TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE – 2012, Vol. 12, No. 1, 251–255

The analysis of the usability of selected stationary load cycles for the assessment of the tractor engine economy

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Summary. The paper analyzes the operating indexes of an AD3.152 engine obtained during three stationary load cycles: an 8-phase cycle and two variants of a 5-phase cycle. The obtained results have been presented and compared based on the weighted averages.

Key words: combustion engine, engine economy, stationary load cycles.

INTRODUCTION

The operating conditions of a combustion engine are closely related to its application. Engines of road vehicles are subject to entirely different loads than stationary ones. The engines of road vehicles are characterized by a high variability of engine loads and speeds as compared to stationary engines for which the loads are frequently changed without changing the engine speed. Because constant operating conditions in the most advantageous ranges of engine speeds cannot be ensured their fuel economy differs and highly depends on proper operation by the personnel. The operation of an engine within the range of engine speeds corresponding to the highest overall efficiency ensures the lowest fuel consumption (highest engine economy). The fulfillment of these conditions is very often impossible due to the nature of the work performed [6, 3]. In order to optimize the process of engine operation and provide evaluation many synthetic operating models have been developed describing their typical application. The highest number of models has been developed for vehicle engines used in transportation. These models serve to determine the ecological characteristics of these engines (high requirements related to the exhaust and noise emission). Ever since the emission limiting standards have been adopted, unified testing procedures were introduced allowing comparison of the engines in terms of environmental impact. The application of the already existing test cycles to a group of vehicles such as farm tractors may lead to great inaccuracies resulting from the different nature of the operation of road vehicles and the said farm tractors. Many variables influence the operation of a farm tractor. These are: geographical location, terrain, soil firmness, changes in humidity, climatic conditions, types of performed works let alone the tractor operator himself [1, 9]. That is why tractor operation models should be developed that take into account the specificity of the performed works and the geographical location.

In the paper the authors attempted to explain whether the indexes of the tractor engine obtained according to the regional model of operation (5-phase) differ from the indexes obtained during tests carried out according to the European Union method of the 8-phase cycle [PN-EN ISO 8178-4] and 5-phase Deutz cycle developed in Germany for farm tractors.

RESEARCH METHODS

The object of the research was a three cylinder, four-stroke diesel engine (AD3. 152). The engine used for the research is a unit fitted in low-power farm tractors widely applied in Polish farms. The engine was fitted in a dynamometer of the Chair of Agrotechnical Systems Engineering of the West Pomeranian University of Technology in Szczecin. The dynamometer was fitted with a HZW Froud brake and other necessary equipment.

The tests were conducted according to three stationary load cycles. The first load cycle that the engine was subject to was the 8 – phase load cycle applicable in the EU member states representative of the off road vehicles and self propelled machinery powered with diesel engines. The second was a 5-phase Deutz load cycle developed in Germany for the assessment and analysis of the exhaust emissions from farm machinery (as the authors reckon, this test better reflects the nature of the works in agriculture). The third test cycle was a 5-phase load cycle developed in the Chair of Agrotechnical Systems Engineering of the West Pomeranian University of Technology in Szczecin reflecting the local operation of farm tractors [2, 4]. This cycle was developed based on the specificity of the local farms and geographical conditions of West Pomerania [5]. The test stand measurements were carried out according to the PN-91/R-36102 standard [8] [7].

The values of the settings of the torques and engine speeds for individual phases of the cycles have been shown in table 1, 2 and 3.

Table 1. Settings of the torques and engine speeds in the 8-phase cycle

Phase	Engine speed n_s/n_{znam}	Torque M_o/M_N	Weight coefficient
I	1	1	0,15
II	1	0,75	0,15
III	1	0,5	0,15
IV	1	0,1	0,1
V	0,6	1	0,1
VI	0,6	0,75	0,1
VII	0,6	0,5	0,1
VIII	0,3	0	0,15

Table 2. Settings of the torques and engine speeds in the 5-phase Deutz cycle.

