DETERMINATION OF THE TRACTOR ENGINE POWER IN THE FIELD CONDITIONS

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Abstract: This article deals with the determination of the tractor engine power in the field condition. Effective engine power is the basic output parameter of the engine. At the evaluation of tractor output parameter, engine power is used for determination of drawbar pull. Engine power is product of torque and angular speed. CAN-Bus reading is widely spread technique in testing. Information about actually torque is also provided, but this information and its value is indicated in percent. For this reason, the direct calculation of engine power is not possible and it is necessary to proceed from other parameters. Application of the engine load and the engine speed for determination of the engine power is the objective of this article. In this paper, the individual steps of model creation including partial calculations mentioned above are described.

Key Words: least squares method, natural neighbor interpolation, CAN-Bus, engine power

INTRODUCTION
In the last years, progress of electronic control systems in vehicles is evident. The growing share of these element is not reflected only in engine control, transmission and other vehicles systems, but also in testing field (Štěrba et al. 2011). Installation of external sensors is not needed to use for measurement. Reading of relevant data can be realized with the use of CAN communication. Network parameters and data transfer are specified by standards, moreover the requirements crossing different categories of vehicles are strict based on line topology. Digital data acquiring brings more benefits like time and cost savings, reduced complications in measuring chains adjustments etc. Fundamental evaluation of performance is based on engine power knowledge. Engine power can be calculated from torque and crankshaft angular speed. At analyzing the data from the vehicle network CAN-Bus, it is clear that information about engine torque is available only in percentage units and not in Nm. For this reason, this data cannot used for calculation the engine power. There is only one solution that offers. It is needed to find out relationship among actual torque, engine speed and engine power, for example in tractor laboratories by eddy current dynamometer. However, published study dealing with similar problems (Sedlák et al. 2010) shows that information about the actual torque corporates errors. For this reason, it is preferable to determine the engine power for example from engine load. The article deals with possibilities of using the engine load and engine speed to determine the power of tractor engine in field conditions. The paper also describes the various steps in the construction of a model showing the relationship among these parameters.

At the drawbar tests, calculation of the engine power is very important, because it can be used for the calculation of traction efficiency. Drawbar pull is calculated by dividing tractive power and efficient engine power. It expresses the efficiency of transfer engine power to pulling power (Bauer et al. 2013, Semetko et al. 1986).

MATERIAL AND METHODS
To determine the relationship among the engine load, engine speed and power, tractor Claas Arion 640 CMATIC was used. Technical specification of the tractor engine is given in the Table 1.
Table 1 Technical specification of the tractor Claas Arion 640 CMATIC

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>DPS</td>
</tr>
<tr>
<td>Number of cylinders</td>
<td>6</td>
</tr>
<tr>
<td>Volume capacity [cm³]</td>
<td>6788</td>
</tr>
<tr>
<td>Nominal engine speed [min⁻¹]</td>
<td>2200</td>
</tr>
<tr>
<td>Type approval value (97/68 EG)¹ [kW/k]</td>
<td>128/174</td>
</tr>
<tr>
<td>Output at nominal engine speed (ECE R 120) [kW/k]</td>
<td>124/169</td>
</tr>
<tr>
<td>Maximal output power (ECE R 120) [kW/k]</td>
<td>130/177</td>
</tr>
<tr>
<td>Maximal torque (ECE R 120) [Nm]</td>
<td>714</td>
</tr>
<tr>
<td>Engine speed at Mtmax [min⁻¹]</td>
<td>1200</td>
</tr>
<tr>
<td>Constant power output range [min⁻¹]</td>
<td>1800–2200</td>
</tr>
</tbody>
</table>

Laboratory measurement took place in the laboratories of the Department of Technology and Automobile Transport at Mendel University in Brno in accordance with OECD. In all tests have been complied with general condition and provision about allowed tolerances of the standard ČSN ISO 789-1. For data acquisition and saving information from bus CAN-Bus, proprietary software created by Department of Technology and Automobile transport was used. DLC (data link connector) was used for connection of the tractor to computer. CAN-Bus network of tested tractor was fully compatible with standard SAE J1939 in specification 2.0B. Communication speed was set to 250 kbps and appropriate messages related to engine power were monitored: actual torque, engine load, torque losses, fuel consumption, temperature of coolant, etc.

Figure 1 Tractor Claas Arion 640 CMATIC in Vehicle laboratories of the Department of Technology and Automobile Transport at Mendel University in Brno

Sampling frequency of measuring chain was set to 20 S/s. For loading the engine and calculation of the engine power, eddy current dynamometer was used. Type of dynamometer: V500 (producer: VÚES Brno, speed [min⁻¹]: 150/1500/3000, power [kW]: 4/500/500, torque [Nm]: 254 / 3184/1592, cooling: water, load: permanent). The dynamometer was connected to the rear PTO of the tractor (see in Figure 1). Dynamometer regulation and saving of measured data was provided by the computer in laboratory.
To determine the relationship among the monitored parameters, measurement in full range of engine speed and engine load was conducted. It was done measuring one nominal and twelve partial characteristics with reduced fuel supply.

