PAPER • OPEN ACCESS

Torque measurement issues

To cite this article: J Goszczak 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **148** 012041

Torque measurement issues

J Goszczak

Department of Vehicles and Fundamentals of Machine Design, Lodz University of Technology, Żeromskiego 116, 90-924 Łódź

E-mail: jaroslaw.goszczak@p.lodz.pl

Abstract. Problems with torque measurement in operational tests are considered. Introduction with torque definition is included. Short overview of different types of torque meters is presented. Own results and remarks about torque measurement and torque meters are quoted. Author takes into account such problems as: electromagnetic and mechanical noise (from componentry, e.g. clutches). Different ways of averaging and their results are discussed. Conclusions based on test results are included in the summary.

1. Introduction

Reliable and repeatable measurement is a crucial matter during every research and in every kind of system which operation is based on torque value. Everybody who have tried to conduct any test knows that it is usually very difficult to achieve pure test result. In the majority of cases it is mandatory to perform some result processing, e.g. hardware or software filtration or to use different statistic functions. This paper is about torque measurement, which is a very important technical parameter, necessary to determine e.g. mechanical efficiency of tested object.

Torque measurement is therefore of fundamental importance in all rotating bodies and applies to the rotation of shafts in many things like pumps, rotational cutting equipment, gearbox shafts, vehicle axles, and electric motors. Torque measurement is also a necessary part of measuring the power transmitted by rotating shafts [1].

The moment of force $\mathbf{M_O}$ about a point O is defined as a cross product of vectors **r**and **F**, where **r** is the position vector from **O** to the point of force application and **F** is the force vector [2].

$$\mathbf{M_O} = \mathbf{r} \times \mathbf{F} \qquad (1)$$

2. Different ways of torque measurement

It is not the main aim of this paper to present a detailed list and description of different types of torque meters which are available today. Nevertheless a short overview will be done. Wider description of different types of torque meters is available in [3].

In general [3], we can share torque measurement into two groups: direct and indirect measurement of the torque. Direct methods consist in measurement of some physical values (usually elastic strain) which varies according to the torque value. After calibration detector gives directly the value of torque (example of direct measurement is described in [4]). Indirect methods consist in measurement of physical values which change can be calculated into torque. It could be for example measurement of force acting on arm, which length is known or measurement of current and rotational speed of electric

motor. Often this kind of indirect torque measurement could be faster, easier and enough precisely in industrial conditions in comparison with direct methods.
Figure 1 presents the classification of torque measurements methods.

