SIMULATION OF CHANGES OF GAS TURBINE ENGINE WORK PARAMETERS EQUIPPED WITH CHANGEABLE GEOMETRY OF AXIAL COMPRESSOR FLOW PASSAGE

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Summary

The paper deals with problem influence of changes variable stator vanes axial compressor settings of gas turbine engine on work parameters of compressor and engine. Incorrect operation of change setting system of variable vanes could make unstable work of compressor and engine. This paper presents theoretical analysis of situation described above and presents results of own researches done on real engine. The next there are presented results of matamatical modelling of changes of gas turbine engine parametres during change of angle setting of axial compressor variable stator vanes but in the most wide angle range than in real researches.

Keywords: gasturbine, axial compressor, variable stator vanes, simulation.

SYMULACJA ZMIAN PARAMETRÓW PRACY SILNIKA TURBINOWEGO WYPOSAŻONEGO W SPRĘŻARKĘ OSIOWĄ O ZMIENNEJ GEOMETRII KANAŁU PRZEPŁYWOWEGO

Streszczenie

Nieprawidłowe funkcjonowanie systemu zmiany ustawienia regulowanych łopatek sprężarki osiowej silnika turbinowego może powodować niestabilną pracę sprężarki przenoszoną na konstrukcję silnika. W artykule zaprezentowana została analiza teoretyczna powyższego zjawiska oraz przedstawiono wyniki badań przeprowadzonych na rzeczywistym obiekcie. Następnie na bazie przeprowadzonych badań określone zostały równania matematyczne opisujące zależności pomiędzy wartościami rozpatrywanych parametrów pracy silnika a kątem ustawienia regulowanych łopatek. Równania te posłużyły do zasymulowania zmian wartości parametrów dla zakresu zmian kąta regulowanych łopatek nieosiągalnego podczas badań na obiekcie rzeczywistym.

Słowa kluczowe: silnik turbinowy, sprężarka osiowa, regulowane łopatki kierownicy, symulacja.

1. INTRODUCTION AND PURPOUSE OF RESEARCHES

When in compressor construction is assembled system of setting change of variable stator vanes its task is made optimal cooperation engine units during permanent improvement of compressor characteristic. Perturbations in operation of this system could cause changes in work of compressor and engine similar like changes caused by changes of rotational speed or polluted interblades ducts of compressor.

Compressor stage unitary work on radius is defined on base of equitation of angular momentum and has form

$$l_{st} = \omega r(c_{2u} - c_{1u}) = u\Delta c_u = u\Delta w_u \qquad (1)$$

where: ω – angular velocity, u – tangential velocity, r – rotor radius,
c_{1u}, c_{2u} – circumferential components of air stream absolute velocity on inlet and outlet rotor blades on radius r, Δc_u, Δw_u – air stream whirl in rotor.

That work is constant on whole depth of rotor blade. The sum of works is unitary work of stage [2]. Involved change of variable stator vanes angle setting during kept at a constant level rotational velocity (constant u) caused change of air stream inlet angle in rotor vane β_1 (Fig. 1). It caused change of axial component of air stream absolute velocity on inlet c_{1a} what is equivalent with change of air mass flow $\dot{m}$ and change of air stream whirl Δw_u in rotor. It influences on efficience and work of stage.

Purpose of investigations made on real engine was determination influence of incorrect operation of axial compressor inlet guide variable stator vanes control system of gas turbine engine on compressor and engine work parameters.

Compressor characteristic is relationship between compression ratio π^*_S, compressor efficiency η_S and air flow mass $\dot{m}$ and compressor rotational velocity n. It makes possible to determine the best condition of compressor and another engine units mating. The characteristic is using to select optimal conditions of air flow regulation and assessment of operational factors on compressor parametres.

