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CHECKING AIRCRAFT ENGINES ADJUSTMENT

Kontrola regulacji silników samolotu

Abstract: *The paper presents a new approach to the process of regulating the basic parameters of a turbine jet engine. It presents a system for monitoring these parameters developed and put into operation and the creation of the so-called phase mapping of the engine speed increment. Its modular structure is described, which allows it to be adapted quite quickly to other types of aircraft engine units. Individual modules are based on mathematical descriptions from the theory of aircraft engines. The phase mapping of the engine speed indicates a dynamic change of this parameter. On this basis, the characteristic ranges and individual points of engine operation are presented. The following are examples of characteristics and their interpretation.*

Keywords: turbojet engine, aircraft engine, aircraft engine adjustment, engine speed, phase portrait

Streszczenie: *W artykule przedstawiono nowe podejście do procesu regulacji podstawowych parametrów turbinowego silnika odrzutowego. Przedstawia opracowany i wprowadzony do eksploatacji system monitorowania tych parametrów oraz tworzenia tzw. odwzorowania fazowego przyrostu prędkości obrotowej silnika. Opisano jego modułową budowę, co pozwala na dość szybkie przystosowanie go do innych typów silników lotniczych. Poszczególne moduły oparte są na opisach matematycznych z teorii silników lotniczych. Odwzorowanie fazowe prędkości obrotowej silnika wskazuje na dynamiczną zmianę tego parametru. Na tej podstawie przedstawiono zakresy charakterystyczne i poszczególne punkty pracy silnika. Zaprezentowano również charakterystyczne przykłady i ich interpretację.*

Słowa kluczowe: silnik turboodrzutowy, silnik lotniczy, regulacja silnika lotniczego, prędkość obrotowa silnika, portret fazowy

1. Introduction

The problem of aircraft engine adjustment is a very important issue from the point of view of flight safety and engine lifetime [3]. An innovative solution supporting adjustment process is the newly developed system for monitoring and diagnosing SO-3 type single-flow turbine jet engines built-up on training aircraft of Polish type TS-11 [1]. Individual system modules are based on mathematical descriptions from the theory of aircraft engines, and the basic relationship between the technical conditions of: thermodynamic cycle of the engine, fuel and kinematic system results from the relationship:

$$\frac{d^2n}{dt^2}+a(n)\frac{dn}{dt}+b(n)n=f\left(m_{pow},m_{pal}\right)\approx f\left(Q_{pal}\right),\ \frac{dn}{dt}=const\frac{M_T-M_S-M_{agr}}{I} \qquad (1)$$

where: n – engine speed;

m_{pow} – air mass flow rate;

m_{pal} – fuel mass flow rate;

Q_{pal} – fuel volumetric flow rate;

I – engine moment of inertia;

M_T – turbine torque;

M_S – compressor torque;

M_{agr} – torque of other engine energy auxiliary units (drive boxes, aggregates, friction etc.).

The block structure of the modules entering the jet aircraft monitoring system is shown in fig. 1.

It is a diagram presenting the possibility of expanding the system with additional modules for the purpose of adaptation to other aviation power units. The blue color shows the line connecting the modules necessary to monitor the operation of the SO-3 (SO-3W) turbine jet engine, while the red color shows the modules that allow the monitoring of the turboprop engine, e.g. the M601T type that drives the PZL-130 "Orlik" aircraft. An analysis of this model indicates that the operation of the aviation power unit is the result of the relationship between the fuel flow rate set by the position of the *DSS* engine control lever and the rotational speed of the n_{TS} turbocharger. In the case of a turboprop propulsion system, this is additionally the result of the relationship between the position of the *DSSŚ* propeller pitch control lever and the rotational speed of the propeller $n_Ś$.

