Research Journal of Applied Sciences 9 (11): 806-811, 2014
ISSN: 1815-932X

The Semi-Natural Test Bench with Virtual Gas Turbine Engine Model for Fuel Supply and Control System Characteristics Investigation

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Abstract: The review of semi-natural stands for studying the characteristics of the various systems of Gas Turbine Engine (GTE) is represented in this study. The study shows the semi-natural test bench for investigation the characteristics of fuel supply and control systems developed in Samara State Aerospace University (National Research University). The stand is different from the described analogs both using the mathematical model of the GTE and real aggregates. Some aspects of controlled object mathematical simulation and the basic approaches for its implementation are described. Developed bench is reported to allow us to simulate and define performances of whole fuel system and particular aggregates in steady-state and transient regimes of operation in the closed and open loop circuits. Additionally, it allows us to perform the analysis of available control system stability margins to carry out the interaction of separate circuits and aggregates to study influence of perturbations and external factors on control system fail safety.

Key words: GTE, fuel supply system, semi-natural bench, tests, parameters of system, mathematical simulation, remote access

INTRODUCTION

Experimental research and theoretical simulations of GTE and their systems are one of the most significant and necessary stages in their design process, further development, testing and certification. As a result experimental research of GTE Control Systems (CS) in the closed circuit are performed as a rule on semi-natural stands with a feedback where real CS equipment works with engine mathematical model. This is due to the tests of an engine control system are usually reduced to inspection of its reliability, serviceability in native construction or close to it, validation of required aggregates and GTE Systems characteristics before their installation on the real engine or aircraft. The problems solved by semi-natural stands are described by Fatikov *et al.* (2005) and (2). Necessity of semi-natural stands application originates if:

- The controlled object is in a design stage while the control units are actually exist
- The object cannot be tested in the laboratory conditions
- The control units have nonlinear characteristics, frictions and noises which were not considered in their equations
- Carry out of full-scale experiments on control unit adjustment on the real object is expensive or not acceptable

The method of integrated studies of GTE aggregates and its systems on semi-natural stands is described by Kulikov *et al.* (2009) and Pogorelov *et al.* (2013). It consists of carrying out of the whole complex of tests in real time with help of integration of real control monitoring and diagnostic systems with GTE mathematical models and its separate systems.

The process of development of GTE semi-natural models and its systems is described by Fatikov *et al.* (2005), Zarubin (2001) and Ryzhikov (2004). The conception of hardware, algorithmic and software support for GTE systems semi-natural simulations for all stages of its life cycle are considered in study (Godovanyuk, 2005).

The GTE mathematical models as a part of semi-natural stand should be adequate and provide real time interacting of engine mathematical model and real fuel aggregates. GTE models embedded into control system allow to execute not only adaptive control algorithms but also to ensure safe diagnostic of the engine and its systems.

The purpose of this study is the describing the semi-natural bench developed in the Samara State Aerospace University (National Research University). The bench includes real fuel aggregates and the mathematical model of gas generator.

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REVIEW OF SEMI-NATURAL SIMULATION STANDS

For the moment there are information in publicly available sources about a variety of stands and techniques providing the semi-natural tests of GTE and its systems. Inozemtsev *et al*. (2008) describes the bench for development of GTE elements mechanizing control laws. The bench consists of GTE Model, its casing (with the dismantled compressor's and turbine's rotors) with fuel metering equipment automation and air intake mechanization devices.

The bench in research (Fatikov *et al*., 2005) has a possibility of a comparative assessment of architectures of embedded real time systems by means of imitative and semi-natural simulations at early development cycles (Pogorelov *et al*., 2013; Balashov *et al*., 2006). This feature favorably distinguishes the bench from other existing solutions (Balashov *et al*., 2007).

In research (Brouwer *et al*., 2000) the semi-natural demonstrational CS with electric executive devices. The characteristics of this CS are selected for GTE AI-25TL used as the demonstrational engine. In research (Gurevich *et al*., 2005) the semi-natural demonstrational control and fuel supply systems of GE with use of electric drives is described.

Thus, the common for all described stands is the possibility to apply the mathematical models of all devices or a combination of both full-scale aggregates and mathematical models of some aggregates. Application of a particular approach depends on a degree of aggregates completion and a type of tests.

SSAU SEMI-NATURAL BENCH

The SSAU semi-natural bench for complex GTE study is based on using of a set of simulation methods, testing techniques and the software and hardware equipment.

