Measurements of tractor power parameters using GPS

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Abstract

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Understanding of the power parameters of an agricultural energy device (tractor) is very important in relation to the final outcome. This understanding is necessary to achieve high performance in combination with low economic costs and favourable ecological conditions. Monitoring the progress of power parameters (torque and engine power) is possible mainly by dynamometer, which is not affordable for common undertaking. The option of using GPS receiver to determine the torque of the engine and its backup torque seems to be an appropriate option. The data thus collected will contribute to the timely detection of defects, and thus prevent the emergence of economic and ecological consequences that are related to the tractor engine.

Keywords: engine torque; acceleration of the tractor; torque backup; GPS

The power of the combustion engine is an important diagnostic sign, especially useful in detecting the conditions of the piston group, engine timing mechanism and fuel system as we as for spark-ignition system of petrol engine. However, power alone is not sufficient to establish the conditions. In a measurement of power output it is necessary to determine the efficiency and secondary effects which were used to achieve this power (Arapatsakos, Gemtos 2008). For example, if the power of a diesel engine is within the tolerance of the nominal value but smoke emissions are above normal, it may be indication of the engine poor technical condition.

Unlike the measurements of power parameters, in terms of engine production or extensive engine repair, significantly simpler diagnostic methods are ordinarily used. It is possible to use accurate dynamometric stands for the measurement of the dismantled engines, or tractors, measuring power parameters directly to power take off (Serrano 2007), but it is not economically feasible for ordinary service. The same applies to the rolling test room for measuring power parameters, but it is not as accurate as a measurement of dismantled engines. While it also offers the use of modern acceleration methods (Hromádko et al. 2007), which are sufficiently accurate and low-cost, the measurement still has some complications particularly for engines equipped with turbochargers and other special electronic controls (Ascanio, Wang 2008).

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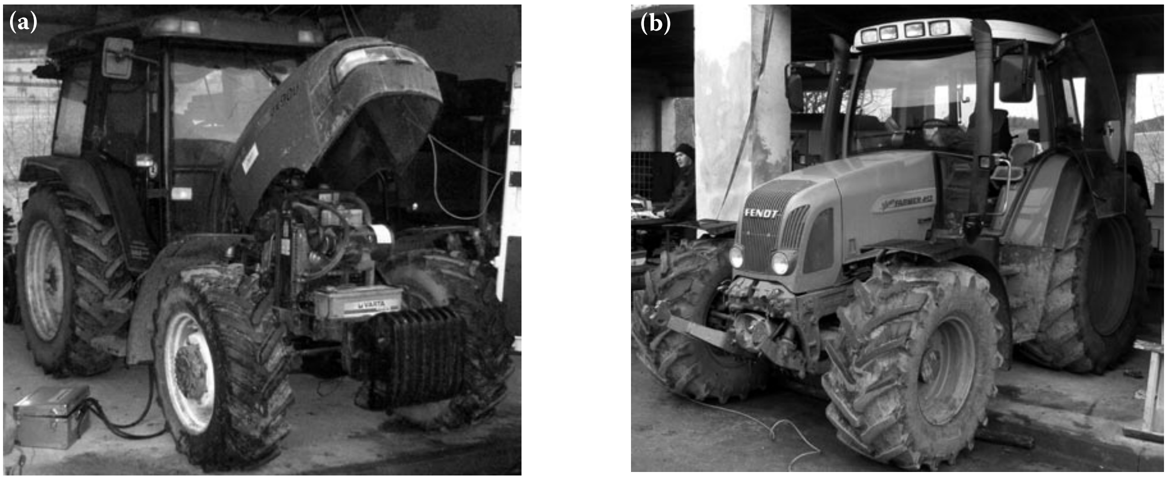

Fig. 1. Tested tractors: (a) Case IH JX 90; (b) Fendt Farmer 412 Vario

The authors of this paper have focused on the acceleration method (Litak, Longwic 2009) of measuring the power parameters applied to the measurement of the tractor while driving on a road. A GPS satellite receiver was selected to capture the course of acceleration. GPS receivers are already widely used (Ryšan, Šarec 2008) in precision agriculture. The power parameters were measured by GPS devices with frequencies of 1 Hz, 5 Hz, and 20 Hz.

