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THE IMPACT OF AIR FILTER ON OPERATIONAL PROPERTIES OF ENGINE WITH THE COMMON RAIL FUEL SUPPLY SYSTEM

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Abstract

The objective of this research project was to determine the percentage impact of dry-medium air filter being used in Fiat Multijet 1.3 JTD engine on its operational properties (engine flexibility and specific fuel consumption). Experiments were performed according to the requirements of research methods specified in the piston combustion engine standard in force. In order to make comparisons, operational parameters of the power unit (torque, effective power and specific fuel consumption) were measured with dry-medium air filter (with a new filter element) being fitted and with air filter being removed. Each point of respective characteristic curves was determined based on four measurements as their mean value. Also boost pressure, which could be of importance for results, was considered in the experiments. However, the degree of EGR valve lift, the operation of which could also appear to be important, was not taken into account. For each measuring point of respective characteristic curves, the ranges of measurement uncertainties were determined. Expanded standard uncertainties were calculated based on the Guide to the Expression of Uncertainty in Measurement. The experiments being carried out allowed concluding that the engine with air filter was less flexible by approx. 20% when compared to that without air filter, whereas its specific fuel consumption was greater by approx. 9%. The degree of air filter pollution affects its flow resistance and, which is related to this, engine torque and its effective power as well as its flexibility decrease but fuel consumption increases.

***Keywords**: air filter, operational properties of engine, engine flexibility, specific fuel consumption, torque, effective power*

1. Introduction

Requirements for vehicle power unit are more and more restrictive because they are related to the process of modern car operation. This enforces an expectation of low fuel demand, whereas on the other hand a good adaptation of vehicle to variable loads being of particular importance under urban driving conditions. An important role is being played by vehicle exhaust gas emission.

When considering the aspects being mentioned above, three most important operational factors should be taken into account [4]:

- low fuel consumption,
- low exhaust gas toxicity,
- high flexibility.

An important element of the engine intake system affecting the aforesaid parameters is air filter. Its job is to stop dusts and pollutants that could enter a car engine with the air and induce its rapid and excessive wear, primarily its piston rings and cylinder bearing surface. In dry-medium air filter, the air is being passed through a paper element which consists of several layers [8].

Air filter should be characterised by the following properties resulting from specific operational requirements [1]:

- high efficiency of dust collection,
- small air flow resistance,
- large dust absorption capacities,
- small dimensions and weight,
- large mechanical durability.

Air flow resistance of the filter element should be at the same time as small as possible since air motion throttling in the air filter could otherwise induce an intolerable decrease in the cylinder filling and the same a lessening of engine performance [2].

The impact of different type air filters on engine power and torque is small, up to 5% [2]. However, the influence of air filter on engine operating parameters is much greater at higher rotational speeds [3].

Earlier experiments [1-3] were carried out for a non-supercharged compression-ignition engine being used in motor trucks or military vehicles.

The author of this paper aimed at determining the percentage impact of air filter on engine operational factors, such as vehicle engine flexibility and specific fuel consumption for a turbocharged compression-ignition engine with the Common Rail system.

2. Research objective and methods

The objective of this study was to determine the percentage impact of dry-medium air filter being used in FIAT Multijet 1.3 JTD engine on its operational properties. Experiments were performed according to the requirements of research methods specified in the piston combustion engine standard [10]. In order to make comparisons, operational parameters of the power unit (torque, effective power and specific fuel consumption) were measured with dry-medium air filter (with a new filter element) being fitted and with air filter being removed.

Each point of respective characteristic curves was determined based on four measurements as their mean value. Also boost pressure, which could be of importance for results, was considered in the experiments. However, the degree of EGR valve lift, the operation of which could also appear to be important, was not taken into account. The characteristic curves being obtained were made in measuring points due to very low ranges of measurement uncertainties.

