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Review

A review on axle torque sensing devices for energy harvesting of tractor implement combination

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Agricultural machines contribute a major portion of the total cost of crop production. Proper matching of tractors and implements is crucial for maintaining high operational efficiency on the farm. If the implementation is specified, the draft will be a function of travel speed for a given soil condition and a cultivation depth. Operating costs for any given tractor or implement can be minimized by selecting an optimum travel speed, or for a given speed the implement width could be optimized to reduce operation costs. This review deliberates on the latest work being done for tractor rear axle torque measurement under dynamic conditions and also the functional principle of instrumented strain-gage based transducers for the farm tractor rear axle was explained to optimize the power requirement of tractor implement combination.

Key words: Telemetry system, transducers, slip rings, microcontroller.

INTRODUCTION

The agricultural tractor is rather a heavy machine and is used for variety of operations from tillage to haulage and that too under diverse conditions. Agriculture demands more power and energy to produce food to feed the ever increasing world population. Inefficient tractor operations increase the cost of production. The need to maintain agriculture profitability is, however, very much dependent upon both the land and machinery productivity. Management decisions related to agricultural machinery can affect plantation profits in many ways. Fuel, interest, labour and timeliness are the pertinent factors that contributed to the tractor's productivity and efficiency. Improvement of tractors operational efficiency has been a subject of considerable research. Operational efficiency can be improved by maximizing work output or minimizing the fuel consumption.

Therefore, to increase operational efficiency further, parameters must be optimized. Reports studies have shown potential saving up to 20% if "Gear Up Throttle Down" technique was performed (Schrock et al., 1986; Chancellor and Thai, 1984; Grogan et al., 1987). Proper match of an implement to a tractor is another aspect of increasing operational efficiency. If the implement is specified, the draft will be a function of travel speed for a given soil condition and a cultivation depth. Operating costs for any given tractor or implement can be minimized by selecting an optimum travel speed, or for a given speed the implement width could be optimized to reduce operational costs. It is necessary to have detailed information on power and energy input of machinery utilized in the area locality. Instrumentation systems to determine energy requirements and efficiencies of tractor-implement systems have been developed by machinery manufacturers, universities and governmental agencies. Research results showed that 20 to 55% of the available tractor energy is wasted at the tire-soil interface. In addition to wasting energy, improper ballast can cause excessive tire wear or soil compaction,

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which may later be detrimental to crop production (Burt et al., 1982).

Agricultural sustainability depends on farm profitability. Thus, farmers are under constant pressure to produce more with less and to reduce production costs through improved operating efficiency. Tractor-implement operating efficiency depends heavily on how well the tractor and implement are matched. When ideally matched, there is less power loss, improved operating efficiency, reduced operating cost, and optimum utilization of capital on fixed costs (Taylor et al., 1991). It is obvious that to increase efficiency of agricultural products; it is needed to increase the machine working efficiency. Therefore, an attempt has been made to identify the availability of suitable sensor to measure axle torque of the tractor under various field operations to match the direct power requirement of the tractor implement combination to avoid the wastage of power and to increase the working efficiency.

REVIEW OF LITERATURE

Recent evolution and merits in electronics and computer technology have made measurements of field performance of tractors and implements much easier. The analysis of the wheel load of a moving vehicle is of great importance for the basic investigation of wheel-soil interaction, tire characteristics as well as for the input and validation of vehicle dynamic simulations. Although the effects of dynamic wheel load on wheel-soil interactions and tractive performance have been considered in many investigations (Wiermann et al., 1999; Botta et al., 2002; Hyung-gyu et al., 2004), the dynamic wheel loads in these studies were kept at constant levels during a given test run. The lack of accurate data for transient wheel load in studying the dynamic performance of vehicle promotes further investigations.

