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Сформульовано і доведено теореми існування та єдиності розв'язків систем рівнянь з частинними похідними, які становлять собою узагальнену математичну модель процесів і апаратів первинної переробки сирих вуглеводнів. Узагальнення дає змогу застосувати принцип уніфікації та типізації щодо розробки методу чисельної реалізації математичних моделей класу процесів (апаратів) первинної переробки сирих вуглеводнів, а доведення відповідних теорем (суть — якісний аналіз) забезпечує коректність застосування узагальненої моделі в прикладних задачах математичного моделювання досліджуваних процесів (апаратів).

Ключові слова: *математична модель, узагальнений математичний опис, системи рівнянь з частинними похідними, теореми існування та єдиності розв'язків.*

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CREATING A COMPUTER MODEL FOR THE DIAGNOSTIC SYSTEM OF DIESEL GENERATOR

Mathematical model of a diesel generator, which includes an integral operator, is considered. Investigated the stability of the computational algorithm.

Key words: *diesel generator, integral model, the stability of numerical implementation.*

Introduction. When you are using a diesel generator for energy supply of the uninterrupted technological processes an important task is to ensure reliable operation of the diesel engine. One way to improve the reliability of the diesel engine it is to control the main operating parameters during operation. Various sensors that placed on its primary nodes are used for measuring motor parameters. Algorithms for control and diagnostics are created on the basis of sensors' data observation.

Since the vast majority of motor parameters vary in time, a perspective approach to organizing of the diagnosis algorithms is the use of a mathematical model of the engine in order to obtain reference values of parameters which are then compared with those incoming from sensors. The most informative operation modes of the diesel engine, in terms of the diagnosis, is a start and moments of abrupt changes in loading, so the process of diagnosing carried out at the beginning of the diesel generator, and during its functioning by artificial increasing (if possible — decreasing) of load. Therefore, to provide the possibility of carrying out the procedure of diagnosing is necessary to construct a mathematical model of the diesel engine with the ability of its functioning in the real time.

Construction of the mathematical model. We will consider a diesel generator with automatic control system as an object of simulation. It contains the following components: a generator, a mechanical and thermodynamic engine system, a fuel supply equipment, a hydraulic servo-amplifier, a pulse-width converter, an electronic regulator, sensors of output of the hydraulic booster and frequency of the shaft rotation (fig. 1).

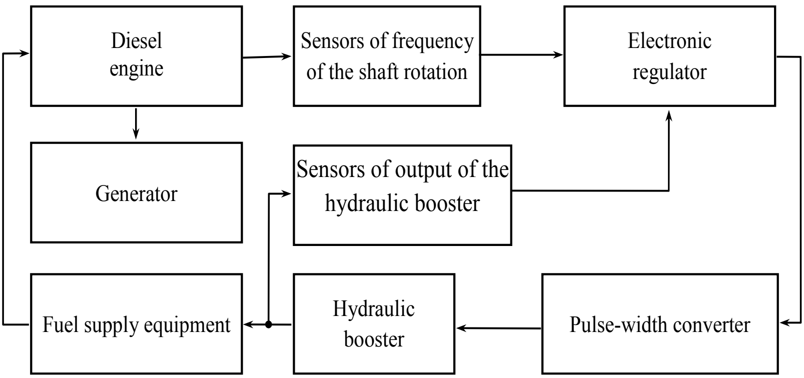

Fig. 1. *Block diagram of the diesel generator*

Let us make the following assumptions for the construction of the mathematical model of the diesel generator: thermodynamic system and apparatus for fuel supply can be represented by linear differential equations; discrete character of the processes in these systems can be negligible, because the cut-off frequency of the system is not less than at least one level lower of magnitude than the frequency passage of outbursts in the cylinders (taking into consideration as a pure lateness); mechanical system is considered as lumped mass; backlash and «dry» friction are small and have no significant effect.

