29th Congress of the International Council of the Aeronautical Sciences
St. Petersburg, Russia; September 7-12, 2014

DEMONSTRATION SYSTEMS OF THE “ELECTRIC” GAS TURBINE ENGINE

O. Gurevich, A. Gulienko, U. Schurovskiy
Central Institute of Aviation Motors (CIAM)

Keywords: *automatic control system with electric drives, fuel system, oil system, electric motor-driven pump*

Abstract

It describes the principles of construction of demonstration control systems, fuel supply and lubricants, developed in CIAM for "electric" gas turbine engine. The characteristics of fuel supply systems with electrical motor-driven pumps with different laws controlling their speed have been compared. Mathematical modeling of processes in the oil system is developed for the dynamic model. The paper presents the results of experimental studies of automatic control system with electric drives on the engine-demonstrator.

1 Introduction

The use of electric technologies in various systems of aircraft and engines is regarded as one of the most promising directions for improving their basic characteristics [1].

According to the concept of the “all electric aircraft” electric energy will be applied in all systems of the aircraft, including the power plant with the gas-turbine engine, where at present hydraulic and pneumatic devices are still used. "Electric" gas-turbine engine (EGTE) can be implemented without air selection from the compressor and Accessory Gear Box (AGB), which drive units of the engine and the plane: pumps, generators, drives of constant turns, etc. In its systems electric devices for drive of the pumps of fuel system and units of mechanization of a gas path are used. For the subweight of rotors of the engine two options are considered: with ordinary rolling bearings and electrical motor-driven lubrication system and with magnetic bearings for which greasing isn't necessary. The second option belongs to more remote prospect because of difficulty of obtaining acceptable mass of magnetic bearings at modern technologies.

Use of the electric drive in the fuel system entails a capability for fuel metering for controlling parameters of working process in the engine when fuel flow value is a function of pump rotational speed (the system without metering device). Moreover, the fuel supply system should be also modified: there is no need in bleed and throttle valves for adjustment of fuel flow at the pump outlet with respect to engine consumption because there is no direct relationship between rotational speeds of the engine shaft and the pump rotor [2].

Application of the electric drive for rotation of compressor guide vanes makes it possible to reduce the number of precession spools-and–sleeves in automatic control system (ACS) components as well as connections in fuel pipelines, decrease fire risk(no kerosene in hydraulic cylinders), to eliminate the influence of the drive operation on the fuel supply system.

Oil system containing supply and scavenge oil pumps and the breather with controlled electric drives allows to increase reliability of start at the subzero temperature of air and after stop of the engine, to reduce oil losses, to reduce the content of air in pumped-out oil, etc. It is reached, generally independent control of flow rate supply and scavenges oil pumps. Herewith the frequency of rotation of pumps doesn't depend on the frequency of rotation of rotors of GTE, unlike the traditional lubrication systems.

Generators for electricity production one of which is a starter-generator are to be mounted directly on the shafts of the rotors of the engine. They are supposed to provide the growing requirements of systems of the "all electric aircraft" in electrical power.

