

INFLUANCE OF CHANGES OF AXIAL COMPRESSOR VARIABLE STATOR VANES SETTING ON GAS TURBINE ENGINE WORK

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Abstract

The paper deals with problem influence of changes settings variable stator vanes axial compressor 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 situation is unacceptable because of mechanical overloads which could damage the engine. This paper presents theoretical analysis of situation described above and presents results of own researches done on real engine.

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

Parameters, abbreviations and subscripts:

α_1	- air stream outlet angle with stator vanes,
α_{KW}	- setting angle of variable stator vanes,
β_1, β_2	- air stream inlet and outlet angles in rotor vanes,
c_a	- axial component of air stream absolute speed,
c_{1a}	- axial component of air stream absolute speed on rotor blades inlet,
$c_{1a.cal}$	- calculating value axial component of air stream absolute speed on rotor blades inlet,
CCS	- space between high pressure compressor and combustor,
CS	- space between low pressure compressor and high pressure compressor,
CO	- combustor,
HPC	- high pressure compressor,
HPT	- high pressure turbine,
η_s^*	- compressor efficiency,
i	- air stream inlet angle on rotor blades,
LPC	- low pressure compressor,
LPT	- low pressure turbine,
LPTPTS	- space between low pressure turbine and power turbine,
\dot{m}	- air mass flow,
n	- compressor rotor speed,
p_{fuel}	- fuel pressure,
P_{nom}	- nominal engine power,
π_s^*	- compression ratio,
TS	- space between high pressure turbine and low pressure turbine,
u	- circumferential speed,
w_1, w_2	- air stream relative speed on inlet and outlet rotor blades,
Δw_u	- air stream whirl in rotor,
z	- number of inlet guide stator vanes,

1. Introduction

A compressor is a part of gas turbine engine especially sensitive on change their technical state during operation process. Polluted atmospheric air flowing in compressor caused permanent change of interblades ducts shape, rise of blades surface roughness and change of compressor rotor mass. It exerts an important influence on compressor stable work, change their characteristic and engine performance and efficiency. 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 of rotational speed or polluted interblades ducts of compressor.

2. Purpose of researches

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 parameters of compressor and engine work.

Compressor characteristic is relationship between compression ratio π_s^* , compressor efficiency η_s and air flow mass \dot{m} and compressor rotational speed n . It makes possible to determine the best condition of compressor and another engine units mating. Characteristic is using to select optimal conditions of air flow regulation and assessment of operational factors on compressor parameters.

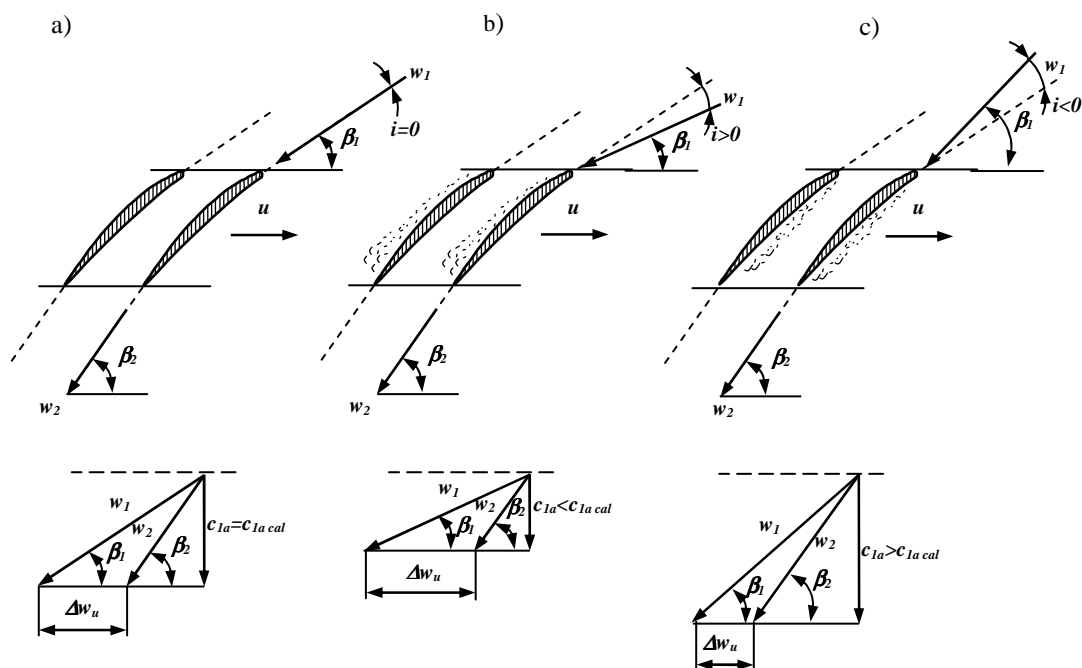


Fig. 1. Schema of flow round of axial compressor rotor blades during constant rotor speed and variable air stream inlet angles: a) calculating inlet angle, b) positive inlet angle, c) negative inlet angle

