

Pre-processing of load data of agricultural tractors during major field operations

Myong-Jin Ryu¹, Md. Shaha Nur Kabir², Youn-Kug Choo², Sun-Ok Chung², Yong-Joo Kim², Jong-Kyou Ha^{3*}, Kyeong-Hwan Lee⁴

¹Innovative Agricultural Machinery R&D Center, LS Mtron Ltd., Jeollabuk-Do, 565-902, Korea

²Dept. of Biosystems Machinery Engineering, Chungnam National University, Daejeon, 305-764, Korea

³Research Institute, Kukje Machinery Co., Ltd., Okcheon, Chungbuk-Do, 373-802, Korea

⁴Dept. of Rural & Bio-Systems Engineering, Chonnam National University, Gwangju, 500-757, Korea

Received on 27 February 2015, revised on 19 March 2015, accepted on 23 March 2015

Abstract : Development of highly efficient and energy-saving tractors has been one of the issues in agricultural machinery. For design of such tractors, measurement and analysis of load on major power transmission parts of the tractors are the most important pre-requisite tasks. Objective of this study was to perform pre-processing procedures before effective analysis of load data of agricultural tractors (30, 75, and 82 kW) during major field operations such as plow tillage, rotary tillage, baling, bale wrapping, and to select the suitable pre-processing method for the analysis. A load measurement systems, equipped in the tractors, were consisted of strain-gauge, encoder, hydraulic pressure, and radar speed sensors to measure torque and rotational speed levels of transmission input shaft, PTO shaft, and driving axle shafts, pressure of the hydraulic inlet line, and travel speed, respectively. The entire sensor data were collected at a 200-Hz rate. Plow tillage, rotary tillage, baling, wrapping, and loader operations were selected as major field operations of agricultural tractors. Same or different farm works and driving levels were set differently for each of the load measuring experiment. Before load data analysis, pre-processing procedures such as outlier removal, low-pass filtering, and data division were performed. Data beyond the scope of the measuring range of the sensors and the operating range of the power transmission parts were removed. Considering engine and PTO rotational speeds, frequency components greater than 90, 60, and 60 Hz cut off frequencies were low-pass filtered for plow tillage, rotary tillage, and baler operations, respectively. Measured load data were divided into five parts: driving, working, implement up, implement down, and turning. Results of the study would provide useful information for load characteristics of tractors on major field operations.

Key words : Agricultural tractor, Field operation, Load data, Pre-processing method

I. Introduction

High-efficiency and high-performance machines are being developed in various industries. In agricultural machine sector, technology development has being rapidly progressed especially in high-efficiency and low-fuel consumption technology such as hybrid and electronic control technique (Ryu et al., 2013). Analysis of load in field operations is helpful for designing the motor output capacity and battery capacity of hybrid tractor. In general, design of major power transmission

parts may vary in working loads. Thus, studies of load measurement and analysis are required for development of new type tractor. Analysis of load during field operation is important for the development of major components and integrated tractors. Kim et al. (1998) measured load at the input shaft of the transmission and final drive shaft of the tractors attaching strain gauges on each axis, and the measured signal was acquired and stored via the wireless system through torque converters. The correlation coefficient between the measured signal and the generating load showed a high degree of accuracy of 0.99.

McLaughlin and Heslop (1993) developed the tractor

*Corresponding author: Tel: +82-043-730-1640
E-mail address: jongkyou.ha@dongkuk.com

instrumentation and data logging system to field test of agriculture tractor. The system had sensors for fuel consumption, engine speed, wheel speed, moving speed, weight of front and rear axle, and torque of front and rear axle. Besides, it had a converter to measure load at three-point hitch. The converter signals were stored in a data logging device after divided, amplified or filtered.

Tractor load can be largely divided into two parts: drawbar load and PTO load. Kim et al. (2009) compared and analyzed the engine full load and drawbar load. The torque load ratio increased from 20% to 80% with less than 5 km/hr pull speed and it was 80 to 110% at speeds faster than 5 km/hr regardless of the pull speed. Kim et al. (2011) performed analysis of the power requirement on major operations of agricultural tractor. Power requirements at major operations (such as plow, rotary tillage, and loader operations) were analyzed during the total operation period and actual field operation period. Averaged power requirement for total operation and actual field operation were 17.5 and 23.1 kW at plow; 19.1 and 24.6 kW at rotary tillage; and 8.9 and 14.9 kW at loader operations, respectively.