Mahmoud et al. (1972) designed and developed a universal, brushless strain-gauge torque meter employing a force-balance system. Full scale reading of recording systems at any given torque range was secured by the use of changeable conical seat inserts and semi-conductor strain gauges. It is of high precision, universal, brushless, strain-gauge, torque meter, to operate over the range of 0 to 50 hp at 540 rev/min. Instead of sensing the twist on a small shaft and transmitting the electrical signal through brushes as done with conventional strain-gauge torque meters they used steel balls and conical shaped seat inserts to produce tension in a stationary steel shell. Strain gauges measure the tension in the shell when torque is applied.

Anderson et al., (1974) designed and developed a tractor rear wheel torque meter and stated the requirements of a driven wheel torque transducer for use in agricultural studies are: installation with minimum disturbance to tractor construction; negligible vertical and side load interactions; ready interchangeability among tractors; and low hysteresis and good linearity. Their design consists of a transducer that could be fitted between the driven wheel mounting, which is usually the brake drum, and the wheel itself would meet the stated requirements. The transducer had to be as thin as possible so as to interfere as little as possible with the original range of wheel track positions. They used a frequency modulated inductive coupling technique to transmit the signals from the revolving torque meter to a stationary receiver, thus, avoiding problems involved in the use of slip rings and brushes.

Musunda et al., (1983) used a set of strain gauges and a commercially available Frequency Modulated (FM) telemetry system on the drive shaft of a four-wheel drive (4WD) tractor for torque measurement. The FM telemetry eliminated the use of slip rings. Rowe and Spencer (1976) developed an instrumented tractor which is used for motion behavior studies on sloping ground. The rear axle torque is measured using a torque meter designed to fit between the brake drum of a rear wheel and the wheel disc. The design of the meter is such that, it is not sensitive to vertical or side loads and is only sensitive to torque about the rear axle. No slip rings are used in the design and signal transmission, which is frequency modulated from the rotating meter to stationary receiver is by inductive coupling.

Al-Janobi et al., (1997) has designed and developed a precision wheel torque and weight transducer for most common agricultural tractors. The developed transducer has to replace the standard wheel centre of the tractor under consideration and connect the wheel hub to the wheel rim. The transducer consists of an outer ring, which is connected to the wheel rim and an inner ring, which is connected to the wheel hub. The two rings are hinged together by three pairs of equally spaced links, and hence these links are tangential to a circle between the inner and outer rings. Each pair of links has a plain clevis bolt at one end and a factory built load sensing clevis bolt at the other end. Each load sensing clevis bolt is oriented so as to measure the force being transmitted along each pair of links. It is a little bit complicated and expensive.

Wolffenbuttel and Foerster (1990) conducted an experiment on axle torque measurement and concluded that, torque sensing has been performed by mainly using strain gauges connected to the axle with slip rings to enable the electrical contacting. They used non contact method for measurement of axle torque based on: (i) optical sensor, (ii) magnetic sensor, and (iii) capacitive sensor. Out of these sensors they preferred capacitive sensor. The capacitive torque sensor is basically a differential angular displacement sensor and is composed of two capacitive displacement sensors mounted on the axle and spaced a certain distance apart in order to enable the measurement of the twist angle (Figure 1).

Dong and Kyeong (1997) used slip ring based

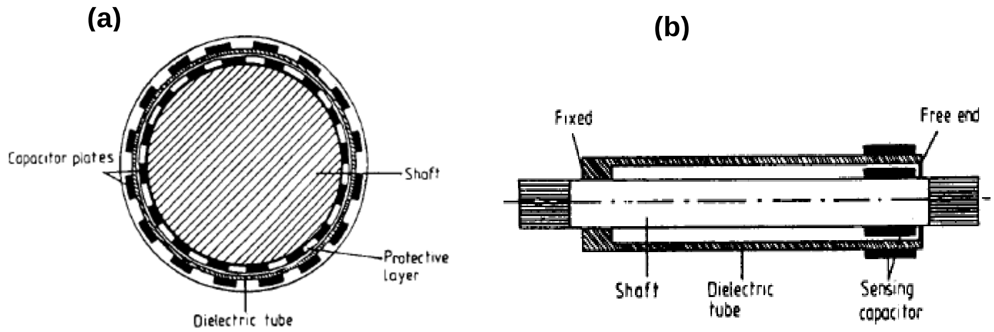

Figure 1. Capacitive torque sensor (a) Cross section and (b) longitudinal section.

