Methods to Reduce the Resonant Stresses Level of Gas Turbine Engines Compressor Rotor Wheels

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Abstract: The approaches to reducing the alternating stresses in the compressor blades, arising at a resonance, are discussed in paper. Maximum alternating stresses in blades of the fifth stage of intermediate pressure compressor (IPC, that operating under the gas flow circumferential variation conditions, are defined on the basis of the forced blade oscillations calculation method. Parametric CFD-model which allows to introduce different stagger angles and circumferentially alternating blade pitch at the guide vanes of IPC fifth stage was created to reduce the stresses. The flow circumferential variation was reduced by changing these parameters and as a consequence the resonant stresses were decreased by more than 2.5 times.

1 INTRODUCTION

Circumferential variation of the gas flow in the channel of gas-turbine engine (GTE) is the major factor, exciting blades oscillations, which lead to blade fatigue destructions (Hynes, Greitzer, 1987). The problem is compounded by the fact that circumferential variation of the gas flow is unsteady and caused by large numbers of both upstream and downstream channel elements (Kuz'michev, Morozov, 1991). Therefore the problem of reduction of blades gas-dynamic excitation is extremely complex and usually solved by using a large number of experiments (Kaya, 2003).

The blades of the fifth rotor wheel (RW5) of five-stage intermediate pressure compressor (IPC) of gas turbine engine was object of research in this paper (Figure 1).

The casing of the engine middle support is located downstream the fifth compressor stage. High pressure compressor is located after the support casing. There are seven unevenly distributed racks of different cross-sections in the channel of support casing. (Figure 2). These racks are the cause of circumferential variation of the gas flow in GTE passage, which leads to increased dynamic stresses in the fifth RW blades, as a consequence, to its breakage.

The goal of this work was to reduce the dynamic stresses in the rotor blades of the IPC fifth stage by means of the blades reprofiling and circumferential variation flow reduction.

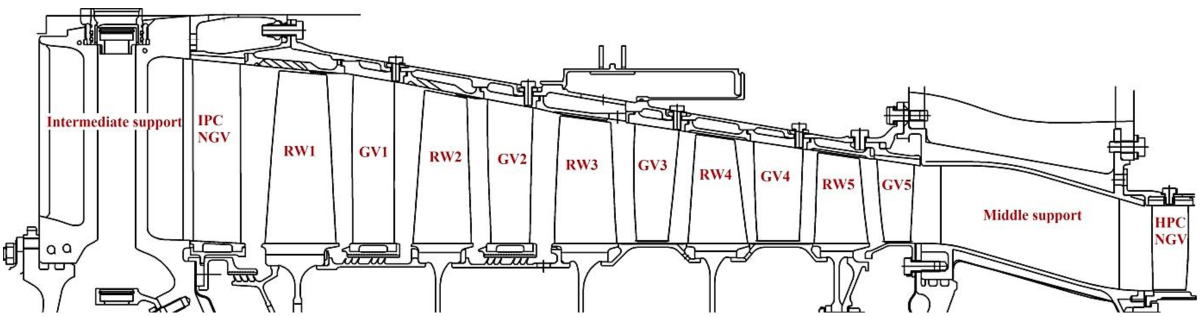

Figure 1: The scheme of investigated compressor blading.

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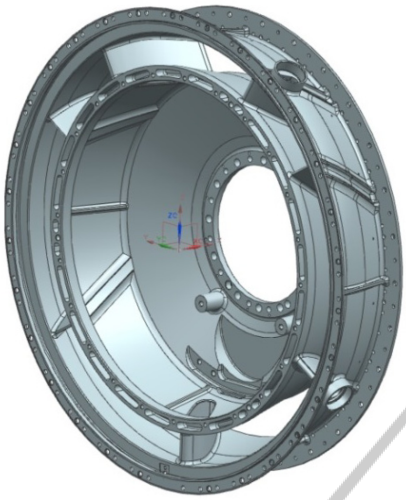


Figure 2: Casing of middle support.

