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A Stationery Loading Unit for Measuring Farm Tractors Power in PTO

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ABSTRACT

The torque and power of a tractor are two important decision making factors when buying an agricultural tractor. These factors are generally extracted through PTO tractor testing. Such testing is accomplished using a device called dynamometer. Since commercial dynamometers are expensive, research efforts are encouraged to develop similar dynamometer for tractor tests. The aim of this study was to fabricate and adapt an automobile brake system to become a PTO shaft brake loading system for measuring torque and power. A commercial torque transducer was fixed to the tractor PTO for both toque and rotational speed measurements. Tests were performed on a Helwan 35 IMT tractor with 26.12 kW of power. The laboratory demonstration test showed that the measurement of torque magnitude at PTO of the tractor was satisfactory. The results were compared to those obtained through loading the same tractor with a shop AW commercial dynamometer and the relative error between the data sets was -2.59%. A t–test showed no significant differences in the averages of power. Considering the results of this study, the PTO shaft brake loading system can feasibly applied to tractor performance evaluation.

Keywords: Disk brake, tractor, PTO, power, dynamometer.

INTRODUCTION

In Egypt, Agricultural tractors are the prime power unit for most agricultural operations such as land preparation and field transportation. The performance data of a tractor are essential for farm machinery management and for manufacturers (Sharma *et al*., 2016). Official tractors testing aims to determine a tractor's torque and power through Power take-off (PTO). Power on PTO is important information needed for deciding which agricultural tractor to buy. It can also be used to assess the performance of different makes and models of tractors (De Farias *et al*., 2016; Grisso *et al*., 2009).

A brake is a device by means of which artificial frictional resistance applied to moving machine member, in order to stop the motion of a machine (Reddy *et al*., 2013). A dynamometer is an instrument for determining power, usually by the independent measure of force, time, and the distance through which the force is moved. Dynamometer may be classified as brake, drawbar, or torsion, according to the manner in which the work is being applied. In addition, it may be classified as absorption or transmission, depending on the disposition of the energy. For testing engines, it must include the following three essential elements: a means for controlling torque, a means for measuring torque, a means for measuring speed. A dynamometer is acceptable for measuring tractor performance as in the study conducted by Sumer *et al.* (2010), who determined the differences between three tractors with similar technical specifications, by means of a PTO dynamometer (Eddy-current) under laboratory conditions. Data analysis showed that the torque values for the three tractors varied directly proportional to the increase in the PTO load steps. Jiankang *et al*. (2011) used a direct current electric dynamometer to determine performance of a tractor PTO. De Farias *et al.* (2017) obtained the values for the torque and effective power of a tractor by using electric parasitic current (Foucault currents) dynamometric brakes. Tamsanya *et al.* (2009) predicted fuel consumption and pollutant emissions of passenger cars using a chassis dynamometer. Bietrasato *et al.* (2015) estimated brake specific fuel consumption of a farm tractor engine using a PTO dynamometer indirectly.

Determining the torque and power of any tractor through Power take-off is necessary, as because they are important factors in farm machinery operation. Therefore, a dynamometer device is required and commercial dynamometers are expensive. Thus, the primary objective of this study was to develop a loading unit for tractor loading during tractors tests. The objective was also to evaluate the feasibility and accuracy of the developed loading unit compared to an AW commercial dynamometer.

MATERIALS AND METHODS

Description of the developed loading unit

The developed loading unit and its accessories were constructed at the Testing and Research Station for Tractor and Farm Machinery in Alexandria Governorate, Egypt. The loading unit was a part of the brake system of an automobile. It was a disk brake. A disk brake (Figure 1) is often used in automobile transmission system to halt a vehicle (Saravanan *et al*., 2016). It is a type of brake that uses calipers to squeeze pairs of pads against a disk in order to create friction, which retards the rotation of an axle either to reduce its rotational speed or to hold it stationary (Babukanth and Teja, 2012). The brake caliper is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disk. In this study, the brake caliper was forced by pulling wire (Abhang and Bhaskar, 2014). In this study, the end of the brake shaft was joined to an adapter to engage with tractor PTO shaft. Figure (2) shows the utilized disk brake. A picture of the entire loading unit is shown in Figure (3) and Figure (4). The dimensions of its frame are shown in Figure (5).

