DESIGN AND TRIAL -FABRICATION OF TORQUE TRANSDUCER, SOME RESULTS

Ngo Nhu Khoa*
College of Technology - TNU

SUMMARY

This article presents some results obtained from design and trial fabrication of torque transducer based on the principle of measuring the deformation of a shaft as torque applied by the strain gauges attached to the shaft. The article also systematically presents the theoretical basis for torsional shaft - designing problems, specification in choosing strain gauge, experimental design; conducting and calibrating methods to construct the characteristics of torque transducer after fabricating.

Keyword: *torque transducer, torque sensor, strain gauge, measuring torque*

INTRODUCTION

Measuring torque is often something that's misunderstood, which can lead to over or under designing of measurement systems. To measure torques in these applications, static torque measuring devices are of interest. There are a lot of commercial torque measuring products available in the world. However, to buy measuring devices as those mentioned in Vietnam is troublesome. With the limited domestic condition, there is still no industrial establishment producing or manufacturing the measuring devices in the form of hand tools.

Structures of torque sensors

Torque transducers with solid circular shafts and with gauges at 45º to the centerline have been being used for many applications. However, this structure is not generally used where precision is important. Hollow circular shaft construction permits increased bending strength. Another structure of interest is the cruciform which will produce high stress or strain values at low values of torque. The cruciform has good bending strength but is difficult to predict because of the fillet effect on torsional stress and stiffness. The modified form of cruciform, which is hollow cruciform, eliminates the fillet effect of the cruciform and produces the 4 bar torsion frame. Thus, it is extensively used for low capacity torque transducer. The square section used for high-capacity transducers has several advantages over its circular counterpart for torque measurements. One of these is the ease with which gauges can be placed on the shaft. Another is increased bending strength when compared to a round shaft. Following is a drawing (Fig 1) showing, in general, structures in use as torque transducers [2].

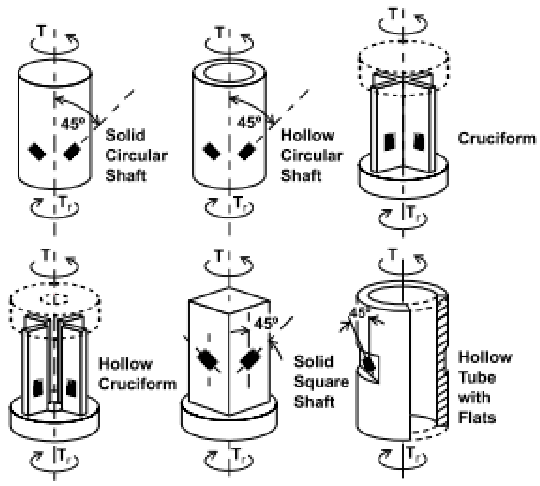


Fig 1. *Typical sections of torque sensor shaft [2].*

In this paper, we focus on a practical torque measurement method based on the deformation of the shaft. The simple model - hollow circular shaft is used.

TORQUE TRANSDUCER DESIGN

Design of the Shaft

* *Tel: 0963 887888*

The strain gauges have been used to measure the stress/strain induced in the torque transducer when the external torque is applied. The shaft is mechanically required to behave like a very stiff, high precision spring while having a surface area large enough for the mounting of strain gauges. When selecting material to be the shaft, its mechanical and thermal properties are both considered, as well as the practicality of manufacturing a spring from this material.

In the present work, a torque transducer of capacity 200 Nm has been studied, then the shaft made of **18Mn2Si steel**, with properties: Young modulus $\boldsymbol{E}$ = 200 GPa; Shear modulus, $\boldsymbol{G}$ = 80 GPA; Ultimate stress $\boldsymbol{\sigma_U}$ = 600MPa; Poisson's Ratio $\boldsymbol{\mu}$ = 0.3.

Design of the shaft involves determining the dimensions and checking the shear stress induced by applied torque. The drawing and dimensions of the shaft are shown in Fig 2.

