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PROTOTYPE OF LOAD CELL APPLICATION IN TORQE MEASUREMENT

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Abstract –Torque laboratory of National Institute of Metrology Thailand has designed and developed the prototype of torque transfer wrench and torque wrench calibrator by using load cell as main device in order to provide low cost torque transfer standard. Loading point of load cell was designed to directly connect to torque measurement axle. Moreover, loading point and base of load cell were supported by elastic part acting as flexure bearing. Torque standard machine and commercial torque transfer wrench were used to compare torque measured by the prototypes, torque transfer wrench and torque wrench calibrator respectively. Simulation from finite element analysis confirms that the design can be used as torque measuring device. Metrological properties are investigated according to standard DKD 3-7 and DKD 3-8. The experiment and calibration result shows that uncertainty is within ±0.08% for torque transfer wrench and within ±0.3% for torque wrench calibrator.

Keywords : Torque wrench calibrator, Torque transfer wrench, load cell

1. INTRODUCTION

Force measurement and torque measurement, both are mass related quantity. Although both measurements seem to be the same field, in fact measurand and influence quantities of both measurements are different. Force measuring instrument, load cell, is designed to measure perpendicular load acting on the loading point of load cell. Eccentric loading, the load acting out of the loading point, causes moment on the load cell, and this moment is the influence quantity of force measurement. Torque measuring device is designed to measure torque around measurement axis under the condition that no force is acting on the axis or constant force is acting on the axis. This force or fluctuation of force is the influence quantity of torque measurement.

Because of the significantly higher cost of torque measuring device than one of load cell, this study is intended to use load cell as a major instrument to build torque measuring device that has characteristics consistent with DKD R 3-7 standard for torque transfer wrench[1] and DKD R 3-8 standard for torque wrench calibrator[2].

2. TORQUE TRANSDUCER DESIGN

Three models of torque measuring devices, Model A Model B and Model C, were designed and built. Model A is torque wrench calibrator while Model B and C are torque transfer wrench. The working principles of all three models are similar. Load cell is used to measure force F, which is the result of torque moment T, acting on loading point of the load cell at the distance r from the rotation axis as in the working principle schematic in figure 1. The pivot is made from elastic part working as flexure bearing. Capacity of load cell can be calculated from fundamental equation as in (1).

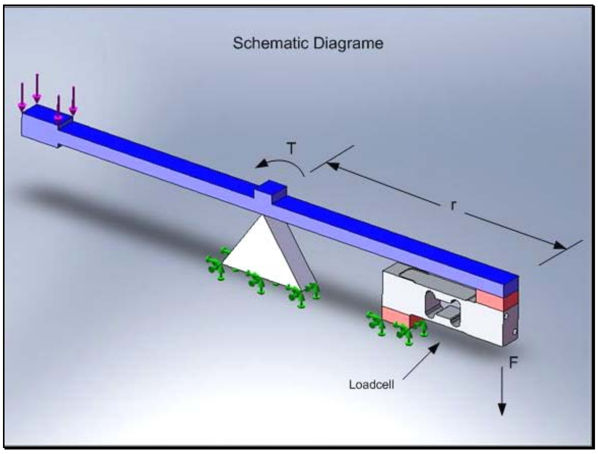

Fig. 1. Working principle schematic.

$$T = F \cdot r$$

where T is torque moment
F is load acting on load cell
r is distance from pivot to the loading point of load cell

In the real design, length of load cell is a part of the lever. Thus, another elastic part besides pivot was also added between base and load cell in order to more clearly define the lever distance from center of pivot to the center of another elastic part. In this research, all three models of the devices used the same load cell model and capacity in order to be comparable. Single-point typed load cells made from anodized aluminium by Tedea-Huntleigh model: 1042, rate capacity: 50 kg, rate output signal: 2 mV/V, are used in this study.

Torque wrench calibrator model A was designed to use flexure bearing made of aluminium and installed in the position that makes load acting perpendicularly to the line of flexure bearing installation as in figure 2 (or flexure bearing under compressive stress).