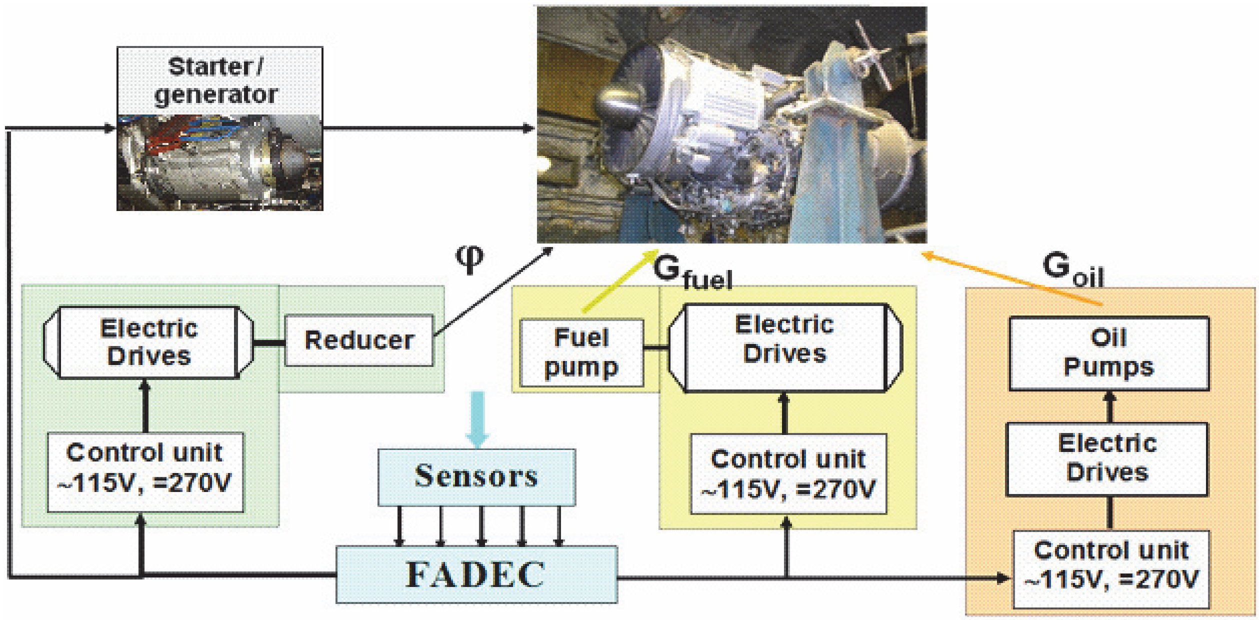

Fig. 1. Schematic diagram of the ACS.

2 Demonstration automatic control system

CIAM together with the developers of aircraft units designed demonstration automatic control system (DACS) with electrically-executive bodies (Fig. 1).

DACS affects the fuel flow into the combustion chamber (Gfuel), the position of guide vanes (GV) and air bleed valves of the compressor, and also controls pumps of the engine lubrication system (Goil). To start the engine and power generation a starter-generator is used.

The system of fuel supply to the combustion chamber includes low-pressure section with the electric centrifugal pump (ECP) with constant rotational speed, and a high-pressure section with the gear-type pump (GP) and the electric motor (ED) with variable rotational speed as dependant on signals from the digital controller.

The guide vane drive mechanism is based on valve electric drive and roller-screw pair and completely displaces guide vanes within 0.5 sec; electric-pneumatic drive of air bypass control valves closes / opens bypass within 0.2-0.3 sec that provides stable engine operation at steady and transient regimes.

Management of coordination of "electric" engine systems are performed by electronic

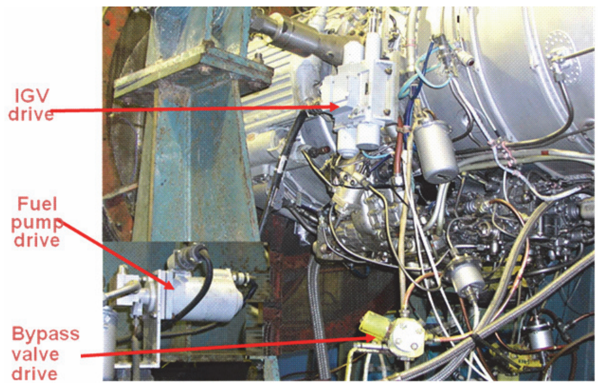

Fig. 2. Location of units on the engine-demonstrator.

digital controller type FADEC, based on an industrial PC with 10 million performance k.op./s, RAM - 512 MB, ROM - 80 GB, the number of I/O is 24/12. Placement units of the system on the engine-demonstrator shown in Fig. 2.

Electrical motor-driven control system has been tested on the semi-natural test bench with a mathematical model of the engine, and also on engine-demonstrator, such as turbofan with a maximum thrust of 2.5 mc.

The controlled electric drive with ac converter-fed motor is used for rotation of the gear-type pump which control block provides control of the electric motor by providing settings of rotor rotational speed or current (torque) in the electric motor coils.

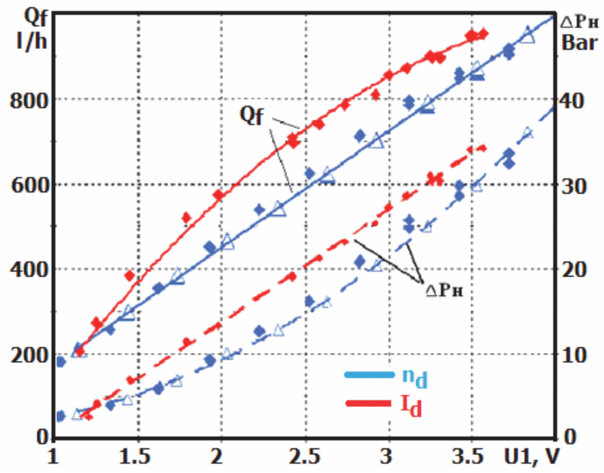

Fig. 3. Flow characteristics of the supply system with electric motor-driven pump

