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FFT analysis of load data during field operations using a 75-kW agricultural tractor

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Abstract : Analysis of load data during field operations is highly important for optimum design of power drive lines for agricultural tractor. Objective of the paper was to analyze field load data using FFT to determine frequency and the energy levels of meaningful cyclic patterns. Rotary tillage, plowing, baling, and wrapping operations were selected as major field operations of agricultural tractor. An agricultural tractor with power measurement system was used. The tractor was equipped with strain-gauge sensors to measure torque of four driving axles and a PTO axle, speed sensors to measure rotational speed of the driving axles and an engine shaft, pressure sensors to measure pressure of hydraulic pumps, an I/O interface to acquire the sensor signals, and an embedded system to calculate power requirement. In rotary tillage, calculated frequency was decreased as travel speed increased. In baler operation, calculated frequency was increased as PTO speed was increased. The calculated peak frequency levels and expected levels were similar. Results of the study would provide information on power utilization patterns and on better design of power drive lines.

Key words **:** Agricultural tractor, Field operation, Load, FFT

I. Introduction

Study for improving the efficiency of fuel use is on-going in various industrial sectors due to both rising fuel prices caused by the decrease of fossil fuels and pollution problems in the global ecosystem caused by the excessive consumption. In case of automotive industry, study and development hybrid cars and electric vehicles to reduce fuel consumption has been progressed (DACO Industrial Research Institute, 2010).

Study to reduce fuel consumption has been progressed also in agricultural sector. Kim et al. (2010) developed a mathematical model to predict the fuel consumption rate of agricultural tractors under various load conditions. Percent errors of the predicted fuel consumption model were from 0.36 to 2.86%, which provided the high performance in various conditions. Park et al. (2010) investigated decreasing rate of fuel consumption by economic drive of 37-kW tractor, and found that fuel consumption rates were decreased by 69% in plow tillage and 54% in rotary tillage, respectively.

The load on an agricultural tractor is dependent on travelling speed and field operations. The loads would vary differently by type of field work, environmental conditions, tractor driving condition. By the accurate information about the load characteristics depending on the type of operations and the status of the tractor, fuel consumption can be reduced with the appropriate driving. Therefore, the load analysis of tractor is highly required to estimate the proper output according to each field operation.

Mclaughlin and Heslop (1993) developed an instrumented tractor and a data logging system to test field experiments for 97-kW agriculture tractors. The developed

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system was equipped with various sensors to measure fuel consumption, engine speed, wheel speed, ground speed, weight of front and rear axle, and toque of front and rear axle. Also a signal converter was used to measure the load from three-point hitch. The signals from each sensor were stored into data logging device through the preprocessing by dividing, amplifying and filtering.

Tractor load can be largely divided into two parts: drawbar load and PTO load. Kim et al. (2009) carried out a study of comparative analysis between the engine full load and drawbar load. At the condition of the engine's maximum output, ratio of drawbar load was generally from 70% to 90%. Also, study of analysis power consumption of a 30-kW tractor during major operations was reported (Kim et al., 2011). Power consumption in major field operations (plow, rotary tillage, loader operation) were examined during total operation period and actual field operation period. Results of averaged power requirement for total operation and actual field operation were 17.5 and 23.1 kW, 19.1 and 24.6 kW, and 8.9 and 14.9 kW, respectively.

FFT (Fast Fourier Transform) converts signals in the time domain into signals in the frequency domain. Periodic characteristic in raw signal can be identified by observing the converted signals in the frequency domain. FFT analysis has been used in various fields. This method is useful for the characterization of video and audio, and noise reduction (Ingle and Proakis, 2007). And the data processing method has been used in medical devices, and fault diagnosis and accident prevention with mechanical system.

Utilization of the FFT analysis were also conducted in the section of agricultural machinery. Cerruto et al. (2010) reported the results of the FFT analyses to evaluate the vibration level from the tractor driver during the operation of pesticide application in a citrus orchard. As results of the FFT analysis, main frequency corresponding to the engine speed was from 35 Hz to 37 Hz. Also, other lower frequency was found at from 2 Hz to 3 Hz that was due to the tractor travels.

