A COMPARISON BETWEEN SUPPORTED AND UNSUPPORTED BEAMS FOR USE IN STATIC TORQUE CALIBRATIONS

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Abstract: In industry, calibration beams are frequently coupled directly to the measurement transducer. This paper aims to quantify the effect of using such a method in contrast to the bearing supported case for a range of commercially available transducers.

Keywords: torque, calibration, unsupported.

1. INTRODUCTION

Calibration beams coupled directly to a test transducer are used in industry for reasons of cost and simplicity, and because this is the manner in which the transducer will be used in many applications. However it is generally accepted that a bearing supported beam is used for measurements of the highest accuracy in order to minimise bending effects on the test transducer.

2. PURPOSE

The aim of the work is to quantify the difference between a bearing supported calibration and an unsupported beam calibration for a range of transducers. A better understanding of the uncertainties involved in an unsupported beam calibration will be gained together with knowledge of the influencing parameters. This work provides guidance in the selection of an appropriate method for the calibration of a torque transducer. It may not be necessary to use a bearing supported beam in all applications.

3. METHODS

Two Norbar calibration beams, were used in the work. The first beam had a capacity of 1.5 kN·m, interfaced via a 1" square drive, and had a total weight of 23.4 kg and a torque radius of 1 m. The second beam had a capacity of 500 N·m, a total weight of 16.6 kg and a 0.5 m torque radius. Three commercially available transducers with different capacities, different geometries, and from different manufacturers, were used for the project, including one with bending bridges. Transducer A had a 2 kN·m capacity with round shaft and bending bridges. Transducer B had a 200 N·m capacity with flange adaptation. Transducer C had a 1 kN·m capacity with round shaft and female squares allowing square drive adaptation.
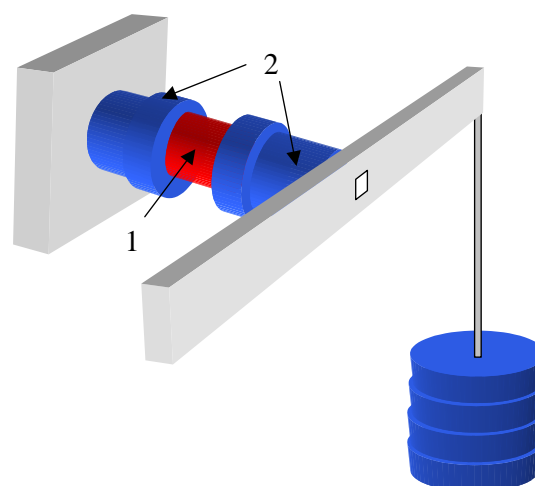

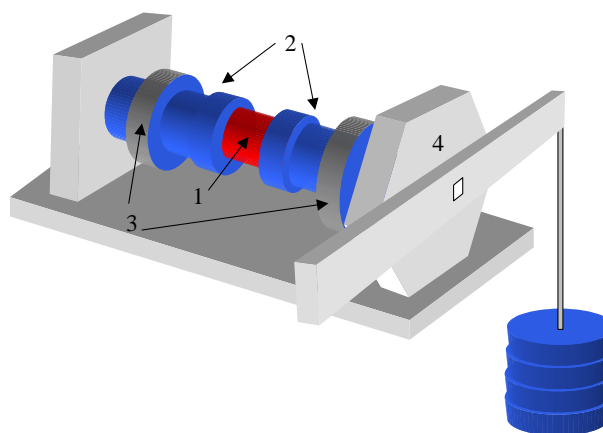Fig. 1. Unsupported calibration beam; (1) transducer; (2) adapters.

Fig. 2. Bearing supported calibration beam; (1) transducer; (2) adapters; (3) flexible couplings; (4) bearing.