3. Test bed

The test bed consisted of the following components:

a) fuel tank – a 750 litre fuel tank designed for diesel oil, made of plastic;
b) fuel pump – to ensure fuel pressure from fuel tank and introduce it into fuel line system;
c) Automex gravimetric fuel flow meter – a component necessary for measuring fuel consumption over time by means of the gravimetric method;
d) Fiat Multijet 1.3 JTD engine – a direct injection 4-stroke turbocharged compression-ignition engine with the Common Rail fuel supply system [9]; it had a catalytic converter but did not include particulate filter trap;

Tab. 1. Engine description according to manufacturer's data [9]

Make: FIAT Type: Multijet 1.3 JTD 16 V	Unit	Value / description
Cylinder diameter	[mm]	69.6
Piston travel	[mm]	82
Compression ratio	-	18.1
Number of cylinders	-	4
Arrangement of cylinders	-	in-line
Injection sequence	-	1-3-2-4
Engine capacity	[cm^3]	1248
Maximum power	[KM/kW]	1 19/51
Rotational speed at maximum power	[min^{-1}]	4000
Maximum torque	[Nm]	145
Rotational speed at maximum torque	[min^{-1}]	1750

Fig. 1. FIAT Multijet 1.3 JTD 16 V engine with air filter being fitted

e) EMX 100 eddy current brake manufactured by Elektromex (Poland) – a device for power take off and measurement in combustion engines being placed on test beds.

Tab. 2. Eddy current brake details [12]

Brake type	EMX100/10000
Maximum absorption power	100 kW
Maximum rotational speed	10000 rpm
Maximum torque	240 Nm
Brake weight	250 kg
Direction of rotation	Any

4. Results

Results of the measurements being performed are presented in Tab. 3 and 4 and Fig. 3 and 4. The engine was fed with a full dose of ON EKODIESEL fuel with the cetane number 51.1. Ambient parameters during the test were as follows:

- ambient temperature $T_a = 294$ K,
- ambient pressure $p_a = 98.5$ kPa,
- relative humidity = 40%.

The power unit torque and its effective power being measured were corrected according to the relations comprised in the Polish standard PN-ISO 15550 [10].

For each measuring point of respective characteristic curves, the ranges of measurement uncertainties were determined. Expanded standard uncertainties were calculated based on the Guide to the Expression of Uncertainty in Measurement [11].

As an example, the values of uncertainties being calculated for engine torque with air filter being dismounted are given below.

The engine without air filter being mounted reached the maximum torque of 140.1 Nm at lower rotational speed ($n=1900$ min^{-1}) when compared to that with air filter being mounted., i.e. 131.0 Nm ($n=2200$ min^{-1}). The torque value is thus larger by 6.9% for engine without air filter (expanded standard measurement uncertainty for engine torque did not exceed 1%). The maximum engine power with air filter was smaller by 1.6% (expanded standard measurement uncertainty for engine effective power did not exceed 0.5%).

The characteristic curves for fuel consumption and specific fuel consumption with air filter being mounted and dismounted are presented below.

Tab. 3. Values of measurement uncertainties for particular engine rotational speeds (air filter dismounted)

n	T_{tq}	$u_A(T_{tq})$	$u_B(T_{tq})$	$U(T_{tq})$	$T_{tq} \pm U(T_{tq})$
[min^{-1}]	[Nm]	[Nm]	[Nm]	[Nm]	[Nm]
1000	71.4	0.27	0.058	0.56	71.4 ± 0.6
1500	124.4	0.38		0.77	124.4 ± 0.8
1700	139.6	0.58		1.16	139.6 ± 1.2
1900	140.1	0.61		1.23	140.1 ± 1.3
2000	138.1	0.32		0.65	138.1 ± 0.7
2200	137.7	0.20		0.41	137.7 ± 0.5
2400	135.2	0.18		0.38	135.2 ± 0.4
2500	134.4	0.06		0.17	134.4 ± 0.2
3000	134.6	0.41		0.83	134.6 ± 0.9
3500	124.2	0.19		0.40	124.2 ± 0.4
4000	115.1	0.13		0.28	115.1 ± 0.3
4500	94.6	0.17		0.37	94.6 ± 0.4