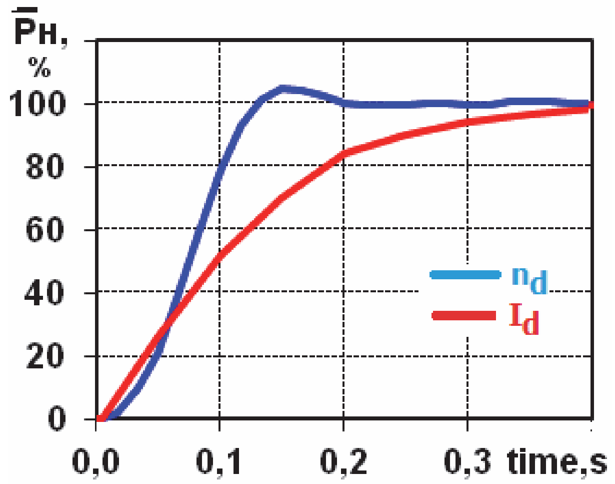

Fig. 4. Transients pressure on outlet of the pump at different methods of ED control

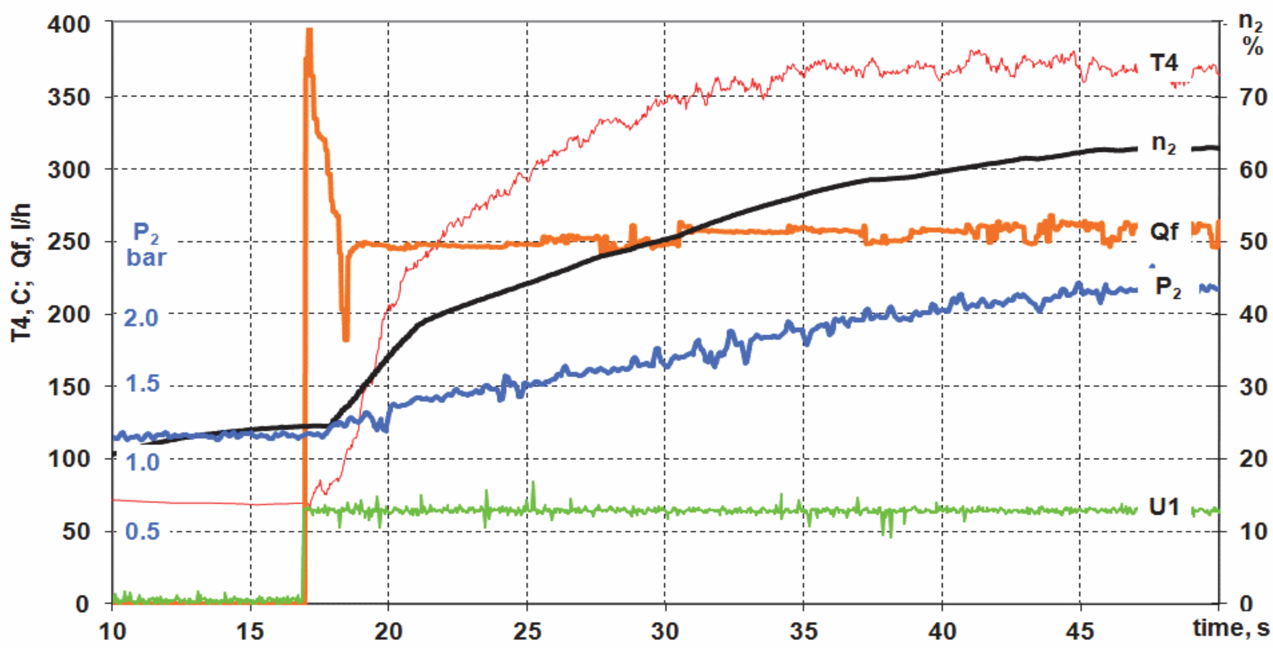

Fig. 5. Transients for starting and stopping the engine

Fuel consumption (Q_F) for both control methods can be changed 7 times at pump rotation speed within 1200 - 9000 r.p.m. In the control process on the basis of r.p.m. fuel consumption there is a linear function of the control signal, and in the control process on the basis of current there is a linear variation in pump differential pressure - Pn (the difference in pressure at the inlet and the outlet).