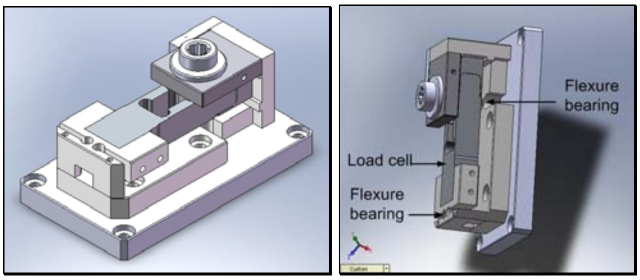

Fig. 2. Torque wrench calibrator model A.

Model A was modified to torque transfer wrench model B by lengthening the base enough to be the lever of wrench as in figure 3. This modification causes the line of cross force parallel to the line of flexure bearing installation (or flexure bearing under shear stress). In model B, flexure bearing was still made from 2 mm×10 mm aluminium, while steel grade DC53 was used for torque transfer wrench model C to make bearing more robust. Besides material of bearing, the major change in model C is that the line of flexure bearing installation is perpendicular to the line of loading as illustrated in figure 4.

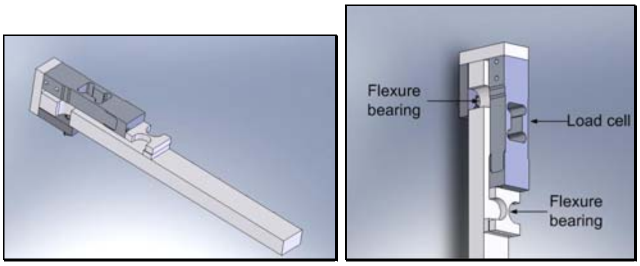

Fig. 3. Torque transfer wrench model B.

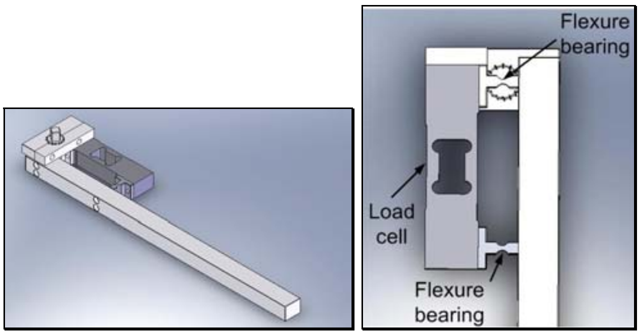

Fig. 4. Torque transfer wrench model C.

3. FINITE ELEMENT ANALYSIS

To confirm the designs, commercial finite element program, COSMOSWorks®, was used to analyze the design, Figure 5 shows stress result of torque transducers model A, B, and C. The stress of load cell was used as an output signal of torque measurement.

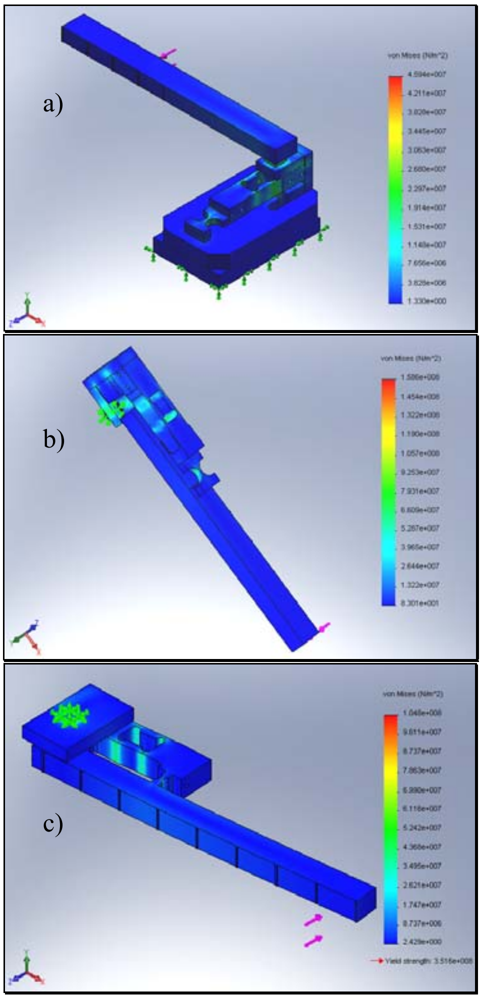

Fig. 5 Stress analysis from finite element of torque transducer a) Model A, b) Model B, c) Model C

For torque wrench calibrator model A, base of transducer was restrained. Normal force was applied on the simulated wrench, which is connected to the measurement axis in order to simulate torque around the axis. However, in torque transfer wrench model B and C, measurement axis were restrained. Input torque is generated from the load acting on the lever of the wrench. Magnitude of load and position of load acting on the lever were varied to determine non-linearity and varied cross force error as shown in figure 6.

