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Engine working modes during tractors operational period

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1. Introduction

Any tractor will function effectively at different working conditions when it is well adapted to the provided work and the optimal engine speed (rpm) is chosen. Operational economy and productivity of the tractor is mostly evident when its engine power is utilized at least 80% and engine speed is as close as possible to the value at which specific fuel consumption is minimal. For the same engine power we can use higher gear and less than specified engine speed – this will result in the same working speed and productivity, whereas fuel consumption will be reduced by 4-6% [1 - 5].

Farmers often hitch up their implements to the tractor by not taking into account optimal engine's run mode, for which certain methodology should be used. In many cases tractors are loaded only partially, i.e. only a part of tractor's power and traction force is utilized. Furthermore, a considerable part of operational time tractors and their engines run idle. Long-time idle run for the tractor and its engine means fuel wasting [2, 3, 6]. It is known [7] that wear of gear and hydraulic machine working under a stable regime is minimal intensity because of no direct contact between working surfaces of friction couples. To prolong the resource of a machine the number of its stops should be reduced to minimum, pauses between stops and starts should be kept shorter than critical time. Not many data is available to see which part of their operational time tractors were working at optimal load, and how they should be operated to obtain maximum economy.

Modern tractors are equipped with hi-tech electronic devices, which control tractors' functions and compile data [8, 9]. Collected in integrated digital microprocessors, this information can be read, transferred to personal computer or printed using special testing equipment and software. Such databases allow us to study engine load factors during tractor's operational period [9 - 11]. This study of engine load factors during tractor's operational period would give us the possibility to evaluate how efficiently and economically tractors were used. Study results would give us directions on how to improve operation of tractors, reduce fuel consumption and minimize harmful impact on the environment.

Objective of the study: to analyze engine characteristics for different speed and load modes during tractor's operational period using information collected in integrated digital microprocessors (Engine Control Units).

2. Methodology

For the study of engine load modes during tractor's operational period, tractor series *Massey Ferguson MF 6499* was chosen. *Massey Ferguson*-integrated digital microprocessors collect the main operational information, such as run intervals combined with engine speed and cyclic fuel injection quantities, also other parameters. Microprocessors accumulate these values for engine run intervals during tractor's operational period and represent them in engine load table and graph named "ECU Load Profile". Using special *Massey Ferguson* software and data cable, it was possible to transfer this engine load profile and its data table to personal computer.

Engine load profile in the table and graphic form represents accumulated run intervals (in seconds) for the tractor during its operational period at different engine run modes [9]. Run modes are assorted according to engine speed and cyclic fuel injection quantities. From the engine load profile and its data table we can see how long engine ran at intervals of 700-900, 900-1100, 1100-1300, 300-1500, 1500-1700, 1700-1900, 1900-2100, and 2100-2300 rpm. The profile also shows how long engine ran at cyclic fuel injection quantities of 0-10, 10-20, 20-30, and so on up to 120-130 mg.

One of the main engine factors, hourly fuel consumption B_d (e.g., kg/h) was determined experimentally. It depends on engine power P_e and specific fuel consumption b_e. Specific fuel consumption b_e (g/kWh) shows how much fuel is consumed for the unit of effective engine power output [2, 3, 12, 13]. We can calculate hourly fuel consumption B_d

$$B_d = \frac{P_e\ b_e}{1000} \tag{1}$$

By knowing hourly fuel consumption B_d (kg) and engine speed n (min^{-1}) we can calculate cyclic fuel injection quantity b_c (mg)

$$b_c = \frac{60\ 1000}{3.6}\ \frac{B_d}{n}\ \frac{n_\tau}{m_c} \tag{2}$$

where m_c is number of cylinders, and n_τ is number of crankshaft revolutions per one cycle of cylinder work.

From Eqs. (1) and (2) we can deduce the following relation between the cyclic fuel injection quantity and engine power, engine speed and specific fuel consumption

$$b_c = \frac{60}{3.6}\ \frac{P_e\ b_e}{n}\ \frac{n_\tau}{m_c} \tag{3}$$

We can see that using above equation we may calculate cyclic fuel injection quantity for the engine by knowing engine power, engine speed and specific fuel consumption for the given engine run mode. Specific fuel consumption depends on engine speed and the load. By knowing relation $b_e = f(P_{e,}\ n)$ we can deduce similar relation for the cyclic fuel injection quantity: $b_c = f(P_{e,}\ n)$.

