TRACTOR PULLING TESTS SUPPORTED BY ECU DATA READING

JIRÍ ČUPERA, PAVEL SEDLÁK, FRANTIŠEK BAUER, MARTIN FAJMAN

Mendel University in Brno, Department of Engineering and Automobile Transport, Zemědělská 1, 613 00 Brno, Tel.: +420 545 132 942,

E-mail: xcupera@node.mendelu.cz, sedlakp@mendelu.cz, bauer@mendelu.cz, fajman@mendelu.cz

SHRNUTÍ

Článek popisuje možnost využití dat ze sběrnice CAN nebo ISO-BUS pro tahové zkoušky traktoru. Zkoušení sestávalo z polních a laboratorních zkoušek, před vlastním polním měřením byl motor zkoušen na dynamometru. Parametry odečtené ze sběrnice CAN byly validovány externími snímači a byla vyhodnocena jejich chyba. Na základě měření bylo shledáno, že chyba prezentovaného zatížení odečteného ze sběrnice CAN je velmi významná. Pro zpřesnění této hodnoty je nutné vytvořit regresní funkci. Model byl dále ověřen a byla vypočtena nejistota. Bylo shledáno, že pro zahrnutí parametrů sběrnice CAN do testovacích procedur je nutné provést předchozí statistickou analýzu parametrů.

KLÍČOVÁ SLOVA: TAHOVÁ ZKOUŠKA TRAKTORU, CAN-BUS, TAHOVÝ VÝKON

ABSTRACT

The article describes the potential for using data from the CAN- or ISO- bus for tractor pulling tests. The testing techniques consisted of both field and laboratory tests; thus, each engine was tested in the laboratory before the field pulling tests. Values of CAN were validated by external instrumentation and their reliability with respect to the true values was analyzed. A significant degree of error was determined at low engine load; thus, for higher precision under the field conditions, it was necessary to use a regression function. The model was verified and its resulting uncertainty was calculated, which led to the conclusion that it is inadequate to take only the data from CAN into account if no further statistical processing is performed.

KEYWORDS: TRACTOR PULLING TEST, CAN-BUS, DRAWBAR POWER

1. INTRODUCTION

With respect to the pulling tests of agricultural tractors, there are always crucial points connected with the problem of how to determine the magnitude of power losses. Losses resulting from the transformation of the effective engine power to pulling force/power can be determined from the power balance of the tractor [3]. Nevertheless, mathematical models of forces and moments representing the balance can only be used if it is possible to obtain or calculate the actual engine power. Similar problems may be encountered in the case of tractor sets used in transportation or in aggregation with various implements. The value of engine power can be calculated as a multiplication of torque and engine speed, which in practice requires the mounting of external sensors. This solution is actually relatively expensive, time consuming; and in many cases, it is not feasible due to lack of space between the engine and gearbox. This is why it seems more effective to use data that are available in a CAN-BUS [7]. The CAN-Bus is currently the most widely used bus for an internal communication network between sensors and control units on vehicles.

Modern tractors are equipped with several electronic control units that communicate with each other directly or using various network bridges. Electronic control units provide regulation for the engine, gearbox among others [9]. For their work they need information from many sensors, which are installed inside a tractor. The processed signals of these sensors are transmitted over digital networks such as the CAN-Bus or other derivative of an asynchronous serial bus [6]. Thus, monitoring and the possibility of recording the parameters transmitting via CAN, particularly during field testing, significantly simplifies the preparation and most significantly reduces the cost of measurement and testing. The question is how precise are the data? This issue is especially important for indirectly measured or calculated parameters. For example, data of instantaneous fuel consumption transmitted via CAN are not directly measured, but are determined indirectly by calculation of nozzle opening time. This method can bring, in most cases, a more significant error than direct measurement. Therefore, to obtain sufficiently accurate values, it is appropriate and in some

cases even necessary to carry out calibration of the data thus obtained from the measuring instruments. Another calculated parameter which can be considered a primary parameter is engine torque or power. The aim of our work is to determine what kinds of data obtained from the network are fit for the determination of the effective engine power. Furthermore, we attempted to analyze available parameters from which the engine power can be calculated and then verify the accuracy of this method. The results obtained in laboratory tests were consequently included into procedures used for pulling force measurements.

2. MATERIALS AND METHODS

Laboratory measurements were performed to achieve the above-mentioned objective. The data acquisition system consists of CAN data logging together with the external sensors on the test bed. The external sensors, or rather their signals, were used for validation of data from the network. Tests were carried out with a John Deere 8320R wheeled tractor, see Figure 1. The main technical data provided by the manufacturer of the tractor engine are listed in Table 1.

