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Development And Research of Gas Engine Multi-Communicated Model with Delay

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Abstract

This article presents the simulation model of a gas engine designed to determine the optimal tuning parameters. The modern market requires the increase of engine power and a simultaneous decrease of fuel consumption [21; 19; 8]. The third important parameter is environmental friendliness [19; 8]. Thanks to computer modeling of the internal combustion engine, these parameters can be balanced [8; 1; 28]. The article presents the mathematical model of a gas-fueled engine, as well as the computer model implemented in the MATLab environment. The simulation results were compared with the parameters of a real engine after the bench test. The object of the study was the KAMAZ 82060 gas engine with the capacity of 260 horsepower. The stand provided the version of the initial data. These are: effective power, fuel consumption per hour, temperature and pressure of the fresh charge at the inlet and the gas temperature in front of the turbine.

The simulation result showed the simulation model deviations of no more than 12%. Thus, we can conclude that the developed computer model of the KAMAZ 82060 engine is quite accurate. In other words, we can conclude that this developed model of the KAMAZ 82060 engine can be used for other studies, or for reconfiguring the engine by changing the design parameters of the selected engine in the computer model.

Keywords

Computer Model, Engine, Truck, Gas Engine

Introduction

Currently, the use of various gases as a motor fuel for vehicles and autonomous power plants becomes more and more common [21; 19; 8; 1]. This is due to both economic and environmental factors: the cost of natural gas is 2 times lower than the cost of gasoline AI-92 on average, and associated oil - 40-60% lower than the cost of natural gas; the use of gas fuel can significantly improve the environmental performance of an internal combustion engine, in particular, the content of harmful emissions in exhaust gases [1; 28; 9].

Therefore, the use of a gas engine in trucks as the main power unit is relevant and necessary.

In connection with the above arguments, the purpose of this work is to develop a computer model of a commercial vehicle gas engine. To achieve this goal, a number of tasks must be completed. First, to develop a mathematical model of a truck gas engine [18]. Secondly, to develop a computer model of a truck gas engine [20; 13; 17]. Thirdly, check the obtained simulation results during bench tests.

Methods

Let us construct a mathematical model based on the calculations of irreversible thermodynamic processes using the method by V.I. Grinevetsky - E.K. Masing [2]. It is advisable to divide the model into subsystems in the order of the engine thermodynamic processes [3; 4; 5].

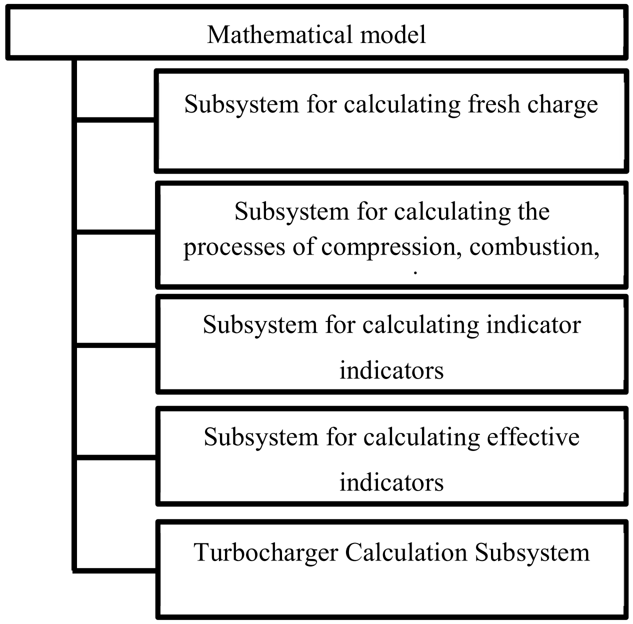

Figure 1: The Mathematical Model Scheme Based on the Calculation of Irreversible Thermodynamic Processes

The first subsystem includes the equations for calculating the fresh charge before starting the engine cylinders and it will be described according to the formulas [6; 10]:

$$\begin{cases} L_0 = \dfrac{1}{0.208}\sum\left(n + \dfrac{m}{4} - \dfrac{r}{2}\right)C_nH_mO_r\,; \\ M_1 = \alpha L_0; \\ p_a = \xi_{\text{вп}} p_k; \\ p_k = \pi_k p_0; \\ T_k = T_0\left[1.04 + \dfrac{\pi_k^{\frac{k-1}{k}} - 1}{\eta_k}\right]; \\ p_r = \xi_{\text{вып}} p_k; \\ \gamma_r = \xi_{\text{оч}} \dfrac{T_k + \Delta T}{\xi_{\text{доз}} T_r} \dfrac{p_r}{\varepsilon p_a - \xi \xi_{\text{оч}} p_r}; \\ T_a = \dfrac{1}{1+\gamma_r}\left(\dfrac{\alpha L_0 T_0 + T_{\text{газ}}}{1 + \alpha L_0} + \Delta T + \gamma_r T_r\right); \\ \eta_v = \xi_{\text{доз}} \dfrac{\varepsilon}{\varepsilon - 1}\dfrac{p_a}{p_k}\dfrac{T_k}{T_k + \Delta T}\left(1 - \dfrac{\xi p_r}{\varepsilon p_a}\right). \end{cases}$$

