Digital Electronic Control of a Small Turbojet Engine MPM 20

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Abstract: Small turbojet engines represent a special class of turbine driven engines. They are suitable for scientific purposes and research of certain thermodynamic processes ongoing in turbojet engines. Moreover such engines can be used for research in the area of alternative fuels and new methods of digital control and measurement. Our research, which is also presented in this article, is headed toward these aims. We evaluate and propose a system of digital measurement of a particular small turbojet engine – MPM 20. Such engine can be considered as highly non-linear large scale system. According to obtained data and experiments we propose different model models of the engine and design of situational control algorithms for the engine with use of certain methods of artificial intelligence as new methods of control and modeling of large scale systems.

1 Introduction

The state of present technologies in technical and also non-technical practice implies creation of growing complexity of systems. Turbojet engine as a complex system is multidimensional highly parametric system with complex dynamics and non-linearities. Its particular property is operation in a broad spectrum of changes in environment (e.g., temperatures from -60 to +40 °C). If we want to secure optimal function of such system, it is necessary to develop models and control systems implementing the newest knowledge from the areas of automation, control technology and artificial intelligence (AI). The present control systems and dynamic models are often limited to control or modeling of a complex system in a certain (often operational) state. However, in practice the turbojet engine finds itself in very different working conditions that influence parameters of its operation and characteristics of behavior. By creation of algorithms of control, it is necessary to create models in the whole dynamic spectrum of the modeled system (turbojet engine) and also its erroneous states. Furthermore we need to design a control system that will secure operation converging to optimal one in all eventual states of environment and also inner states of the system represented by its parameters. Except implementation of classic algorithms of control, it is possible to design such systems of control and models by use of progressive methods of artificial intelligence [1]. In the article, we will focus on implementation methods of situational control as a framework method, which is suitable for use in design of dynamic models and systems of control of turbojet engines with use of intelligent elements that comply with full authority control digital systems standards.

2 Control Systems of Turbojet Engines

The main global aim of control of turbojet engines is similar to other systems and that is increasing their safety and effectiveness by reduction of costs. This demands application of new technologies, materials, new conceptions of solutions [7] and also development in systems of control and regulation of aircraft turbojet engines and processes ongoing in them.

Demands for control and regulation systems result mainly from specific properties of the object of control – a turbojet engine. Among the basic functions of control systems of turbojet engine belong the following ones – manual control, regulation of its parameters and their limitation. Manual control and therefore choice of regime of the engine is realized by a throttle lever according to a flight situation or expected maneuver. By regulation of a turbojet engine we understand such a kind of control where the chosen parameters of the engine are maintained on certain set levels, thus keeping its regime.

In the past the classical control systems of turbojet engines were implemented mainly by hydro-mechanical elements, which however suffered from deficiencies characteristic for such systems. Among such deficiencies were, high mass of such systems, inaccuracies due to mechanical looses and low count of regulated parameters. However development of electronic systems and elements is ongoing, which will allow to increase precision of regulation of parameters of turbojet engines and their count to secure more complex and precise regulation of turbojets.

Use of electronics and digital technologies in control systems of turbojet engines has brought: [7]:

- lowering of mass of control system
- higher complexity of control – The count of regulated parameters used to be 3 to 7 by hydro-mechanical systems, however the digital systems operate with 12 to 16 parameters;

- increasing of static precision of regulation of different parameters (for example, precision of rotations from ±0.5% to ±0.1%, precision of regulation of temperature from ±12K to ±5K
- increase in reliability, service life and economics of operation of the driving unit of an aircraft;
- easier backup, technology of use and repairs, possibility of use of automatic diagnostics.

By design of solution of a control system for a turbojet engine, it is necessary to build an appropriate mathematical model of the engine. The ideal approach to design of electronic systems is a modular one, from hardware or software point of view. This implies use of qualitative processing units that are resistant to noises of environment and also realization of bus systems with low delays is very important in this approach. Further improvement in quality of control can be achieved by implementation of progressive algorithms of control, diagnostics and planning in electronic systems. These algorithms have to be able to asses the state of the controlled system (turbojet engine in our case), then parameterize action elements and they have to be able to control the engine under erroneous conditions represented in outer environment or as errors in subsystems of the engine itself. Prediction of such states represents an area to incorporate predictive control system. Methods of situational control bound with elements of artificial intelligence supply many robust tools for solution of afore mentioned problems and sub-problems.

