Assessment of the stability of the gas-diesel automatic control system

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Abstract. Any steady-state operation of the engine is evaluated by qualitative and quantitative parameters. For internal combustion engines, the qualitative parameter is the speed of the crankshaft, and the quantitative parameter is the engine torque. There are functional dependencies between these parameters, the graphical representation of which is called speed characteristics. However, the transition modes of engines are much more complex than the established ones, especially in gas-diesel engines, where the relationship between the parameters of the engine and the characteristics of the gas supply units is quite complex, and the transition process is accompanied by a change in the parameters of its working process over time and is a dynamic mode.

1. Introduction

When converting motor-tractor diesels to gas diesels, it is most expedient to carry out re-equipment using combined mixing, since this does not require expensive reworking of the engine itself. At the same time, it is necessary to make design changes to the fuel-supply system that ensure the required ignition dose of liquid fuel in gas-diesel mode, and on the basis of the air supply system, create a gas-air mixture supply system that interacts with the frequency control of the rotation, which should ensure the similarity of the engine performance in diesel and gas-diesel mode [1-3].

Taking into account the design features of the diesel fuel equipment, the simplest technical solution for converting it to gas-diesel is a dual-mode power control option with a modified standard diesel regulator as a maximum speed limiter. However, the analysis of the bench tests, and in particular the regulatory characteristics, showed that when the speed decreases from the nominal value, a significant decrease in engine power occurs, and, importantly, the nominal coefficient of torque reserve \( K_{\mu} \) is not provided [4-6].
2. Methods and Materials

The main cause of the dynamic mode is the violation of the equality of the moments \( M_v \) and \( M_i \), i.e. the difference in the characteristics of the energy input and output, as a result of which the engine accumulates or consumes energy. At the same time:

\[
M_v = M_v(n, h_F, t),
\]

where \( n \) - engine crankshaft speed;
\( h_F \) - numerical provisions of fuel supply regulators;
\( t \) - coolant temperature.

The main parameters that characterize the dynamic mode of the gas-diesel engine are the speed of rotation of the shaft and the temperature of the coolant. When analyzing its dynamics, it is necessary to have graphs of transients [7-9].

The differential equation of the gas-diesel engine as an object of regulating the speed of the shaft when operating in a non-steady state can be represented by the equation:

\[
2\pi J (dn/dt) = M_d - M_b,
\]

where \( J \) - the moment of inertia of all moving elements of the engine brought to the shaft axis.

Equation (2) is a nonlinear differential equation, where:

\[
M_d = M_d(n, h_F); \quad M_b = M_b(n, \varphi).
\]

where \( \varphi \) - disturbing effect.

When linearizing these functions, we get:

\[
T_d \sigma' + \sigma = k_1 \mu - k_2 \lambda,
\]

where \( T_d = 2\pi J / F_y \) - engine time constant, s;
\( k_1 = (\partial M_d / \partial h_F)_0 (H_{F_a} / F_y n_a) \) - motor gain by control action;
\( k_2 = (\partial M_b / \partial \varphi)_0 (\varphi_a / F_y n_a) \) - external load gain of the motor;

\( \sigma = d\sigma / dt \) - the rate of change in the speed of rotation of the shaft in the transient process.

The time constant \( T_d \) of a gas-diesel evaluates its inertial properties and depends on the stability factor. It determines the time of the conditional transition process, in which the change in the speed of rotation of the shaft would occur at a constant speed equal to the speed of the frequency change at the initial moment of the actual transition process. The gain factor \( k_1 \) shows how much the frequency \( n \) will change when the gas mixer-dispenser flap is moved by one or a percentage of its total volume. It characterizes the effectiveness of the regulatory impact on gas-diesel. The gain factor \( k_2 \) determines the response of the motor at the speed \( n \) to the return action on the external load. This effect is perceived by the engine as a change in torque when changing the speed mode under the influence of external factors [10-12].

Therefore, to ensure the dynamic properties of gas-diesel, it is necessary to evaluate the stability control system used on it as its ability to return to the equilibrium state after the application of perturbations.

3. Results and Discussion

The main and primary feature of the classification of the speed regulators of the internal combustion engine is the energy that is used to rearrange the control bodies of the fuel supply equipment. In relation to gas-diesel this is the valve of the gas mixer-dispenser, made on the principle of direct action [13-15].
The controller meter consists of three elements: a sensing element, a reference element, and a comparison element (or summing element). The transfer mechanism changes the scale and sign of the output coordinate of the meter. The schematic diagram of this controller is shown in figure 1.

If there is a violation of the steady-state mode of the gas-diesel engine as a result of a decrease in the external load, the speed of rotation of the cam shaft 1 (figure 1) and the centrifugal force of the loads 2 will increase. Under the action of the centrifugal force, the coupling 3 begins to move, overcoming the force of the driving spring 4. As a result, the lever 5 will turn relative to the support 6 and, by means of the rod 7, will move the valve of the gas mixer-dispenser in the direction of reducing the gas supply. If the external load on the motor increases, the regulator works in the same way, but in the opposite direction [16-18]. The equilibrium position of the coupling of the regulator 3, corresponding to the specified speed mode, is determined by the static equilibrium of the forces acting on it: restoring $E$ and supporting $A$, i.e. $E_0 = A_0$.

![Figure 1. Schemes of micro-explosions of water drops in oil.](image)

The magnitude of the restoring force depends on the spring tension of the task (spring damper gas divider) and is a function of moving the clutch $\eta$ and $E = E(\eta, x)$, and maintain $A$ is determined by the total mass of centrifugal cargo $m$, radius of rotation $r$, which can be expressed through the output coordinate meter $\eta$, and speed of rotation $\sigma$: $A = F(m, \eta, \sigma)$.

![Figure 2. Possible transients: 1 – unstable; 2 – stable.](image)

A graphical expression of the process of transition of the control system to a stable state is shown in figure 2.

**4. Conclusion**

In this case, the dynamics of the control process is described by differential equations, and therefore the stability analysis consists in studying the solution of these equations. The presented stability theory analyzes the influence of disturbing factors on the movement of the control system.
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