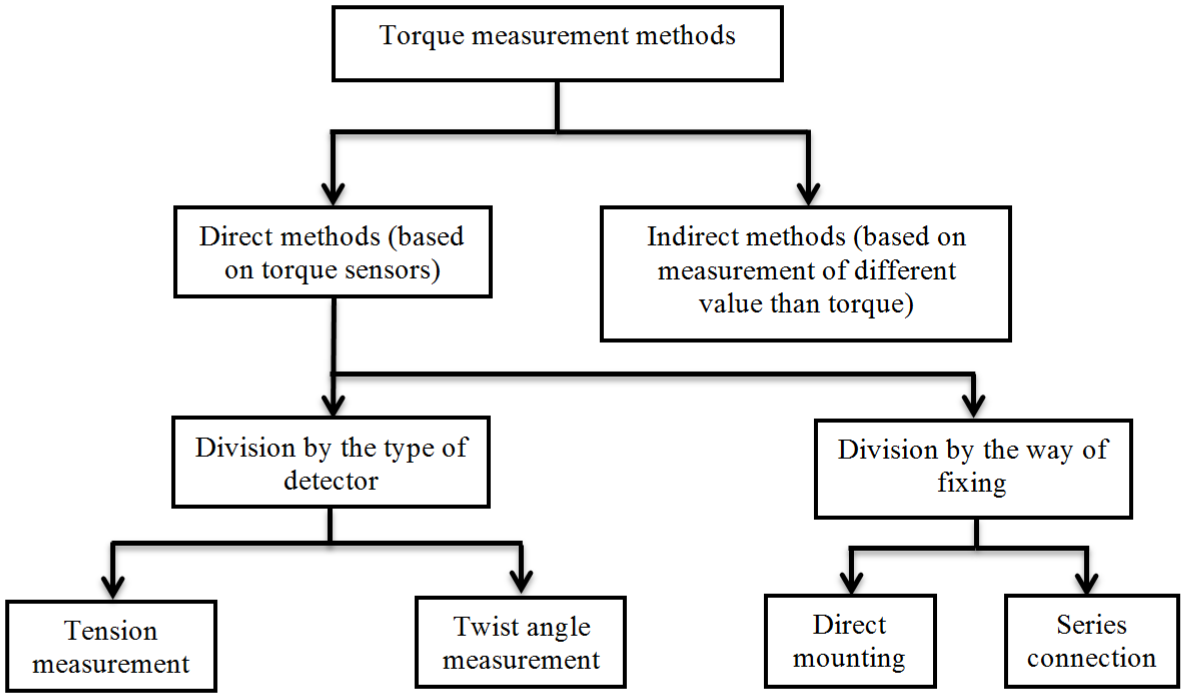

Figure 1. Classification of torque measurement methods [3].

Two ways of torque mounting can be distinguished. The first one, series connection is when the sensor transmit the whole value of torque in the mechanical circuit, i.e. that two ends of shafts are connected by torque meter. It is by far the most popular solution. The second one occurs when the sensor is mounted directly on twisted element which transmits torque (usually on the shaft). In this case it is necessary to design a non-series detector and calibrate it.

Nowadays, we can distinguish such types of torque meters:

- Strain gauges type, which based on changing of strain gauges resistance under the elongation.
- Surface Acoustic Wave (SAW)- this technology based on the sensors resonant frequency changing due to deformation.
- Magnetoelastic- in this case torque is measured by changing of magnetic permeability of ferromagnetic material.
- Piezoelectric reaction torque sensors- twisting of quartz discs positioned between metal plates cause a strain. This phenomena enable to generate electric charges on the surfaces.
- Optical- two optical elements (discs) are placed at the opposite ends of the torsional element. Due to the twisting relatively to each other, amount of light which goes through both discs changes and it is measured by detector.
- Inductive- two cores' coils are twisting relatively to each other. The change of inductance is connected with measured signal.

Figure 2 shows the classification of torque measurement sensors. You can read more about torque meters principles of operation for example in [3], [5], [6], [7], [8]. [9].
When applying directly the torque definition it is possible to design an original solution of torque sensor, for example developed in the existing machine, like in [4] or [10].

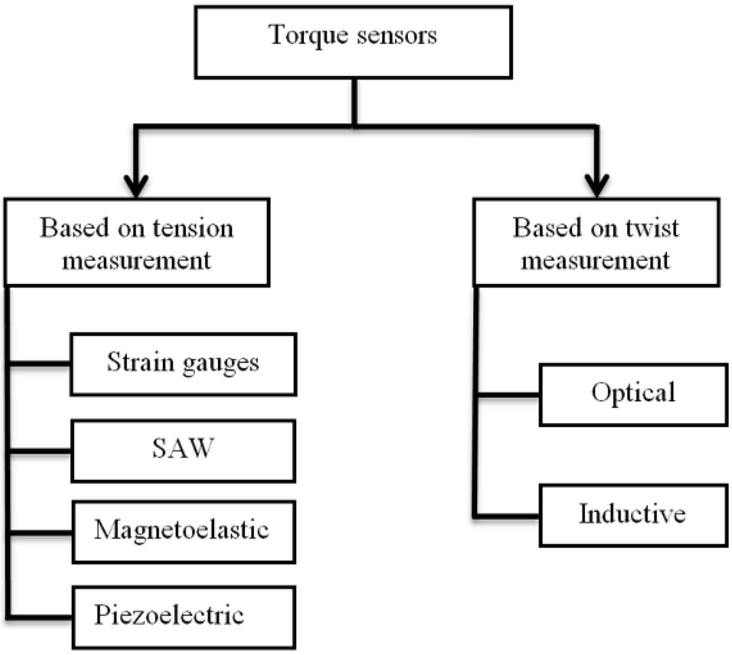

Figure 2. Classification of torque measurement sensors [3].