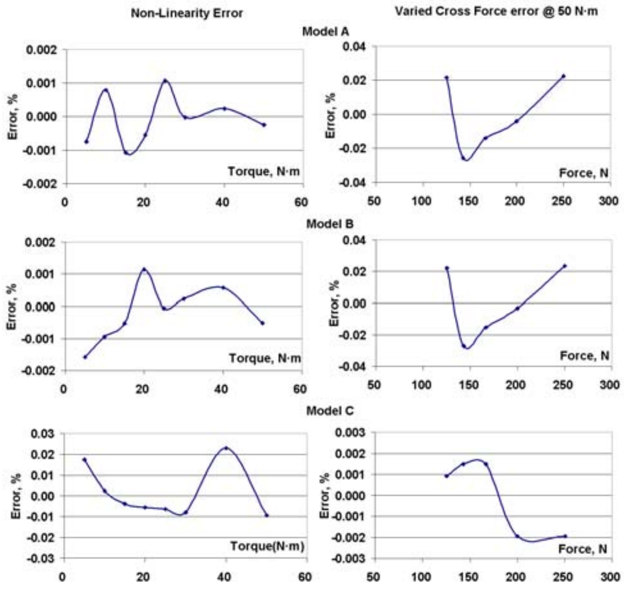

Fig. 6. Non-linearity and varied cross force error

The errors of three models are under 0.1%, which is consistent with DKD R 3-7 and DKD R 3-8 standard. Model C gave the lowest error. This could be the result from different material of elastic part. Steel was used as bearing in model C, so it can support cross force better than aluminium bearing.

4. EXPERIMENTAL RESULT

Figure 6 shows the fabricated torque as the model designed in this research.

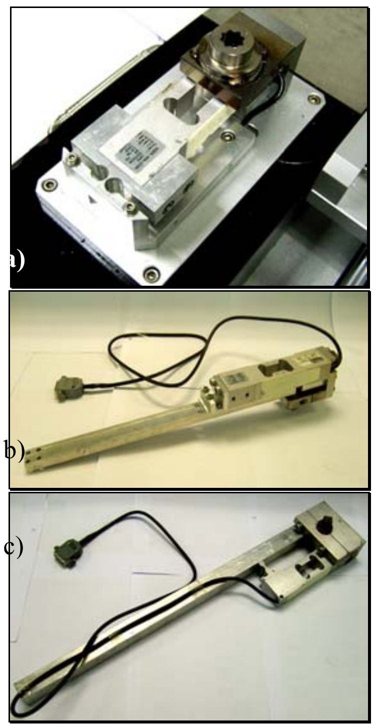

Fig. 6. Fabricated torque transducer
a) Model A, b) Model B, c) Model C

The preliminary study started from study of effect of flexure bearing, zero drift, full load drift and hysteresis of load cell and torque standard as shown in figure 7. This test shows that flexure bearing is the factor increasing creep and stress relaxation of all three models of torque measuring devices.