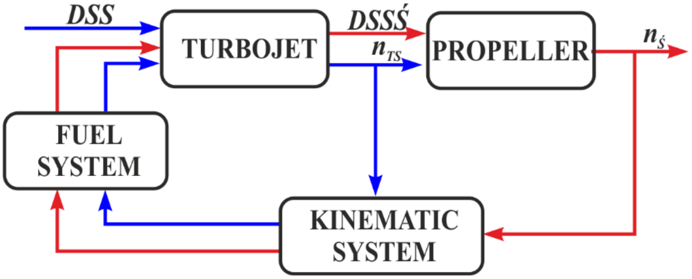

Fig. 1. Diagnostic block model of an aviation power unit: blue line - for SO-3 engine, red line - for M601T engine; DSS - engine control lever, DSSŚ - propeller pitch control lever, n_{TS} - turbocharger rotation speed, $n_{Ś}$ - propeller rotation speed

Analysis of the state of adjustment and at the same time the technical condition of the power supply system based on the above-presented block model is possible using the so-called expert model, based mainly on the rule table module and database (fig. 2).

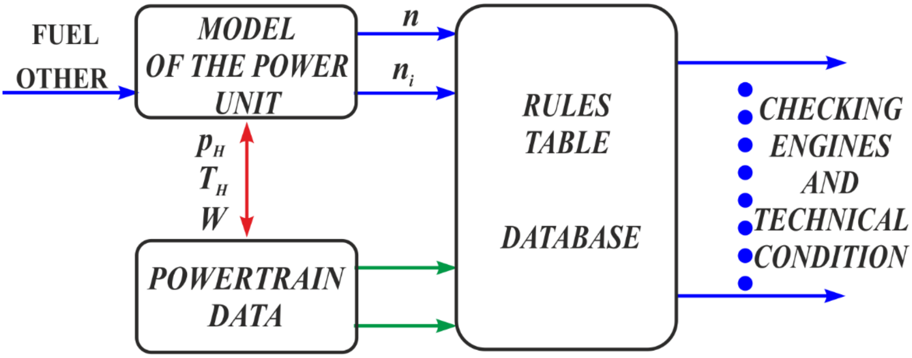

Fig. 2. The concept of an expert system for analyzing the work of aviation propulsion units: n_i - rotational speed, p_i - analyzed operating parameter, p_H - ambient pressure, T_H - ambient temperature, w - humidity

The system uses the concept of minimizing the number of control signals observed (engine operating parameters). After quantitative and qualitative analysis of the differences between the obtained phase portrait of the analyzed power unit and the reference portrait, it was found that a sufficient signal to identify the adjustment status and technical condition of the power supply units is the engine speed n. In the case of engines turboprop or multi-rotor, generally speaking, an additional signal is the rotational speed of the propeller or second rotor assembly n_i.

A very important element is also the methodology of recording the signals, which allows the correct identification of the scope of work of the propulsion system. For single-flow turbine jet engine SO-3 (SO-3W), the signal registration process is carried out during the ground test, but only in the phase marked in grey in fig. 3.

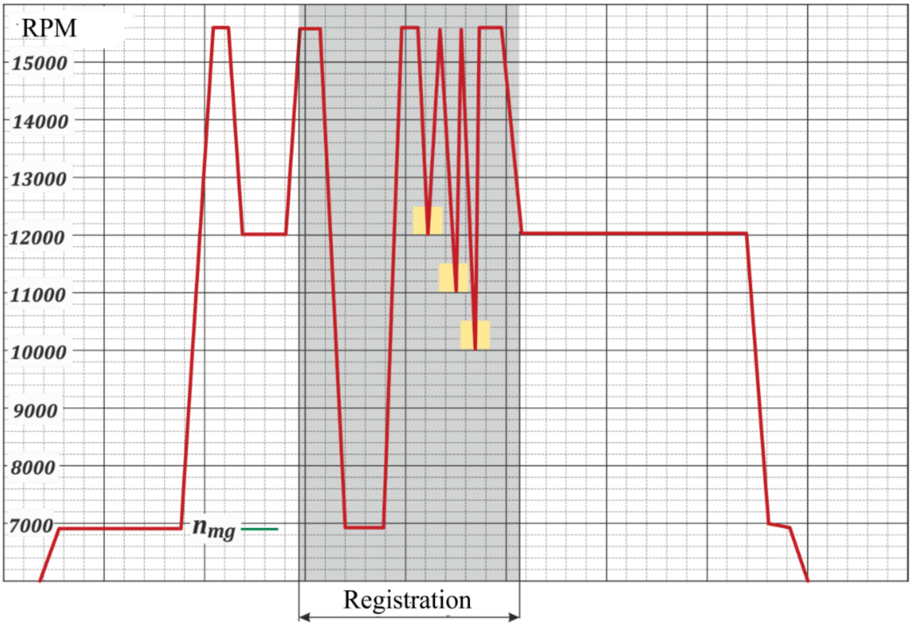

Fig. 3. Time course of the ground test on a single-flow engine SO-3 (SO-3W)

