AIR COOLED DIRECT INJECTION DIESEL ENGINE MAIN OPERATING PARAMETERS ANALYSIS DURING THE CHANGE IN ROTATIONAL SPEED

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Abstract: *Four-stroke air cooled, direct injection diesel engine Torpedo BT4L912 during rotational speed variation was investigated in this paper. By using the measurement results obtained at engine brake was calculated several main operating parameters in each engine rotational speed. Rotational speed was varied from 1000 rpm to 2300 rpm. Calculated engine operating parameters are engine torque, effective power, engine brake mean effective pressure, specific effective fuel consumption and volume fuel consumption per engine process. The highest obtained engine torque amounts 338.8 Nm and the highest engine effective power amounts 71.76 kW. Specific effective fuel consumption has the lowest value of 197.42 g/kWh at engine rotational speed of 1800 rpm. Regarding several calculated engine operating parameters, optimal operating point of the analyzed engine is at 1800 rpm.*

Keywords: *DIESEL ENGINE, DIRECT INJECTION, ENGINE BRAKING, ENGINE OPERATING PARAMETERS*

1. Introduction

Experimental measurements are the basis for internal combustion engine operating parameters analysis, [1] and [2]. Parallel to internal combustion engine measurements, numerical simulations have been developed to ensure easier, faster and much cheaper investigations of engine operating parameters, regardless if it was investigated gasoline or diesel engines [3].

If in the focus was diesel engines, as in this paper, it should be noted that today was known several types of diesel engine numerical models: 0D (zero dimensional) models [4], multizone models [5], quasi dimensional models [6] and [7], while the last and most detailed ones are CFD (Computational Fluid Dynamics) models [8]. In order to determine the accuracy and precision of each numerical model, they must necessarily be validated in several different measurement points of the tested engine. Because of that fact, experimental engine measurements are inevitable.

To reduce diesel engine emissions and improve engine operating parameters, researchers are intensively involved in implementing combustion of different alternative fuels in existing diesel engines. A complete review of green fuels as alternative fuels for diesel engines is presented in [9] while the review of performance, combustion and emission characteristics of bio-diesel fuelled diesel engines presented authors in [10].

In this paper was presented change in the main operating parameters of four-stroke air cooled, direct injection diesel engine Torpedo BT4L912 during rotational speed variation. Based on the measurement results obtained at engine brake was calculated several main operating parameters and presented for a various engine rotational speed. Those operating parameters were engine torque, engine effective power, engine brake mean effective pressure, specific effective fuel consumption and volume fuel consumption per engine process. The change of last two operating parameters was calculated by using data for fuel density and fuel tank volume, along with the time for the fuel consumption from the fuel tank. For the wide range of engine rotational speeds was obtained recommended operating area of the analyzed engine.

2. Air cooled, four-stroke, direct injection diesel engine specifications

The investigated engine was four-stroke air cooled, direct injection diesel engine Torpedo BT4L912. The main engine characteristics along with necessary brake and fuel specifications are presented in Table 1.

Table 1. *Engine and brake specifications*

Number of cylinders	4
Cylinder diameter	102 mm
Cylinder stroke	120 mm
The total operating volume	3922 cm^3
Cylinder cooling	With air
Brake arm length	0.714 m
Fuel tank volume	100 cm^3
Fuel density	830 kg/m^3
Fuel lower heating value	42700 kJ/kg

3. Engine measurement results and measuring equipment

Engine measurement was performed on the engine test bench in the company Torpedo, Rijeka, Croatia. Used measuring equipment in the majority is owned by the same company, Fig. 1.

Brake force was read directly on the brake Schenk U1-30. The engine rotational speed was measured by inductive encoder on the brake shaft. Volumetric fuel consumption was measured by using a photocell.

Cylinder pressure was measured with a data acquisition device (analogue-digital system). An analogue signal was amplified through the amplifier and converts to digital signal, which can be further processed. The data acquisition device has a microprocessor MC 68020 (32 Bit and 16.7 MHz) along with co-processor MC 68881 (16.7 MHz). In this device are included two analogue-digital converters (resolution of 12 Bit) with maximum of $2 \cdot 4 \cdot 10^5$ measurements in second (five measurements for one engine crank angle). Cylinder pressure was measured in the first engine cylinder with quartz sensor Kistler - Type 7061 which measurement range is from 0 to 200 bars.