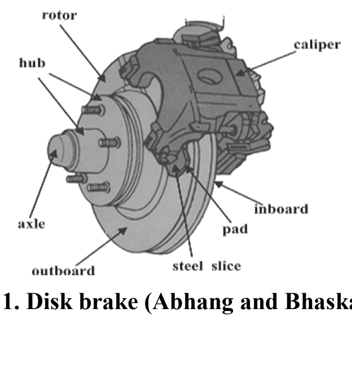

Figure 1. Disk brake (Abhang and Bhaskar, 2014).

Figure 2. Brake shaft jointed to an adapter to engage with tractor PTO shaft

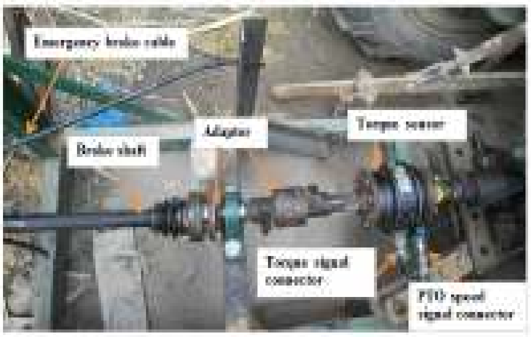

Figure 3. Torque sensor attached to tractor PTO and brake shaft

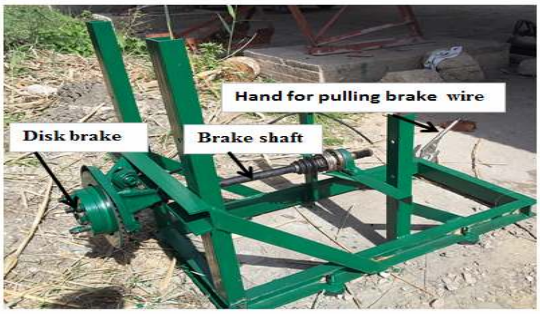

Figure 4. Loading unit

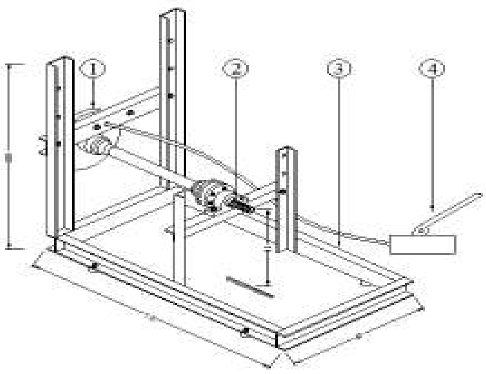

Figure 5. Dimensions of frame for loading unit (1: disk brake, 2: PTO adaptor, 3: frame and 4: Hand for pulling brake wire).

The maximum torque applied on the brake shaft was calculated using the following formula (Yahya *et al*., 2004):

$$P = \frac{2\pi NT}{60000} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Where; P is power output in kW, N is PTO revolution in rpm, and T is torque in Nm. A Helwan 35-IMT tractor having a maximum power of 26.12 kW at 2200 rpm operating at standard PTO speed of 540 rpm would produce a maximum torque of 462.14 Nm on the shaft. The maximum shear stress in the solid shaft is subjected to a torque load, which is given as follows (Allan, 1980; Loewenthal, 1984):

$$\tau = \frac{16T}{\pi D^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where: τ is the shear stress in MPa, T is the applied torque in MN.m, D is the brake shaft diameter of 25 mm. The calculated shear stress (τ) was 150.7 MPa. The allowable shear stress for the solid shaft is given as follows (Yahya *et al*., 2004):

$$\tau_{allow} = \frac{0.57S_{yt}}{f_s} \quad \ldots\ldots\ldots\ldots(3)$$

Where: τ_{allow} is the allowable shear stress in MN/m^2, S_{yt} is the yield strength in MN/m^2, and f_s is the dimensionless safety factor and it was selected to be 1.5 (Loewenthal, 1984). The material used for the brake axle is hardened-steel having a Young's Modulus of 193 N/mm$^{2;}$ yield stress of 720 N/mm^2 and a tensile ultimate strength of 784 N/mm^2 (Ahire and Munde, 2016). Based on the given brake shaft material strength, the brake shaft is suitable for the applied torque.

