

Modeling of power and torque curves of a diesel at the design stage

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Abstract. An external speed characteristics outlines the upper limit of the field of possible operating conditions of the engine. With its help, therefore, it is possible to judge the extreme values of the indicators and parameters of the engine when it is running at a specific speed of the crankshaft. It is at the external speed characteristics of the engine parts are subjected to the greatest mechanical and thermal loads, the maximum is also the smoke of the exhaust gases of diesel engines. This indicates the particular importance of techniques that allow to determine the performance of the engine in the modes of external speed characteristics. Get external speed characteristics when testing the engine on the test bench. However, this possibility is not always available, especially it is not at the design stage. When calculating the cycle, the engine performance is obtained in two modes – rated power and maximum torque. Therefore, the external speed characteristics, built by calculation is important at the stage of justification of the main indicators and parameters of the designed engine.

1 Establishing the problem statement

Curves of the external speed characteristics (ESC) shows the limit of the field of possible operating conditions of the engine. With its help, therefore, it is possible to define engine operation parameters when it is running at a certain rotational frequency of the crankshaft. It is at the external speed characteristics of the engine parts are subjected to the greatest mechanical and thermal loads, the maximum is also the smoke of the exhaust gases of diesel engines [1-4]. These points to the particular importance of techniques that allow to determine the performance of the engine in the ESC modes. Get ESC when testing the engine on the test bench. However, this possibility is not always available, especially it is not at the stage of design. When calculating the cycle, the engine parameters are obtained in two modes – nominal power and maximum torque. Therefore, the ESC, built by calculation

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is important at the stage of definition of the main indicators and parameters of the designed engine.

The procedure of calculating the effective engine torque T_{iq} (or mean effective pressure p_{me}) and fuel consumption rate B , i.e., the parameters more closely connected with in-cylinder processes, is as follows. Effective power P_e and effective specific fuel consumption rate b at various engine speeds n , etc. can be determined by using the well-known formula [2]:

$$P_e = (1/3) \cdot 10^{-4} \pi T_{iq} n; \quad (1)$$

$$b = 1000B/P_e. \quad (2)$$

For the sake of generality and applicability of the computational procedure to the ESC parameters of engines with diverse power and speed, it is worth to use the dimensionless dependencies:

For engine speed n_x :

$$\xi_n = (n_x - n_{T_{iq\max}}) / (n_{nom} - n_{T_{iq\max}}); \quad (3)$$

For effective engine torque T_{iqx} :

$$\eta_{T_{iq}} = (T_{iqx} - T_{T_{iq\max}}) / (T_{T_{iq\max}} - T_{T_{iqnom}}); \quad (4)$$

For fuel consumption rate B_x :

$$\eta_B = (B_x - B_{T_{iq\max}}) / (B_{nom} - B_{T_{iq\max}}); \quad (5)$$

For effective power P_{ex} :

$$\eta_{P_e} = (P_{ex} - P_{eT_{iq\max}}) / (P_{enom} - P_{eT_{iq\max}}); \quad (6)$$

For specific fuel consumption rate b_x :

$$\eta_b = (b_x - b_{T_{iq\max}}) / (0,5b_{nom}). \quad (7)$$

Here, T_{iq} and $T_{iq\max}$ are the current and maximum values of effective engine torque, respectively, and T_{iqnom} is the effective engine torque in the operating mode with nominal power. Indices $T_{iq\max}$ and nom labeling dimensionless parameters ξ_n , and η_B , η_{P_e} , η_b mean that the values n , B , P_e and b are taken in the operating modes with maximum engine torque $T_{iq\max}$ and nominal, respectively, whereas in the absence of indices, these parameters denote the current values. Transformation of independent variables n , T_{iq} , B , P_e , b to dimensionless variables ξ_n , $\eta_{T_{iq}}$, η_B , η_{P_e} , η_b is made by using equations. (3) to (5).