At Norbar, calibrations were carried out on each transducer using one of the two unsupported beams, where possible connecting directly to the transducer. The beam interfaced via a square drive and so this calibration was performed at four orientations.
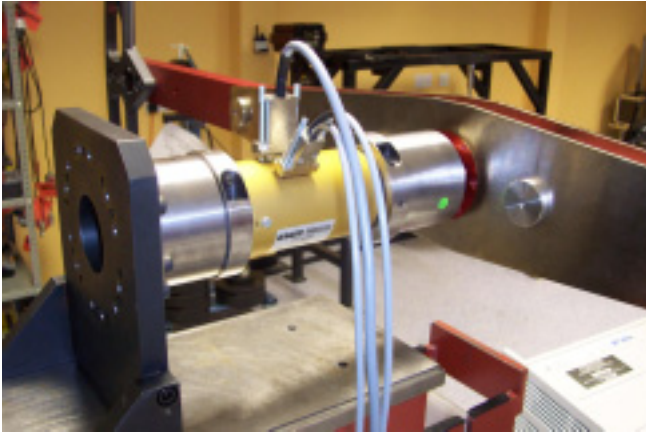
Fig. 3. Unsupported beam calibration at Norbar.

The NPL 2 kN·m standard machine was used to provide a reference calibration for all transducers [1]. This machine has a vertical torque axis with an uncertainty in applied torque of 0.002 %. A pair of flexible couplings was used in the calibration. All calibrations were performed to DIN 51309 [2].

Fig. 4. NPL 2 kN·m machine.

Measurements were also taken using the bending bridges of transducer A to determine the bending moments introduced by each method of torque application. A double loading test was undertaken at Norbar to determine the susceptibility of each transducer to bending loads. This involved loading both ends of the calibration beam, so that the same torques were applied as in a normal calibration but using double the load.
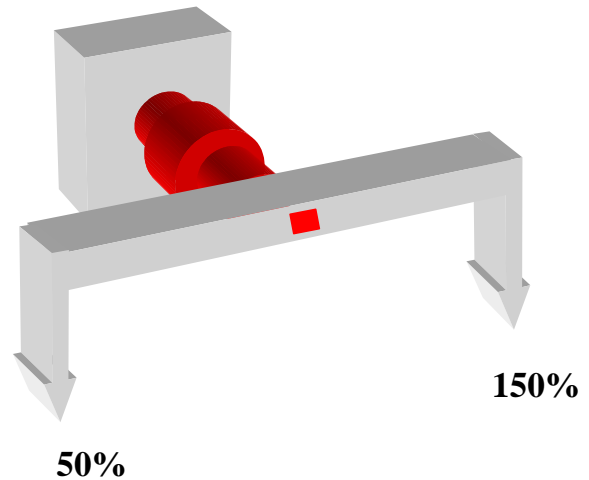

Fig. 5. Schematic for the double load test.

4. RESULTS

4.1 Calibration of transducers in NPL 2 kN·m machine

All transducers were calibrated at NPL to provide a reference value. Fig. 6 summarises the calibration results for the three transducers.

