Advanced Methods of Measurement and Situational Control of a Small Turbojet Engine

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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. According to obtained data and experiments we propose models of situational control of such engine with use of certain methods of artificial intelligence. Resulting global model is aimed at cooling of such engine under certain regimes of operation and may also be expanded onto more complex engines.

Keywords: turbo-jet engines, artificial intelligence, neural networks, digital measurement

1 Introduction

Present state of technological development and growing complexity of systems offers many challenges and also opportunities to achieve better results. In the area of jet propulsion, terms like safety, economic profitability and at the same time high efficiency come into foreground. The traditional systems of control are becoming obsolete and a with the need to satisfy the mentioned terms it is needed to incorporate the newest technologies of control even for use in older systems to bring them up to nowadays standards. It wouldn't be economically favourable to test such technologies within expensive and also very complex big turbojet engines also with regard to safety. Therefore a special class of turbojet engines designated as small turbojet engines can be used as an ideal test-bed for differently aimed experiments in this area. Our research is headed towards three basic aims.

1 Digital measurement of turbojet engines, which means digital real-time measurement of different state and diagnostic parameters of such engines.

2 Design and implementation of new control algorithms of turbo-jet engines, especially the situational control algorithms incorporating methods of artificial intelligence.

3 The aim resulting from the previous points is to explore possibilities of use of alternative fuels in turbojet engines.

All these aims comply and put emphasis mostly on safety issues of turbo-jet engines. Other special feature resulting from our third aim is direct use of old obsolete small turbojet engines as sources of energy with use of cheap alternative fuels. We have to take in consideration that there exists a huge number of such small turbojet engines in old aircraft that are in non flying condition. Such engines can be refurbished and used again for other purposes. All knowledge obtained by experiments with such engine can be expanded to higher levels and certain principles may be used for design of particular algorithms of control that could also be used in normal class turbojet engines.

2 Turbojet Engines

Aircrafts' turbo-compressor engines represent one specific class of complex systems. They represent high dimensional objects of control with the existence of cross bindings between inputs and outputs which are created by the complex thermo-mechanical processes ongoing in the inner parts of an engine with dominating load. Except the poly-functional and crossing dependencies also other dependencies may arise by synthesis of the control elements, which can seriously influence the functionality and integrity of the whole mechatronic object (engine+aircraft). General aim of control of high dimension objects, objects with s_{ij} parameters is to obtain the optimal quality and stability of the whole control circuit. Techniques of solution of this task are represented by two basic approaches [3]:

1 Achievement of local extremes (minimum, or maximum) of every of the control variables. This approach is the most common one nowadays. The effective method by this approach is the comparison of desired parameters of an engine with the actual parameters, by a certain control system.

2 Achievement of a global (general) extreme by a general quality marker which is dependant upon all control variables. Such marker may be specific fuel consumption by an aircraft turbo-compressor engine which is the resulting variable of a whole complex of parameters.

For evaluation of control quality, except these main approaches, other criteria are used, as susceptibility of a system to changes of object characteristics. Small susceptibility of a system to changes of object parameters has a great impact for function of the whole system. Also from this point of view, it is suitable to use methods of situational control and situational classes with according control algorithms. This means control of an engine, also in its critical states and thus to secure low susceptibility of the control system to erroneous state of the engine.

As mentioned before ATCE (Aircraft Turbo-Compressor Engines) are characterized by some unique characteristics compared to other engine classes (rocket, scramjet, piston, atom). Also from the complexity point of view the individual types of ATCE differ greatly. ATCE can be generally divided upon the basis of technical design into the following classes [10]:

1. According to the number of shafts (single shaft, double shafts, ... , n-shafts)
2. According to the number of air streams (single stream, double streams, triple stream)
3. According to the compressor type (radial, axial)

The basic scheme of a double shaft, single stream ATCS is shown in the following figure:

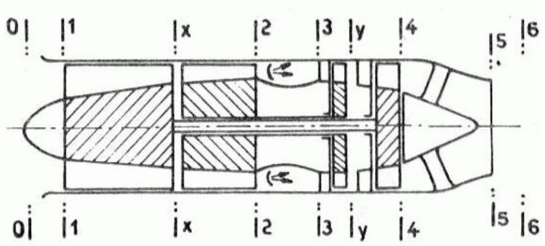

Figure 1

Scheme of a single stream double shaft engine [14]

2.1 Small Turbojet Engine MPM 20

Our experimental engine has been derived from the TS – 20 engine, what is a turbo-starter engine previously used for starting engines AL-7F. The engine has been adapted according to [11] and used in experiments described in [11]. According to this rebuilding, the engine has been rebuilt to a state, where it represents a single stream engine with radial compressor and single one stage non-cooled turbine and outlet jet. The basic scheme of the engine is shown in the Figure 1.