Analytically, the max shear stress induced in the torque transducer is 35.57 MPa, and the normal strain induced is 3.3×10^{-4}due to a 200 Nm torque applied.

Selection of the Strain Gauge

The strain gauge itself must also be selected and installed with care. There are a lot of strain gauge types in the market world. However, it's not really available in the domestic and the pricing is especially high when ordering from foreign trade companies. In the present work, a couple of Uniaxial 45°, strain gauges Z23-MA-2-350-11 are used. Dimension base: length x width = 13x7; GF = 2.06±2% and Resistor = 350 Ohm [7].

Selection of the Adhesive

This step in torque transducer assembly is extremely important. The bond between the strain gauge and the shaft must be rigid and strong enough to completely transmit strain to the gauge over the operating temperature range. The adhesive should also be easy to prepare and apply. Some of the adhesives available are cyanoacrylate adhesive, epoxy adhesives, and high-performance adhesives [4]. Cyanoacrylate adhesives are easy to prepare and apply but sensitive to moisture, thus, reduces its life to only some months. However, the moisture has very little effect to this application, so this adhesive could be suitable for the work.

In the present work, the Extra 4000 adhesive is selected. Instant Adhesive E4000 is particularly suited for bonding porous materials such as wood, cork, paper, leather or fabric. Temperature resistance values, °C - 54 to 82; Shear strength, psi 3000 to 3700 [8].

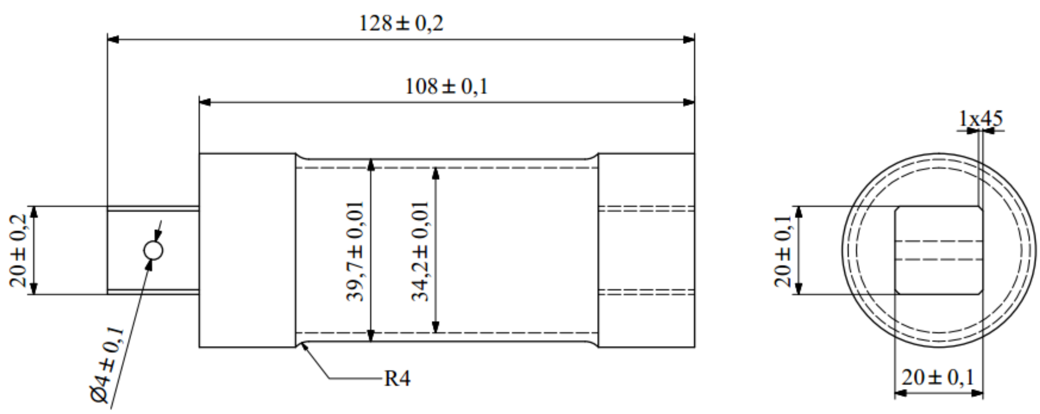


Fig 2. *Dimensional model of torque sensor [3]*

Assembling the torque transducer

The surface is properly cleaned and has to be dirt free for effective fixing of the strain gauge.

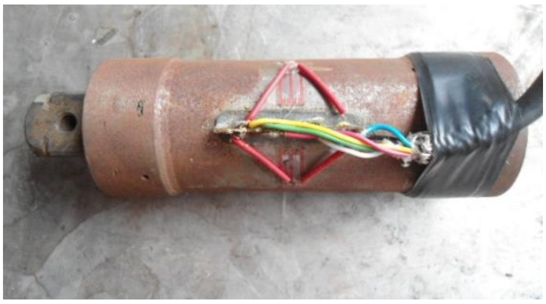


Fig 3. *The Torque transducer*

Strain gauges are located in the shaft by using a special tape. First, glue is applied to one surface with one drop of glue for one inch square. Then, the surfaces are fastened together in 35 to 50 seconds. It takes 24 hours to finish the post curing stage of the assembly process at room temperature. The connections are constructed according to the Full Wheatstone bridge configuration.