Engine characteristics for tractor series MF 6499 are presented in Fig. 1 (results of tests, which were carried out in tractor testing station "Cemagref", France; Test report № 15588, approbation OCDE/OECD, approval: 2/2390, January 10, 2008) [14].

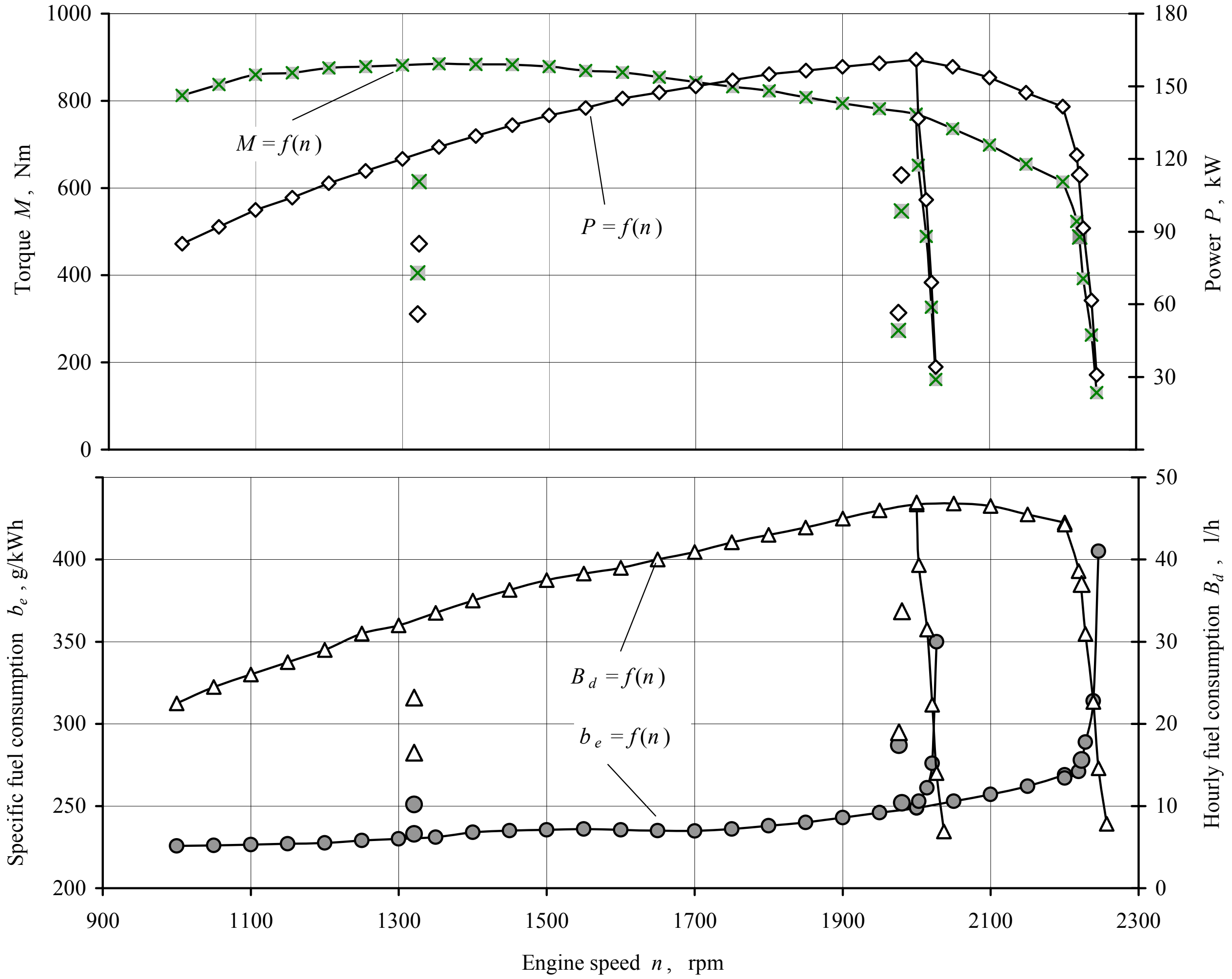


Fig. 1 Engine characteristics for *Massey Ferguson MF6499* [14]