Phase	Engine speed n_s/n_{znam}	Torque M_o/M_N	Weight coefficient
I	0,95	0,88	0,31
II	0,85	0,48	0,18
III	0,53	0,4	0,19
IV	1	0,15	0,2
V	0,4	0	0,12

Table 3. Settings of the torques and engine speeds in the 5-phase regional cycle

Phase	Engine speed n_s/n_{znam}	Torque M_o/M_N	Weight coefficient
I	0,9	0,8	0,08
II	0,9	0,45	0,06
III	0,65	0,7	0,45
IV	0,65	0,45	0,17
V	0,3	0	0,25

RESULTS OF TESTS

The unit fuel consumption was not analyzed and was not calculated for: phase VIII of the 8 – phase cycle, phase V of the Deutz and regional cycles as these phases characterize the engine idle speed, at which the effective

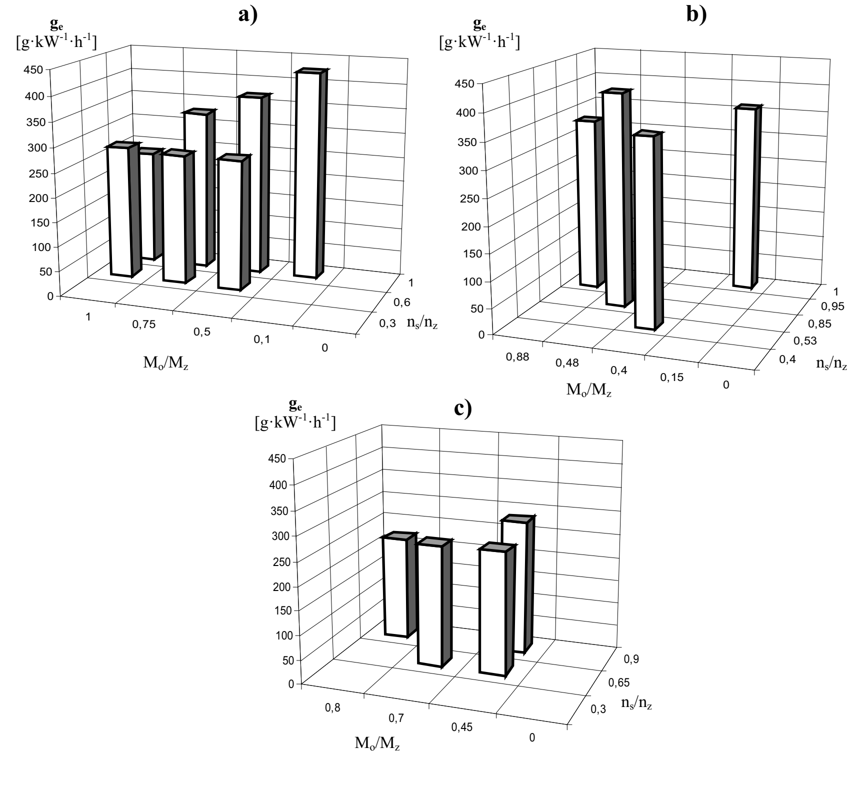

Fig. 1. Average values of the unit fuel consumption in the cycles: a) 8-phase, b) Deutz 5-phase, c) regional 5-phase

power is not generated. Based on the performed measurements and calculations it has been ascertained that the lowest unit fuel consumption 237,52 $g \cdot kW^{-1} \cdot h^{-1}$ was obtained in phase I of the 8-phase load cycle (Fig. 1a). In phases VII, VI and V the unit fuel consumption was higher by 13,8% (phase VII), 13,5% (phase VI) and 16,9% (phase V) respectively as opposed to phase I of this cycle. For phase III the unit fuel consumption was higher than for phase I by 58,2% (phase III) and 40,3% (phase II) respectively. The greatest increase (by 82,6%) as compared to the unit fuel consumption in phase I was obtained for phase IV of the 8-phase load cycle and it amounted to 466,43 $g \cdot kW^{-1} \cdot h^{-1}$.

Based on the performed measurements of the AD3.152 engine the authors calculated that the highest unit fuel consumption i.e. 409 $g \cdot kW^{-1} \cdot h^{-1}$ was obtained in phase II of the Deutz 5-phase load cycle (Fig. 1 b). In the other 3 phases of the cycle the unit fuel consumption was lower by 18,4% (phase I), 13% (phase III) and 12,3% (phase IV) respectively. The lowest unit fuel consumption of 333,11 $g \cdot kW^{-1} \cdot h^{-1}$ was obtained in phase I of the load cycle.

The average values of the unit fuel consumption for the 5-phase regional load cycle have been shown in Fig. 1c. The lowest unit fuel consumption obtained in phase I was 221,18 $g \cdot kW^{-1} \cdot h^{-1}$. For phase II a growth was observed (by 17,2%) of the unit fuel consumption as compared to phase I and a growth by 16,3% was observed for phase III. The highest unit fuel consumption, higher by 28,3% than phase I was observed in phase IV and amounted to 283,5 $g \cdot kW^{-1} \cdot h^{-1}$. The weighted average unit fuel consumption for the tested engine for each of the cycles is: for the 8-phase cycle 308,8 $g \cdot kW^{-1} \cdot h^{-1}$, for the Deutz cycle 358 $g \cdot kW^{-1} \cdot h^{-1}$ and for the 5-phase regional cycle 258 $g \cdot kW^{-1} \cdot h^{-1}$ respectively.

