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VARIATIONS IN EXPLOITATION CHARACTERISTICS OF TRACTORS DEPENDING ON PRE-IGNITION ANGLE OF THE ENGINE

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Abstract. Maintenance of tractors on small private farms in Bosnia and Herzegovina is not given sufficient and adequate attention. Consequences of such a trend reflect on exploitation characteristics of tractors, significantly increases fuel consumption and environmental pollution. The goals of the research focused on the part of the issue related to the influences of different pre-ignition angle of the engine on the available power at the PTO shaft and increase of the specific fuel consumption. The research was conducted in the laboratory and experimental facilities of the agricultural machinery testing station in 2015 at the Butmir range, Sarajevo. The obtained results indicate that the tractor power at PTO shaft varied from 21kW do 45kW, that is in a range from 46.6 - 100 %. Variation of the engine power caused changes in fuel consumption which in the plough mode varied from 4.01- 6.86 $kg \cdot h^{-1}$ of fuel (D-2). Cost-wise, this influenced variations from 2.25 to 4.72 $€ \cdot h^{-1}$ in the idle mode (stand gas) and from 5.57 to 8.81$€ \cdot h^{-1}$ in the plough mode. The obtained results confirmed the hypothesis that regular maintenance in accordance with manufacture's standards needs to be implemented; otherwise the costs of consequences will exceed the maintenance costs several times.

Key words: *tractor, maintenance, engine power, fuel consumption.*

INTRODUCTION

In order to understand the importance of the pre-ignition for the process of combustion of fuel in diesel engines, one needs to be familiar with the overall process of

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supply, purification and combustion. It is understandable that manufacturers of engine continuously strive to improve the combustion system in other to better utilize the energy potential of the fuel. More recent generations of engines have computer controller combustion systems. However, in practice, hydro-mechanic systems of distribution of fuel are still dominant in agriculture tractors. The quantities are does through a high pressure pump which can be of rotary or linear type, but the deviations of the fuel quantity per cylinder should not exceed ±2%. In the case of such older types of engines, Kozarac et al. [3] the time for injection of fuel is limited to a period from 1/300 to 1/800 parts of second. Computer controlled engines (*„Common Rail“*) have a much higher injection pressure (up to 2,000 Bar), and the injection velocity is measured in thousandths of a second.

Technical designs of engines continuously follow the perfecting of the quality of fuel Šilić et al. [6] which are expressed in respective cetane number, that is a ratio between the volume of fast burning cetane (n-hexane) and the volume of slow burning cetane (á- *Methylnaphthalene*). The process of combustion also depends on physical-chemical features of the diesel fuel such as, viscosity, chemical stability, percentage of sulphate, etc. Depending on the working conditions of the engine different additive are added to the fuel to enhance the combustion process, prevent solidification of paraffin, improve the chemical stability, prevent development of soot and tar pitch, which contaminate the environment and partly remain in the engines.

Bearing in mind the listed characteristics of engines and fuels, special attention needs to be given to regular maintenance which can significantly influence the performance. The pre-ignition angle of the engine can be one of the reasons for improper combustion of fuel. Therefore the goal of the research is to draw attention to the negative consequences of this factor and the requirement to do regular maintenance.

MATERIAL AND METHODS

The research was done in laboratories and experiment stations using a Zetor model 63.41 tractor assembly with double reversible plow. The part of the research done in the laboratories was related to different levels of adjustment of the pre-ignition angle and measuring of power with electric brake at PTO shaft and was conducted at the Testing station for agriculture machines of the Agriculture and Food Sciences Faculty in Sarajevo. The adjustments of the pre-ignition angle were done using the comparative and goniometric method for adjustment of angle. The goniometric method implied adjusting the pre-ignition angle with a comparator, and the comparative method implied a use of a template used also in the testing of exploitation characteristics of the tractor assembly. The following levels of adjustment of pre-ignition angle were applied:

A - Deviation of up to 10% (-17.8^0 early ignition /A´/; -16.2^0 late ignition /A″/);

B - Deviation of up to 20% (-19.5^0 early ignition /B´/; -14.5^0 late ignition /B″);

C - Deviation of up to 30% (-20.4^0 early ignition /C´/: -12.7^0 late ignition /C″/);

K - Adjustments made according to manufacturer's regulations (Control).

Any deviation of the pre-ignition angle in comparison to the manufacturer's norm of 17^0 reflects on the power of the engine and other exploitation characteristics of the tractor. By calibrating the high pressure pump to inject fuel prior to 17^0 causes a change in the work of the engine, which is manifested in a way that the engine is noisier and has seemingly bigger power.