2.1 Basic Types of Control Systems of Turbojet Engines

From the point of view of use of electrical and electronic systems in controls the turbojet control systems can be roughly divided into following sets: [2]:

- electronic limiters,
- Partial Authority Flight Control Augmentation (PAFCA,
- ‘High Integration Digital Electronic Control’ (HIDEC); ‘Digital Engine Control’ - (DEC); ‘Full Authority Digital Electronic Engine Control’ – (FADEEC)).

The division of control systems into these three levels is not absolutely distinct, as systems on higher level as for example HIDEC system can utilize control mechanisms as electronic limiters. For example FADEC systems are often realized as single or double loop control systems with utilization of PI control algorithms or electronic limiters with estimation filters [6,13]. Example of such FADEC algorithm is shown in Figure 1 [6].

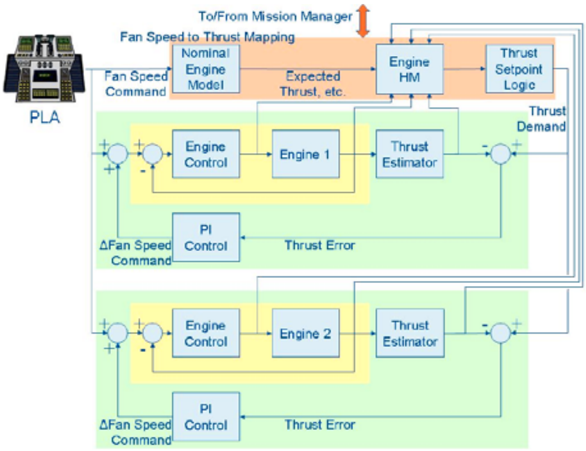

Figure 1

FADEC control system with implemented PI electronic controllers

Such engine control systems are often integrated into the whole framework of an aircraft control system.

2.2 FADEC Control Systems of Turbojet Engines

There are of course many possibilities and methodologies applicable to control systems of turbojet engines, which are FADEC compliant. Such application has to cope with strong non-linearity and changing structure of models and constants during operation of a turbojet engine. Such intelligent system should also be able to form decisions and predict faults either in control circuit or the object of turbojet engine itself. Therefore intelligent turbojet engine control is often bound with design of intelligent diagnostics systems [15] that also deal with control of an engine during its long-term deterioration. Example of such control based on diagnostics modules is shown in Figure 2.

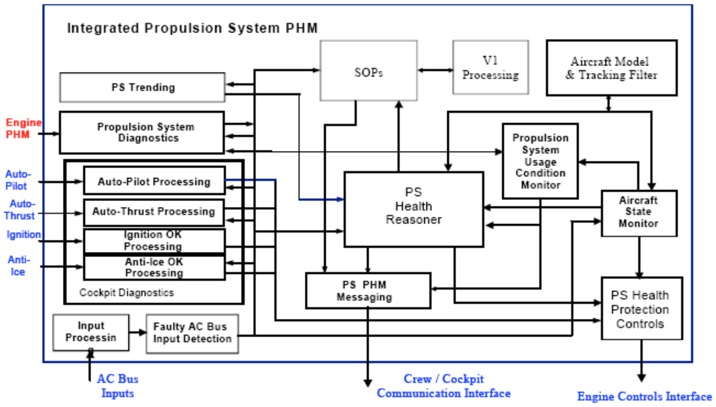

Figure 2
Diagnostic FADEC control system of a turbojet engine [15]

The control system in this case is based on intelligent PHM (Prognostics Health Management) of the engine. Diagnostic systems of turbojet engines can be further realized by means of artificial intelligence. In design of diagnostic and control system which would control the engine in its erroneous states and act long before actual critical states develops itself; we need to form exact dynamic models of the engine. In design of classic control systems only first to second order linear models are commonly used. Methods of AI however offer possibilities of modeling the dynamic parameters of an engine in multi variable space with great precision in the whole range of operation of engine. Such models can have precision within 2% of standard error in whole area of operation of a jet engine [1,2]. Integrated model used for control of a turbojet engine can be seen in Figure 1. Importance of modeling during operation of a turbojet engine can be further extended to fault detection of sensors and other parts of control system and the engine itself. In design of control system, the architecture also plays a significant role. Two common architectures can be presently found in design of turbojet engine FADEC control systems [13]. The first one is the centralized one, which is reliable and well understood, but on the other hand has many drawbacks like inflexibility, high weight, complicated fault detection, etc. This architecture is shown in Figure 3.