3. Own remarks about torque measurement

3.1 Torque meter mounting

In case of mounting torque meters in series connection, what is by far the most popular solution due to freely available different torque transducers from many manufacturers it is important how the torque meter will be installed at the test bench. In case of the modern sensors "T" series (figure 3) from HBM company it is possible the only one way of mounting. Rotating part (rotor) is installed in series connection, the second part (stator) functions as the antenna and as the power supplier for the stator. Between the antenna and the stator it is a gap, 2÷3mm big. This original solution, called flange torque meter allows to reduce significantly the noising phenomena of bending, tensile, and compressive forces which are unavoidable due to a geometric errors in the shaft train [11].

Figure 3. T series torque meter from HBM [12].

In conventional solutions with twisted shaft, the length of the torque meter is significantly bigger than the diameter (height) of the sensor. This fact contributes to the necessity of elimination the forces caused by e.g. mounting errors because those forces disturb the torque measurement. What is more, in this type of torque meters it is mandatory to remember about locking a housing of the sensor to prevent from turning.
In terms of this type of torque meters we can distinguish at least three possibilities of mounting:

- The first of two most popular ways of fixing the torque meter is to catch the housing of the sensor 3 by the handle, stiffly connected with the ground as it is shown in the figure 4. Near clutches 2 are used additional bearings 1, which bear driven and braking shafts. This solution aims to not load additionally the bearings inside torque meter by forces from geometric errors in the shaft train and weight of the both parts of the shaft. Drawbacks of this method are the necessity of expansion the test bench, deterioration of dynamic characteristics of sensors and occurrence of hysteresis phenomena due to the application the additional bearings near the sensor.

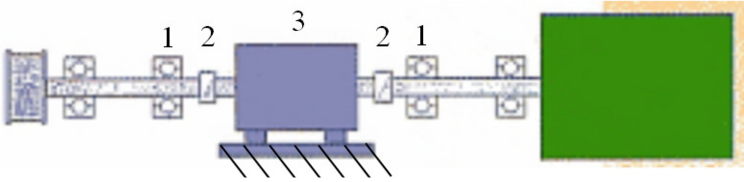

Figure4. Torque meter montage with additional bearings[11].

- The second popular way of torque meter installation is to suspend the sensor by two clutches as it is shown in the figure 5. This solution is mainly used for small rotational speed values[13] and torque meters which weight is small in comparison to the stiffness of both parts of the shaft. This solution is simpler than the previous one (it is not necessary to use a handle and an additional bearings) but we have to prevent the housing against turning and try to diminish the geometry errors in the test bench to minimum because every imperfections are reduced only by clutches.

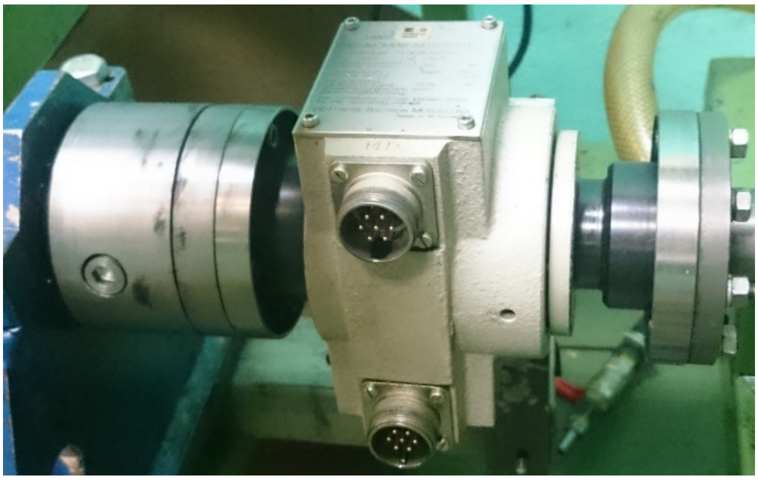

Figure 5. Torque meter suspended by two clutches.

