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A NEW METHOD OF USABILITY EVALUATION OF AGRICULTURAL TRACTORS BASED ON OPTIMUM WORKING INDEX [OWI]

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Summary. The paper includes a presentation of a new usability evaluation method of agricultural tractors in terms of optimum utilization of the engine performance map. The series of types of the Ursus tractors was compared based on the Optimum Working Index (OWI) created for this purpose. The usability of the tractors was evaluated for a model of an average farm of Pomorze Zachodnie. It was found that the Ursus 932/34 tractor is the most suitable type for the farm model under consideration.

Key words: agricultural tractor, combustion engine, optimum index, usability.

INTRODUCTION

The issue of grading the power of engines in series of types arises during the production of tractors. This means that the purchaser selects a tractor of different power, higher as a rule, than the optimum power required for the machinery fleet in his possession. The deviation from the selection of appropriate power causes a situation that numerous types of work are done with higher power contribution than actually needed [Bręczewski, Krysztofiak 1999].

In addition to the energy losses related to the growth of weight of the tractor, the losses related to the dropping of general efficiency of the engine working on part loads and, consequently, to the growth of the unit fuel consumption [Wajand, Wajand 2000] play a significant role. Such situation can be partly improved through appropriate strategy of gear setting in the power unit. Therefore, it is advantageous to obtain an torque optimally high torque within the same power range, at the engine speed possibly low. Thanks to the application of a reducer and a torque amplifier in farm tractors, the number of speeds is much higher than in e.g. motor-vehicles. Several various gear settings and their corresponding engine speeds are possible within one operating speed of the tractor. The fact is also used for the optimization of the tractor's engine operation, particularly with low and medium loads through the application of the GUTD (Gear Up Throttle Down) driving technique, which may give fuel consumption savings reaching up to 20% [Grisso, Pitman 2001].

The usability of the tractor is mainly defined through the OECD tests, clearly characterizing the tractor's indexes and parameters obtained at tests carried out according to a uniform technology [Kruczkowski 2001]. However, an assessment and improvement of the vehicle's working indexes in terms of the engine operating fuel economy should be based on the time density characteristics, considering the engine work scheme in its specific application as it is done in road motor-vehicle tests [Cichy 1986; Wisłocki 1989; Danilecki 2007]. There are no such tests for the agricultural tractor operation. Some scarce tests carried out in this scope only prove the fact of incomplete use of the tractor engine power on farms indicating the possibility of an improvement of the operation through an optimum selection of gear ratios [Saglam, Akdemir 2002].

The paper suggests a new method of tractor usability assessment. The assumed basis for the assessment was a dimensionless index, determining the extent to which the engine work corresponds to optimum conditions. Due to lack of such an index in automotive technology, it was given the name OWI (Optimum Working Index) [Koniuszy 2007a; Koniuszy 2007b].

TESTING METHODS

The classic preparation of universal characteristics of a combustion engine consists in measuring the engine's operating indexes, at least in 50 points determining the working levels and the approximation of values obtained by such points. The map thus obtained presents the full picture of unit fuel consumption g_e. While creating universal characteristics restricting the measuring point number to 9 [Jahns et al. 1990], a model method technique may be used. According to the tests, the optimum performances for most spark ignition engines used in farming, plotted onto the dimensionless universal characteristics are similar [Jahns et al. 1990; Wisłocki 1989]. The optimum engine work takes place in point g_e with the lowest fuel consumption.

If the engine operates with N_s power within the range from 0% to 100% of N_{znam} rated power, the optimum engine operation points can be determined, corresponding to the minimum unit power consumption g_e for each N_s power value given, Fig. 1. The analysis presented below, for a graphic interpretation, requires one dimensionless scale of both axes. Therefore, the following determination was introduced (1):

$$x = \frac{n_S}{n_N}, y = \frac{M_S}{M_N}, c = \frac{N_S}{N_{znam}}, \tag{1}$$

of which:
n_s – engine momentary speed,
n_N – engine speed at rated power,
M_s – engine momentary torque,
M_N – torque at rated power,
N_s – momentary engine power,
N_{znam} – engine rated power.

It was also assumed that the OWI interpretation would take place in the field of the engine universal characteristics as a static characteristics. The assumption was made due to the lower share of non-stationary states as compared to motor-vehicles whose operating parameters, such as fuel consumption, etc. are assessed through dynamic tests [Romaniszyn 2004].

The selection of optimum simple engine operation may be assumed according to the general characteristics of a specific type of engine or group of engines of a similar structure. The assumption made in the example under analysis concerned the similarity of dimensionless universal characteristics for more than 80% of tractor engines [Wang, Zoerb 1989].