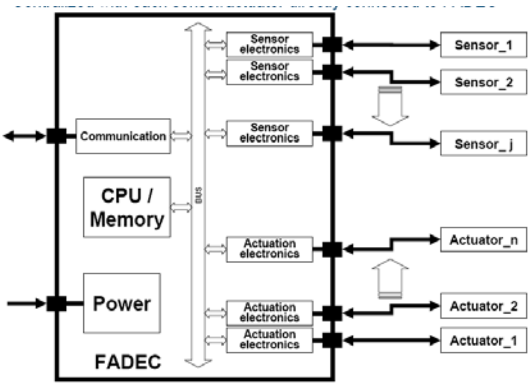

Figure 3
Centralized FADEC architecture [13]

The other usable architecture for design is the distributed architecture (Fig. 4). Its main advantage is high flexibility, easier fault detection and isolation, its cons are mainly higher complexity, communication unknowns and deterministic behavior and it requires new technologies, i.e. high temperature electronics for use in turbojet engines.

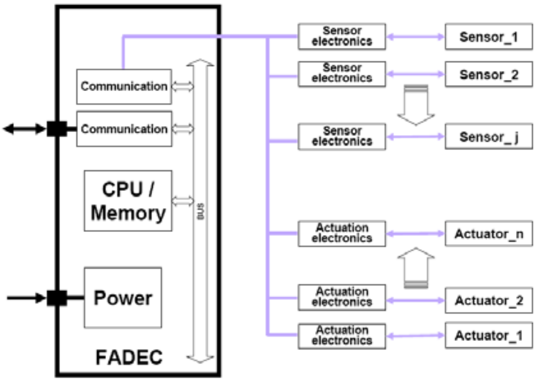

Figure 4
Decentralized FADEC architecture [13]

2.3 Methodology of Situational Control in Turbojet Engines

Methodology of situational control is one of the possible methods of control of complex systems [1,9], however it is necessary to say that as a frame method, it integrates in itself also other methods of control of complex systems. Situational control can incorporate methods of decentralized control, multi-agent system, catastrophe theory, ‘anytime control’, etc. The basic paradigm of situational control lies in the fact that a complex system can find itself principally in endless count of state, however resources, strategies and means of control of such system are usually limited. Solution of this problem lies in design of time invariant situational classes (frames) that have their strategies of control assigned.

Because, the creation of exact mathematical model describing all dynamic properties of a complex system like a jet engine is, use of methodology of situational control and modeling bound with data oriented methods of sub-symbolic artificial intelligence is a usable approach to design of models and systems of automatic control for turbojet engines. Neural networks and fuzzy inference systems show up here as appropriate methods implemented in hybrid architectures with paradigm of situational control. For example use of fuzzy inference systems by design of algorithm for control of cooling of turbine blades lowers absolute mean error in simulations from 5°C to 0.2°C compared to use of a classic relay regulator [1,3]. Similarly by use of a hybrid neuro fuzzy architecture bound with methodology of situational modeling a dynamic model of a small turbojet engine MPM 20 has been created with absolute percent error <2% across whole area of operation of the engine. [1,5]. The results show that use of these methods bound with modern algorithms of learning, we will be able to create a situational system of control of a turbojet engine with full authority.

3 Design of FADEC Control System for MPM 20 Engine

Small turbojet engine MPM 20 is constructionally derived from turbo-starter TS-20, which has been used for rotating a rotor of a normal sized engine by its start-up. The small turbojet engine MPM 20 is a single stream, single shaft turbojet engine with single stage one sided radial compressor, bound combustion chamber, single stage un-cooled gas turbine and fast exhaust nozzle [7].

3.1 Principle of Operation of a Small Turbojet Engine MPM 20

Air is flowing into rotating rotor of compressor. After pressing the air, the whole temperature is increasing, static temperature, static pressure and speed of air are also increasing, The air is flowing from the compressor in radial direction and enters diffuser that changes the kinetic energy of the air into pressure. The diffuser also divides air uniformly for the combustion chamber. In the combustion chamber, chemical energy of fuel is change into temperature. The gas turbine changes the pressure and temperature energy of gases into kinetic energy and further into mechanical work. The stator is created as a system of narrowing channels, where potential energy of gasses. The gasses flowing through the rotor change their moment of movement and create work of the turbine which drives the compressor. Beyond the turbine, the gasses have still higher pressure than the outer atmosphere and are flowing into the outlet. In the exhaust nozzle the temperature and pressure energy is changed into kinetic energy that creates thrust of the engine [5].