The reliability of CAN data at different engine speeds and loads was observed over the full speed characteristics of the engine measured

TABLE 1: Main characteristics of the tractor JD 8320R.

TABULKA 1: Základní parametry traktoru JD 8320R.

Parameter	Value
Rated power	239/320 [kW/hp]
Max. power without boost	255/347 [kW/hp]
Max. power with boost	261/355 [kW/hp]
Rated engine speed	2,100 min ⁻¹
Torque	1,419 Nm at 1 500 min ⁻¹
No. of cylinders	6
No. of valves	24
Bore	118.4 [mm]
Stroke	136 [mm]
Compression ratio	16.3
Displacement	9,000 cm ³
Air supply	Turbocharger
Injection type	Common Rail

FIGURE 1: Eddy current dynamometer connected to the PTO of tractor JD 8320R.

OBRÁZEK 1: Traktor JD 8320R připojený přes vývodovou hřídel na vířivý dynamometr.

via the rear PTO. All characteristics were measured at steady states. The full speed characteristic was constructed from the rated engine power curve and twelve partial load branches, in total from 235 points. Engine torque was measured using a test bench equipped with a V500 eddy current dynamometer (Figure 1), which was connected to the rear output shaft of the tractor (PTO). Technical features of the dynamometer are given in Table 2. The regulation of the dynamometer and data acquisition is provided by the vehicle management computer system and a higher data server system. Dynamometer speed is measured using an incremental sensor LUN 1326.02-8, which forms a part of the dynamometer. The signal from the sensor is adjusted by a forming circuit and transmitted to the measuring system. A steady mode of the engine parameters was determined by measuring the exhaust temperature and the temperature of lubricating oil in the engine. Also measured were the intake air temperature, exhaust temperature, air temperature in the laboratory, barometric pressure and relative humidity. Temperatures were measured using a K-thermocouple, barometric pressure using a piezoresistive sensor. Readings from all the sensors were continuously stored in the memory of the computing system. The PTO speed for all tests was set at 1000 rpm. Since the fuel consumption taken from the CAN-BUS is presented in volumetric units, the instantaneous temperature of the fuel needs to be monitored to determine the density of the fuel and its recalculation to mass flow. Specific gravity of fuel, depending on its temperature, was established in a laboratory measurement of the density of the fuel using Mohr's scales. The readings were fitted using a second-degree polynomial. A regression equation was determined for each measurement.

Simultaneously with the measurement of engine torque and PTO speed, the actual fuel consumption rate was also recorded via two

FIGURE 2: Coriolis mass flow meters Sitrans FC MassFlo Mass 6000 used for fuel consumption metering.

OBRÁZEK 2: Coriolisovy průtokoměry Sitrans FC MassFlo Mass 6000 určené pro měření spotřeby.

Coriolis mass flow meters, as well as intake air temperature, inlet air pressure, engine oil temperature, engine coolant temperature and temperature of exhaust gases. Measurement of fuel consumption was carried out using the Coriolis mass flow meter Sitrans FC MASSFLO Mass 6000. In order to minimize the possible effect on the fuel supply system, two independent flow meters were used. Figure 2 shows the connection method. Sitrans FC MASSFLO Mass 6000 is an accurate flow meter with a range of 0–300 kg/h, and its accuracy is 0.1% of the reading.

CAN data were logged in the same time base as previous external measurements. CAN data were taken from the network backbone and consist of the following parameters: engine speed, engine load, actual fuel consumption, actual torque, demand torque, temperature of fuel, air supply, engine oil etc. A detailed description of measurements and measuring devices used is shown in reference [2]. For all tests performed, the general requirements according to standard ISO 789-1 have been met [11].

Processing the data from the CAN-BUS was realized with our proprietary software developed for measuring according to the SAE J1939 recommendation. Data obtained from the evaluation of laboratory tests were verified during the pulling test. Measurements of drawbar characteristics were carried out under field conditions on stubble after harvesting wheat [4]. The pulling force was measured by an HBM load cell connected between tractors, see Figure 3. Values of force were enhanced by ground speed and theoretical velocity. These parameters can be used for drawbar performance and slip ratio evaluation. In addition, readings from the CAN of the tractor were added to the above-mentioned values of all field tests performed. A detailed description of the methodology of measurement of drawbar properties and their evaluation is given in the reference [1; 2]. Drawbar characteristics were extended by plots of engine effective power obtained from an equation derived from the results of laboratory tests.

