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ANALYTICAL DETERMINATION OF THE CHARACTERISTICS OF ENGINE POWER FIAT 1.3 JTD

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Abstract

Combustion engines are commonly used in car propulsion systems. They belong to a group of heat engines, i.e. those that convert the heat obtained from combustion of liquid or gaseous fuels into mechanical work. Engine parameters, such as power output (P^d), torque (T_{tq}) and adaptability to variable traffic [motion] conditions, represent vehicle motion and its functional properties. The torque (T_{tq}) and the crankshaft speed (n) are measured directly with the use of dynamometer at specific measurement conditions but the power (P^d) is determined indirectly. The relationships between these parameters are presented using external characteristics. They allow determination of engine adaptability to changes in the resistance to motion, i.e. its flexibility (E).

In the paper, flexibility and analytical determination of the power and torque curves through application of Leidemann's formulas are discussed. Results of the research conducted with the use of turbocharged compression-ignition engine equipped with Common Rail fuel system are presented. The correlation between the power and torque curves based on Leidemann's formulas and the real curves obtained on the basis of experimental research (with application of engine dynamometer) are verified. Finally, evaluation of the method applied for determining the power curves by the speed range of FIAT 1.3 JTD engine was made.

Keywords: *combustion engines, power, torque, engine flexibility*

1. Introduction

Flexibility of combustion engine is an important parameter speaking about engine traction properties. It can be characterised most plainly as automatic adaptability of engine to variable loads and speeds. High expectations of car users in relation to car engines enforce the necessity of improving the flexibility factor at part engine loads. To determine the flexibility factor, the power and engine torque characteristics need to be known. Approximate characteristics may be made without tests, knowing only the values of rated power and maximum torque and speeds corresponding to them. For this purpose, Leidemann's formulas are used.

Leidemann's formulas have the following form [1]:

$$N_x = N_N\left(\alpha\frac{n_x}{n_N} + \beta\frac{n_x^2}{n_N^2} - \frac{n_x^3}{n_N^3}\right) \text{ [kW]}, \tag{1}$$

$$M_{ox} = 9554.14\frac{N_x}{n_x} \text{ [Nm]}, \tag{2}$$

where:

N_x – engine power at torque n_x,
N_N – rated power,
n_N – rated power rotations,
M_{ox} – engine torque at speed n_x, α,
β – coefficient.

Coefficients α and β, used in Leidemann's formulas, assume different values, depending on the method of engine supply. The values of these coefficients specified in literature [2, 3] are well fitted for determining the external characteristics of engine. Traction parameters of engine at its part load are also important, and even more important, for operational purposes.

The external characteristics made with Leidemann's formulas using the coefficients specified in literature do not reflect the real characteristics of part power. This study aims at verification to what extent Leidemann's formulas are fitted for determining the part power and whether these formulas may be corrected by appropriate changes in coefficients α and β so that the courses of these characteristics being drawn with them reflect the real courses as closely as possible.

2. Test bed

Research centres perform specific tests in special laboratories on test beds, termed engine test bench, to determine real engine parameters, such as power output, fuel consumption, etc., being called engine-working parameters.

Depending on the needs, the scope of these tests can be very diverse: from basic measurements of power and fuel consumption to complex scientific research, depending on the equipment of engine test bench.

At the Department of Motor Vehicles Operation, Western Pomeranian University of Technology in Szczecin, tests were conducted on a test bed presented in Fig. 1.

