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# Design and Development and Evaluation of a Strain Gauge Type Brushless Torque Meter for Silage Corn Yield Monitoring

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**Abstract**

In this article a strain gauge type brushless torque meter was designed and fabricated. The innovative part of this apparatus is the data logging system which uses MMC card. To accomplish this goal, a compact electronic circuit was designed, constructed and mounted on a special connecting shaft rotating at 1080 rpm and transmitting power from tractor's *pto* shaft to a silage corn harvester. In order to evaluate the system linearity and repeatability, static laboratory test was performed. The output signals showed excellent linearity and also repeatability with high correlation with transmitted torque changes. Field test was also conducted to evaluate the performance of this torque meter as a real time mass flow rate sensor in silage corn yield monitoring. Results showed high correlation between electronic circuit's output and mass flow rate with $R^2$ of 0.97. Finally a silage corn yield map was prepared using this technique for a typical test field.

***Keywords:*** Precision Farming, Strain gauge, Mass flow Sensor, Yield map

## INTRODUCTION

Measuring the torque transmitted by a rotating shaft in real time is one of the most important and difficult process in the field of engineering measurement and instrumentation. Several types of torque meters are available for different working conditions. Examples are; strain gauge based transducers, laser beam sensors, non contact magnetic sensors, etc. all for measuring the torsion of a rod subjected to applied torque. Among these different types, non contact types are more preferred due to the fact that transmitting output signal from a rotating shaft is very difficult.[6]

Brown (1979) registered a new type of inductive torque meter in US patent department which consisted of two gears at the two ends of a torsion rod and in close proximity to the windings that make a mutual induction. By counting the generated pulses of induction with respect to the gears, the transmitting torque was calculated by determining the phase difference between the two ends of the torsion rod.[1]

One of the most important indexes in evaluating farm machineries which receive their rotary power from tractors' *pto* shaft, is measuring the instantaneous consuming torque of the machines continuously and precisely. These real time measurements help us to know the changes of machine performance during different work conditions. By studying this parameter we could understand the variability which existed within the field. So this method can help us in precision farming applications such as a mass flow sensing, continues soil strength measurement, etc.

Mahmud et al. (1972) designed and constructed a strain gauge based torque meter in order to measure the instantaneous torque variations of farm machineries which receive their required rotary force from tractors' pto shaft. They used a technique which enabled them to measure the tensile force of bolts, instead of measuring the shaft torsion. The main advantage of this technique was that it didn't need slip ring for data transmission.[4]

Savoie et al. (2002) equipped a forage harvester with five types of mass flow sensors and also a high-dump wagon instrumented with four weighing load cells as a platform scale system to check the sensors accuracy. Their results showed that Impact force in the spout produced a very good linear correlation with mass flow rate ($R^2$=0.95). Feed roll displacement sensor produced the second best linear correlation with mass flow rate ($R^2$=0.863). Torque measurement at the pto shaft and at the cutter head required a moisture correction to improve correlation with mass flow rate. The capacitance–controlled oscillator was poorly correlated with mass flow rate but yielded the best correlation with moisture content ($R^2$=0.66).[7]

Kumhala and Prosek (2003) used torque meter and force impact sensor simultaneously on a mower conditioner. The goal of these scientists was finding a linear relation between mass flow rates and the output of two sensors. They found fine correlation of 0.89 and 0.96 for torque sensor and force impact sensor respectively. But they concluded that impact sensor was better in compared with torque sensor method because of none expensively and none sensibility to which kind of crops that was harvested.[3]

Miklenda et al. (2006) used a modern mower conditioner equipped with a torque meter and tachometer in order to measure instant mass flow rate in accordance with instant power consumption changes of forage harvester. After that they conducted evaluation tests in field conditions they found significant statistical dependence between power consumption and instant mass flow rate at 99% confidence level. By using this technique and also DGPS receiver which was mounted on a harvester, they prepared a yield map for a test field.[5]