Therefore compressor should be so controlled in operational range of rotational velocity that the compressor and engine mating line has a stock of stable work. The main rule of compressor control during change of their rotational velocity or flow intensity is to keep up the stream inlet angles *i* value near zero. One of the most popular ways of axial compressor control is changing their flow duct geometry by application of inlet guide stator vanes or variable stator vanes of several first compressor stages [2].

This solution makes possible to change of air stream inlet angle on rotor blades of compressor stages by change of stator vanes setting angles during change of compressor rotational velocity. Fig. 1 illustrates, on example one stage of compression, rule of regulation of variable stator vanes.

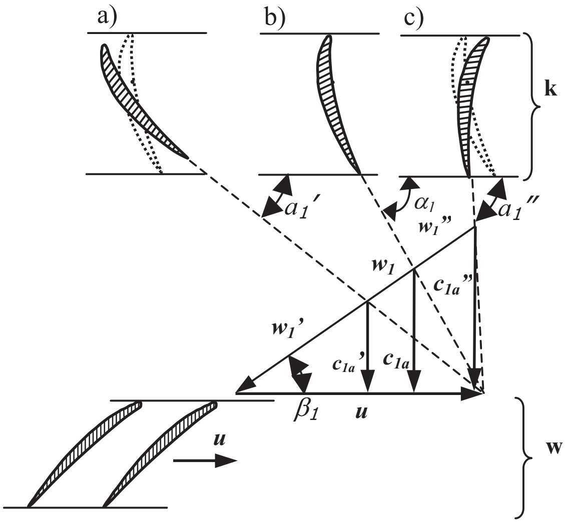

Fig. 1. Essence of control of compressor’s axial stage by changing the setting angle of stator vanes ring at changeable air flow velocity; a) decreased axial velocity, b) calculation axial velocity, c) increased axial velocity, **k** – variable stator vanes ring, **w** – rotor vanes ring

For average values of operational range of compressor rotor speed is situation on Fig. 1b – speed values and directions with subscript 1. In this situation is intermediate angle setting of stator vanes. Air stream inlet angle on rotor blades do not cause disturbance of stream flow by interblades ducts. For lower values of compressor rotor speed and in consequence lower values of absolute axial component velocity c_{1a}', it is necessary to reduce the stream outlet angle of variable stator vanes α_1 (Fig. 1a). The angle reduction range should allow keeping the same value of stream inlet angle on rotor blades. Analogical situation takes place during work of compressor with higher rotational speed. For higher rotational speed absolute axial component speed c_{1a}'' increases. In this situation for keeping stable work of compressor and in consequence constant value of stream inlet angle on rotor blades, it is necessary to increase the stream outlet angle of variable stator vanes – Fig. 1c.

Application in gas turbine engine construction of control system of flow ducts geometry has a bearing on run of unstable processes.

2. OBJECT OF RESEARCHES

The object of researches is type DR 77 marine gas turbine engine, which is part of power transmition system of war ship. It is three-shaft engine with can-ring-type combustor chamber and reversible power turbine.

In compressor construction configuration of this engine there are used inlet guide stator vanes which make possibilities to change setting angle incidance (change of compressor flow duct geometry) in depend on engine load. This process is operated by control system which working medium is compressed air received from last stage of high pressure compressor. On Fig. 2 is presented block diagram of flow control signal of variable stator vanes system.

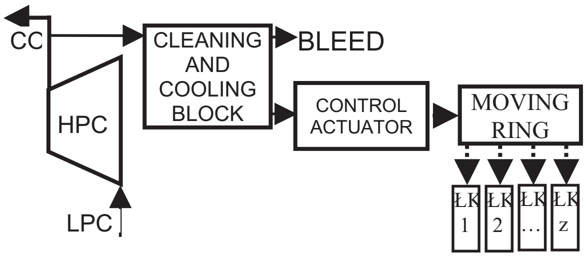

Fig. 2. Block diagram of stator vanes change setting mechanism; CO – combustor, HPC – high pressure compressor, LPC – low pressure compressor, ŁK – variable stator vane

Compressed air from last stage of high pressure compressor is supllied to working space of control actuator by cleaning and cooling block. Compressed air exerts pressure on control actuator elements. It causes moving of control piston which is connected with moving ring. This ring moves on circumference of compressor body. Ring is connected with stator vanes by levers. When the ring is moving stator vanes realize rotational motion changing the air stream outlet angle α_1 (Fig. 1).

