Characteristics of transmission efficiency in power driveline of agricultural tractors

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ABSTRACT

Complex gear shifting and high speed-reduction ratio reduce the transmission efficiency in power driveline of agricultural tractors. According to a field test, the power transmission efficiency of a tractor in transporting operations was estimated about 70%. However, the actual efficiency was found by the experiment to fluctuate in a range of 56 to 87%. Therefore, the constant efficiency model commonly used for a simulation of power drivelines is not likely to simulate its performance more accurately. In order to predict power transmission efficiency more accurately, a new model was proposed and the new concepts of the maximum efficiency and sticking torque were introduced. The error mean between the measured and the predicted efficiencies was about 2.3% in mean. The new model reflecting the transmission characteristics in the power driveline of tractors could be used to analyze and predict the power transmission performance of tractors more accurately.

Key Word : transmission, maximum efficiency, sticking torque

INTRODUCTION

Tractor power is transmitted from the engine to the final drive wheels through the power driveline which is comprised of clutch, gear box, differential gears and final drive shafts. The engine power has a property of high speed and low torque. However, tractor needs a power of low speed and high torque to perform farm works such as tillage, rotovating, transportation, leveling and so forth. The gear box plays a role of converting the engine power to the type of power that tractor needs to work.

Tractor transmission has following characteristics. First of all, the speed-reduction ratio is very high. The ratio at the creep speed often is about 2000:1 while passenger cars have a ratio of about 20:1. The tractor transmission accordingly requires a number of shifting gears. The number of shifting gears in a tractor is usually 8-16. The gear box of the tractor transmission is composed of three shifts, front-rear shift, main shift and sub shift. Since farm works require various types of torque and speed combinations the tractor transmission must satisfy such requirements. Lastly, the driveline of the tractor transmission is plural. It is usually equipped with three drivelines, rear wheel driveline, front wheel driveline and power-take-off driveline. The rear wheel driveline is a main driveline transmitting power to propel the rear wheels. The front wheel driveline is optional to propel the front wheels when a large traction force is required. The pto driveline transmits power to drive the implements attached to the tractor. These characteristics of the tractor transmission have made the structure of its power driveline very sophisticated, which is also inefficient in power transmissions.

The transmission efficiency of tractors has not been studied actively. Most of the studies done were mainly concerned with passenger cars to which a constant efficiency model was commonly applied. The constant efficiency model assumes that the efficiency is always constant regardless of the transmitted torque and speed. Lucas(1984) reported that the efficiency of a manual shift transmission for passenger cars was about 90% but the actual efficiency fluctuated from 70 to 110% during the cars was running. Taborek (1957) reported that the overall transmission efficiency can be obtained by multiplying the efficiencies of the components in the driveline. Transmission efficiencies of clutches, high reduction gears, low reduction gears, differential gears and bearings are estimated to be about 99%, 95%, 98%, 95% and 98-99%, respectively.

In this study it was intended to evaluate the actual power transmission efficiency of a tractor driveline and analyze its characteristics. Using the results of the analysis a model was developed to predict the power transmission efficiency of tractor driveline more accurately.

MATERIALS AND METHODS

The tractor used for the efficiency measurements was a medium sized diesel tractor of which rated power and speed were respectively 41 ps and 2600 rpm. The weight of the tractor was 1855 kgf. Fig. 1 shows a schematic diagram depicting the power transmission of a tractor. The transmission is a type of manual shift and composed of a clutch, a gear box, differential gears, final reduction gears and final drive shafts. The clutch is a single disk and dry type. The gear box is composed of three shifts, a directional shift(Front, Rear), a main shift(1, 2, 3, 4) and a sub shift(High, Mid, Low, Low Low).