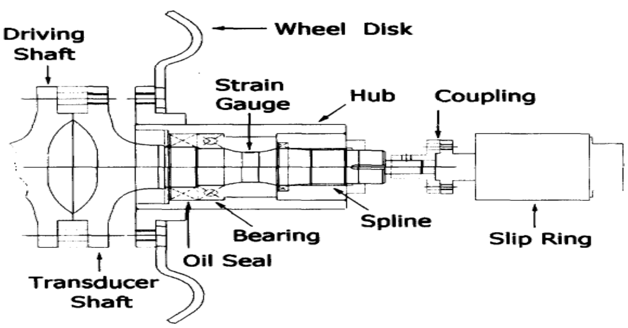

Figure 2. Set up for measurement of axle torque

technique to measure the axle torque requirement of different agricultural operations in which strain gauges have been mounted on axle shaft as shown in Figure 2. In order to evaluate accurately the effect of change in dynamic wheel load on the overall performance of an off-road vehicle, it is necessary to measure the soil reaction directly on the drive axle for analyzing the correlations between the dynamic wheel load and the wheel-soil contact forces as well as the wheel slip. Gobbi et al. (2005) developed an instrumented hub for measuring all the three forces and three moments acting on a wheel in order to characterize front and rear tractor tires both on road and off road. Furthermore, some commercial transducers are available for measuring forces and moments applied to wheel hub of both on road and off-road vehicles (Rupp and Grubisic, 1997; Spath, 2001; Decker and Savaidis, 2002), but they require complex hardware and materials, and are very expensive. It should be noted that, the use of instrumented hub for measuring wheel forces might essentially change the characteristics of wheel-tire assembly such as stiffness and weight. Therefore, it may be difficult to evaluate the real characteristics of the system. Accordingly, a new method which not only requires simple materials and design but also can adapt for different applications is necessary for measurement of the forces acting on wheels.

Measurements of wheel torque have received considerable attention in tractive performance studies. Instrumentation that measures the wheel torque and angular velocity would enable the tractive of the drive wheel to be investigated. Some researcher found a common method for wheel torque measurements was strain gauges with a slip ring mounted either at the outer end of the axles or on the top of the wheel mudguard to transfer the strain gauge signals to stationary recording equipment (Tompkins and Wilhelm 1982; McLaughlin et al., 1993; Al-Janobi et al., 1997). The other method, telemetry is that of actually transmitting the strain gauge signal through the use of radio-frequency transmitters mounted on shaft and picking up the signal by means of a receiver placed nearby (Palmer 1985; Watts and Longstaff 1989; Snyder and Buck 1990).

Kheiralla et al., (2003) has designed and development a drive wheel torque transducer for an agricultural tractor. The unit adopts a design having an extension shaft mounted in between the rear wheel axle flange and rear wheel rim of a tractor. Resistance type strain gauges were bonded on the shaft circumferential surfaces into a Wheatstone bridge circuitry for a standard torque measurement configuration. The bridge circuitry on each side of the rear drive axle was interfaced to a data acquisition system on board a tractor via a slip ring at the drive shaft end.