Nguyen and Inada (2011) identified the characteristics of variations in wheel-load and vibrations from the tractor of rear axle using the FFT. The experiments were conducted on an asphalt road and sandy loam field at different experimental conditions with approximate forward speeds of 0.6, 1.6 and 2.6 m/s, and tire inflation pressures of 330 and 80 kPa. Results showed that there was no significant relation between wheel-loads and vibrations while wheel loads were remarkably affected by the change of tire pressure and travelling speed.

Objectives of this study were 1) to measure the load data of major components in an agricultural tractor by field operations, and 2) to investigate the characteristics of the load data using FFT analysis.

II. Materials and methods

1. Experimental design

Experiments were conducted from April 1st to June 30th, 2011, at paddy fields. Field conditions were after barley harvesting and before rice transplanting. Plow tillage, rotary tillage, baler operation and wrapping

Table 1. Experiment condition of field operations.

	Plow tillage	Rotary tillage	Baler operation	Wrapping operation
Levels of transmission speed	L3(3.77 km/h) L4(5.41 km/h)	L1(1.87 km/h) L2(2.64 km/h)	L4(5.41 km/h) M1(5.11 km/h)	H1(13.08 km/h)
Levels of PTO speed	-	P1(585 rpm) P2(756 rpm)	P1(585 rpm) P2(756 rpm)	-

Fig. 1. 75-kW agricultural tractor used in the study.

Table 2. Specifications of the 75-kW agricultural tractor.

Item	Specifications
Size (mm)	4,000×2,677×2,640
Weight (kg)	3,260
Engine power (kW)	75
PTO power (kW)	65

operation were selected as the major field operations. Levels of transmission and PTO speed of each operation were selected through interview with farmers. Experimental conditions were two levels of plow tillage, four levels of rotary tillage and baler operation, and one level of wrapping operation (Table 1).

2. Specifications of agricultural tractor and implements

Figure 1 and Table 2 show photo and specifications of the agricultural tractor (L7040, LS Mtron Ltd., Korea) used in this research. Dimensions of the tractor were 4,000 x 2,677 x 2,640 (L x W x H) mm, and total mass was 3,260 kg. Tractor rated output of engine was 75 kW at 2,500 rpm and the output of PTO was 65 kW. The theoretical efficiency of transfer power is 85 to 95% with the type of mechanical manual transmission. Hydraulic pump was directly connected to the engine. The theoretical discharge rates of main and auxiliary pump were 12 and 6 cc/rev, respectively.

Table 3 is specifications of the implements used. Plow (SW-PS2408, Sewoong Machinery Co., Korea) had blades and rotary (WJ230E, Woongjin Machinery Co., Ltd., Korea) had 54 blades. And, baler (F550, MCHale Engineering Ltd., Ireland) has 18 rollers and bale wrapper (RF1500, ELHO Co., Netherlands) has cable control system.

3. Major components and load measurement system

Table 4 shows the selected major measurement and

Table 3. Specifications of the implements used.

	Plow tillage	Rotary tillage	Baler operation	Wrapping operation
Size (mm)	2,395×2,420×1,165	1,050×2,580×1,380	4,050×2,550×2,450	2,500×2,100×2,650
Weight (kg)	502	815	3,500	820
Working width (mm)	2,488	2320	1230	Bale 1500
Characteristic	2 x 4 blades	9 x 6 blades	18 rollers	Cable control

Table 4. Selected major components and specifications of the sensors.

Sensor	Measurement data	Model	Range	Accuracy
Strain gauge	Toque	CEA-06-250US-350	0~350 Ohms	± 0.4%
Encoder	Rotational speed	SR-10M/E60	0~6000 rpm	± 1 rpm
Pressure sensor	Hydraulic pressure	P6A	0~500 bar	± 0.2%
Flowmeter	Fuel consumption	M05	0.003~0.8 L/min	± 0.5%
Radar speed sensor	Travel speed	Radar sensor 3	0.53~107.8 km/h	± 3 %
Thermocouple	Temperature	Thermocouple T	-200~350 °C	± 1°C

specifications of sensor. Measurement method of rotation speed and torque of transmission input shaft and the PTO input shaft were the same. Rotation speed of transmission and engine were at a 1:1 ratio. Rotational speed of transmission input shaft was measured using a built-in tachometer. Torque of the transmission and PTO input shaft were measured using strain gauge (CEA-06-250US-350, Micro Measurement Co., USA). To monitor signals generated from the strain gauge, the principle of wheatstone bridge was applied.

