.5267
200	4.5239
0	2.5275
200	4.5246
0	2.5280
200	4.5245

$\bar{d}rec$ 1.9969

Maximum exctiation voltage
12 V

0	2.5291
200	4.5269
0	2.5297
200	4.5273
0	2.5297
200	4.5274

$\bar{d}$ max 1.9977

$$\frac{\bar{d}\,max - \bar{d}rec}{\bar{d}\,max}\times 100$$

0.038%

hence difference due to change in excitation voltage = 0.038%

5. Environmental tests

5.1 Temperature sensitivity at zero torque ~ *change in zero output with change in temperature.*

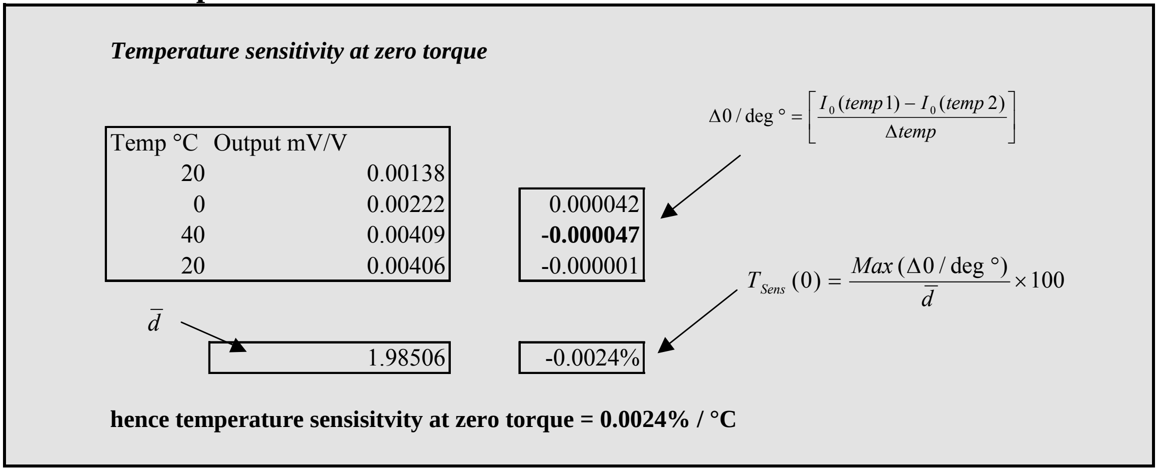
a. Set the temperature to 20 ° C and record the zero output.
b. Set the temperature to the lower limit of the compensated temperature range. Record the zero output.
c. Set the temperature to the upper limit of the compensated temperature range. Record the zero output.
d. Set the temperature to 20 ° C and record the zero output.
e. For each temperature change calculate the change in zero torque output and divide by the change in temperature. Take the maximum of these 3 figures and express as a percentage of maximum deflection per degree Celsius**.**

$$\Delta 0/\deg^{\circ} = \left[\frac{I_0(temp1) - I_0(temp2)}{\Delta temp}\right]$$

$$T_{Sens}(0) = \frac{\mathrm{Max}(\Delta 0/\deg^{\circ})}{\bar{d}}\times 100$$

where:
I_0(temp1) *is the zero output at the first temperature;*
I_0(temp2) *is the zero output at the second temperature;*
Δtemp is the difference between the two temperatures;
$\bar{d}$ *is the maximum deflection at 20 °C.*

Worked example



Temperature sensitivity at zero torque

Temp °C	Output mV/V	
20	0.00138	
0	0.00222	0.000042
40	0.00409	**-0.000047**
20	0.00406	-0.000001