This range is the deceleration of the engine from the maximum range to the range of low gas rotation speed, waiting for the rotation speed to settle in this range and acceleration from the low gas range to the maximum speed range. From the maximum range, after determining the rotational speed, a cycle of three so-called repetitive accelerations.

This is accomplished by abruptly moving the DSS engine control lever from the maximum to the minimum range and simultaneously observing the speed value. As soon as the rotational speed drops to 12,500 rpm, the DSS is moved rapidly from the minimum to the maximum range. At the same time, the rotational speed is observed on the indicator after reaching the maximum rotational speed range again, followed by rapid DSS adjustment to the minimum range and observation of the rotational speed.

When the value of 11,500 rpm is reached, the DSS rapidly switches to the maximum range. The next, third acceleration is carried out similarly, with the only difference that after reaching the rotational speed of 10,500 rpm there is a rapid DSS change from the minimum to the maximum range. Within the maximum range, the speed is set and in principle the signal recording can be switched off after that.

2. Results

For the quantitative and qualitative assessment of transient processes (acceleration, deceleration and renewed acceleration), the majorant and minorant methods were used. Acceleration and deceleration majorants create a contour that limits the working area of the engine. Acceleration and deceleration minorants create a contour inside the workspace that determines the maximum duration of the engine transients. The shape of majorants and minorant depends on the environmental conditions at which the test was carried out and on the structure of the fuel system.

The influence of individual operational and factory adjustment points and damage to SO-3 engine fuel system aggregates on the dynamic characteristics of the system is determined by the method of variable separation (quantitative assessment while maintaining the qualitative assessment features), i.e. according to a determined monoselective plan [2].