Experimental characteristics of the fuel supply system are shown in Fig. 3, where dark blue lines – control on the basis of r.p.m. and and red lines - on the basis of current.

Dynamic characteristics of the fuel supply system for control on the basis of electric motor shaft r.p.m. and current in electric motor coils are different. In case of control on the basis of r.p.m. the transition time from 200 l/hr (the pump outlet pressure divided by max. pump pressure - $P_p = P_p/P_{p.Max}$ - is equal to 2% as shown in Fig. 4) to 1050 l/hr (P_p = 100% as shown in Fig. 4) is 0.2 s that it is two times less than in case of control on the basis of current with a stepwise change in the control signal determining the fuel flow. Therefore, control on the basis of r.p.m. is preferable. Control on the basis of current can be considered as a backup control algorithm.

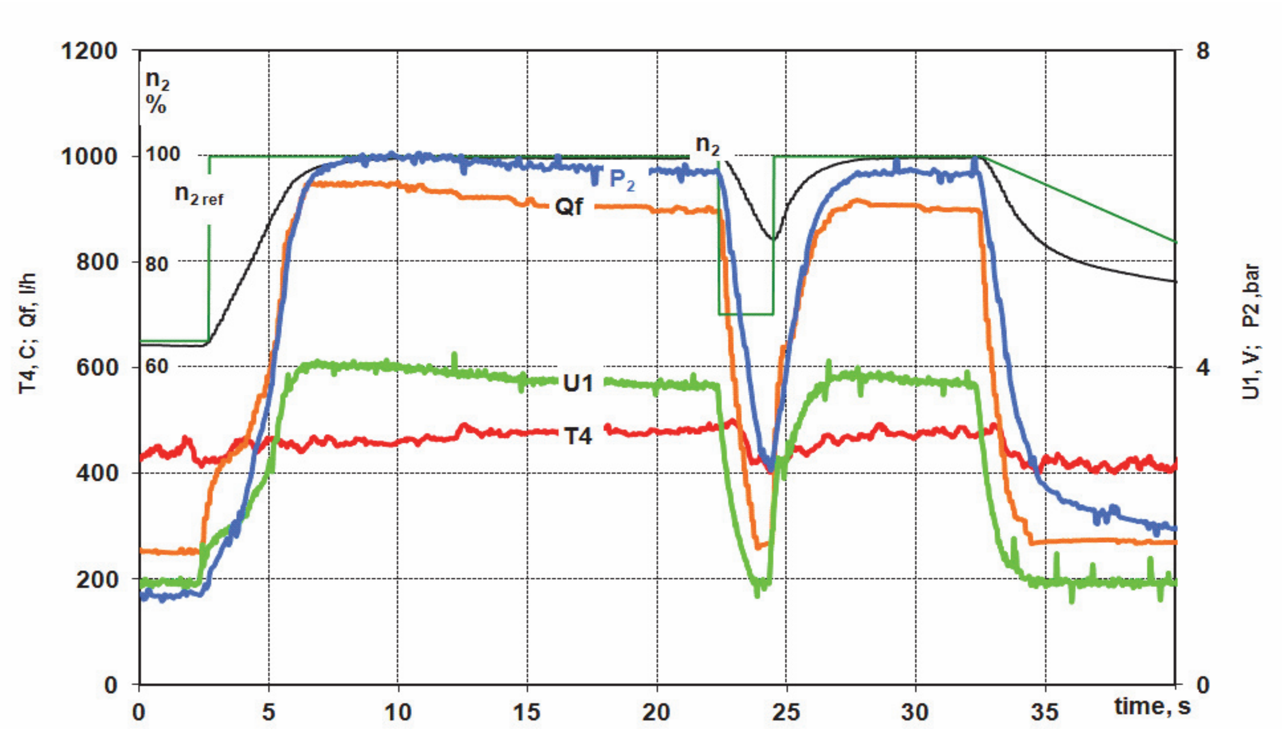

Fig. 6. Transients processes of the engine parameters

The study of the electric drive system on the engine was provided for the engine steady operation from IDLE to MAX as well as for starting, acceleration, advanced acceleration, deceleration and stopping.

In startup conditions (Fig. 5) the starter drives the HPC rotor and at n_2 = 24 % (17-th second) the digital control unit in compliance with the preset control program sends U1 signal to provide IDLE mode.