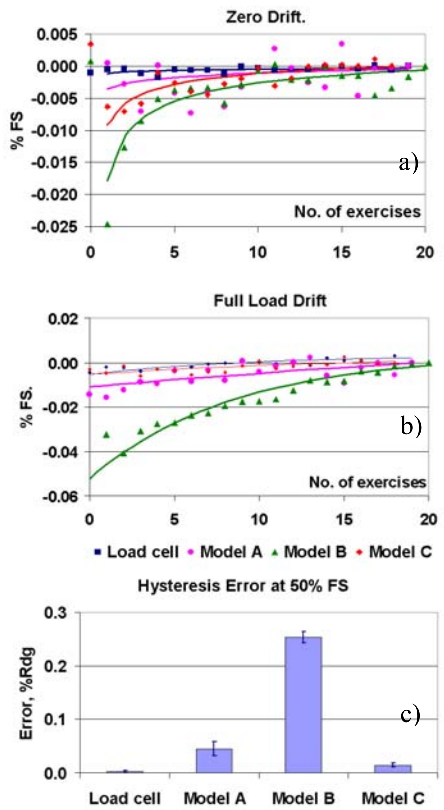

Fig. 7. a) Zero drift, b) Full load drift, c) Hysteresis error

After preliminary test, torque wrench calibrator model A was calibrated according to DKD R 3-8 by using commercial torque transfer wrench as calibration standard with uncertainty $(2\sigma) \pm 0.2\%$ and torque transfer wrench model B and C, were calibrated according to DKD R 3-7 by torque standard machine as calibration standard with uncertainty $(2\sigma) \pm 0.03\%$. The calibration results of transducers model A,B and C are shown in figure 8,9, and 10 respectively.

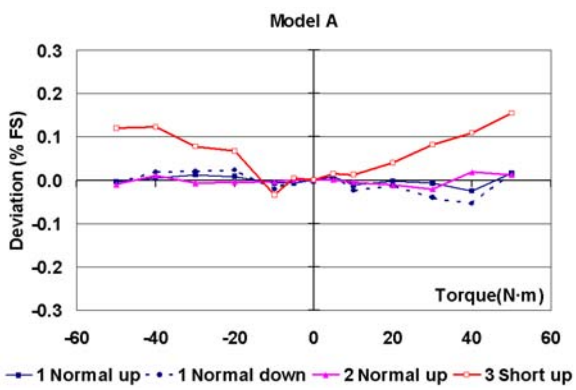

Fig. 8. Calibration result of transducer model A.

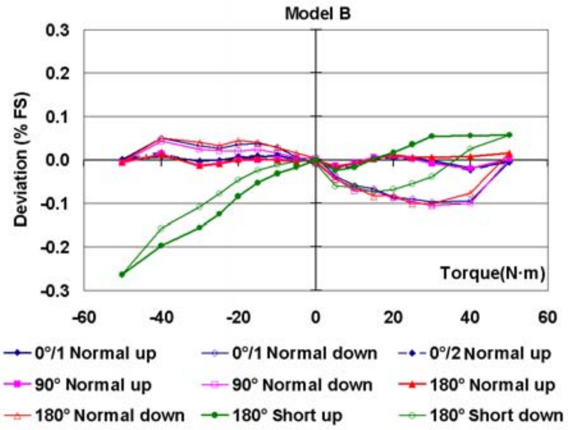

Fig. 8. Calibration result of transducer model B.

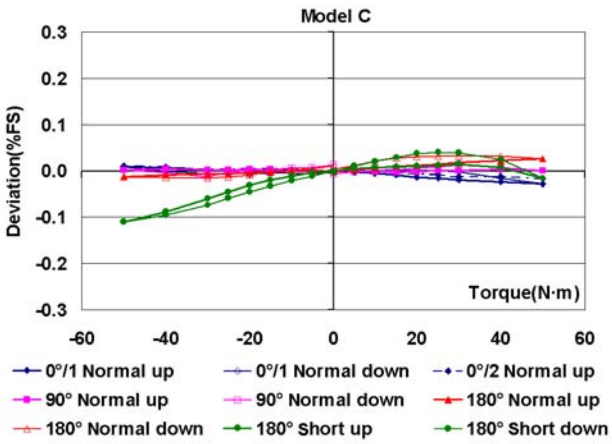

Fig. 8. Calibration result of transducer model C.

Metrological properties according to DKD standard, repeatability b', reproducibility due to mounting position b, reproducibility due to varied cross force b_l, zero error f_0, hysteresis error h, and interpolation error f_a, were calculated and shown in table 1,2, and 3.

Table 1. Metrological properties of transducer Model A.