2 METHOD FOR DYNAMIC STRESSES CALCULATION

Method for dynamic stresses calculation in RW blades of the IPC fifth stage was created at the first stage (Shklovets, Popov, Kolmakova, 2012). This method consisted of four stages.

1. Calculation at the required engine mode (take-off mode and idle mode) is performed for the IPC sector model in the software package *NUMECA Fine Turbo*. The sector model also comprises inlet guide vane (IGV) of high pressure compressor (HPC), middle and intermediate engine supports. Radial profiles of total pressure, total temperature and flow direction in the section behind the rotor wheel of IPC fourth stage were determined as the result of this calculation.

2. The “full circle” compressor model calculation with boundary conditions obtained in the IPC sector model calculation is performed in the software package Ansys CFX (Bochkarev, Dmitriev, Kulagin, Makeenko, Mosoulin, Mossoulin, 1993). Full circle model consists of the following blade rows: IPC fourth guide vane (GV4), fifth rotor wheel, fifth guide vane (GV5), middle support and HPC inlet guide vane (IGV). Gas-dynamic load having an effect at the IPC fifth RW blades and considering gas flow circumferential variation caused by the middle support racks was determined in this calculation.

3. The calculation of the fifth RW blades natural frequencies is performed in the software package *Ansys Mechanical*. Based on this calculation, RW frequency diagram construction and IPC rotor speeds, at which the resonance may occur, are carried out.

4. Gas load is represented as a combination of backward traveling waves of load (harmonic waves) using the object-oriented programming language APDL, built in Ansys. Further dynamic calculation at the resonance mode in resonance with the most dangerous harmonic is performed. This method is presented schematically in Figure 3.

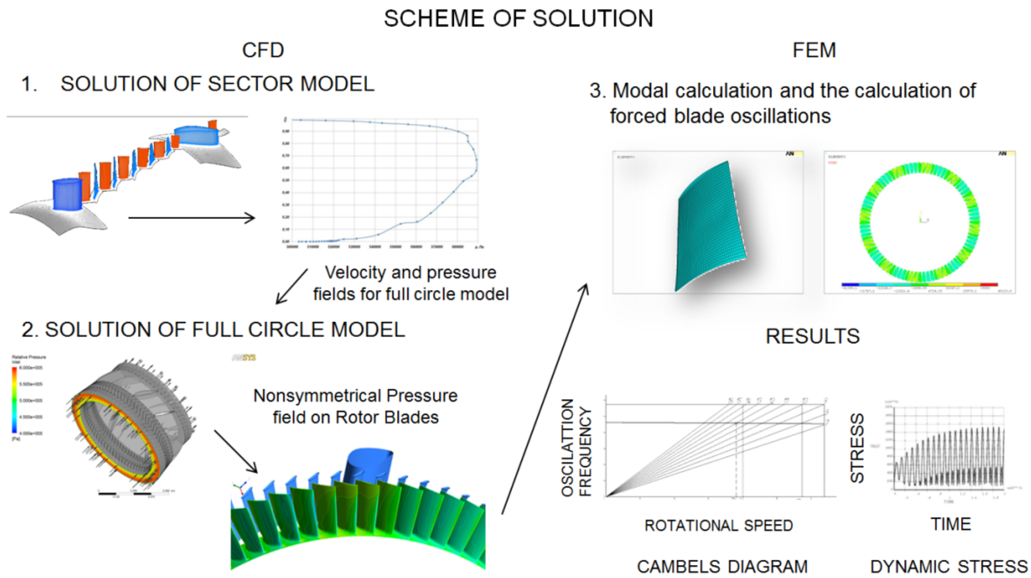


Figure 3: The scheme of method for calculation compressor rotor blades forced oscillations.

3 THE MEASURES FOR BLADES ALTERNATING STRESSES MITIGATION

The following areas were selected as measures to reduce the resonant stresses level:

- the usage of the blades with special Shvarov's profile at last rotor wheel;
- the usage of the guide vane in front of the middle support, with the blades set having different stagger angles and with circumferentially alternating blade pitch.

Also, special attention was paid to the fact that the number of blades with stagger angles different from the standard should be as low as possible.