RESULTS AND DISCUSSION

Mentioned above, engine load, speed and engine power were major measured parameters. Engine power is labeled as the power on PTO. Since, the force (measured with the dynamometer) was not measured on engine crankshaft, but on the PTO shaft. PTO power and engine output is slightly different due to the mechanical losses. Figure 2 is 3D chart showing measured values.

Data, in the chart (Figure 2), was used for intersperse of surface and for calculation surface equation. As independent a variables entering into the calculation, the load and engine speed were used. The dependent variable was PTO engine power. For the calculation of the equation, software Statistica 12 and Microsoft Excel 2013 (for checking of calculation) was used. For the calculation was used polynomial regression analysis using the least squares method. Calculated equation (2) has the form:

\[
\text{Engine power PTO} = -127,9808 + 0,1571 \cdot \text{Engine rev} + 0,2311 \cdot \text{Engine load} - 5,96 \cdot 10^{-5} \cdot \text{Engine rev}^2 + 0,0008 \cdot \text{Engine rev} \cdot \text{Engine load} - 0,001 \cdot \text{Engine load}^2
\]  

Determination index was calculated $R^2 = 0.99$. This value indicates that a high percentage of points corresponds with the calculated model. However, as absolute member show, the low engine speed and engine load will evince negative PTO power. This is also evident in the graphic expression of the equation (Figure 3).
As is evident from Figure 3, not only low values of the engine speed, but also a high value of speed at low engine load indicate the negative PTO power. In this areas, negative power is realistically impossible to achieve. For this reason, using of this model for determining engine power would be very inaccurate. Hence, used polynomial regression analysis by the least squares method is inappropriate and it is needed to use another method. Another possible solution was to use the Natural Neighbor Interpolation using Watson algorithm.

Natural neighbor interpolation is a method of spatial interpolation. The natural neighbor algorithm uses a circular areal-based procedure for interpolation. It is the most general and robust method of interpolation available to date. The method is based on Voronoi tessellation of a discrete set of spatial points. It produces a conservative, artifice-free, result by finding weighted averages, at each interpolation point, of the functional values associated with that subset of data which are natural neighbors of each interpolation point (Watson 2002).

The natural neighbor relationships of data are specified by the shared natural neighbor circles. The Watson algorithm uses a simple weighted average of the \( z \) values of the natural neighbors of the interpolation point. This type of linear interpolation in natural neighbor coordinates is the equivalent of planar interpolation in rectangular coordinates. No gradient information is used for the non-tension interpolant. For the tension interpolant, natural neighbor gradients are computed using the natural neighbors of a data point, but not the data point itself. A compound exponential blending function is used to add the influence of the gradients and render the interpolant at the nodes. The blending function does not use the tension directly, modifying it in accord with an outlier or roughness index. For data fitted well by smooth functions, the highest tension setting is likely to produce the greatest accuracy.

From the description mentioned above, the result of interpolation is not one equations (as in the previous case), but the matrix points that will subsequently be used as an input matrix for calculation the PTO power from speed and engine load. The matrix used for description of relationship among the PTO power, load and engine speed contained 16 384 points. Graphical representation of this matrix is shown in Figure 4.
As shown in Figure 4, data of matrix in areas with low engine load does not contain negative values of engine power and can be used for further processing. Subsequently, this data was transported into the software created for the purpose of reading relevant data from the CAN-Bus network and for determination PTO power. This program was created on the platform of LabVIEW.

As shown in Figure 4, it is possible to further notice of the slumps of engine power at high engine speeds (highlighted area). This decline is not caused by incorrect interpolation, but the regulator of the engine. This regulator intentionally reduced engine power. This effect is not seen in Figure 3 due to inaccurate calculated model.

Before the starting field measurements, it was also examined whether the PTO power determined by the calculated model exhibits deviations from the engine power measured in the laboratory. The errors in determining the performance fluctuated only in interval ± 0.25 kW. This is very small difference. Hence, this procedure is possible to use with high precision for calculation of the engine power of the tractor. As shown some studies (for example Čupera and Šmerda 2009), it is necessary to bear in mind, that before using the data from the CAN-Bus network, verify their accuracy is needed, or rather calibration of vehicle internal sensors is needed by accurately laboratory sensors.

CONCLUSION

The results of the paper show that the data from the network CAN-Bus is possible to use to determine engine power. Mentioned process is very accurate, fast and cheap, but at determining, the relationship among the individual parameters have to be sufficiently choose the appropriate calculating method.

The high level of vehicles electrification that take over control not only of engine combustion process, but also other vehicle systems. Topology of this systems allow their using at vehicle measurements. In recent years, reduction price and time-consuming arise in field measurements. Before each measurement, checking the accuracy of the sensors should be done. It is allowing to avoid introduce of needless errors in the vehicles system testing.
ACKNOWLEDGEMENTS
The presented work has been prepared with the support of IGA MENDELU IP 10/2016 “Verification of the model force action in a three-point hitch”.

REFERENCES