In cleaning and cooling block are holes. During researches air stream was bleeded by holes and less air was supplied to actuator. It caused change of setting angle α_{KW} of variable stator vanes. In consequence of that change flow duct geometry was changed.

Experiment was carry out an engine load $0{,}5P_{nom}$ taking into consideration atmospheric conditions. For this load setting angle of variable vanes has value $\alpha_{KW} = -4^o$. During change engine load in whole range from idle to full load setting angle α_{KW} of variable vanes changes in range from -18^o to $+18^o$. Realizing experiment a few parameters of engine work was measured and registered for three different setting angle α_{KW} of variable vanes: A— $\alpha_{KW} = -4^o$, B— $\alpha_{KW} = -11^o$, C— $\alpha_{KW} = -18^o$. Tab. 1 presents measured and registered parameters of engine work.

Tab. 1. Parameters of engine DR work measured during researches

Parameter	Measurement range	Parameter name
n_{LPC}	0 - 20000 [min^{-1}]	low pressure rotor speed
n_{HPC}	0 - 22000 [min^{-1}]	high pressure rotor speed
n_{PT}	0 - 10000 [min^{-1}]	power turbine rotor speed
p_1	-0,04 - 0 [MPa]	subatmospheric pressure on compressor inlet
p_{21}	0 - 0,6 [MPa]	air pressure on low pressure compressor outlet
p_2	0 - 1,6 [MPa]	air pressure on high pressure compressor outlet
p_p	0 - 10,0 [MPa]	fuel pressure before injectors
T_1	-203 - 453 [K]	air temperature on compressor inlet
T_{42}	273 - 1273 [K]	exhaust gases temperature on inlet power turbine

3. RESULTS OF RESEARCHES

Fig. 3 presents results of experiment. There are presented those parameters which are the most sesitive on change of vanes setting angle. Change vanes setting from position *A* to position *C* caused increase air flow resistance by stator vanes. In consequence of that subatmospheric pressure on compressor inlet p_1 decreases. It causes pressure decrease in next parts of compressor and engine flow duct (Fig. 3bc). In this way reduced air density flowing by compressor, for stable quantity of stream fule supllied to combustor, causes increase of compressors rotor speed. The most visible is increase of low pressure compressor rotor speed (Fig. 3a) caused by directly influence on this compressor incorectly setting variable stator vanes.

Gasodynamical connection between low pressure compressor and high pressure compressor absorbs disturbances work of low pressure compressor which are transferred on high pressure compressor. Therefore range of change high pressure compressor rotor speed is lower than low pressure compressor. In this experimental it is below 1% and it is in measuring error of sensor range.

Change of subatmospheric pressure is above 5% undisturbed value of this parameter. Changes of low and high pressure compressor outlet presure are adecuately above 1,3% and above 2,4% undisturbed value of angle setting $\alpha_{KW} = -4^o$.

Changes of pressure and air mass flow intensity values accompanied disturbing work of compressor, during constant fuel mas flow intensity in combustor, caused enrichment of fuel mixture. As a result of that, temperature combustor outlet gases increases. In experiment was confirmed tendency changes of gases tempertaure values even though range of thoses changes is in measuring error of sensor range.