It is possible to track the current condition of the tractor engine by determining its power parameters. The engine condition is major contributor to ecological and economical functioning in all work operations (Jílek et al. 2008; Müller et al. 2009).

METHODOLOGY AND ASSUMPTIONS OF MEASUREMENT

The methodology consists of measuring the acceleration of the tractor, usually at the highest gear on solid pavement from idle speed to normal running speed. During this time, the tractor's position is tracked by the GPS sensor. The Case IH JX 90 (Case IH, St. Valentin, Austria) and Fendt Farmer 412 Vario (AGCO GmbH, Marktoberdorf, Germany) were selected for the tests (Fig. 1).

The first tractor, a Case IH JX 90, was chosen in order to test a tractor with a mechanical transmission.

Technical parameters of Case IH JX 90:

- tabulated nominal engine power: 63 kW at 2,500 1/min (54.6 kW at 2,500 1/min measured at the power take-off),
- course of the power parameters measured at the power take-off is in Fig. 2,
- backup torque 37% (measured 31%).

The second tractor, the Fendt Farmer 412 Vario, was selected as an example of the newer type of variator transmission.

Technical parameters of Fendt Farmer 412 Vario:

- rated engine power: 88 kW at 2,100 1/min (82.9 kW at 2,100 1/min measured at the power take-off),
- course of the power parameters measured at the power take-off is in Fig. 3,
- excess torque of 50% (measured 54%).

Basic parameters of the used GPS device (Fig. 4) are:

Garmin (Garmin Corporation, Taipei, Taiwan)
Model: eTrex Vista Cx
Scanning frequency: 1 Hz
Accuracy – speed: 0,05 m/s (steady mode)
Accuracy – position: < 15 m
Qstarz (Qstarz International, Taipei, Taiwan)
Model: BT-Q1000X
Scanning frequency: 5 Hz
Accuracy – speed: 0,1 m/s
Accuracy – position: < 3 m
Dewetron (Dewetron, Graz, Austria)
Model: VGPS-200C
Scanning frequency: 20 Hz
Accuracy – speed: 0,028 m/s
Accuracy – position: < 0,4 m

In terms of evaluation, results should be expressed in terms of certain assumptions important for their treatment. Since the acceleration proceeds on the pavement, the follow resistances are overcome with the combination during the drive:

Air resistance depends on the square of the speed and given the maximum speed of the tractor

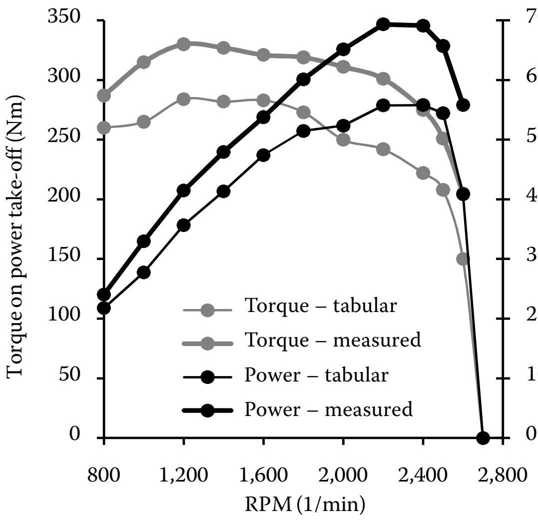

Fig. 2. Case IH JX 90 power parameters – tabular and measured (modified adjustment of the injection pump)

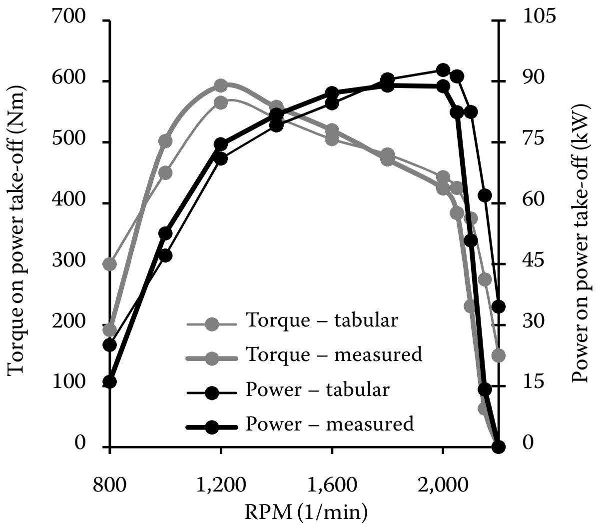

Fig. 3. Fendt Farmer 412 Vario power parameters – tabular and measured

(40 km/h), it is calculated only by tens of Newton and therefore can be neglected. When measuring, it is necessary to select, if possible, windless conditions. If the headwind is blowing the same speed as the tractor speed, magnitude of air resistance increases 4 times.