Compressor unstable work is explained on Fig. 1. This Fig. presents schema of flow round of axial stage compressor rotor blade which is moving with constant rotational speed n . For this stage is made change of air flow intensity \dot{m} . Fig. 1a presents schema of flow round for optimal stage efficiency. Relative speed vectors w_1 and w_2 have parallel direction to center line of blade profile. It causes laminar flow of air stream in interblades ducts. Decrease of air flow intensity (Fig. 1b) for constant circumferential speed u causes decrease axial component of air stream absolute speed c_a .

It takes effect increase of air stream inlet angle i on rotor blades. This situations favours tearing off laminary boundary layer on convex blades surfaces and forming vortex regions.

Similar effect takes place on concave blades surfaces (Fig. 1c) when air flow intensity \dot{m} increases during constant circumferential speed u .

For critical values of air stream inlet angle i by formatted vortex regions of lower pressure, can occure air stream back off in inlet compressor direction. It could cause rapid rise of stream fluctuations transmited on engine construction. This situation is undesirable and dengerous on account of mechanical and thermal overload of engine construction [2].

Therefore compressor should be so controlled in operational range of rotational speed that the compressor and engine mating line has a stock of stable work. The main rule of compressor control during change of their rotational speed or flow intensity is to keep up the stream inlet angles i values 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].

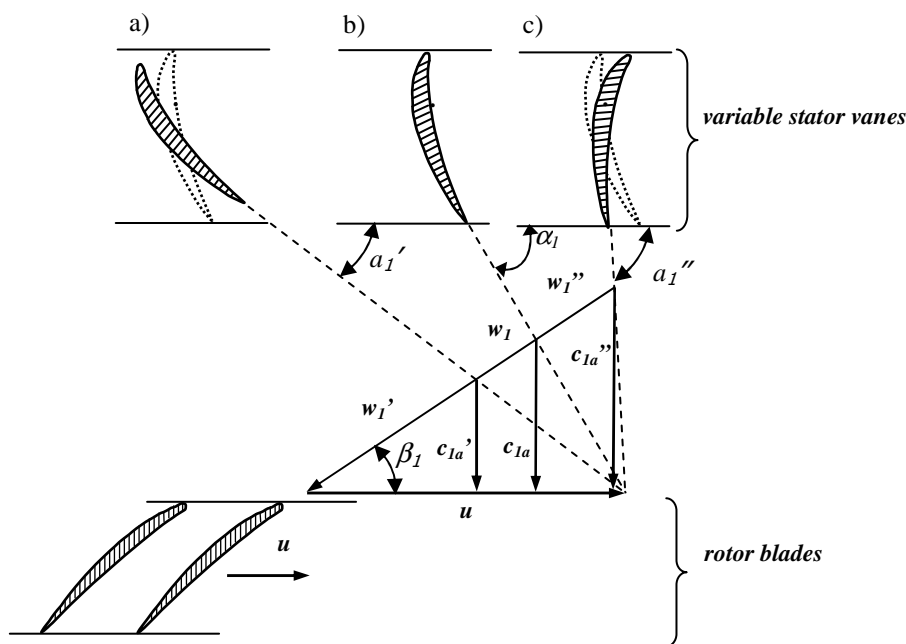


Fig. 2. Axial compressor stage control by change of setting angle of stator vanes during changing speed of flow stream: decreasing axial speed, b) calculating axial speed, c) increasing axial speed

This solution makes possible to change of air stream inlet angle on rotor baldes of compressor stages by change of stator vanes setting angles during change of compressor rotational speed. Fig. 2 illustrates, on example one stage of compression, rule of regulation of variable stator vanes.

For average values of operational range of compressor rotor speed is situation on Fig. 2b – 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 speed c_{1a}' , it is necessary to reduce the stream outlet angle of variable stator vanes α_1 (Fig. 2a). 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. 2c.

Application in gas turbine engine construction of control system of flow ducts geometry has a bearing on run of unstable processes [3].

3. Object and course of researches

The object of researches is type DR 77 marine gas turbine engine. It is three-shafts engine with can-ring-type combustor chamber and reversible power turbine. Fig. 3 illustrates block diagram of DR gas turbine engine with marked control sections of flow duct and measuring parameters.