The average values of the hourly fuel consumption were calculated for the individual phases of the load cycles and have been shown in graphs in Fig. 2 (a –8 phase cycle; b –Deutz cycle, c – regional cycle). For the 8-phase load cycle the lowest value was observed for phase VII and amounted to 3,34 $kg \times h^{-1}$ and the highest was observed for phase II - 8,213 $kg \times h^{-1}$.

Fig. 2b presents the average hourly fuel consumption in the Deutz load cycle. The highest hourly fuel consumption of 6,69 $kg \times h^{-1}$ was obtained in phase I of the load cycle. In the other phases due to a lower engine load a drop in the fuel consumption took place by: 38% (phase II), 39% (phase III), 58% (phase IV) respectively. The lowest hourly fuel consumption occurred for phase IV of the cycle and amounted to 2,79 $kg \times h^{-1}$.

Fig. 2c presents the obtained average values of the hourly fuel consumption for the individual phases of the regional 5-phase cycle. The lowest hourly fuel consumption was observed for phase IV – 3,06 $kg \times h^{-1}$ and the highest for phase I – 5,2 $kg \times h^{-1}$ (higher by 69,9% as compared to cycle IV).

In all the cycles the authors observed the occurrence of the lowest hourly fuel consumption in the last but one phase of the individual cycles. The weighted average hourly fuel consumption for the tested engine for each of the cycles is: 8-phase - 6,34 $kg \times h^{-1}$, Deutz - 4,71 $kg \times h^{-1}$ and for regional 5-phase - 3,81 $kg \times h^{-1}$.

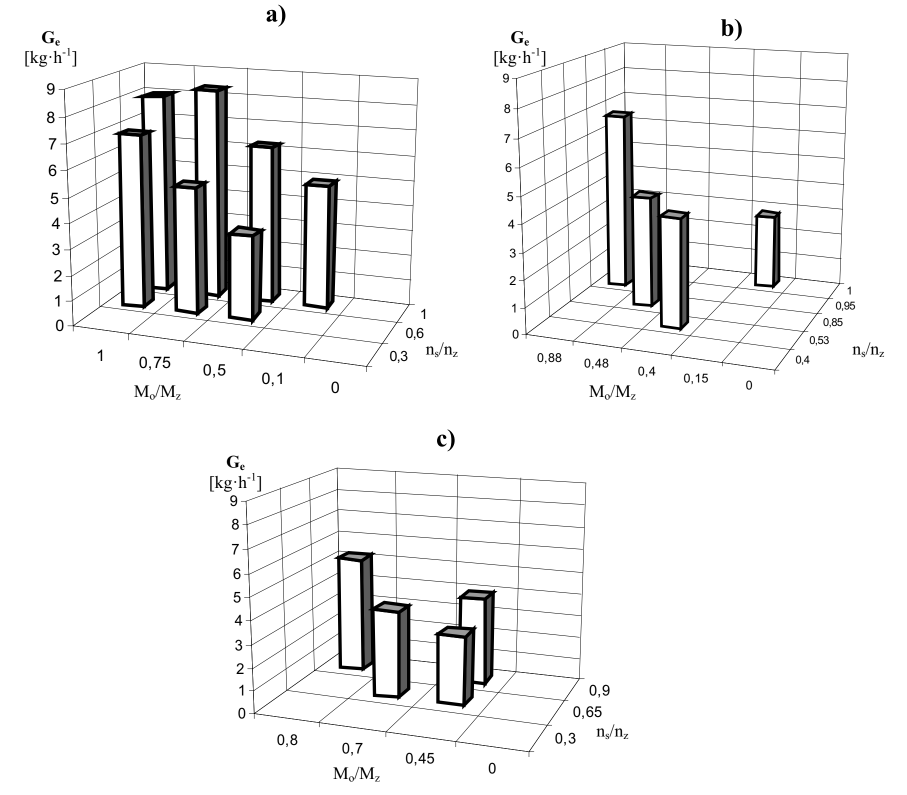

Fig. 2. Average values of the hourly fuel consumption in the cycles: a) 8-phase, b) Deutz 5-phase, c) regional 5-phase