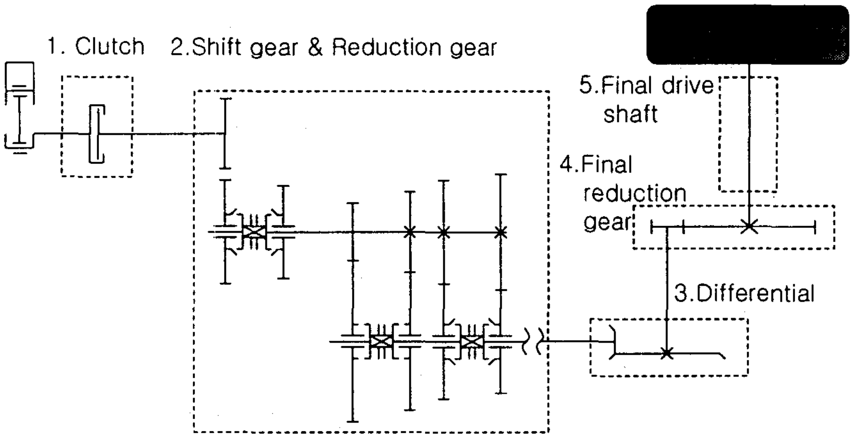

Fig. 1. Schematic diagram of power driveline of the tractor transmission.

To evaluate the efficiency of the tractor driveline, the torques and speeds were measured at the input shaft of the transmission and at the final drive shaft of the tractor. A strain-gaged torque meter was installed on the input shaft of the transmission. A non-contact telemetry system was used to transmit the measured signals to the data logger. The strain-gaged wheel torque meters were also installed on the final drive shafts of the

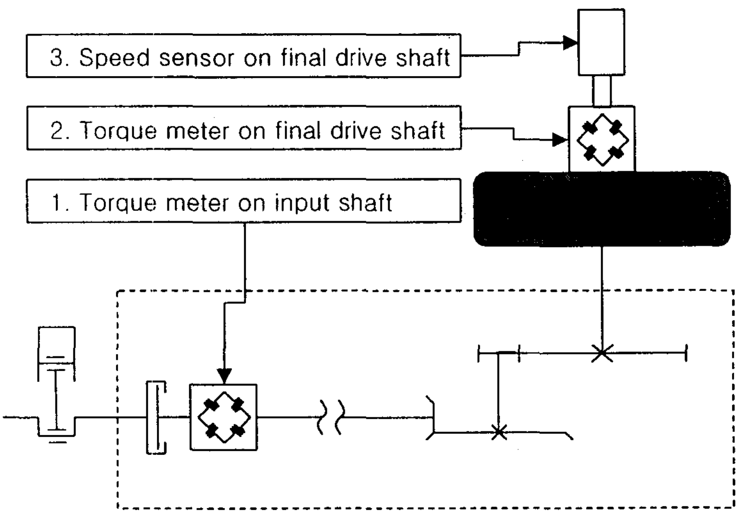

Fig. 2 Torque meters and speed sensor mounted on the tractor.

rear tires. To measure the speed of the final drive shaft, a rotary encoder was mounted on the outside of the wheel torque meter as shown in Fig. 2.

Because power is a product of torque and speed, both should be measured to calculate the power. Since the power dirveline can be assumed rigid, a linear relationship between the speeds of the input shaft and the final drive shaft can be made. Thus, the measurement was made only for the speed of the final dirve shaft and the speed of the input shaft was calculated using the relationship.

The torque and speed were measured during the transporting operations. The tractor pulled a trailer carrying a load of 2 tons on the inclined farm road of 2-3 degrees. When the tractor traveled with a constant speed litter load was exerted on the tractor. However, in the case of a quick start a heavy inertia load acted on the tractor.