- The next possibility of torque meter mounting is shown in the figure 6. This solution is similar to the first one described in this paper but the main difference is that additional bearing are not before clutches like in the figure 4 but behind. This way of torque meter fixing is rather rare and can be used when the errors in the shaft train are relatively big. In this case those additional forces (mainly bending forces) will be taken by additional bearings and will not acting on the transducer with inner bearings. In this solution a deterioration of dynamic characteristic and hysteresis phenomenon may be observed but if the influence of those disadvantages are less than the effect of forces from mechanical noise in the test bench, this design could be beneficial.

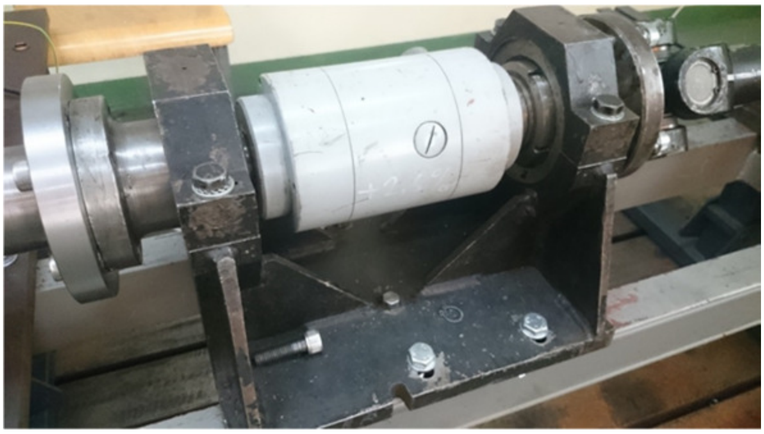

Figure 6. Torque meter suspended by two bearings.

3.2 Bench mechanical noise

In the previous subsection it was pointed out the issue of geometry errors which are one of the reasons of the mechanical noise. The author of this paper called by mechanical noise every mechanical origin phenomena which disturb the value of the torque measured by torque meter.

Figure 7 depicts the basic type of assembly errors. The real error is a superposition of different forms of offsets.

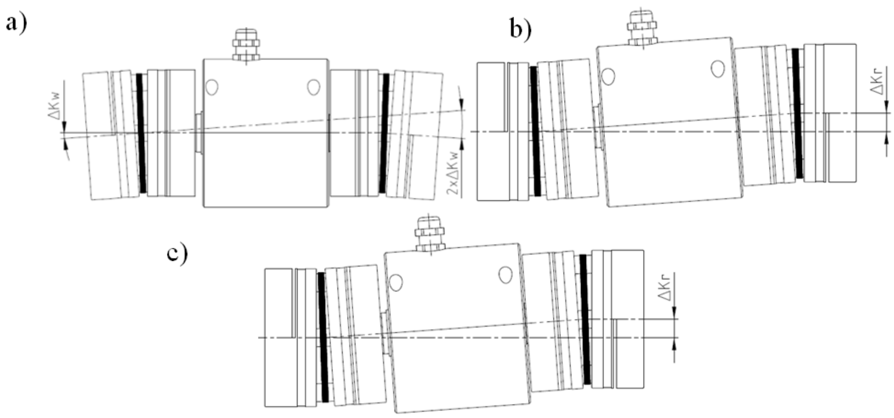

Figure 7. Different types of assembly errors: a) radial angular offset, b) radial parallel offset, c) axial offset [14]

To confirm the thesis of the mechanical noise caused by above mentioned assembly errors the test was perform. The shaft of the big test bench with powertrain of 160 kW was driven evenly by a rope which was wound on the driven shaft of the test bench. In the powertrain the torque meter with range 15 Nm was applied.

This way of driving (instead of typical use of electric motor from the test bench) was performed to omit the additional pulsation of torque value caused by rotational speed control mode of the inverter, which keeps in this mode constant rotational speed instead of current. Figure 8 presents the test results which confirm the assumption. One grid equals to 1,5 Nm so the mechanical noise equals to almost 1,5 Nm.