Rotational speed of the four-axle were measured by encoder (60 pulse encoder) embedded in the slip ring (SR-10M/E60, MI-Scientific Co., USA). And, torque of four-axle was measured using four element full-bridge strain gauge which was same to transmission and PTO torque.

The required pressure and flow rate of the hydraulic pump power were measured and calculated. The pressures of main and auxiliary hydraulic pump were measured using installed pressure sensor (P6A, HBM, Germany). Because rotational speed of the engine and hydraulic pump are proportional, flow rate was calculated by using the rotational speed and the theoretical discharge rates of each pump.

Fuel consumption by the engine was measured using a flow meter (M05, NURITECH, Korea) that was installed at fuel supply hose. Radar speed sensor (Radar sensor 3, DICKEY-John, USA) was measure ground speed at the under the bonnet, center to the front axle. Temperature of fuel, transmission, oil and ambient were measured using T type of thermocouple to ensure the reliability of accurate measurement.

Load measurement system was consisted of three 8-channel data acquisition unit (QuantumX MX840, HBM, and Germany) in order to concurrently measure 18 signals. A data acquisition device has advantage of receiving both analog and digital signals simultaneously, and easily removes noise by their own built-in FPGA (Field Programmable Gate Array). Torque and pressure signal were transferred to analog input channels with sampling rate of 19.2 kHz and resolution of 24 bit per channel. And, rotational speed of the engine and four-axle were transferred to digital input channels with sampling rate of 1 MHz. The measured sensor signals were transmitted to the laptop using the firewire (IEEE 1394) communication. Measurement program was developed using Catman (version 3.1, HBM, Germany).

4. Analytical method of load data

In this study, periodic characteristic of load data of an agricultural tractor was analyzed by FFT method. The maximum number of rotational speed of the engine was 2600rpm. So, measured rate should be greater than 217 Hz to confirm the accurate periodic characteristics. Measured rate of data acquisition unit of used in this study was 200 Hz. Load data of

Table 5. Expected frequency in rotary tillage and baler operation by FFT analysis.

Operation	Levels	Travel speed (km/h)	PTO speed (rpm)	Expected frequency (Hz)
Rotary tillage	L1P1	1.23	644	41
	L1P2	1.19	679	43
	L2P1	1.69	604	36
	L2P2	1.98	663	39
Baler operation	L4P1	4.21	658	44
	L4P2	3.89	756	50
	M1P1	3.56	593	40
	M1P2	2.55	810	54

PTO shaft in rotary tillage and baler operation were analyze. FFT analysis was performed using Matlab (version 2010a, The MathWorks Inc., USA) and 'Pwelch' function with 50% overlap and hamming window.

Considering the rotational speed of PTO shaft and characteristics of implements, load patterns could be predict. In case of rotary, 6 blades were attached around each of 9 flanges. If the rotary shaft makes one turn, soil would be failed 6 times. Frequency levels of 41, 43, 36 and 39 Hz were predicted using a rotational speed of shaft (Table 5). And, in case of baler, 44, 50, 40 and 54 Hz were predicted, because number of the pick-up device blades was four.

III. Results and discussion

1. Comparison of designed and actual speed of travel and PTO

Table 6 shows difference of designed and actual levels of travel and PTO speeds. In all operation, measured travel speeds were slower than the designed speed. Actual travel speeds were slower than the designed speeds due to load and slip by soil strength at working. But, overall, actual PTO speeds were higher than designed speeds. In rotary tillage, PTO speed at P1 level was higher, and at P2 level was lower. And in the baler operation, measured PTO speed was greater than the designed speed.

2. FFT analysis results

Table 7 and figure 2 show specific frequency by FFT analysis in rotary tillage. Overall, calculated frequency was decreased as travel speed increased. In the L1 level of transmission speed, expected and calculated frequency levels were very similar. The peak frequency levels of PTO input shaft torque was found at 42 and 43 Hz with L1P1 and L1P2 l levels, respectively. But, in the L2 level, calculated frequency and expected

Table 6. Comparison of designed and actual speed of travel and PTO.