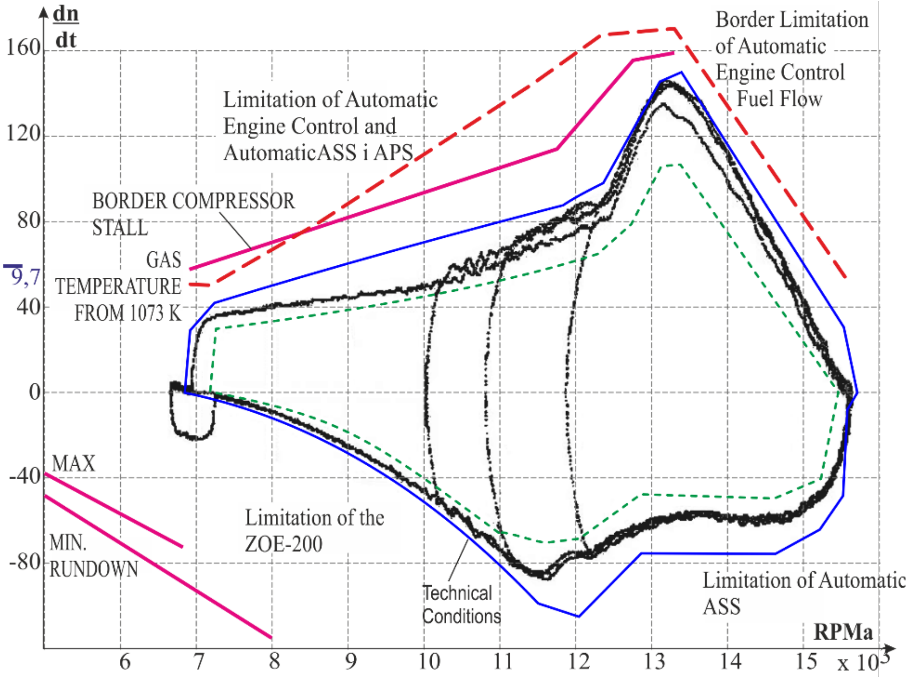

Fig. 4. Phase mapping of the SO-3 engine speed increment

3. Creating an expert system database

To develop the expert system database for aviation propulsion units, it was necessary to perform ground tests to record phase portraits showing changes in rotational speed of individual propulsion units. In addition, it was necessary to carry out simulation tests, the purpose of which was to determine the impact of typical operational regulation settings on the shape of the phase portrait, which allowed the creation of a database for the expert system, which was then used in the rules table (fig. 2).

The impact of the impact of individual operational and factory control settings and damage to aggregates (their sets) of turbine jet engines (single- and multi-rotor) power supply systems on the dynamic characteristics of individual systems was determined by separating variables according to a determined monoselective plan [2]. As a result, the impact of only one variable (over-regulation / damage simulation) was determined each time and a family of dynamic characteristics was determined. After determining the family of characteristics, each time the setting / technical condition was returned to its original position.

Examples of obtained waveforms of phase mapping of rotational speed increase for a SO-3 (SO-3W) turbine jet engine are shown in the figures below.

Figure 5 presents the influence of the maximum engine speed limiter on the shape of the obtained phase portrait. Its effect is already served at a speed above 13,500 rpm. However, it fundamentally affects the value of the maximum speed obtained by the SO-3 engine, and additionally affects the deceleration process in its first phase. This has an impact on the speed of decrease of the rotational speed of this engine within the range of maximum rotational speeds to lower values.

Figure 6 shows another example of a fairly significant influence of the operational regulation setting, in the form of a change in the height of the control shims in the PUH pneumatic limiter of the APS engine acceleration automaton, on the acceleration process and additionally on the value of the obtained maximum rotational speed.

The above also shows an impact on the first phase of the decommissioning process. In the event of an increase in the height of the shims (line 2), the quite noticeable moment of the APS pneumatic switch actuation is noticeable at a rotational speed of about 12,700 rpm. However, during excessive reduction of the height of the shims package, there is practically no such characteristic break point, indicating the activation of the APS pneumatic switch (line 1).

In addition, there is quite a strong slowing down of the speed increase (extension of the engine acceleration time), reduction of the obtained value, maximum speed, and in addition - there is no repeatability of the course of this line. The stabilization of the maximum rotational speed $n_{\max}$ increases over time as a result of a very slow "entry" to the set value.

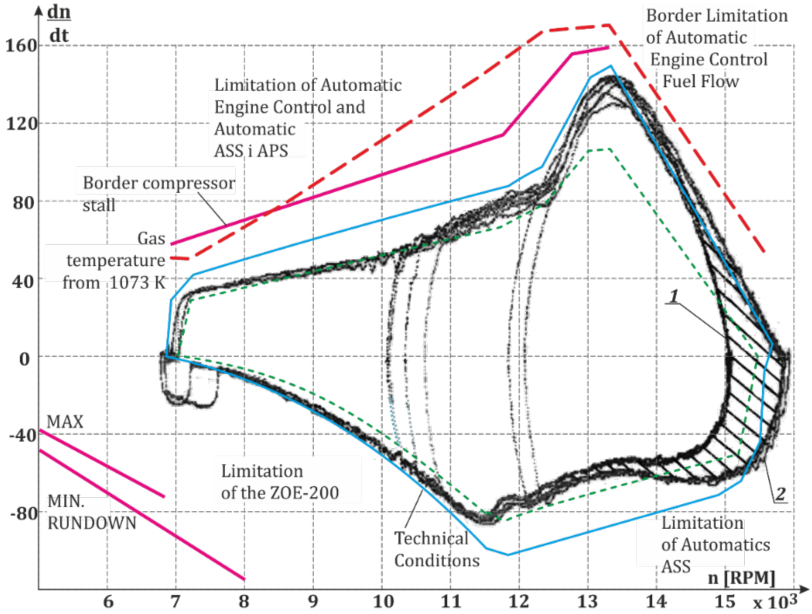

Fig. 5. Impact of the SO-3 engine speed limiter impact on the shape of the phase portrait: 1 - screwing 10 turns relative to the initial setting, 2 - screwing 8 turns relative to the initial setting