The experimental part of the research included measuring of fuel consumption during ploughing. The volumetric method of consumption expressed in liters was applied, specifically consumption per units surface area (L/ha) and specific consumption (g/kwh) Lulo et al. [4]. The volumetric method was the basis for calculation of the other two forms of listed consumption. The volumetric consumption was translated into mass consumption through application of the following formula:

$$q=V[l]\cdot\delta\ [kg\ m^{-3}] \quad (1)$$

The results obtained from conducted measuring were processed with application of standard mathematical-statistic methods, presented in appropriate tabular breakdowns and graphs and discussed in relation to results obtained by other authors. In the work we applied the Spearman's *correlation coefficient*, which is often used for measuring of the relations among variables and when it is not possible to apply the *Pearson's correlation coefficient*.

RESULTS AND DISCUSSION

In case of a tractor engine with a properly adjusted high pressure pump the engine had an average engine power of 39.04 kW, and the average torque of 189.65Nm, and the average number of Rotation at the PTO shaft of 511.35 min^{-1}. Other statistic indicators are given in Table 1.

Table 1. Indicators of tractor performance at a pre-ignition angle of 17^0 (K control)

Pre-ignition angle 17^0 (K- control)	*N_0*	*Min.*	*M ax.*	*Mean*	*Std. Deviation*	*Variance*	*Skewness*
Rotation on PTO (min^{-1})	*23*	*384*	*609*	*511.35*	*73.61*	*5418.78*	*-0.31*
Torque (Nm)	*23*	*97*	*230*	*189.65*	*37.81*	*1429.68*	*-0.99*
Power on PTO shaft (kW)	*23*	*24*	*45*	*39.04*	*5.07*	*25.77*	*-1.60*

No – Number of measurements';
Skewness - measure of asymmetry data.

The simulation of movement of high pressure pump to an early ignition phase of up to 10% reflected on reduction of the average power of the engine to 38.33 kW, lower average torque of 174.78 Nm, as well as a lower average number of Rotation on the PTO shaft, which was at the level of 543.27 min^{-1}.

Table 2. Indicators of tractor performance at a 10% deviation of the pre-ignition angle

Deviation of 10% (A′ and A″)	*Angle*	*N_o*	*Min.*	*Max.*	*Mean*	*Std. Deviation*	*Variance*	*Skewness*
Rotation on PTO (min^{-1})	*17.8^0*	*30*	*368*	*615*	*543.27*	*74.34*	*5527.65*	*-1.13*
	16.2^0	*30*	*370*	*613*	*543.20*	*74.19*	*5504.50*	*-1.12*
Torque (Nm)	*17.8^0*	*30*	*96*	*226*	*174.78*	*5.23*	*1241.71*	*-0.44*
	16.2^0	*30*	*96*	*224*	*174.72*	*5.29*	*1245.82*	*-0.44*
Power on PTO shaft (kW)	*17.8^0*	*30*	*24*	*44*	*38.33*	*5.12*	*26.29*	*-1.16*
	16.2^0	*30*	*24*	*44*	*38.40*	*5.16*	*26.66*	*-1.17*

When the high pressure pump was moved to the late ignition phase of up to 10% it caused a reduction in the average power of the engine to 38.40 kW and a smaller average torque at the level of 174.72 Nm. The average number of Rotation at the PTO shaft totaled 543.20 min^{-1}. When the high pressure pump was in the position of an early ignition phase (10-20%) it caused a reduction of average power of the engine to 36.30kW and a lower torque, which was at the level of 162.42Nm. In such a position of the pump the average number of Rotation at the PTO shaft totaled 552.10 min^{-1}.

Table 3. Indicators of tractor performance at a 10-20% deviation of the pre-ignition angle

Deviation of 10-20% (B–early; B-late)	*Angle*	*N_0*	*Min.*	*M ax.*	*Mean*	*Std. Deviation*	*Variance*	*Skewness*
Rotation of PTO (min^{-1})	*19.5^0*	*30*	*424*	*615*	*552.10*	*60.95*	*3715.33*	*-0.73*
	14.5^0	*29*	*401*	*620*	*552.00*	*67.50*	*4556.38*	*-0.84*
Torque (Nm)	*19.5^0*	*30*	*93*	*208*	*162.42*	*32.58*	*1061.69*	*-0.50*
	14.5^0	*29*	*95*	*224*	*162.43*	*37.71*	*1422.59*	*-0.42*
Power on PTO shaft (kW)	*19.5^0*	*30*	*23*	*41*	*36.30*	*5.00*	*25.04*	*-1.22*
	14.5^0	*29*	*24*	*43*	*36.48*	*5.55*	*30.83*	*-1.27*