where L_0 – the theoretically required amount of air in moles or cubic meters for the combustion of 1 mole or 1 m^3 of fuel (moles of air / moles of fuel or m^3 of air / m^3 of fuel);

α - the excess air coefficient, taken equal to $\alpha = 1.05$, to ensure reliable ignition of the mixture from a spark when they use hydrocarbon fuel and combustion efficiency;

$\xi_{\text{вп}} = 0.8 -$ the drag coefficient of the intake system, and $p_k -$ the intake pressure;

$\pi_k -$ the degree of pressure increase during the boost equal to $\pi_k = 2.1$, $p_0 -$ atmospheric air pressure equal to $p_0 = 0.10$ MPa;

$T_0 -$ air temperature equal to $T_0 = 298K(25^0\text{C})$, $k = 1.4 -$ adiabatic index, $\eta_k = 0.71 -$ adiabatic compressor efficiency;

$\xi_{\text{вып}} = 0.9 -$ the coefficient taking into account the resistance of the exhaust tract, depending on its design and operating factors;

$T_r = 825K -$ the temperature of the residual gases Tr has a slight effect on the filling of the cylinders with a fresh charge and is taken on the basis of experimental data;

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γ_r – the coefficient of residual gases;
$\xi_{\text{оч}}$ – cleaning factor;
$\xi_{\text{доз}} = 1.1$ – dosage factor;
$\Delta T = 10$ – lowering the charge temperature in the charge air coolers;
$\xi = 1.01$ – the ratio of the heat capacity of residual gases and fresh charge;
$\varepsilon = 9$ – excess air ratio;
R - gas constant;
$9T_{\text{газ}} = 280K;$
η_v – the coefficient of filling the cylinders with fresh charge;
The second subsystem contains the equations for describing and calculating the processes of compression, combustion and expansion [10; 15]:

$$\begin{cases} p_c = p_a \varepsilon^{n_1}; \\ T_c = T_a \varepsilon^{n_1 - 1}; \\ \mu_{\text{sh.}} = \dfrac{\mu_0 + \gamma_r}{1 + \gamma_r}; \\ p_z = 0.85 p_{zp} = 0.85 \left(\mu_{\text{sh.}} \, p_c \dfrac{T_z}{T_c} \right); \\ p_b = \dfrac{p_z}{\varepsilon^{n_2}}; \\ T_b = \dfrac{T_z}{\varepsilon^{n_2 - 1}}; \end{cases}$$

, where p_{zp} – the calculated gas pressure at the end of combustion, and $T_z = 2426\text{K}$ – the temperature of the combustion products;
To calculate the indicator and effective values, the following systems of equations were drawn up:
Indicators (indicative) of the cycle [6; 22]:

$$\begin{cases} p_i = \varphi_{\text{п}} p_{ip}; \\ p_{ip} = \dfrac{p_a \varepsilon^{n_1}}{\varepsilon - 1} \left[\dfrac{\lambda}{n_2 - 1} \left(1 - \dfrac{1}{\varepsilon^{n_2 - 1}} \right) - \dfrac{1}{n_1 - 1} \left(1 - \dfrac{1}{\varepsilon^{n_1 - 1}} \right) \right]; \\ \eta_i = \dfrac{p_i R M_1 T_k}{22.4 p_k \eta_v H u}; \\ \nu_i = \dfrac{3600}{Hu \, \eta_i}; \\ q_i = \nu_i \, Hu; \\ N_i = \dfrac{p_i i V_h n}{30 \tau_{\text{д}}}. \end{cases}$$

