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DESIGN, ANALYSIS AND TESTING OF THE TORQUE METER DEVICE

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ABSTRACT: The importance of force measurement systems for industry and agriculture continues to increase gradually and progressively. Load cells measure forces and weights and increase efficiency and effectiveness in many applications. With the help of advanced technology, more user-friendly and highly-accurate force measurement systems need to increase rapidly to meet production requirements. Although there are different test setups for the torque and force measurements of the systems used in our country, there is a need for torque and draught force measuring devices for tractors. In today's technology, the torque meter has become very important in industry and other fields. Torque meter is a device that measures and records the torque in a rotating system such as engine, crankshaft, gearbox, rotor. In this study, solid state modelling, analysis and production for the torque meter were carried out in order to develop the most suitable torque measuring device. The selection of the appropriate design minimizes the errors of the production. Therefore, Finite Element Analysis (FEA) was conducted in order to produce the most appropriate torque measuring device for a given range. According to the results of the analyses, it was decided to choose the most suitable material due to the elongation value of the material and dimensions & shape of the torque meter. Force versus voltage output plot indicated high-R2 value (0.9834) in regression model demonstrating the regression line fits the data better. It is shown that the system is consistent because the resulting value is very close to 1.

Keywords: Elongation, Force, Load Cell, Strain Gauge, Torque Meter, Wheatstone Bridge.

TORKMETRE CİHAZININ TASARIMI, ANALİZİ VE TEST EDİLMESİ

ÖZ: Sanayi ve tarım için kuvvet ölçüm sistemlerinin önemi her geçen gün önemi artmaya devam etmektedir. Yük hücreleri, kuvvetleri ölçmek ve birçok uygulamada verimliliği ve etkinliği artırmak için tartım ve kuvvet ölçümü yaparlar. İleri teknolojinin yardımıyla, daha kullanıcı dostu ve doğruluğu yüksek kuvvet ölçüm sistemleri, üretim gereksinimlerini karşılamak için hızla artmaya ihtiyaç duyarlar. Ülkemizde kullanılan traktörlerin tork ve kuvvet ölçümleri için farklı test kurulumları olmakla birlikte sistemler için tork ve kuvvet ölçüm cihazı ihtiyacı bulunmaktadır. Günümüz teknolojisinde torkmetre, endüstri ve diğer alanlarda çok önemli hale gelmiştir. Torkmetre, motor, krank mili, şanzıman, rotor gibi dönen bir sistemdeki torku ölçen ve kaydeden bir cihazdır. Bu çalışmada, katı modelleme ile tasarım, analiz ve üretim en uygun tork ölçüm cihazı hedeflenerek gerçekleştirilmiştir. Uygun tasarım seçimi üretim hata oranını en aza indirmektedir. Bu yüzden belirlenen aralıklar için en uygun tork ölçüm cihazını imal etmek için sonlu elemanlar analizi kullanılmıştır. Malzeme uzama değeri, torkmetre boyut ve formuna bakılarak analiz sonuçlarına göre en uygun malzeme seçimine karar verilir. Gerilme-kuvvet grafiğinde görüldüğü gibi, yüksek R^2 değeri (0,9834) regresyon modelinden elde edilmiştir. Bu değerin 1'e yakın olması sistemin tutarlı olduğunu göstermiştir.

Anahtar Kelimeler: Gerinim Ölçer, Kuvvet, Tork Ölçer, Uzama, Yük Hücresi, Wheatstone Köprüsü.

1. INTRODUCTION

Load cells are widely used to measure forces and increase efficiency. Load cells are sensors commonly used in industry to measure force or weight. They are especially used in weighing instruments, check scales, multi-head scales. As the performance of these machines is increasing (operating speeds can exceed hundred weights per minute), their costs and dimensions are constantly decreasing.

Load cell is able to analyze force, weight, moment, stress, strain, displacement etc. in real time. It is a mechanical part that is used to measure physical change. The electronic board is an electronic part that is used to process the signal coming from the load cell. The software is the medium that processes the signals produced by the electronic card and displays it to the user.

Torque meters and load cells are designed using 3d solid state modelling. In order to observe the measurement performance of torque meters and load cells, some parameters such as weight, stress, strain, displacement should be calculated. Finite Element Analysis (FEA) is a virtual analysis method to calculate the required parameters without manufacturing and testing in real environment. It is very vital to investigate the torque meter performance both virtual and testing environment.

