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

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Abstract

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 results of own research done on real engine. The next there are presented results of mathematical modelling of changes of gas turbine engine work parameters during change of angle setting of axial compressor variable stator vanes but in the most wide angle range than in real research.

Keywords: *gas turbine engine, axial compressor, variable stator vanes, modelling*

1. Introduction and purpose of research

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 (Fig. 1):

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

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. 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 efficiency and work of stage [2].

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 parameters.

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.

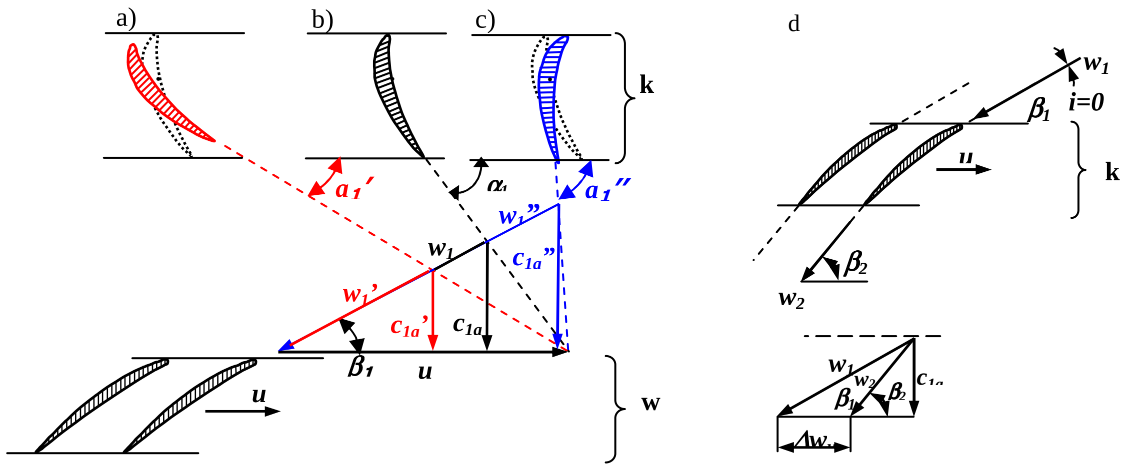

Fig. 1. Essence of control of compressor's axial stage by changing the setting angle of stator vanes ring at changeable air flow velocity; a) decreased axial velocity, b) calculation axial velocity, c) increased axial velocity, d) schema of flow round of axial compressor rotor blades during constant rotor speed and constant air stream inlet angles; ***k*** *– variable stator vanes ring,* ***w*** *– rotor vanes ring*

For average values with 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 value of 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 inertance of unstable processes.

2. Object of research

The object of researches is type DR77 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.

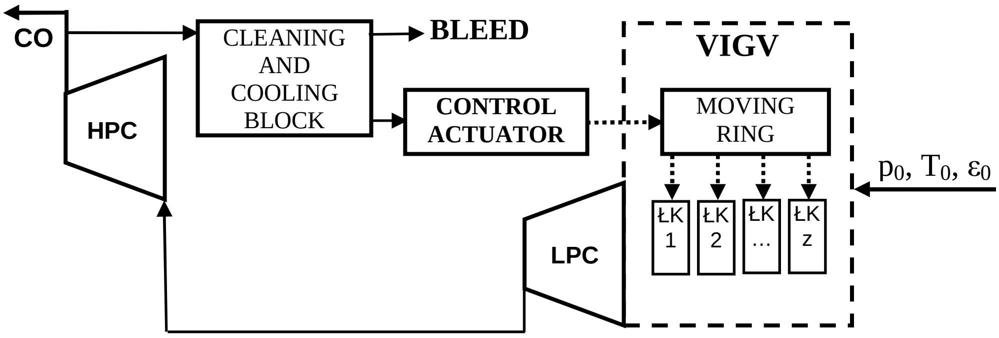

Fig. 2. Block diagram of stator vanes change setting mechanism LPC; CO – combustor, HPC – high pressure compressor, LPC – low pressure compressor, ŁK – variable stator vane, VIGV – variable inlet guide vanes

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 low pressure compressor body. Ring is connected with variable 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 $0{,}5P_{nom}$. 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 in this same time parameters of engine work.

Tab. 1. Parameters of engine DR77 work measured during researches

Parameter	Measurement range	Unit	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 research

Fig. 3 presents results of experiment. There are presented those parameters which are the most sensitive on change of LPC guide 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 guide stator vanes.

