Analysis of load severeness for the transplanter PTO by planting condition

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Introduction

Background

- The global market for transplanter in 2013 reached $10,650 million dollars, and it is expected to reach to $15,150 million dollars in 2018
- Farmers are demanding transplanter that can fast transplanting for save time and money
- Transplanting speed affects the load on the transplanter, fast transplanting affects the fatigue life of the machine, and reduces durability

Purpose

- The purpose of this study was to analyze the load severeness of the transplanter PTO shaft during field operation by planting condition.

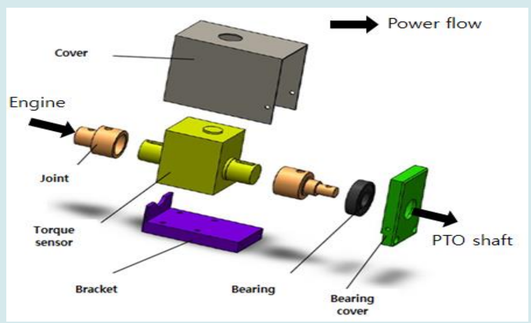
Materials and Methods

Specification

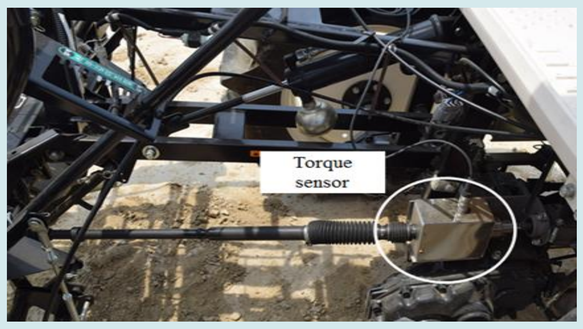
- The transplanter (PF2R, Yanmar, Japan) used in this study had a total mass of 615 kg and dimensions of 3,160 × 1,725 × 1,925 mm (length × width × height)
- The rated power of the transplanter was set at 7.1 kW at an engine revolution speed of 3,600 rpm

Load measurement system

- In order to measure the loads acting on the PTO shaft of transplanter, a load measurement system was installed on the transplanter
- A load measurement system was constructed with torque sensors (TRS605, FUTEK, USA) to measure the torque of a PTO shaft, a measurement device to acquire sensor signals, and embedded system to calculate the damage sum



(a) Torque sensor assembly diagram



(b) Installed torque sensor transplanter PTO shaft

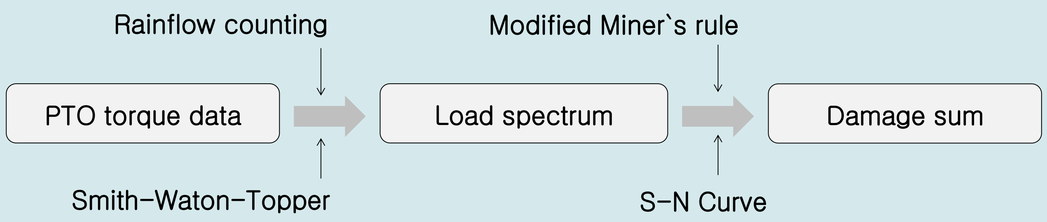
Fig. 1 Torque sensor used in this study

Field experiments

- Field experiments were conducted four planting distances (26, 35, 43, and 80 cm) and three planting depths (level 1, 5, and 10) on a field with similar soil conditions
- The ground speed was selected as driving gear levels 2 (0.9 m/s)

Load analysis

- The load of the transplanter PTO shaft was analyzed by collecting load signals, analyses of load spectra, and calculations of damage sum



- The load data was converted to a load spectrum using the rain-flow counting method and SWT (Smith Watson Topper) equations in Eq. (1)

$$T_e = \sqrt{(t_a + t_m)t_a} \quad (1)$$

where T_e is the equivalent torque (Nm), t_a is the torque amplitude (Nm), and t_m is the mean torque (Nm)

- The number of cycles had to be extended to the total transplanter usage time in Eq. (2)

$$N_T = 3600NLh \quad (2)$$

where N_T is the total number of load cycles (cycles), N is the number of cycles of the measured torque (cycles/s), L is the lifespan of the transplanter (year), and h is the annual usage time (h/year)

- The S-N curve was obtained for the material of the PTO shaft, SCM 420H, using the ASTM standard 2004 in Eq. (3)

$$N = 10^{\left(6-6.097\log\left(\frac{S}{223}\right)\right)} \quad (3)$$

where N is the number of cycles and S is the shear stress (MPa)

- To calculate the damage sum, the equivalent torque of the load spectrum was converted to stress in Eq. (4)

$$S = \frac{16T}{\pi d^3} \quad (4)$$

where S is the stress (MPa), T is the equivalent torque (Nm), and d is the diameter of the shaft (mm)

- The damage sum was calculated by dividing the number of fatigue life cycles by the number of cycles

$$D_t = \sum_{i=1}^{k} \frac{n_i}{N_i} \quad (5)$$

where D_t is the damage sum, n_i is the number of cycles, and N_i is the fatigue life (cycles)