Delivery of the measured data to the data acquisition system might be incomplete due to the generation of tractor's vibration and noise, electrical impacts. Noise from the measurement system can make additional undesirable effects to the irregular distribution of data (Richard and Donald, 2010). Oh et al. (2011) removed white noise using wavelet transform to develop a diagnostic system in an engine-assembly line. Hansson et al. (2003) filtered torque signal with a fifth order Butterworth digital low-pass filter before it was used as input for the calculations of the fuel efficiency. The cut-off frequency for the low-pass filter was defined so that the transients caused by the system after the transducer was not reduced, but the variations at each combustion cycle in the engine were eliminated. At an idle engine speed of 900 rpm,

30 power strokes were performed each second, and an upper limit for the cut-off frequency was 30 Hz. Kim (2012) measured the transmission shaft torque and performed pre-processing of that data using the discrete Kalman filter. RMS value of measured data and designed data was 6.7 Nm, which means that it was very effective to remove random noise in time domains. Therefore, the pre-processing of data is required for efficient analysis before performing the load analysis. It is possible to perform efficient analysis through pre-processing such as outlier removal, filtering, and work division. The purpose of this study was to perform pre-processing procedures (outlier removal, low-pass filtering, and data division) to the major field operations (plow tillage, rotary tillage, baling, bale wrapping, and loading) data of agricultural tractors (30, 75, and 82 kW) for better analysis of tractor load data.

II. Materials and Methods

1. Load data measurement

A load measurement system was equipped in the tractors (30, 75, and 82 kW). The measurement system was equipped with three 8-channel data acquisition unit (QuantumX MX840, HBM, and Germany), which enable to measure 18 signals. Torque at the four wheel shafts, transmission, and PTO input shaft were measured using strain gauge (CEA-06-250US-350, Micro Measurement Co., USA). Experiments were in triplicate. Rotational speed was measured by an encoder (60 pulse encoder) embedded in the slip ring (SR-10M/E60, MI-Scientific Co., USA). The pressures of the hydraulic main and auxiliary pump were measured using a pressure sensor (P6A, HBM, Germany). Flow rates were calculated by using the rotational speed and theoretical discharge rates of each pump. Fuel consumption at the engine was measured by a flow meter (M05, NURITECH, Korea) which was installed

Table 1. Specifications of the tractors and characteristics of the soils used for the experiment

| Item | Specifications of tractors and characteristics of the soil | | | |
|------------------------|--|-------------------|------------|-------------------|
| | 1st experiment | 2nd experiment | | 3rd experiment |
| Engine power (kW) | 30 | 75 | | 82 |
| Tractor size (mm) | 3,359×1,100 ×2,415 | 4,000×2,677×2,640 | | 4,250×2,350×2,910 |
| Tractor weight (kg) | 1,584 | 3,260 | | 5,112 |
| Site | Icheon | Wanju | Suwon | Hampyeong |
| Soil type | Sandy loam | Loam | Sandy loam | Silt loam |
| Soil water content (%) | 15.7 | 21.3 | 28.4 | 29.8 |
| | 5 cm | 948 | 2,124 | 784 |
| Cone index | 10 cm | 1,894 | 2,285 | 1,666 |
| (kPa) by depth | 15 cm | 1,470 | 2,445 | 2,450 |
| | 20 cm | 1,208 | 2,451 | - |
| | | | | 1,949 |

at fuel supply hose. Radar speed sensor (Rader sensor 3, DICKEY–John, USA) was used to measure the working speed at the under the bonnet, centered at the front axle. Temperatures of fuel, transmission, oil, and ambient were measured by a thermocouple (T–type).

Table 1 shows the three types of tractor and soil specification information for each test site. Experiments with 30 kW and 75 kW tractors were performed in 3 places such as Icheon, Wanju, and in Suwon; whereas experiments with 82 kW tractor were only in Hampyeong, Jeollanam–do, Korea.

