Modelling of the isodromic rotation frequency controller

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Abstract. It is researched a model of the automatic control system (ACS) of the gas turbine engine (GTE) rotor rotation frequency with an isodromic regulator. Modelling of the ACS of the GTE rotor rotation frequency is done in the Mathlab system using Simulink blocks. Transient processes occur in the ACS including the isodromic controller. It makes possible to analyze the influence of the controller parameters on the quality of the dynamic characteristics of the ACS in order to justify the choice of these parameters. Because of the transient processes modelling, the dependencies were obtained in the process of stabilizing the GTE mode: changes in the isodromic, proportional and total components of the GTE control action; change in rotor rotation frequency. It allows providing the necessary stability margins for the ACS and obtaining its optimal dynamic characteristics by changing the productivity of the throttle package and the position of the feedback piston mechanical stop.

1. Introduction

One of the main elements of the gas turbine engine automatic control system is the rotor rotation frequency regulator. With the appearance of electronic control systems on modern engines, a hydromechanical regulator is always used as a backup regulator to ensure reliable operation of the fuel supply control system to the main combustion chamber. Therefore, strict requirements are imposed on the static and dynamic characteristics of such regulators. Such characteristics can be obtained using modern modeling methods without conducting an experimental studies on test benches.

2. Task and object of the research

The main feature of the most frequently used hydromechanical regulators of rotor rotation frequncy [1], or rather the hydraulic drive of inclined washer (IW) of the GTE fuel pump (Figure 1), is the presence of two pistons in a single hydraulic cylinder: a piston directly acting on the inclined washer (IW piston) 20 and a piston, covered by rigid feedback (FB piston) 18. In this case, the movement of the IW piston and a change as a result of this in fuel consumption into the combustion chamber can occur:

− with a stationary FB piston 18 (when it is on mechanical stops) due to a change in the volume between the pistons cavity (BPC);
− when moving the FB piston 18 together with the IW piston 20 with a locked BPC [2].

Due to rigid feedback (RFB), the FB piston (RFB includes FB piston rod, lever 15, connected to the movable sleeve 5 of the spool 3 moves proportionally to the change of the position of the spool 3 (y). This position is determined by the signal from the output of the regulator's measuring device, i.e.

y÷Δn. The movement of the FB piston, which is limited by mechanical stops, occurs together with the FB spool 16, made on its rod [3]. The movement of the FB piston through the hydraulic connection is controlled by spool 3, therefore, the coordinate of the FB spool m_{FB} is also proportional to Δn, that is, m_{FB} ÷ Δn.
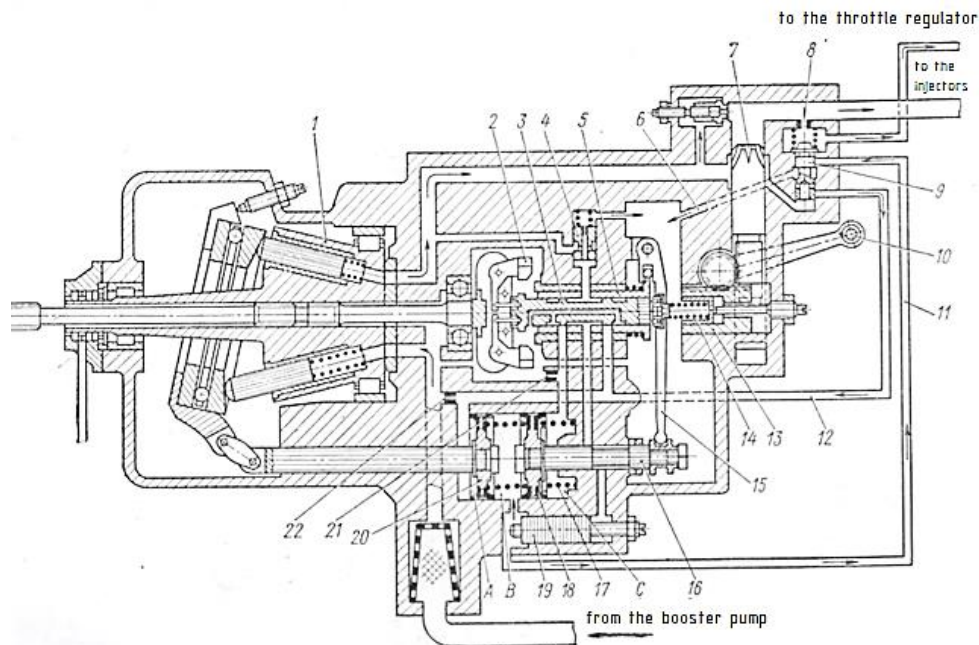
Figure 1. Pump-regulator of fuel supply to the GTE main combustion chamber. *Source: Minin P and Trifonov A 1964 Avtomatika aviatsyonnykh dvigatiliey* [1].