$\bar{d}$ = 1.98506

-0.0024%

$$\Delta 0/\deg{}^{\circ} = \left[\frac{I_0(temp\,1) - I_0(temp\,2)}{\Delta temp}\right]$$

$$T_{Sens}(0) = \frac{Max(\Delta 0/\deg{}^{\circ})}{\bar{d}} \times 100$$

hence temperature sensisitvity at zero torque = 0.0024% / °C

5.2 Temperature sensitivity at maximum calibration torque ~ *changes in the sensitivity of the transducer with change in temperature.*

a. Set the temperature to 20 °C.
b. Preload the transducer according to the procedure in Section 3.
c. Record the zero torque output. Apply the maximum calibration torque three times, each time taking a reading after at least 30 seconds. Record the zero torque output prior to the application of each torque. Calculate the mean deflection for the three readings.
d. Set the temperature to the lower limit of the compensated temperature range. Follow the procedure in step c.
e. Set the temperature to the upper limit of the compensated temperature range. Follow the procedure in step c.
f. Set the temperature to 20 °C. Follow the procedure in step c.
g. For each temperature change calculate the change in the mean deflection and divide by the change in temperature. Take the maximum of these 3 figures and express as a percentage of maximum deflection per degree Celsius**.**

$$\Delta d/\deg{}^{\circ} = \left[\frac{\bar{d}(temp1) \ \ - \bar{d}(temp2)}{\Delta temp}\right]$$

$$T_{Sens}(Max) = \frac{\mathrm{Max}(\Delta d/\deg{}^{\circ})}{\bar{d}} \times 100$$

where:

$\bar{d}$ (temp1) is the mean deflection at the first temperature;

$\bar{d}$ (temp2) is the mean deflection at the second temperature;

Δtemp is the difference between the two temperatures;

$\bar{d}$ is the maximum deflection at 20 °C.

Worked example

Temperature sensitivity at maximum calibration torque

Temp °C	Mean deflection mV/V	
20	1.99753	
0	1.98419	**-0.000667**
40	2.00475	-0.000514
20	1.99721	-0.000377

$\bar{d}$ 1.98506

-0.034%

$$\Delta d / \deg{}^{\circ} = \left[\frac{\bar{d}(temp\ 1) - \bar{d}(temp\ 2)}{\Delta temp} \right]$$

$$T_{Sens}(Max) = \frac{Max(\Delta d / \deg{}^{\circ})}{\bar{d}} \times 100$$

hence temperature sensitivity at maximum calibration torque = 0.034% / °C

6. Dynamic

6.1 Frequency response (electronic) ~ *characterised by magnitude of the system's response.*

a. Introduce a small AC signal into the torque measuring device and measure the output signal at the output of the indicating device.
b. Slowly increase the frequency (f) of the AC signal and measure the change in the amplitude of the output signal plotting an output against frequency graph.
c. The graph should be reasonably linear until the frequency reaches the limits of the electronic bandwidth or edge of any low-pass filter. The frequency (f) at which output (f)=0.707*output$_{Max}$ can be taken as a measure of the bandwidth of the system or frequency response.