Transient processes in variation of engine parameters (n_2 - HPC rotational speed, Q_F – fuel consumption, U1 - control signal to the pump electric drive and T4 – gas temperature at the HPT outlet) when changing the r.p.m. controller setting ($n_{2\ set}$) by 5 % ("narrow" changes) and when increasing $n_{2\ set}$ from 62 % to 100 % (acceleration process) and decreasing $n_{2\ set}$ (deceleration) ("wide" changes) are shown in Fig. 6. Transient process in variation of controlled variable (n_2) are smooth; the control signal from the control unit is processed by the electric pump drive almost without a delay (see U1 and Q_F in Fig. 6). Transition time from 62% n_2 to 95% n_2 is 3.2 s that is in compliance with engine requirements specifications.

Stopping is provided by sending U1 control signal equal to zero to the pump electric drive. In this case, fuel flow decreases down to zero within ~0.8 s.

Tests have shown that the automatic control system allows the engine with the required characteristics for steady state and transient conditions.

3 Demonstration electrical motor-driven oil system

In CIAM the demonstration oil system with electrical motor-driven pumps is developed in order to assess the effectiveness of this system and experimental development of ways to control operation of the pump. Principle diagram of this system is shown in Fig. 7.

The system comprises an oil tank OT, from which oil is supplied to the input of the supply pump(SP), which supplies oil to the oil chamber OC of the bearing. Pumps ScP_1 and ScP_2 provide pumping oil from the OT to the AGB. Pump ScP_3 pumps oil from the AGB to the oil tank. Compressor supplies air (Gair) to the oil chamber. There is a breather system (Gbreath). Each pump is rotated by a controlled ED change in speed which provides inverter power (IP).

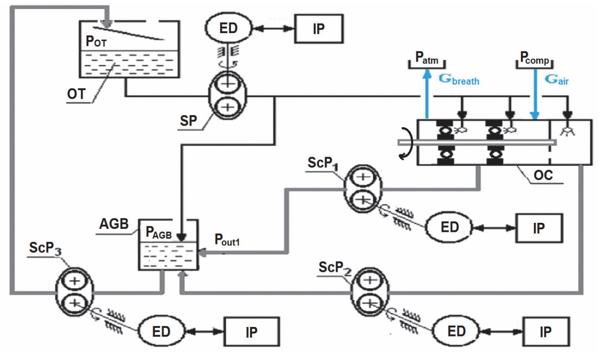

Fig. 7. Schematic diagram of the demonstration electric motor-driven oil system.

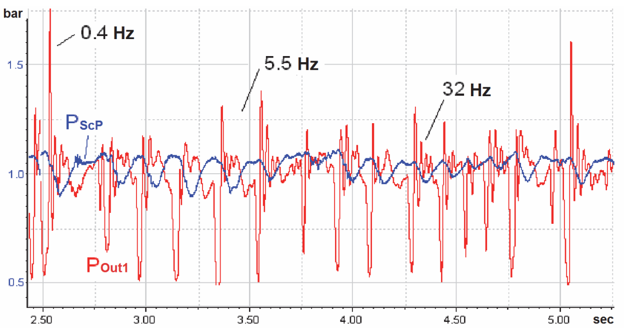

Fig. 8. Polyharmonic fluctuations in oil evacuation path.

An experimental study of the characteristics of such oil system has shown that if the pump is working on pure oil (without fraction of air), the stable operation of the pump with the ability to change the pumping tenfold is ensured. If set the stepwise disturbance on rotational speed of scavenge oil pump, then transients in the system are aperiodic. If scavenge oil pump operating at oil-air mixture, then transients have an oscillatory nature and possible of overshoot of the parameters (pressure, flow, etc.). Pressure fluctuations in the outlet conduit of scavenge oil pump SP_1 are of polyharmonic character: there is a low frequency 0.3...0.5Hz,increased frequency of 32 Hz and the natural frequency of 5.5 Hz (Fig. 8).

Dynamic mathematical model of the system designed to investigate the causes of these phenomena, and select the electrical-driven pumps control laws. Mathematical model can count on steady and transient operating pressure, temperature, flow rate of the working fluid content in the nodes of the air entering the cavity of the oil-gas path of the engine, taking into account the thermal characteristics of the liquid and gas depending on the temperature, pressure and volumetric gas content.

Mathematical model is based on a modular principle, representing a set of differential, integral and algebraic equations that reflects the relationship occurring in the system of hydraulic, gas and thermal processes based on discharge and power characteristics of pumps and actuators. Solution of the system model is carried out in a computer program by direct numerical calculation without iterations. Homogeneous model is used to describe a two-phase mixture in the pipeline, which is considered as a homogeneous compressible Newtonian liquid and an ideal gas [3].