The three graphs show typical characteristic curves. Transducer A shows particularly good reproducibility. For transducer B the sensitivity changes direction around 120 N·m producing an unusual shape to the graph.
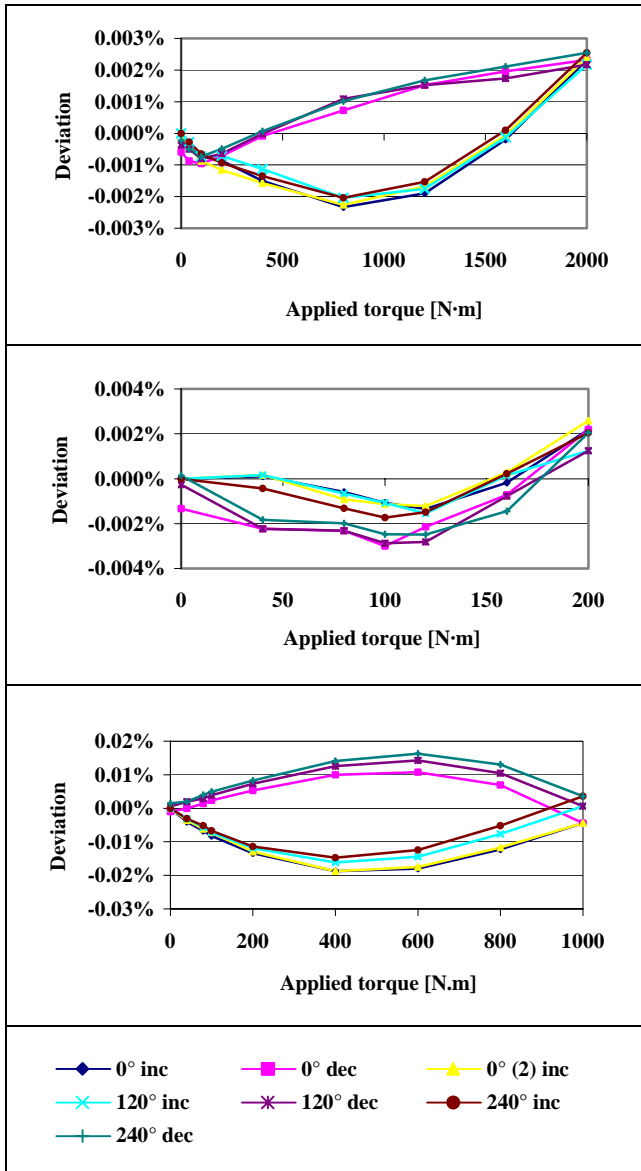
Fig. 6. Percentage deviation from a straight line fit for clockwise torque for transducers A, B, and C, for a bearing supported calibration.

Fig. 7. Percentage deviation from a straight line fit for clockwise torque for transducers A, B, and C, for an unsupported beam calibration.

4.2 Calibration of transducers at Norbar

Transducers A and C were calibrated with the 1.5 kN·m beam. Transducer B was calibrated with the 500 N·m beam. Taking the reference value from the NPL calibration the percentage deviations from a straight line fit are calculated for the unsupported beam calibration.

