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Thin-walled tube load cell for bolt torsion test

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Abstract. The purpose of this research is to know that thin-walled load cell can be used properly to measure the torque for high quality bolt torsion testing. The load cell made from SUS 304 tube completed with four holes was designed. It was developed from the previous one that using intact tube. For strain sensing in orientation at +45 degree and -45 degree, two rosette strain gages were used in the opposite position. The strain gages connected in full Wheatstone bridge configuration to a Computing Data Log-ger. Set up calibration equipment for torsion load only was built for this load cell and the result is constant 12.85 for Data Logger setting. A torque wrench was used for setting maximum load applied and load cell with Data Logger measure and counting the actual torque. For the experiment two size hexagonal zinc coated steel bolt M8 and M10 were used for testing sample. Test result shows that all samples can reach mini-mum torque load that mentioned in specification.

1. Introduction

In this research we were testing structural bolts using a set up consisting of a thin-walled tube load cell connected with a data logger to measure torque. The load cell was developed from the

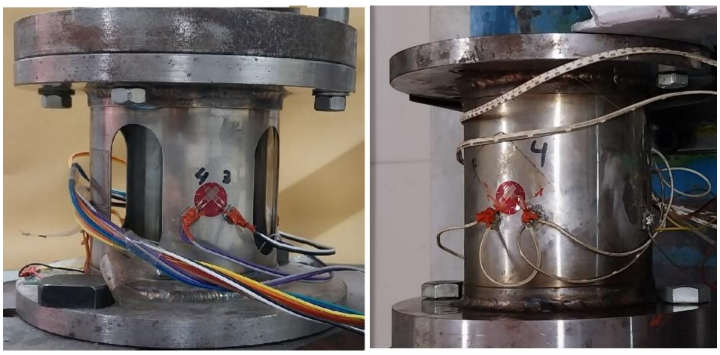

Figure 1. Thin-walled tube load cell, previous version (right) and current version with four holes.

previous version. The difference is there are four holes in symmetrical position around the wall. These holes were made to increase sensitivity for detecting longitudinal and tangential strain on the tube surface without sacrificing the load cell body strength. The previous version and current version load cell showed in Figure 1.

For load cell calibration we use a set up that can load pure torsion on the load cell. It consists of an arm, sling wire, pulley, and some dead weight to give various torsion loads.

For further research we wish to upgrade our load cell from measuring static torque to measuring dynamic torque. Though the calibrating process is the same, measuring dynamic torque is more complicated due to the transmitting signal from rotating part to the stationary part. Muftah et al did this dynamic torque measurement using V-shaped strain gauge on a rotating shaft using a slip ring to transmitted signal from rotating shaft to the stationary part achieving linearity error dan hysteresis less than 0,5 % with a torque up to 8 Nm [1].

The purpose of this research is to know that thin-walled tube load cell can be used properly to measure the torque for high quality bolt torsion testing. This research was done at Basic Phenomenon laboratory, Mechanical Engineering Department Universitas Trisakti.

2. Literature review

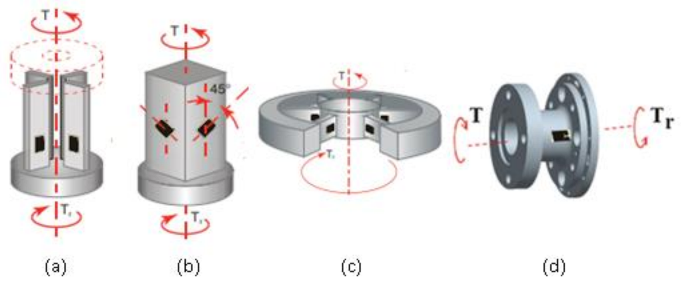

Figure 2. Various type of load cell, (d) is hollow tube load cell [2].

2.1 Loadcell

There are various types of load cell for measuring strain from torque load, some of them are shown in Figure 2 [2]. Hollow tube load cell is the type of loadcell we use in this research.

Another application of this load cell can be used on robotic joints. It requires high sensitivity in one torque component while a very low sensitivity for other components of torque and forces. Though Farhad et al uses different load cell design, which is a hollow hexaform load cell, it achieves sensitivity of 45,7 mV/Nm and torsional stiffness of 3,4 x 10^4 Nm/rad for the type B sensor and 96,5 mV/Nm and torsional stiffness of 1,5 x 10^4 Nm/rad [3].