Tab. 4. Expanded standard measurement uncertainties for all variables

n	$T_{tq\,F} \pm U(T_{tq\,F})$	$T_{tq} \pm U(T_{tq})$	$B_F \pm U(B_F)$	$B \pm U(B)$	$p_{b\,F} \pm U(p_{b\,F})$	$p_b \pm U(p_b)$
[min^{-1}]	[Nm]	[Nm]	[g/s]	[g/s]	[kPa]	[kPa]
1000	70.1 ± 0.6	71.4 ± 0.6	0.65 ± 0.02	0.59 ± 0.02	81	81
1500	78.0 ± 0.5	124.4 ± 0.8	1.05 ± 0.02	1.39 ± 0.02	481	581
1700	116.2 ± 1.0	139.6 ± 1.2	1.56 ± 0.04	1.65 ± 0.04	772	832
1900	127.0 ± 1.2	140.1 ± 1.3	1.76 ± 0.03	1.78 ± 0.03	792	972
2000	129.9 ± 0.7	138.1 ± 0.7	1.95 ± 0.03	1.85 ± 0.02	852	1042
2200	131.0 ± 0.5	137.7 ± 0.5	2.05 ± 0.03	2.01 ± 0.02	952	1122
2400	130.0 ± 0.4	135.2 ± 0.4	2.23 ± 0.07	2.08 ± 0.07	1072	1172
2500	128.4 ± 0.2	134.4 ± 0.2	2.52 ± 0.02	2.20 ± 0.02	1092	1172
3000	129.8 ± 0.9	134.6 ± 0.9	2.86 ± 0.03	2.75 ± 0.03	1152	1192
3500	121.0 ± 0.4	124.2 ± 0.4	3.17 ± 0.03	3.08 ± 0.03	1112	1132
4000	113.0 ± 0.3	115.1 ± 0.3	3.31 ± 0.02	3.38 ± 0.02	1022	1072
4500	100.1 ± 0.4	94.6 ± 0.4	3.37 ± 0.03	3.25 ± 0.03	952	992

Tab. 4a. Expanded standard measurement uncertainties for all variables

n	$P_F^d \pm U(P_F^d)$	$P^d \pm U(P^d)$	$b_F \pm U(b_F)$	$b \pm U(b)$
[min^{-1}]	[kW]	[kW]	[g/kWh]	[g/kWh]
1000	7.4 ± 0.2	7.5 ± 0.2	316.2 ± 7.8	279.0 ± 6.9
1500	11.3 ± 0.2	19.5 ± 0.3	334.5 ± 4.6	253.5 ± 3.5
1700	19.5 ± 0.3	24.9 ± 0.3	288.0 ± 5.8	234.0 ± 4.7
1900	24.0 ± 0.3	27.9 ± 0.3	264.0 ± 2.6	225.7 ± 2.2
2000	27.3 ± 0.2	29.0 ± 0.2	257.1 ± 2.7	226.9 ± 2.0
2200	30.2 ± 0.2	31.7 ± 0.2	244.4 ± 1.2	225.1 ± 1.1
2400	32.7 ± 0.2	34.1 ± 0.2	245.5 ± 7.1	217.4 ± 6.3
2500	34.9 ± 0.2	35.2 ± 0.2	259.9 ± 1.5	222.4 ± 1.3
3000	41.4 ± 0.3	42.3 ± 0.3	248.7 ± 2.1	231.1 ± 2.0
3500	45.5 ± 0.2	45.6 ± 0.2	250.8 ± 2.2	240.3 ± 2.1
4000	47.5 ± 0.2	48.3 ± 0.2	250.9 ± 0.4	248.7 ± 0.4
4500	46.4 ± 0.3	44.7 ± 0.3	261.5 ± 0.3	260.4 ± 0.3

where: n – engine rotational speed, $T_{tq\,F}$ *– engine torque with air filter being mounted,* T_{tq} *– engine torque with air filter being dismounted,* B_F *– engine fuel consumption with air filter being mounted,* B *– engine fuel consumption with air filter being dismounted,* $p_{b\,F}$ *– engine boost pressure with air filter being mounted,* p_b *– engine boost pressure with air filter being dismounted,* P_F^d *– engine effective power with air filter being mounted,* P^d *– engine effective power with air filter being dismounted, engine specific fuel consumption with air filter being mounted,* b *– engine specific fuel consumption with air filter being dismounted,* u_A *– type A standard uncertainty,* u_B *– type B standard uncertainty,* U *– expanded standard measurement uncertainty of a particular variable.*