From the engine characteristics presented in Fig. 1 we can see that engine power corresponds to the specified power value or exceeds it $(P \geq P_e)$ when engine speed is in the range of 1600-2200 min^{-1}. The highest power is reached when engine speed is 2000 min^{-1}. The lowest specific fuel consumption is when engine speed is in the range of 1050-1350 min^{-1}. In this speed range (1050-1350 min^{-1}), when specific fuel consumption is at its lowest, engine power is 95-125 kW. The specified engine power is reached and the lowest fuel consumption is obtained when engine speed is close to 1700 min^{-1}.

Relation between calculated cyclic fuel injection quantities, engine power and engine speed for specific engine run modes, $b_c = f(P_{e,}\ n)$, is presented in Fig. 2. From the chart (Fig. 2.) we can see that cyclic fuel injection quantity depends on engine power and speed. It is evident that for the same engine power, when the engine speed, is lower higher cyclic fuel injection quantity is needed.

To determine engine run time distribution during tractor's operational period at different engine speed and load ranges, we need engine power dependence on cyclic fuel injection quantities and engine speed.

From engine power and hourly fuel consumption characteristics that are presented in Fig. 1 we can draw specific fuel consumption dependences on hourly fuel consumption for specific engine run modes (Fig. 3).

From Fig. 3 we can see that specific fuel consumption for specific engine run modes depends on hourly fuel consumption according to the following equation

$$b_e = k_1\ (B_d)^{-k_2} \qquad (4)$$

where k_1 and k_2 are coefficients that depend on engine load and speed.

By knowing cyclic fuel consumption quantity b_c (mg) and engine speed n (min^{-1}) we can deduce hourly fuel consumption B_d (kg).

We express power P_e from Eq. (1), enter mathematical expressions b_e and B_d, and obtain equation, which shows how power depends on engine speed and cyclic fuel injection quantities

$$P_e = \frac{0.06\, n\, b_c}{k_1 \left(\frac{0.06\, n\, b_c}{1000} \frac{m_c}{n_\tau} \right)^{-k_2}} \frac{m_c}{n_\tau} \qquad (5)$$

From Eq. (5) we can see that to calculate engine power, it is enough to know cyclic fuel injection quantity for the given operation mode, and also coefficients k_1 and k_2.

For the study of engine load modes during tractor's operational period two tractors *Massey Ferguson MF 6499* were chosen, which had worked similar hours in different farms. The first tractor had been operated for 1586 hours, and the second one – for 1656 hours. For the study of engine load modes during tractor's operational period "ECU Load Profiles" were transferred from tractor-integrated digital microprocessors to the PC. From "ECU Load Profiles", charts were drawn representing tractors' operation hours' distribution during their operational period in different engine speed and power modes.