2.2 Threaded Fastener

Threaded fasteners are commonly used to form mechanical connections in many applications, from automotive to structural steel and many others, primarily because they are inexpensive and easy to assemble and disassemble. To ensure the strength connection tightening bolts are important. There are several tightening strategies used for bolted joints in the industry, such as torque control, angle control, yield control, and stretch control. Tightening over the yield point is a relatively new method for achieving higher preloads in screwed joints, at least in the automotive industry. In the construction and railway industries, however, the so called *torque and angle method* [4,5,6] also known as turn-of-nut method or angle controlled tightening, has been in use for a quite long time.

For some special applications, angle controlled tightening strategy is used where maximum fastener strength utilization and more consistent clamp load are required [7].

Bolts/screwed joints can fail either under pre-loading due to tightening of bolt or from external loading. Pre-loading includes torsional shear stress caused by the friction of the threads, crushing of the threads, tensile stress due to stretching of bolt, etc. External forces on bolt can induces tensile stress, shear stress or both depending on how the bolt joints are connected [8]. Bolt failure under tension either by pre-loading or external loading can be reduced by increasing the threaded length [9].

In this research we focused on the shear stress due to initial loading from tightening on how much torque is applied until the bolt fractured. Although the most common fails due to fatigue, it is also noted that the low tightening torque can cause separation between the members which leads to higher cyclic stress. For static loading this phe-nomenon is negligible but worth mentioning. [10]

2.3 Bolt torsion testing

Indonesia National Standard SNI: 8458:2017 conduct method for testing high quality bolt tightening. The method is to define torque value set on torque wrench to reach minimum specific clamp forces [11].

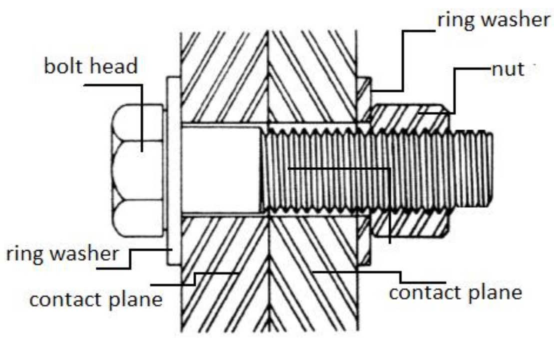

Figure 3. Bolt installation on calibration apparatus [11]

In this method, torque value comes from torque wrench setting. Bolt tightening must be continuously done without impact till reach the pre-set torque.

3. Experiments

3.1 Equipment & materials

This experiment is using own design and built thin-walled tube load cell as shown in Fig. 4. The tube material is SUS 304 with two couple rosette strain gage FCA 6-11 for measuring strain in orientation of +45 and -45 degree. The strain gages have a gage factor 2.11 with 120 Ohm resistance. This load cell was also completed with two strain gages for measuring strain in axial direction but not used in this application. These two rosettes were connected in full Wheatstone bridge circuit to Computing Data Logger.

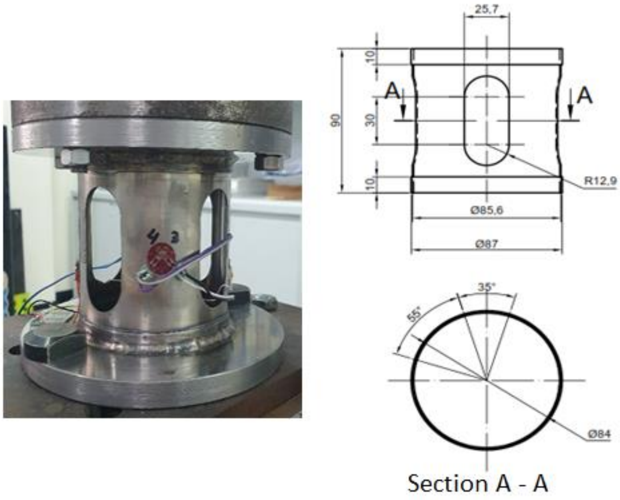

Figure 4. Thin-walled tube loadcell

The computing data logger was used for counting and recording torque from loadcell. A torque wrench was used for loading torque on bolt specimen.

Fig. 5 and Fig. 6 shows set up equipment for loadcell calibration. A digital scale is used to measure the force that is in same plane and perpendicular to moment arm. This force comes from the weight that hanging by cable sling trough a pulley. For calculation we use data from the scale.