Operation	Levels	Travel speed (km/h)		PTO speed (rpm)	
		Designed	Measurement	Designed	Measurement
Plow tillage	L3	3.77	2.04		
	L4	5.41	2.04		
Rotary tillage	L1P1	1.87	1.23	585	644
	L1P2	1.87	1.19	756	679
	L2P1	2.64	1.63	585	604
	L2P2	2.64	1.98	756	663
Baler operation	L4P1	5.11	4.21	585	658
	L4P2	5.11	3.89	756	756
	M1P1	5.41	3.56	585	593
	M1P2	5.41	2.55	756	810
Wrapping operation	H1	13.08	1.75		

Table 7. FFT analysis results for rotary tillage.

Level of transmission and PTO speed	Travel Speed (km/h)	PTO Speed (rpm)	Expected frequency (Hz)	Calculated frequency (Hz)
L1P1	1.23	644.17	41	42
L1P2	1.19	678.67	43	43
L2P1	1.69	604.10	34	35
L2P2	1.98	663.12	39	36

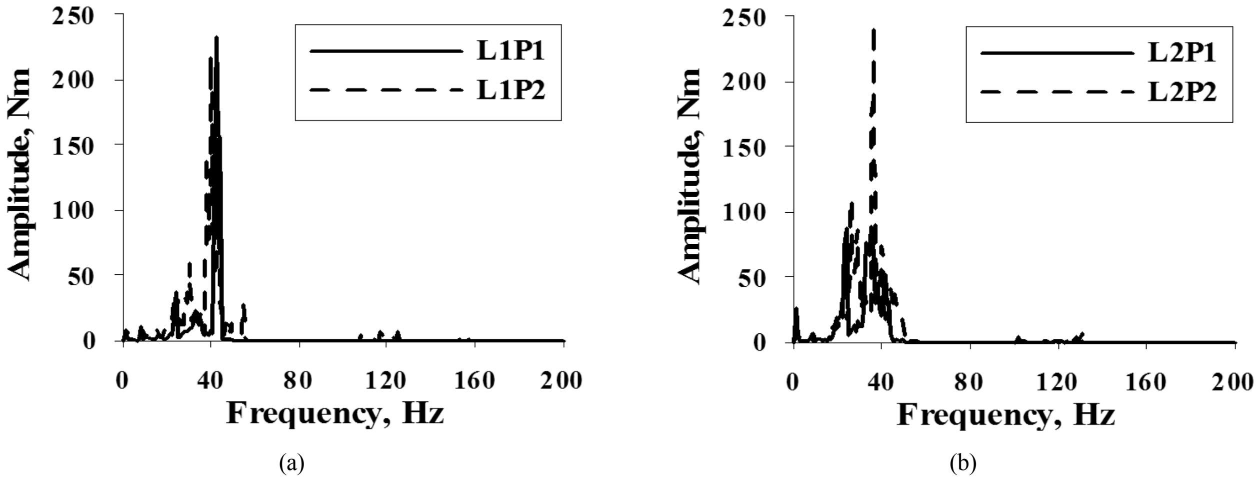

Fig. 2. Result of FFT analysis of rotary tillage: (a) L1P1 and L1P2 level of transmission and PTO speed, (b) L2P1 and L2P2 level of transmission and PTO speed.

Table 8. FFT analysis results of baler operation.

Level of transmission and PTO speed	Travel Speed (km/h)	PTO Speed (rpm)	Expected frequency (Hz)	Investigated frequency (Hz)
L1P1	4.21	657.51	44	44
L1P2	3.89	756.04	50	50
L2P1	3.56	593.17	40	40
L2P2	2.55	810.80	54	54