Kamgar et al. (2008) designed and constructed a new type of torsion rod torque meter which measured the phase difference between the two ends of the rod using two notched discs attached to the ends of the rod with two laser beam transmitters and receivers. The receiver transistor switches the internal timer of an 8051 series microcontroller on and off, thus the phase difference can be calculated by measuring the time difference between switching the timer on by front end of the rod and switching the timer off by the other end of the rod. They used this torque meter in order to find a correlation between transmitted torque to the chopper harvester and silage corn feed rate (kg/s). After laboratory calibration test they found a linear relationship between these two parameters with good correlation coefficient of r=0.99 and finally a linear calibration equation with $R^2$ of 0.98.[2]

In this article a new type of strain gauge-based torque meter which could be easily mounted between tractors' *pto* shaft and the driven shaft of the farm machineries was designed and constructed. This type of torque meter was selected because of its high precision in measuring the torque variations and also less space requirement compared to the other methods such as torsion rod method. So far, the most important drawback of this method is the need for providing an exciting voltage to Wheatstone bridge and also transmission of the bridge output voltage from a rotating shaft without being affected by environmental noise. The most common method of doing these important jobs is using slip rings and brushes. But this method is not suitable in a dirty media as in agricultural field conditions. Thus in this investigation a new method of data acquisition system was designed and developed in such a manner that the output signal of the strain gauge bridge was received by an AVR microcontroller via its ADC port and stored on a MMC card for further processing.

## MATERIALS AND METHODS

### Construction of Mechanical Parts

These parts should be constructed in such a manner that can be easily mounted between tractors' *pto* shaft and chopper harvester and also an electronic control circuit and battery package can be installed on this shaft and rotate with the shaft. By using ASABE Standards for *pto* shaft, a special male and female connecting shaft was constructed as shown in figure1. Two boxes were installed on the shaft in order to place the electronic control circuit and battery package inside them.

### Strain-Gauge Specifications

A full bridge strain gauge with ±45 degree rosette with respect to the main axis was bought from a Japanese precision instrument manufacturer company TML, and installed on a connecting shaft according to the installation guides of the manufacturer (Figure2). The specifications of the strain gauge can be seen in product specification label shown in figure 3.

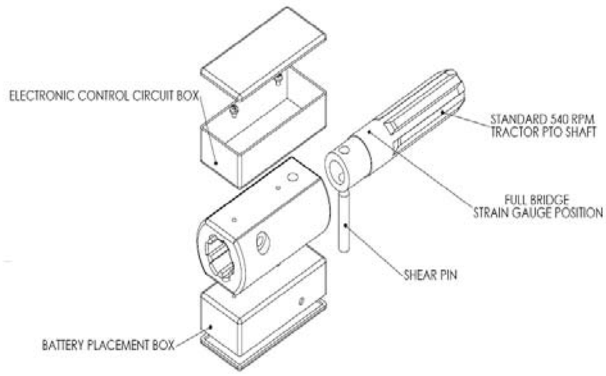


**Fig.1.** Detailed schematic drawing of mechanical parts and assembly

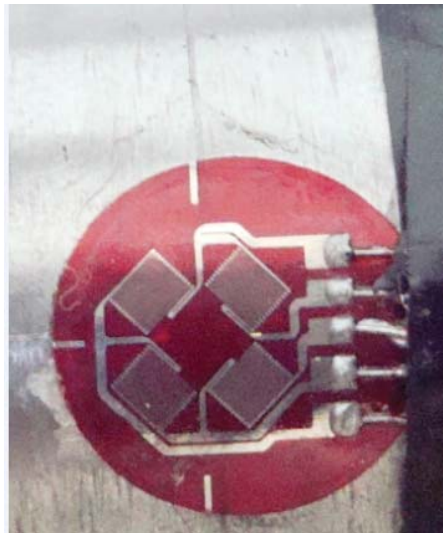

**Fig.2.** The full bridge stain gauge rossete.

| | | | |
|---|---|---|---|
| TYPE | FT-2-350-4S-11 | | TEST CONDITION 23°C 50%RH |
| LOT NO. A510541 | BATCH NO. FA26K | GAUGE FACTOR | |
| GAUGE LENGTH | 2 mm | 2.06 | ±1 % |
| GAUGE RESISTANCE | 350±1.0 Ω | TEMP. COMPENSATION FOR | 11 ×10$^{-6}$/°C |
| QUANTITY | 3 | TRANSVERSE SENSITIVITY | 1.0 % |

**Fig.3.** Product specification label of the torque meter

### Design and Construction of An Electronic Control Circuit

The supplying voltage of Strain Gauge Bridge was provided by an electronic circuit placed in a water proof box mounted on a rotating shaft. This control circuit should also receive the output signal of Wheatstone bridge, amplify and send it to the ADC port of Atmega8 AVR microcontroller and finally save it on MMC(Multi Media Card) card data logger. The schematic map and constructed board of the electronic circuit are shown in figures 4 and 5, respectively.