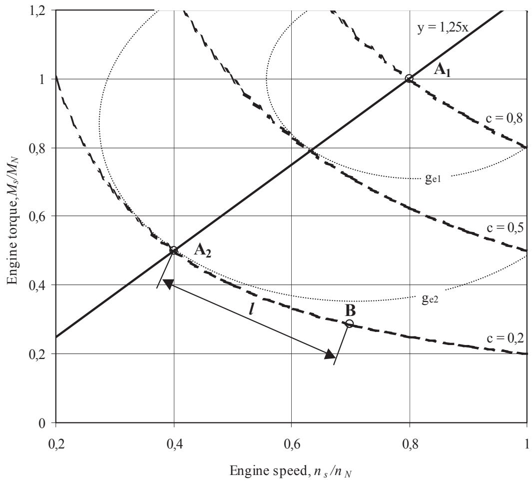

Fig. 1. Graphic interpretation method of the OWI

Point A_2 in Fig. 1 was plotted at where the curve of unit fuel consumption g_e becomes tangent to the constant power curve c=0,2. The power constants c are determined by the dependency (2):

$$c = x \cdot y. \tag{2}$$

The subsequent points thus marked for each power c course make an approximate linear correlation that may simply be drawn, giving the coordinates of two points. The first point A_1 is characterized by the coordinates of g_e, minimum, in this case $x_{A1}=1$ and $y_{A1}=0,8$. The second point A_2 is determined according to the correlation between the torque and the speed of point A_1 (3) [Wang, Zoerb 1989]:

$$x_{A2} = y_{A2} \cdot \frac{x_{A1}}{y_{A1}}. \tag{3}$$

For example, if $y_{A2}=0,5$ then $x_{A2}=0,4$. Upon linking of the two points a straight line with the following equation was obtained (4):

$$y = a \cdot x + b. \tag{4}$$

Thus, the measure of absolute optimization index is the distance of a given engine work point B from the optimum straight line measured along the arc of curve c. The length of the c curve arc determined by points A_2 and B can approximately be defined by simple A_2–B. The coordinates of point B are known from the measurement, while the coordinates of point A_2 can be determined from a set of equations (5):

$$\begin{cases} y_{A2} = a \cdot x_{A2} + b \\ y_{A2} = \dfrac{c_{A2,B}}{x_{A2}} \end{cases}. \tag{5}$$

After transformation of the set of equations (5) the following function was obtained (6):

$$a \cdot x_{A2}^2 + b \cdot x_{A2} + c_{A2,B} = 0, \tag{6}$$

the solution whereof being one positive radical (7):

$$x_{A2} = \frac{-b + \sqrt{\Delta}}{2 \cdot a}, \Delta = b^2 - 4 \cdot a \cdot c_{A2,B}. \tag{7}$$

The coordinate y_{A2} can be determined from dependency (5). Finally, the geometric length of section l being the optimization measure of one engine operation point (8):

$$OWI = l = \sqrt{(x_B - x_{A2})^2 + (y_B - y_{A2})^2}, \tag{8}$$

for the set of engine operation points, the optimization measure is the expression (9):

$$OWI = l = \frac{\sum_{i=1}^{n} t_i \cdot l_i}{\sum_{i=1}^{n} t_i}, \tag{9}$$

of which:
t – engine work time share at load given in the general engine work time.

The series of the Ursus tractor types was accepted for the analysis. Selected technical data of the tractors are presented in Table 1.

The usability of the tractors was assessed for a model of an average farm in Pomorze Zachodnie, determining the agricultural engineering procedures made with the use of tractors, based on the technological charts of particular cultivations (Table 2).

Table 1. Selected technical data of the tractors

No	Tractor symbol	Engine rated power, N_{znam} [kW]	Number of speeds front/back	Tractor's weight without additional weights [kg]	Maximum driving speed [km/h]
1	2812	28	8/2	2200	25,82
2	3502	34,6		1810	23,37
3	3512/14	34,6		2500/3030	24,44
4	4512	44,1		2980	24,27
5	4514	44,1		3300	28,17
6	5312/14	52,2		3090/3405	28,65
7	6012/14	60		3350/3600	29,73
8	912/14	57,5	16/8	3970/4520	25,50
9	1012/14	72	12/6	4180/4570	
10	1222/24	85		4250/4970	
11	1614	115		5028	27,16
12	932/34	57,5	16/8	4300/4760	29,40
13	1042/44	66	12/6	4120/4740	
14	1134	72		4820	
15	1232/34	85		4570/5100	
16	1634	115		5190	27,16
17	1734	125	16/8	5620	32,66

Table 2. List of agricultural engineering procedures at the analyzed model farms [Wiśniewski, Siekacz 1994]

Procedure symbol	Cultivation procedure	Plant	Machine		Working speed, v_o, [m/s]	Work. time, t, [h]	Power demand	
			Symbol	Work. width a, [m]			Towing, N_u, [kW]	Engine, N_s, [kW]
A	Skimming	Corn	U043/1	1,7	1,50	67	18,9	31,5
B	Ploughing	Wheat	U024	1,0	1,35	50	27,0	45,0
C		Rape		1,0	1,35	40	20,3	33,8
D		Corn		1,0	1,33	52	15,3	25,5
E	Soil preparation	Sugar beet	U708/2	2,5	1,66	25	16,6	27,1
F		Corn		2,5	2,20	33	12,8	21,4
G	Sowing	Wheat	S045/2	6,0	1,60	40	14,4	24,0
H		Rape		6,0	1,60	40	10,6	17,7
I		Corn		6,0	1,43	33	8,6	14,4
J	Fertilizing	Sugar beet	N218/2	2,2	1,00	61	17,7	29,5
K	Transport	Wheat	T070	-	4,50	37	14,8	24,7

Next, with the use of Microsoft Excel Solver, the optimum engine speeds were determined on particular gear settings at which the specific tractor would obtain the required powers and driving speeds closest to (no lower than 10%) those given in the assumptions with the minimum, i.e. the most advantageous OWI. This was the foundation for making a ranking list of tractors by accessibility of the largest number of speeds in all kinds of field work.