The FB spool is made in such a way that when the FB piston is located on the mechanical stops [4], the FB spool groove connects the BPC either with the fuel supply from the constant pressure valve (CPV) 4 through the throttle package (TP) 19, or with a drain [5]. When the FB piston is on the right stop, made on the FB piston rod, the BPC cavity is connected to the fuel supply [6]. When the FB piston is at the left stop of the piston in the cylinder body, the BPC cavity is connected to the drain. At the same time, the IW piston begins to move relative to the stationary FB piston at a constant velocity [7]. It is determined when fuel is supplied to the BPC [8] (that is, when the fuel consumption in the main combustion chamber (MCC) is increased by the RRF) only by the capacity of the throttle package (TP) 19 installed between the FB spool and BPC [9]. When draining fuel from the BPC (that is, when the fuel consumption is decreased by regulator) - by the amount of fuel drained from it through the holes in the housing, opened by the right shoulder of the FB spool [10]. In this case, the flow characteristic of the FB spool has the form of a relay link characteristic with a dead zone [11]. In such cases, the regulator works as an isodromic "I" regulator, which ensures a constant rate of change in fuel consumption, i.e.:

$$\dot{G}_f = k_{iz} * sign\,(\Delta n) = \pm const, (1)$$

where $\dot{G}_f$ is rate of change in fuel consumption (dG_f/dt); k_{iz} is isodrome gain, actually equal to the specified rate of change in flow rate; $sign\,(\Delta n)$ – the sign of the number n equal to ± 1.

The choice of the capacity of the TP 19 is carried out taking into account the fact that during the operation of the "I" component of the regulator (for example, at large Δn in the process of engine acceleration), the excess fuel created by it is greater than the excess created by the throttle regulator. Otherwise, the throttle regulator will not be able to work [12].

When the FB piston is between the mechanical stops, the FB spool locks the BPC [13]. In this case, when the FB piston moves according to the commands from the spool 3, both pistons move together as a whole, providing a change in G_f proportionally to Δn:

$$G_f = k_p * \Delta n, \quad (2)$$

where k_p is the gain of the proportional component of the controller. In this case, the RRF regulator works as a proportional "P" regulator.

For the stable operation of the stabilization system of the GTE rotor rotation frequency, which includes an isodromic regulator, the inclined washer (IW) of the fuel pump must have a dead zone (DZ) in the relay characteristic of the hydraulic drive [14]. Such a zone in the considered regulator is set by the FB spool, which turns on the isodrome only when the FB piston is installed on mechanical stops. In this case, the distance between the stops will be the dead zone [15].

3. Solution to the problem

A model of the gas turbine engine with an automatic control system including an isodromic rotor rotation frequency regulator is made in Mathlab using Simulink blocks and is shown in Figure 2.
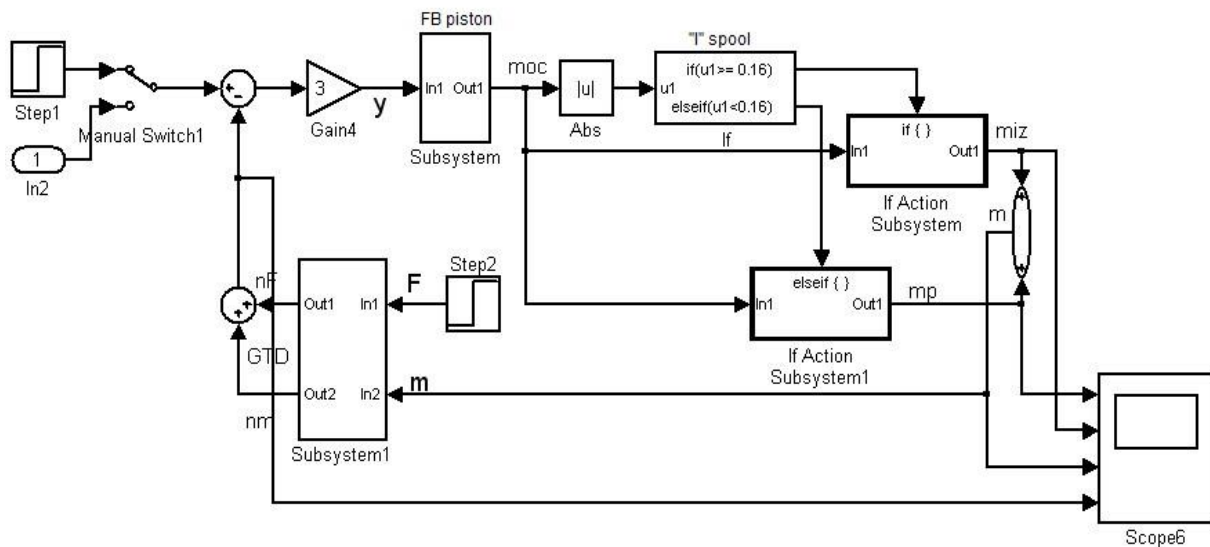
Figure 2. Model of the ACS of the GTE RRF with isodromic regulator