3.2 System of Automatic Control of MPM 20

3.2.1 Stabilization System of MPM 20

The control system of MPM 20 is corresponding to its purpose as a single regime turbo-starter of a normal sized turbojet. This control system stabilizes the work of the engine on one preset regime. (that means one level of rotations per minute of its rotor). Control of the engine is realized by aggregate, which can have preset level of fuel flow by start-up of the engine and for the regime of its stable operation. In the regime of stable operation, the fuel system is influenced by an action element, which works as a proportional transfer element (P element) according to pressure P_2 (pressure beyond the compressor). That means that by lowering of pressure supplied by the compressor the fuel from the fuel pup is run into backline and fuel supply is thus lowered into engine, what bring decrease in rotations per minute. The function of this element can be described as:

$$Q_{pal} = f(P_2) \tag{1}$$

This system is stabilization system of the engine, because it proportionally increases fuel supply by startup and secures stable and safe operation of the engine, because it is a robust hydro-mechanic element. This system however doesn’t allow dynamic changes in regime during operation of the engine, because the constant of amplification of the element given by stiffness of the spring is preset to a constant level and the engine works on constant rotations. Operation of the engine is possible in the constructionally most straightforward variant by implementation of a system of releasing the air from this action element by a controlled release vent.

3.2.2 Digital Control of MPM 20 Engine

Because our aim is hardware and software implementation of a digital system of automatic control of MPM 20, control of the air release from the action element is realized by a circuit including gate valve, oil-fuel pump 414AF-3 and PIC 16F84A microcontroller. To manipulate with the gate valve a servo-vent is used, and this servovent is controlled by PIC 16F84A microcontroller. The basic structure of this control circuit loop is shown in Figure 5.

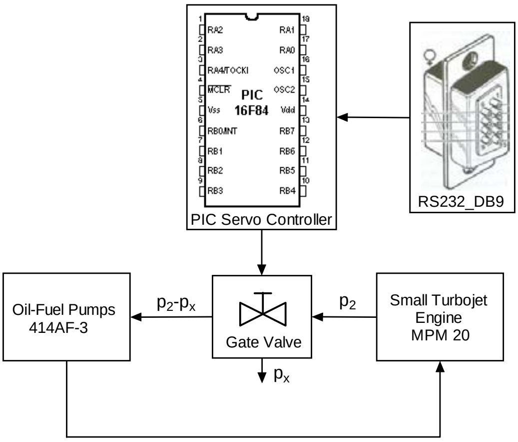

Figure 5
Control circuit loop for digital control of the MPM 20 engine

The gate valve acts as an air vent, which releases a certain amount of pressure, thus decreasing the pressure on the feedback fuel line in oil fuel pump 414AF-3, so the resulting pressure can be expressed as (P_2-P_x) *[at]*. Because the action element acts as a proportional transfer element by decreasing pressure in front of the oil-fuel pump, we decrease the amount of fuel flowing into the engine. Full digital control system with digital realtime measurement system is shown in Figure 6.

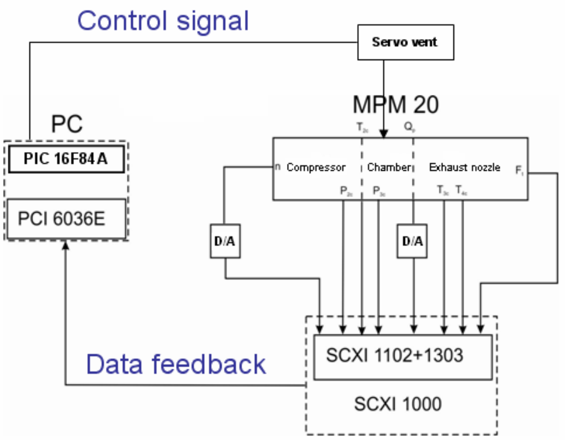

Figure 6
Fully digital control circuit for MPM 20 engine

3.2 Situational Control System Design for MPM 20 Engine

By design of control system for the MPM 20 engine, we consider two basic approaches. In broader scope it will be the situational control methodology and control by a single parameter and in more focused scope it will be anytime control and control by two parameters. The proposed structure of situational control system uses paradigm and schemes described in [3] or in [8]. The whole conception of the situational control system is decomposition of operational states into time spaced situational frames (classes) and every situational frame has one corresponding control algorithm (or controller) assigned to it. Anytime control techniques are more focused because their aim is to control the system in specific critical states or situational frames. By those critical states we mean the deficiency in data for the controller due to system's overload or failure of certain components in control circuit. Anytime control techniques offer possibilities how to avoid these critical states, so that the controlled system would flexibly react to changes of outer environment and could survive deficiency of processing time, data and resources [16].