Torque is calculated by measuring the torsion of the shaft by means of angular displacement or elongation sensors. For this purpose, special torque meters can be used by connecting directly to the shaft other than flanges or bearing. The other method is based on the measurement of twisting of the shaft according to the applied load. The transmission of the signal resulting from the applied load depends on whether the shaft is rotating or not. If the shaft is rotating, the rotating sensors on the shaft can transmit their signals with the electronic signal processing card using with or without wireless systems [1].

In this study, a torque meter was designed, analysed and tested in order to develop a simple solution for industrial and other applications requiring torque measurements.

2. LITERATURE REVIEW

Within the scope of this study, plastic-based composite plates exposed to preloads and the adhesive bonds of these plates to examine the creep effect against time, an apparatus for this purpose was designed and manufactured. Static load in the tensile direction at different forces on the test setup was able to apply. The preload value of the axial force applied to the samples could be transferred to the samples with the torque meter [2].

In this study, a three-dimensional force transducer and a real-time force measurement system were used to measure force changes at the coupling points of tractors. The wireless force measurement system was developed. This system had ability to measure forces in three dimensions. Test results showed that the force measurement system had close results with compare to the commercially used load cells. Additionally, this system had an ability to obtain field data with using wireless communication and force results can be investigated by graphic based screen [3].

In this study, the traction performance of an agricultural tractor was analyzed according to the soil moisture content. In this experimental study, a load measurement system was mounted on the tractor using a wheel torque meter, a proximity sensor, a six-component load cell and a data acquisition system [4].

A novel model-based filtering technique for load cells was proposed in this work to ensure short settling time in dynamic weighing through load cells. The filters obtained, referred to as Shaper-Based Filters (SBFs), were based on the convolution of load cell signals with a sequence of a few impulses, typically between two and five impulses. The amplitudes and time instants of these impulses were computed through the system dynamic model, the level of admissible residual oscillations in steady-state filtered signal and the desired robustness [5].

The review discussed the strain sensing technology used in multi-axis force sensors. Electrical resistance voltages have been the standard mechanism for measuring induced voltage in the sensor structure for decades. Although they are ubiquitous, these sensors have limitations that are impractical in many applications. Specifically, the advantages offered by fiber Bragg gratings include: (a) immunity to electromagnetic interference, (b) reduced size and weight, (c) superior strain resolution, (d) environmental stiffness, and (e) optical multiplexing. Although semiconductor strain gauges and capacitive sensing are available in the literature, they are primarily used in exceptional cases such as miniature force sensors [6].

A column-type sensing element was designed as a multi-component force/moment sensor by attaching strain gauges. The ratio of length to diameter (L/D) for the sensing element was designed analytically and verified by finite element analysis. To reduce the interference error of each loading component, this article proposed a method of separation by addition and subtraction using the signals of strain gauges [7].

This study discusses a new method for evaluating the torque output of an orbital motor. The method involved evaluating the pressure within each chamber, taking into account the handling characteristics of the machine. Depending on the pressurization, instantaneous normal contact forces were evaluated using geometric intersection and validated contact mechanics relationships. The net torque output from the simulation was compared with the ideal values and those obtained from the experiments in terms of both instantaneous and average values. Comparison of the results showed that the proposed approach could predict the torque output trend with always less error than experimental values, but this deviation is observed under only a few operating conditions [8].

The traction load measurement system was developed to measure field data for traction performance evaluation during tillage operations. A 78 kW farm tractor was used to build a load measuring tractor. The aim of this study was to analyze the traction performance of an agricultural tractor according to soil moisture content (SMC). A load measurement system was assembled using a wheel torque meter, a proximity sensor, a six-component load cell, and a data acquisition system. Thus, the traction efficiency at the highest SMC level was 95.3% at the lowest SMC level. Therefore, the results from this study provided an approach for evaluating tractor traction performance based on SMC levels [9].

This study presented an innovative design for a multi-capacity force measuring device. It was proposed that this instrument could replace a set of force transducers constructed to cover a specified force measurement range. It also provided a solution to the constraints limiting the use of an ordinary force converter where it was recommended to use a force converter at a load below 10% or above 100% of its rated capacity. The capacity of the system was doubled from 10 kN to 20 kN [10].