Positioning of the high pressure pump to a late ignition phase (10-20%) influences a reduction of average power of the engine (36.48kW) and a lower average torque (162.43 Nm). In the respective position of the pump the average number of Rotation on the PTO shaft was 552.00 min^{-1}. After shifting the high pressure pump to the early ignition phase (20-30%) the average power of the engine was reduced to 34.48kW, torque to 149.43Nm, and the number of Rotation at the PTO shaft was je 539.03min^{-1}.

Table 4. Indicators of tractor performance at a 20-30% deviation of the pre-ignition angle

Deviation 20-30% (C–early; C-late)	*Angle*	*N_0*	*Min.*	*M ax.*	*Mean*	*Std. Deviation*	*Variance*	*Skewness*
Rotation on PTO (min^{-1})	*20.40^0*	*30*	*411*	*602*	*539.03*	*60.95*	*3715.33*	*-0.73*
	12.75^0	*29*	*396*	*615*	*543.21*	*67.50*	*4556.38*	*-0.84*
Torque (Nm)	*20.40^0*	*30*	*80*	*194*	*149.43*	*32.58*	*1061.69*	*-0.50*
	12.75^0	*29*	*86*	*215*	*156.62*	*37.77*	*1426.67*	*-0.43*
Power on PTO shaft (kW)	*20.40^0*	*30*	*21*	*40*	*34.48*	*5.01*	*25.11*	*-1.24*
	12.75^0	*29*	*22*	*41*	*34.52*	*5.48*	*30.11*	*-1.30*

Shifting of the high pressure pump to the late ignition phase (20-30%) reduced the average power of the engine to 34.52 kW and the average torque to 156.62 Nm. The average number of Rotation at the PTO shaft was 543.00 min^{-1}. After shifting the high pressure pump to late ignition mode (above 17^0) the tractor worked more quietly (seemingly nice sound of the engine) but its power declined. The power of the tractor engine in case of a deviation of the pre-ignition angle of up to 10% caused a reduction of the power at the PTO shaft by 0.85 kW, deviation of between 10 to 20 % cause a reduction of power by 2.7 kW and a deviation of the pre-ignition angle at the level from 20 to 30% caused a reduction of power by 4.66 kW. Asymmetrical data processed by skewness method was in the range -1.16 to -1.60.

In case of diesel engines, shifting of the angle caused tapping in the engine as well as a delay in ignition of fuel. In the late ignition phase the combustion of fuel was incomplete. Researches done by other authors noted the same occurrence. According to Šilić et al. [6] delays in combustion that exceed 0.002 seconds, result in a bigger quantity of fuel in the combustion area and causes rapid (peak) combustion which is accompanied with strong noise. Continuation of the analysis of the described occurrence shows (Fig. 1) that tapping (throbbing) in the engine causes an additional increase in pressure, but negatively reflects on the noise and vibrations.

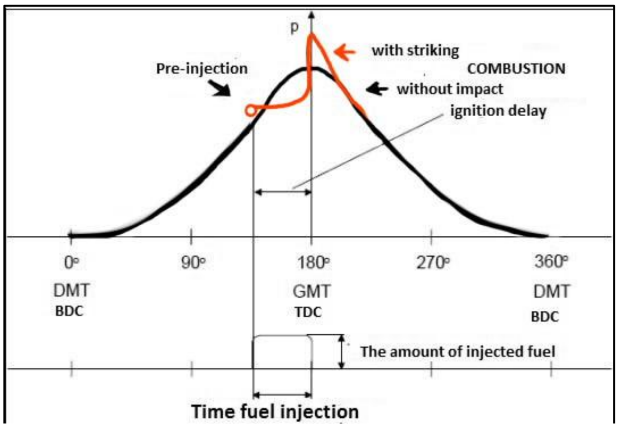

Figure 1. Combustion process in a diesel engine (taken over)

Shifting of the high pressure pump from the optimum pre-ignition area reflects on exhaust gases. Specifically the engine exhausts gases of black or white color. The combustion process takes place in all diesel engines and is higher in the case of high-speed engines than in the case of low-speed engines. Eriksson [2] in his dissertation stipulates that early ignition time produces a pressure of so called "early development", which results in a sudden increase of pressure which can be considered as an early expansion.