On the base of results of experiment there were determined mathematical equations modelling changes of particular engine work parameters in function of variable inlet guide stator vanes setting angle α_{KW} :

$$n_{SNC} = 0,7449\alpha_{KW}^2 + 2,602\alpha_{KW} + 9234,5 \quad (2)$$

$$n_{SWC} = 0,0204\alpha_{KW}^2 - 1,1224\alpha_{KW} + 12598 \quad (3)$$

$$p_1 = -10^{-6}\alpha_{KW}^2 - 10^{-6}\alpha_{KW} + 0,0077 \quad (4)$$

$$p_{21} = 10^{-16}\alpha_{KW}^2 + 0,0029\alpha_{KW} + 2,9814 \quad (5)$$

$$p_2 = 2\cdot 10^{-16}\alpha_{KW}^2 + 0,0143\alpha_{KW} + 8,1771 \quad (6)$$

$$T_{42} = 0,0204\alpha_{KW}^2 + 0,1633\alpha_{KW} + 526,33 \quad (7)$$

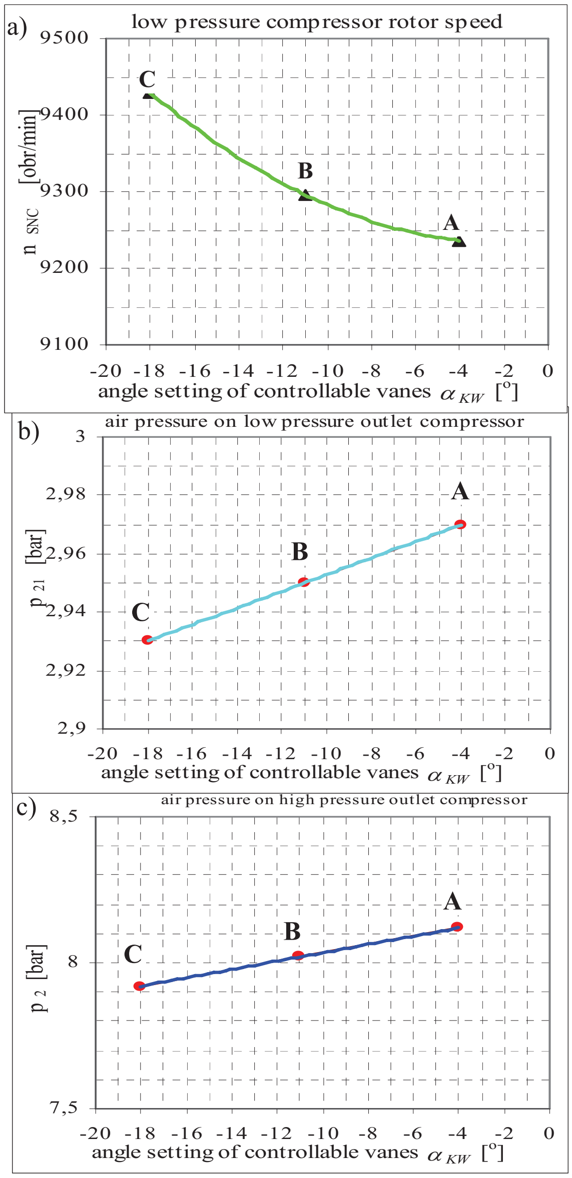

Fig. 3. Change of engine work parameters in function of variable inlet guide stator vanes setting angle: A-$\alpha_{KW} = -4^o$, B-$\alpha_{KW} = -11^o$, C-$\alpha_{KW} = -18^o$

Fig. 4 presents results of mathematical modelling of engine work parameters. Modelling was cary out an state engine load what was equivalent unchangable fuel mass flow. In this case range of change of variable inlet guide stator vanes setting angle α_{KW} was widen from -18° to +18°. Researches in range α_{KW} from -4° to +18° were not possilble to realize on real engine. It is caused by technical restrictions on the engine.

