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MODEL FOR CALCULATION OF CHARACTERISTIC PARAMETERS FOR THE MARINE MOTORS

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ABSTRACT
Intensive development of Internal Combustion engines - motors has important helping tool, and that is mathematical modeling and specific calculation of parameters in the motor that are difficult to measure. With mathematical modeling of thermodynamic processes can be predicted the processes during the heavy and small design changes without creation of expensive real motor (with high number of variations). In this workshop is developed zero-dimensional model, which will describe with high accuracy processes that occurs in multi-cylindrical diesel motor with blow-out. The aim of this workshop is to introduce the mathematical model and present the calculated results in an example of diesel motor with blow-out. Calculated results are compared with experimental data for marine motor ***Cummins,*** *type* ***N14-M****, presented in form of the speed of the power characteristic, rotating momentum and specific fuel consumption. Also, the results of the simulation will be shown for the temperature and pressure in cylinder for number of rotations* $n = 1200\ min^{-1}$ *and* $n = 1800\ min^{-1}$*, in function of rotating angle of the motor's shaft.*
Keywords: reciprocator, simulation, modeling, manifold, etc.

1. INTRODUCTION

Work processes that develop in the motor (engine) are complex. For their calculation are used several methods, one of them is quasi steady-state method. This method takes in consideration processes that occur in the reciprocator cylinder, valves, intake and exhaust manifold. The condition of gases (pressure and temperature) inside the manifold in the specific time is constant. Mathematical model developed is based on the above mentioned model. By using this model we can observe the influential of following parameters: injection angle, intercooler efficiency, turbocharger characteristics, etc, which directly influence the energetic parameters of the motor.

2. BASIC ASSUMPTION AND EQUATION USED FOR MATEMATIC MODELING

For modeling simplification, the motor (engine) used is divided into: reciprocator engine (cylinder, Figure 1) and its components (support elements, Figure 1). In general, this motor is an open thermodynamic system. It is also known as system with variable mass and contents of gases. With the help of the model of reciprocator, engine parameters can be calculated in one master cylinder of a multi-cylinder engine, while the manifolds and other components of the model are not separated during the suitable model of the multi cylinder engine. Interaction between the master cylinder and other components is calculated within manifolds. Effects of other cylinders depends on the appropriate phase angle

Based on the laws for ideal gas, conservation of mass and first law of thermodynamics for open system are:

$$p = R \cdot \rho \cdot T \,, \qquad \dot{m} = \sum_j \dot{m}_j \quad \text{and}$$

$$\dot{E} = \sum_j m_j h_j - Q_w - \dot{W} \; ... \qquad (1)$$

Equations for pressure and temperature variability in the cylinder:

$$\dot{p} = \frac{\rho}{\partial\rho / \partial p} \cdot \left(-\frac{\dot{V}}{V} - \frac{1}{\rho}\frac{\partial\rho}{\partial T} \cdot - \frac{1}{\rho} \cdot \frac{\partial\rho}{\partial\Phi} \cdot \dot{\Phi} + \frac{\dot{m}}{m} \right) (2)$$

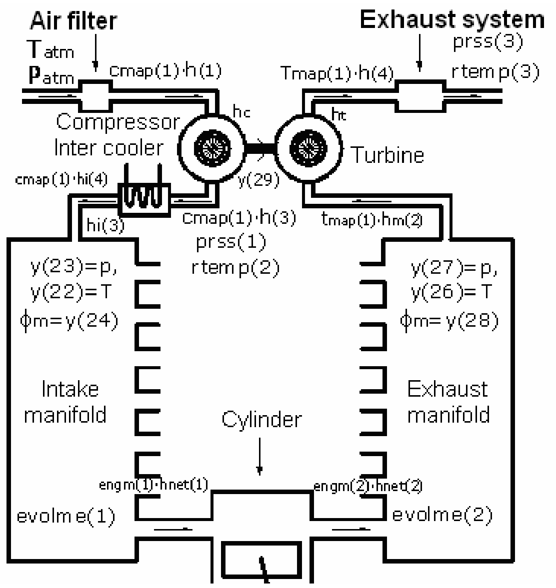

Figure 1. Model view

$$\dot{T} = \frac{B}{A} \cdot \left(\frac{\dot{m}}{m}(1 - \frac{h}{B}) - \frac{\dot{V}}{V} - \frac{C}{B} \cdot \dot{\Phi} + \frac{1}{B \cdot m}(\sum_j \dot{m}_j \cdot h_j - \dot{Q}_W) \right) ... (3)$$