Comparing Fig. 6 with Fig. 7 shows how the calibration result changes when using an unsupported beam. It is important to notice the change in scale on the graphs. The top two graphs for transducers A and B show a divergence in measurement series resulting in worse reproducibility. For transducer C all four measurement series have shifted by a similar amount, so while the effect on the reproducibility is less, the difference in the mean calibration result is much greater. Transducer C had the worst reproducibility when calculated with a supported beam, but the best reproducibility when calibrated with an unsupported beam.
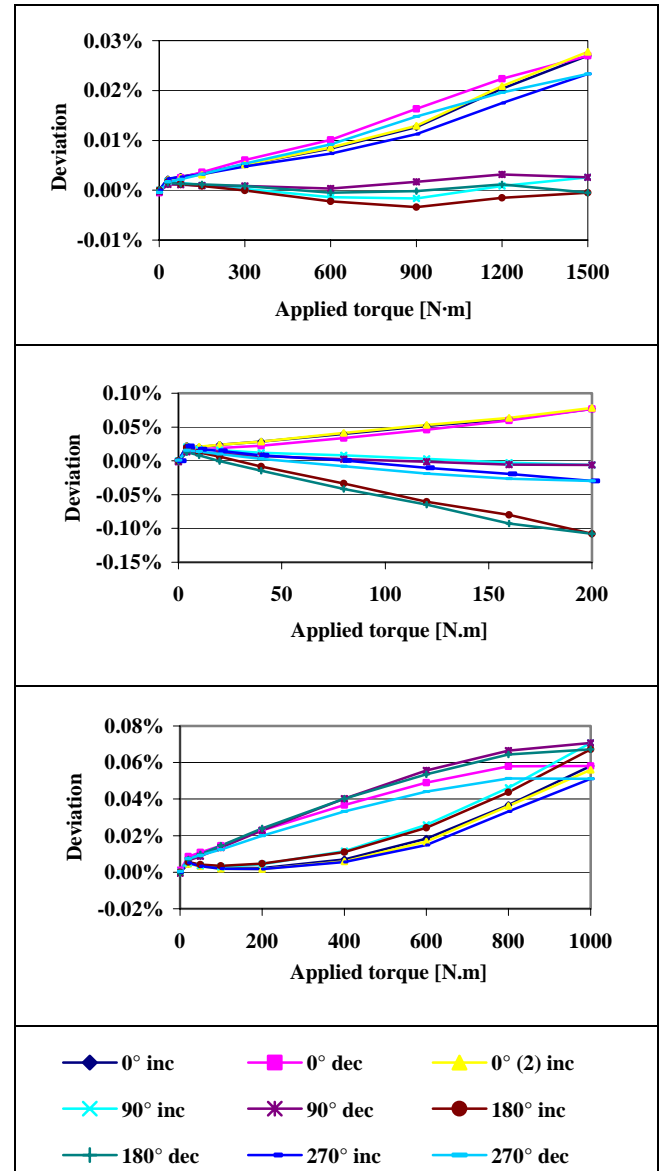
Fig. 8 shows the percentage deviation of the individual measurement points for transducer A calibrated with the Norbar unsupported beam when compared to the NPL reference measurement. For 20 % of the range and above, the mean deviation is less than 0.02 %. While in the 0° and 270° orientations the deviation is much greater, when calibrated symmetrically the mean deviation is approximately half of the worst case. However below the 20 % mark the relative sensitivity increases, and rises sharply below the 10 % mark. This may be attributable to bending moments. Below 20 % the weight of the beam becomes significant in relation to the torque being measured.
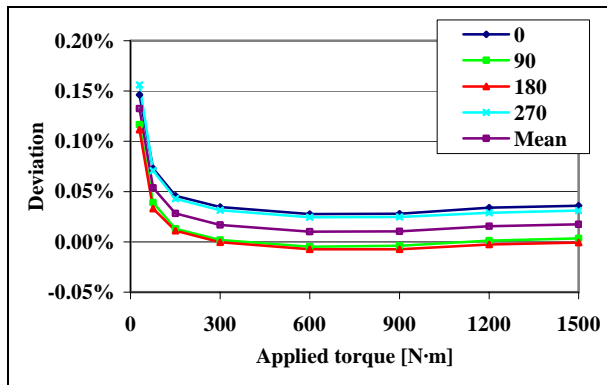
Fig. 8. Relative deviation of transducer A calibrated with Norbar unsupported beam from the NPL reference calibration.

Fig. 9 shows the percentage deviations of the mean values for all three transducers. The graph is truncated to focus on the 20 % - 100 % region. Below 20 % the curves rise steeply as shown in Fig. 8. Fig. 9 shows that between 20 % and 100 % transducer A shows a fairly constant 0.02 % offset. For transducer B the percentage deviation rises steadily with decreasing torque. Transducer C shows a constant 0.06 % offset.
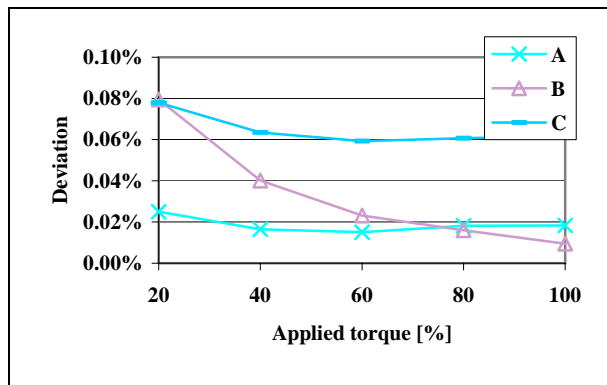

Fig. 9. Relative deviation of transducers A, B and C calibrated with Norbar unsupported beam from the NPL reference calibration .

4.3 Double load tests

From the double load tests a pair of values was obtained for each calibration point. The first value was for the single load test and the second value for the double load test. The difference in deflections between the pair of values can be taken as a measure of the influence of bending on the torque sensitivity.