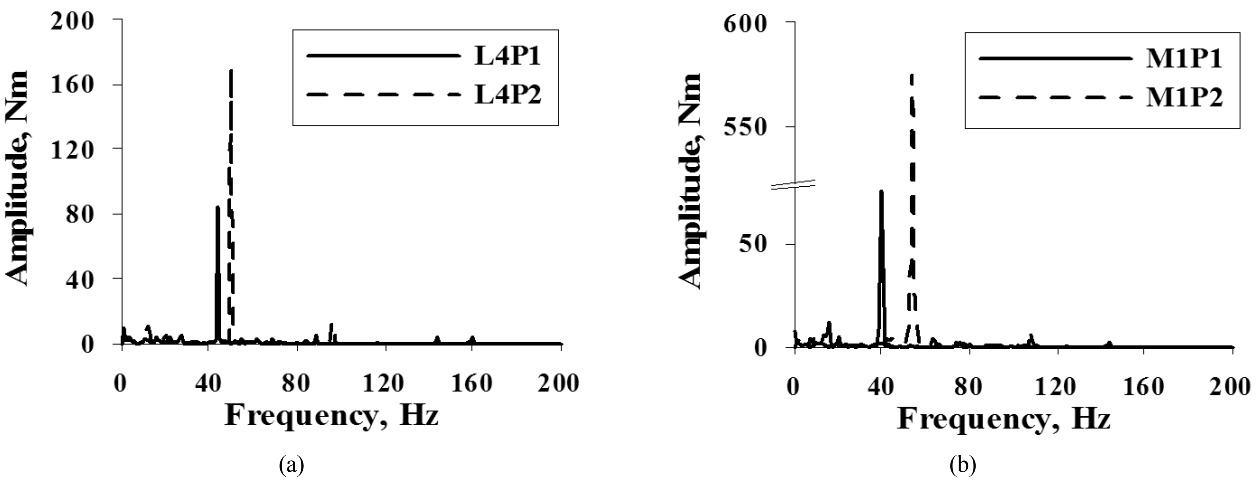

Fig. 3. Result of FFT analysis of baler operation: (a) L4P1 and L4P2 level of transmission and PTO speed, (b) M1P1 and M1P2 level of transmission and PTO speed.

were a little different. The calculated peak frequency levels of PTO input shaft torque were found at 35 and 36 Hz, and expected peak frequency were found at 34 and 39 Hz. In L2P2 level, calculated frequency was more less than expected. One of possible explanation of this result is the change of soil failure distance by increase of working speed.

In baler operation, the calculated peak levels were 44, 50, 40 and 54 Hz at L1P1, L1P2, L2P1 and L2P2 levels (Table 8 and Fig. 3). The calculated frequency levels were increased as PTO speed was increased. Results showed that the calculated peak frequency levels and expected levels were similar, possibly because the PTO load patterns were not affected by working speed and soil characteristics.

IV. Conclusions

In the study, load data of an agricultural tractor at major field operations (plow tillage, rotary tillage, baler operation and wrapping operation) were analyzed by FFT method. Major findings were summarized as followings.

1. In the rotary tillage, calculated frequency was decreased as travel speed increased. And, at the L1 level of transmission speed, expected and calculated frequency levels were very similar. But, at the L2 level, calculated frequency and expected were a little different.
2. In baler operation, calculated frequency was increased as PTO speed was increased. And, the calculated peak frequency levels and expected levels were similar.

In the future, study of development of load simulation and performance evaluation will be carried out.

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References

Cerruto E, Emma G, Manetto G. 2010. Whole body vibrations of tractor driver in citrus orchard. In: Proceedings of the International Conference Ragusa SHWA2010. pp. 396-403, Ragusa, Italy.

DACO Industrial Research Institute. 2010. Development Trends and Market Outlook of Global Hybrids Cars and Electric Vehicles. DACOIRI Publishing Co., Seoul, Korea.

Ingle VK, Proakis JG. 2007. Digital Signal Processing Using MATLAB. Cengage Leaning, Stamford, CT, USA.

Kim SC, Kim KU, Kim DC. 2009. Analysis drawbar load acting on tractor engine at maximum drawbar power. Journal of Biosystems Engineering 34(2):71-76.

Kim SC, Kim KU, Kim SS. 2010. Modeling of fuel consumption rate for agricultural tractors. Journal of Biosystems Engineering 35(1):1-9.

Kim YJ, Chung SO, Park SJ, Choi CH. 2011. Analysis of power requirement of agricultural tractor by major field operation. Journal of Biosystems Engineering 36(2):79-88.

Mclaughlin NB, Heslop LC. 1993. A general purpose tractor instrumentation and data logging system. Transactions of the ASAE 36(2):265-273.

Nguyen VN, Inaba S. 2011. Effects of tire inflation pressure and tractor velocity on dynamic wheel load and rear axle vibrations. Journal of Terramechanics 48:3-16.

Park SH, Kim YJ, Kim DH, Kim CK, Jung SC, Kim HJ, Jang Y, Kim SS. 2010. Development of eco driving system for agricultural tractor. Journal of Biosystems Engineering 35(2):77-84.