3. MATERIAL AND METHOD

3.1. Computer Aided Engineering (CAE) Analysis

Conceptual design and three-dimensional solid state modeling of the torque meter were made using Autodesk Inventor program (Figure 1). Static structural analysis was performed in order to observe the stress behavior of the product design and to provide input to the design with Finite Element Analysis method. Local meshing method was used in order to investigate the behaviors of the torque meter. AISI 1050 and 4140 steel materials were used due to mechanical properties. In the second stage, the prototype was manufactured by applying machining processes.

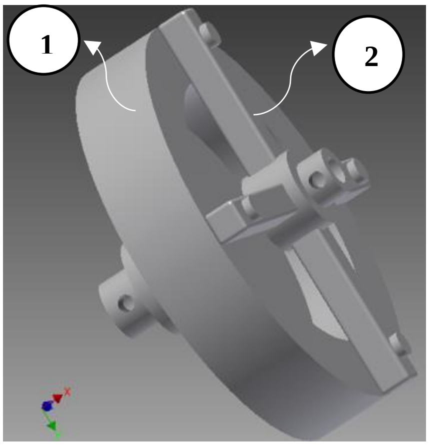

Figure 1. 1050 (1) and 4140 (2) Steel Assembly.

3.2. Mechanics

A torque sensor, torque converter or torque meter is a sensor used to measure the torque value and use the data obtained in a rotating mechanism such as a motor, crankshaft, gearbox, gearbox, rotor, bicycle crankshaft or cap torque tester. Measuring the dynamic torque value can be said to be difficult to measure because the measurement data requires the transfer of some influence (electrical, hydraulic or magnetic) from the obtained shaft to a static system. Torque meter is used to obtain the applied strain values. Newer types of torque converters add conditioning electronics and an A/D converter to the rotating shaft. The electronic cards then read the signals and convert the signals into a high level analog output signal value such as +/- 5-10V DC [11].

Figure 2. Custom designed 3D Force Transducers [11].

The strain gauge torque meter is used as a force transducer. Mechanical part of these transducers are custom designed torque measuring device with different ranges of 0-100 Nm, 0-500 Nm, 0-2000 Nm, 0-10000 Nm and 0-20000 Nm (Figure 2).

3.3. Electronics

The designed system has a torque meter, an ADC, an MCU, an RF Module and a PC. For sensing force variations on three-point linkage, Wheatstone Bridge is used on torque meter. The analog voltage outputs on bridges were amplified with an instrumentation amplifier and converted to digital signal using 24 bit ADC. Digitalized values processed by the MCU and transferred to PC via RF signals. The PC provides us graphical monitoring the processed field data in real-time. In order to decrease the noise on Torque meter, the regulated DC power source has been used for supplying Wheatstone bridge. And also for this purpose cable shields have been connected to the ground as shown in Figure 3 [3].

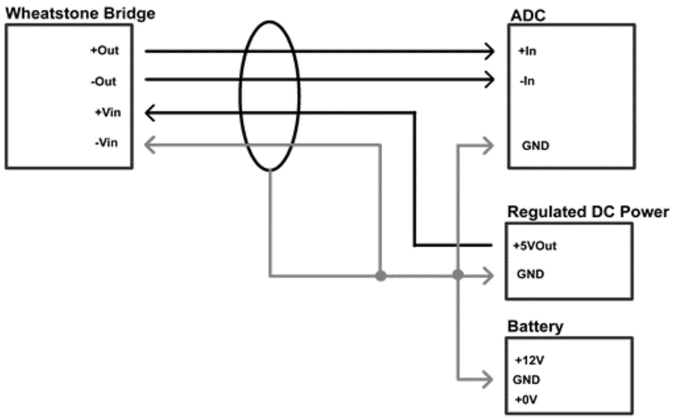

Figure 3. Shield Grounding for Noise Reduction [3].

4. RESULTS AND DISCUSSION

Stress analysis was performed by applying moment and force at different values to the torque meter. The findings showed that the designed torque meter was appropriate for measuring torques accurately and precisely.

4.1. Displacements in Torque Meter

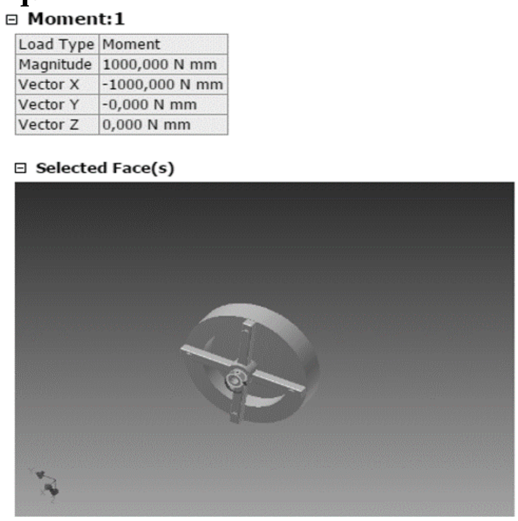

Figure 4. Application of a torque of 1000 Nmm.