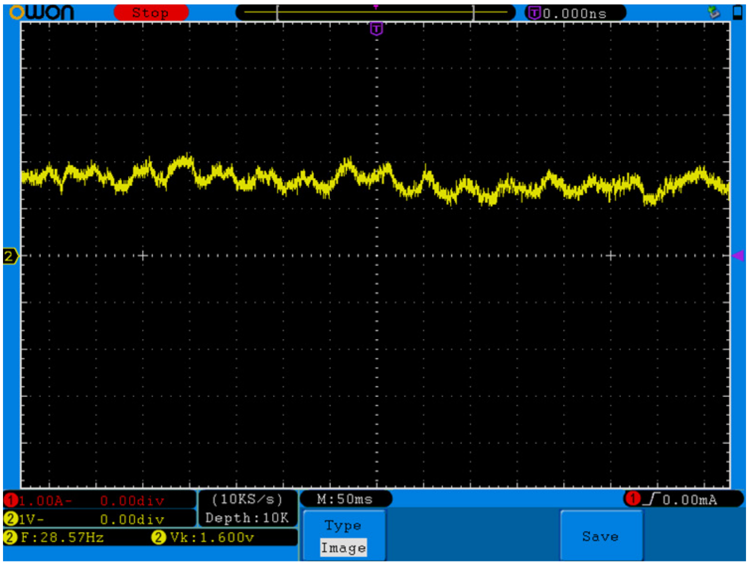

Figure 8. Mechanical noise test results

3.3 Electrical noise

Beyond mechanical noise measurement values could be disturbed by an electrical noise. We can distinguish noise caused by incorrect power supply tension, electromagnetic noise or potential difference on different test bench elements. When conducting a research it is vital to pay attention to noise of mains frequency 50Hz.

Popular source of noise in electrical grid are inverters. The basics rules to reduce the electrical noise caused by them are:

- Using electrical filters in a wiring, both before and behind the inverter.
- Putting the inverter into Faraday cage.
- Using shielded cables.
- Good ground of all devices.

If the electrical noise is caused by the supply voltage it is likely that beneficial will be:

- Using mains filters.
- Checking the ground of all devices at the test bench.
- Using a uninterruptible power supply with possibly big capacity of the battery (in this case we have to remember about protection against electromagnetic noise) or if it is possible use a battery as a source of power, during the tests.

To reduce the electromagnetic noise it is advisable to:

- Put all electronic devices into Faraday cage.
- Use possibly short shielded cables.

Another way to reduce the electrical noise is to apply galvanic isolation and to use e.g. opto-isolators. What is more, every device at the test bench should have the same ground to avoid any differences of electric potential.

Next crucial issue is to use digital transmission of data if it is available. If the torque meter has both the analog and digital output it is definitely more beneficial to use digital one. If the data processing is being done in the housing of the sensor, the housing acts as a Faraday cage. From the housing comes out the digital signal which is much more resistant to a noise.

3.4 Data averaging

Due to an occurrence of the unavoidable phenomena causing equally by mechanical and electrical noise but also other phenomena (e.g. due to the accuracy of the sensor) it is at least sometimes a need to average the test data in order to reduce the oscillations of the torque value to some assumed range. It could be necessary i.e. if we want to use a digital indicator. Fast changing values in a big range makes it impossible to read the value.

The reducing of oscillations is possible by using different filters but in the static measurement often could be enough a simple averaging by function implemented in digital oscilloscopes what is shown in the figure 9,10 and 11. Those data were recorded directly one after another in the same conditions at the test bench. N-fold averaging means that currently displayed curve is the average of n curves. In all screens (figures 9 to 11) one grid corresponds to 0,75 Nm.

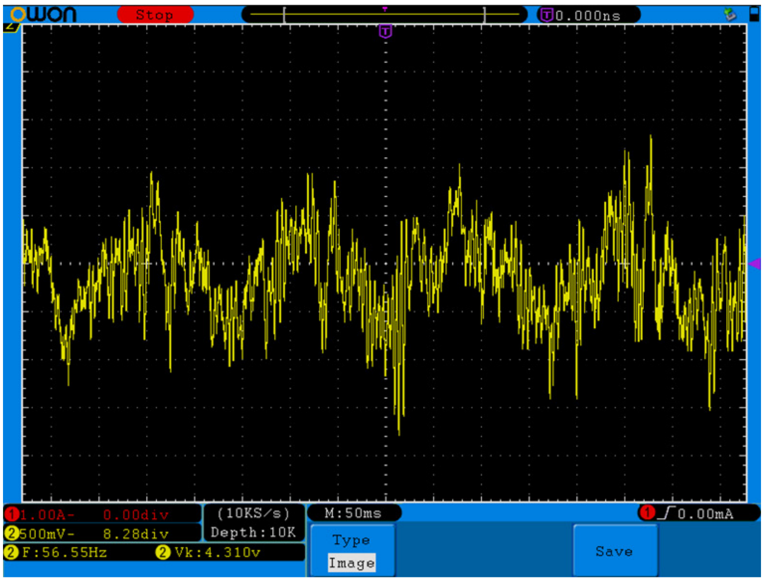

Figure 9. The curve of the torque value without any averaging.