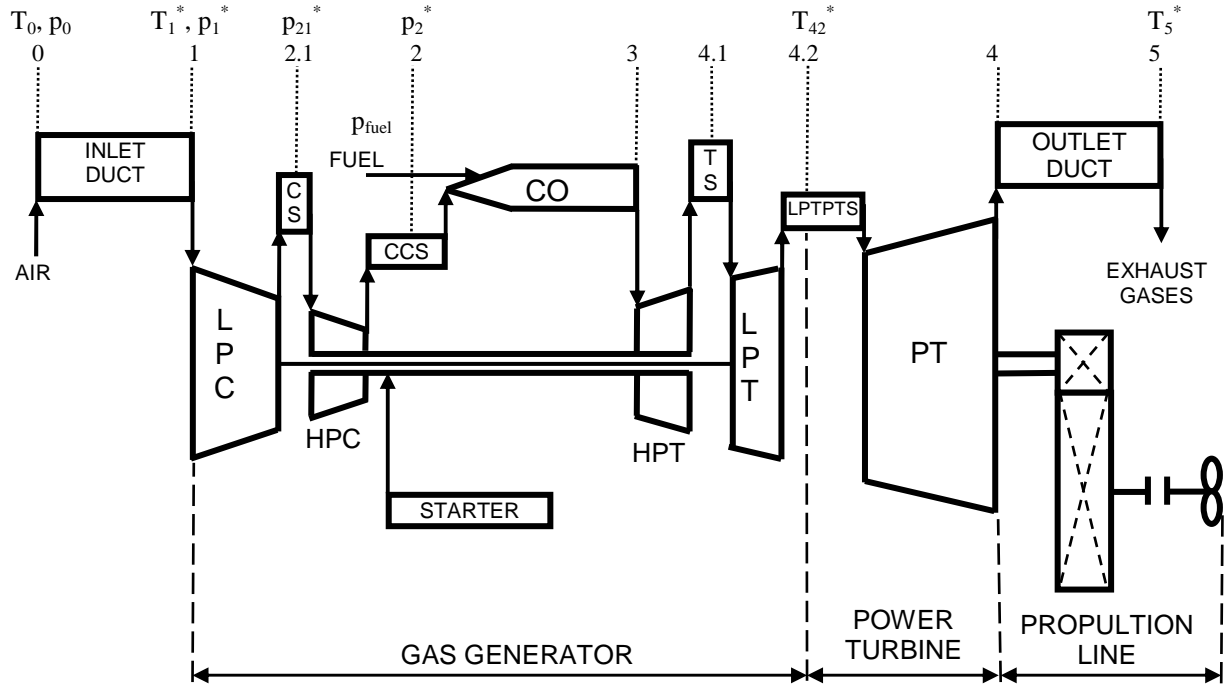


Fig. 3. Block diagram of DR gas turbine engine

In compressor construction configuration of this engine there are used inlet guide stator vanes which make possibilities to change setting angle incidence (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. 4 are presented elements of control system of variable stator vanes.

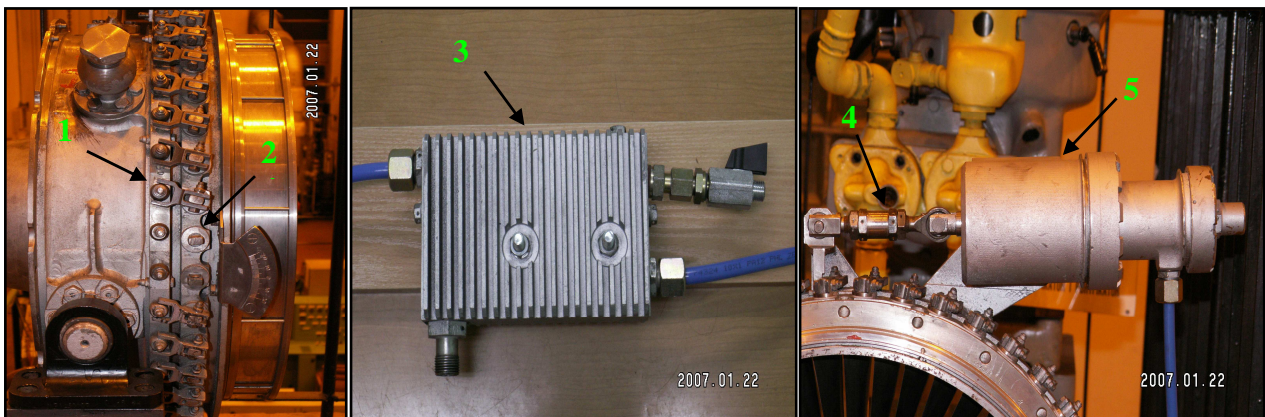


Fig. 4. Elements of control system of variable stator vanes DR type engine
1 – moving ring, 2 – stator vane, 3 – cleaning and cooling block, 4 – strand, 5 – control actuator

Block diagram of flow control signal is presented on Fig. 5. Compressed air from last stage of high pressure compressor is supplied 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_l .