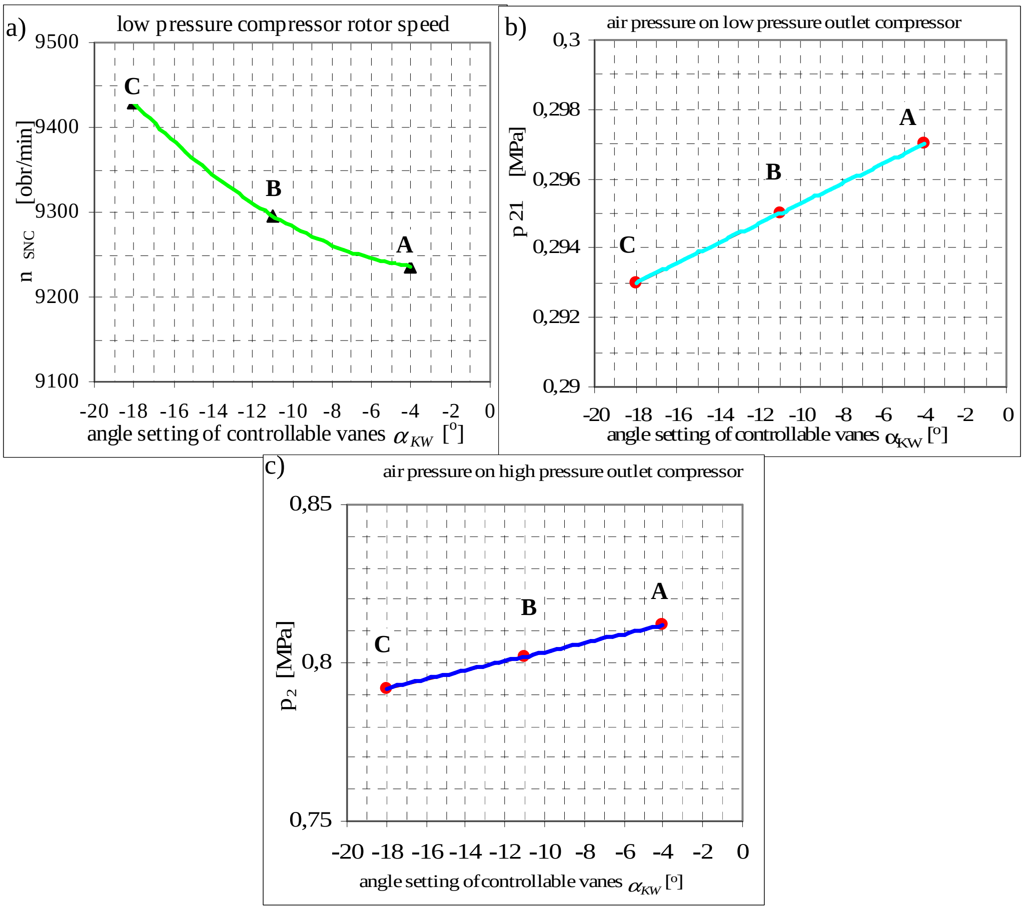

Fig. 3. Change of engine work parameters values in function of variable inlet guide stator vanes setting angle:
A - $\alpha_{KW} = -4^o$*, B -* $\alpha_{KW} = -11^o$*, C -* $\alpha_{KW} = -18^o$

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 range.

Change of subatmospheric pressure is above 5% stable 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 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. 4 presents results of solution of an mathematical equations describing of changes of engine work parameters values. 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^o to +18^o. Researches in range α_{KW} from -4^o to +18^o were not possilble to realize on real engine. It is caused by technical restrictions on the engine.