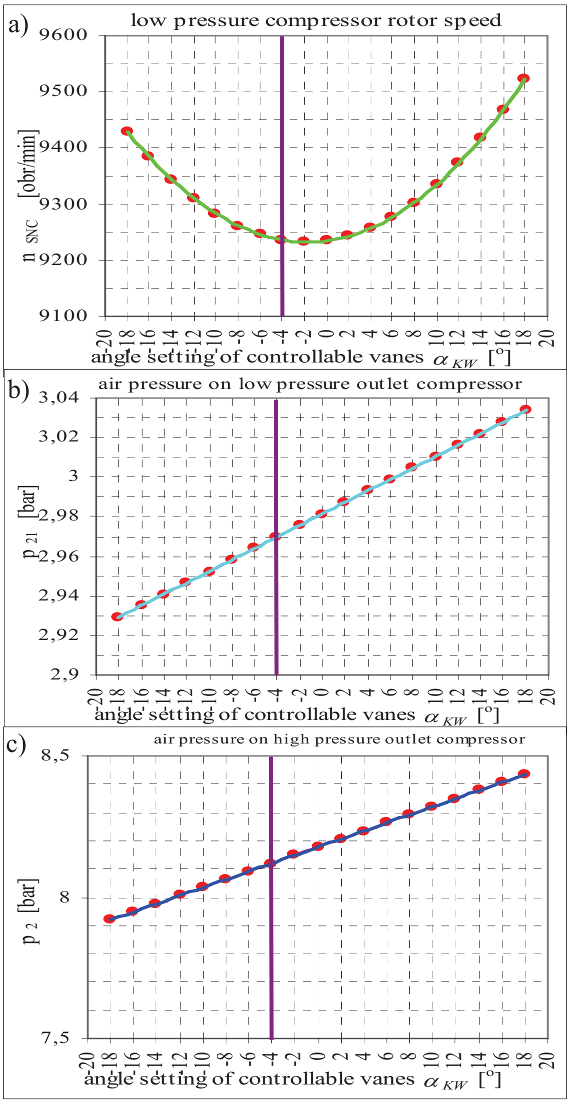

Fig. 4. Change of engine work parameters in function of variable inlet guide stator vanes setting angle gotten during mathematical simulation

Change of variable inlet guide stator vanes setting angle α_{KW} from -4° to +18° caused increase of stream outlet angle of variable stator guide vanes α_1 (Fig. 1). It decreases air flow drag on low pressure compresor inlet that caused decrease of subatmospheric pressure. During keeping constant engnie load (constant fuel mass flow) absolute axial component velocity c_{1a} increases. It exerts an influence on air mass flow $\dot{m}$ increase. Simultaneously the absolute axial component velocity c_{1a} increase caused decrease of air stream whirl in rotor Δw_u. The effect of above is reduction of the compressor stage unitary work – equation (1). In consequence of that low pressure compressor rotor speed increases (Fig. 4a). In connection with decrease of subatmospheric pressure it caused increase of air pressure on low pressure outlet compressor (Fig. 4b). In spite of slight decrease of high pressure compressor rotor speed the increase of air pressure on low pressure outlet compressor involves increases of air pressure on high pressure outlet compressor (Fig. 4c). This slight decrease of high pressure compressor rotor speed caused increase of gases flow drag in next gas turbine engine units for the combustor. The effect of above is slight increase of exhaust gas temperature on power turbine inlet.

4. CONCLUSIONS

On the base realized theoretical consideration and experimental researches we can draw a conclusion that incorrect operation of control system of inlet guide variable stator vanes or first stages stators vanes gas turbine engine compressor exerts negative influence on compressor work and engine performances. Multi-shaft construction of gas turbine engine reduces effects of incorrectly setting of variable vanes. Therefore compressors of three-shaft gas turbine engine do not require variable stators vanes as many stages as compressor of two-shaft engine with the same achievements.

Preliminary researches confirm necessity for making inspection of correct operation of variable stator vanes system control. It makes possibility of elimination this factor from group of factors informing about technical state of engine which are identified during diagnostic inspections.

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