Sample bolts are hexagon steel zinc plated ISO 4017 grade 8.8 for M8x30 and grade 5.8 for M10x20.

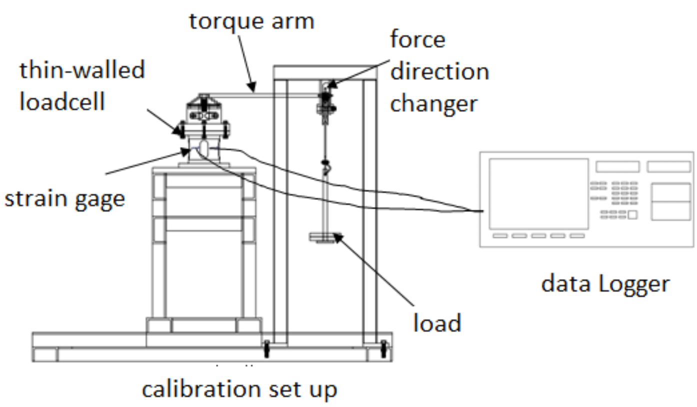

Figure 5. Calibration set up using Data Logger

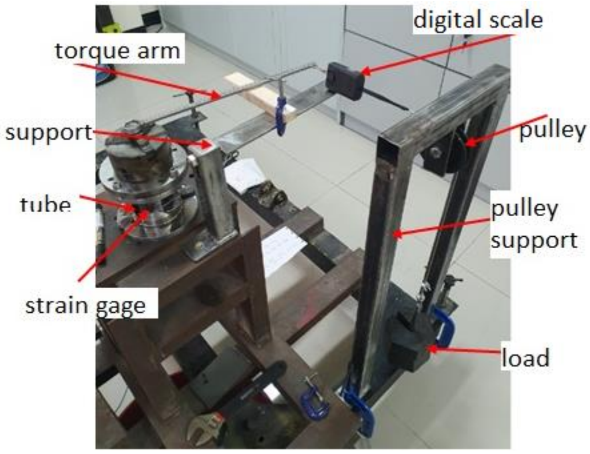

Figure 6. A photograph of loadcell calibration set up from above.

Sample bolts are hexagon steel zinc plated ISO 4017 grade 8.8 for M8x30 and grade 5.8 for M10x20.

3.2 Experimental method

The step by step of the experiment method is shown in Fig 7.

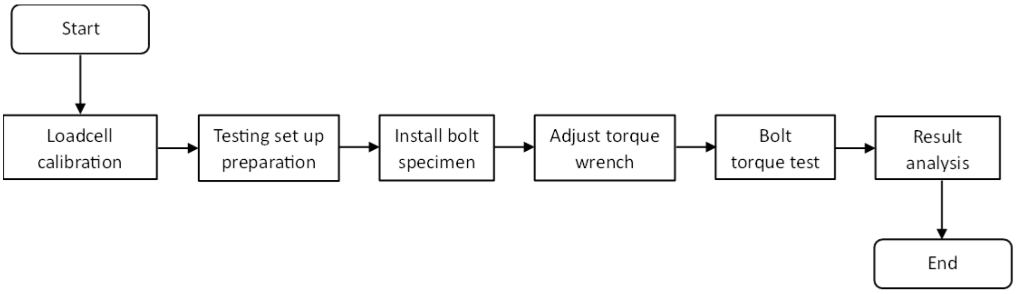

Figure 7. Step by step in experiment

Set up equipment for bolt testing is shown in Fig 8. The sample bolt positioned with head on top, between head and nut there are two pieces steel plate. The nut was clamped with chuck that connected to load cell flange.

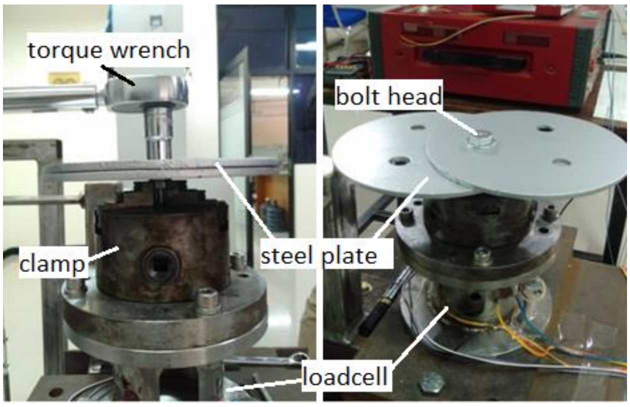

Figure 8. Set up for bolt torsion testing, position before wrench applied (right photo).