EXPERIMENTAL SETUP

The experimental setup is shown in Figure 4. Where:

- Torsional moment is induced by a torque device (Figure 5); Torque range from 0 to 1000Nm (manual control with rotation speed 0.6 rpm to 1 rpm). The magnitude of torsional moment applied to the shaft is determined by the numerical visual display DC Strain gauge tranducer, Model 3570 [1]. The torque device is calibrated by a torsional response, with displayed voltage: V_{out} = 0.0026*M_z.

- The modul Wide Bandwidth Strain Gauge Input, Model 3B18 of Analog Drive [6] has been used for the strain gauge amplifier (K_B); with standard Range ±30 mV (3 mV/V sensitivity at V_{EX} = +10V) and ±10 mV (3 mV/V sensitivity atV_{EX} = +3.33 V).

- An Arduino UNO Rev 3 embedded microprocessor [5] programmed for the work serves as a controller for the digital panel indicator using a 7 segment led display.

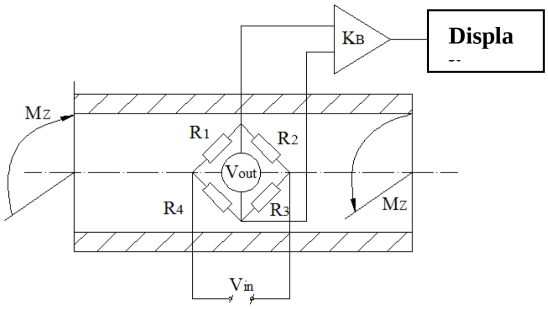


Figure 4. *Experimental setup diagram*

Figure 5. *Torque device*

RESULT AND ANALYSIS

Calibration Factor (CF)

The digital panel indicator gives an output display on its screen in millivolts (**V_D** in mV). Then, the output voltage of the bridge of strain gauges used in a bridge configuration with voltage excitation of 10V is determined as:

$$V_o = \frac{V_D}{K_B} \ (mV) \qquad (1)$$

Where,

- V_D is the voltage displayed on the digital panel indicator;
- V_O is output voltage of the bridge;
- K_B = 400 is amplifier gain of the Strain Gauge Input, Model 3B18.

Then

$$\frac{V_O}{V_{EX}} = \frac{\Delta R}{R} = GF * \varepsilon \qquad (2)$$

Here,

- V_{EX} = 10V is excitation voltage;
- R = 350 Ohm is resistance of gauge;
- ΔR is the resistancechange of gauge.
- ε is the normal strain at the surface of the torque shaft as torque is applied.

The Strain gauge tranducer 3570 gives an output display on its screen in millivolts (V_{out}

in mV). And the calibration factor (CF) had been calibrated before: $\boldsymbol{M_z} = \mathbf{0.0026}/\boldsymbol{V_{out}}$. Then, the torque can be determined from these results.

The normal strains at the surface of the torque shaft conducted from the experiments are shown in the Table 1 [3].

Then, by MS excel, slope of torque -strain curve in Graph 1 is determined. We get:

$$M_z = 893919*\varepsilon \quad (3)$$

Equation (3) shows the relationship between torsional moment and torsional deformation of material fabricating to be the shaft. The elastic modulus E = 200GPa is normally used for steels, however, in fact, each material has its own elastic modulus value. Thus, the experiment to build up the moment – deformation relationship for $18Mn_2Si$ steel allows the redefine of actual elastic modulus of this steel.

$$E = \frac{893919(1+\mu)}{W_P}$$

$$E = \frac{893919(1+0.3)}{5516.76E-9} = 210.65\ GPa$$

The values of true Young modulus of the shaft material (E) are calculated and listed in Table 2. Again, by MS excel, slope of output voltage – torque is calculated. This slope value is considered as the calibration factor (CF):

$$V_D = 2.0E\text{-}5*\boldsymbol{Torque}\ (\text{mV}) \quad (4)$$

Equation (4) can be used to develop a program for the digital panel indicator, so that it can be suitably calibrated to give an output display on its screen (N-m). Then, the value of the torque measured by the transducer can be displayed directly on the screen of the digital panel indicator.