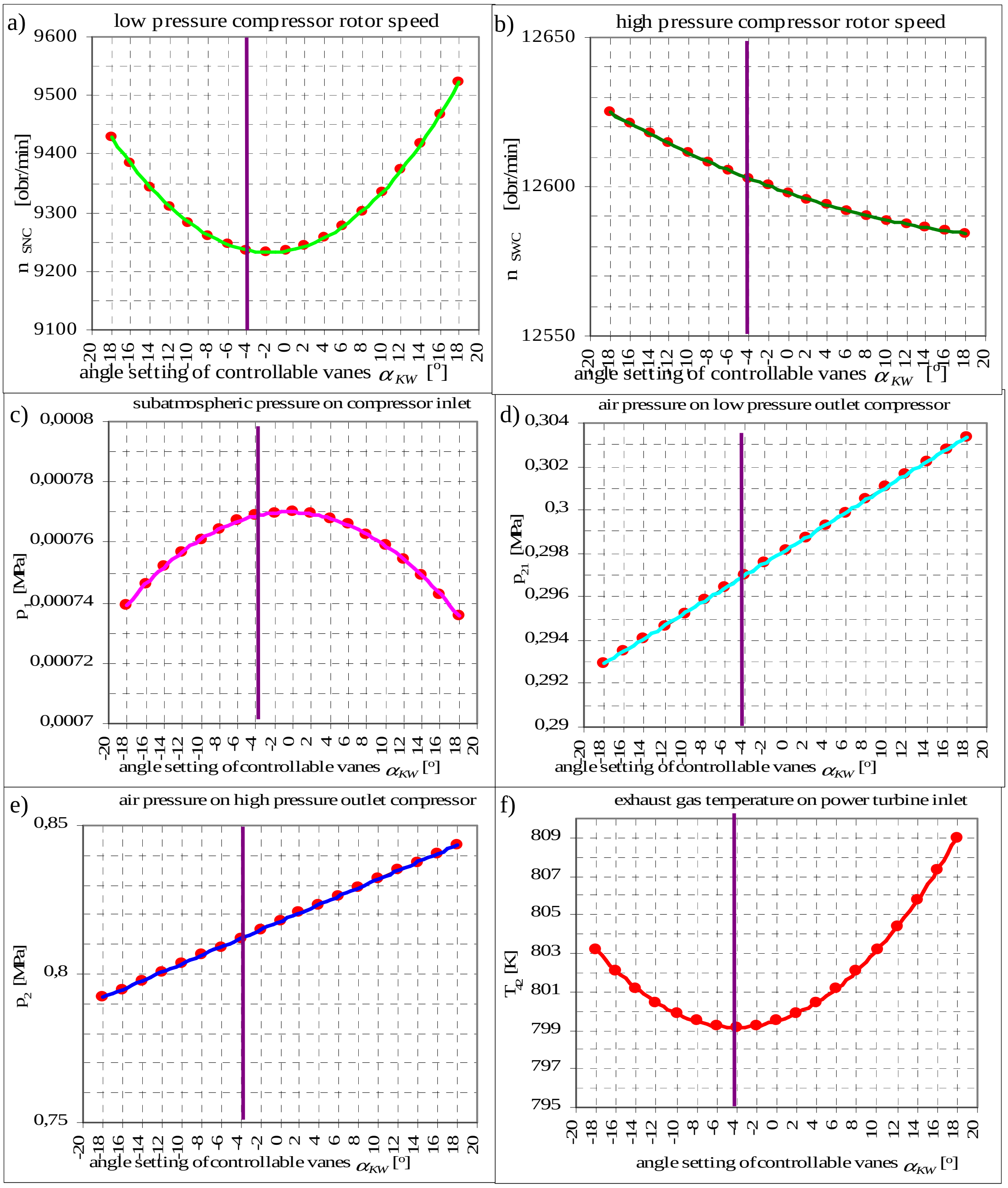

Fig. 4. Change of engine work parameters values in function of variable inlet guide stator vanes setting angle gotten during mathematical simulation

4. Conclusions

Change of variable inlet guide stator vanes setting angle α_{KW} from -4^o to +18^o caused increase of flowing air stream outlet angle α_1 (Fig. 1). It decreases air flow drag on low pressure compressor inlet that caused decrease of subatmospheric pressure. During keeping constant engine 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. 4d). 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. 4e). 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.

Multi-shaft construction of gas turbine engine reduces effects of incorrectly setting of variable stator 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 deteriorating technical state of engine which are identified during diagnostic inspections.

References

[1] Charchalis A.: *Diagnostics of marine gas turbine engines* (in Polish). Published by Polish Naval Academy, Gdynia, 1991.

[2] Dżygadło Z. et al.: *Rotor units of gas turbine engines* (in Polish). Transport and Telecommunication Publishing House (WKiŁ), Warszawa, 1982.

[3] Korczewski Z.: Wirkowski, P., *Modelling gasodynamic processes within turbine engines' compressors equipped with variable geometry of flow duct*, IV International Scientifically-Technical Conference "Explo-Diesel & Gas Turbine '05", Gdańsk-Międzyzdroje-Kopenhaga, Wyd. Politechnika Gdańska, Gdańsk 2005, 227-236.

[4] Marschal D.J., Muir D.E., Saravanamuttoo H.I.H.: *Health Monitoring of Variable Geometry Gas Turbines for the Canadian Navy*, The American Society of Mechanical Engineers 345 E, 47 St., New York, N.Y.10017.

[5] Wirkowski, P., *Influence of changes of axial compressor variable stator vanes setting on gas turbine engine work*, V International Scientifically-Technical Conference POLISH CIMAC "Explo-Diesel & Gas Turbine '07", Gdańsk-Stockholm-Tumba, Published by Gdańsk University of Technology, Gdańsk 2007, 511-518.

[6] Wirkowski P.: *Modelling the characteristics of axial compressor of variable flow passage geometry, working in the gas turbine engine system*, Polish Maritime Research, No 3/2007, Published by Gdańsk University of Technology, Gdańsk 2007, 27-32.

[7] Wirkowski P.: *Gas turbine engine work parameters in conditions of changeable geometry of axial compressor flow duct*, 11TH International Conference „Computer systems aided science, industry and transport"- TRANSCOMP 2007, ZAKOPANE 3-6 December 2007, Published by Radom University of Technology, Radom 2007, 383-388.