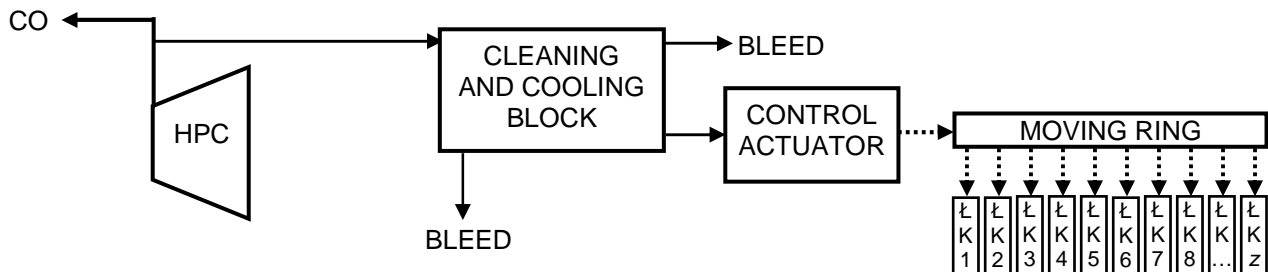


Fig. 5. Block diagram of stator vanes change setting mechanism;
CO – combustor, HPC – high pressure compressor, LK – variable stator vane

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

Experiment was carried out at an engine load $0,5P_{nom}$. For this load setting angle α_{KW} of variable vanes takes value -4° . During change engine load in whole range from idle to full load setting angle α_{KW} of variable vanes changes in range from -18° to $+18^\circ$. Realizing experiment a few parameters of engine work were measured and registered for three different setting angles α_{KW} of variable vanes: A — $\alpha_{KW} = -4^\circ$, B — $\alpha_{KW} = -11^\circ$, C — $\alpha_{KW} = -18^\circ$. 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}	$0 \div 20000 \text{ [min}^{-1}\text{]}$	low pressure rotor speed
n_{HPC}	$0 \div 22000 \text{ [min}^{-1}\text{]}$	high pressure rotor speed
n_{PT}	$0 \div 10000 \text{ [min}^{-1}\text{]}$	power turbine rotor speed
p_1	$-0,04 \div 0 \text{ [MPa]}$	subatmospheric pressure on compressor inlet
p_{21}	$0 \div 0,6 \text{ [MPa]}$	air pressure on low pressure compressor outlet
p_2	$0 \div 1,6 \text{ [MPa]}$	air pressure on high pressure compressor outlet
p_p	$0 \div 10,0 \text{ [MPa]}$	fuel pressure before injectors
T_1	$-203 \div 453 \text{ [K]}$	air temperature on compressor inlet
T_{42}	$273 \div 1273 \text{ [K]}$	exhaust gases temperature on inlet power turbine

4. Results of researches

Fig. 6 presents results of experiment. Parameters depend on time of measure and setting angle of variable stator vanes. On Fig. 6 are presented those parameters which are the most sensitive to 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 (Fig. 6c). It causes pressure decrease in next parts of compressor and engine flow duct (rys. 6de). In this way reduced air density flowing by compressor, for stable quantity of stream fuel supplied to combustor, causes increase of compressors rotor speed. The most visible

is increase of low pressure compressor rotor speed (rys. 6a) caused by directly influence on this compressor incorrectly setting variable stator vanes. Range of change this parameter is above 2% value of rotational speed for undisturbed angle setting of vanes.