, where p_i – specific work of the cycle;
p_{ip} – average design indicator pressure;
$\varphi_{\text{п}} = 0.94$ – the coefficient of the diagram completeness;
η_i – indicative efficiency;
$Hu = 35000 \frac{\text{кДж}}{\text{кг}}$ – the lowest heat of combustion;
ν_i – indicative gas consumption;
q_i – indicative heat consumption;
N_i – indicated power;
$\tau_{\text{д}} = 4$ – engine stroke;
$i = 8$ – number of cylinders;
n – crankshaft rotation speed (min^{-1}).
Effective cycle indicators [6; 27]:

$$\begin{cases} p_e = p_i\eta_м; \\ \eta_e = \eta_м\eta_i; \\ \nu_e = \dfrac{3600}{Hu\eta_e}; \\ q_e = \dfrac{3600}{\eta_e}; \\ N_e = \dfrac{p_e i V_h n}{30\tau_д}; \\ M_{k.e} = \dfrac{9550N_e}{n}; \\ V_t = N_e\nu_e. \end{cases}$$

where $p_e -$ the effective pressure;

$\eta_м = 0.8$ –mechanical efficiency;
η_e –effective efficiency;
$\nu_e -$ effective gas consumption;
$q_e -$ effective heat consumption;
$N_e -$ effective power;
$M_{k.e} -$ effective torque;
$V_t -$ gas consumption per hour.

To describe the operation of a turbocharger, the following system of equations has been compiled:

$$\begin{cases} G_k = \dfrac{V_t\alpha l_0}{3600}; \\ G_t = \dfrac{V_t + 0.98G_k}{3600}; \\ M_k = \dfrac{C_{p_{возд}} \times G_k(T_k - T_0)}{w_{тк}}; \\ M_T = \dfrac{c_{p_{ог}} \times G_T(T_b - T_T)}{w_{тк}}; \\ T_т = T_b\left(\dfrac{p_r}{p_b}\right)^{\frac{k-1}{k}}; \\ w_{тк} = \dfrac{1}{I_{тк}}\displaystyle\int_o^t (M_T - M_k - M_c)dt. \end{cases}$$

, where $G_k -$ the second air flow rate through the compressor;
$G_t -$ the second gas flow rate through the compressor;
$M_k -$ compressor torque;
$M_T -$ turbine torque;
$T_т -$ gas temperature in front of the turbine;
$k -$ polytrope exponent;
$w_{тк} -$ angular speed of the TKR rotor;
$M_c = 1.05 -$ the moment of resistance arising as a result of the TKR rotor rotation;
$I_{тк} -$ the moment of TKR rotor inertia.

To build a computer model of the KAMAZ 82060 engine with the capacity of 260 horsepower on the basis of the above-mentioned systems of equations for calculation of irreversible thermodynamic processes, “Simulink” program was chosen in the MatLab package.

First of all, you need to develop a TKR subsystem since it calculates the input parameters for the internal combustion engine, more precisely the temperature of the fresh charge before entering the supercharged cylinder [27; 29; 7].

After building the TCR subsystem, it is necessary to build the model in the following order: intake process, residual gas parameters model, compression process, combustion process, expansion process, indicators and the effective cycle indicators.

A computer model of a truck gas engine built using the Simulink tool from the MatLab package is shown on Figure 2:

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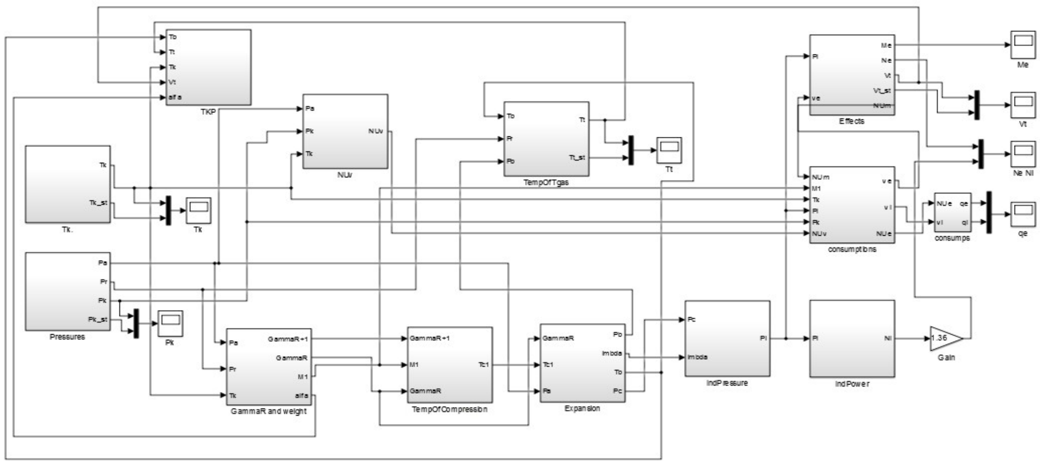

Figure 2: Computer Model of a Truck Gas Engine

The model consists of 13 subsystems, each of which calculates irreversible thermodynamic processes in accordance with the previously developed mathematical model [12; 14].