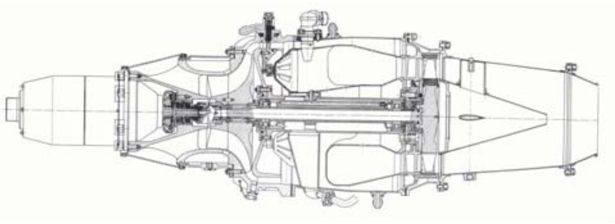

Figure 2
Scheme of the MPM 20 engine [11]

The following parameters are measured, in order to obtain a model of this engine.

- air temperature at the outlet from the difusor of the radial compressor - $\mathbf{t_{2C}}$;
- gas temperatures infront of the gas turbine - $\mathbf{t_{3C}}$;
- gas temperature beyond the gas turbine - $\mathbf{t_{4C}}$;
- static pressure of air beyond the compressor $\mathbf{p_2}$;
- static pressure of gases infront of the gas turbine $\mathbf{p_3}$;
- static pressure of gases beyond the gas turbine $\mathbf{p}_4$;
- fuel flow $\mathbf{Q_{pal}}$;
- rotations of the turbine/compressor, $\mathbf{n_1}$.

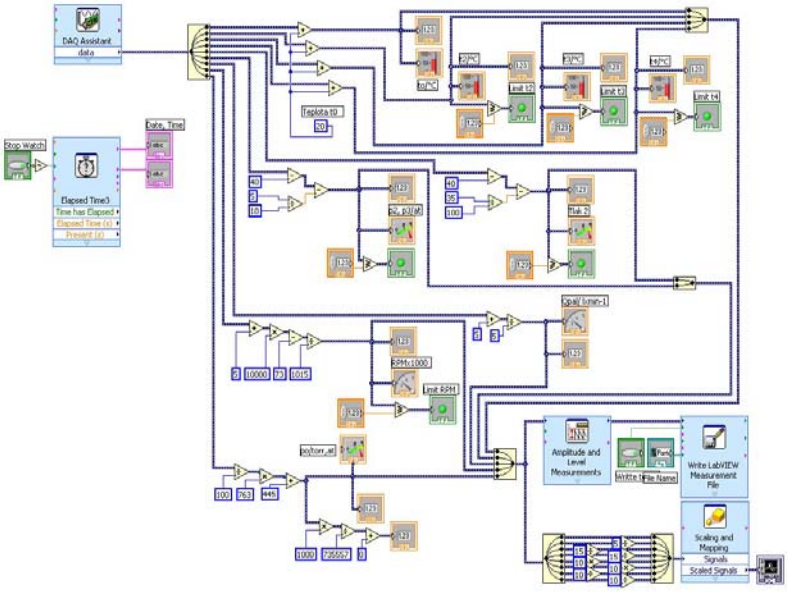

Figure 3
Scheme of the measurment circuit

The scheme of measurement including all sensors needed is shown in the Figure 3. All sensors, except fuel flow and rotations sensor, are in fact analogue which in and have voltage output. This is then digitalized by a SCXI measurement system and corresponding A/D converter and sent through a bus into computer. Every parameter is measured at a sampling rate of 1 KHz (that means acquiring 1000 samples per second). The whole scheme of measurment is shown in Figure 3.

The whole arangement of the measurment chain and engine in the experimental room, is shown in the Figure 4.

