

A trailer-mounted PTO torquemeter system

C. VIGNEAULT¹, G. ST. AMOUR¹, D. J. BUCKLEY¹, D. I. MASSÉ¹, P. SAVOIE², and D. TREMBLAY²

¹Engineering and Statistical Research Centre, Research Branch, Agriculture Canada, Ottawa, ON K1A 0C6; and ²Agricultural Engineering Department, Laval University, Ste. Foy, QC G1K 7P4. Contribution no. I-909, received 11 March 1987, accepted 4 August 1988.

Vigneault, C., St. Amour, G., Buckley, D. J., Massé, D. I., Savoie, P. and Tremblay D. 1989. **A trailer-mounted PTO torquemeter system.** *Can. Agric. Eng.* **31**: 89-91. A torquemeter system for measuring the power and torque delivered by tractors to PTO driven implements is described. The system was mounted on a trailer which provides support for three-point hitch or drawbar-pulled equipment. Tests were conducted to compare the torquemeter data with dynamometer readings and to calibrate the torquemeter. The filed test data were stored on a cassette recorder which permitted transfer of the data to a computer. Programs were written to analyze, graph and report the data.

INTRODUCTION

Many agricultural implements are driven by the tractor PTO. To study and compare the energy efficiency of such implements, it is necessary to measure the power to drive them. As power is the product of the torque and the rotational speed, both parameters should be measured simultaneously to provide accurate power data. Industrial torque transducers and tachometers are available but must be adapted to withstand agricultural field conditions.

This paper describes a torquemeter system designed to provide the following characteristics:

- able to operate under field conditions;
- a data acquisition system and program to store data during field tests;
- a trailer to support the torquemeter and on which any PTO-driven implement can be attached;
- measurement accuracy with less than 2% error of full scale.

SYSTEM DESCRIPTION

Sensors

Many techniques for measuring the torque in rotating shafts exist (Norton 1969). The torque transducer selected (Lebow Model 1106-20k, Eaton Advanced Electronics, Troy, Mich.) provides an analog torque signal and a pulse output proportional to shaft speed (Anonymous). The torque is sensed with a strain gage bridge mounted on the rotating shaft (Fig. 1). Connections between the strain gage and the stationary transducer housing are provided by slip rings.

Shaft speed is detected by a magnetic pick-up which senses each tooth of a 60-tooth gear mounted on the rotating shaft. The transducer has a maximum torque measurement capacity of 2260 N m⁻¹ and maximum sensing speed of 6500 rpm. The transducer can support torques up to 150% of measurement capacity without damage and has a torsional stiffness of 294930 N m⁻¹ rad⁻¹. The strain gages are temperature compensated over a range of 21-76°C, with a temperature coefficient of $\pm 0.0036\%$ of full scale per degree Celsius. The overall

accuracy of the torque transducer over a temperature range of 10°C is thus expected to be within $\pm 0.2\%$ of full scale. The rated accuracy and repeatability of the torque transducer are within $\pm 0.1\%$ and $\pm 0.05\%$ of full scale rating, respectively.

The torquemeter is connected between the PTO of the tractor and the implement via shafts with universal joints on both ends (Fig. 2). This coupling method eliminates torque measurement errors that might be introduced by shear or bending stresses being transferred to the torque transducer shaft from the tractor or the implement. A bolted disk attachment system was designed to permit easy connection with standard PTO couplings (Anonymous 1982). The disks are 150 mm diameter by 12.7 mm thick with six attachment holes. A disk was attached to each end of the torque transducer shaft to accommodate several standard PTO couplings. The torquemeter assembly can thus be connected between the components of any standard PTO transmission system.

Data acquisition system

A data acquisition system (DAS) was constructed under contract by TES Ltd., Ottawa, Ont. according to specifications by Agriculture Canada. The DAS continuously monitors the signals from the transducer, converts the analog torque and pulsating speed signals to digital values, and displays them on a liquid crystal display every second. A resettable timer provides time data and can be reset at the start of each test. The torque, speed and time data were stored on a cassette recorder (Memtec Model

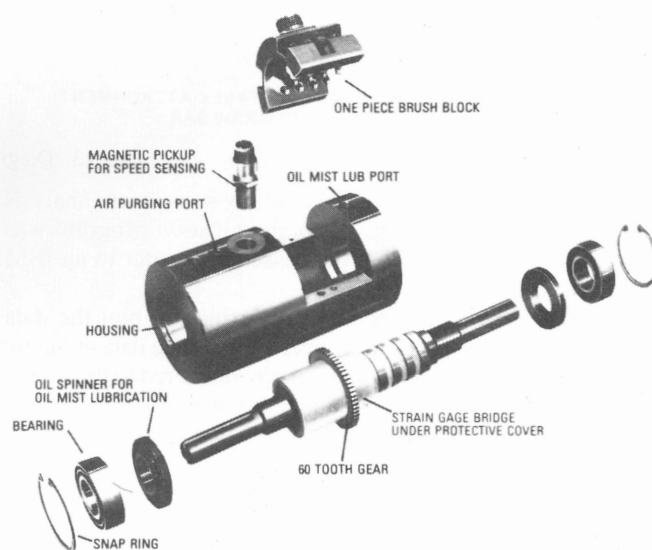


Fig. 1. Exploded view of rotating shaft torque sensor with slip rings (Lebow products torque sensor and dynamometer catalog 250c).