Torque sensor

The torque on the PTO was measured by a commercial torque sensor (type Lebow, model 1228-20 K, capacity 20000 IN. Ib. It was connected to the brake shaft and to the tractor PTO through adaptors as shown in Figure (3). Rotational PTO speed was measured utilizing a magnetic pick-up frequency sensor which was located above 60 teeth (target gear), which was fixed on the torque sensor (Figure 6).

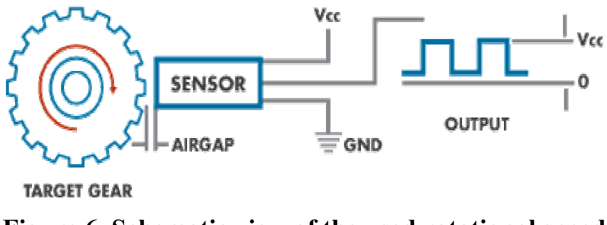

Figure 6. Schematic view of the used rotational speed sensor

Calibration

A static calibration test of the torque sensor was carried out to obtain values to the Daytronic data PAC model 10k4 for calculating the torque. The calibration test for torque transducer was performed as procedures described by El-Gwadi (2005). Dead weights, each weighing 20kg were added. The torque arm was 60cm long. Figure (7) illustrates calibration curve with high correlation in loading mode.

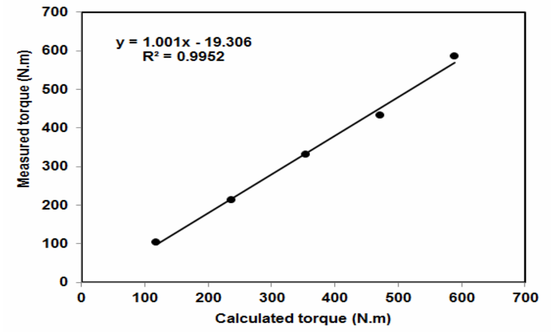

Figure 7. Calibration torque sensor

Data acquisition system

A Daytronic data PAC model 10k4, which included different channels, was used. These channels could measure the signal of strain gage circuit output in the desired SI units of "Nm" and rotational speed of "rpm". A laptop computer was used for data recording and storage, as shown in Figure (8). The PAC unit conditioned the output signal into proper engineering units and the computer stored these incoming data and communicated with the data PAC.

Figure 8. The Daytronic data PAC model 10k4 and laptop computer

Demonstration test

Generally, tractor tests are conducted to assess power-takeoff (PTO) performance. In this study, the developed loading unit was utilized to apply varying loads by pulling brake wire by the hand (Figure 5) to slow PTO rotation until engine stop. The tests were conducted in open air. Moreover, special arrangements were done to measure PTO speed (Figure 6). During the tests, the torque and rotational speed were recorded every 1 second. The load applied by the unit followed the operating curve of the engine at full throttle. The measurement was taken in steps, starting from the minimum PTO speed to the maximum PTO speed (540 rpm). This was observed on laptop screen.

Commercial AW shop PTO dynamometer

To compare the power obtained by utilizing the developed loading unit, an AW commercial PTO dynamometer was utilized to measure the PTO torque and PTO speed. Its model was Nebraska 200, Torque rating1355Nm, range (PTO & engine) speeds is 0 -3600 rpm. Before the test, some arrangements were required for the dynamometer as seen in its catalogue.

Statistical analysis

The data were statistically analyzed in order to verify the significance of the differences between the power values obtained by the developed unit and the observed values from the AW dynamometer, through the t-Student test, with a 5% probability error ($P \geq 0.05$).