Table 1. *Normal strains of the torque shaft*

Torque (N-m)	***ε***	***Torque (N-m)***	***ε***
4,60	5,18495E-06	85,44	0,000102852
5,36	6,26068E-06	106,13	0,000115655
13,79	1,5534E-05	113,79	0,000122779
19,16	2,3483E-05	115,33	0,000134527
33,72	4,05704E-05	115,71	0,00013559
34,10	4,12743E-05	133,33	0,00014698
43,68	5,08859E-05	143,68	0,00016228
53,26	6,08495E-05	150,96	0,00016869
53,64	6,43204E-05	157,09	0,00017165
59,00	7,25971E-05	163,60	0,00018069
81,23	8,79005E-05	169,35	0,00018576
84,29	0,000102852	177,78	0,00019176

CONCLUSIONS

The present work demonstrates in detail the design and implements studies of torque transducers with capacities up to 200 Nm. It also points out the role of calibration in the design of the torque transducers.

The true values of the Young modulus of the shaft material determined are close to these values of general material.

The experiments proved that the glue and the bonding method used execute a good result.

The modul Signal Conditioning I/O 3B18 used as a strain gauge amplifier showed a low-cost, versatile method of transferring analog transducer signals to a data acquisition, monitoring or controling systemwithout inherent noise, non-linearity, drift and extraneous voltages.

The metrological characterization of the torque transducer yielded good results in terms of its low uncertainty, which is ± 0.46% (at $K_B = 400$).

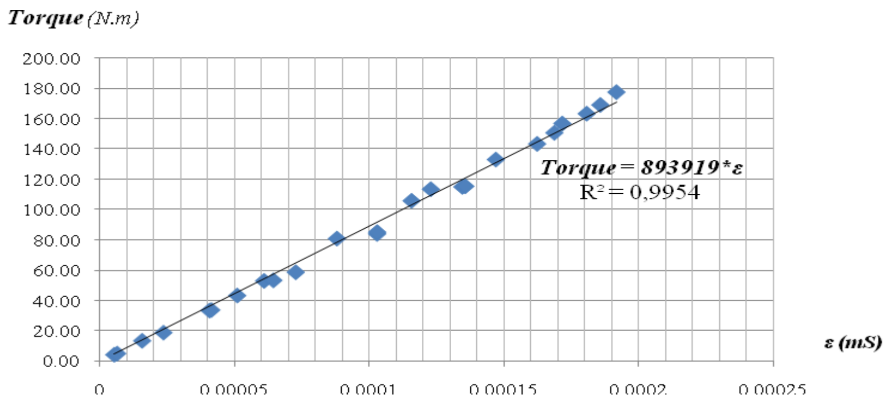
Further work is progressing on developing the torque transducers of other nominal capacities and will be reported in the near future.

Acknowledgement

The works described in this paper was supported by Thai Nguyen university of Technology for a research project. Also, author expresses thanks to Mr. Nguyen Huu Quan, Ms. Nguyen Thu Huong for helping in implementing these experiments.