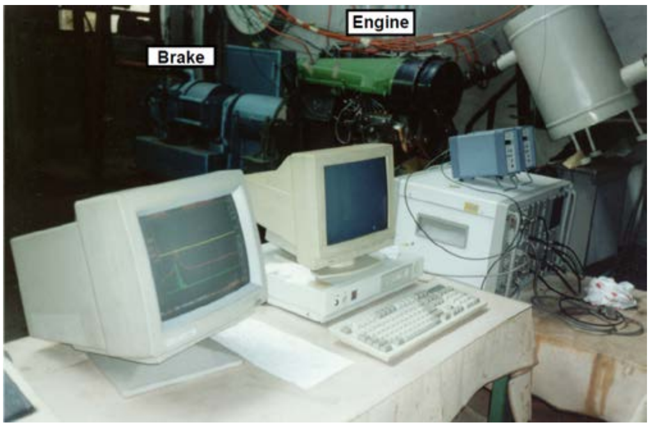

Fig. 1. *Diesel engine Torpedo BT4L912 connected to brake during the measurements*

Engine measurement was carried out in a way that after engine start, maximum rotational speed has been achieved without any load. After that the braking force gradually increased and the engine rotational speed decreased. For the engine analysis provided in this paper, necessary measured operating parameters are presented in Table 2 and those are: engine rotational speed, brake force and time for the fuel consumption from the fuel tank.

Table 2. *Torpedo BT4L912 obtained measurement results*

Test No.	Engine rotational speed (rpm)	Brake force (N)	Time for the fuel consumption from the fuel tank (s)
1	2300	406.98	17.9
2	2200	436.40	17.8
3	2000	453.07	19.1
4	1800	474.64	23.7
5	1600	460.91	23.2
6	1500	460.91	24.5
7	1400	457.97	25.9
8	1200	437.38	29.6
9	1000	388.34	35.7

4. Equations for calculating engine main operating parameters according to measured results

At each engine rotational speed torque was calculated according to the equation:

$$M = F \cdot R \tag{1}$$

where M (Nm) is torque, F (N) is brake reaction force and R (m) is the brake arm's length on which the reaction force is measured - Table 1.

Engine effective power delivered to power consumers was calculated by using an equation:

$$P_{ef} = \frac{M \cdot 2 \cdot \pi \cdot n}{60 \cdot 1000} \tag{2}$$

where P_{ef} (kW) is engine effective power and n (rpm) is engine rotational speed.

Engine brake mean effective pressure was calculated according to the equation:

$$p_{ef} = \frac{P_{ef}}{n_a \cdot V_{tot,op}} \cdot 6 \cdot 10^5 \tag{3}$$

where p_{ef} (bar) is an engine brake mean effective pressure and $V_{tot,op}$ (cm^3) is the total engine operating volume - Table 1. Engine active rotational speed n_a (rpm) which takes into account only the engine processes with fuel injections is equal to:

$$n_a = \frac{2 \cdot n}{\tau} \tag{4}$$

where τ is engine stroke (analyzed engine is a four-stroke engine).

Specific effective fuel consumption was calculated by using an equation:

$$b_{ef} = \frac{V_{ft} \cdot \rho_f}{t_{ft} \cdot P_{ef}} \cdot 3.6 \tag{5}$$

where b_{ef} (g/kWh) is specific effective fuel consumption. V_{ft} (cm^3) is a fuel tank volume - Table 1, ρ_f (kg/m^3) is fuel density - Table 1 and t_{ft} (s) is time for the fuel consumption from the fuel tank - Table 2.

Volume fuel consumption per engine process was obtained by using an equation:

$$V_{pp} = \frac{V_{ft}}{n_a \cdot t_{ft} \cdot z} \cdot 6 \cdot 10^4 \tag{6}$$

where V_{pp} (mm^3/proc.) is volume fuel consumption per engine process and z is the number of engine cylinders - Table 1.