RESULTS AND DISCUSSION

Fig. 3 shows the time histories of the torques measured at the input shaft of the transmission and the final drive shaft of the tractor for 15 seconds. The speed of the final drive shaft was also given in Fig. 3. The engine governor was set to have an engine speed of 2600rpm before the measurement begin and kept unchanged during the measurement. The torque load acting on the input shaft increased rapidly up to 200 N.m at the time of starting and declined thereafter to a constant level of 50 N.m. The input shaft of the transmission was overloaded at the time of starting. The rated and maximum engine torques were about 112 N.m and 130 N.m, respectively. The torque loads acting on the input shaft and the final drive shaft showed a similar trend although their magnitudes

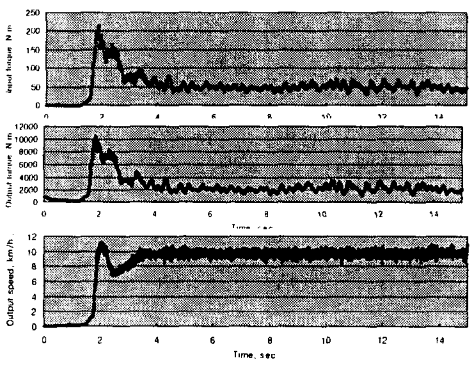

Fig. 3 Measured torque and speed

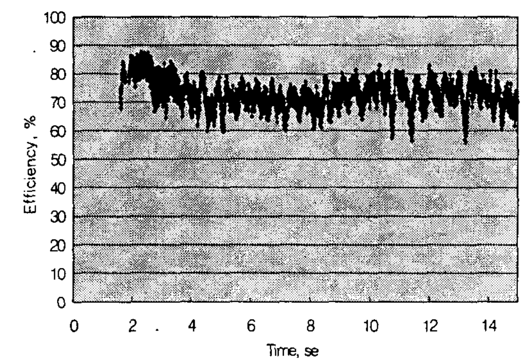

Fig. 4 Transmission efficiency determined using the measured data.

were quite different.

Fig. 4 shows the power transmission efficiency calculated using the data of Fig. 3. The efficiency fluctuated in a range of 56-87% and the mean efficiency was estimated to be 72.5%. As shown in Fig. 4 the transmission efficiency is not constant but variant during the tractor operates.

From the data of Figures 3 and 4, it was noted that the transmission efficiency varied with torque. The efficiency fluctuated as the torque did. A new model developed in this study was based on such a torque-variant efficiency.

The model was comprised of two components, a maximum efficiency and a sticking torque. The maximum efficiency is that component of the efficiency which varies in proportional to the transmitted torque. The sticking torque is that component of the efficiency which is induced from the constant component of the power loss. The model may be expressed mathematically as Eq. (1).

$$\begin{aligned} \eta_{TM} &= \frac{T_{out}}{T_{in} \cdot N} \times 100 \\ &= \eta_{\max}\left[1 - \frac{T_{stick}}{T_{in}}\right] \times 100 \qquad \text{when } T_{in} \geq T_{stick} \\ &\quad 0 \qquad\qquad\qquad\qquad\quad \text{when } T_{in} < T_{stick} \end{aligned} \tag{1}$$

where, η_{TM} = actual efficiency of transmission, %

η_{max} = maximum efficiency of transmission, %

T_{out} = torque at final drive shaft, N.m

T_{in} = torque at input shaft, N.m

N = reduction ratio of selected shift gear

T_{stick} = sticking torque of transmission, N.m

From the data of Fig. 3, the maximum efficiency was determined as 86.9 % and the sticking torque as 8.6 N.m. Fig. 5 depicts the transmission efficiency as a function of the input torque. It was noticed that the efficiency was zero when the input torque was less than the sticking torque. For the input torques greater than the sticking torque, the efficiency increased rapidly up to 70%. When the input torque was the same as the rated engine torque i.e. 112 N.m, the efficiency was 80%. For the input torques greater than about 112 N.m the efficiency still increased but the increasing rate was very low.