Plow tillage, rotary tillage, baling, wrapping, and loader operations were selected as the major field operations of agricultural tractors. Load data at the transmission input shaft, PTO input shaft, main hydraulic pump, and axillary hydraulic pump were measured three times. Field operations were carried out by setting different driving levels in each experiment of load measuring tractor. In the small power (30 kW) tractor experiments the engine speed and driving speed were set to 2,600 rpm and 3 km/h, respectively for plow tillage, rotary tillage, and loader operation. Each operation was carried out on working level 1. At the other powers (75 kW and 82 kW) experiments, transmission and PTO speeds were selected through interviews with farmers. Load measurement were carried out for plow tillage, rotary

tillage, baling operations, and wrapping operation on level 2, level 4, level 4, and level 1, respectively in the experiment with 75 kW tractor. At 82 kW tractor plow tillage, rotary tillage, and baling operations were performed on level 3, level 4, and level 4, respectively. Table 2 shows type of field operations, levels of travel, and PTO speed of tractors.

The specifications of the equipment used as attachment to each type tractor are shown in Table 3. In the first experiment with 30 kW tractor, plow (TS–6P, Young Shin Co., Korea) with six blades run round and rotary (R175MG, LS Machinery Co., Korea) equipped with the L–shaped blade were used. In the second experiment with 75 kW tractor, plow (SW–PS2408, Sewoong Machinery Co., Korea) with eight blades, rotary (WJ230E, Woongjin Machinery Co., Ltd., Korea), baler (F550, MCHale Engineering Ltd., Ireland), wrapping machine (RF1500, ELHO Co., Netherlands) were used. In the third experiment with large capacity 82 kW tractor, plow and rotary were same as second experiment, but baler (RF2135, Vicon Co., Norway) was different with working width of 2,100 mm.

2. Pre-processing of load data

Pre-processing was performed to remove noise and

Table 2. Travel and PTO speeds of the agricultural tractors used in the experiment.

| Operation | Level of travel and PTO speed | | |
|--------------------|-------------------------------|--|--|
| | 1 st experiment | 2 nd experiment | 3 rd experiment |
| Plow tillage | 3 km/h* | L3 (3.77 km/h) L4 (5.41 km/h) | L2 (2.64 km/h) L3 (3.77 km/h) L4 (5.41 km/h) |
| Rotary tillage | 3 km/h | L1P1 (1.87 km/h, 585 rpm**) L1P2 (1.87 km/h, 756 rpm) L2P1 (2.64 km/h, 585 rpm) L2P2 (2.64 km/h, 756 rpm) | L1P1 (1.87 km/h, 585 rpm) L1P2 (1.87 km/h, 756 rpm) L2P1 (2.64 km/h, 585 rpm) L2P2 (2.64 km/h, 756 rpm) |
| Baler operation | 3 km/h | L4P1 (5.41 km/h, 585 rpm) L4P2 (5.41 km/h, 756 rpm) M1P1 (5.11 km/h, 585 rpm) M1P2 (5.11 km/h, 756 rpm) | L2P1 (2.64 km/h, 585 rpm) L2P2 (2.64 km/h, 756 rpm) L3P1 (3.77 km/h, 585 rpm) L3P2 (3.77 km/h, 756 rpm) L4P1 (5.41 km/h, 585 rpm) L4P2 (5.41 km/h, 756 rpm) |
| Wrapping operation | - | H1 (13.08 km/h) | - |
| Loader operation | 3 km/h | - | - |

* Driving speed

** PTO rotational speed

Table 3. Specifications of the implements used for the experiments.

| Operation | Implement specifications | | | | |
|----------------|-------------------------------|-------------------|-------------|--------------------|---------------|
| | Model | Size (mm) | Weight (kg) | Working width (mm) | Comments |
| Plow tillage | TS-6P (Taesung, Korea) | 2,180×1,870×1,200 | 484 | 1,900 | 2×3 blades |
| | SW-PS2408 (Sewoong, Korea) | 2,395×2,420×1,165 | 502 | 2,488 | 2×4 blades |
| Rotary tillage | WJ175A (Woongjin, Korea) | 900×1,950×1,020 | 395 | 1,750 | 7×6 blades |
| | WJ230E (Woongjin, Korea) | 1,050×2,580×1,380 | 815 | 2,320 | 9×6 blades |
| Baling | F550 (MCHale, Ireland) | 4,050×2,550×2,450 | 3,500 | 1,230 | 18 rollers |
| | RF 2135 (Vicon, Norway) | 4,600×2,540×2,450 | 2,950 | 2,100 | Net wrapping |
| Wrapping | RF1500 (ELHO, Netherlands) | 2,500×2,100×2,650 | 820 | Bale 1500 | Cable control |

thereby improve analysis of data. Among the methods, outlier removal, filtering, and data discretization were employed to make minimize the changes of load data and make the data analysis easier. Fig. 1 shows the power profile when a 75 kW tractor carries out plow tillage. The negative data were considered as outliers and should be removed or changed for effective data analysis. It was difficult to carry out

the analysis of the time domain due to severe degree of changes in power consumption data of the transmission shaft and engine. This processing of the data does not affect the natural frequency. Various degree of required power was confirmed over time. Because this data contained both the data of plowing operation and the driving and turning operations those were not preceded the operation. Therefore,