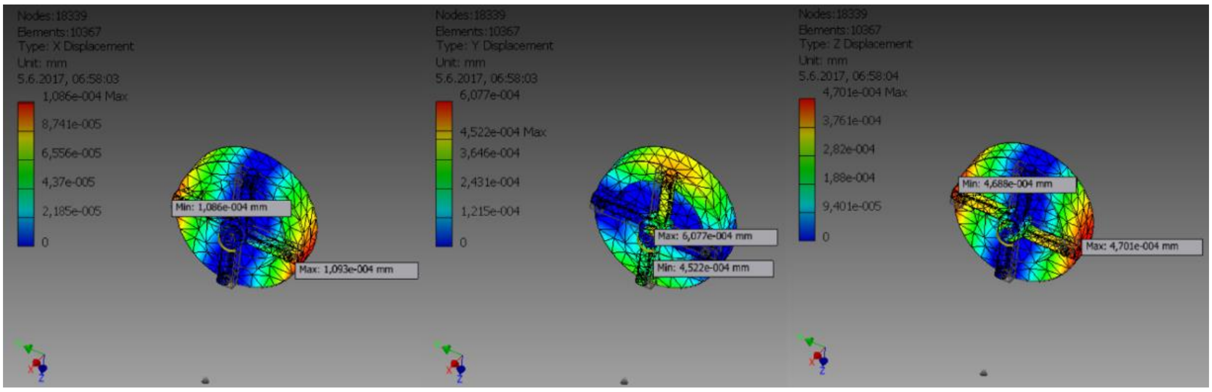

Figure 5. Displacement on the X, Y and Z axis.

Structural analysis or stress analysis ensuring the correct selection of materials and the correct use of materials determined the safety coefficients of the current system and to optimize the material, cost, production time and strength values in the manufacturing processes.

The maximum elongation for AISI 4140 steel was 25.7% and the maximum elongation for AISI 1050 steel was 9% and then the AISI 1050 steel was fixed at the fixed point, while the other force and torque were applied separately to the shape (Figure 4). The maximum elongation value of 25.7% was the desired value in order to find the places where the strain gauges are glued. Some of these forces and moments are 1000 N, 10000 N, 1000 Nmm and 10000 Nmm, respectively (Figure 5). The dimensions of the developed torque meters were checked iteratively and a number of stress analyzes were performed to select the proper materials.

For the suitable elongation, the required stress and strain values were taken as reference. The principal stress and strain values on all axes were taken as reference. As a result of the detailed examination, a number of steel materials were tested and two types of steel were identified for production as AISI 4140 and AISI 1050 Steel.

4.2. Torque Meter Test Results

The tests were conducted after the torque meter manufacturing phase was completed. Since the value of the multimeter is very small when the test is performed, the amplifier circuit must be designed and developed. Thus, the instrumentation amplifier, INA128 was used. This process is also called as signal conditioning.

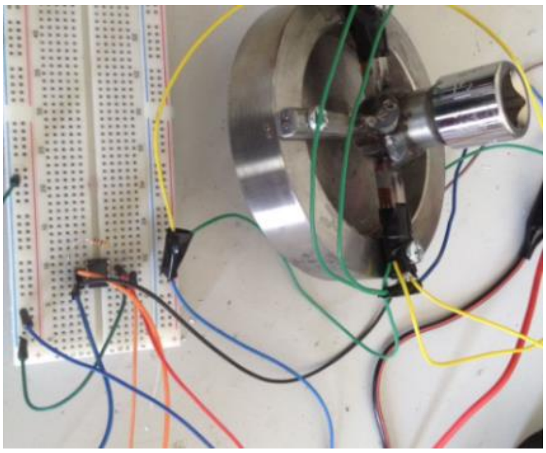

Figure 6. Combination of INA 128 with torque meter.