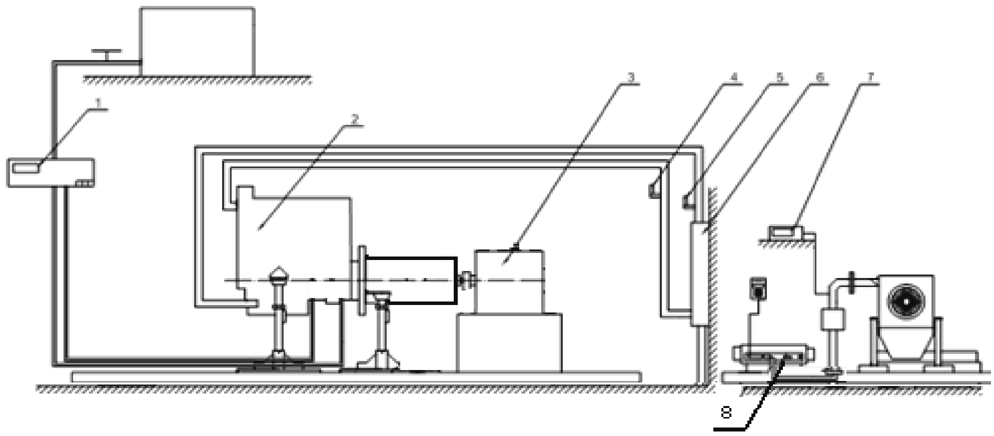

Fig. 1. Schematic diagram of a test bed with a FIAT 1.3JTD MultiJet engine 1 – AMX 212F fuel-flow meter, 2 1.3JTD engine, 3 – AMX 100 eddy-current brake , 4 – coolant thermometer, 5 – coolant thermometer, 6 coolant tank, 7 – exhaust gas temperature meter, 8 – MDO 2 smoke meter with control panel.

One of important elements on the test bed is a break loading FIAT 1.3 JTD MultiJet combustion engine with smooth adjustment of the value of set load. During the test, AUTOMEX AMX 100 eddy-current brake and AUTOMEX AMX 212F fuel-flow meter were used.

3. Modification of Leidemann's coefficients

Modification of coefficients in Leidemann's formulas consists in selection of such values so that they correspond to a specific type of fuel supply system.

In order to find coefficients α and β, formulas (1) and (2) need to be transformed, and boundary conditions for both coefficients need to be determined in the following way:
Leidemann's formula for the engine power in the general form is as follows:

$$N_x = N_N\left(0.5\frac{n_x}{n_N} + 1.5\frac{n_x^2}{n_N^2} - \frac{n_x^3}{n_N^3}\right), \tag{3}$$

while the torque is:

$$M_{ox} = 9554.14\frac{N_x}{n_x}. \quad (4)$$

Boundary condition for $n_x=n_N$ is as follows:

$$N_{\max} = N_{\max}\left(\alpha\frac{n_N}{n_N} + \beta\frac{n_N^2}{n_N^2} - \frac{n_N^3}{n_N^3}\right)/N_{\max}. \quad (5)$$

After dividing the sides of relationship (5) by N_{max}, the following is being obtained:

$$1 = \alpha + \beta - 1, \quad (6)$$

thus:

$$\alpha + \beta = 2. \quad (7)$$

Boundary condition for $n_x = n_M$ is as follows:

$$N_x = N_{\max}\left(\alpha\frac{n_M}{n_N} + \beta\frac{n_M^2}{n_N^2} - \frac{n_M^3}{n_N^3}\right)/N_{\max}. \quad (8)$$

After dividing the sides of relationship (8) by N_{max}, the following is being obtained:

$$\frac{N_M}{N_{\max}} = \alpha\frac{n_M}{n_N} + \beta\frac{n_M^2}{n_N^2} - \frac{n_M^3}{n_M^3}. \quad (9)$$

By entering formula (4) and relationship $e_n = n_N/n_M$ into relationship (9), the following is being obtained:

$$\frac{\frac{M_{\max}n_M}{9554.14}}{\frac{M_N n_N}{9554.14}} = \alpha\frac{1}{e_n} + \beta\frac{1}{e_n^2} - \frac{1}{e_n^3}. \quad (10)$$

After shortening the relationship (10) and substituting it with the formulas below:

$$e_M = \frac{M_{\max}}{M_N},\ e_N = \frac{n_N}{n_M}, \quad (11)$$

the following is being obtained:

$$e_M\frac{1}{e_n} = \alpha\frac{1}{e_n} + \beta\frac{1}{e_n^2} - \frac{1}{e_n^3}/e_n. \quad (12)$$