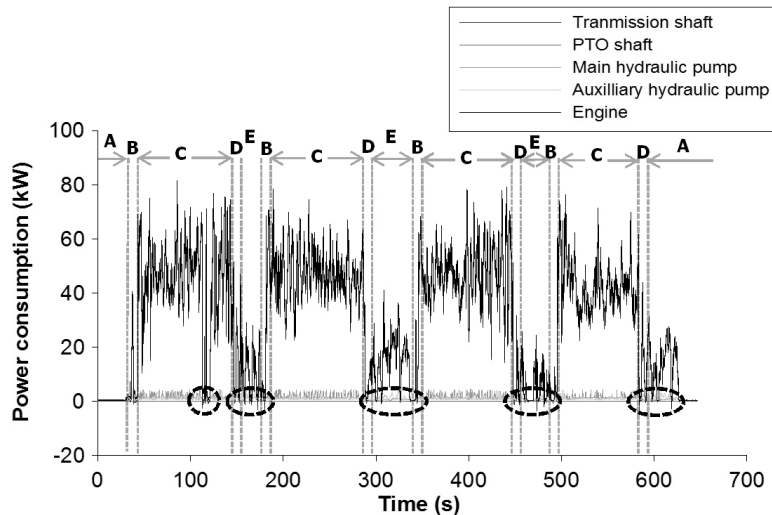


Fig. 1. Outlier and data separation of power consumption of major devices: (A) Driving, (B) Implement down, (C) Working, (D) Implement up, (E) Turning.

separation of the whole period is necessary for the analysis and comparison of data.

(1) Removal of outliers

The load measurement system used in the experiments was designed for measurements in the field. The internal issues such as the output characteristics of the sensor and measurement device, and external problems such as vibration and noise of tractor occurred during the field operations, resulting in creating invalid data. Since there were data beyond the scope of the measuring range of the sensor and a severe change of power and load factor data, the correlation check used was to determine the presence of outliers. The data to be an outlier was removed or processed with different values that does not change the characteristics within the range of the data pattern according to type and load factor of the field operations. After removal of outliers in the time domain and frequency domain, the results were compared (average, maximum, minimum, and deviations).

(2) Filtering

White noise is one of the typical background noises which are the outputs of all frequencies within a certain frequency range (Yun and Bae, 2012). The load

data was measured with 20 Hz sampling speed for 30 kW and 82 kW tractor, and 200 Hz sampling speed for 75 kW tractor. 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. Generally, the white noise is present in the speed range; thus it can be measured within the sampling rate. Filtering these noises was necessary not to affect the frequency analysis. There are several filtering methods in the frequency domain: high-pass filtering, low-pass filtering, and band-pass filtering. The unnecessary components should be removed to evaluate the frequency characteristics. Therefore, low-pass filtering was performed for removal of noise where less characteristics change of load data were available.

For selecting the excluded frequency, the characteristics of power transmission was considered for each load data and must be applied while considering the engine rotation speed as 2600 rpm as it was required to select the excluded frequency more than 86.6 Hz because of losing the load characteristics according to the rotation of axis excluding 86.6 Hz less frequency. In addition, the frequency over 33.2 Hz was selected for

Table 4. Data separation criteria for the 75-kW tractor (Example).