In development and design of FADEC (Full Authority Digital Engine Control) compliant control system, situational control methodology approach has been used. It is similar in to the one described in previous chapter, what means we use a gating neural network as a classifier of situational frames and system of controllers to handle those situational frames. We use concepts of traditional situational control and formatter control of complex systems [3]. The system has been described in [2] or in [8]. The resulting physical architecture including analyzers of input (X), state (Z), output (Y) and desired (R) parameters is shown in the Figure 7.

Blocks designated as $S_{i,j,k}$ represent controllers for different situational frames, which result from the situational decomposition of operation of the engine in three levels [1]. Within the frame of anytime control methods, we will deal with proposal of a simplified dynamic model of the small turbojet engine. The model will incorporate two input parameters compared to the more complex situational model, which is dependant on the fuel supply parameter only. The model will result from measurements of change to fuel supply and different cross-sections of exhaust nozzles. Simulation of temporary failure in input data (sampling errors) of the system (or designed dynamic model). Design and implementation of anytime control algorithm for the constructed mathematical model and critical states. This will include design of multi-parametric system of automatic control, in our case with two inputs and multiple outputs. Research and observation of flexibility and quality of regulation of the designed system according to measured data and other possible critical states of action units (for example in case of blockage of outlet nozzle or total failure in data measuring current cross-section, etc.). Approaches that lie under the terms 'anytime control', 'anytime processing' serve for proposal of decisions in real time. They are intelligent supervisor systems using interactive algorithms and have a modular structure [16].

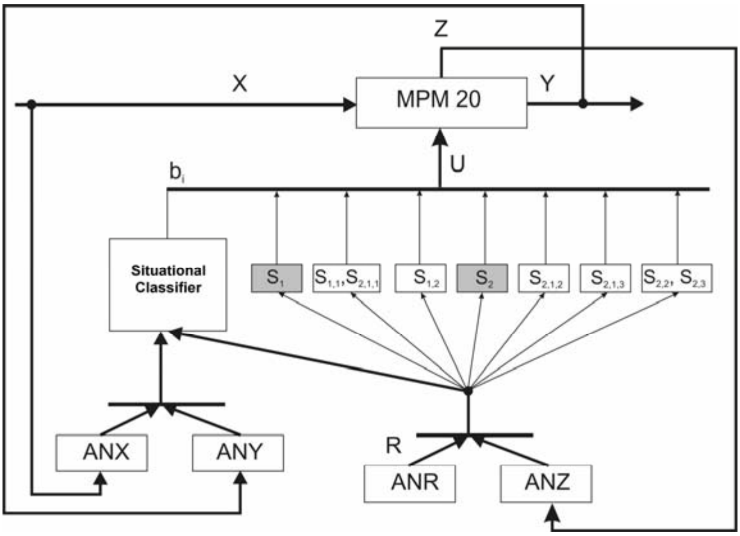

Figure 7

Situational control system architecture for MPM 20 engine

Conclusions

The object of a small turbojet engine MPM 20 provides us an ideal test bed for research of methods in the areas of non-linear dynamic systems modeling and design of advanced control algorithms. Further research will be done in the area of situational modeling that will be headed towards broadening of input parameters of the situational model of the engine and further refinement of situational classes designation. In this area we will be aimed at use of automatic algorithms to find boundaries between situational frames within multivariate space of parameters contrary to their setting by an expert. Anytime control algorithms represent other area of our interest with great possibilities of application of intelligent algorithms that will deal with critical states of operation of the engine and will be further embedded in the whole system of situational control of the engine. Design of such algorithms demands also further refinement of proposed models. All research in the areas of situational modeling, situational control and anytime algorithms should bring new quality of control and modeling in the area of turbojet engines and we expect this knowledge to be also expanded to other areas of technical systems.

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