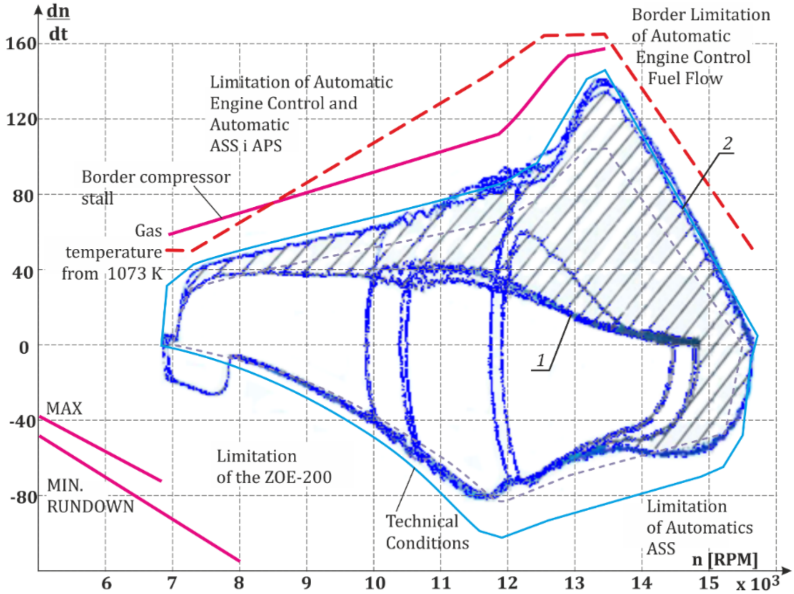

Fig. 6. The impact of the selection of the height of shims in the APS PUH limiter on the shape of the phase portrait of the SO-3 engine speed increase: 1 - height reduction by 0.3 mm, 2 - height increase by 0.5 mm

Figure 7 presents the impact of changing the p_2 pneumatic nozzle on the shape of the phase portrait of the SO-3 (SO-3W) engine speed increase. The figure clearly shows the differences in waveforms. The most significant changes occur only during the acceleration of this engine, and almost throughout its entire duration - from about 7200 rpm to 14200 rpm. In the case of a 1.9 mm nozzle, in the final phase of acceleration, in the rotational speed range of about 13000 rpm, the engine speed increase line dangerously approaches the pumping limit. In this case, it is absolutely necessary to reduce the nozzle to reduce the angle of the line and move away from the compressor pump border. Point A indicates the moment of actuation of the pneumatic switch, which as a result of reducing the nozzle shifts towards higher values of rotational speed with simultaneous decrease of acceleration (dn/dt) - along the A-A line. Such imaging indicates a very large impact of this operational control unit on the shape of the phase portrait and the obtained acceleration time determining the so-called "Breakage" of the engine [5].