1. NUv - this system calculates the filling ratio.
2. Expansion - this subsystem calculates gas temperature and pressure, gas temperature at the end of expansion, during expansion, the working mixture pressure during compression, as well as the rate of pressure increase.
3. TKR - this subsystem calculates the torques of the turbine and compressor, which are the part of the turbocharger.
4. Tk - this subsystem calculates the temperature of the fresh charge before entering the cylinder. The output parameters of the subsystem are the temperatures of the fresh charge before entering the cylinder after the simulation and the test result.
5. Pressures - the subsystem calculates the fresh charge pressure at the inlet (Pk), the pressure of the fresh charge at the end of the intake (Pa) and the pressure of the residual gases (Pr). In this subsystem, the Pk_st parameter is implemented as an output parameter to compare the results of the fresh charge pressure calculation at the inlet and the bench test results.
6. GammaR and weight - the grammar and weight subsystem is used to calculate the amount of the working mixture (M1), the residual gas ratio (Gamer) and the excess air ratio (alfa).
7. Tt - calculates the gas temperature in front of the turbine.
8. TempOfCompession - the subsystem has calculated the temperature of the working mixture during compression.
9. IndPressure - This subsystem is used to calculate the indicator pressure (or specific duty cycle) Pi.
10. IndPower - this subsystem calculates the power indicator.
11. Consuptions - this subsystem calculates the gas consumption indicator:
12. Consumps - this subsystem calculates the indicator (qi) and effective (Ke) heat consumption.
13. Effects - this subsystem is necessary to calculate effective torque, power and fuel consumption per hour.

Results and Discussion

To assess the model reliability, a stand with the KAMAZ 82060 engine (the capacity of which makes 260 horsepower) was taken. In order to make the model to operate in the mode of the selected engine, it is necessary to select several values involved in the engine test as input parameters, namely: n - the number of the crankshaft revolutions; P0 - Atmospheric air pressure; μ0 - the coefficient of molecular change of the combustible mixture; α - the excess air coefficient.

The initial data values are shown in Table 1.

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Table 1: Input Parameters

n (min^{-1})	P_0 (MPa)	μ_0	α
2200	0.1360	0.97	1.19
2000	0.1350	0.85	1.18
1800	0.1345	0.80	1.17
1600	0.1340	0.75	1.16
1400	0.1320	0.60	1.14
1200	0.1300	0.57	1.14
1000	0.1280	0.52	1.16

One of the main indicators of engine performance is its power. Figure 3 shows the graphs of the indicator behavior (top line) and effective engine power (bottom line) depending on the crankshaft speed.

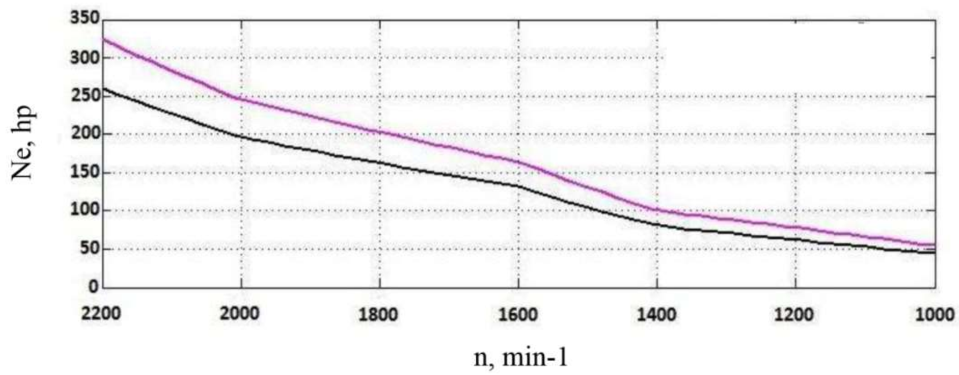

Figure 3: The Graph of the Indicative (Lower Line) and Effective Power (Upper Line) depending on the Crankshaft Speed.

As you can see from the graph 3, the stated effective motor power corresponds to the accuracy of 1%. The graph also shows that the power in the model is higher than the effective power. This is due to the fact that indicative indicators are always better than effective mechanical losses in terms of efficiency.

The next, no less important indicator of engine performance is fuel consumption per hour. Fig. 4 shows the graphs of hourly cost changes for simulations and tests depending on the crankshaft speed.