Mk N·m	b'/X %	b_l/X %	f_0/X_E %	h/X %	f_a/X %
50	0.00	-0.14		-	0.01
40	0.05	-0.17		0.04	0.00
30	0.02	-0.17		0.06	-0.02
20	0.02	-0.13		0.02	-0.02
10	0.03	-0.13		0.05	-0.04
5	0.07	-0.14		0.07	0.04
0			0.00		
0			-0.01		
-5	-0.07	0.12		-0.09	0.03
-10	-0.02	-0.15		-0.07	0.02
-20	-0.04	0.18		-0.04	0.00
-30	-0.03	0.14		-0.01	0.00
-40	-0.01	0.15		-0.02	-0.01
-50	-0.01	0.13		-	0.01

Table 2. Metrological properties of transducer Model B.

Mk N·m	b'/X %	b/X %	b_l/X %	f_0/X_E %	h/X %	f_a/X %
50	0.002	0.010	-0.043		-	0.135
40	0.007	0.020	-0.061		0.085	0.020
30	0.002	0.012	-0.081		0.164	-0.089
25	0.008	0.005	-0.059		0.195	-0.144
20	0.018	0.005	-0.008		0.235	-0.197
15	0.017	0.010	-0.003		0.261	-0.286
10	0.023	0.004	0.038		0.264	-0.433
5	0.032	0.015	0.084		0.291	-0.621
0	0.000	0.000	0.000	0.010		
0	0.000	0.000	0.000	-0.011		
-5	-0.032	-0.021	-0.133		-0.112	0.694
-10	-0.002	-0.030	-0.152		-0.104	0.550
-15	-0.008	-0.012	-0.192		-0.101	0.444
-20	-0.004	-0.008	-0.210		-0.081	0.342
-25	0.000	-0.010	-0.232		-0.072	0.256
-30	-0.006	-0.011	-0.237		-0.070	0.159
-40	-0.011	-0.004	-0.261		-0.046	-0.057
-50	-0.001	-0.004	-0.259		-	-0.210

Table 3. Metrological properties of transducer Model C.

Mk N·m	b'/X %	b/X %	b_l/X %	f_0/X_E %	h/X %	f_a/X %
50	0.010	0.027	0.041		-	0.068
40	0.014	0.030	0.020		0.013	0.011
30	0.012	0.032	0.007		0.028	-0.048
25	0.015	0.030	0.004		0.036	-0.078
20	0.018	0.033	0.004		0.042	-0.109
15	0.015	0.034	0.008		0.043	-0.135
10	0.012	0.031	-0.004		0.042	-0.166
5	0.019	0.021	-0.022		0.050	-0.192
0	0.000	0.000	0.000	0.006		
0	0.000	0.000	0.000	-0.013		
-5	-0.031	-0.016	-0.050		-0.064	0.129
-10	-0.015	-0.003	-0.057		-0.028	0.099
-15	-0.009	-0.007	-0.059		-0.017	0.078
-20	-0.007	-0.009	-0.067		-0.018	0.060
-25	-0.006	-0.008	-0.079		-0.016	0.044
-30	-0.004	-0.008	-0.088		-0.018	0.026
-40	-0.003	-0.010	-0.100		-0.009	-0.010
-50	-0.002	-0.011	-0.097		-	-0.036

According to the result, these in-house manufactured torque measuring instruments can be classified as follows. Model A: Class 1, Model B: Class 0.5 , Model C: Class 0.2 with expanded uncertainty (2σ) ±0.30% (linear fitting function), 0.20± % (cubic fitting function), and ±0.08% (cubic fitting function) respectively.

5. CONCLUSION

Load cell can be applied as torque measurement instrument in this research. Creep stress relaxation and hysteresis error of torque standard depends on the property of load cell and flexure bearing. Magnitude of varied cross force error depends on the line of flexure bearing installation and its material. The installation line that is perpendicular to the cross force gives lower varied cross force error. Besides lower cost than any commercial torque standard, these models' metrological properties conforms with DKD R 3-7 and DKD R 3-8 with measurement uncertainty $(2\sigma)\pm0.3\%$,±0.2% , ±0.08% for model A, model B, and model C respectively. Another advantage of building torque standard by load cell is we can set protection level to be IP 67 or IP 68 by selecting load cell as required IP protection, which is hard to find in commercial torque measuring device at this time.

REFERENCES

[1] DKD-R 3-7, "Static calibration of reference torque wrenches", October 2003
[2] DKD-R 3-8, "Static calibration of torque wrench calibration devices", October 2003