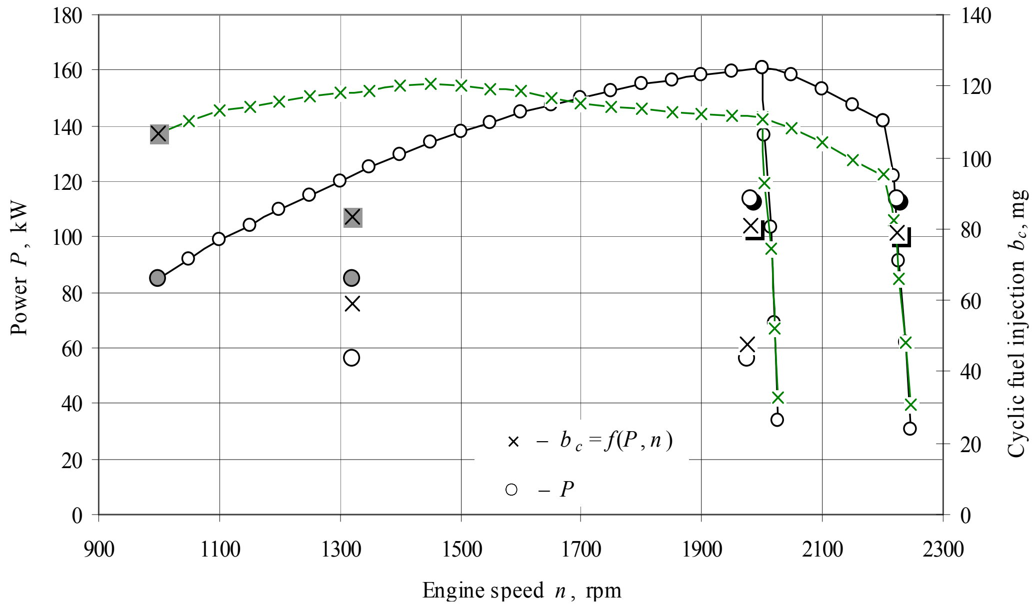


Fig. 2 Relation between cyclic fuel injection quantities, engine power and engine speed

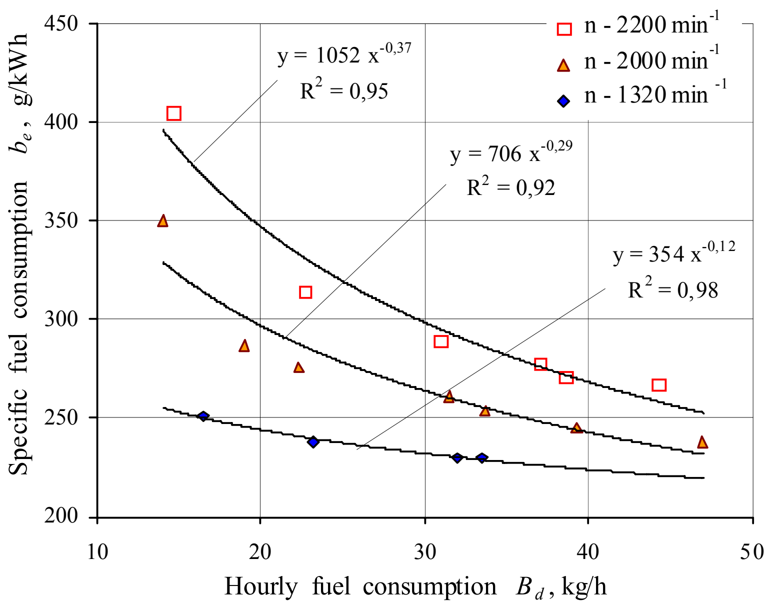


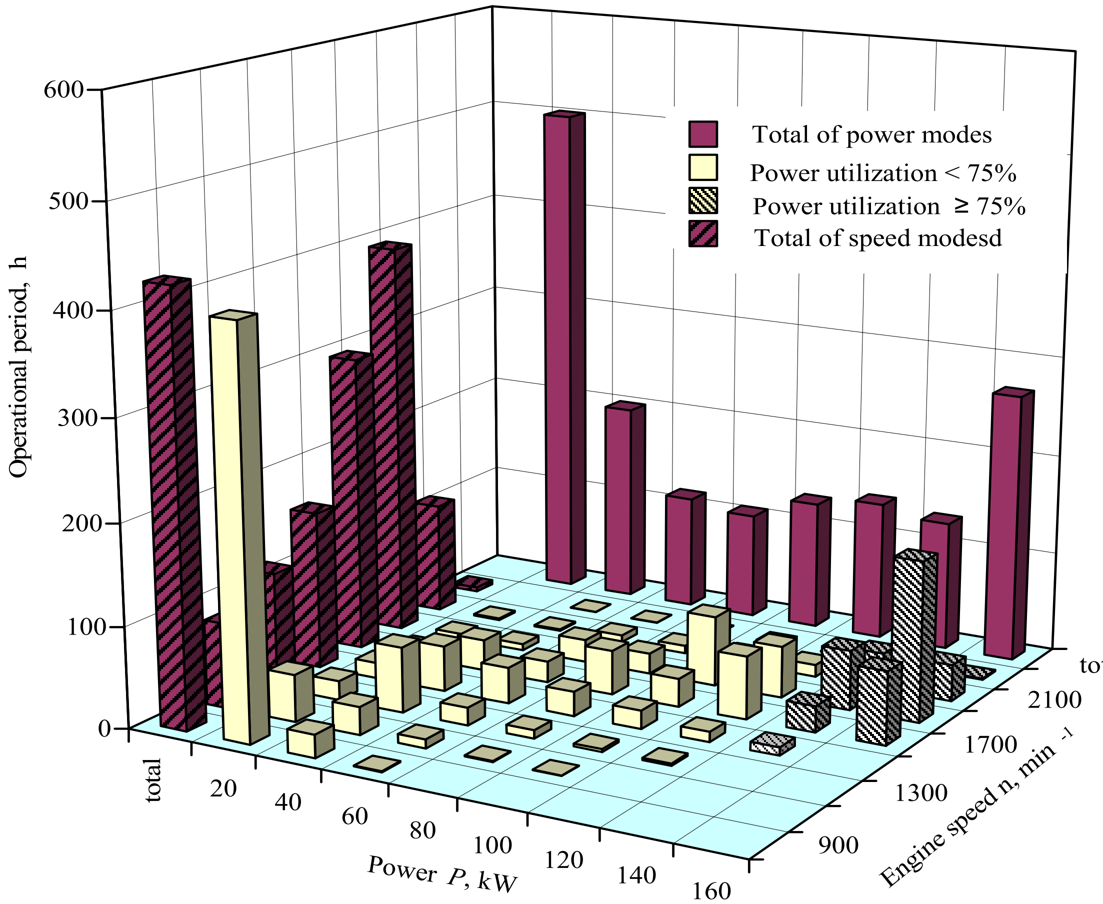
Fig. 3 Specific fuel consumption dependences on hourly fuel consumption