The functions of FB spool 16 (Figure 1) are performed by the "if" block (Figure 2). Depending on the value of the input signal, this block provides the "I" or "P" regulator activation.

When the FB spool is on the stops (if $|m_{FB}| <= 0.16$), the "P" regulator turns on, when the FB spool is between the stops (if $|m_{FB}| >= 0.16$), the "I" regulator turns on. In the example shown, the DZ is ±0.16 or 0.32.

The model of the IW piston 8 (Figure 1), when it is controlled by the FB piston with the BPC locked, is shown in Figure 2 by the "if action subsystem1" block.

This element starts to work when the "P" regulator is turned on, that is, when the value $|m_{FB}| <= 0.16$. The gain k_P of the "P" regulator in this case is equal to 1.

The model of the IW piston 20 (Figure 1), when it is controlled by feeding (or draining) fuel into the BPC through the FB spool 16 and DP 19, is shown in Figure 2 by the "if action subsystem" block. In this case, the speed of movement of the IW piston depends only on the flow characteristic of the FB spool, which has the form of a relay link with a DZ.

The block starts to work when the "I" regulator is turned on, that is, when $|m_{FB}| >= 0.16$. The gain of the isodromic regulator k_{iz} is assumed as 0.2.

The model of block "subsystem" in Figure 2 (this is a model of the FB piston, covered by rigid feedback, for which the input "In4" is the signal "y÷Δn" from the output of the measuring device of the regulator, and the output is "Out3", the coordinate of the piston m_{FB}) is shown in Figure 3.
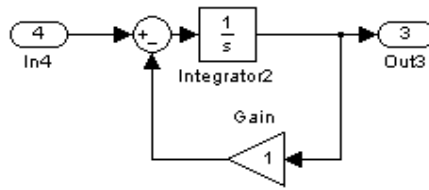
Figure 3. Model of the "subsystem" block

In this case, the feedback gain k_{FB} is equal to 1.

The GTE model in Figure 2 is represented by the "subsystem 1" block [3]. The first input signal of the block (In1) is a disturbing effect F, and the output (Out) is a change in the rotor rotation frequency of the engine n as a result of the action F. The second input signal (In2) is a control action in the form of a change of the fuel supply G_F from the regulator output, and the output (Out2) - change in the rotor rotation frequency of the engine n as a result of changes in G_F. The GTE model is shown in Figure 4.
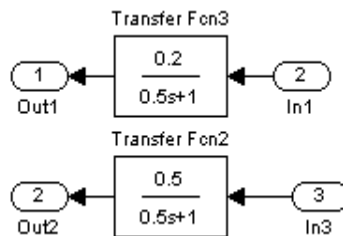
Figure 4. Block "subsystem 1" model

In this case, the time constant of the gas turbine engine in terms of the rotation frequency is taken equal to 0.5 s, the coefficient of amplification of the gas turbine engine in terms of fuel consumption is 0.5, and in terms of disturbance – 0.2.