Gas exchange process (intake and exhaust) is modeled with one dimensional quasi – steady flow equation:

$$\dot{m} = c_d \cdot A_{gj} \cdot \frac{p_o}{R \cdot T_o} \cdot \sqrt{\gamma \cdot R \cdot T_o} \left\{ \frac{2}{\gamma - 1} \left[(\frac{p_s}{p_o})^{\frac{2}{\gamma}} - (\frac{p_s}{p_o})^{\frac{(\gamma+1)}{\gamma}} \right] \right\}^{\frac{1}{2}} \qquad ... (4)$$

Combustion is modeled by using Watson's relations:

$$\dot{M}_t(\tau) = \beta \cdot \dot{M}_p(\tau) + (1 - \beta) \cdot \dot{m}_d(\tau) \qquad ... (5)$$

Ignition delay is calculated with equation:

$$ID = A \cdot p^{-n} \exp(E / R \cdot T) \qquad ... (6)$$

Convective heat transfer ($\dot{Q}_c$) is calculated in all engine processes while radioactive transmission (Q_r) only for the combustion process:

$$\dot{Q}_C = \alpha \cdot A \cdot (T_g - T_W) \qquad \dot{Q}_r = k_r \cdot A \cdot (T_g^4 - T_W^4) \qquad ... (7)$$

Engine losses are calculated using Millington and Hartles expression:

$$F = A_\varepsilon + 7.0 \cdot (\frac{n}{1000}) + 1.5 \cdot \left(\frac{v_m}{1000} \right)^2 \qquad ... (8)$$

Change in rotor speed according to the turbocharger dynamics ($\dot{\omega}$) is calculated based on the dynamics of the turbocharger:

$$\dot{\omega} = \left[\dot{m}_c \cdot (h_1 - h_2) + \dot{m}_t \cdot (h_8 - h_9) - B \cdot \omega^2\right] / J \cdot \omega^2 \quad \text{... (9)}$$

3. COMPARISON OF MODEL PERFORMANCE RESULTS AND MANUFACTURERS DATA

For program testing, Technical data (Table 1) and Effective Performance data (Table 2) of the engine **Cummins** type **N14-M** are taken for the comparison.

Table 1. Engine parameters

Describe of engine	Turbocharger diesel engine, intercooler, water cooling system
Bore	5.5 inch = 139 mm
Stroke	6 inch = 152 mm
Connecting road length	12 inch = 304.8 mm
Compression ratio	17 : 1
Number of cylinders	6
Engine swept volume	14.0 l
Intake manifold volume	5.5 l
Exhaust manifold volume	7.8 l
Injection timing	17 deg BTC
Intake valve opens	11 deg BTC
Intake valve closes	32 deg ABC
Exhaust valve opens	35 deg BBC
Exhaust valve closes	16 deg ATC

Table 2. Effective performance

rpm	**1800**	**1600**	**1400**	**1200**
Value	Heavy duty			
rpm	1800	1600	1400	1200
kW	358	260	182	120
g/kW-h	193	195	207	220
l/h	82.7	60.6	44.87	31.9

In Fig. 2, Fig. 3 and Fig. 4 are shown results achieved by simulation of processes which are power, rotation momentum and specific fuel consumption compared with measurements of manufacturer (full line).