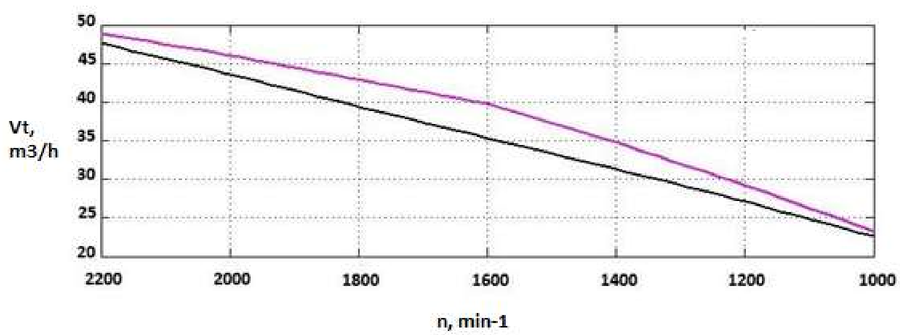

Figure 4: The Graph of Simulation (Top Line) and Test (Bottom Line) Hour Cost. The Graph shows that the Difference between Simulation and Testing is no more than 12%.

Further, they compare the fresh charge pressure at the inlet (Figure 5), the fresh charge temperature (Figure 6), and the temperature of the gases in front of the turbine (Figure 7).

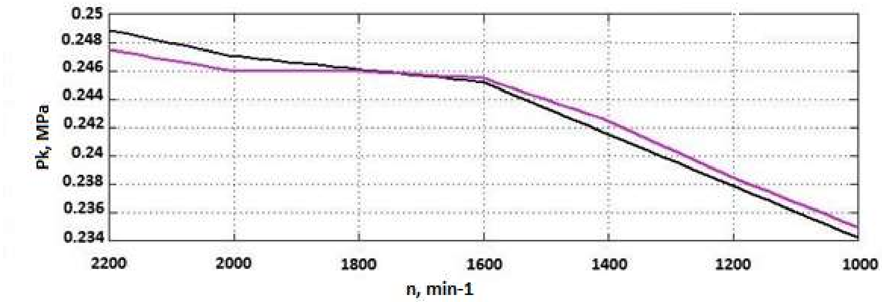

Figure 5: The Graphs of Fresh Charge Pressures at the Inlet

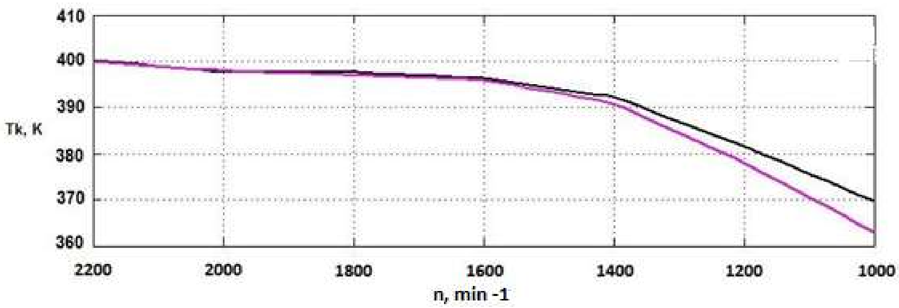

Figure 6: The Graphs of Fresh Charge Temperatures at the Inlet

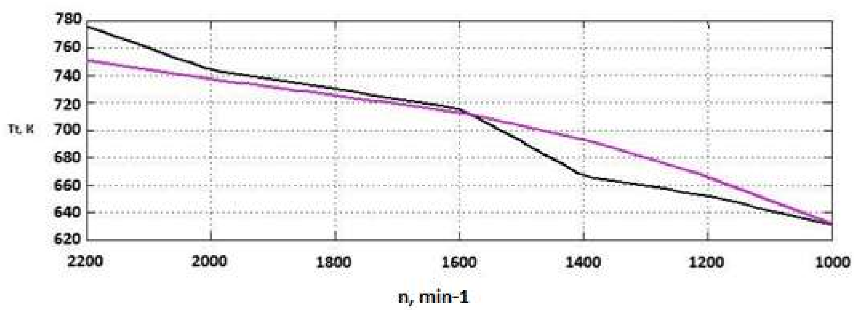

Figure 7: The Graphs of Gas Temperatures in Front of the Turbine

Conclusion

The simulation result showed the deviation of the simulation model which made no more than 12%. Thus, we can conclude that the developed computer model of the KAMAZ 82060 engine is quite accurate. In other words, we can conclude that this developed model of the KAMAZ 82060 engine can be used for other studies, or to reconfigure the engine by changing the design parameters of the selected engine in the computer model.

The developed mathematical model made it possible to develop a simulation model. The resulting model will allow to carry out simulation tests for other engines of different power by changing some design parameters of the engine or changing the characteristics of the engine. Also, the computer model can be used for further research or for reconfiguring the engine by changing the design parameters of the selected engine in the computer model.

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