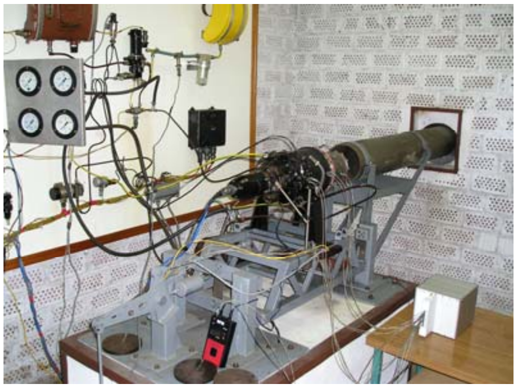

Figure 4

Experimental engine MPM 20

The engine is only allowed to run for 60 s. at current fuel flow input. This limits the measurments only to this extent, but it is sufficient time to observe its startup and stable regime behaviour. From the diagnostic and control point of view, temperature behind the turbine T_4 is most important. The following graph shows course of temperature during one engine run.

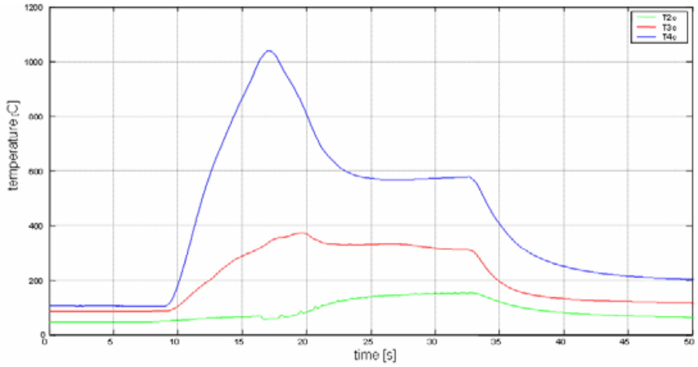

Figure 5

Temperatures of the engine during one run

The figure shows start-up condition of the engine till time 25 seconds. We can see the temperature T_{4c} to rise up to 1100 Celsius degree. This indicates a dangerous state of the engine due to possible damage by such high temperatures. The aim of control of this engine is to neglect such state and at the same time to secure its optimal work during its stable regime. The other aim of modeling and control is to design cooling of this engine to secure its longer operation and to enable us to use alternative fuels.

3 Situational Control of Turbo-jet Engines

Situational control was designed for the control of complex systems, where the traditional cybernetic models weren't sufficient [7]. Model proposed in [9] wasn't sufficient to control systems characterized by features like unique, dynamics, incompleteness and indeterminacy of description, ambiguity and presence of a free will. For systems, where it is difficult to describe their specific structure and behavior and where the presence of a human factor has an unforeseeable character and also where the system is developing by itself in time, methods of situational control have been developed [8]. More general approach to situational control is formatter control of complexes [1] Formatter control of a complex means not only the control of its parameters, but also the control of the form of a complex. Following scheme is showing the functional scheme of situational control of a complex system [8].

For the design of a system respecting the requirements of control in anytime, the following algorithm is proposed [8]:

a) description of the structure and function of the controlled complex system,

b) global goal designation,

c) classification of erroneous operational states and their causes,

d) classification and description regimes functions of the control, that are assigned to individual erroneous states,

e) algorithmization of individual regimes of control,

f) implementation.

3.1 Situational Control of Small Turbojet Engine MPM - 20

To design such control algorithm for the mentioned engine we will focus in this article only on point d) to f), which represent key elements in the case of our small turbojet engine.

According to Figure 5, we can define three basic situational frames. The first one would represent the startup of the engine. The second regime would represent stable operation of the engine and its regulation by means of fuel flow reduction and the third one would represent cooling regime of the engine. Every situational frame needs other regulation approach.

1 **Situational frame 1** – aggressive reduction of fuel flow in order not to exceed maximal construction temperature of turbine and to diminish temperature's overshoot.

  Strategy of control – control according to pressure beyond radial compressor $\mathbf{p_2}$**.** At the present state this is done by means of proportional two stage regulation.

2 **Situational frame 2** – stable operation of engine. This frame represents the stable operation of the engine. The engine has to be susceptible to control inputs and respond to desired levels of rpm's, which represent the state parameter of the engine

  Strategy of control – the control has to be done with regard to desired rotations per minute of the engine and regard to temperature beyond the turbine, which cannot exceed its maximal values and also maximal rates. Fuzzy algorithms are proposed for this purpose.

3 **Situational frame 3** – cooling regime. This frame represents a regime where, the temperature T_{4c} is being lowered by at least 200 [C^0] to cool the blades of the turbine to allow their cool down. This regime is extremely important by use of alternative fuels – as the planned hydrogen.