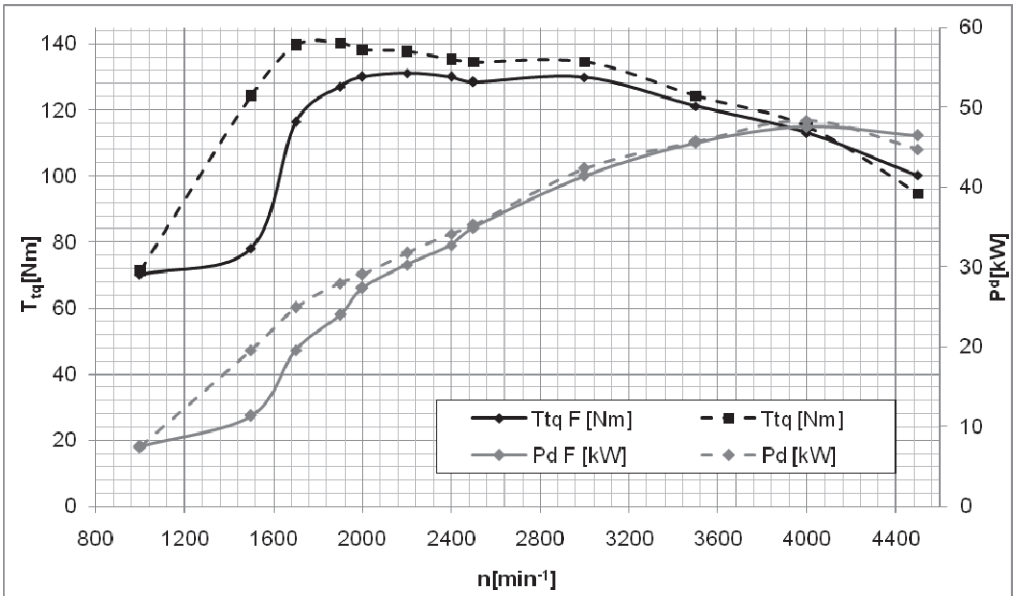

Fig. 3. Engine external characteristics with air filter being mounted and dismounted

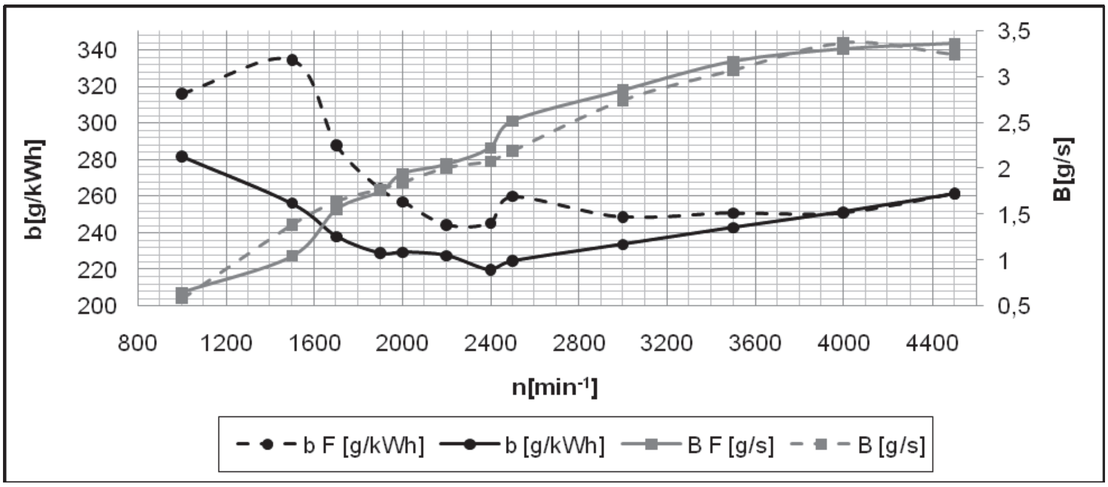

Fig. 4. Engine fuel consumption and engine specific fuel consumption curves with air filter being mounted and dismounted

Specific fuel consumption was lower within the whole effective range of rotational speeds for the engine without air filter. This was mainly due to lower fuel consumption.