The usual period of combustion of fuel in engines Kozarac et al. [3] various from 0.0007 to 0.003 seconds. If the period of concealed combustion is too big (exceeds 0.002 sec), then a larger amount of fuel is accumulated in the combustion area, which will ultimately lead to the simultaneous combustion of fuel. The consequence is that the pressure and temperatures rapidly increase above the usual values. This occurrence is often called "peak combustion" or "rigid work" of the diesel engine. Peak combustion is not desirable because it burdens parts of the engine mechanism and can cause negative consequences.

The testing of the influence of the pre-ignition angle on the power of the engine and the torque were confirmed by the positive correlation factors. Correlations between the engine power and the size of the angle of the high pressure pump were at the level of 0.01 and 0.05. Correlations with the torque were at the level of 0.01.

Consumption of fuel depending on the pre-ignition angle. The analysis of fuel consumption revealed that deviation from manufacturer's norm (17^0) result in significant increase of fuel consumption. Results obtained are presented in Table 5.

Deviations of the pre-ignition angle in relation to the manufacturer's norm (17^0) caused significant increase in fuel consumption. The biggest increase in fuel consumption was recorded in the „C-late" case and amounted to 1.91 kg/h that is by 109.12%. The presented indicators confirm that work with technically irregularly tuned tractor engine can exceed multiple times the costs of regular maintenance. As for the exploitation indicator of fuel consumption, other authors obtained similar results. In example, in their research Filipovic et al. [1] stipulated that the change of working speed in the ploughing mode from 5 km/h to 7 km/h increased consumption for 10.32%; Mileusnic et al. [5] stipulated that during ploughing at 30 cm the fuel consumption varied from 26-36 l/ha, or when calculated in percentages this means that consumption increased by 38.46%.

Table 5. Fuel consumption in relation to pre-ignition angle

Pre-ignition	*Fuel consumption (kg)*		*Increase in fuel consumption (%)*	
	Stand gas 800 min^{-1}	*Ploughing (1500 min^{-1})*	*Stand gas 800 min^{-1}*	*Ploughing (1500 min^{-1})*
Manufacturer's norm (17^0)	*1.75*	*4.01*	*0*	*0*
10% Deviation (A-early)	*1.95*	*4.38*	*11.11*	*9.20*
10% Deviation (A-late)	*2.02*	*4.53*	*15.10*	*12.94*
20% Deviation (B-early)	*2.80*	*5.78*	*59.54*	*44.10*
20% Deviation (B-late)	*3.07*	*5.66*	*74.93*	*41.11*
30% Deviation (C-early)	*3.51*	*6.58*	*99.72*	*64.05*
30% Deviation (C-late)	*3.67*	*6.86*	*109.12*	*71.03*

Table 6. Fuel costs in relation to pre-ignition angle

Pre-ignition angle	*Fuel consumption (€/h)*	
	Stand gas 800 min^{-1}	*Plough 1500 min^{-1}*
Manufacturer's norm (17^0)	*2.25*	*5.16*
10% Deviation (early)	*2.50*	*5.63*
10% Deviation (late)	*2.59*	*5.82*
Up to 20% Deviation (early)	*3.59*	*7.43*
Up to 20% Deviation (late)	*3.94*	*7.27*
Up to 30% Deviation (early)	*4.50*	*8.46*
Up to 30% Deviation (late)	*4.72*	*8.82*

Effect of pre-ignition angle on fuel costs. The level of technical education of a large number of farmers is not at the level that would enable them to fully grasp the presented results of the research. If the obtained results are transformed and expressed as a loss of money then the farmers get a much clear picture of the importance of this issue. Definition of fuel consumption can be used to calculate the costs that are directly correlated. The fuel costs are calculated on the basis of the price of diesel fuel in BiH, which currently is at the level of 2.10 KM/l (1.07 €). Breakdown of fuel costs in relation to the pre-ignition angle is given in Table 6.

In case of fine-tuned pre-ignition angle, fuel costs totaled 2.25 €/h on stand gas (idle mode) and 5.16 €/h in plough mode. After shifting the angle (deviation, A-early, up to 10%) the fuel costs totaled 2.50 €/h, that is 5.63 €/h in the plough mode. Fuel costs increased with the simulated deviation from the prescribed pre-ignition angle. In the plough mode in case of a 20.4^0 pre-ignition angle the difference in fuel consumption in relation to manufacturer's norm (17^0) was at the level of 3.67 €/h.