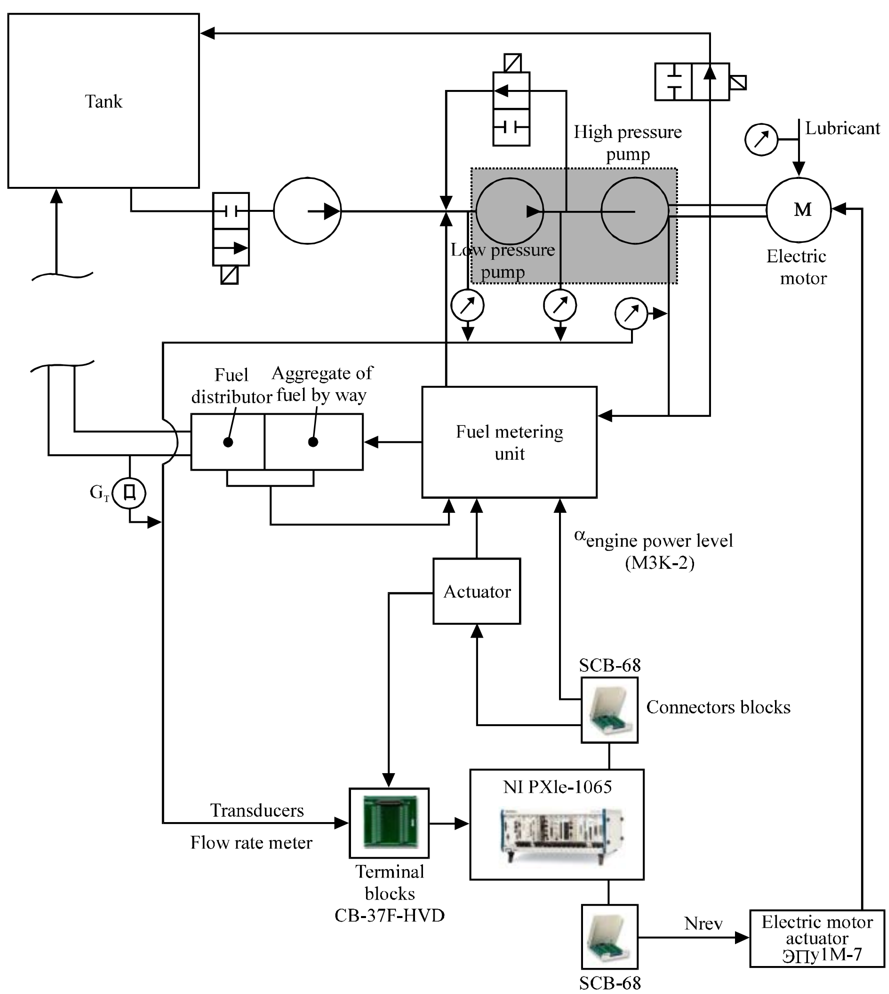

Fig. 1: The key diagram of the SSAU hybrid bench

The key diagram of the SSAU hybrid bench is presented in Fig. 1. PXI NI module includes the mathematical model of the engine which is explicitly described in research (Gurevich *et al*., 2010; Blyumin, 2012). The mathematical model provides control of fuel aggregates by three key control parameters:

- Rotational speed of the pump drive unit electromotor. It aligned with a GTE rotor rotational speed at a software level. The three-phase thyristor drive unit with a numerical control is used as a motor drive
- A Fuel Metering Unit (FMU) angle of pitch. It simulates the feedback signal from GTE to the FMU rotational velocity sensor
- An angle of the engine power control installed on FMU

The layout diagram of the developed hybrid bench for studying working processes of the full-scale fuel aggregates is given in Fig. 2. Imitation of fuel bypassing (drain) from aggregates which have not been installed was provided with installation of corresponding nozzles.

The simulation mathematical model needs the values of system parameters to accurate bench control. In practice pressures in key points and also flows in imitators of circuits of combustion chamber injectors are most required. Necessary values get unilaterally by pressure or flow sensors as well as by feedbacks from drive units (for example an angle of engine power control). Signal converters are necessary for the hybrid bench control by means of GTE virtual mathematical model. As a result, the electric drive of the engine power control mounted on FMU is installed in the system.

The hardware of the bench (processors, memory, converters, distribution panels, etc.) is assembled from the standard industrial computer equipment focused on real time operation. Models of the engine and its systems are created by means of visual simulation in software package LabView.

Operating conditions of full-scale aggregates have been made maximally close to real operation conditions. Therefore, conditions for location of full-scale aggregates in altitude-temperature chamber and on vibration tables have been provided.