Table 2. *Torque - Output Voltage of torque transducer system data set [3]*

Torque (N.m)	V_o (mV)	Torque (N.m)	V_o (mV)	Torque (N.m)	V_o (mV)	Torque (N.m)	V_o (mV)
1	2,30444E-05	31	0,000714376	61	0,00140571	91	0,002097038
2	4,60888E-05	32	0,00073742	62	0,00142875	92	0,002120083
3	6,91331E-05	33	0,000760464	63	0,0014518	93	0,002143127
4	9,21775E-05	34	0,000783509	64	0,00147484	94	0,002166172
5	0,000115222	35	0,000806553	65	0,00149788	95	0,002189216
6	0,000138266	36	0,000829598	66	0,00152093	96	0,00221226
7	0,000161311	37	0,000852642	67	0,00154397	97	0,002235305
8	0,000184355	38	0,000875686	68	0,00156702	98	0,002258349
9	0,000207399	39	0,000898731	69	0,00159006	99	0,002281393
10	0,000230444	40	0,000921775	70	0,00161311	100	0,002304438
11	0,000253488	41	0,00094482	71	0,00163615	101	0,002327482
12	0,000276533	42	0,000967864	72	0,0016592	102	0,002350527
13	0,000299577	43	0,000990908	73	0,00168224	103	0,002373571
14	0,000322621	44	0,001013953	74	0,00170528	104	0,002396615
15	0,000345666	45	0,001036997	75	0,00172833	105	0,00241966
16	0,00036871	46	0,001060041	76	0,00175137	106	0,002442704
17	0,000391754	47	0,001083086	77	0,00177442	107	0,002465748
18	0,000414799	48	0,00110613	78	0,00179746	108	0,002488793
19	0,000437843	49	0,001129175	79	0,00182051	109	0,002511837
20	0,000460888	50	0,001152219	80	0,00184355	110	0,002534882
21	0,000483932	51	0,001175263	81	0,00186659	111	0,002557926
22	0,000506976	52	0,001198308	82	0,00188964	112	0,00258097
23	0,000530021	53	0,001221352	83	0,00191268	113	0,002604015
24	0,000553065	54	0,001244396	84	0,00193573	114	0,002627059
25	0,000576109	55	0,001267441	85	0,00195877	115	0,002650103
26	0,000599154	56	0,001290485	86	0,00198182	116	0,002673148
27	0,000622198	57	0,00131353	87	0,00200486	117	0,002696192
28	0,000645243	58	0,001336574	88	0,00202791	118	0,002719237
29	0,000668287	59	0,001359618	89	0,00205095	119	0,002742281
30	0,000691331	60	0,001382663	90	0,00207399	120	0,002765325



Graph 1. *Torque - Normal strain of the shaft [3]*

REFERENCES

1. Daytronic Corporation, 1997. 3500 Instrument series instruction manual.
2. Lebow Products. Load, Force, Reaction torque, Rotation torque, Wireless elemental torque instrumentation. Full Line Catalog, 15th Edition, 2006.
3. Nguyen Huu Quan, 2014. Design, Fabrication a hand torque transducer. Master thesis, In Vietnamese.
4. Lackof.org/chico/papers/TechContribs
5. http://www.arduino.cc
6. http://www.analog.com
7. http://www.showa-sokki.co.jp
8. http://www.permatex.com

TÓM TẮT

MỘT SỐ KẾT QUẢ TRONG VIỆC CHẾ TẠO TRỤC MẪU ĐO MOMEN XOẮN

Ngô Như Khoa*

Trường Đại học Kỹ thuật Công nghiệp – ĐH Thái Nguyên

Bài báo trình bày một số kết quả đạt được trong việc tính toán và chế tạo trục mẫu đo momen xoắn dựa trên nguyên lý đo biến dạng trục mẫu chịu xoắn nhờ các tấm biến dạng - điện trở được dán trên trục. Đồng thời, bài báo cũng trình bày một cách hệ thống về cơ sở lý thuyết phục vụ bài toán thiết kế trục mẫu chịu xoắn; cơ sở lựa chọn strain gauge, phương pháp đo và cân chỉnh để xây dựng đặc tuyến của thiết bị đo sau khi chế tạo.

Keywords: *momen xoắn, strain gauge,*

Ngày nhận bài:23/4/2015; Ngày phản biện:11/5/2015; Ngày duyệt đăng: 31/5/2015

Phản biện khoa học: *PGS.TS Vũ Ngọc pi – Trường Đại học Kỹ thuật Công nghiệp - ĐHTN*

* *Tel: 0963 887888*