3. Results and discussions

Two charts, Figs. 4 and 5, represent operation hours' distribution of two *Massey Ferguson MF 6499* tractors in different engine speed and power modes during operational period; the first tractor was operated for 1586 hours, and the second one – for 1656 hours correspondingly.

We can see that considerably big part of operation time for both tested tractors is concentrating at the modes of low engine speed (700-900 min^{-1}) and low power (less than 20 kW). Such engine speed corresponds to the idle engine mode [9]. In this idle mode the first tested tractor operated for 401 hour, amounting to 25% of total operation time, and the second tractor – for 339 hours, amounting to 20% of total operation time.

In presented operation hours' distribution charts (Figs. 4 and 5) we can clearly see in which modes the trac-



	700-900	900-1100	1100-1300	1300-1500	1500-1700	1700-1900	1900-2100	2100-2300	Total
0-20	401	47	19	16	11	5	2	0	**501**
20-40	23	27	65	45	31	6	1	0	**200**
40-60	1	9	18	36	21	23	7	0	**114**
60-80	0	1	8	24	44	20	8	0	**106**
80-100	0	0	3	18	28	69	9	0	**129**
100-120	0	0	2	10	63	51	12	1	**139**
120-140	0	0	0	8	26	59	36	1	**130**
140-160	0	0	0	0	72	159	36	1	**268**
Total	**425**	**84**	**115**	**157**	**296**	**393**	**111**	**4**	**1586**