By multiplying the sides of relationship (12) by e_n, the following is being obtained:

$$e_M = \alpha + \beta\frac{1}{e_n} - \frac{1}{e_n^2}. \quad (13)$$

By entering relationships (7) and (13) into a set of equations where α and β are unknowns, the following is being obtained:

$$\begin{cases} \alpha + \beta = 2, \\ e_M = \alpha + \beta\frac{1}{e_n} - \frac{1}{e_n^2}, \end{cases} \quad (14)$$

which is modified to the following form:

$$\begin{cases} \alpha = 2 - \beta, \\ \beta = \frac{e_n^2\left(e_M - 2\right) + 1}{e_n - e_n^2}. \end{cases} \quad (15)$$

In order to solve this set of equations, the values of torque flexibility factor and speed range coefficient need to be known for currently operated engines.

4. Test results

As a result of the tests conducted on the test bed at the Department of Motor Vehicles Operation (DMVO), Western Pomeranian University of Technology in Szczecin, the following data were obtained being presented in Tab. 1.

Tab. 1. Comparison of benchmark and simulation engine operation parameters

Item	Engine speed [min^{-1}]	Leidemann's formulas α=0.996; β=1.004		KEPS		Difference ΔN [%]	Difference ΔM [%]
		M_{x1} [Nm]	N_{x1} [kW]	M_{omax} [Nm]	N_e [kW]		
1	1000	145.0	15.2	73.2	7.7	96.1	98.0
2	1200	147.7	18.6	87.0	11.0	68.2	69.8
3	1400	149.8	22.0	107.1	15.7	39.5	39.9
4	1600	151.3	25.3	141.0	23.6	6.8	7.3
5	1800	152.2	28.7	142.5	26.9	6.3	6.8
6	2000	152.5	31.9	142.5	29.9	6.4	7.0
7	2200	152.2	35.0	138.1	31.8	9.7	10.2
8	2400	151.2	38.0	137.4	34.6	9.5	10.0
9	2600	149.7	40.7	137.7	37.5	8.3	8.7
10	2800	147.5	43.2	137.4	40.3	7.2	7.4
11	3000	144.8	45.5	134.9	42.4	7.0	7.3
12	3200	141.4	47.4	133.2	44.7	5.8	6.2
13	3400	137.4	48.9	127.9	45.5	7.5	7.4
14	3600	132.8	50.0	123.0	46.4	7.8	8.0
15	3800	127.6	50.8	118.9	47.3	7.2	7.3
16	4000	121.8	51.0	114.2	47.8	6.7	6.6
17	4200	115.4	50.7	108.3	47.6	6.5	6.6
18	4400	108.4	49.9	101.2	46.7	7.0	7.1

The FIAT 1.3 JTD MultiJet engine testing also allowed the e_M and e_n values to be obtained, through which the values of coefficients α and β – which would best fit the simulation characteristics to the real one, in that case being obtained on the DMVO engine test bench – can be similarly corrected. By substituting the data from the table above into formula (11), the following results were obtained:

$$e_M = 1.25,$$

$$e_n = 2.$$

Next, after substituting them into the set of equations (15), the new form of coefficients is being obtained:

$$\alpha = 0.996,$$

$$\beta = 1.004.$$

Therefore, Leidemann's formulas, together with new coefficients, will be as follows:

$$N_x = N_{max}\left(0.996\frac{n_X}{n_n} + 1.004\frac{{n_X}^2}{{n_N}^2} - \frac{{n_X}^3}{{n_N}^3}\right)[\text{kW}], \quad (16)$$