The new axes of coordinates are parallel to the old ones (with actual values of ESC parameters), while the origin of coordinates is set to the intersection of straight line $n_{T_{iq\max}} = const$ (in the old sets of coordinates) with the curves of the corresponding ESC parameters. Figure 1 shows the ESC for the diesel with a regulator curve.

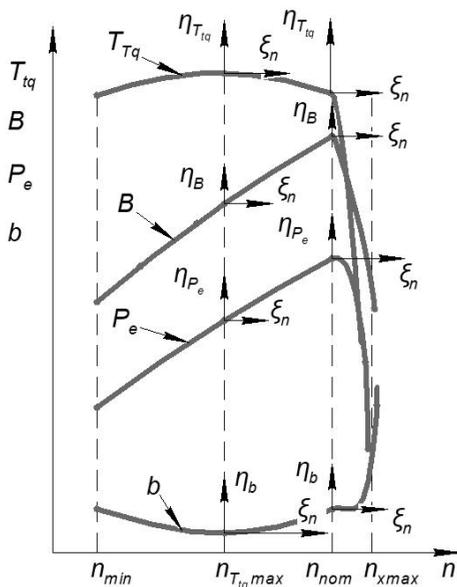


Fig. 1. Systems of dimension and dimensionless coordinates for ESC.

2 Analysis of achievements and publications

In the work [1] the method of tuning the fuel supply control during the diesel refinement using the model of ESC, which allowed to carry out the target formation of indicators of external high-speed characteristics, is given. This once again showed the importance of developing a model for the construction of ESC.

Also, this problem is considered in work [5,6], which is devoted to modeling the pollution of exhaust gases of internal combustion engines depending on the temperature inside the engine cylinder.

3 The purpose of the study

Power and torque curves on the external speed characteristic (ESC) simulate engine operation on the transportation vehicle during its motion under conditions of variable road resistance but only at a fixed and marginal position of the fuel supply actuator. So, the purpose of the study is to develop methods for modeling the ESC of the piston engine at all modes of operating at the design stage.

4 Research methods

For the ESC parameters, the dimensionless axes of coordinates $\xi_n - \eta_{T_{tq}}$, $\xi_n - \eta_{P_e}$, $\xi_n - \eta_B$ and $\xi_n - \eta_b$ are used. For the regulator curve, transformation to dimensionless coordinates is made relative to the set of coordinates with the origin located at line $n_H = const$ according to the formulae:

for engine speed n_x :

$$\xi_n = (n_x - n_{nom}) / n_{nom} ; \tag{8}$$

for effective engine torque T_{iqx} :

$$\eta_{T_{iq}} = (T_{iqx} - T_{iqnom}) / T_{iqnom}; \tag{9}$$

for fuel consumption rate B_x :

$$\eta_B = (B_x - B_{T_{iqnom}}) / B_{nom}. \tag{10}$$

If parameters P_e and b are modeled, then the values of T_{iq} and B are determined by using equations (1) and (2).

The calculations indicate that the use of dimensionless parameters in coordinates $\xi_n - \eta_{T_{iq}}$, $\xi_n - \eta_B$ and $\xi_n - \eta_b$ allows one to obtain the common relative ESC for diesels, gasoline engines, and turbocharged diesels [4-10].

Figure 2 shows the curves for effective engine torques $\eta_{T_{iq}} = f(\xi_n)$ and fuel consumption rates $\eta_B = f(\xi_n)$ for 20 two-cylinder and three-cylinder Ruggerini diesels of models MD, RD, and RF.