The results of the simulation of the transient process in the automatic control system of the GTE RRF (the model of which is shown in Figure 2) caused by the change in the disturbance F is shown in Figure 5, obtained using the block "Scope 6" (Figure 2).
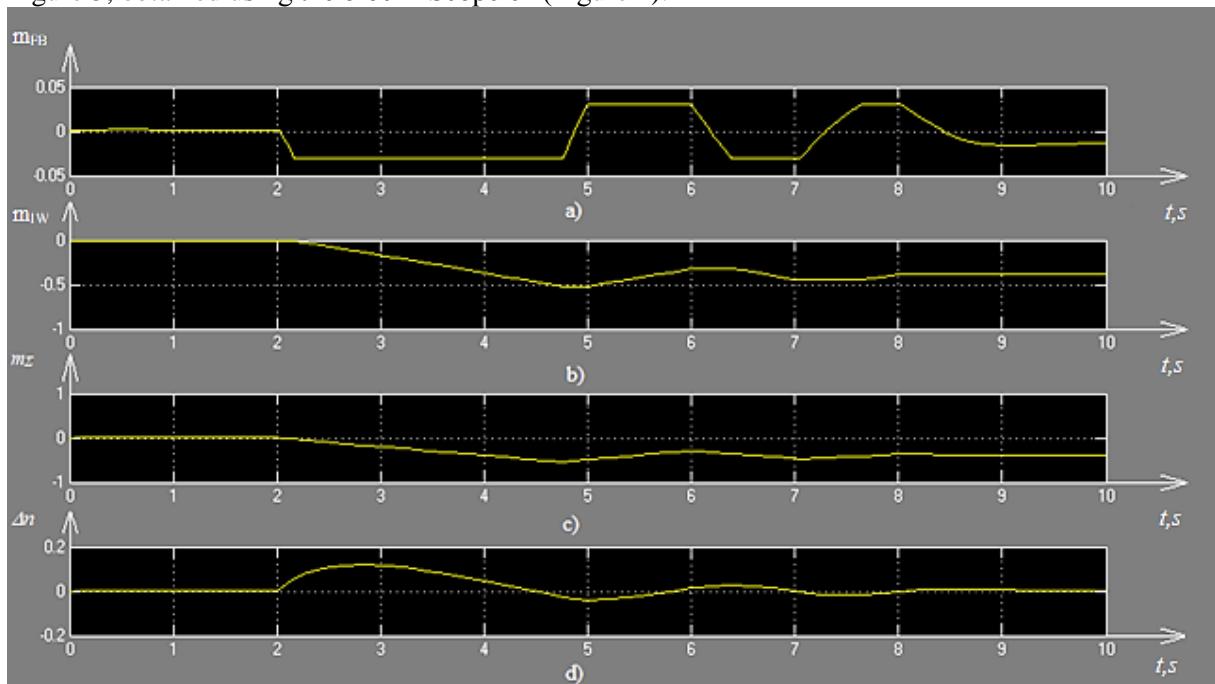
Figure 5. Oscillograms of the transient process in the ACS with an isodromic regulator.

Figure 5a – the change in transient process of the position of FB piston with the FB spool $m_{FB}(t)$. In fact, this is a change in the "P" component of the control action. During the transition of the FB piston from one stop to another, the BPC remains locked and the IW piston with the FB piston move as a whole, providing a change in the position of the IW, and therefore G_F in proportion to Δn.

Figure 5b – the change in the transient process of the isodromic ("I") component of the control action. As soon as the FB piston with the FB spool stands on one of the mechanical stops (horizontal regions in Figure 5a), the BPC is connected either to the fuel supply from the CPV or to the drain cavity. At the same time, the "I" component starts to work, that is, the IW piston begins to move at a constant speed:

$$m_f = sign\,(\Delta n) * k_{iz}, (3)$$

providing $\dot{G}_F = k_{iz}$.

Figure 5c – the change in the resulting control action on the GTE with sequential actuation of "P" and "I" components of the control action shown in Figure 5a, 5b. This happens until Δn in the transient process becomes less than the dead zone. After that, the FB piston together with the IW piston move together, and only the "P" component works.

Figure 5d - the process of changing the deviation of the rotor rotation frequency from the set value $\Delta n(t)$ at the resulting control action shown in Figure 5c.

Conclusion
In the result of the study of the transient process caused by an abrupt change in the control action on the gas turbine engine, using a simulation model, the following were obtained:
− dependences of changes in isodromic and proportional components of the control action in time;
− change in the engine rotor rotation frequency during the transient process;
− the possibility, by changing the performance of the throttle package and the position of the mechanical stops of the FB piston, to obtain the optimal nature of the change in the rotor rotation frequency without unacceptable temperature overshoots and with the necessary acceleration characteristics.

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