5. Engine operational properties

Operational properties being determined during the research are as follows: engine flexibility and specific fuel consumption.

Engine flexibility is its automatic capability of adaptation to variable loads and rotational speeds. It defines the possibility of vehicle acceleration under load [4, 5]. Motor car with a flexible engine is able to move even within one gearbox ratio with variable resistance, to motion without downward change. This parameter is being calculated as a product of torque flexibility and rotational speed flexibility [5].

As a result of simulation based on these experiments, engine flexibility assumed the following values:

Tab. 5. Comparison of engine flexibility with air filter being mounted and dismounted

without air filter	with air filter
$e_n = \frac{n_{P^d}}{n_{T_{tq}}} = \frac{4000}{1900}\left[\frac{\min^{-1}}{\min^{-1}}\right] = 2.11$ $e_{T_{tq}} = \frac{T_{tq\max}}{T_{tqP^d_{\max}}} = \frac{140.1}{115.1}\left[\frac{Nm}{Nm}\right] = 1.22$ $e = e_n \cdot e_{T_{tq}} = 2.56$	$e_{nF} = \frac{4000}{2200} = 1.82$ $e_{T_{tq}F} = \frac{131.0}{113.0} = 1.16$ $e = e_{nF} \cdot e_{T_{tq}F} = 2.11$

where: e_n *– flexibility of engine rotational speed,* $e_{T_{tq}}$ *– flexibility of engine torque,* e *– total flexibility,* n_{P^d} *– engine rotational speed at which maximum power is being obtained [min*$^{-1}$*],* $n_{T_{tq}}$ *– engine rotational speed at which maximum torque is being obtained [min*$^{-1}$*],* $T_{tq\max}$ *– maximum engine torque [Nm],* $T_{tqP^d_{\max}}$ *– engine torque at its maximum power [Nm].*

The value of engine flexibility without air filter is larger by 21.6% from that with air filter. When considering expanded standard measurement uncertainties for engine torque at particular rotational speeds, they did not exceed a deviation of 1% (permissible deviation according to the standard PN–ISO 15550 [10] = 2%). Therefore, it is possible to state that air filter decreased engine flexibility within approx. 20%. The engine with air filter being dismounted and mounted was an average flexible engine [5].

Specific fuel consumption defines the quantity of fuel being consumed by engine during a time unit falling on a power unit [8]. It is an indicator of engine operation economy since it speaks about how much chemical energy being contained in fuel should be consumed by engine to generate a power unit. At the same time, it is inversely proportional to its overall efficiency [4].

As a result of these experiments, specific fuel consumption assumed tie following values:

Tab. 6. Lowest specific fuel consumption

	without air filter	with air filter
n	$b \pm U(b)$	$b_F \pm U(b_F)$
[min^{-1}]	[g/kWh]	[g/kWh]
2200	225.1 ± 1.1	244.4 ± 1.2
2400	217.4 ± 6.3	245.5 ± 7.1

The engine with air filter reached the lowest specific fuel consumption being equal to 244.4 g/kWh at a rotational speed of 2200 min^{-1}, whereas that for the engine without air filter amounted to 217.4 g/kWh at a rotational speed of 2400 min^{-1}.

Specific fuel consumption is larger by 12.4% for the engine with air filter being mounted which, while considering expanded standard uncertainties within 3%, amounts to about 9%.

6. Conclusions

The experiment being carried out allowed obtaining the following conclusions:

- engine without air filter would allow better vehicle adaptation to variable loads (engine flexibility larger by approx. 20%); however, this is not possible due to very short operation (damage to the piston–rings–cylinder assembly by atmospheric air dust),
- specific fuel consumption was lower by about 9% for the engine without air filter, which speaks about its greater overall efficiency,
- it is possible to assume that the degree of air filter pollution affects its flow resistance and, which is related to this, engine torque and its effective power as well as its flexibility decrease but fuel consumption increases,
- the argument being mentioned above indicates that the filter element of air filter should be frequently replaced, according to manufacturer's recommendations.

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