In case of early pre-ignition with a deviation of 19.5^0 before the upper dead center, in comparison to the normally tuned ignition, fuel costs totaled 3.59 €/h at 800 min^{-1} in the plough mode, and at 1500 min^{-1} the value was doubled and totaled 7.43 €/h.

CONCLUSIONS

On the basis of conducted research which encompassed laboratory work, field work, research of literature and processing of data we draw the following conclusions:

- The average power of tested tractor engine with a fine-tuned pre-ignition angle totaled. 39.04kW. After simulated shifting of the pre-ignition angle the engine power significantly decrease and reached the following values:
  - In case of an early and late pre-ignition with an up to 10% deviation the average power totaled 38.33 kW;
  - In case of early pre-ignition (20% deviation) the average power totaled 36.30 kW, while in the case of late pre-ignition (20% deviation) the average power totaled 36.48 kW:
  - In case of early pre-ignition (30% deviation) the average power totaled 34.48 kW, while in the case of late pre-ignition (30% deviation) the average power totaled 34.52 kW.
- The effect of the pre-ignition angle on fuel consumption was tested in the stand gas (idle mode) (800 o/min^{-1}) and the plough mode (1 500 o/min^{-1}). In case of a normally tuned pre-ignition angle the consumption at 800min^{-1} was 1.75 kg/h, and at 1500 min^{-1} it totaled 4.01 kg/h. After simulated shifting of the pre-ignition angle the fuel consumption significantly increased. The following values were recorded:
  - 10% deviation (A-early), consumption at 800min^{-1} was 1.95 kg/h, and in the plough mode at 1500min^{-1} 4.38 kg/h;
  - 10% deviation (A-late), consumption at 800min^{-1} was 2.02 kg/h, and in the plough mode at 1500min^{-1} 4.53 kg/h;
  - 20% deviation (B-early), consumption at 800min^{-1} was 2.80 kg/h, and in the plough mode at 1500min^{-1} it was 5.87 kg/h;
  - 20% deviation (B-late), consumption at 800min^{-1} was 3.07kg/h, and in the plough mode at 1500min^{-1} 5.66 kg/h;
  - 30% deviation (C-early), consumption at 800min^{-1} was 3.51 kg/h, and in the plough mode at 1500min^{-1} 6.58 kg/h;
  - 30% deviation (C-late), consumption at 800min^{-1} was 3.67 kg/h, and in the plough mode at 1500min^{-1} 6.86 kg/h;
- Financial indicators of fuel consumption varied from 2.25 to 4.72 €/h with no load on stand gas and from 5.57 to 8.81 €/h in plough mode with a double furrow plough.

The obtained results confirmed the hypothesis that servicing of agriculture tractors should be done regularly and in accordance with manufacturer's norms as otherwise the consequences will exceed several times the costs of regular maintenance.

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PROMJENA EKSPLOATACIONIH SVOJSTAVA TRAKTORA U ZAVISNOSTI OD UGLA PREDPALJENJA MOTORA

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Sažetak: Održavanju traktora na malim privatnim posjedima u Bosni i Hercegovini ne posvećuje se dovoljna pažnja. Posljedica takvog stanja odražava se na eksploataciona svojstva traktora, te značajno povećava potrošnju goriva i zagađenje okoline. Ciljevi istraživanja fokusiraju se na dio problematike koja sagledava uticaj različitog ugla predpaljenja motora na raspoloživu snagu traktora na priključnom vratilu (PTO) i povećanje specifične potrošnje goriva. Istraživanja su izvedena u laboratorijskim i eksperimentalnim uslovima ispitne stanice za poljoprivredne mašine u Sarajevu, na destinaciji “Poligona Butmir” u 2015. godini. Dobiveni rezultati ukazuju da je snaga traktora na PTO varirala u rasponu od 21kW do 45 kW, što u procentualnim pokazateljima iznosi 46,6 - 100 %. Varijacije snage motora prouzrokovale su promjenu potrošnje goriva koja je iznosila u oranju od 4,01- 6,86 $kg \cdot h^{-1}$ nafte (D-2), dok se navedena potrošnja goriva u finansijskim pokazateljima kretala u rasponu od 4,41 do 9,23 $KM \cdot h^{-1}$ na štandgasu i od 10,9 do 17,23 $KM \cdot h^{-1}$ u oranju. Dobiveni rezultati su potvrdili hipotezu da servisiranje poljoprivrednih traktora treba izvoditi redovno i prema tvorničkim normativima, u protivnom posljedice višestruko nadmašuju troškove servisiranja.

Ključne riječi: *traktor, servisiranje, snaga motora, potrošnja goriva.*

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