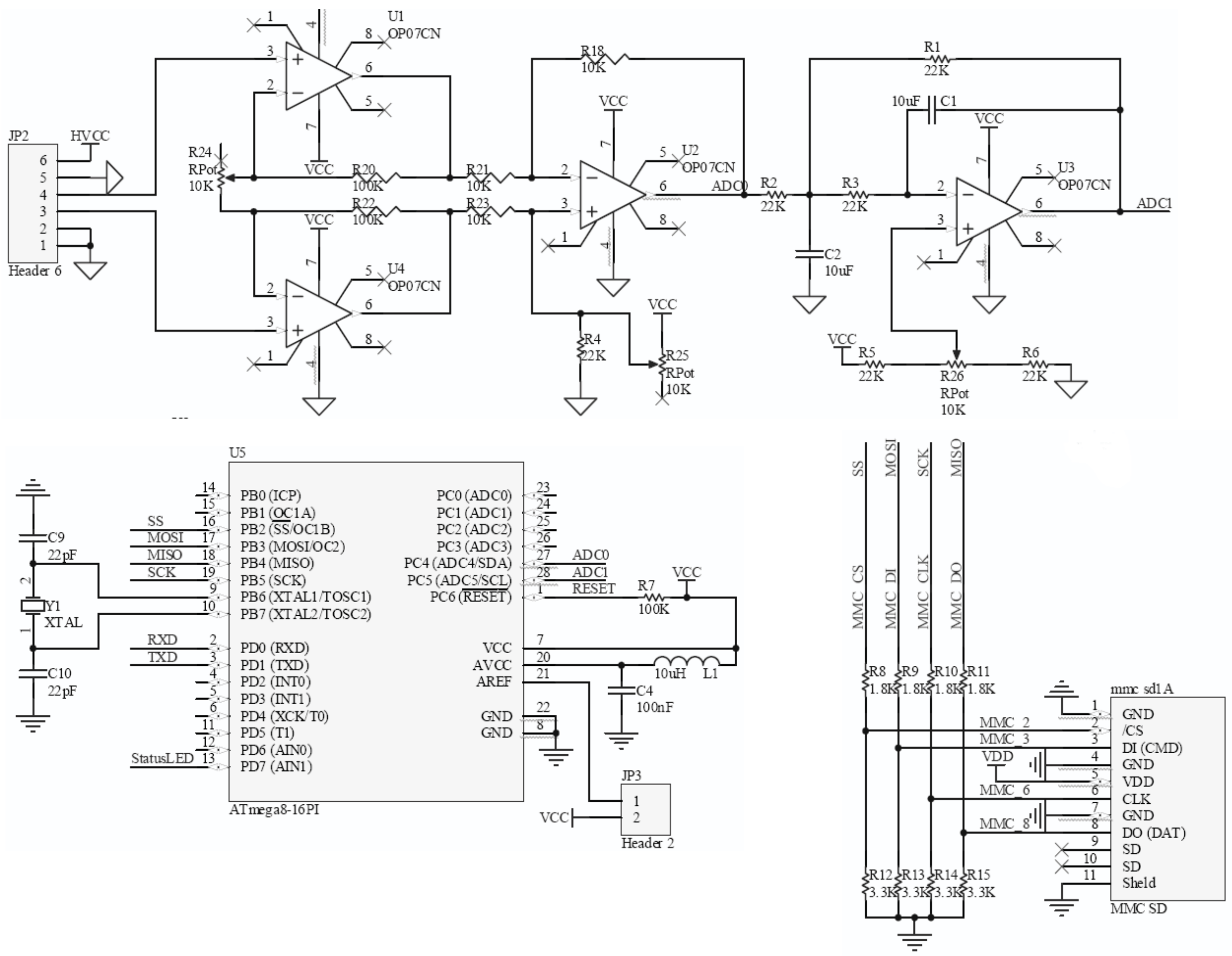


**Fig.4.** Shematic map of electronic circuit

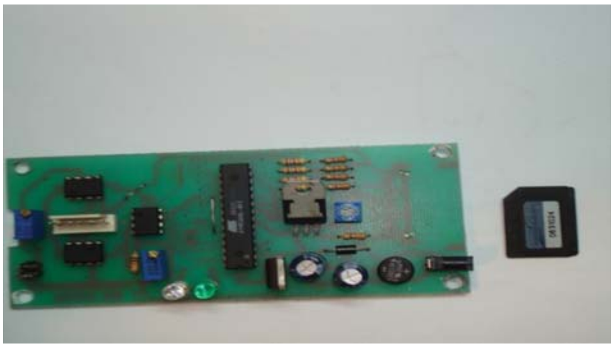

**Fig.5.** Constructed electronic circuit board and MMC memory card.

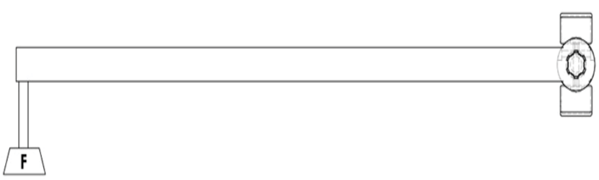


**Fig.6.** Schematic figure of torque wrench that was used to calibrate the torque meter

**Evaluation of Torque Meter Performance**

***Laboratory test***

In order to evaluate the torque meter performance, laboratory tests were conducted using a torque wrench as shown in figure-6. These tests were performed in order to check the linearity and repeatability of the torque meter output signal at different torque levels. The tests were conducted at 9 treatments of torque levels from 0 to 800 N.m with 100 N.m steps In 5 replications in loading and unloading modes.

***Field tests***

The main goal of this investigation was to find a relationship between the torque transmitted by tractors' *pto* shaft with respect to load variation on chopper harvester due to crop yield changes. To accomplish this, first a calibration test was performed with artificially feed rates of 6, 8 and 10 kg/s. These feed rates were selected according to ground speed of the tractor and weighing samples which were randomly harvested from the field in order to find a linear equation between crop yield changes