Figure 9. Torque load direction (left photo) and collecting data with data logger.

Torque direction and data collecting with computing data logger are shown in Fig. 9. The testing conducts on steel bolts M8x30 and M10x20.

4. Result and discussion

4.1 Calibration result

The result of calibration presented on Table 1

Data from Table 1 becomes a reference in determining constant for data Logger torque counting. The constant is 12.85 for result torque in N mm. The relationship between theoretical torque from Table 1 and Data logger Torque is shown in Fig. 10.

Table 1. Force and torque loading for calibration

Load [kg]	Force from scale		Torque
	[kg]	[N]	Nmm
0	0	0	0
1	0,98	9,61	3511,44
2	1,97	19,33	7058,71
3	2,97	29,09	10623,90
4	3,96	38,80	14171,17
5	4,95	48,51	17718,44

Fig 10 shows that theoretical torque and data logger torque are almost similar and linear with deviation less than 3 percent. This is more sensitive than using hub sprocket type [12] especially for low and precision applications. So, the equipment is ready for bolt torsion testing.

4.2 Torsion testing

For each bolt M8 and M10 we use three samples. Torque applied gradually increase till bolt weakened due to torque overloading.

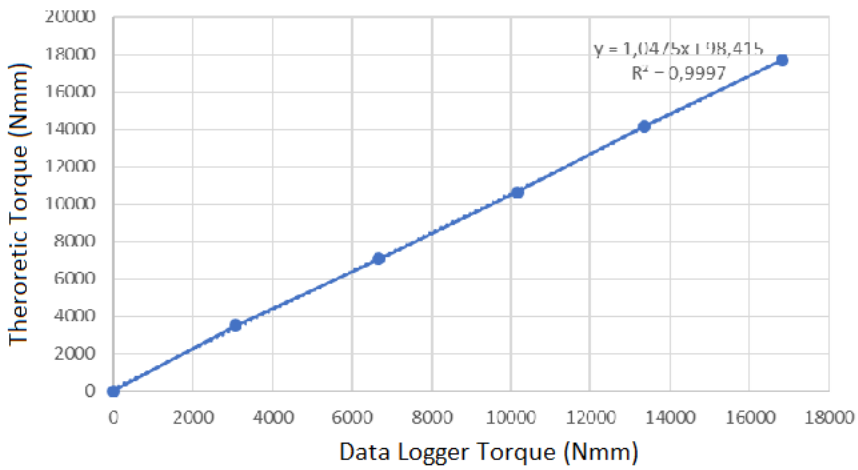

Figure 10. Graph from theoretical torque vs Data Logger torque.

The testing results for bolt M8 and M10 are shown in Table 2.

From Table 2, the lowest maximum torque for bolt M8 is 31,09 Nm. It's higher than torque on specification for grade 8.8 i.e., 28.8 Nm. For M10 the lowest torsion is 43.27 Nm that is higher than specification for grade 5.8 i.e., 30.85 Nm.

The bolt condition after testing shows in Fig 11. Some samples are totally fracture and some others were still intact and not broken.

Table 2. Torsion results for bolt M8 and M10

Sample	Max torque (Nm)	t_{max} (MPa)
M8		
1	31,09	407
2	36,87	483
3	33,79	442
average	33,92	444
M10		
1	46,26	293
2	43,27	274
3	43,27	274
average	44,26	280

Figure 11. Bolt condition after testing, one at the right is condition before tested.

5. Conclusion

The thin-walled tube load cell with Computing data Logger can be satisfy for data recording bolt torque testing. Calibration was performed to ensure linearity and sensitivity of load cell for precise measurement. The calibration result shows that in the given load range 0 to 18 Nm the load cell provides accurate measurement with load deviation less than 3 %. The torque measurement for all bolt meets the specifications standard ISO 4017 grade 8.8 for M8x30 and grade 5.8 for M10x20. This demonstrates load cell's sensitivity for high quality bolt torsion testing.

6. Acknowledge

Many thanks to our mentor Dr Ir Soeharsono, MSc for providing the load cell and direction for load cell applications during research in our laboratory.

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