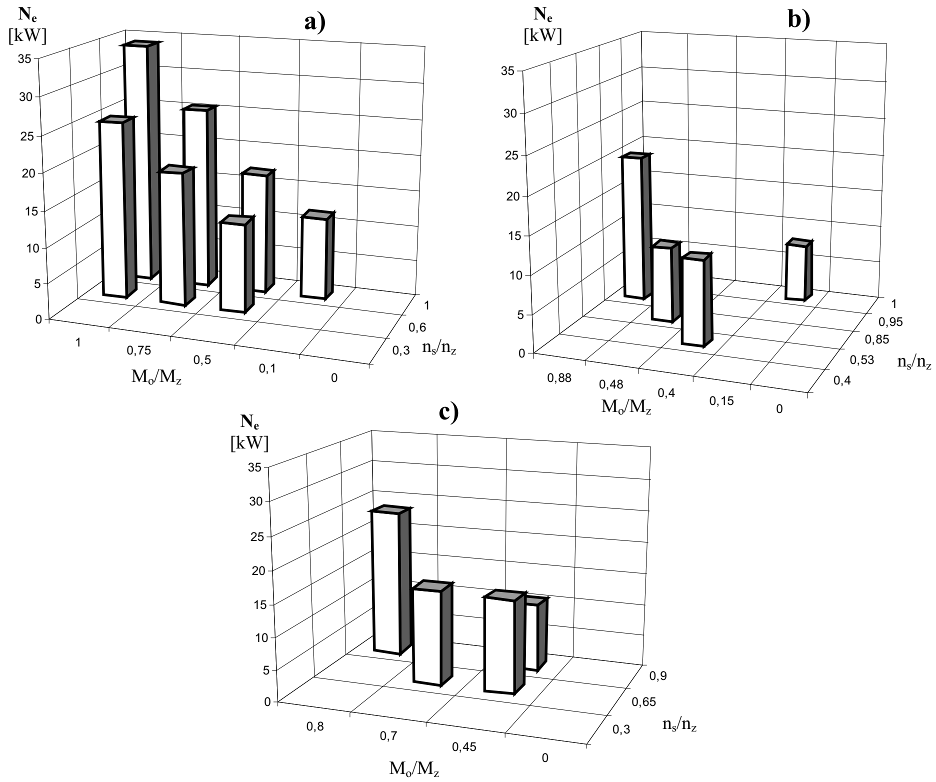

Fig. 3. Average values of the effective power in the cycles: a) 8-phase, b) Deutz 5-phase, c) regional 5-phase

Fig. 3 presents the average values of the effective power obtained for the tested engine in the individual phases of the test cycles.

In the 8-phase cycle the lowest power of 11,5 kW was obtained in phase IV, the highest of 33,9 kW in phase I of the cycle. The highest effective power was obtained in phase I of the Deutz cycle i.e. 19,82 kW. The other analyzed phases have shown a reduction of the effective power. The lowest effective power of 7,68 kW was obtained in phase IV of the tested load cycles. In the regional 5-phase cycle the lowest value was obtained in phase IV and amounted to 10,54 kW. The highest power of 23,4 kW was obtained in phase I. The weighted average effective power for the tested engine for each of the cycles is for the 8-phase cycle 21,3 kW, Deutz cycle 13,2 kW and regional 5-phase cycle 18,9 kW.

Due to a different number of phases, values of torque and engine speed in the individual test cycles we cannot directly compare the results obtained in the individual phases. Taking the coefficients o weight assigned by the cycle authors to the subsequent phases we can determine the weighted averages of the selected indexes of the operation of the given AD3.152 engine. Figures 4,5,6 show the weighted average indexes of work i.e.: effective power N_e, hourly fuel consumption G_e and unit fuel consumption g_e. Analyzing the obtained results we can state that the tested cycles are different in terms of the indexes of the engine work, particularly g_e – the index of the engine economy.

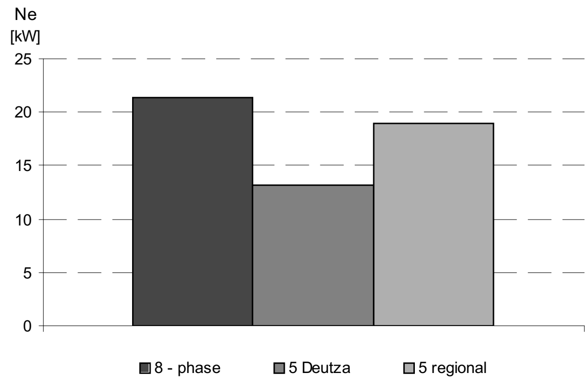

Fig. 4. Weighted average values of the effective power index N_e [kW]