5. Change in engine calculated main operating parameters with discussion

For each measurement point, at each engine rotational speed, engine torque was calculated by using equation (1). At the maximum engine rotational speed of 2300 rpm, engine torque amounts 290.5 Nm, Fig. 2. With the decrease in the engine rotational speed from maximum value, engine torque firstly continuously increases. The highest value of engine torque was obtained at 1800 rpm and amounts 338.8 Nm. During further decrease in the engine rotational speed from 1800 rpm, engine torque continuously decreases and at the lowest rotational speed of 1000 rpm engine torque has the lowest value of 277.2 Nm. As analyzed engine is air cooled type, available torque range from 277.2 Nm to 338.8 Nm for observed rotational speeds is satisfactory.

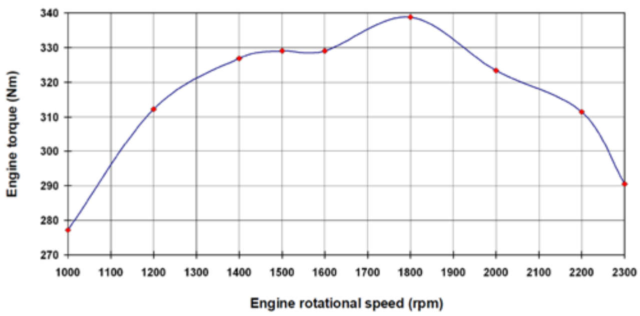

Fig. 2. *Engine torque change in relation to engine rotational speed*

Engine effective power which is delivered by the outlet coupling to the power consumers was calculated for each measured engine rotational speed according to equation (2). At the lowest engine rotational speed of 1000 rpm, engine effective power is the lowest and amounts 29.03 kW, Fig. 3. With the increase in the engine rotational speed from the lowest one, engine effective power continuously increases up to 2200 rpm. At 2200 rpm, effective power has the highest value which amounts 71.76 kW. In the range from 2200 rpm to 2300 rpm, engine effective power decreases and at the highest rotational speed (2300 rpm) effective power is equal to 69.97 kW.

If compared the change of analyzed engine torque, Fig. 2, with change of engine brake mean effective pressure, Fig. 4, it can be seen that both parameters have identical trends. Brake mean effective pressure was calculated by using equations (3) and (4). At the lowest engine rotational speed of 1000 rpm is observed the lowest brake mean effective pressure which amounts 8.88 bars.

With the increase in the engine rotational speed from the lowest one, brake mean effective pressure continuously increases and reaches the maximum value of 10.85 bars at the 1800 rpm. From the engine rotational speed of 1800 rpm up to 2300 rpm, brake mean effective pressure continuously decreases and on the highest engine rotational speed of 2300 rpm it amounts 9.31 bars.

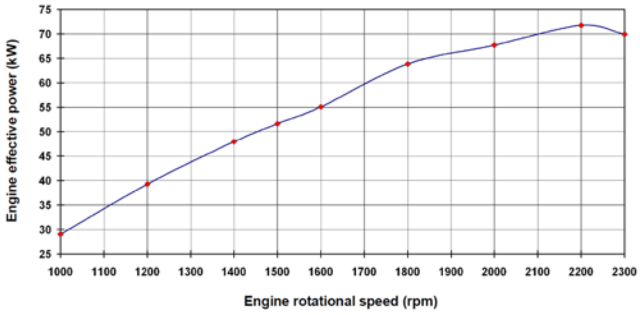

Fig. 3. *Engine effective power change for various observed engine rotational speeds*

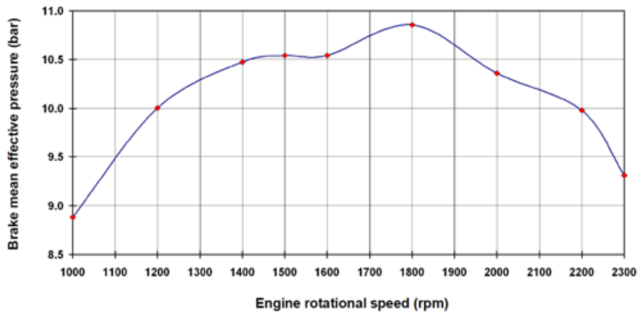

Fig. 4. *Change in brake mean effective pressure for various engine rotational speeds*

Specific effective fuel consumption was calculated by using measured values for each observed engine rotational speed, according to equation (5). Trend of specific effective fuel consumption of the analyzed engine is similar to diesel engines investigated by the other authors, [11] and [12]. With the increase in the engine rotational speed, specific effective fuel consumption firstly decreases to the lowest value, after which follows its increase. In Fig. 5 is not presented trendline for specific effective fuel consumption change, calculated values for each engine rotational speed were connected with a line in order not to approximate the real data.