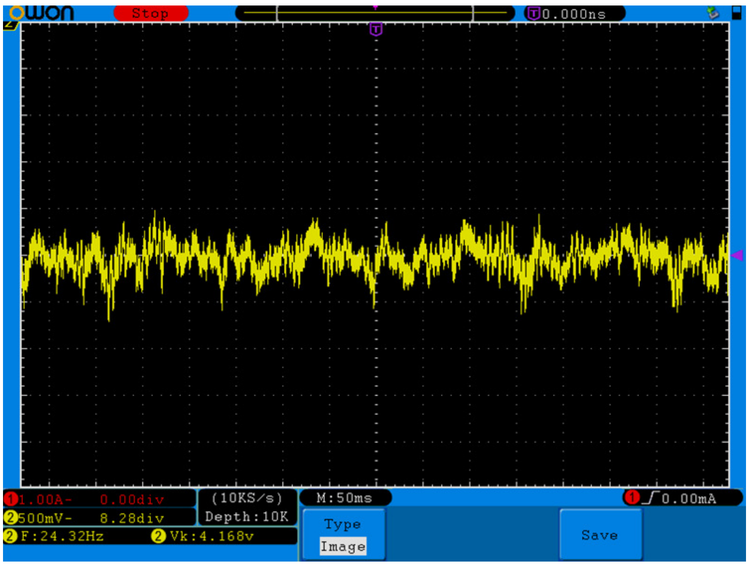

Figure 10. The curve of the torque with fourfold averaging.

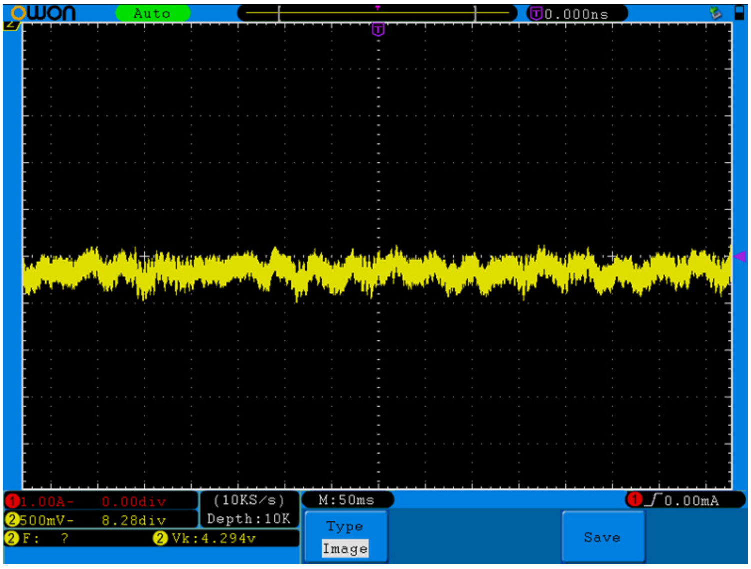

Figure 11. The curve of the torque with 64-fold averaging.

This method of averaging is not suitable for the dynamic process. In this case we cannot average the data from even about one minute.
During the tests it was noticed that the main impact for torque value has the noise proportional to the rotational speed of the shaft. This assumption is confirmed by the data recording presented in the figure 12, where is visible the repetitive shape of two revolutions of the shaft disturbed by mechanical noise (caused by e.g. assembly errors).
Based on these observations it appeared an idea to average the shape of torque value in each revolution. In such a solution it is necessary to measure simultaneously the rotational speed to change the averaging period, preferably directly in the torque meter.
The realization of this idea needs to elaborate a new algorithm which should be executed in the sensor. The work on the algorithm and then testing the proposal are currently being developed.

