CZASOPISMO TECHNICZNE
WYDAWNICTWO POLITECHNIKI KRAKOWSKIEJ
z. 6-M/2004 (ROK 101) ISSN 0011-4561

A. N. GOTZ, S. M. FROLOV*

MODELING OF EXTERNAL SPEED PERFORMANCE OF DIESEL AT DESIGN STAGE

1. INTRODUCTION

Modes of external speed performance (ESP) simulate engine operation on the transportation vehicle during its motion under conditions of variable road resistance but at a fixed and marginal position of the fuel supply actuator. Most often, all ESP modes occur at vehicle acceleration at full throttle (in gasoline engines) or at marginal position of the main controller string (diesels). The ESP is the upper bound of the engine operation map and is specific for nearly each engine. However for the given engine type (or model) the deviations of performance parameters in ESP operating modes are insignificant. Therefore to obtain the ESP some mean parameters are used since the ESP is the important information source for determining actual loads on engine elements. This latter issue is the reason that there are continuous attempts to develop a computational methodology aimed at obtaining the ESP which would be as close to the experimental ESP as possible. Reported in [1], is the procedure of plotting the effective power curve in engine ESP operating modes, adopting its value at nominal engine speed to be 100%. In other words, the basis for obtaining the N_e curve is the nominal operating mode. Although this procedure is referred to as the common relative ESP for four- and two-stroke engines, it does not deal with ESP parameters. In [2, 3], empirical relationships in the form of polynomials are reported which allow one to perform calculations and to plot the ESP. As noticed in [2], these relationships are rather approximate and require corrections. In [4], diesels with a single-cylinder volume $V_S \leq 0{,}5$ dm^3 are referred to as the Low-Capacity Diesels (LCD). We will follow this definition below.

2. MODELING OF ESP PARAMETERS

The procedure of calculating the effective engine torque T_{tq} (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 formulae:

*A. N. Gotz, S. M. Frolov, Institute of Chemical Physics, Vladimir State University, N.N. Semenov, Russia.

$$P_e = \pi T_{tq} n / 3 \cdot 10^4 \qquad (1)$$

$$b = 1000B/P_e \qquad (2)$$

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

- For engine speed n:

$$\xi_n = (n - n_{T_{tq\max}})/(n_n - n_{T_{tq\max}}) \qquad (3)$$

- For effective engine torque T_{tq}:

$$\eta_{T_{tq}} = (T_{tq} - T_{tq\max})/(T_{tq\max} - T_{tqn}) \qquad (4)$$

- For fuel consumption rate B:

$$\eta_B = (B - B_{T_{tq\max}})/(B_H - B_{T_{tq\max}}) \qquad (5)$$

- For effective power P_e:

$$\eta_{P_e} = (P_e - P_{eT_{tq\max}})/(P_{eH} - P_{eT_{tq\max}}) \qquad (6)$$

- For specific fuel consumption rate b:

$$\eta_b = (b - b_{T_{tq\max}})/(0{,}5b_n) \qquad (7)$$

Here, T_{tq} and $T_{tq\max}$ are the current and maximum values of effective engine torque, respectively, and T_{tqH} is the effective engine torque in the operating mode with nominal power. Indices $T_{tq\max}$ and H 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 $T_{tq\max}$ and nominal, respectively, whereas in the absence of indices, these parameters denote the current values. Transformation of independent variables n, T_{tq}, B, P_e, b to dimensionless variables ξ_n, $\eta_{T_{tq}}$, η_B, η_{P_e}, η_b is made by using Eqs. (3) to (5). The new axes of coordinates are parallel to the old ones (with actual values of ESP parameters), while the origin of coordinates is set to the intersection of straight line $n_{T_{tq\max}}$ = const (in the old sets of coordinates) with the curves of the corresponding

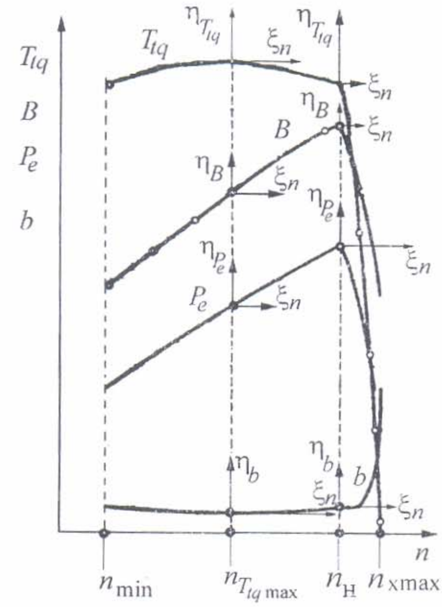

Fig. 1. Systems of dimension and dimensionless coordinates for ESP

ESP parameters. Figure 1 shows the ESP for the diesel with a regulator branch. For the ESP parameters, the dimensionless axes of coordinates ξ_n c $\eta_{T_{tq}}$, ξ_n c η_{P_e}, ξ_n c η_B and ξ_n c η_b are used. For the regulator branch, transformation to dimensionless coordinates is made relative to the set of coordinates with the origin located at line $n_{\text{н}}$ » const according to the formulae:

c For engine speed n:

$$\xi_n \text{ » } \bar{\ } n \text{ c } n_{\text{н}} \tilde{\ } / n_{\text{н}} ; \tag{8}$$

c For effective engine torque T_{tq}:

$$\eta_{T_{tq}} \text{ » } (T_{tq} \text{ c } T_{tq\text{н}}) / T_{tq\text{н}} ; \tag{9}$$

c for fuel consumption rate B:

$$\eta_B \text{ » } (B \text{ c } B_{T_{tq\text{н}}}) / B_{\text{н}} . \tag{10}$$

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

The calculations indicate that the use of dimensionless parameters in coordinates ξ_n c $\eta_{T_{tq}}$, ξ_n c η_B and ξ_n c η_b allows one to obtain the common relative ESPs for diesels, gasoline engines, and turbocharged diesels [5, 6].

Figure 2 shows the curves for effective engine torques $\eta_{T_{tq}}$ » $f\bar{\ }\xi_n\tilde{\ }$ and fuel consumption rates η_B » $f\bar{\ }\xi_n\tilde{\ }$ for 20 two-cylinder and three-cylinder Ruggerini diesels of models MD, RD, and RF. As seen from Fig. 2, the discrepancy of the data is insignificant which makes it possible to plot the average curves $\eta_{T_{tq}}$ » $f\bar{\ }\xi_n\tilde{\ }$ and η_B » $f\bar{\ }\xi_n\tilde{\ }$ and approximate them as:

$$\eta_{T_{tq}} \text{ » } 0{,}0911\xi_n^3 \text{ c } 1{,}0775\xi_n^2 \text{ c } 0{,}0272\xi_n \text{ ı } 0{,}0136; \tag{11}$$

or

$$\eta_{T_{tq}} \text{ » c} 2 \cdot 10^{\text{c}13}\xi_n^4 \text{ ı } 0{,}0911\xi_n^3 \text{ c } 1{,}0775\xi_n^2 \text{ c } 0{,}0272\xi_n \text{ ı } 0{,}0136 ; \tag{12}$$

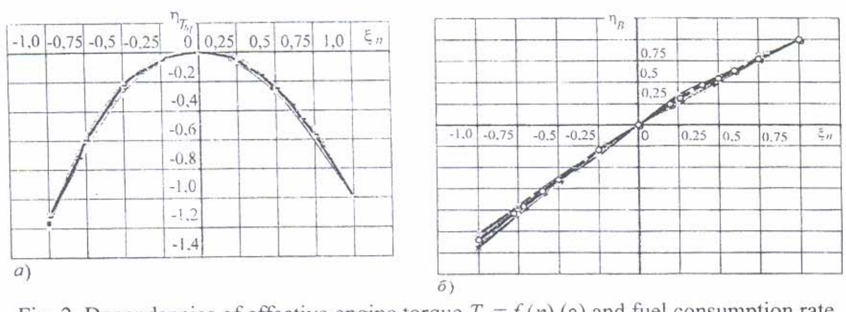

Fig. 2. Dependencies of effective engine torque $T_{tq}=f_1(n)$ (a) and fuel consumption rate $B=f_2(n)$ (b) on the engine speed n in dimensionless coordinates for 20 low-capacity diesels and their averaged (generalized) fits

$$\eta_B \approx -0{,}1923\xi_n^2 + 1{,}185\xi_n + 0{,}004; \qquad (13)$$

or

$$\eta_B \approx 1\cdot 10^{-14}\xi_n^3 - 0{,}1923\xi_n^2 + 1{,}185\xi_n + 0{,}004. \qquad (14)$$

The analytical dependencies of Eqs. (11) to (14) allow one to plot the common [1] or generalized ESP for LCD (without turbocharging), as well as to model the ESP at the design stage. Figure 3 shows $\xi_n - \eta_{T_{tq}}$, $\xi_n - \eta_{P_e}$ and $\xi_n - \eta_B$ plots in dimensionless coordinates. With regard for Eq. (1), the following approximating polynomials have been obtained for power P_e:

$$\eta_{P_e} \approx -0{,}614\xi_n^2 + 1{,}678\xi_n - 0{,}0022; \qquad (15)$$

or

$$\eta_{P_e} \approx -0{,}1981\xi_n^3 - 0{,}614\xi_n^2 + 1{,}8111\xi_n - 0{,}0022. \qquad (16)$$

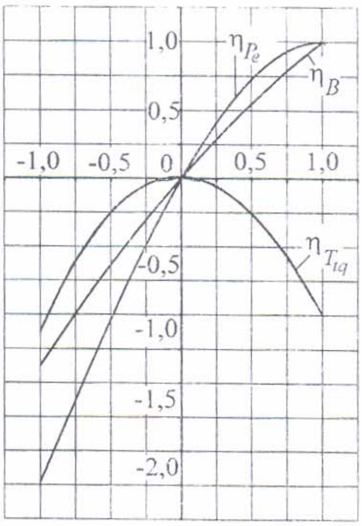

Fig. 3. Uniform ESP in dimensionless coordinates

As an example, consider 4Ч8,8/8,5 Lombardini diesel (*LDW* 2004 *CHD*) [7]. Experimentally obtained ESP parameters for this diesel are presented in the table 1 below (columns 1 to 5).