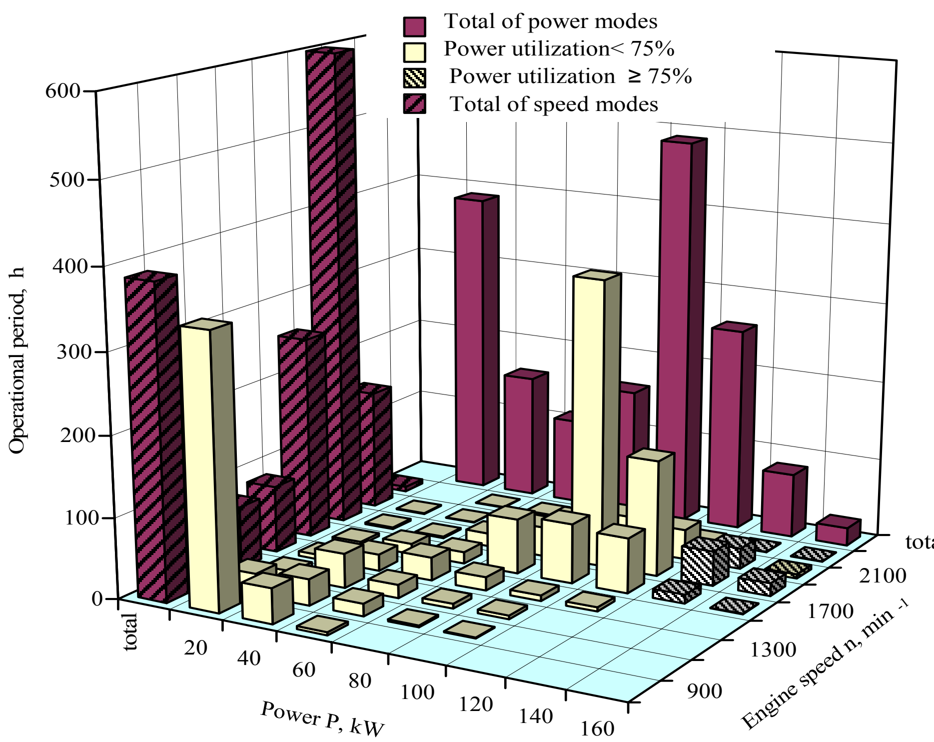
Fig. 4 Operation hours' distribution in different engine speed and power modes during operational period for the first *Massey Ferguson MF 6499* tractor, which was operated for 1586 hours

tors were utilized for technological processes (higher columns). While utilized for technological processes, both tractors were operated in similar engine run modes (1500-2100 min^{-1}). The biggest part of operational period tractors' engines ran at 1700-1900 min^{-1}. In this engine speed mode (1700-1900 mim^{-1}) the first tractor operated for 393 hours, or nearly 25% of total operational time, and the second tractor – for 618 hours, or more than 37% of total operational time. In engine speed mode of 1500-1700 min^{-1} the first tractor operated for 296 hours, or 19% of total operational time, and the second tractor – for 255 hours, or 15% of total operational time. We may conclude that while the tractors were utilized for technological processes, their engine speed modes were selected reasonably from economical point of view.

From the same charts (Figs. 4 and 5) we can see that engine load modes for both tractors were different. While utilized for technological processes, the first tractor was mostly operated in 140-160 kW engine power modes. In this engine power mode (140-160 kW) the first tractor operated for 268 hours, which amount to 17% of total operational time. While utilized for technological processes, the second tractor was mostly operated in 80-100 kW engine power modes. In this engine power mode (80 -100 kW) the second tractor operated for 488 hours, which amount to approximately 30% of total operational time. In this mode only 50-60% of engine power is utilized.

At recommended tractor engine load, when its power was utilized at least 80%, the first tractor operated approximately 25% of total operational period, or approximately 50% of "technological" time (when engine power was 60-160 kW). The second tractor at the engine load, when its power was utilized at least 80%, operated approximately 6% of total operational period, or approximately 10% of "technological" time.

The presented results and their analysis show that studying engine's speed and load modes, using information collected in integrated microprocessors (Electronic Engine Control Units), we may reveal tractor's operation quality.



	700-900	900-1100	1100-1300	1300-1500	1500-1700	1700-1900	1900-2100	2100-2300	**Total**
0-20	339	27	8	6	4	2	1	0	**387**
20-40	44	33	43	21	13	2	1	1	**157**
40-60	4	15	16	29	15	17	11	1	**108**
60-80	0	2	6	17	68	37	27	1	**157**
80-100	0	1	5	7	74	357	43	1	**488**
100-120	0	0	0	5	69	144	38	1	**256**
120-140	0	0	0	0	11	43	26	0	**81**
140-160	0	0	0	0	1	16	5	1	**23**
Total	**386**	**78**	**77**	**84**	**255**	**618**	**151**	**6**	**1656**

Fig 5 Operation hours' distribution in different engine speed and power modes during operational period for the second *Massey Ferguson MF 6499* tractor, which was operated for 1656 hours

4. Conclusions

The study showed that it was possible to analyze engine load modes for *Massey Ferguson MF 6499* tractor during its operational period using information collected in integrated microprocessors.

While both tested tractors were utilized for technological processes, their engine speed modes were selected reasonably from economical point of view. The biggest part of operational period tractors' engines ran at 1700-1900 rpm.