Parameterization of the full circle compressor model was carried out for the introduction GV5 different stagger angles and circumferentially alternating blade pitch.

At the first stage of creating a parametric model the support racks and blades of GV5 were divided into groups. For this purpose the development drawing of the blade row in the circumferential direction was carried out. The assumption that for several blade groups will be given the same stagger angle and blade pitch parameters was made for IPC GV5 blades. When introducing the different stagger angles the key factor was the minimum number of changeable blades as the manufacturing a large number of blades with different geometry greatly increase the production costs. The quantity of the variable blades in group was specified by the number in brackets (Table 1).

Then, the maximum blade stagger angle within the joint groups was determined. The stagger angle was not changed for the GV5 blades located in the racks plane of symmetry, the first and last blades in the group. Changing of the stagger angles within the groups were performed linearly. Blades arranged on opposite sides of the racks plane of symmetry were rotated in opposite directions relative to the initial position (Figure 4). Moreover the blades located closer to the front were rotated by a larger angle. If the blade was rotated on closing (increase of the stagger angle) before the angle value there is a sign "+" if on opening (decrease of the stagger angle) - sign "-".

The number of removable blades was not restricted when blade pitch were changed. Parameter of alternating blade pitch was set within 0.35...0.35 of the base pitch. The sign "-" means that in the region between the blades the pitch is decreased, while "+" - the pitch is increased. The number indicates the maximum blade pitch increase (decrease) in the group in relative values from the nominal pitch with evenly spaced blades. Position of extreme blades in groups was not changed when introducing the circumferentially alternating blade pitch. The law of pitch changing was also linear. Thus, the universal parametric model which allows to the introduction different stagger angles and circumferentially alternating blade pitch at the IPC fifth stage was created.

4 OPTIMIZATION CALCULATIONS OF THE DYNAMIC STRESSES IN THE IPC FIFTH ROTOR BLADE

Calculations of dynamic stress for 11 variants of the IPC fifth stage were performed using a parametric model (Shklovets, Popov, Kolmakova, 2013). Blade with a special Shvarov's profile was used as the fifth stage rotor blade in all the variants. The variants differed from each in values of different stagger angles and alternating blade pitch parameters of IPC GV5. At the same time the first variant corresponded to the base GV5.

The calculation results of the dynamic stresses which arise at a resonance with the strongest 12th harmonic, parameters of each variant as well as the total number of GV variable blades of IPC fifth stage are shown in Table 1.

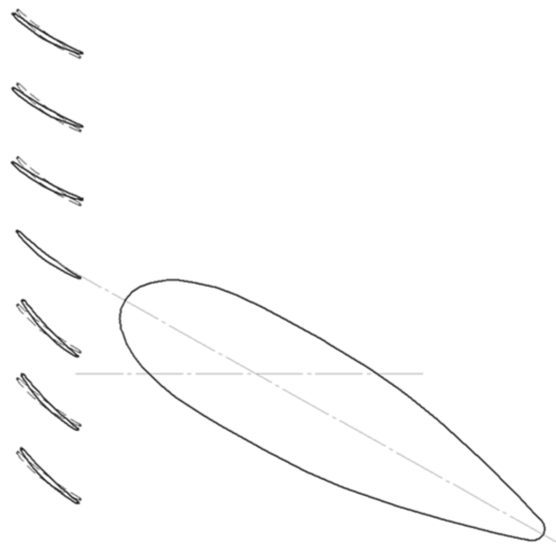


Figure 4: Rotation scheme of guide vane blades.

Table 1: The results of the parametric IPC model calculation.