FIGURE 3: Measurements of drawbar properties of wheeled tractor JD8320R.

OBRÁZEK 3: Měření tahových vlastností kolového traktoru JD8320R.

3. RESULTS

The accuracy of results of engine power calculation also depends on the selection of the parameter describing engine load. The actual torque (M_{tact}) was selected as being the most precise. Nominal characteristics measured over the PTO is shown in the graph, see Figure 4. The graph shows that the actual torque follows the course of the rated torque. The problem for the further use of this parameter of the data is that it is presented as a percentage. Thus, direct conversion into real values was done by synchronizing layers of CAN readings and results of dynamometer readings, see Figure 5.

It is clear from the very first view of full speed characteristics that for low torque values the engine ECU calculates parameter M_{tact} with a considerable error. In detail, the error increases with the growth of engine speed, which can be seen from isoline plots of actual torque given as percentages. Towards higher actual torque the error decreases. In addition, the highest value of actual torque crossed the tractor torque of 108% nominal value. It is also important to realize the uncertainty of M_{tact} calculation due to changes in the technical condition of the engine. Summarizing the above, it is evident that determination of the engine torque cannot be expressed as a simple conversion. Thus,

TABLE 2: Technical specification of used dynamometer V500.

TABULKA 2: Technická specifikace dynamometru V500.

Parameter	Unit	Value
Type of dynamometer	[-]	V 500 (Eddy current)
Speed	[min ⁻¹]	150 1 500 3 000
Power	[kW]	4 500 500
Torque	[Nm]	254 3 184 1 592
Cooling	[-]	water cooled
Load capacity	[-]	permanent

FIGURE 4: Nominal engine characteristics of the JD 8320R tractor, curves of torque M_t measured via PTO (Nm), actual torque M_{tact} logged from CAN (%) and engine load (%) calculated by the engine ECU.

OBRÁZEK 4: Jmenovitá otáčková charakteristika traktoru JD8320R, průběhy momentu měřeného přes vývodovou hřídel (Nm), průběhu aktuálního momentu M_{tact} ze sběrnice CAN (%) a zatížení motoru vypočteného řídicí jednotkou motoru.

to improve the precision of the value representing actual engine power we used regression functions. The comparison between the mentioned values of engine power was done on the basis of knowledge of real values – power measured over the PTO. The equation of used surface describing engine power in relation to engine speed and actual torque, takes the form:

$$P = A + B.n + C.n^2 + D.M_{tact}^2 + E.n.M_{tact} \quad (1)$$

where: P – engine power (kW)

n – engine speed (min⁻¹)

M_{tact} – actual torque CAN (%)

A, B, C, D, E – regression coefficients as special physical quantities with their own units.

The chart of isolines is constructed as follows. We keep the planes parallel to the xy plane (engine speed-torque) at the corresponding heights (selected power values), these intersect the regression surface at intersections whose projections in the xy plane constitute the isolines for constant power.

Results of statistical evaluation are presented in Tables 3 and 4. The F-test results of the regression equations are listed in Table 3. The high significance of the calculated function is apparent. The high dependence demonstrated by the tightness of the index value determination $I_2 = 0.99880$, i.e. 99.88% of

variance is explained by calculated regression functions. Also, the t-test of regression coefficients listed in Table 4 shows the high significance of the calculated coefficients. The graph of the calculated regression surface is shown in Figure 6.

An analysis of residual deviations (see Figure 7) shows significant deviations of low values calculated from the regression surface. In connection with the variability of the measured data, we examined the expression of measurement uncertainty in accordance with CSN P ENV 13005 [10]. The set of maximum permissible errors of measurement and the measuring instruments was determined by standard uncertainty of measurement. To ensure 95% probability of a correct result, expanded uncertainty of measurements was subsequently calculated. Determination of engine power of the JD 8320R tractor derived from the regression equation can be expressed as $P = (P \pm 4)$ kW. As a relative expression, the expanded uncertainty was 1.9%.

The equation derived from the results of laboratory tests was used for adjustment of field measurements of the pulling properties of the tractor. Drawbar tests were carried out in a field with sandy-loamy soil on the stubble after harvesting wheat. The test tractor was loaded by a crawler tractor, see Figure 3. Measurement of pulling characteristics was performed at steady speeds according to the OECD methodology Code 1 and 2, and ISO 789-9. Drawbar properties were measured in the tractor gears 5, 7, 9 and 11. Both axles were powered. Drawbar power and efficiency were calculated for all the measured pulling forces from the derived equation. The results are plotted in drawbar characteristics shown in Figure 8. The characteristic curves are plotted as pulling performance and efficient power for the individual transmissions gears, depending on the pulling force. The graph also shows the course of the drive wheel slip. The drawbar characteristics exhibit obvious differences in both curves measured on the same gear. This difference represents the power loss in the transmission and

TABLE 3: Analysis of spread.