At the engine load, when its power was utilized at least 80%, the first tractor operated approximately for 25% of total operational period, and the second one – only for 6% of total operational period.

Both tractors' engines ran at idle for 20-25% of total operational period.

Studying engine's speed and load modes by using information collected in integrated microprocessors, we may reveal tractor's operation quality.

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VARIKLIO DARBO REŽIMAI TRAKTORIŲ EKSPLOATACIJOS METU

R e z i u m ė

Traktoriai dirba ekonomiškai ir našiai, kai jų variklių galia panaudojama ne mažiau kaip 80%, o sūkiai yra kiek galima mažesni. Straipsnyje analizuojama traktorių eksploatacijos trukmė variklio greitiniais ir apkrovos režimais. Įvertinama galimybė tyrimams panaudoti elektroniniuose valdymo blokuose kaupiamą informaciją. Tyrimai atlikti naudojantis traktorių *Massey Ferguson* elektroniniuose valdymo moduliuose sudaromomis ir saugomomis histogramomis „ECU Load Profile“. Šiose histogramose traktorių darbo trukmė eksploataciniu periodu grupuojama, sumuojama ir išsaugoma pagal variklio sūkius ir ciklinį degalų tiekimą. Atlikta teorinė analizė ir pateikta variklio galios, sūkių ir ciklinio degalų tiekimo priklausomybių lygtis. Tyrimų rezultatuose pateikti dviejų traktorių *Massey Ferguson MF 6499* eksploatacijos trukmės, variklio sūkių ir galios režimais grafikai. Atlikta jų analizė. Nustatyta, kad variklio greitinių ir apkrovų režimų tyrimai, panaudojant elektroniniuose valdymo blokuose kaupiamą informaciją, atskleidžia traktoriaus eksploatacijos kokybę.

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ENGINE WORKING MODES DURING TRACTORS OPERATIONAL PERIOD

S u m m a r y

Operational economy and productivity of the tractor is mostly evident when its engine power is utilized at least 80% and engine speed is as low as possible. The paper analyzes engine operation intervals in different engine speed and load modes during tractor’s operational period. A possibility is revealed how to use information collected in tractor-integrated digital microprocessors, or “Electronic Engine Control Units”. The study was carried out using engine load table and graph, called “ECU Load Profile”, obtained from *Massey Ferguson* tractor-integrated Electronic Engine Control Units. Engine operation intervals during tractor’s operational period are assorted according to engine speed and cyclic fuel consumption, accumulated and saved as these profiles. Theoretical analysis was carried out and equation presented for the relation between engine power, engine speed and cyclic fuel consumption quantities. In the study results two charts are presented showing two *Massey Ferguson MF 6499* tractors’ operation intervals’ distribution by different engine speed and power modes during tractors’ operational periods. The study showed that engine speed and load modes’ analysis using information obtained from tractor-integrated digital microprocessors reveals tractor’s operation quality.

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РЕЖИМЫ РАБОТЫ ДВИГАТЕЛЯ ВО ВРЕМЯ ЭКСПЛУАТАЦИИ ТРАКТОРОВ

Р е з ю м е

Трактора работают экономично и производительно, когда мощность их двигателей используется больше чем 80%, а обороты двигателя – наименьшие. В статье анализируется продолжительность эксплуатации тракторов при их скоростных и нагрузных режимах. Оценена возможность использования информации, которая накоплена в блоках электронного управления двигателя. Исследования проведены используя „ECU Load Profile“ гистограммы, которые сохранены в электронных блоках управления тракторов *Massey Ferguson*. В этих гистограммах рабочее время тракторов в течение эксплуатации, группируется, суммируется и сохраняется относительно оборотов двигателя и циклической подачи горючего. Выполнен теоретический анализ и представлены уравнения связи мощности двигателя, оборотов и циклической подачи горючего. В результате исследования получены графики распределения продолжительности работы двух тракторов *Massey Ferguson MF 6499,* во время эксплуатации, в режимах оборотов и нагрузки двигателя. Проведен их анализ. Определено, что исследования скоростных и нагрузных режимов, используя в электронных блоках управления накопленную информацию, раскрывает качество работы тракторов во время эксплуатации.

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