| Operation | Separation part | Data separation criteria | | | | | |
|----------------|-----------------|--------------------------|--------------------------|-----------------|-----------------|------------------------------------|---|
| | | Engine speed (rpm) | Transmission torque (Nm) | PTO speed (rpm) | PTO torque (Nm) | Main hydraulic pump pressure (bar) | Auxiliary hydraulic pump pressure (bar) |
| Plow tillage | Driving | < 2,300 | < 50 | 0 | 0 | < 50 | < 50 |
| | Implement down | ≥ 2,300 | ≥ 50 | 0 | 0 | > 50 | < 50 |
| | Working | ≥ 2,300 | ≥ 100 | 0 | 0 | ≥ 50 | < 50 |
| | Implement up | ≥ 2,300 | ≥ 50 | 0 | 0 | ≥ 50 | < 50 |
| | Turning | < 2,300 | < 50 | 0 | 0 | < 50 | ≥ 50 |
| Rotary tillage | Driving | < 2,000 | < 20 | < 100 | < 40 | < 40 | < 30 |
| | Implement down | ≥ 2,000 | ≥ 20 | ≥ 100 | ≥ 40 | ≥ 40 | < 30 |
| | Working | ≥ 2,000 | ≥ 35 | ≥ 500 | ≥ 150 | ≥ 40 | < 30 |
| | Implement up | ≥ 2,000 | < 20 | < 500 | < 40 | ≥ 40 | < 30 |
| | Turning | < 2,000 | < 20 | < 100 | < 40 | < 40 | ≥ 50 |

the PTO shaft. For the load of PTO shaft, the excluded frequency was selected considering the rpm until the generated power was delivered from the engine to the PTO shaft but the frequency over 60 Hz was selected for rotary tilling and the frequency over 66 Hz was selected for baling operation while considering the gear ratio of the PTO shaft and working machine, the number of working days etc.

(3) Distribution of working area

The largest load occurred during the field operations of tractor and various load characteristics of the major powertrains were found and the degree of variations of the load was very large. At each working operation, the load characteristics generated at the main power devices appeared differently. For the development of load simulation, it was required to separate the working operations and analyze their characteristics of load.

In general, the working operation of tractor is classified into driving, turning, working process. In this study, the classification criteria were designed to classify the driving section of load data. The classification criteria were varied according to tractor capacity, type of operation, driving level. For plow tilling, the number of engine revolution, torque of transmission shaft, hydraulic pressures at main and

auxiliary pump were considered. PTO speed and torque were only considered in rotary tillage and baling operation. Table 4 shows the data parameters to a 75 kW tractor at plow tillage and rotary tillage.

III. Results and Discussion

1. Pre-processing of load data

(1) Removal of outliers

Outliers were confirmed from the load data those were out of driving range of power unit and found with incorrect changes while considering the before and after data of other power units, and the data showed the same value without any changes were considered as outliers and such types of data were removed.

The negative values at the power transmission were found in all field operations. These values were generated due to the vibration or the backward movement during travelling. Considering the real situation and for the further analysis at time domain, these values were changed to 0. Similar to other operations, the transmission shaft torque data was confirmed below 0 for rotary tilling and was not processed as 0 but changed to a suitable value after confirming the rotation speed of engine and driving

Table 5. Comparison of basic statistics before and after outlier removal for the load data of the 75 kW tractor

| Operation | Data type | Average | | Maximum | | Minimum | | Std. deviation | |
|----------------|--------------------------------|---------|--------|---------|--------|---------|-------|----------------|-------|
| | | Before | After | Before | After | Before | After | Before | After |
| Plow tillage | Transmission shaft torque (Nm) | 85.80 | 79.40 | 482.38 | 329.47 | -21.31 | 0.00 | 74.12 | 61.87 |
| | PTO shaft torque (Nm) | 168.11 | 167.88 | 498.17 | 348.40 | -118.62 | 0.00 | 86.30 | 85.89 |
| Rotary tillage | Transmission shaft torque (Nm) | 34.71 | 34.71 | 79.23 | 79.23 | -0.93 | 0.00 | 9.44 | 9.73 |
| | Main pump pressure (MPa) | 3.90 | 3.88 | 12.85 | 7.12 | 2.12 | 2.12 | 0.74 | 0.65 |
| Baling | Transmission shaft torque (Nm) | 25.88 | 25.89 | 164.56 | 164.56 | -32.68 | 0.00 | 30.25 | 30.24 |
| | PTO shaft torque (Nm) | 54.88 | 54.89 | 485.05 | 485.05 | -58.11 | 0.00 | 42.34 | 42.33 |
| Wrapping | Transmission shaft torque (Nm) | 45.33 | 45.51 | 338.11 | 338.11 | -222.36 | 0.00 | 68.21 | 68.29 |