  Strategy of control – limit of the fuel input with regard to temperature beyond turbine $T_{4.}$

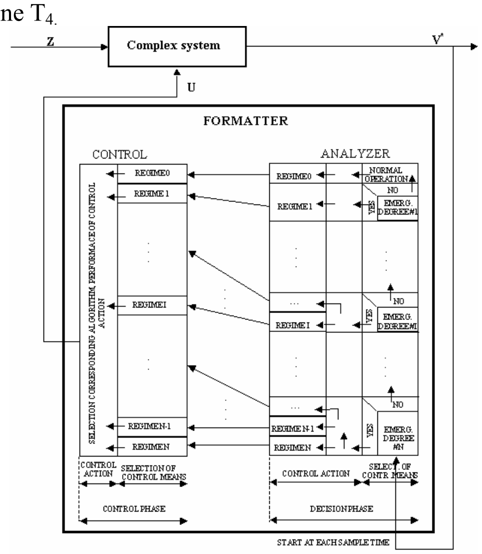

Figure 6
The functional scheme of a cycle in situational control

In the basic approach, we have to be able at first classify any of the regimes in real time and according to the classified frame engage the needed regime. Therefore the following global architecture of the control system is proposed.

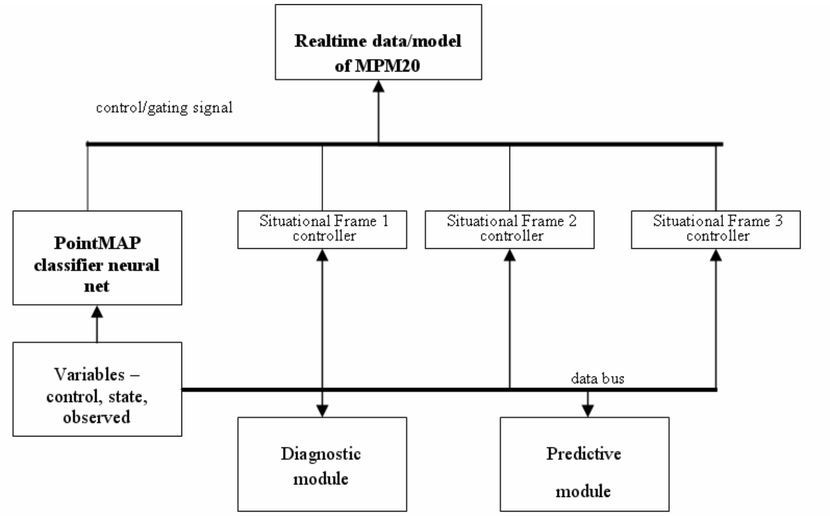

Figure 7
The functional scheme of a cycle in situational control

The neural network of PointMAP architecture is used as the classifier. It represents a progressive memory based learning system that continuously evaluates the information value of each of its coding nodes and that uses the information value to prune nodes both during and after training [2]. It transforms the multi dimensional space of engine's parameters into control signal which engages the individual controlers according to actual state of engine. Situational frame controller is in the present state designed as a distinct electro-mechanical system. Controllers 2 and 3 are proposed as software fuzzy controllers. The algorithms expanded to more complex models can be found in this work [5]

3.2 Design of the Fuzzy Turbine Blades Temperature Controller

One of the proposed regimes of the engine is the cool down regime, where it is necessary to lower the turbine blades temperature, either due use of alternative fuels such as helium, which produce high temperature or to lengthen the operation of our engine. One of our aims of research is to design cooling mechanism for cooling of normal sized turbojet engines and our small engine is used only as high temperature gas flow generator.