Taking into account these assumptions the mathematical model of diesel system is describe by the system of equations in operator form [1]

$$\left.\begin{aligned} &p\omega_d = K_{dg}\left(m_d - m_o\right);\\ &\left(T_{ts}^2 p^2 + 2\xi_{ts} T_{ts} p + 1\right) m_d = K_{ts} g;\\ &\left(T_{fa}^2 p^2 + 2\xi_{fa} T_{fa} p + 1\right) g = K_{fa} e^{-\tau_0 p} h;\\ &\left(T_{hs} p + 1\right) h = -K_{hs} S. \end{aligned}\right\} \quad (1)$$

Where ω_d, m_d are the angular velocity and moment of the torsion shaft diesel respectively; m_o is the point of load; g, h, S are the source coordinates of the fuel supply equipment and hydraulic servo-amplifier respectively; K_{dg} is the total shaft drive moment of inertia of a diesel engine and generator ; T_{ts}, T_{fa}, T_{hs}, are time constants of thermodynamic system, fuel supply equipment and hydraulic servo-amplifier respectively; τ_0 is delay ($\tau_0 = 2\pi/\omega_d z + 0{,}27/\omega_d$), where z is the number of cylinders; ξ_{ts}, ξ_{fa}, are damping coefficients of thermodynamic systems and fuel supply equipment; K_{hs} is hydraulic servo-amplifier gain factor.

The delay chain with the transfer function $W_1(p) = Y(p)/X(p) = e^{-p\tau_0}$ is presented in the form of equivalent Volterra integral operator:

$$y(t) = \int_0^t \delta(t - \tau_0 - \tau) x(t) d\tau, \quad (2)$$

where $\delta(x)$ is Dirac function.

The gauge of frequency of rotation of the shaft is described by the inertial element with transfer function $W_2(p) = \dfrac{K_4}{T_{sf} + 1}$, where $K_4 = 1$; $T_{sf} =$ 0,015 s.

The model of an electronic controller consists of a proportional link of gain factor K_1 and boosting link with the transfer function $W_3 = \dfrac{T_\omega p}{T_4 p + 1}$, which are paralleled connected. Parameter values are $K_1 = 1$; $T_\omega = 0{,}1 \div 0{,}5$ s; $T_4 = 0{,}0001$ s.

The model of the sensor block of a hydraulic booster consists of connected proportional link and gain factor K_2 connected in parallel, and forcing link with the transfer function $W_4(p) = \dfrac{K_{shb}}{T_{shb}p + 1}$, where $K_2 = 0{,}2\ \text{mm·s}^{-1}$; $K_{shb} = 0{,}005 \div 0{,}8\ \text{mm}^{-1}$; $T_{shb} = 0{,}01 \div 0{,}08$ s.

Diesel engine options are the following: $K_{dg} = 31{,}96$; $T_{ts} = 0{,}1264$ s; $T_{fa} = 0{,}0316$ s; $T_{hs} = 0{,}02$ s; $\xi_{ts} = 0{,}395$ s; $\xi_{fa} = 0{,}19$; $K_{hs} = 1{,}67$.

To be able to calculate standard regime parameters at the control points of the diesel system, it is appropriate to carry out the decomposition of the model by the physical principle (fig. 2). The model synchronizes with the real object by using the signal ω_d from the sensor of frequency of rotation of its shaft. A – D are the control points.

As the system is composed of heterogeneous elements, the construction of the model we will use a variety of methods of mathematical description: for both diesel engine and pulse-width converters we will use integral Volterra operators; for sensors of rotational speed shaft and output of hydraulic booster, electronic regulator, hydraulic booster, servo-engine of fuel supply we ill use transfer functions accordingly.

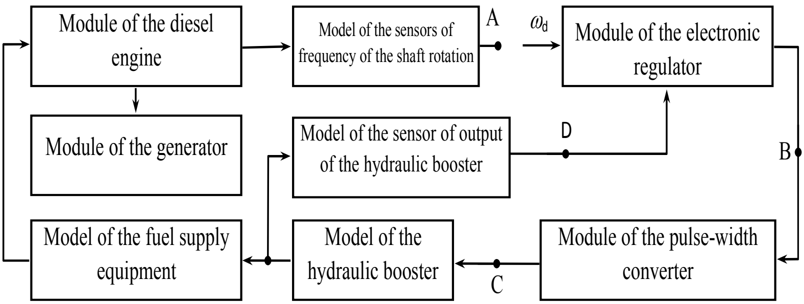

***Fig. 2.** Block diagram model of diesel generator*

The using of the integrated macro model for describing the dynamics of the diesel engine is due to the presence in its structure delay chain, and for describing the pulse-width converter is due to the presence of signals, which are described by the functions with discontinuities of the first kind.