RESULTS AND DISCUSSION

The variations of torque and power with PTO speed for a Helwan 35 IMT tractor that was by applying steps load by the developed loading unit in the test are shown in Figure (9). The maximum power was about 17kW and occurred at a PTO speed of 425 rpm and at a torque of 392 N.m. By comparing the PTO powers by t-Test: Paired Two Sample for means. A different percentage is seen in the mean value by relative error of -2.59% without significant level when analyzing the power values obtained by the developed loading unit and by AW dynamometer as shown in Table (1). The low value of power observed in the developed loading unit might be explained by the controlling the applied load on the PTO shaft.

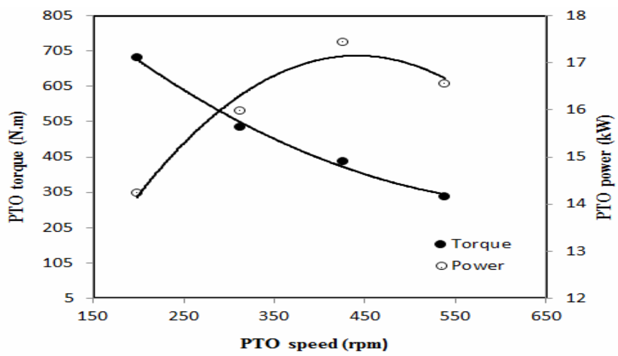

Figure 9. Variations of torque and power with PTO speed for Helwan 35 IMT tractor which was loaded by the developed loading unit in procedures.

Table 1. Comparison between PTO powers by means t-Student test (P≥0.05), for Helwan 35 IMT tractor.

	PTO power obtained by applying load by the developed loading unit	PTO power obtained by applying load by AW dynamometer
Mean	16.06343	16.40843
Variance	1.824445	2.273905
Observations	4	4
Pearson Correlation	0.985386	
Hypothesized Mean Difference	0	
df	3	
t Stat	-2.37712	
P(T<=t) one-tail	0.048936	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.097872	
t Critical two-tail	3.182446	

CONCLUSION

A loading unit that was a part of disk-type brake system of an automobile was developed and utilized to apply a load on the PTO of a tractor having 26.12 kW of power, instead of using a commercial dynamometer. The end of the brake shaft was jointed to an adapter to engage with the tractor PTO shaft. A commercial torque transducer was used to measure the PTO torque and the rotational PTO speed. A different percentage is seen by relative error of -2.59% without significant level when analyzing the power values obtained by applying a load by the developed loading unit and by AW dynamometer.

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وحدة تحميل ثابتة لقياس القدرة على عمود الإدارة الخلفي لجرار زراعي

ممدوح منياوي

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يعتبر عزم الدوران والقدرة من الجرار معلومات مهمة لصانع القرار عند شراء جرار زراعي. ويتم الحصول على عزم الدوران والقدرة من الجرار من خلال اختبار معملي بمساعدة وسيلة تحميل تسمى دينامومتر. والجهود البحثية لها دور مهم في إيجاد وسائل تحميل مماثلة للدينامومتر التجاري ذي التكلفة العالية. لذا، الهدف الرئيسي من هذه الدراسة تطوير واستخدام منظومة فرامل لسيارة لتحميل عمود الإدارة الخلفي للجرار لغرض قياس عزم الدوران والقدرة. وتم وضع محس للعزم ولسرعة عمود الإدارة الخلفي للجرار ومن خلال يد الفرملة تم تحميل الجرار وتم قياس العزم والسرعة . وأجريت الاختبارات لجرار حلوان 35 IMT جرار قدرته 26.12 كيلوواط. وأظهرت القياسات بوحدة التحميل أن عزم الدوران والقدرة على عمود الإدارة الخلفي للجرار كانا متقاربان عند المقارنة ما ما تم الحصول عليه من خلال وحدة تحميل تجارية بمتوسط خطأ نسبي قدره 2.59- %. ومن خلال النتائج وجد أن الوحدة قادرة على الاستخدام اثناء اختبار الجرارات الزراعية ذي القدرة المنخفضة وتوصى الدراسة بتصنيع الوحدة محليًا وذلك لحساب القدرة المستنفذة على عمود الأدارة الخلفى للجرار مباشرة, الأمر الذي يغني الجهات البحثية ومحطات الاختبارات المحلية عن شراء الدينامومترات غالية الثمن.