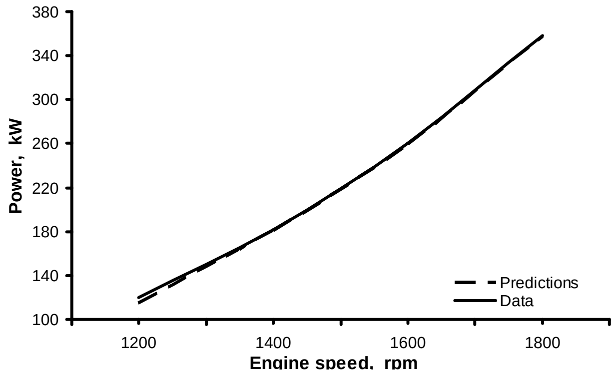

Figure 2. Power as a function of engine speed

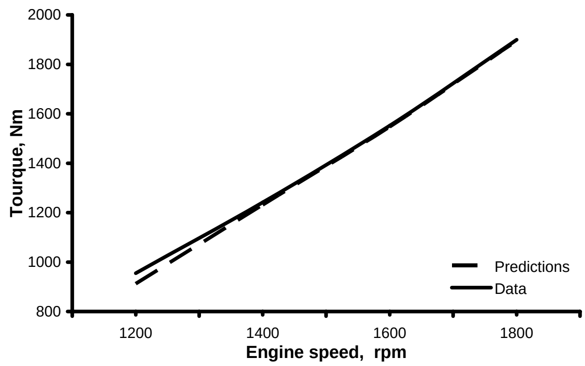

Figure 3. Torque as a function of speed

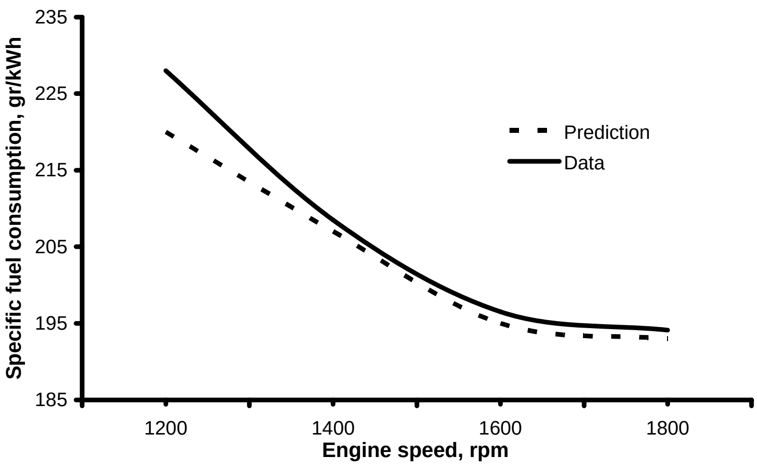

Figure 4. Specific fuel consumption as a function of engine speed

4. RESULT OF SIMULATIONS FOR PRESSURE AND TEMPERATURE IN THE CYLINDER

From the program, besides effective parameters of the engine, there can be gained other data in the function of crank shaft angle:

- Pressure, Temperature and average equivalent ratio in the cylinder,
- Pressure, Temperature and average equivalent ratio in the intake manifold,
- Pressure, Temperature and average equivalent ratio in the exhaust manifold,
- Mass flow through intake valve,
- Mass flow through exhaust valve,
- Velocity through exhaust valve, etc.

Next are shown some examples of calculation of temperature and pressure in the engine cylinder in conjunction with rotating angle of engine shaft, for two values of speed 1200 min^{-1} and 1800 min^{-1}.

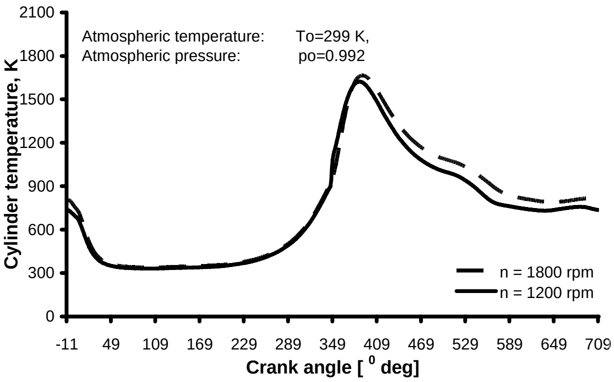

Figure 5. Cylinder pressure predicted by the simulation as a function of crank angle

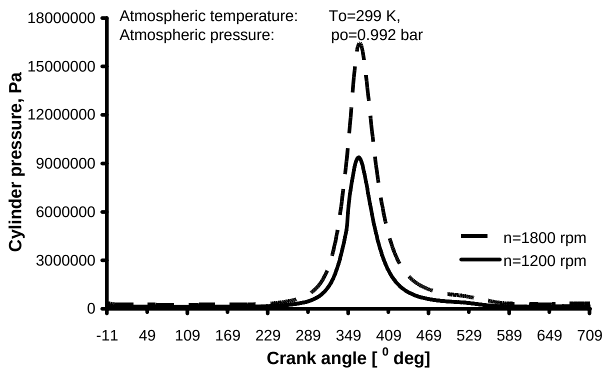

Figure 6. Cylinder temperature predicted by the simulation as a function of crank angle

5. CONCLUSIONS

The curves in the graphs for power, torque and specific fuel consumption as a function of engine speed, for constant loading are closing the experimental data. The difference between simulation and experimental results is around 1 % - for higher number of rotations and 4 % - for lower number of rotations. The causes for this disproportion in case of lower number of rotations of the engine shaft are: adopted values of empirical constants are higher (which haven't changed in dependence of number of rotations) for the heat transmission and engine losses. Results achieved from mathematical model are based in fixed value of injection angle for full range of number of rotations, but in reality, injection angle depends on rotation numbers of engine shaft.

6. REFERENCES

[1] Heywood, J.B., Internal Combustion Engine Fundamentals, McGraw-Hill Book Company, 1988,

[2] Lajqi N., Modelimi i proceseve te motorët dizel shumë cilindrik me fryrje me përdorimin e paketëve bashkohore softuerike, punim i doktoraturës, Prishtinë 2006.,

[3] Dobovišek Ž., Černej A., Mirković M., Filipović I., "Simuliranje Procesa Klipnih Motora SUS", Sarajevo, 1983,

[4] Jankov Rade., Matematičko Modeliranje Strujno-Termodinamičkih Procesa i Pogonski Karakteristika Disel-Motora, Beograd 1984.