Constructing a computer model. For the numerical implementation of the structural model we will use blocks of Volterra integral operators and standard Simulink blocks (fig. 3). We find the kernel of integral operators by differentiating the transient response of the appropriate subsystems or analytically. Diesel engine subsystem consists of two series connected blocks of integral operators. The first block implements the model (2), and the second implements Volterra integral operator according:

$$y(t)=3,26\int_0^t (e^{-6(t-\tau)}\cos(31,05(t-\tau))-5,06e^{-6(t-\tau)}\sin(31,05(t-\tau))-$$
$$-e^{3,13(t-\tau)}\cos(7,26(t-\tau))+22,03e^{3,13(t-\tau)}\sin(7,26(t-\tau)))x(\tau)d\tau.$$

Subsystems of the hydraulic booster sensor (fig. 4) and electronic regulator (fig. 5) are implemented with the involvement of the standard Simulink blocks.

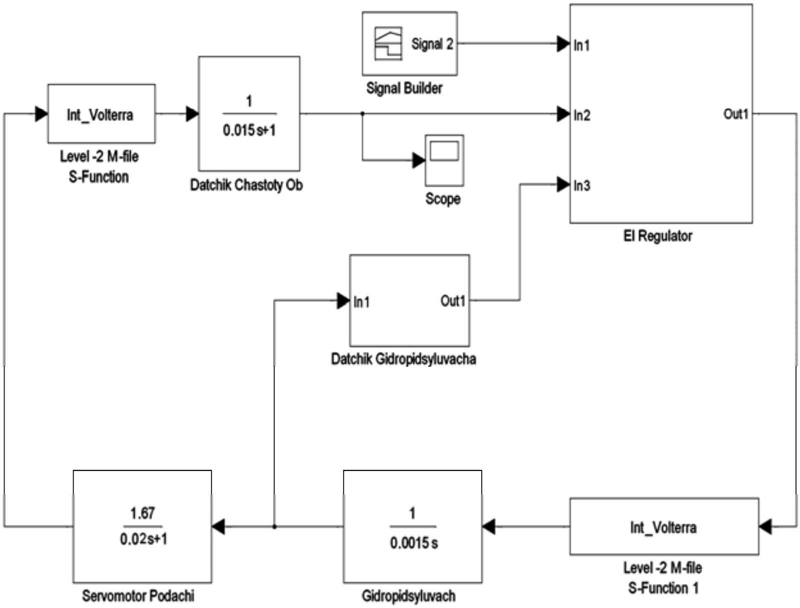

Fig. 3. *Simulink model of the diesel engine*

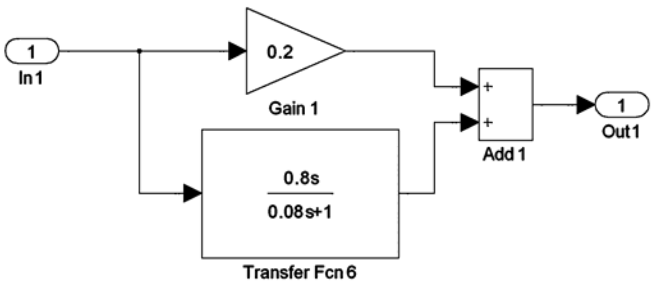

Fig. 4. *Simulink model of the hydraulic booster sensor subsystem*

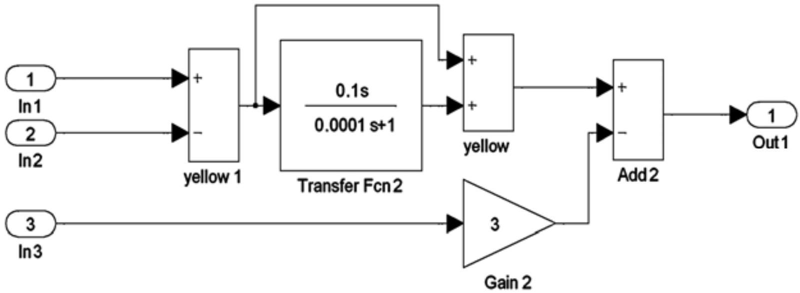

Fig. 5. *Simulink model of the electronic regulator subsystem*

The peculiarities of the integrated dynamic models as nonparametric models are that their construction and periodically correction can be carried out on the basis of the received transient response of components of the system they reflect.

The results of computational experiments. The carried out computational experiments have shown efficiency of the model in the simulation of the dynamics the engine launching (fig. 6). To calculate ω_d simulink model with closed loop (ω_d = A) was used.