Variant number	Parameter of different stagger angles, maximum stagger angles (number of blades) for the groups:			Parameter of alternating blade pitch for the groups:						
	2, 5, 6	1, 3, 7	4 (3)	1, 7	2, 6	3	4	5	Number of variable blades	Dynamic stresses MPa
1	0	0	0	0	0	0	0	0	0	86.7
2	0	0	0	0.3	0.3	0.3	0.3	0.3	0	115.98
3	3 (6)	3 (6)	3 (8)	0	0	0	0	0	42	43.791
4	3 (6)	3 (6)	3 (8)	0.3	0.3	0.3	0.3	0.3	42	31.877
5	3 (6)	6 (6)	9 (8)	0	0	0	0	0	42	37.536
6	0	0	0	0.35	0.35	0.35	0.35	0.35	0	86.95
7	0	0	0	-0.3	-0.3	-0.3	-0.3	-0.3	0	105.94
8	0	0	0	-0.15	-0.15	-0.15	-0.15	-0.15	0	137.741
9	6 (2)	6 (2)	6 (2)	0	0	0	0	0	14	46.737
10	0	6 (2)	6 (2)	0	0	0	0	0	8	57.214
11	6 (2)	6 (2)	6 (4)	0	0	0	0	0	16	44.426

From the data presented in Table 1, it is clear that a significant reduction of the dynamic stresses in the RW of IPC fifth stage at resonance with the 12th harmonic was achieved when applying the Shvarov's profile at rotor blades and introducing the different stagger angles at GV of the IPC fifth stage. Thus the level of dynamic stresses at resonance with the 12th harmonic was 86.7 MPa when using RW5 blades with the Shvarov's profile and the base GV5. And when the Shvarov's profile at RW5 and also different stagger angles and alternating blade pitch parameters of IPC GV5 were used (variant No 4 in Table 1, changeable GV5 blades value is 42) the level of dynamic stresses at resonance with the 12th harmonic was 31.9 MPa (reduced by 2.7 times).

However, the usage of RW5 blades with the Shvarov's profile and GV5 blades with different stagger angles (variant No 9 in Table 1, changeable GV5 blades value is only 14) the level of dynamic stress is not much large than in variant No 4 – 46.7 MPa (reduced by 1.85 times).

4.1 Analysis of Circumferential Variation Calculation for the IPC Fifth Guide Vane Variants Giving the Largest Dynamic Stresses Reduction

The relative static pressure profiles in the cross section following the IPC RW5 at mid-span for the basic compressor case and compressor variant No 4 are shown in Figure 5 for the idle mode. The Figure 5 shows the basic version in blue and modernized (variant No 4) – in red. Marked pressure peaks correspond to the support racks and areas near them.