$$F_v = c_x \times S \times \rho \times \frac{v^2}{2} \quad (1)$$

where:
F_v – air resistance (N)
c_x – coefficient of air resistance (–)
S – frontal area of the tractor (m^2)
ρ – density of air (kg/m^3)
v – tractor speed (m/s)

Rolling resistance, same as air resistance, depends on the speed of the tractor (besides the state of the tire and road), but as this dependence is very mild, in practice, as well as in this paper are viewed as constant.

$$F_r = g \times m \times f(v) \quad (2)$$

where:
F_r – rolling resistance (N)
g – acceleration of gravity (m/s^2)
m – weight of the tractor (sets) (kg)
$f(v)$ – coefficient of rolling resistance, depending on the speed of the tractor (–)

Gradient resistance, an attempt was to select a road, where the slope approaches zero. The altitude of the selected road was measured with a GPS receiver equipped with a barometric altimeter. The force resulting from the gradient resistance, in addition to rising slope (change of altitude) also depends on the weight of the tractor. The rising resistance can be neglected in calculation, because it was measured on a slope below 2% (size of force are hundreds of Newtons). While the road is more inclined, and the slope is constant, then the gradient resistance is also constant and does not affect the final course of acceleration.

Fig. 4. GPS sensors: (a) Garmin, (b) Qstarz, (c) Dewetron

$$F_s = m \times g \times \cos(\alpha) \quad (3)$$

where:

F_s – gradient resistance (N)
m – weight of the tractor (sets) (kg)
g – acceleration of gravity (m/s^2)
α – angle of slope (°)

Mechanical resistance is dependent on the loss of power between the engine and the driving wheels. The value of these losses depends primarily on the number and type of gear sets. Analysis shows that these losses depend on the speed (engine speed), but this dependence can be ignored (low dependence and low travel speed of tractor).

Resistance of inertia, during acceleration it is necessary to overcome the inertia mass of all rotating parts of the engine, gears, shafts and the wheels themselves. This can be expressed as the single number reduced to a wheel circumference. Value of the resistance, in addition to inertia moment, depends on the angular acceleration (in the case of reduction to the wheel circumference is it the angular acceleration of the wheel) and the radius of the wheel.

$$F_I = I_k \times \frac{\varepsilon}{r} \quad (4)$$

where:

F_I – acceleration resistance (N)
I_k – moment of inertia of the rotating mass of the tractor reduced on the tractors wheel circuit (kg/m^2)
ε – angular acceleration of tractor (rad/s^2)
r – tractor wheel radius (m)

Acceleration resistance depends on the weight of the tractor and the longitudinal acceleration of the tractor. The course of longitudinal acceleration is fully in line with the course of engine torque, which is the main prerequisite for the authors.

$$F_a = m \times a \quad (5)$$

where:

F_a – acceleration resistance (N)
m – weight of the tractor (sets) (kg)
a – acceleration of the tractor (sets) (m/s^2)

The conclusion of all assumptions is that either the individual resistors can be eliminated (the resistance gradient), ignored (air resistance) or with regard to speed it can be rated as constant (mechanical resistance, rolling resistance). Only the acceleration resistance and resistance of inertia, which expresses the course of the power parameters by the course of acceleration, remain. From a practical point of view, the course of power parameters can be obtained as the course of acceleration which is multiplied by a constant. This constant includes the driving resistances (therefore also the moment of inertia of rotating masses), the overall transmission gear ratios between the engine and wheels. It is determined in comparison with the tabular data or the measured data (e.g. dynamometer) of the power parameters. Tabular or measured value of the constant is taken as real and true information, which is only divided by the accel-

Table 1. Tractor Case IH JX 90: torque measured on power take-off and acceleration converted into torque (GPS 1, 5, and 20 Hz)