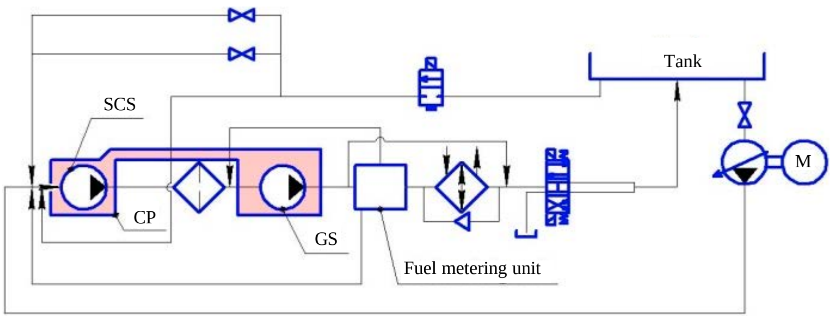

Fig. 2: The layout diagram of the hybrid bench; SCS: Screw Centrifugal Stage; CP: Centrifugal Pump; GS: Gear Stage

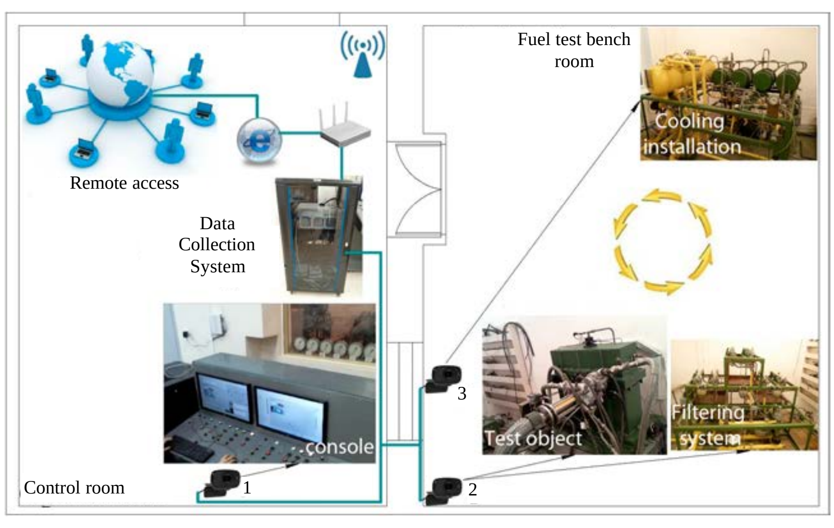

Fig. 3: The distributed network circuit

The developed semi-natural bench operates as a part of the distributed remote access network (Fig. 3). It allows using global network internet to perform experiments on the remote engine bench or to perform tests using flight data directly from the airplane.

Exterior participants are submitted a possibility to observe the tests or meagrely participate in their holding by getting the remote access through a multidropping server. Tests data are recorded in the special distributed database and stored there for the subsequent analysis and processing by means of a special server.

GTE MATHEMATICAL SIMULATION

Following operation of the engine is generally simulated: input air behind the ventilator is divided into two flows-internal G_{B1} and external G_{B2}. The whole internal flow is compressed by low and a high pressure compressors and enters a combustion chamber where fuel G_T is fed. The combustion chamber is simulated by the heat balance equation. The energy gained from fuel combustion in the combustion chamber is partially used up in the high pressure turbine and partially used up on the low pressure turbine and eventually goes to rotors rotation. An internal and external gas flows are mixed in the mixing chamber creating pressure, temperature and a gas flow rate at a nozzle entry.

Fan characteristics, the low and high pressure compressors are simulated within the entire low and a high pressure frequency range to realize a possibility to reproduce transient processes in the engine in full operating mode range (idling-take-off). As a result numerical values of parameters are obtained in all modes including idling.

The mathematical model includes two procedures of process gas generator dynamics reproduction. A part of this model uses a piecewise linear approximation principle for the throttle characteristics obtained experimentally from the real engine and other part is full-size.

The model is realized in a visual programming software package NI LabView that allows to perform hybrid tests of such models together with real hydromechanical aggregates using equipment of National Instruments company.

The control and measuring system of the semi-natural bench had been created by means of the package LabVIEW (Fig. 4). A set of system possibilities includes:

- Monitoring and processing parameters taken from flow, pressure sensors, rotational speed sensor of the pump rotor and the angle drive of fuel flow control unit
- Generate control action to change of a rotational speed of the pump rotor both in a manual mode and in a model mode operation with impact on engine control lever
- Drill and monitoring of alarm conditions

The front panel NI LabVIEW (Fig. 4) displays the full three-dimensional model of all control objects as a virtual gas turbine engine, its units and in general, bench in real time with image location of sensors that allows you to visualize some of the modes of their research and to provide a remote user design data units.