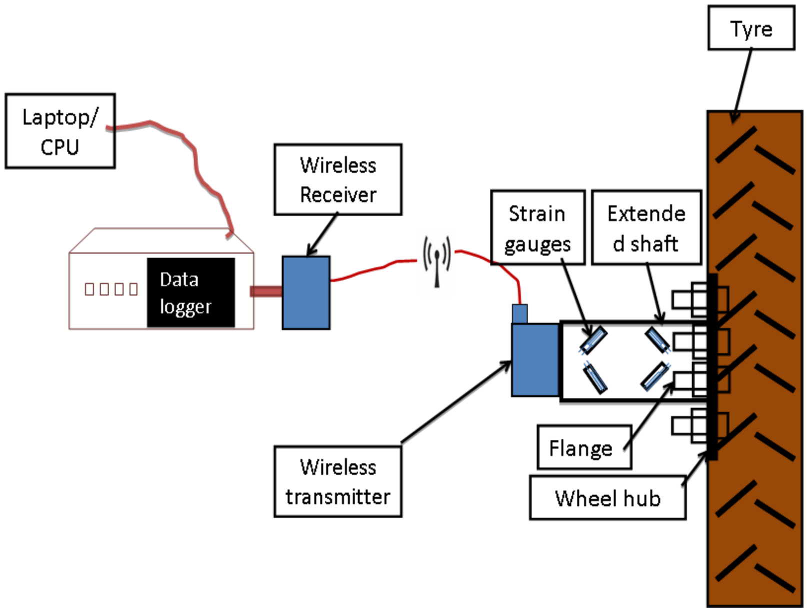

Figure 3. Interfacing of telemetry system to the axle torque sensor.

Besselink (2004) conducted an experiment on axle torque measurement, for this they have used torque load cells mounted on the input shaft. They used hydraulic system in which the pressure drop across a motor is a function of torque and rotational speed. With a set of calibration curves, the torque can be determined from the measured pressure drop and the rotational speed. An extra benefit in terms of analysis, is that, the torque distribution between the drive wheels is able to be determined because the torque input is measured for each drive wheel.

Gobbi et al., (2005), developed a new instrumented wheel hub for farm tractor tyres, developed with very simple hardware which can be connected directly (in a statically determined way) to the rim and, by means of strain gauges, it is able to measure all the three forces and three moments acting on a wheel hub. The steady-state characteristics of two farm tractor pneumatic tires have been measured both on an asphalt road and on soft soil. The longitudinal and the lateral slips have been applied and the corresponding longitudinal and lateral forces have been measured. The self-aligning torque has been measured as well.

Nang et al., (2009) developed an instrumentation system for measuring dynamic axle load of farm tractor and they introduced a simple method for monitoring transient axle load of a moving farm tractor and analyzed the influences of tire configuration and ground profile on axle-load variations. The tests were conducted on asphalt road and sandy loam field using a 2WD farm tractor at different tire inflation pressures and concluded that for measuring the vertical soil reaction is comparatively simple and capable of monitoring the dynamic axle load as vehicle moves on different ground profiles.

NOVEL TECHNOLOGY FOR DYNAMIC AXLE TORQUE MEASUREMENT

Most of the wheel torque transducers developed are designed to work in specific tractors for the required precision and usually are quite expensive. There is need for a general precision wheel torque transducer suitable for the most common agricultural tractors in the field. It is relatively easy to design a transducer to measure the torque transmitted to a tractor wheel. The main problem is in transmitting the torque signals from the revolving wheel to the stationary onboard data logging system. Also, it is difficult to measure the vertical and horizontal forces acting on a wheel in motion and there is no easily accessible interface between the revolving wheel and the tractor chassis.

Based on the past study it was observed that, a method for wheel torque measurements was strain gauges with a slip ring mounted at the outer end of the axle to stationary recording equipment is suitable with slight modifications. The life span of slip rings were too short due to continuous rotation of the sensor, therefore a method telemetry system was proposed to transmit sensor signal from the sensor to receiver and is shown in the Figure 3. This system mainly consists of an amplifier to amplify the strain gauge output to avoid errors at the microcontroller; microcontroller based electronic circuit to receive the signal from amplifier and to send the received signal to transmitter which in turn transmit signal to the receiver which is connected directly to a computer.

CONCLUSIONS

This paper has introduced a simple method of monitoring transient rear axle torque measurement sensor for proper tractor implement matching to increase the working efficiency. A simple telemetry system has been proposed to transmit the signal from the sensor to the data acquisition system or computer through a receiver with the help of a microcontroller based electronic circuit.

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