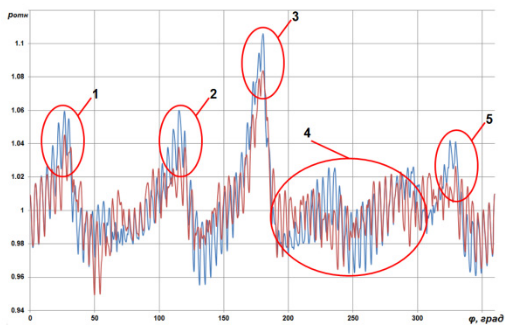
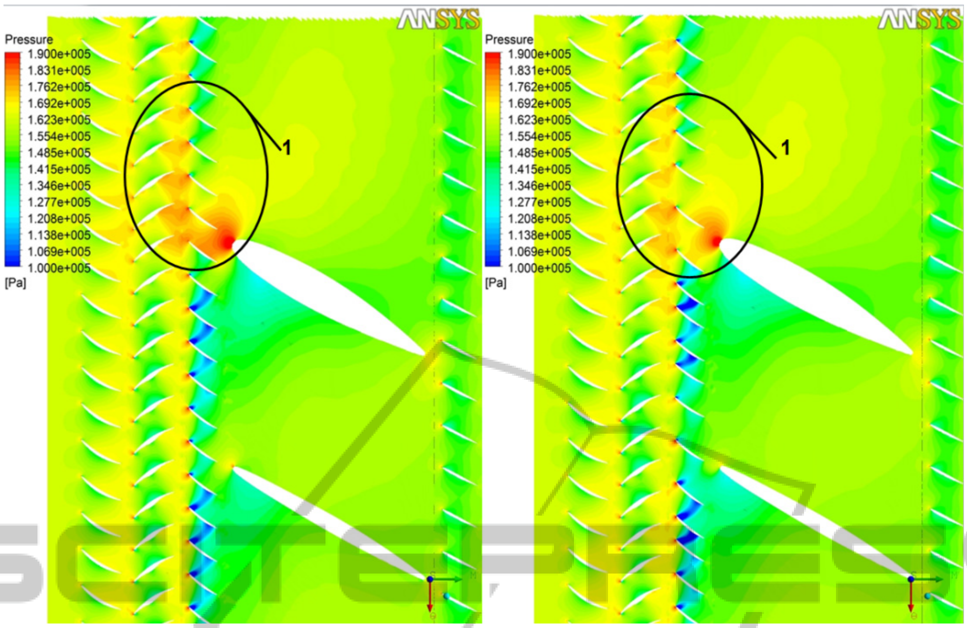
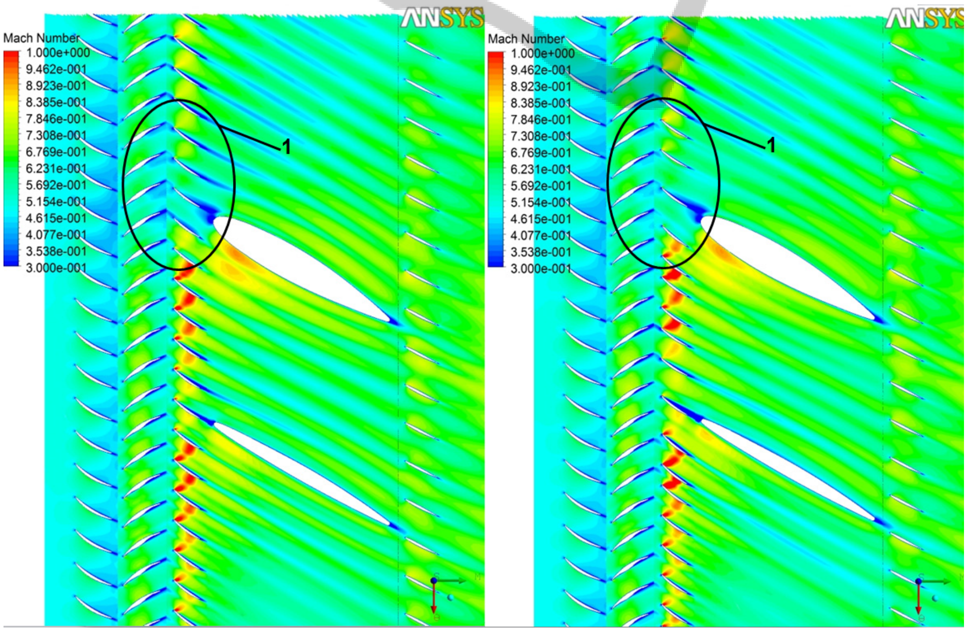


Figure 5: Relative static pressure variation in the section following the IPC RW5 at mid-span.



Base variant Variant No4

Figure 6: Static pressure field close to support rack in area 1.



Base variant Variant No4

Figure 7: Mach number field close to lower support rack.

Comparison of static pressure distribution fields at mid-span the base compressor case and variant No 4 (Table 1) at area 1 are shown in Figure 6. A similar comparison for the flow Mach number is shown in Figure 7.

Apparently from the presented graphs and static pressure distribution fields static pressure peaks decrease is observed for modernized variant (No 4) compared to the base compressor case at the areas 1, 3 and 5. In addition, the more periodicity and more uniform flow field is achieved for all specific areas.

5 CONCLUSIONS

Thus, the following results were achieved in the course of this work:

1. Significant reduction of the dynamic stresses in the IPC fifth rotor wheel at resonance with the twelfth harmonic was achieved. More specifically, the dynamic stresses were reduced by one half compared with the RW5 with Shvarov's profile and base variant of GV5.

2. It was found that the different blades stagger angles and alternating blade pitch introduction allows to "flatten" the circumferential variation in the cross section following the IPC RW5.

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