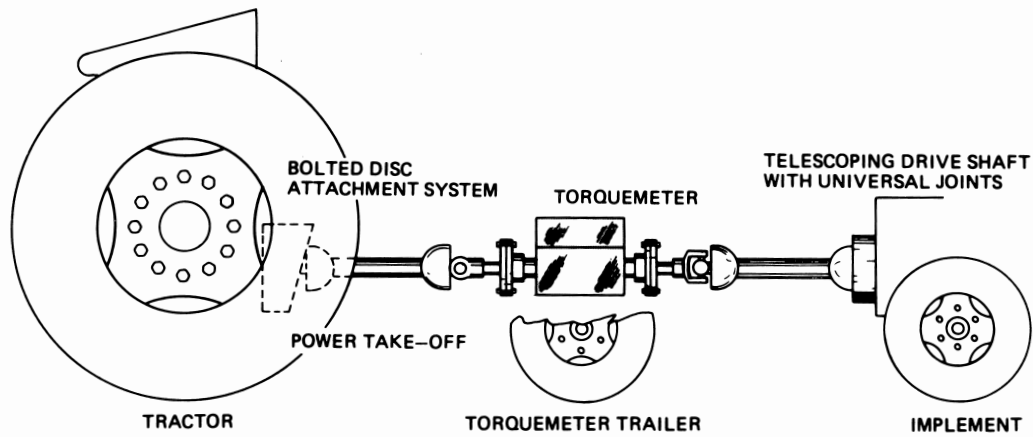


Fig. 2. PTO tractor, implement and torquemeter assembly.

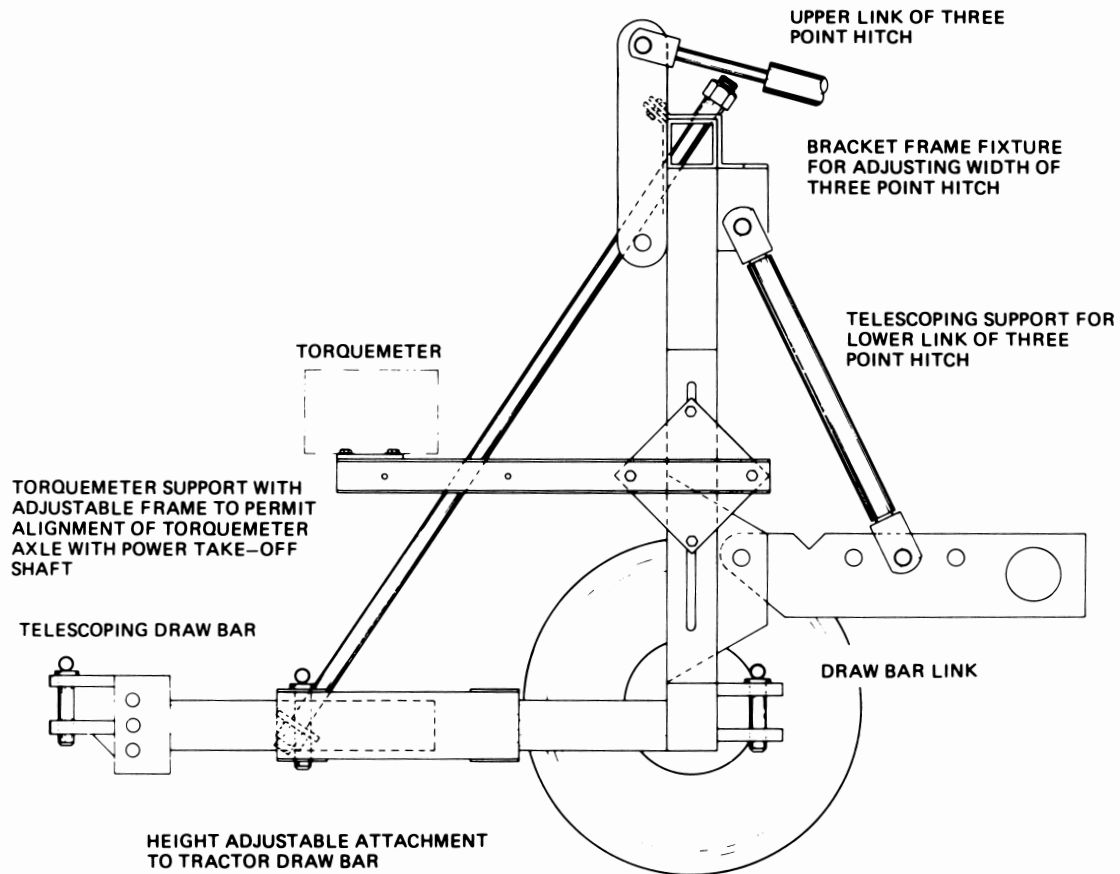


Fig. 3. Diagram of the trailer.