Fig. 10 shows the full-scale output for single and double loading, measured in four positions, for each of the three transducers. Each of the transducer outputs exhibit sine wave geometry. The effects of double loading affects the amplitude of the sine wave and hence the reproducibility. However the shift is not completely symmetrical as there is a change in the mean value. For transducer C it can be seen that the double loading affects the transducer in all four measurement planes much as expected from the calibration curve in Fig. 7. Transducer B shows the greatest susceptibility to bending. The greatest difference obtained

from the double load test from each graph was incorporated into the uncertainty calculation.
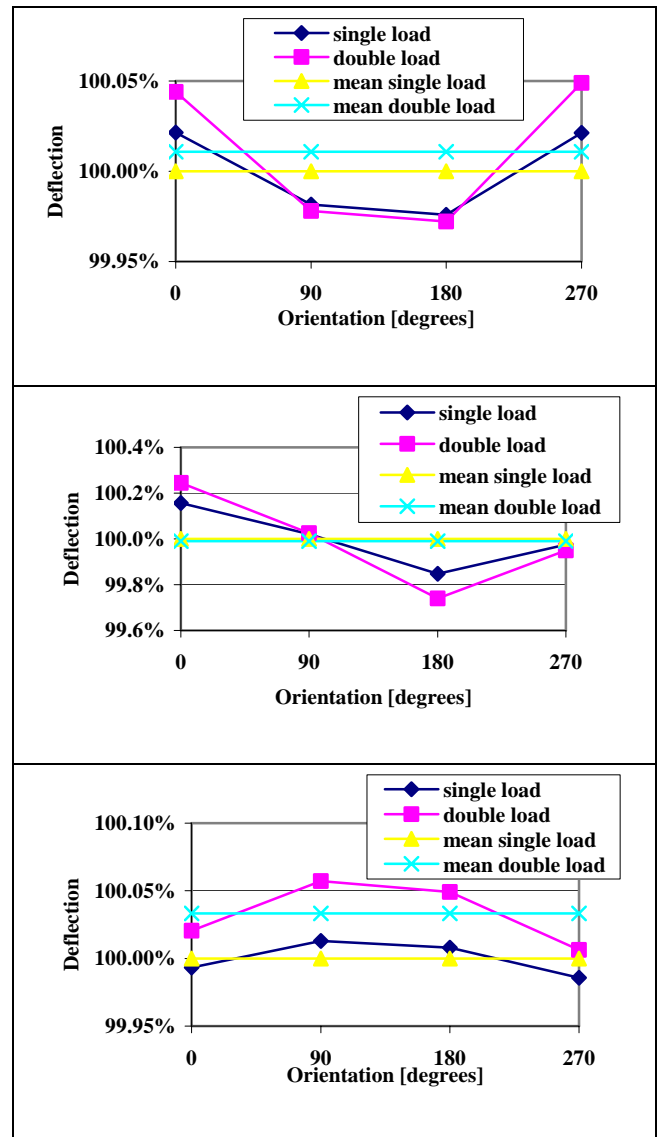

Fig. 10. Double load tests for transducers A,B and C. 100 % is taken as full scale deflection for single loading.

4.4 Bending tests

The bending bridges of transducer A were used to determine the bending moments introduced by each method of torque application.
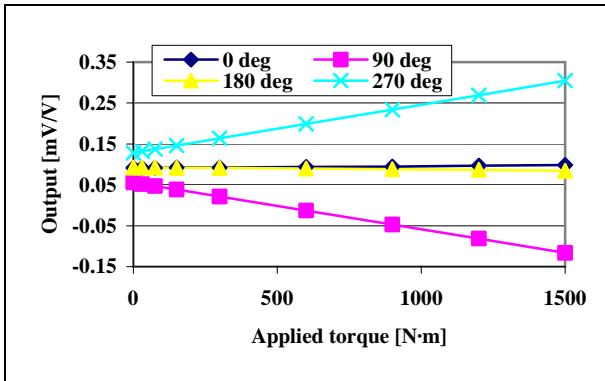

Fig. 11. Output from the bending bridge of the Raute TT1 for an unsupported calibration.