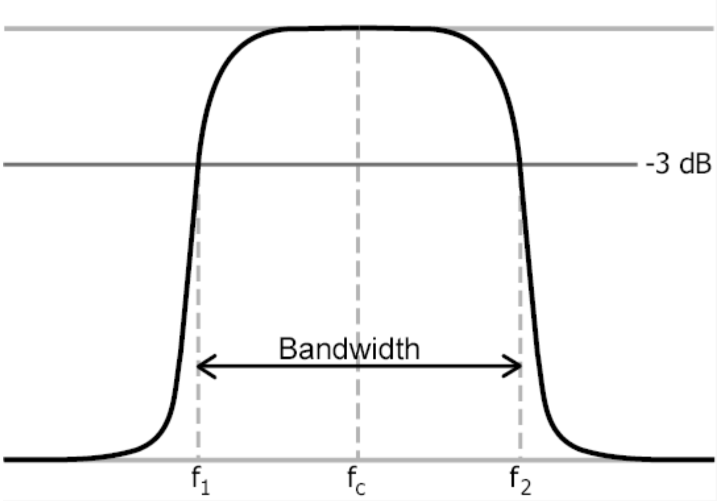


Figure 7. Example of the frequency response for a system

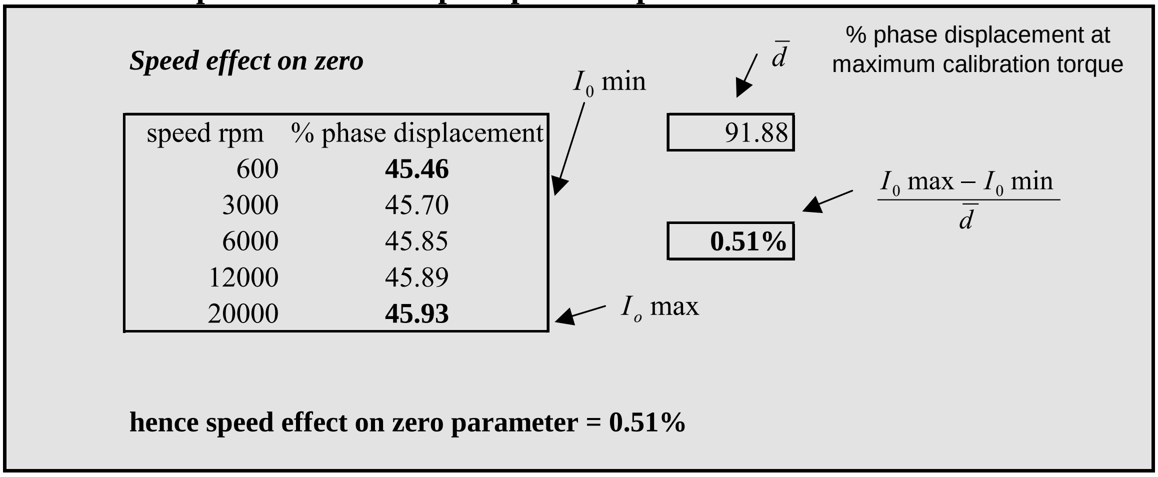
6.2 Speed effect on zero ~ *changes in the zero output of the transducer due to rotational effects.*

a. Preload the transducer according to the procedure in Section 3.
b. Record the zero torque output.
c. Rotate the transducer at 5 equally spaced rotational speeds up to the maximum rotational speed of the device. If the device is used over a large speed range, 5 equally spaced rotational speeds can be chosen on a logarithmic scale.
d. At each speed, record the output after a period of at least 30 seconds.
e. Rotate the transducer in the opposite direction and repeat the test.
f. Calculate the maximum difference between the zero outputs.
g. The speed effect on zero shall be taken as this difference expressed as a percentage of maximum deflection.

$$\frac{I_0 max - I_0 min}{\bar{d}}$$

where:
I_0max is the maximum zero output across the range of speeds;
I_0min is the minimum zero output across the range of speeds;
$\bar{d}$ is the mean deflection at the maximum calibration torque.

Worked example – In this example a phase displacement transducer was used.



Speed effect on zero

speed rpm	% phase displacement
600	**45.46**
3000	45.70
6000	45.85
12000	45.89
20000	**45.93**