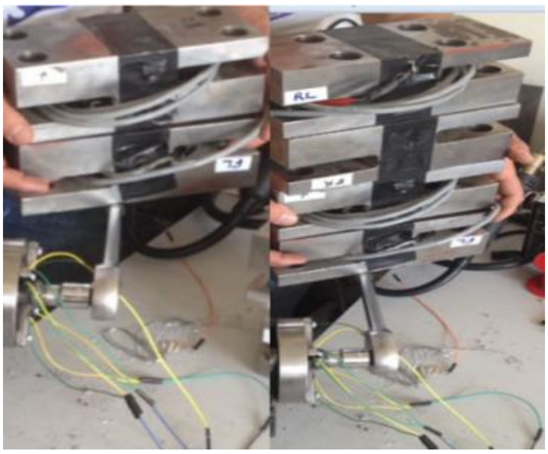

Figure 7. Application of 139.3 N and 278.6 N forces on the torque meter.

Then, a torque meter was applied to the small scale and the voltage change values were observed. The observed values can be seen in Table 1.

Table 1. Force and Voltage Values for Torque meter.

Force (N)	Voltage (V)
139.3	11.73
209.1	11.35
278.2	11.05
350.1	10.74
439.9	10.16

A minimum of 130 N forces was taken in order to conduct the calibration. The voltage values were then taken by applying force separately from small to large, and the resulting values were plotted (Figure 8).

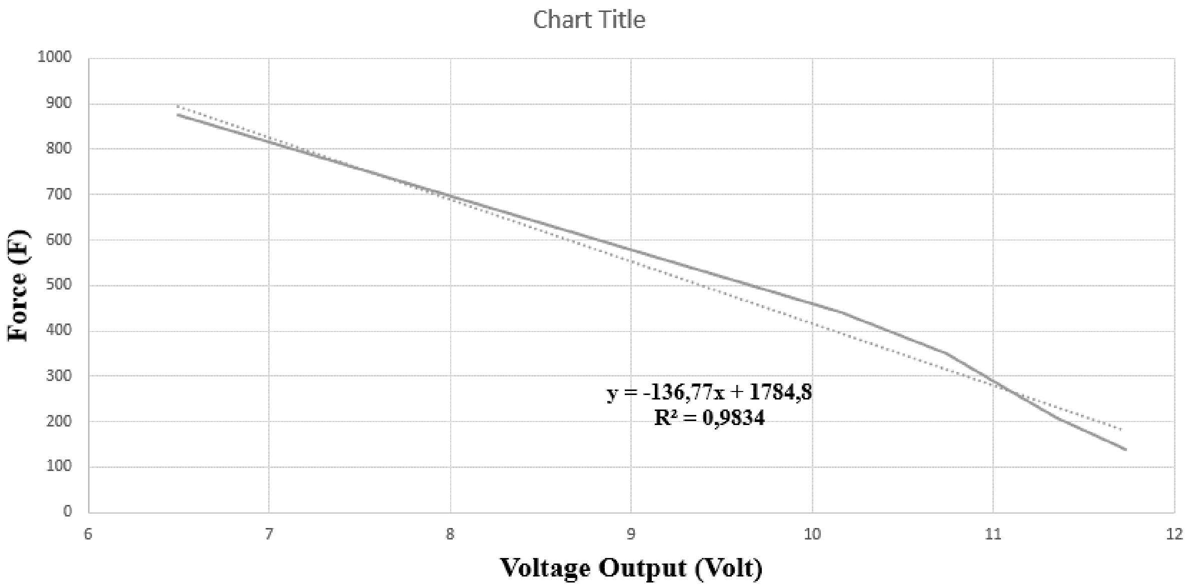

Figure 8. Force versus Voltage Values.

When the table is examined in detail, the y formula gives the force value and R^2 value is found to be 0.9834. It is shown that the system is consistent because the resulting value is very close to 1.

CONCLUSION

In this experimental study, a number of criteria were aimed to facilitate the manufacturing process for the development of torque meter. These aimed criteria are the choice of material, stress, strain and displacement properties of the material under different torques. In addition, accuracy, precision and range of the measurement are other important features. The selected material provided the desired stress and strain values for the expected elongations. When selecting the material, several iterative FEA analyses were conducted. The size and shape of the torque meter were optimized for sensitive measurement. After the drawing, it was decided that there should be two types of steel. After comparing the obtained values with theoretical values the minimum and maximum torque values of the product were determined. These steels were identified as AISI 1050 and AISI 4140 steel. AISI 1050 is a steel with high stress value, low elongation steel and AISI 4140 steel stress value lower than other steel and higher elongation value. In the next step of this study, it is aimed to investigate the torque meter performance both virtual and testing environment.

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