The temperature beyond turbine parameter is crucial for whole optimal operation of engine. Higher temperature at the turbine means higher output and lower fuel consumption. So if the engine is running at its maximal regime the point is to obtain and keep the highest possible temperature outside the turbine while keeping the blades at their maximum allowed construction temperature limit. Cooling systems that are presently used are usually done by the traditional relay systems. Despite their high reliability degree they are not able to obtain good quality of control. To obtain better quality of control a fuzzy regulator was proposed and to be able to control the system in it's erroneous states. Mamdani type PD fuzzy regulator is used. This means our fuzzy regulator is a MISO system (Multiple Input Single Output). Following simplified equations are used to describe the system:

$$T_0 \frac{d\nu}{dt} + \nu(t) = -k_0 \varphi \tag{1}$$

T_0 – time constant of the actuator engine

k_0 – coefficient of the cooling efficiency

φ – angle of opening of the cooling system

Equation describing the actuator in a simplified form is:

$$T_m \ddot{\varphi}(t) + \dot{\varphi}(t) = k_1 u \tag{2}$$

T_m – time constant of the actuator

k_1 – coefficient of the mechanical reduction

After incorporating equations (1) and (2) into a global control circuit using PD (described in a more precise way in [6]) fuzzy regulator following results shown in Figure 7 are obtained. This shows that this regulator is much more efficient and precise than the relay control system. The results of the fuzzy controller compared to a traditional mechanism of different modeled relays (relay 1 – without hysteresis, relay 2 – with single hysteresis, relay 3 – with double hysteresis). The simplified equation describing the relay with double hysteresis is shown in the following figure:

$$T_0 T_M i^{(3)}(t) + (T_0 + T_M) i^{(2)}(t) + i^{(1)}(t) = \begin{cases} k_0 k_1 k_2 B\_while\_|i| < C; \\ -k_0 k_1 k_2 B\_while\_|i| > C \\ -k_0 k_1 k_2 B\_while\_|i| < C \\ k_0 k_1 k_2 B\_while\_|i| > C \\ k_0 k_1 k_2 B\_while\_|i| < C, etc \end{cases} \tag{3}$$

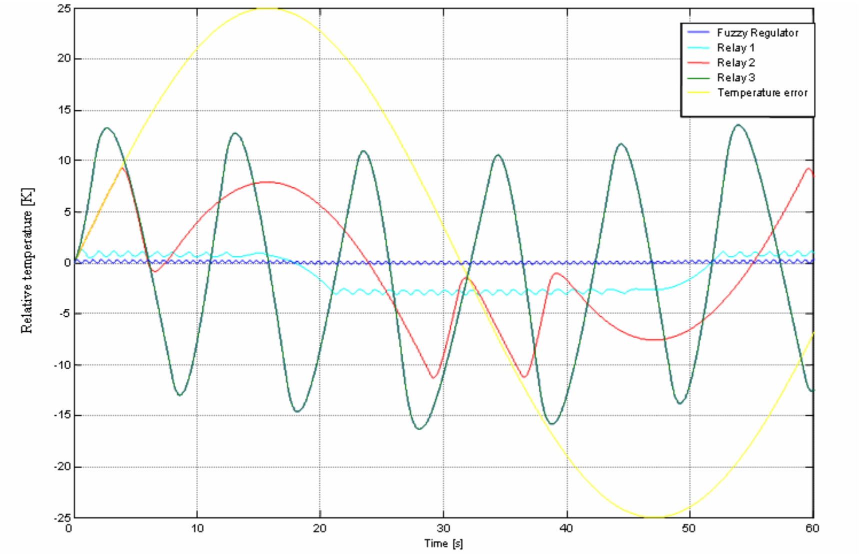

Figure 8

Fuzzy cooling control system

The figure clearly shows that regulation by a fuzzy controller brings considerably better results than any of the relay controllers. This controller will be further used in the whole situational control algorithm as shown in Figure 7. Possibilities of use of such regulation and other types of control systems using intelligent methods [12] will be further investigated with coolled turbine blades type.

Conclusion

Situational control of complex system is based upon the situational classification, situational estimation and situational recognition of an actual situation into premeditatedly prepared situational frames (classes). A corresponding control strategy (regime) is then associated with these frames, which has to secure a function of the complex and according to circumstances also its return into a normal, or desired state. Together with the mentioned problem areas, questions of proposal of general control architecture come into foresight and also incorporation of principles and methods of artificial intelligence allowing adaptation not just in offline, but also in online mode of operation [13]. The proposed system is one of the possible realizations of situational control of a small aircraft turbo-compressor engine with hybrid neuro-fuzzy architecture, which can be also expanded to real sized turbojet engines. The methodology is also suitable to meet the requirements of use of alternative fuels in small turbojet engines A system using methods of situational control will bring more optimal and safer operation of these engines.

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