and instantaneous torque variation. After that, a test was performed in order to use this technique as a mass flow sensor for precision farming applications to prepare a yield map for silage corn crop. To proof the accuracy of the suggested technique a platform scale weighing system was also used.

## RESULTS AND DISCUSSION

### Results of Linearity, Repeatability and Calibration Tests

As it can be seen in table1, regarding to the negligible percentage of coefficient of variation (C.V.) and standard deviation of 8 bits digital output signal of electronic circuit, there was no significant variation between different replications which can proof the repeatability of the torque meter. On the other hand, linearity test of the torque meter was checked using $R^2$ of calibration equation as shown in figure7.

**Table 1.** Mean standard deviation and coefficient of variation of torque meter data.

| Treatments (N.m) | No. of collected data | Mean | St. Dev. | C.V. (%) |
|---|---|---|---|---|
| 0 | 100 | 108.00 | 0.0 | 0.000 |
| 100 | 100 | 114.00 | 0.0 | 0.000 |
| 200 | 100 | 120.01 | 0.1 | 0.038 |
| 300 | 100 | 126.99 | 0.1 | 0.078 |
| 400 | 100 | 133.00 | 0.0 | 0.000 |
| 500 | 100 | 139.08 | 0.3 | 0.194 |
| 600 | 100 | 146.00 | 0.0 | 0.000 |
| 700 | 100 | 152.00 | 0.0 | 0.000 |
| 800 | 100 | 158.48 | 0.5 | 0.315 |