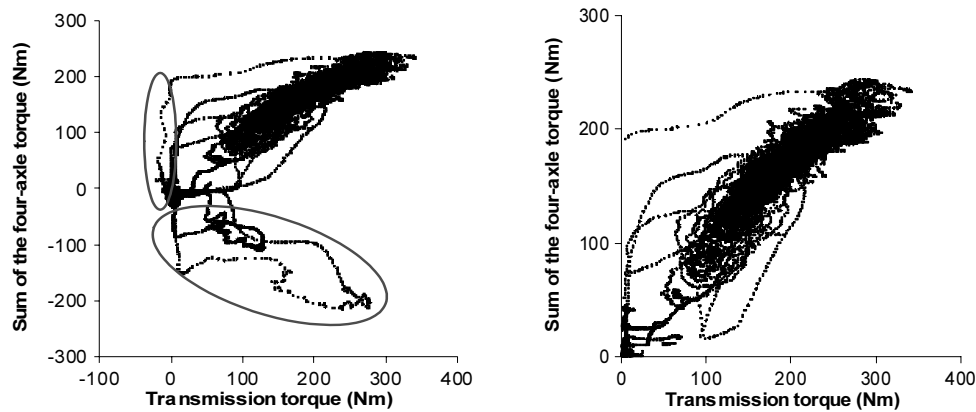


Fig. 2. Scatter plot (transmission torque vs. total axle torque) of a 75 kW tractor during plow tillage: before (left) and after (right) outlier removal.

speed, before and after data, and the natural frequency. Table 5 shows the comparison of statistical parameters before and after outlier removal at the load data of the 75 kW tractor.

The negative PTO shaft torque data were changed to 0. The outliers were identified for rotary tillage and baler operations where the power transmitted to the working machine using a PTO shaft. In addition, before and after data was changed while considering the number of revolutions of PTO shaft from rotary tilling, confirming the data beyond instantaneous suitable degree of changes. After processing of outliers, there was no change of its specific characteristics

such as mean and standard deviation of data and the data specific frequency was also not affected and the factors affecting the future analysis were removed for easier analysis. Fig. 2 and 3 show the outlier removal process during plow tillage operations at the 75 kW tractor.

(2) Filtering

The low-pass filtering was performed in order to remove the white noise that existed in the load data of transmission shaft and PTO shaft. Considering the driving characteristics of power unit, the filtering was performed not to affect its specific characteristics.

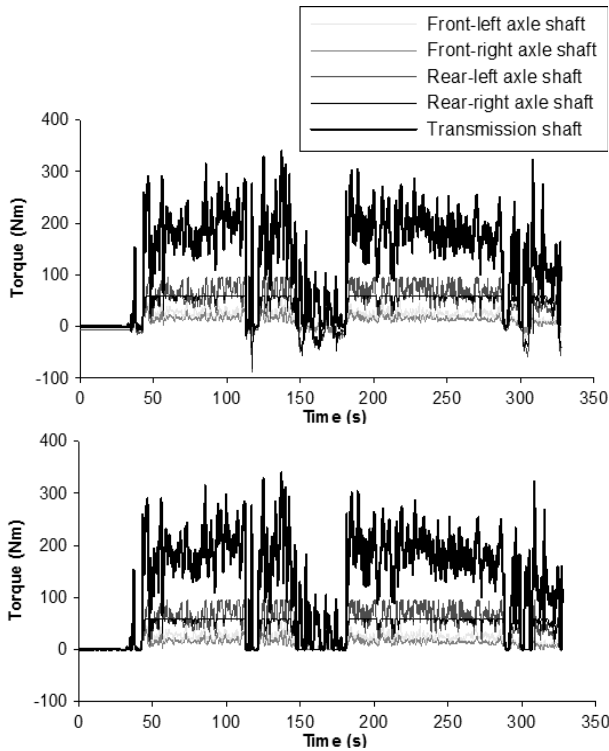


Fig. 3. Transmission and wheel shaft torques vs. time during plow tillage: before (top) and after (bottom) outlier removal.

The filtering was performed selecting 86.6 Hz or over 90 Hz for transmission input shaft while considering the number of revolutions of engine; 60 Hz in case

of PTO shaft for rotary tilling; and 66 Hz for the baling operation as excluded frequency (Table 6). After filtering, the processed data was compared with the original ones and no significant differences were found; RMSE were very low.

(3) Distribution of working area

Results of working division classification of the load data and the characteristics of major power unit at each division were appeared differently. The load in the transmission shaft was higher in the working than driving of the tractor. But at the turning section, the load was found higher in the auxiliary hydraulic pump when was used for steering control. Torque of transmission shaft during the lifting up and down was the largest among all operating routines. After classification, the unnecessary results were reduced through the outlier removal and noise filtering; resulting in the reduction of steps and time.