91.88

0.51%

hence speed effect on zero parameter = 0.51%

7. Glossary

***Applied torque* ~** the torque applied to a transducer by a torque machine or rig.
Deflection ~ the difference between the output at an applied torque and the output with no applied torque.
***Stabilisation* ~** the process of allowing a transducer and readout, to acclimatise to new conditions. This may be the environmental conditions in a laboratory or a change in the applied torque.
***Resolution* ~** the smallest increment that can be measured by the indicating unit or if the readout is fluctuating half the magnitude of the largest fluctuation.
***Mounting position* ~** the particular orientation of a transducer in the torque machine or calibration rig. The transducer is calibrated symmetrically in several orientations to eliminate any positional dependencies. This is measured by the reproducibility of the transducer.
***Misalignment* ~**any offset between the two ends of the machine or rig to which the transducer is connected. This offset may be radial, angular or axial. The offset will introduce parasitic forces into the transducer, which can influence the measurement result.
***Uncertainty* ~** The applied torque for a particular rig should have an associated uncertainty which takes into account all of the contributing parameters and are traceable to calibration certificates for mass and length etc. Similarly the measurement result for a calibration will have an associated uncertainty. This will include the uncertainty of the applied torque together with transducer parameters such as reproducibility measured during the calibration. More information on working out calibration uncertainties can be found in some of the standards listed in this guide.
Static torque calibration ~ a process where discrete torque increments are applied in a stepwise manner with time allowed for stabilisation of the transducer at each applied torque.
***Continuous torque calibration* ~** a process where applied torque is applied in a continuous linear manner up to the maximum calibration torque The process takes a fraction of the time of a static torque calibration and data from the transducer can be recorded continuously. The applied torque, applied by the torque machine is usually measured by a calibrated reference torque transducer.
***Reference torque transducer* ~**a high performance transducer that can be used to measure or control the applied torque of a torque machine or as a transfer standard to provide a comparison between different torque machines.
***Long terms stability / drift* ~** the change in the output of the transducer over a significant time period such as the interval between successive calibrations.

8. Acknowledgements

The author would like to acknowledge the support of the following individuals and companies, for their contributions to the project including technical input, provision of data and the loan of equipment.

Mr Chanchal Bahra, Instron Ltd.
Mr Pete Goddard, Alpha Technologies UK.
Mr Malcolm Habens, Datum Electronics Ltd.
Mr Peter Lewis, Applied Measurements Ltd.
Mr Paul Miles, Industrial Measurements Ltd.
Mr Ben Van Millingen, Torquemeters Ltd.
Mr Barry Pratt, Norbar Torque Tools Ltd.
Mr Jeff Tanner & Dr Serghei Sandacci, Sensor Technology Ltd.

The pictures in figures 1 (right) and 6 are reproduced with the kind permission of the PTB.

Finally the author would like to acknowledge the financial support of the National Measurement System of the Directorate UK Department of Innovation, Universities and Skills.

9. References

[1] BS 7882:1997; Calibration and classification of torque measuring devices.

[2] DIN 51309:1998; Calibration of static torque measuring devices.

[3] Robinson A, 2007 The Design, Development and Commissioning of a 2 kN·m Torque Standard Machine. *CalLab, Jan – Mar.*

[4] Merlo S, 2001 The uncertainty of torque primary standards: a comprehensive analysis. *Measurement 29 pp. 279-285.*

[5] Brüge A, Peschel D and Röske D, 2000 The influence of misalignment on torque transducers. *Proceedings of the 16th Imeko World Congress, Vienna, Austria, vol. III, pp. 13-17.*

[6] Röske D, 1998 Investigation of the Influence of Disturbing Components on the Torque Measurement. *Proceedings of the 16th Imeko TC3 Conference, Taejon, Korea, pp. 280-285.*

[7] Brüge A, 1996 Influence of eccentric mounting on the calibration of torque measuring devices. *Proceedings of the 15th Imeko TC3 Conference, Madrid, Spain, pp. 255-259.*

[8] Peschel D, 1993 Mechanical parasitic components and their influence on the calibration of torque transducers. *Proceedings of the 13th Imeko TC3 Conference, Helsinki, Finland, pp. 91-96.*

[9] Peschel D, Röske D; 1999 Determination of creep value using short-term creep. *Proceedings of the 15th Imeko World Congress, Osaka, Japan, vol. III, pp. 245-249.*

[10] Pratt B, Robinson A, 2006 A comparison between supported and unsupported beams for use in static torque calibrations. *Proceedings of the 18th Imeko World Congress, Rio.*

[11] Röske D, Peschel D, 1997 Investigations into the alternating torque calibration of torque transducers. *Proceedings of the 14th Imeko World Congress, Tampere, Finland, vol. III, pp. 72-78.*

[12] Röske D, 2003 Discussion on calibration results for alternating torque in comparison with single cw and acw torque calibrations. *Round table TC3 17th Imeko World Congress, Dubrovnik.*