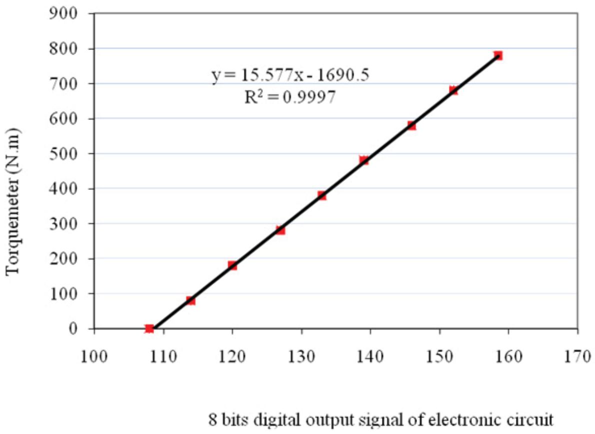


**Fig.7.** Best fit line and calibration equation for torque meter

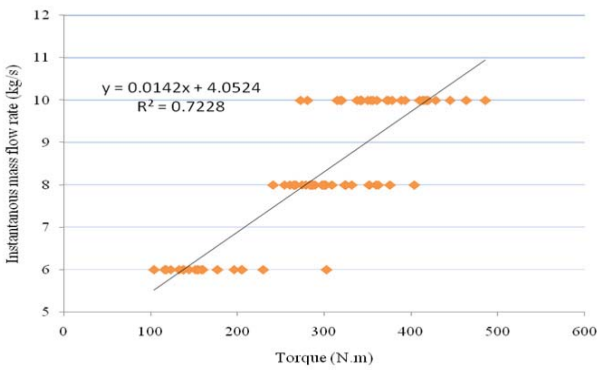


**Fig.8.** Torque varations and torque overlaps which occured in different treatments of mass flow rates

### Results of Field Test

#### *Calibration Test*

As it was mentioned above, first a calibration test was conducted to find a calibration equation for further use of the torque meter as an instantaneous mass flow sensor, but as it can be seen in figure8, because of high amount of torque variations at each feed rate the equation was unreliable, thus by using statistical analysis, a confidence interval was determined for each artificial feed rates (table-2) and then a calibration equation was calculated (Figure9).

#### *Preparing A Yield Map*

By using the calibration equation shown in figure-9 a yield map was prepared for a typical field at agricultural research station of Shiraz University. Statistical analysis of predicted mass flow rates by using the torque meter sensor were not significantly different from real amount of mass flow rates which platform scale weighing system measured at 5% of confidence limit.

The results of yield map (Figure 10) shows the mean yield of 6 kg/s with standard deviation of 2.42 kg/s. The minimum yield was 3 kg/s and the maximum yield was 13 kg/s.

**Table 2.** Confidence interval for torque values for each treatments

| treatment | Mean | No. data | St. Dev | St. Error of Mean | T value | Confidence interval |
|---|---|---|---|---|---|---|
| 6 kg/s | 163.53 | 19 | 47.78 | 10.96 | 2.1 | 23.2 ± 163.53 |
| 8 kg/s | 304.7 | 30 | 39.26 | 7.17 | 2.04 | 14.62 ± 304.7 |
| 10 kg/s | 372.82 | 28 | 51.98 | 9.82 | 2.05 | 20.51 ± 372.82 |

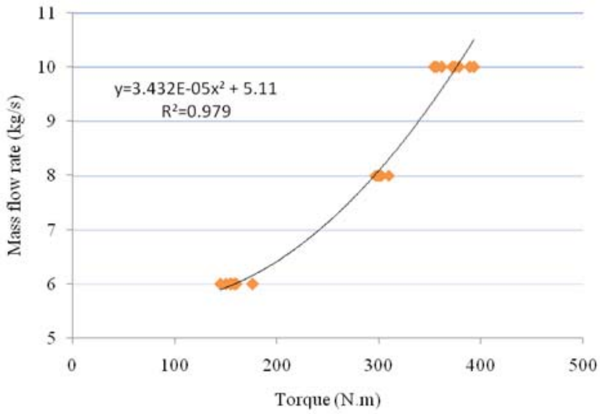


**Fig.9.** Calibration equation of the torque meter as an instantanous mass flow rate sensor

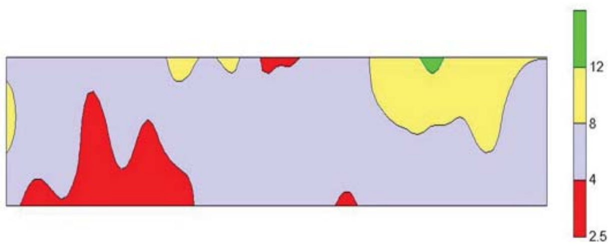


**Fig.10.** A typical yield map of silage corn.

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