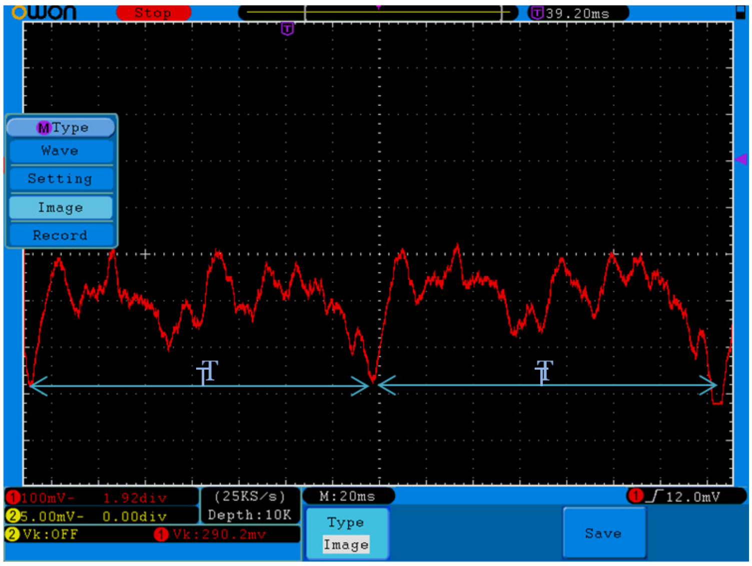

Figure 12. The screen shot from oscilloscope with shape of torque from two shaft revolutions.

4. Summary
Nowadays on the market there is a big choice of different torque meters. It is possible to select the most suitable design and measurement method of the sensor but none of the torque meters is prevented from noise. Every user of torque meters is responsible to provide a good conditions for torque measurement. It is vital to minimize the mechanical noise in the powertrain caused inter alia by assembly errors, prevent all the devices against electrical noise and to choose correct method of torque meter installation including proper type of clutches which enable to compensate the mounting offsets.

References
[1] Morris A S and Langari R 2015 *Measurement and Instrumentation: Theory and Application* (United States of America: Hayton J.) chapter 18 p 557
[2] Latash M L and Zatsiorsy O 2015 *Biomechanics and Motor Control : Defining Central Concepts* (United States of America: Nikki Levy) chapter 1 p 4
[3] Kamiński M 2012 Czujniki momentu obrotowego *Pomiary Automatyka Robotyka* **5** 20-27
[4] Decner A and Iskierski L 2015 Torque measurement in industrial conditions *Napędy i Sterowanie* **7/8**139-143
[5] Sadowski A andŻółtowski B 2012Non-contact measurement methods of torque *Logistyka* **6**915-924
[6] Skala B 2004 The torque measurement based on various principles *Prace Instytutu Elektrotechniki* **220** 17-27
[7] Naruszewicz W 2007 *Automatyka B2B*Accessed: 30.04.2016 http://automatykab2b.pl/technika/760-pomiary-momentu-obrotowego#.V0GL3uR34hS
[8] BOSCH 2014 *Czujniki w pojazdach samochodowych* (Warszawa: WKiŁ) pp 70-77
[9] Honeywell International Inc. 2005 Accessed 29.04.2016 https://www.element14.com/community/servlet/JiveServlet/previewBody/16410-102-1-50374/White%20Paper_SAW%20Torque%20Sensor%20Technology.pdf
[10] Dudziak M, Malujda I and Talaśka K 2014 Torque measurement in worm aglomeration machine *Zeszyty Naukowe. Transport / Politechnika Śląska* **82** 67-73
[11] Zajączkowski J Accessed 3.05.2016 http://www.hbm.com.pl/art11.html
[12] HBM Accessed 4.05.2016 http://www.hbm.com/en/3004/t40b-torque-transducer-with-a-rotational-speed-measuring-system/
[13] Pomianowski R Accesed 5.05.2016 http://www.sensorat.alpha.pl/momentomierze.html
[14] KTR Accesed 7.05.2016
https://www.ktr.com/fileadmin/ktr/media/Manuals/49011pl000000.pdf