It is important for semi-natural test bench to establish a reliable protection system from failures both at the software and hardware levels. The bench implements

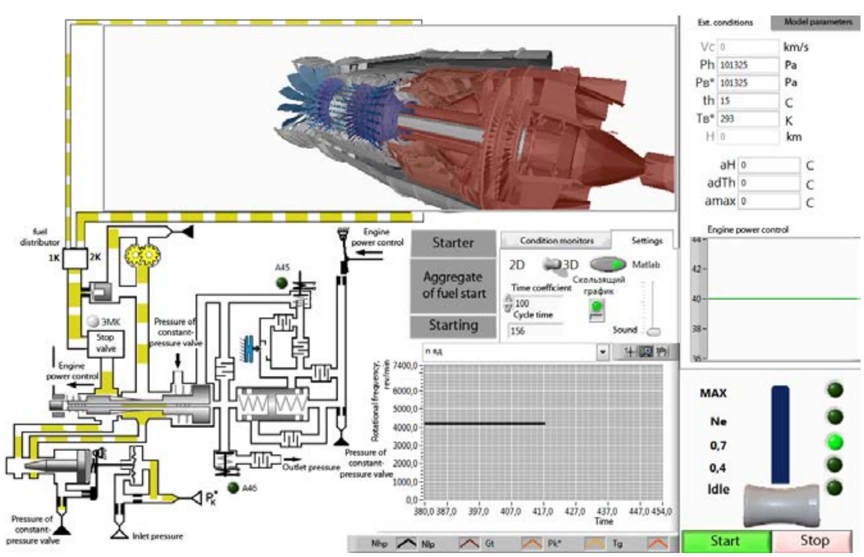

Fig. 4: Front panel of NI LabVIEW

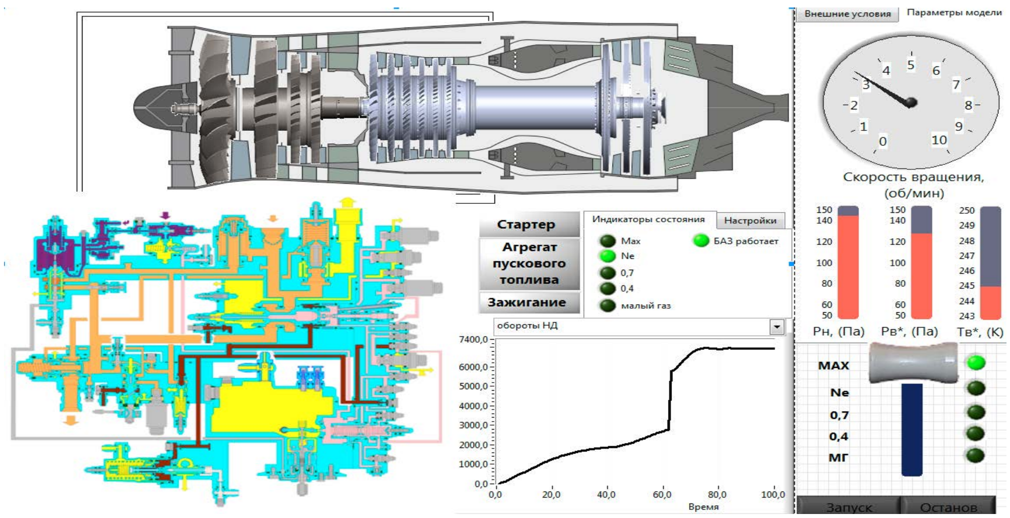

Fig. 5: A general view of the interface

protection on analog remote control bench systems as protection against accidental pressing, restriction of research units without preliminary oil and fuel injection and other. The program utilizes a protection against accidental rupture data with the bench which in its turn duplicated in analogue form on the remote control.

We had used LabVIEW Software as a programming language and it allowed the end user to quickly make changes in the mathematical model (Fig. 5). We used control design and simulation modules for the control system modeling. These modules include all the necessary virtual instruments for modeling of dynamic units in the system.

Various numerical methods for solving the differential equations for example, some kinds of a Runge-Kutta Method are accessible to the user. The model can be run with so quickly as it allows the computer and taking into account the real time that imitate the behavior of real engine when this is realized the possibility of user interaction with the simulated process. A general view of the program interface is presented in Fig. 5.

CONCLUSION

Developed bench allows to model and to determine the characteristics of system and its aggregates for steady and transient states modes of operation in closed-loop and open-loop schemes to analysis of disposable supplies of stability control systems to perform the interaction of separate loop and aggregates, to investigate the effect of perturbations and external factors, the performance of the control system failure. Bench allows to:

- Reduce the amount and timing of expensive tests on the engine and aircraft
- Obtain a certificate of compliance test object specified parameters immediately after the test while the product is on the bench
- Simulate accident conditions that are not permitted in the engine testing process

Universality of the bench is that it can be adapted for any control system investigation, regardless of the control type, components structure and their interconnection.

However, developed bench also has several disadvantages. The main of them at this point the engine model used in seminatural bench does not account of all pertrubations in the control system.

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