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_{tq}, B and b are determined first. This allows one to determine the current values of dimensionless ESP parameters $\eta_{T_{tq}}$, η_{P_e}, η_B, η_b of the engine being designed by using Eqs. (4) to (7). Dividing the range from $n_{\min}$ to $n_{T_{tq}\max}$, as well as that from $n_{T_{tq}\max}$ to n_n by several intervals (see the table 1), one can calculate the value of ξ_n (column 6) by Eq. (3). For 4Ч8,8/8,5 diesel, $n_{\min}$ = 1600; $n_{T_{tq}\max}$ = 2000 min^{-1}; n_n = 3000 min^{-1}; $T_{tq\max}$ = 128,9 N·m; $T_{tq\text{н}}$ = 112.3 N·m; $B_{T_{tq}\max}$ = 7,2 kg/h; $B_{T_{tq\text{н}}}$ = 9,9 kg/h. From Eqs. (4) and (5):

$$\eta_{T_{tq}} \approx (T_{tq} - 128{,}9)/(128{,}9 - 112{,}3) \qquad (17)$$

$$\eta_B \approx (B - 7{,}2)/(9{,}9 - 7{,}2) \qquad (18)$$

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

Table 1

ESP parameters of 4Ч8,8/8,5 diesel (LDW 2004 CHD)

Experimental parameters						Calculated parameters			
n [min^{-1}]	P_e [kW]	T_{tq} [N·m]	B [kg/h]	b [illegible]	ξ_n	P_e [kW]	T_{tq} [N·m]	B [kg/h]	b [illegible]
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

Similarly, the substitution of Eq. (18) in the left-hand-side of Eq. (13) and the use of ξ_n from column 6 of the table 1 will give the values of $B_n\ f_2(n)$ presented in column 9. The specific fuel consumption rate b can be obtained using Eq. (2).

3. CONCLUSION

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

Supported by Grant No. TO2-13.0-1014 of the Ministry of Education of Russian Federation and Federal Program "Integration".

REFERENCES

[1] Lenin I. M., Kostrov A. V., Malashkin O. M., et al., *Automotive and Tractor Engines.* Part 1. *Theory of Engines and Fuel Supply Systems for Them,* Ed. By I. M. Lenin, High School Publ., Moscow 1976.

[2] Kolchin A. I., Demidov V. P., *Calculation of Automotive and Tractor Engines,* High School Publ., Moscow 2002.

[3] Diachenko N. Kh., Dashkov S. N., Musatov V. S., et al., *High-speed Piston Internal Combustion Engines,* Mashgiz, Moscow 1962.

[4] Gotz A. N., Mokeeva V. N., Efros V. V., *Design parameters and specific features of diesels for the means of small mechanization,* Dvigatelestroenie, 1990, No. 12, p. 35-38.

[5] Gotz A. N., Gavrilov A. A., *Modeling of external speed performances at the design stage,* Tractors and Agricaltural Machinnes, 2003, No.8, p. 31-36.

[6] Gotz A. N., Gavrilov A. N., Gorbunov P.V., *Generalized external speed performance of gasoline engine,* Modern Problems of Improving of Piston Engines, Proceedings of the 9th International Conference, Vladimir State University, Vladimir 2003, p. 135-137.

[7] Arlotti A., *The new Lombardini CHD watercooled diesel engine series*, Motor Sympo '88, High Tatras–Strbske Pleso, 1988.

Abstract

New approaches to model external full-load curve Diesel performance at predesign stage applying dimensionless indices have been developed. The model is based on performances of realistic prototype engines with like design. For obtaining engine parameters as functions of the crank rotation speed it is sufficient to consider the engine cycle at two operational modes with maximal and nominal torque.

MODELOWANIE ZEWNĘTRZNEJ PRĘDKOŚCIOWEJ CHARAKTERYSTYKI SILNIKA DIESEL NA ETAPIE PROJEKTOWANIA

Streszczenie

W pracy zostało przedstawione nowe podejście do modelowania zewnętrznej krzywej osiągów dla pełnego obciążenia Diesla na etapie przedprojektowym przy zastosowaniu bezwymiarowych wskaźników. Model określano na podstawie osiągów rzeczywistych silników prototypowych podobnych do projektowanych. Dla otrzymania parametrów silnika w funkcji obrotów wału korbowego istotne jest rozważanie cyklu pracy dla dwu rodzajów działania z maksymalnym i nominalnym momentem.