Revolutions per minute (1/min)	Torque – measured on power take-off (Nm)	Acceleration converted into torque		
		1 Hz (Nm)	5 Hz (Nm)	20 Hz (Nm)
800	287.0	207.5	230.3	213.6
1,000	315.0	253.5	291.6	299.3
1,200	330.0	299.6	324.6	330.0
1,400	327.0	330.0	330.0	329.3
1,600	321.0	328.3	318.8	314.8
1,800	319.0	295.4	304.2	298.1
2,000	311.0	250.4	294.4	284.9
2,200	301.0	216.4	284.8	274.8
2,400	275.0	190.9	250.3	261.6
2,500	251.0	162.9	208.5	250.3
2,600	205.0	101.0	138.0	233.2

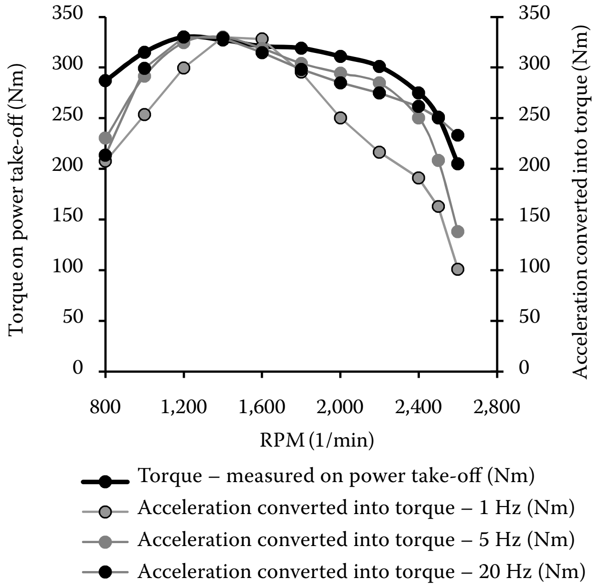

Fig. 5. Power parameters of Case IH JX 90 and their course measured by GPS

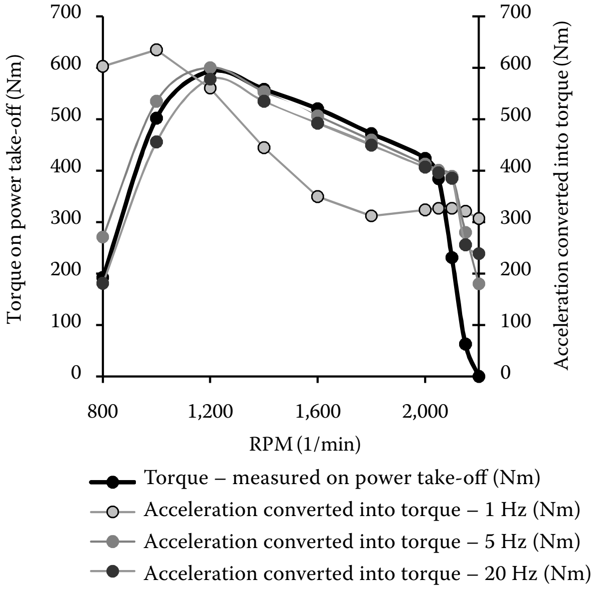

Fig. 6 Power parameters of Fendt Farmer 412 Vario and their course measured by GPS

eration and this constant is available for further measurements. In other measurements, the result is given as the product of the measured acceleration and the above-mentioned constant in form of the power parameters (6):

$$M = k \times a \quad (6)$$

where:

M – torque of the tractor engine (N m)

k – constant (kg m)

a – acceleration of the tractor (sets) (m/s^2)

RESULTS

The two tractors were measured according to the previously described methodology. Results for the Case IH JX 90 are shown in Fig. 5 and Table 1. From the information gathered it is evident that the use of GPS for determining the engine torque is possible. Very good results can be achieved with GPS sensor at 5 Hz and 20 Hz. The sensor with a frequency of 1 Hz was an outdated tourist GPS and the results cannot be compared with the torque characteris-

Table 2. Tractor Fendt Farmer 412 Vario: torque measured on power take-off and acceleration converted into torque (GPS 1, 5, and 20 Hz)