TABULKA 3: Analýza rozptylu.

	Df	SS	MS	F	Significance F
Regression	4	853310,8	213327,7	48654,99	0
Residual	232	1017,2	4,38		
Sum	236	854328			

TABLE 4: Determined coefficient values and their significance.

TABULKA 4: Výsledky testování koeficientů a jejich významnosti.

	Coefficients	Error of mean	t stat	P - value
A	-15,37	4,43794	-3,464	0,000633
B	0,0149	0,005636	2,656	0,00846
C	-1,74E-05	1,72E-06	-10,105	3,96E-20
D	-0,00102	0,000168	-6,065	5,32E-09
E	0,001553	1,32E-05	117,453	1,2E-208

FIGURE 5: Full speed characteristics of actual torque acquired from the CAN-Bus of the JD 8320R tractor measured via PTO.

OBRÁZEK 5: Úplná charakteristika aktuálního točivého motoru ze sběrnice CAN traktoru JD 8320R měřená přes vývodovou hřídel.

FIGURE 6: Engine power surface plot of the JD 8320R tractor with respect to engine speed n (min^{-1}) and engine torque M_{tact} (%) read from CAN.

OBRÁZEK 6: Povrchový graf výkonu motoru traktoru JD 8320R v závislosti na otáčkách motoru n (min^{-1}) a aktuálního točivého momentu M_{tact} (%) ze sběrnice CAN.

includes wheel slip. The power loss at maximum pulling power reached 73.5 kW. Moreover, for low gears (5 and 7) the engine could not reach maximum torque. The highest pulling force is limited by the contact area between tires and the surface. Similar results were described in [5; 8]. The maximum engine torque was achieved at higher gears (9 and 11).

FIGURE 7: Plot of residuals between measured and calculated values of engine power.

OBRÁZEK 7: Graf reziduálních odchylek mezi měřeními a vypočtenými hodnotami výkonu motoru.

FIGURE 8: Drawbar characteristics of the tractor JD 8320R.

OBRÁZEK 8: Tahová charakteristika traktoru JD 8320R.

3. CONCLUSION

Currently, almost all vehicles are equipped with one of several communication networks. The tractors usually use the CAN BUS, which is used to transfer data between control units. The data from the network can be used, for example, in the field tests without installation of expensive measuring equipment. The article describes the possibility of using digital data from the network to determine

the immediate tractor engine power. It specifies the procedure for deriving the regression equation from data obtained in laboratory measurements of engine parameters. The calculated regression function was used to determine engine power during pulling tests. From these results it is clear that the mentioned procedure allows the determination of power loss in field tests. To establish whether the regression function may also include another engine (the same type) we performed an experiment in the same way using the tractor JD8320RT (track type). Regression coefficients were almost identical. The derived regression function can be used in other testing procedures, such as the use of tractor in transport, or in different field works. In these cases it is possible to evaluate the engine load and therefore the economy of its operation. Another example of the use of regression function can be a parameter which would be transmitted via ISO-BUS for active implements.

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LIST OF NOTATIONS AND ABBREVIATIONS

CAN-BUS (CAN)	A serial vehicle bus designed for transmission of messages between microcontrollers.
ECU	generic term for any regulation system that controls one or more of the electrical systems or subsystems (e.g. engine ECU).
Engine load	SAE J1939 describes engine load as the ratio of actual engine percent torque (indicated) to maximum indicated torque available at the current engine speed, clipped to zero torque during engine braking.
ISO-BUS	A communication protocol for agriculture. The standard (ISO 11783) specifies a serial data network for control and communications on forestry or agricultural tractors and implements.
Mtact	Actual Engine – Percent Torque provides a window to the engine's desired torque output when no speed/torque request commands are actively controlling the engine. In the calculation of Actual Engine – Percent Torque, the output of the engine's idle governor must be considered, along with the impact of the engine's full load governor, smoke controls and other internal limiting logic.

OECD

The Organisation for Economic Co-operation and Development, within the context of this contribution we refer to their standards for testing tractors (Code 1, Code 2).

PTO

Power Take Off – a splined driveshaft used to provide power to attachments or separate machines.

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