2500, MFE Corp., Salem, N.H.) to allow subsequent analysis of data on a microcomputer. A communication program was used to transfer the data from the cassette recorder to an IBM PC computer.

A program was written to analyze, print and plot the data on the computer. The program converts the torque data to metric units and plots the torque and total energy delivered to the implement as a function of time. The equation used to calculate the energy transferred through the torquemeter was:

$$E = 2 \pi \tau n t$$

where:

- E = energy (J),
- π = torque ($N \cdot m$)
- n = revolution (s^{-1}), and
- t = time (s)

Trailer design

The trailer was constructed with a three-point hitch attachment and a drawbar to support or pull any implement under test. The attachments were designed to meet ASAE Standards S203.10 (Anonymous 1982), S217.10 (Anonymous 1979) and S349.1 (Anonymous 1980) to allow testing of implements designed for tractors in category three or below and under 168 kW. The width and length of the trailer (Fig. 3) were adjustable, to allow attachment to any tractor size in these categories. The trailer was designed to support an implement with a maximum weight of 37.11 kN as specified in the standard S217.10 (Anonymous 1979). An enclosure was mounted on the side of the trailer to house the DAS.

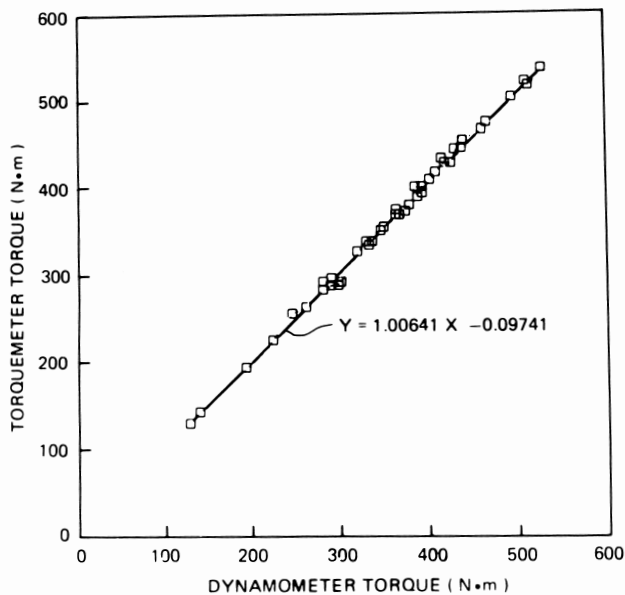


Fig. 4. Comparison of the torque readings from the torquemeter (y) and the torque applied by the dynamometer (x).

TEST PROCEDURES, RESULTS AND DISCUSSION

The dynamometer system used to test and calibrate the torquemeter was a Clayton Stationary Dynamometer 17-300 cm (EL Monte, Calif., U.S.A.). The dynamometer has a turbine to which the mass of water is adjustable. A scale is connected to the turbine casing to measure the torque developed by the turbine. The lever length of the dynamometer is 3200 mm. The torque developed by the dynamometer was calculated by multiplying the lever length by the force measured. The accuracy of the dynamometer was found to be $\pm 2\%$ of full scale. This error corresponded to 2% of the minimum torque used to calibrate the torquemeter and represented the maximum error inherent in the calibration procedure. Seven test series were performed in a range between 135 and 540 N m. The Clayton dynamometer readings were found systematically lower than those of the torquemeter. However, the difference is small (8.1 N m) and practically constant throughout the tested range. This difference was subtracted from the torquemeter results by the computer program and the corrected readings were compared with those of the Clayton dynamometer (Fig. 4) to establish the relationship between torquemeter readings and applied torque.

A linear regression was calculated and gave a slope of 1.00641 and an intercept of -0.09741 .

A Student's *t*-distribution was performed. This confirmed that the slope and intercept values were not significantly different from their theoretical values even though the accuracy of the Clayton dynamometer is less than the specified accuracy of the torquemeter (2% compared to 0.2%).

An electronic tachometer was used to verify the accuracy of the speed sensor in the torquemeter and no detectable errors were found between 100 and 1200 rpm.

The torquemeter was field-tested with manure pumps and hay harvesters. These tests proved that the torquemeter is rugged enough to be used under field conditions. However, vibrations in the trailer, created by the tractor or the implement, disturbed the operation of the cassette recorder. The cassette recorder was removed from the trailer and installed on the tractor to solve the problem.

CONCLUSION

A trailer-mounted torquemeter for monitoring the torque and energy delivered to PTO-driven implements was developed. A data acquisition system with a cassette recorder provided a means for recording torque, speed and time data in the field. The torquemeter performance was compared with a standard dynamometer and the results indicated good correlation and accuracy. The torquemeter was field-tested with PTO-driven manure pumps and forage harvesters showing that the torquemeter is suitable for field use.

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