At the lowest engine rotational speed (1000 rpm) specific effective fuel consumption is the highest and amounts 288.33 g/kWh. With the increase in the engine rotational speed from the lowest one, specific effective fuel consumption decreases until 1800 rpm. At 1800 rpm specific effective fuel consumption has the lowest value which amounts 197.42 g/kWh. From 1800 rpm up to the highest engine rotational speed of 2300 rpm, specific effective fuel consumption continuously increases and on 2300 rpm it has a value equal to 238.58 g/kWh.

Volume fuel consumption per engine process (VFCPP) was calculated for each measured engine rotational speed, according to equation (6). At the lowest engine rotational speed of 1000 rpm, VFCPP amounts 84.03 mm^3/proc, Fig. 6. Increase in the engine rotational speed from 1000 rpm causes that VFCPP firstly slightly increase at 84.46 mm^3/proc. (1200 rpm) after which follows the continuous decrease up to 1800 rpm. At the 1800 rpm, VFCPP has the lowest value which amounts 70.32 mm^3/proc. From 1800 rpm to 2000 rpm VFCPP increases and amounts 78.53 mm^3/proc. at 2000 rpm. Finally, from 2000 rpm until the highest engine rotational speed, volume fuel consumption per engine process continuously decreases and amounts 72.87 mm^3/proc. at the 2300 rpm.

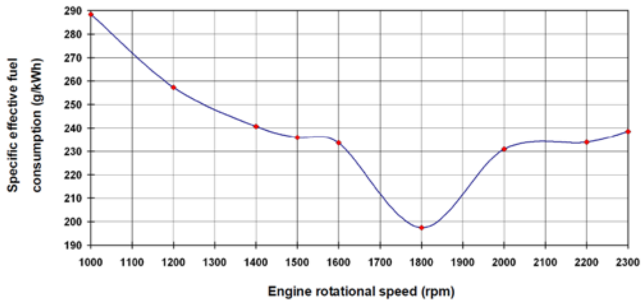

Fig. 5. *Specific effective fuel consumption change for various engine rotational speeds*

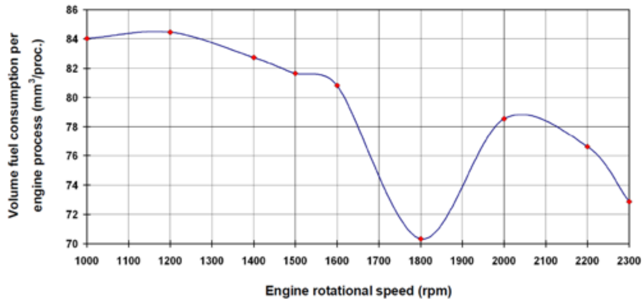

Fig. 6. *Volume fuel consumption per engine process change for various observed engine rotational speeds*

6. Conclusion

In this paper were analyzed changes in the main operating parameters of four-stroke air cooled, direct injection diesel engine Torpedo BT4L912 during rotational speed variation. Several main operating parameters for each measured engine rotational speed was calculated in order to obtain complete insight into the engine operating characteristics.

The highest obtained engine torque amounts 338.8 Nm and the highest engine effective power amounts 71.76 kW. Highest torque and highest effective power were not obtained at the same engine rotational speed. Engine brake mean effective pressure has the same trend as engine torque. The highest value of engine brake mean effective pressure amounts 10.85 bars.

The lowest specific effective fuel consumption was obtained at 1800 rpm and amounts 197.42 g/kWh. At the same engine rotational speed was also obtained the lowest volume fuel consumption per engine process which amounts 70.32 mm^3/proc.

The final conclusion, which can be derived from the presented calculated results, is that the optimal operating point of the analyzed engine Torpedo BT4L912 is operating point at 1800 rpm. In that operating point engine has the highest torque and the lowest specific effective fuel consumption. Also, in that operating point analyzed engine has the lowest volume fuel consumption per process.

7. Acknowledgments

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8. References

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