The assumptions of the mathematical model: the pressure, temperature and flow rate are equal in both phases over the pipe section; there are no phase transitions; not taken into account evaporation and condensation; the mass fraction of gas in the nodes at the entrance of the piping and pressure loss its length (travel, local, etc.) are subject to the additivity rule.

The basic equations of oil system are the equations of motion of two-phase mixture in the pipe to the pressure drop on the lumped resistance and inertia of the mixture. Also takes into account the change in pressure in the gas-liquid chamber with inlet / outlet air flow working environment gear pump with variable volume and hydraulic efficiency and equation of calculate the rotor speed transmission "pump-motor."

Testing of the developed mathematical model is made by filing the stepwise control signal to change discharge of supply and discharge pump with subsequent comparison of experimental and computational processes. Figure 9 shows the transients on the output pressure of supply oil pump by increasing his performance.

Transients are pressure supply oil pump at the outlet while increasing its productivity similar to aperiodic. Time response of each parameter to steady-state mode in the supply path is 0.9…1.0 seconds. This time is determined mainly by inertial properties of the motor rotor.

Transients in the path of pumping oil are shown in Fig.10. It is seen that the initial stage

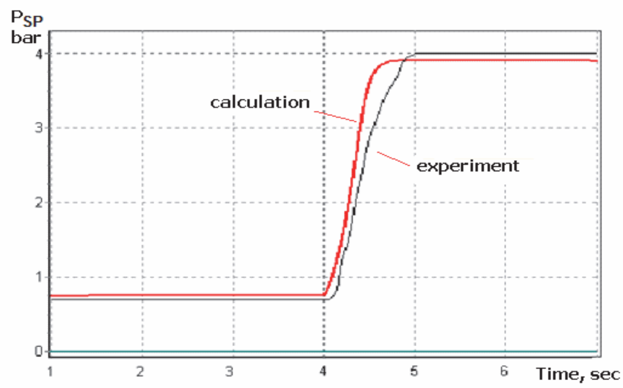

Fig. 9. Transients pressure on outlet of the oil supply pump.

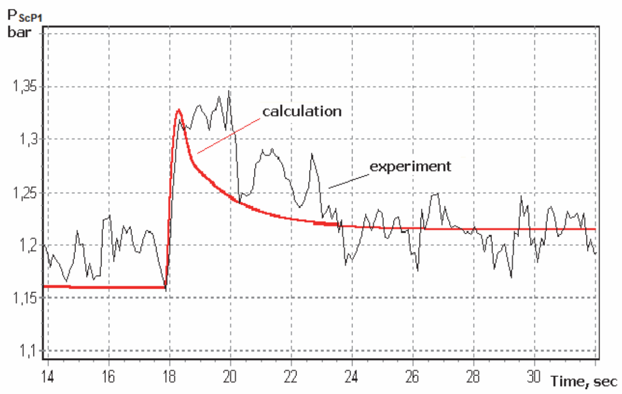

Fig. 10. Transients pressure on outlet of the oil scavenge pump.

of pressure changes at the pump outlet lasts almost equally - time response is 1.5 seconds, and then the processes sharply different. In this case we have the overshoot and damped oscillations pressure with a frequency of 0.3 Hz, which may be explained the compressibility of the oil-air mixture in the path of pumping. In this case we have the overshoot and pressure damped oscillations with a frequency of 0.3 Hz, which are due to the compressibility of the oil-air mixture in the path of pumping. Time response to the new mode increases and is about 8 seconds, i.e. time of transition processes in the path pumping out almost ten times more time processes in the supply path. This time depends on the time response of value of gas content in the oil chamber and is accompanied in the experiment damped oscillatory processes.

Experimental studies of the demonstration oil system on a standalone stand when working with simulator of oil chamber with two radial ball bearings have shown that provided a tenfold change in oil flow from 2 to 20 l / min at a pressure in outlet of supply oil pump 4 ... 5 kgf/cm^2. Delivery of scavenge oil pump exceeds supplying oil to the oil chamber 2…4-fold. These characteristics correspond to the conditions operation oil system with electrically-driven pumps on the engines.

4 Conclusion

The results of calculations and experimental studies of the characteristics of control systems, fuel supply and lubrication developed with using electrical technology, have shown that such systems provide a gas turbine engine work with the required characteristics for steady state and transient conditions.

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5 Contact Author Email Address

mailto: goulienko-contrl@ciam.ru

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