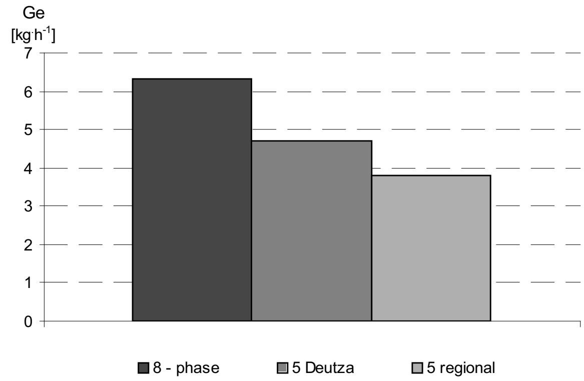

Fig. 5. Weighted average values of the hourly fuel consumption index G_e [kg×h^{-1}]

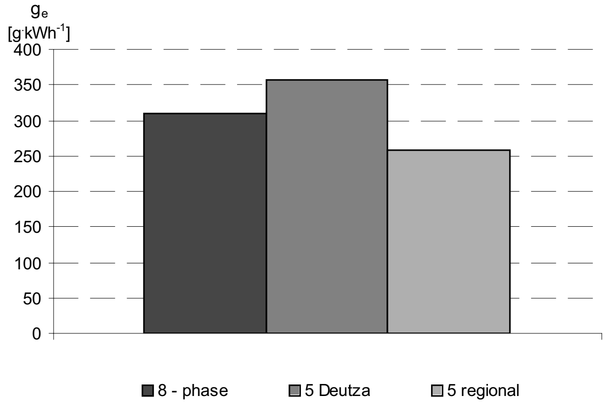

Fig. 6. Weighted average values of the unit fuel consumption index g_e [$g{\cdot}kW^{-1}{\cdot}h^{-1}$]

The highest weighted average effective power N_e was obtained by the engine operating according to the 8 – phase cycle. This power amounted to 21,3 kW. In the Deutz cycle the weighted average effective power was 13,2 kW. For the regional 5-phase cycle developed for the area of the West Pomeranian the weighted average effective power was 18,89 kW.

When analyzing the weighted average hourly fuel consumption we can observe that the 5 – phase cycles show a lower fuel consumption as compared to the 8 – phase cycles. The results obtained for the 5 – phase cycles are G_e= 4,71 $kg{\times}h^{-1}$ for the Deutz cycle and G_e=3,81 $kg{\times}h^{-1}$ for the regional 5 – phase cycle. For the 8 – phase cycle G_e was determined on the level of 6,34 $kg{\times}h^{-1}$. The difference between the 8- phase cycle and the 5 – phase cycles falls in the range from 25,7% to 39,9%.

The highest weighted average unit fuel consumption g_e was for the Deutz cycle and amounted to 358 [$g{\cdot}kW^{-1}{\cdot}h^{-1}$]. For the 8 – phase cycle the unit fuel consumption was lower by 13 % as compared to the Deutz cycle. The lowest value was calculated for the regional 5 – phase cycle - 258 [$g{\cdot}kW^{-1}{\cdot}h^{-1}$], which is a value lower by 24 % as compared to the Deutz cycle.

The most important index related to the economy level of the engine operation is unit fuel consumption. The lower the unit fuel consumption the better the overall efficiency the engine has. The regional 5 – phase cycle ensures the obtainment of the lowest unit fuel consumption hence, the operation of the engine according to this model leads to a fuel economy and contributes to the reduction of the exhaust emissions.

CONCLUSIONS

1. The weighted average engine work indexes obtained in the tested cycles (AD3.152) were significantly different from each other, thus confirming the assumption that stationary load cycles should be developed depending on the region and specificity of the engine application.
2. From the performed research it results that the weighted average hourly fuel consumption and effective power obtained in the 5-phase load cycles were lower than the values obtained in the 8 – phase cycle.
3. The analysis has shown that the obtained work indexes of the engine operating according to the regional 5 – phase cycle are more advantageous in terms of economy as compared to the other two analyzed load cycles.

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ANALIZA PRZYDATNOŚCI WYBRANYCH STACJONARNYCH CYKLI OBCIĄŻEŃ DLA OCENY EKONOMICZNOŚCI SILNIKÓW CIĄGNIKÓW

S t r e s z c z e n i e. Praca analizuje parametry eksploatacyjne silnika AD3.152 uzyskane w ciągu trzech stacjonarnych cykli obciążeń: 8-fazowego i dwóch wariantów 5-fazowego cyklu. Uzyskane wyniki zostały przedstawione i porównane w oparciu o średnie obciażeń.

S ł o w a k l u c z o w e: silnik spalinowy, ekonomiczność silnika, stacjonarne cykle obciążeń.