Fig. 11 shows the output for an unsupported beam. The bending bridge shows bending in the 90°/270° plane. The y-axis intercepts for the 90° and 270° lines represent the bending due to the weight of the beam alone. This corresponds to a force of 315 N.

4.5 Comparison between the 1.5 kN·m and the 500 N·m unsupported beams

To provide a comparison transducer B was calibrated a second time using the 1.5 kN·m unsupported calibration beam. The heavier 1.5 kN·m beam shows a greater deviation from the NPL reference value (see Fig. 12). However it should be noted that the 500 N·m beam with only 0.5 m radius takes double the load. This supports the view that the deviation is caused by the weight of the beam in relation to the capacity of the transducer.
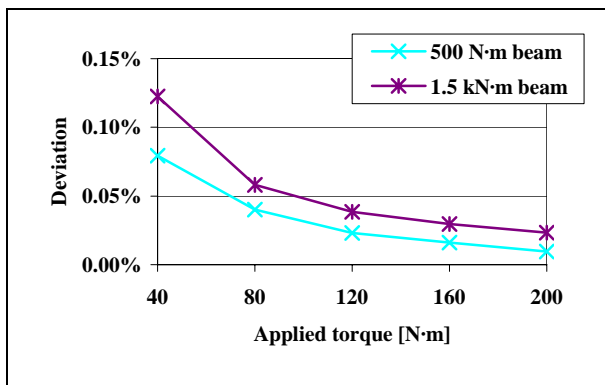

Fig. 12. Relative deviation of Norbar unsupported beam from NPL calibration.

4.6 Uncertainties and E_n ratios

The uncertainties for each calibration were calculated according to DIN 51309. This includes parameters for repeatability, reproducibility, zero signal, interpolation, and resolution. The NPL torque standard machine has an uncertainty in applied torque of 0.002 % and the total

calculated uncertainty for each calibration point (U1, U3, and U5) excludes any allowance for bending effects. The unsupported beam has an uncertainty of 0.02 % and the total calculated uncertainty for each calibration point (U2, U4, and U6) includes an allowance for bending effects.

The E_n ratio was calculated between the NPL reference calibration and the Norbar unsupported beam calibration for each transducer. Uncertainty U2 includes an allowance for bending of 0.028 % calculated from the double load tests - excluding this allowance still produces an E_n ratio of less than unity for a range of 20 % to 100 %.

Table 1. Transducer A – Uncertainties and E_n ratio.

Torque	NPL ref.	1.5 kN·m beam	U1	U2	E_n Ratio
N·m	mV/V	mV/V	%	%	
75	0.050351	0.050384	0.0054	0.0451	1.43
150	0.100703	0.100741	0.0054	0.0412	0.91
300	0.201409	0.201460	0.0051	0.0449	0.56
600	0.402825	0.402891	0.0051	0.0413	0.39
900	0.604249	0.604340	0.0056	0.0422	0.35
1200	0.805680	0.805826	0.0062	0.0448	0.40
1500	1.007118	1.007303	0.0069	0.0465	0.39

Uncertainty U4 includes an allowance for bending of 0.1 % calculated from the double load tests using the 500 N·m capacity beam - excluding this allowance still produces an E_n ratio of less than unity for the range of 20 % - 100 % for the 500 N·m capacity beam.

Table 2. Transducer B – Uncertainties and E_n ratio.

Torque	NPL ref.	500 N·m beam	U3	U4	E_n Ratio
N·m	mV/V	mV/V	%	%	
40	0.300156	0.300391	0.0052	0.1756	0.45
80	0.600300	0.600542	0.0048	0.1750	0.23
120	0.900447	0.900662	0.0046	0.1769	0.13
160	1.200627	1.200814	0.0046	0.1714	0.09
200	1.500810	1.500954	0.0047	0.1756	0.05

Uncertainty U6 includes an allowance of 0.044 % for bending calculated from the double load tests. The non-symmetrical characteristics of this transducer with regard to bending produces an E_n ratio of greater than unity.