$$M_{ox} = 9554.14\frac{N_X}{n_X}[\text{N}\cdot\text{m}]. \quad (17)$$

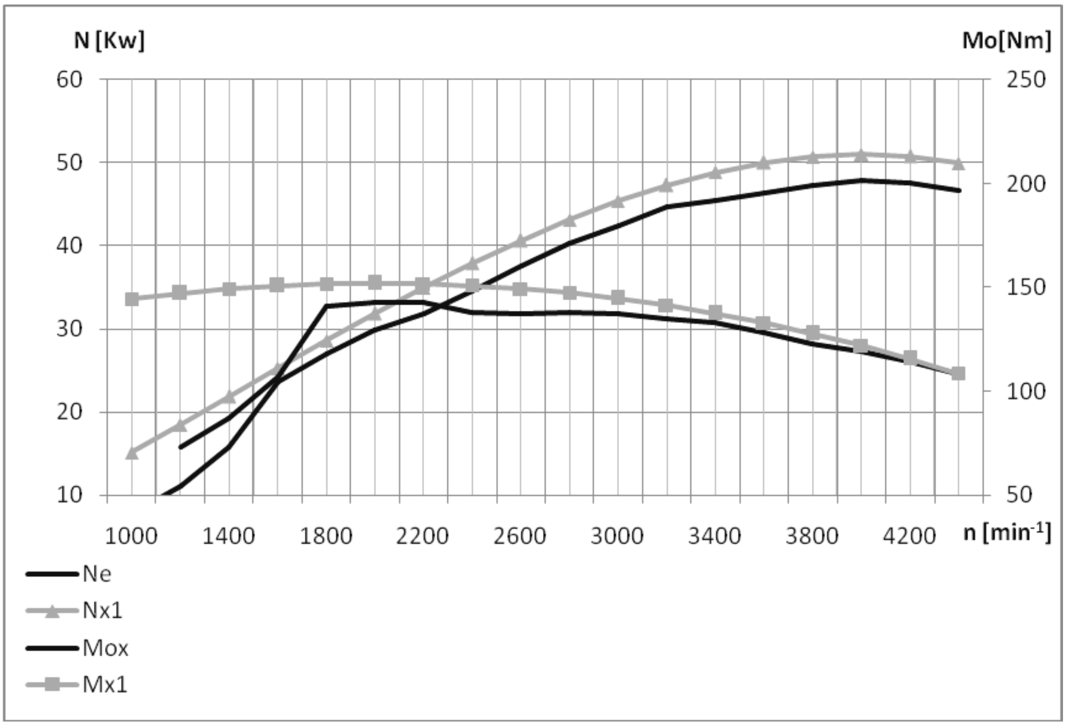

Fig. 2. Comparison of the DMVO and simulation characteristics for new coefficients α and β

The power and torque curves with new coefficients α and β differ little from those that use the coefficients obtained by the authors [3]. Nevertheless, there is a difference in favour of the curves where coefficients á and â were obtained on the basis of DMVO test results. The simulation characteristics made on the ground of these coefficients is closer to the DMVO characteristics than that being made with coefficients from literature. It is obvious because the coefficients being obtained by the authors [3] are the mean value so that they correspond to broad range of engines as possible whereas new coefficients are based on the parameters of tested FIAT 1.3 JTD MutliJet engine only. Thereby, new values of the coefficients in Leidemann's formulas seem to be more suitable for making the simulation characteristics for this engine.

5. Conclusions

As a routine, the external characteristics of engine are made during tests on engine test bench. A labour-intensive procedure requires the engine positioned on a test bed and then to be connected to a test installation and the strictly specified number of measurements to be made to obtain reliable data. In the age of computer technology, it seems appropriate to use simulation to shorten and simplify these procedures. Leidemann's formulas may be used for that, allowing the course of external characteristics to be roughly determined, i.e. relationships N_e, M_o, g_e as f (n).
Knowledge of the main engine operation parameters only, i.e. M_{omax}, n_{Momax}, M_N and n_N, being usually specified in engine technical specifications, allows the approximate course of engine torque and power to be determined on the basis of Leidemann's formulas.

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