IV. Conclusions

On this study, the preprocessing works such as

Table 6. Statistical parameters of the load data before and after the low-pass filtering for the major field operations.

| Operation | Data type | Cut off frequency (Hz) | Avg. (Nm) | Max. (Nm) | Min. (Nm) | Std. Dev. | RMSE |
|----------------|--------------------------------|------------------------|-----------|-----------|-----------|-----------|--------|
| Plow tillage | Transmission shaft torque (Nm) | Raw data | 171.75 | 294.62 | 41.10 | 34.83 | 0.0218 |
| | | 90 | 171.73 | 295.90 | 10.12 | 34.81 | |
| Rotary tillage | PTO shaft torque (Nm) | Raw data | 171.75 | 294.62 | 41.10 | 34.83 | 0.0431 |
| | | 60 | 171.69 | 294.08 | 1.33 | 34.64 | |
| Baling | PTO shaft torque (Nm) | Raw data | 171.75 | 294.62 | 41.10 | 34.83 | 0.0431 |
| | | 66 | 171.71 | 294.08 | 1.33 | 34.64 | |

Table 7. Power consumption by the major parts of the 75 kW tractor during plow tillage depending on the operating routines (Unit: kW)

| Separation part | Power consumption | | | | |
|-----------------|--------------------|-----------|---------------------|--------------------------|-------------|
| | Transmission shaft | PTO shaft | Main hydraulic pump | Auxiliary hydraulic pump | Engine |
| Driving | 8.77±9.16 | 0.00±0.00 | 0.04±0.04 | 0.05±0.06 | 8.85±9.24 |
| Implement down | 24.17±22.19 | 0.00±0.00 | 0.09±0.08 | 0.05±0.05 | 24.31±22.31 |
| Working | 46.54±9.86 | 0.00±0.00 | 0.26±0.17 | 0.07±0.03 | 46.87±9.97 |
| Implement up | 38.72±14.43 | 0.00±0.00 | 0.35±0.16 | 0.06±0.04 | 39.13±14.60 |
| Turning | 13.74±8.87 | 0.00±0.00 | 0.06±0.04 | 0.08±0.08 | 13.87±8.96 |

removal of outliers, low-pass filtering, and classification of working routines were performed in order to analyze the load data efficiently. The unrealistic data (e.g., negative values) were removed and processed by checking the correlation with other load factors. A low-pass filtering was performed selecting 90 Hz as the excluded frequency of the transmission shaft load data considering the number of engine revolutions; and considering the gear ratio of PTO shaft rotational speed and working machine, no of working days, 60 Hz was selected as excluded frequency for rotary tilling, and 66 Hz for the baling operations. According to the criteria used for the load data of major power unit, the working divisions was classified into driving section, working section, turning section, and working machine lifting up and down section. After the pre-processing of load data, efficient analysis of time domain and frequency domain could be possible.

Acknowledgement

This research was supported by Korea Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry and Fisheries, Ministry of Agriculture, Food and Rural Affairs, Republic of Korea.

References

- Hansson P-A, Lindgren M, Nordin M, Pettersson O. 2003. A methodology for measuring the effects of transient loads on the fuel efficiency of agricultural tractors. *Applied Engineering in Agriculture* 19(3):251-257.
- Kim DC, Kim KU, Lee JW. 1998. Development of a load spectrum of tractor transmission. *Journal of Biosystems Engineering* 23(6):539-548.
- Kim GW. 2012. Driveline output torque estimation using discrete Kalman filter. *Transactions of KSAE*. 20(4):68-75.
- 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 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.
- Oh SD, Kim YJ, Seo HY, Lee TH, Lee JW. 2011. Diagnostic system for crashing and damping signals in engine-assembly line. *The Korean Society of Mechanical Engineers* 35(8): 965-970.
- Richard SF, Donald EB. 2005. *Theory and design for mechanical measurements*. John Wiley & Sons Inc. CAL. USA.
- Ryu MJ, Kang SW, Chung SO, Kim YJ, Lee DH, Choi CH. 2013. Load characteristics of 30 and 75 kW agricultural tractors during field operations. *ASAE Annual International Meeting*, Paper number 131590237, St. Joseph, Mich.: ASAE.
- Yun JJ, Bae MJ. 2012. On an adaptation of announcement sound level in white noise environment. *Journal of the Institute of Electronics Engineers of Korea - Signal Processing* 49-SP (1).