Table 3. Transducer C – Uncertainties and E_n ratio.

Torque	NPL ref.	1.5 kN·m beam	U5	U6	E_n Ratio
N·m	mV/V	mV/V	%	%	
40	0.079233	0.079353	0.0224	0.0583	2.42
80	0.158487	0.158651	0.0155	0.0560	1.78
100	0.198107	0.198305	0.0139	0.0560	1.73
200	0.396263	0.396570	0.0092	0.0559	1.37
400	0.792683	0.793185	0.0086	0.0558	1.12
600	1.189220	1.189930	0.0081	0.0563	1.05
800	1.585857	1.586815	0.0078	0.0560	1.07
1000	1.982527	1.983753	0.0074	0.0565	1.08

Transducer C was also calibrated with a torque indicator, which displayed the transducer's output in N·m. This is typical of the instrumentation used in many industrial applications. There is an increase in the uncertainty for the lower torque values because of the reduced resolution of 1 part in 10 000 which produces an E_n ratio of less than unity. In addition to restricting the classification, which in turn allows for an increase in the uncertainty of the applied torque, the reduction in resolution masks the effect of the increase in sensitivity produced by the unsupported beam for the range 2 % - 20 %.

4.7 Classification to Din 51309

Working to DIN 51309 transducer A achieves Class 0,05 classification on all but interpolation at the 2 % reading.

Table 4. Classification of transducer A unsupported beam calibration to DIN 51309.

Torque	Class					
N·m	Repeata-bility error	Reprodu-cibility error	Error of zero signal	Reversib-ility error	Interpol-ation (2nd degree)	Interpol-ation (3rd degree)
0			0.05			
30	0.05	0.05		0.05	0.1	0.1
75	0.05	0.05		0.05	0.05	0.05
150	0.05	0.05		0.05	0.05	0.05
300	0.05	0.05		0.05	0.05	0.05
600	0.05	0.05		0.05	0.05	0.05
900	0.05	0.05		0.05	0.05	0.05
1200	0.05	0.05		0.05	0.05	0.05
1500	0.05	0.05		0.05	0.05	0.05

Including the uncertainty of the unsupported calibration beam the calibration achieves an overall classification of 0.1 in the range 2 % to 100 %. Transducer B achieves a 0.1 overall classification in the range 20 % - 100 % using the 1.5 kN·m beam and a 0.2 overall classification in the range 20 % - 100 % using the 500 N·m beam. Transducer C achieves a 0.1 classification in the range 4 % to 100 % of scale.

5. CONCLUSION

The work demonstrates that an unsupported beam can be used to calibrate a transducer to the highest levels of classification under certain conditions. The best transducer was within 0.02 % of the reference value between 20 % and 100 % of the range. A simple bending test in conjunction with such a calibration was used to determine the susceptibility of each transducer to bending moments, and to provide a bending contribution in the overall measurement uncertainty calculation. Including this bending parameter, the E_n ratios for the calibrations showed quite good agreement.

The worst affected region is in the range from 0 % to 20 % where the weight of the beam is most significant in relation to the torque being measured.

The geometry of the transducer is an important factor to consider when using unsupported beams. The research shows that much depends on the design of the transducer under test. It is best practice to use a beam with a capacity that is commensurate with the transducer being calibrated. The distance between the beam and transducer should be minimised and alignment should be considered. It is also important to calibrate transducers in a symmetric manner to minimise the influences from bending.

Unsupported beams are flexible and easy to use, and in many instances replicate the way a transducer is subsequently used. They are well suited for the calibration of the many forms of torque measuring device found in general use in industry up to 1.5 kN·m capacity. Any bending and sensitivity effects should be allowed for within the calibration uncertainty budget - with these factors taken into consideration, it is possible to perform fit-for-purpose calibrations, to high levels of accuracy over the whole of a transducer's range.

REFERENCES

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[2] DIN 51309 February 1998. Materials testing machines Calibration of static torque measuring devices.