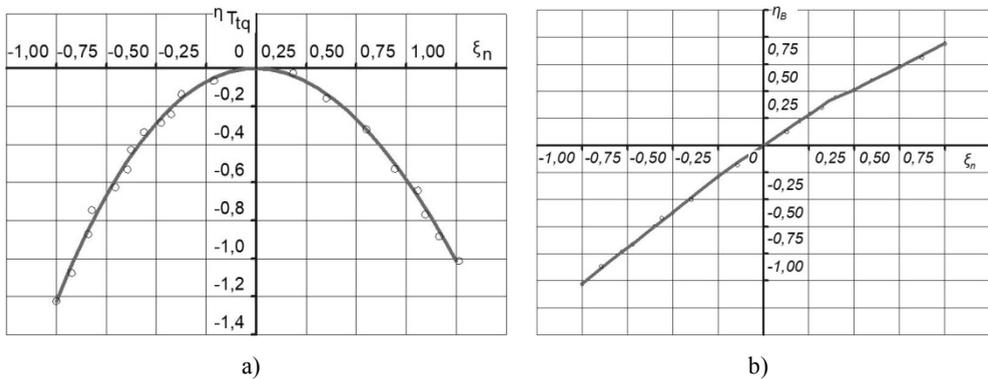


Fig. 2. Dependencies of effective engine torque $T_{iq} = f1(n)$ (a) and fuel consumption rate $B = f2(n)$ (b) on the engine speed n in dimensionless coordinates for 20 low-capacity diesels and their averaged (generalized) fits.

As seen from Fig. 2, the discrepancy of the data is insignificant which makes it possible to plot the average curves $\eta_{T_{iq}} = f(\xi_n)$ and $\eta_B = f(\xi_n)$ and approximate them as:

$$\eta_{T_{iq}} = 0,0911\xi_n^3 - 1,0775\xi_n^2 - 0,0272\xi_n + 0,0136; \tag{11}$$

or

$$\eta_{T_{iq}} = -2 \cdot 10^{-13} \xi_n^4 + 0,0911\xi_n^3 - 1,0775\xi_n^2 - 0,0272\xi_n + 0,0136; \tag{12}$$

$$\eta_B = -0,1923\xi_n^2 + 1,185\xi_n + 0,004; \tag{13}$$

or

$$\eta_B = 1 \cdot 10^{-14} \xi_n^3 - 0,1923\xi_n^2 + 1,185\xi_n + 0,004. \tag{14}$$

The analytical dependencies of equations (11) to (14) allow one to plot the common [1] or generalized ESC for low-capacity diesels (LCD) (without turbocharging), as well as to model the ESC at the design stage. Figure 3 shows $\xi_n - \eta_{T_{iq}}$, $\xi_n - \eta_{P_e}$ and $\xi_n - \eta_B$ plots in dimensionless coordinates.

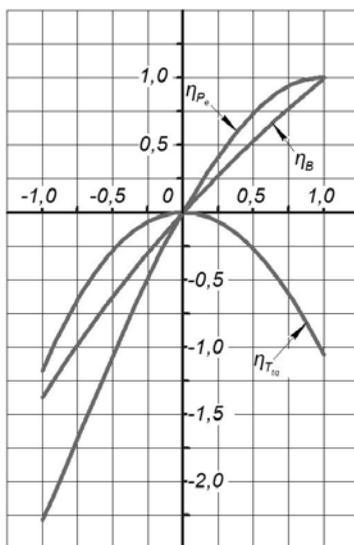


Fig. 3. Uniform ESC in dimensionless coordinates.

With regard for equation (1), the following approximating polynomials have been obtained for power P_e :