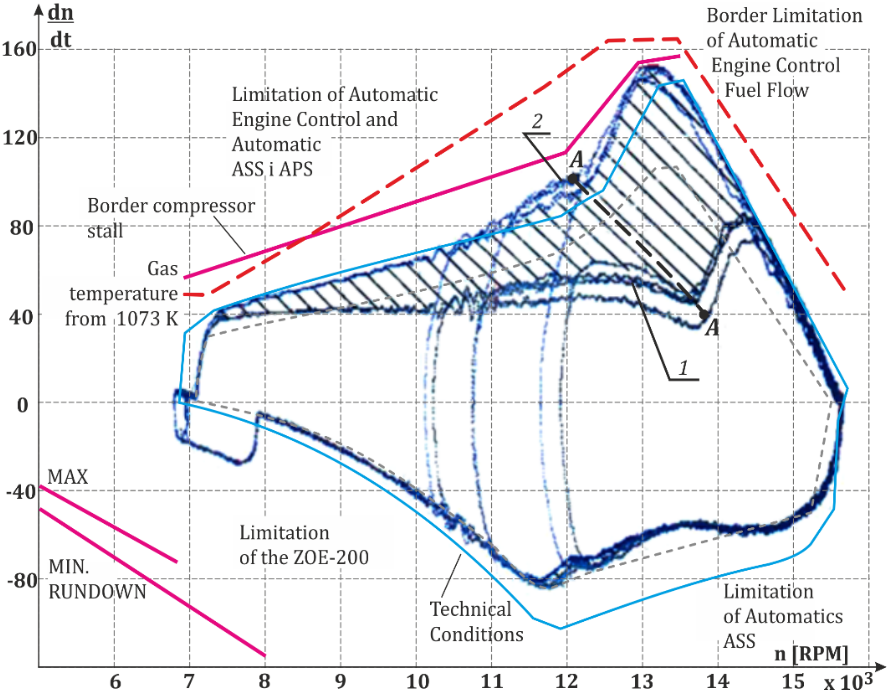

Fig. 7. Impact of changing the p_2 nozzle on the shape of the phase portrait of the SO-3 engine speed increase: 1 - no nozzle (so-called 0.0 nozzle), 2 - 1.9 mm diameter

This is a very important parameter of any turbine jet engine, which is decided, among others about aircraft maneuverability.

The proposed method enables precise observation of the shape of the phase stream, thanks to which it is possible to determine the actual changes of this shape as a result of changing the setting of the K-15 engine operating control units.

This allows you to specify the method (method) for adjusting the fuel system of aircraft engines. The tests also showed the possibility of separating the phase portrait of the rotational speed of the turbine driving the compressor from the phase portrait of the rotational speed of the propeller for turboprop engines of the M601T type during checking their adjustment. This applies to all multi-rotor constructions, including two-pass ones, e.g. type RD-33 operated in MiG-29 aircraft.

4. Conclusion

From the point of view of flight safety for aircraft users, it is important that the assessment of the current technical condition of the engine, i.e. its diagnosis and detection of the causes of breakdowns, is carried out using the best and most effective methods. The selection of parameters for the analysis of the current and future situation is important in this aspect, which requires extensive knowledge of the work of aviation power units. This means that the higher the level of knowledge and the more operational parameters of aviation propulsion systems are measured and recorded during operation, the better the recognition of the current technical condition of the object and its components (assemblies).

However, to be able to effectively identify the operation of jet turbine engines and properly assess their technical condition, adjustment, etc., an important element is the extensive knowledge of the construction and operation of standard and innovative aviation propulsion structures.

For the assessment of the work of aviation propulsion systems, it is important to correctly register such parameters that contain the most information useful in the process of technical condition identification. This is all the more important as the systems for recording and processing selected engine operating parameters not only allow for ongoing assessment of their technical condition, but also for predicting the period of further reliable operation, i.e. forecasting and analysis of the causes that led to possible damage . In other words, a lot of knowledge about the principles of operation of aircraft engines, their work circulation and the use of modern monitoring systems allow not only for a proper analysis of the causes of the fault, but also - for the forecast of the future work of monitored components of aviation power units. This has a positive impact not only on the improvement of flight safety, but also on the improvement of economic performance indicators. Some of the parameters - the most important for operational safety, such as rotor speed values, exhaust gas temperature, hull vibrations are visualized in the aircraft cabin.

Analyzing the problem of identifying the characteristic ranges of turbine aircraft engines, it should be emphasized that the most popular and commonly used are the so-called time series. By default, they are obtained by reading from flight recorders. However, the use of time waveforms is very limited and basically allows you to identify the scope of engine operation and the time spent in this range. Less popular, but more effective in terms of analysis of the scope of work and the dynamics of changes in the basic parameters of the engine is the so-called phase mapping (phase portrait) of the increase of the analyzed parameter (e.g. rotational speed). With the help of phase mapping, the main ranges of engine operation were analyzed, i.e. engine start-up, engine acceleration and deceleration processes, and engine overrun (shut down). This allowed to determine the characteristic fragments of the engine work in the analyzed range and their impact on the shape of the phase mapping.

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