Fig. 6 shows a comparison between the predicted and measured efficiencies. The predicted efficiency was computed by using Equation (1). The measured efficiency was

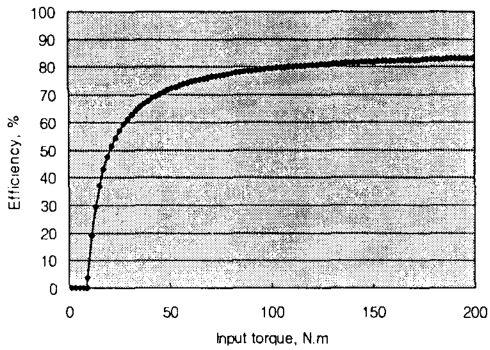

Fig. 5 Predicted efficiency versus input torque.

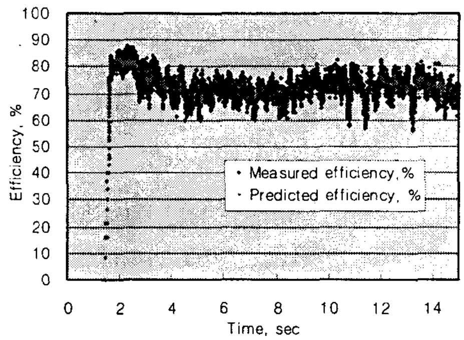

Fig. 6 Comparison between measured and predicted efficiencies.

determined from the torques measured at the input shaft and the final drive shaft, respectively. The predicted and measured efficiencies varied in a similar fashion. The error mean between the measured and predicted efficiencies was 2.3% and its standard deviation was 1.8%.

The maximum efficiency is obtained when an infinitely large torque was transmitted. The maximum efficiency also varies with the loss of power which is proportional to the transmitted torque. Frictional force is exerted on all parts of the power driveline such as gears, clutches, bearings, etc and causes a power loss. The frictional force is proportional to the torque-induced force normal to the frictional surface. Therefore, the maximum efficiency can be determined from the loss of power which is proportional to the transmitted torque.

The sticking torque is the minimum torque required to overcome the friction of the power driveline. The sticking torque can be represented by a loss of power which is constant regardless of the transmitted torque. Even though a power is not transmitted through the driveline, all parts in the driveline are still subjected to a load due to their weights. Especially, a normal load by the rear wheels acts on the bearings in the final drive shaft. Such forces generate frictional forces and act as a source of sticking torque.

The transmission gear engaged for the transportation to measure the torque loads was sub shift H. The load measurement was conducted with 4 sub shift gears H1, H2, H3 and H4. Table 1 shows the maximum efficiency and the sticking torque determined from the measured torque loads and speed with each gears. Regardless of the shift gears the maximum efficiency was estimated to be about 87% and the sticking torque about 10 N.m.

The maximum efficiency and the sticking torque can be determined from the torque loads and speed measured at the input shaft of the transmission and at the final drive shaft of the tractor. If the maximum efficiencies and the sticking torque for the parts in the driveline are all known, an overall efficiency can be obtained by multiplying them.

Table 1. Maximum efficiency and sticking torque with sub shift gears H1, H2, H3 and H4

	η_{max}, %	T_{stick}, N.m
H1	86.9	8.6
H2	86.7	9.8
H3	86.0	10.7
H4	86.9	9.7

SUMMARY AND CONCLUSION

The power transmission efficiency for the power driveline of a tractor was investigated experimentally and its characteristics were revealed. In the experiment, the torque loads and speeds were measured at the input shaft of the transmission and the final drive shaft of the tractor during transporting operations on farm roads. The transmission efficiency computed using the measured data fluctuated from 56% to 87%, which indicated that the efficiency is not a constant value but variant depending on the transmitted torque. A new model for the transmission efficiency was developed using this concept of variable characteristics of the actual efficiency. The efficiency predicted by the model was compared with that determined using the measured data. The predicted and measured efficiencies varied in a similar fashion. The error mean was 2.3% and its standard deviation was 1.8%. The model was evaluated as capable of predicting the performance of power transmission of tractors more accurately.

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