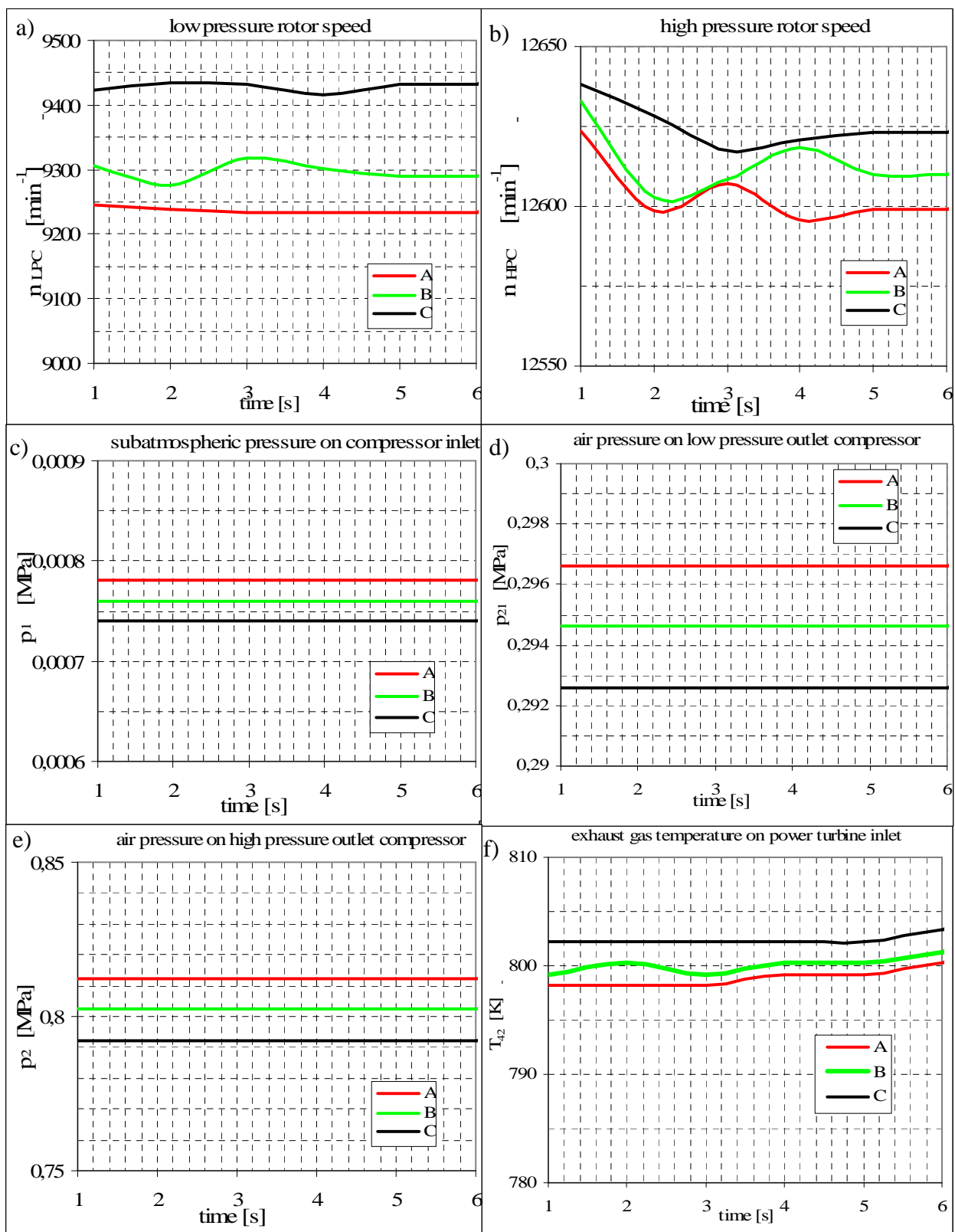


Fig. 6. Change of engine DR work parameters in function of variable inlet guide stator vanes setting angle:

A — $\alpha_{KW} = -4^\circ$, B — $\alpha_{KW} = -11^\circ$, C — $\alpha_{KW} = -18^\circ$

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 pressure are adequately above 1,3% and above 2,4% undisturbed value of angle setting $\alpha_{KW} = - 4^\circ$.

Changes of pressure and air mass flow intensity values accompanied disturbing work of compressor, during constant fuel mass 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 temperature values even though range of those changes is in measuring error of sensor range.

5. Conclusions

On the base realised 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 stator 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.

References

- [1] Balicki, Wł., Szczeciński, St., *Diagnozowanie lotniczych silników turbinowych*, Wydawnictwo Biblioteka Naukowa Instytutu Lotnictwa, Warszawa 1997.
- [2] Dźygadło, Z., *Napędy Lotnicze. Zespoły wirnikowe silników turbinowych*, Wydawnictwa Komunikacji i Łączności, Warszawa 1982.
- [3] Korczewski, Z., *Identyfikacja procesów gazodynamicznych w zespole sprężarkowym okrętowego turbinowego silnika spalinowego dla potrzeb diagnostyki*, AMW, Rozprawa habilitacyjna, Gdynia 1998.
- [4] 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, str. 227÷236, Gdańsk 2005.
- [5] 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.