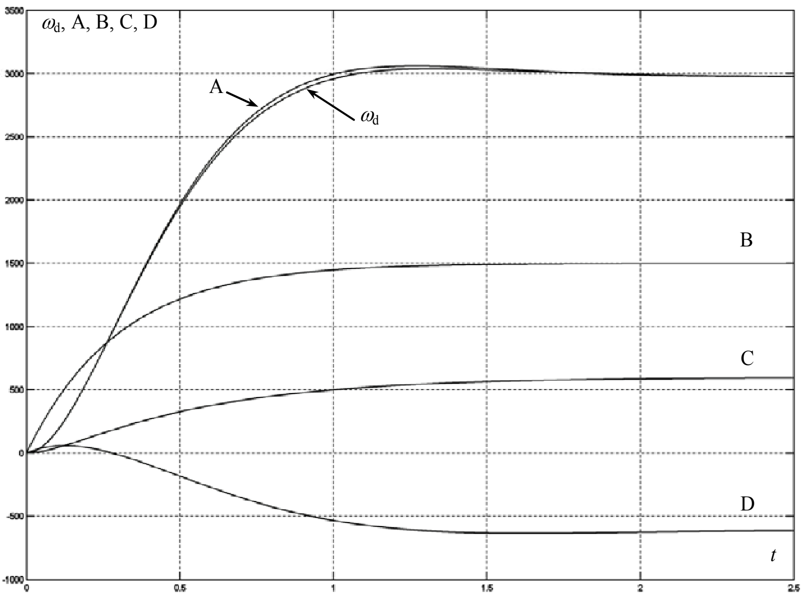

Fig. 6. *Simulation of diesel generator launching dynamics*

Research of noise immunity of models was carried out at different levels of high-frequency noises [2]. In the model which contains Volterra integral operators blocks the stability is maintained at the level of noises till 15% while in the original model at the level of noises of 3% a divergence computational process is already observed. Fig. 7 shows the results of simulation of the diesel generator with high levels of the high-frequency noises signals 15% which incoming from the sensors of frequency of the shaft rotation and hydraulic booster output.

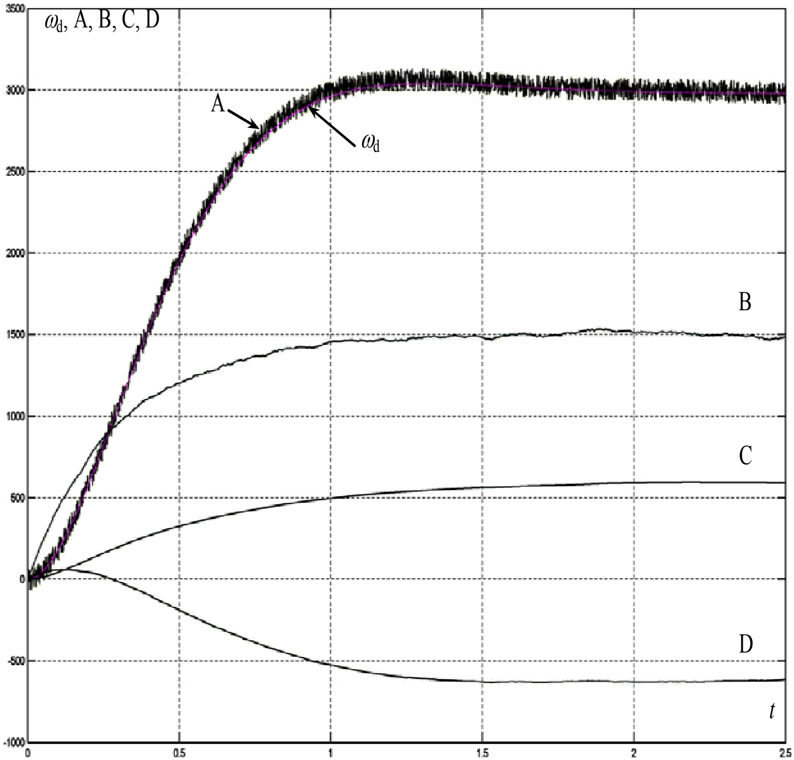

Fig. *7. Simulation of diesel generator with the level of the hindrances on the sensor 15%*

Conclusions. Therefore, the meaning of the replacement of some subsystems by the integral macro model is that the resulting computer model as a whole has the raised computational stability. The resulting computer model as well has a lower computational complexity while preserving the required accuracy than the original model. It enables its use in the systems of real time with significant noise levels in the signal.

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Розглянуто математичну модель дизель-генератора, яка включає ланку інтегрального оператора. Досліджено стійкість обчислювального алгоритму.

Ключові слова: *дизель-генератор, інтегральна модель, стійкість числової реалізації.*

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