Results and discussion

Torque data

- The average torque on the transplanter PTO shaft increased significantly as the planting distance decreased from 80 to 26 cm
- Also, the average torque on the PTO shaft increased as the planting depth increased from level planting depth level 1 to 10

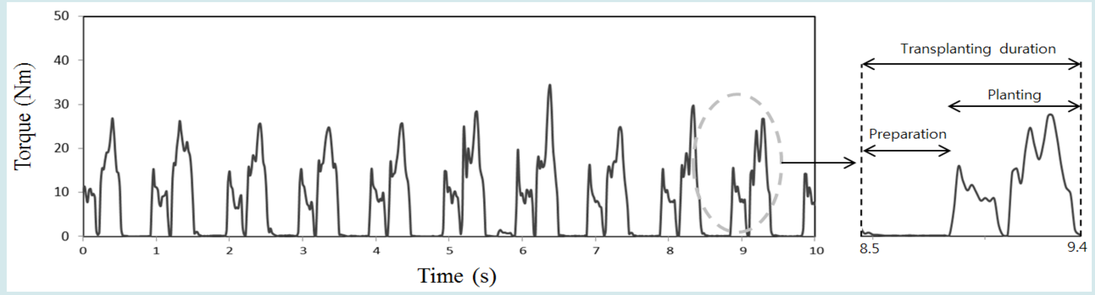


Fig. 2 Example of torque on the PTO at planting distance 43 cm and planting depth 105 mm

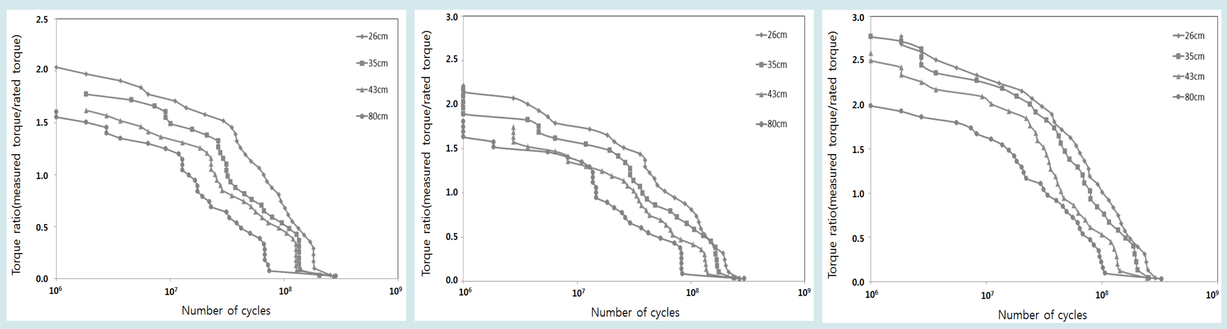
Table. 1 Average torque (Nm) on the transplanter PTO by planting depth and planting distance

Planting distance (cm)	Planting depth (mm)		
	Level 1 (85)	Level 5 (105)	Level 10 (136)
26	13.10 ± 7.37[1]	14.38 ± 8.34	17.22 ± 11.15
35	13.08 ± 6.85	13.88 ± 7.26	16.03 ± 10.21
43	12.59 ± 6.33	13.47 ± 6.92	15.33 ± 8.93
80	10.88 ± 6.57	12.88 ± 6.86	14.16 ± 9.16

[1] Average ± standard deviation

Load spectrum

- The torque ratios were similar in the high-cycle region from 10^8 to 10^9 cycles.
- When the planting distance decreased and planting depth increased, the torque ratio on the transplanter PTO shaft increased



(a) Planting depth level 1 (85 mm) (b) Planting depth level 5 (105 mm) (c) Planting depth level 10 (136 mm)

Fig. 3 Load spectrum of the PTO at different planting distances (26, 35, 43, and 80 cm)

Relative severeness

- The load severeness on the transplanter PTO shaft increased as planting distance decreased and planting depth increased

Table. 2 Relative severeness by planting depth and planting distance

Planting distance (cm)	Planting depth (mm)		
	Level 1 (85)	Level 5 (105)	Level 10 (136)
26	6.13	10.82	58.24
35	4.31	7.53	45.52
43	1.88	3.05	22.55
80	1.00	1.53	5.49

Conclusions

- The load severeness increased as planting distance decreased and planting depth increased
- The results of this study provide useful information for the optimum design of a transplanter PTO considering field load
- Future studies need to provide basic data for the design of the transplanter by considering the working speed and various work conditions

References

- Kim, W.S., Chung, S.O., Choi, C.H., Cho, J.S., Choi, D.S., Kim, Y.S., Lee, S.D., Hong, S.J., Koo, S.M., Kim, Y.J., 2016. Analysis of the PTO torque of a transplanter by planting condition. J. Biosyst. Eng. 41 (4), 313-318.
- Kim, Y.J., Chung, S.O., Choi, C.H., 2013. Effect of gear selection of an agricultural tractor on transmission and PTO load during rotary tillage. Soil Till. Res. 134, 90-96.
- Lee, D.H., Kim, Y.J., Chung, S.O., Choi, C.H., Lee, K.H., Shin, B.S., 2015. Analysis of the PTO load of a 75kW agricultural tractor during rotary tillage and baler operation in Korean upland fields. J.Terramech. 60, 75-83.