$$\eta_{P_e} = -0,614\xi_n^2 + 1,678\xi_n - 0,0022; \tag{15}$$

or

$$\eta_{P_e} = -0,1981\xi_n^3 - 0,614\xi_n^2 + 1,8111\xi_n - 0,0022. \tag{16}$$

5 Results of the study, discussion and inferences

At the design stage, after calculating the engine operating cycles in two modes, nominal and with maximum engine torque, the values of P_e , T_{iq} , B and b are determined first. This allows one to determine the current values of dimensionless ESC parameters $\eta_{T_{iq}}$, η_{P_e} , η_B , η_b of the engine being designed by using equations (4) to (7). Dividing the range from n_{min} to $n_{T_{iq}max}$, as well as that from $n_{T_{iq}max}$ to n_n by several intervals (Table 1), one can calculate the value of ξ_n (column 6) by equations (3). For 4 Ch8,8/8,5 diesel, $n_{min} = 1600$; $n_{T_{iq}max} = 2000 \text{ min}^{-1}$; $n_{nom} = 3000 \text{ min}^{-1}$; $T_{iqmax} = 128,9 \text{ N}\cdot\text{m}$; $T_{iqnom} = 112,3 \text{ N}\cdot\text{m}$; $B_{T_{iq}max} = 7,2 \text{ kg/h}$; $B_{T_{iqnom}} = 9,9 \text{ kg/h}$. From equations (4) and (5):

$$\eta_{T_{iq}} = (T_{iqx} - 128,9)/(128,9 - 112,3); \tag{17}$$

$$\eta_B = (B_x - 7,2)/(9,9 - 7,2). \tag{18}$$

As an example, consider 4Ch8,8/8,5 Lombardini diesel (LDW 2004 CHD) [11-12]. Experimentally obtained ESC parameters for this diesel are presented in the Table 1 below (columns 1 to 5).

Table 1. ESC parameters of 4Ch8,8/8,5 diesel (LDW 2004 CHD).

Experimental parameters						Calculated parameters			
n, min^{-1}	P_e, kW	T_{iq}, Nm	$B, \text{kg/h}$	$b, \frac{\text{g}}{\text{kWh}}$	ξ_n	P_e, kW	$T_{iq}, \text{N}\cdot\text{m}$	$B, \text{kg/h}$	$b, \frac{\text{g}}{\text{kWh}}$
1	2	3	4	5	6	7	8	9	10
1600	21,15	126,2	5,9	280	-0,4	21,18	126,3	5,8	278
1700	22,72	127,6	6,2	276	-0,3	22,72	127,6	6,2	274
1800	24,20	128,3	6,6	273	-0,2	24,22	128,5	6,5	272
1900	25,60	128,6	6,9	270	-0,1	25,67	129,0	6,9	270
2000	27,00	128,9	7,2	268	0,0	27,05	129,1	7,2	268
2100	28,30	128,7	7,5	266	0,1	28,35	128,9	7,5	266
2200	29,60	128,4	7,8	265	0,2	29,57	128,3	7,8	265
2300	30,80	127,8	8,1	265	0,3	30,70	127,4	8,1	264
2400	31,80	126,5	8,4	265	0,4	31,72	126,2	8,4	265
2500	32,72	124,9	8,6	265	0,5	32,64	124,6	8,7	265
2600	33,60	123,4	8,9	266	0,6	33,44	122,8	8,9	266
2700	34,33	121,4	9,2	268	0,7	34,11	120,6	9,2	268
2800	34,80	118,6	9,4	270	0,8	34,65	118,1	9,4	271
2900	35,10	115,5	9,6	274	0,9	35,06	115,4	9,6	275
3000	35,30	112,3	9,9	280	1,0	35,32	112,4	9,9	280

Now, substituting equation (17) in the left-hand-side of equation (11) and using the numerical values of ξ_n from column 6 of the table one arrives at the results of the calculation, $T_{iq} = f_1(n)$, presented in column 8 of the table. To calculate P_e , equation (1) is used (column 7).

Similarly, the substitution of equation (18) in the left-hand-side of equation (13) and the use of ξ_n from column 6 of the table will give the values of $B = f_2(n)$ presented in column 9. The specific fuel consumption rate b can be obtained using equation (2).

A good agreement between calculated and measured data allows one to recommend this methodology for modeling the ESC at the design stage of LCD.

The proposed method of modeling the external speed characteristics allows to evaluate the capabilities of the newly designed engine, and, in addition, allows you to pre-form a rational external characteristic of the engine for a particular purpose. This will eliminate the dips in the torque curve on the ESC.

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