TEST RESULTS

Table 3 includes a comparative list of the Ursus tractor types and numbers of gear settings corresponding to them, including the speeds of the engine crankshaft for minimum values of OWI.

Tractor 932/34 came first in the ranking that obtained the minimum OWI in nine out of eleven agricultural engineering procedures. Tractors 1134 (seven procedures) and 5312/14 (six procedures) occupied the subsequent positions. According to Table 4, the optimum agricultural engineering procedure for all the tested tractors was ploughing for rape cultivation. Transport was the most disadvantageous procedure in terms of engine fuel economy. The optimization criteria assumed for transporting were met for two tractors only: 2812 and 1042/44. However, it must be pointed out that tractor 2812 could not perform procedures: A, B, C, J due to the engine rated power being too low. The most advantageous for the farm model given, would be a fleet composed of tractors: 932/34 and 1042/44.

The usability assessment method of the tractors presented herein disregarded the traction properties of the tractors, including without limitation the type of tractor drive (2x4 or 4x4). Therefore, the complete analysis of the working usability should include the type of soils and land configuration on which the farm is located.

CONCLUSIONS

1. The highest working usability for the analyzed farm model was presented by tractor 932/34.
2. Tractors: 2812, 3502, 3512/14, 4512/14 did not meet the criterion of power required at the farm.
3. The optimum agricultural engineering procedure, in terms of engine fuel economy, was ploughing for rape cultivation.

Table 3. Optimum gear ratios and engine crankshaft speeds; 1...4 – number of gear, L – with reducer, H – without reducer, W – with torque amplifier

No.	Tractor symbol	Procedure symbol											Ranking position
			A	B	C	D	E	F	G	H	I	J	K	
		No of gear/engine crankshaft speed [rpm]												
1	2812		x	x	x			1H/1560	4L/1660			x	3H/1680	VI
2	3502		4L/1920	x		4L/1730				1H/1440	1H/1300	3L/1860		IV
3	3512/14		4L,1H/ 1920	x		4L,1H/ 1730								VII
4	4512			x	4L/1570					1H/1130	1H/1020	3L/1460		V
5	4514		4L/1510	x		4L/1360								VII
6	5312/14		4L/1530	3L/1830		4L/1380	1H/1420	2H/1260	1H/1330					III
7	6012/14			3L/1700	4L/1480									VII
8	912/14				4LW/1510			3HW/1200		2H/1100	2H/1000	1HW/1410		IV
9	1012/14		4L,2HW/ 1300	4LW/1560	1H/1350	4L,2HW/ 1170						3L/1260		IV
10	1222/24			1H/1430	2HW/1240		2H/1110		2H/1050			3L, 4LW/1160		IV
11	1614			3L/1230	1H/1070							1HW/1000		VI
12	932/34		3L/1460	3LW/1740	4LW,1HW/ 1510	3L/1310	4L,1H/ 1350	2H/1200	1H/1270	2HW/1100	2HW/1000			I
13	1042/44			4LW/1620				2H/1120	2HW/1190			3LW/1320	4H/1200	IV
14	1134		4L,1H/ 1300	4LW,1HW/ 1560	3L/1350	3L/1300	2HW/1210		2HW/1140			3LW/1260		II
15	1232/34					4L,1H/ 1080						4LW,1HW/ 1160		VII
16	1634			3L/1230	1H/1070							1HW/1000		VI
17	1734		2HW/990	3L/1180	4L,1H/ 1020									VI

4. The most disadvantageous operating conditions of the engine were shown by the tractors during the transport.

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NOWA METODA OCENY PRZYDATNOŚCI EKSPLOATACYJNEJ CIĄGNIKÓW ROLNICZYCH NA PODSTAWIE WSKAŹNIKA OPTYMALIZACJI OWI

Streszczenie. W artykule przedstawiono nową metodę oceny przydatności eksploatacyjnej ciągników rolniczych pod względem optymalnego wykorzystania pola podaży mocy silnika. Na podstawie stworzonego wskaźnika optymalizacji OWI (Optimum Working Index) porównano typoszereg ciągników Ursus. Przydatność eksploatacyjną ciągników oceniano dla modelu przeciętnego gospodarstwa rolnego na Pomorzu Zachodnim. Stwierdzono, że do rozpatrywanego modelu gospodarstwa najlepiej nadaje się ciągnik Ursus 932/34.

Słowa kluczowe: ciągnik rolniczy, silnik spalinowy, wskaźnik optymalizacji, przydatność eksploatacyjna