Revolutions per minute (1/min)	Torque – measured on power take-off (Nm)	Acceleration converted into torque		
		1 Hz (Nm)	5 Hz (Nm)	20 Hz (Nm)
800	192.0	602.5	270.8	180.9
1,000	502.0	634.5	534.7	455.7
1,200	593.0	560.1	600.0	577.6
1,400	558.0	444.5	553.0	534.9
1,600	520.0	349.4	506.1	492.1
1,800	472.0	312.0	459.1	449.4
2,000	424.0	323.5	412.2	406.6
2,050	384.0	326.8	400.5	395.9
2,100	231.0	326.8	388.7	385.2
2,150	63.0	321.1	280.0	256.0
2,200	0.0	307.1	180.0	238.6

Table 3. Backup torque – Case IH JX 90 and Fendt Farmer 412 Vario (%)

Tractor	Table backup	Dynamometer measured backup	GPS 1 Hz	GPS 5 Hz	GPS 20 Hz
Case IH JX 90	37	31.47	72.83	31.84	31.84
Fendt Farmer 412 Vario	50	54.43	74.43	54.34	49.94

tics due to the high inaccuracy of the 1 Hz sensor. Graphical dependencies are created in MS Excel as the polynomial trendline.

The backup torque for the Case IH JX 90 tractor was found by measuring the power take-off with a dynamometer: Case 31.47% (Table 3). Observed results for backup torque from each GPS sensor are for 1 Hz 72.83%, for 5 Hz 31.84%, and for 20 Hz 31.84%. The results are consequently comparable.

The problem in assessing the log from the GPS device is displacement, which is dependent on the quality of this device, and which may complicate the correct deduction of the backup torque. The authors therefore recommend measuring the tractor with a set GPS sensor on a particular track and under specific conditions, which can be easily repeated and set as standard. Standards can be easily converted directly to the torque by using tabulated values and the observed rate. Courses can be compared for any other measurements in similar conditions. Any changes to the value of torque (acceleration) from the standard and the extrapolated changes to the backup torque, which mainly results from changes the technical conditions of the engine, can also be compared.

The backup torque was found for the Fendt Farmer 412 Vario tractor by measuring the power take-off (Fig. 6, Table 2) 54.43 % (Table 3). Observed result of backup torque from each GPS sensors are for 1 Hz 74.43%, for 5 Hz 54.34%, and for 20 Hz 49.94%. The Fendt Farmer 412 Vario tractor had a problem with the automatic gearbox. It is necessary to ensure that moving from the idle speed to maximal speed proceed with constant gearing.

DISCUSSION AND CONCLUSION

Power parameters are a good diagnostic sign for assessing the technical conditions of the combustion engine, but in practice they are difficult to detect (Hromádko et al. 2007; Jílek 2008). As a rule, the dynamometer is not available for detecting them directly. From the mathematical point of view, the torque and engine power are directly proportional to acceleration. It is possible to measure acceleration (Litak, Longwic 2009), and in turn, to derive course of the power parameters and the backup torque.

In the paper the acceleration of two tractors is measured by the use of GPS devices with scanning frequencies of 1, 5, and 20 Hz. The tractors used are the Case IH JX 90 with a mechanical gearbox and the Fendt Farmer 412 Vario with variator transmission. The results indicate that the use of an outdated tourist 1 Hz GPS device provided inaccurate information. By contrast, 5 and 20 Hz GPS sensors showed accurate outcomes.

The Case IH JX 90 tractor was measured by the dynamometer torque backup of 31.47% and the GPS sensor with a frequency of 5 and 20 Hz was measured at both 31.84%. Fendt Farmer 412 Vario tractor was measured by the dynamometer torque backup 54.43%, using GPS at 5 Hz 54.34%, and 20 Hz 49.94%. The problem may be that it is necessary for each individual GPS search points for calculate the backup torque and the measured points fit right continuous functions. In terms of fitting would be better not to work with the scanning frequency in Hz, but the frequency adaptable to driving speed and logged the location of a preset distance travelled or the change of speed.

The authors of this paper believe that if the acceleration is measured by any GPS sensor when the tractor is new, you can create a standard that can be quite accurate by a coefficient to the measured value of torque. Assuming the same rate, the same track and similar climatic and technical (tyre pressure, air temperature, slope etc.) conditions, data from a GPS device may be directly converted to torque and the backup torque inferred from the torque data. It can thus contribute to increasing economic and ecological running of tractor.

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