Analysis of dependence of the 2FSI subsystem parameters on the labyrinth seal diameter of the centrifugal compressor in the gas pumping unit

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Abstract. The system of centrifugal compressor GTU has several 2FSI subsystems: impeller, labyrinth seals (LS), dummies, etc. The article analyzes dependence of one subsystem - the labyrinth seal - on its diameter. The effect of this parameter on the wave processes occurring in labyrinth seals during vibrations of the rotor is studied. A solution is obtained for a nonstationary aeroelastic three-dimensional gas flow problem in deformable LS. The amplitude-frequency characteristics of the gas dynamic and vibration parameters of the LS CC of GTU are obtained. Time dependences of the gas-dynamical force and the work of gas-dynamic forces in the LS zone at different rotor diameters are obtained.

1. Physical statement

The computational model of the labyrinth seal was considered, which is a set of the LS gas-dynamic gap and the LS steel ring in a 3D statement. The change in the gas dynamic force in time, calculated through the pressure field acting directly on the rotor [1-6], was monitored. The rotor motion of the was described by the harmonic law with given amplitude and frequency [7-11]. When assigning the rotor oscillation frequency, the blade frequency and the rotational frequency were taken into account. The rotor geometric characteristics were varied and their influence on the wave processes occurring in the labyrinth seals during rotor vibrations was estimated. At the LS inlet and outlet, a differential pressure was set. Particular attention was paid to evaluation of wave processes in the circumferential direction [12-18]. As a parameter of the investigated dependences, the rotor diameter in the LS zone is adopted.

2. The solid staging

The solid model (basic variant) is a circular gas-dynamic gap of LS with width 37 mm, height 500 µm and diameter 422 mm. The solid-state LS ring is a complex stepped construction (Figure 1). The construction material is steel, the pressure drop is not taken into account, the working medium is perfect gas.

The plan for carrying out the computational experiment on studying resonances in the 2FSI subsystem "labyrinth seals" (LS) of GTU is shown in Table 1. The parameters vary with respect to the "basic variant".

Table 1. The plan for the computational experiment.

№ of variant	1 (BV[1])	2	3
D_{rotor}, mm	422	294	550

(BV[1]) - basic variant

The calculation lasts 8.5 hours when examining the perfect gas and absence of pressure drop. Preliminary calculations have shown that the calculation time increases and reaches 48 hours for variants corresponding to real gases and presence of pressure drop in the LS. The amount of computational resources required is limited by the ANSYS capabilities for parallelizing the durability part of 2FSI calculations. Acceleration of calculations of the structure stress-strain state in the 2FSI statement was observed when only up to 8 cores (1 node) were used. With a further increase in the number of calculation cores, the count rate did not increase.
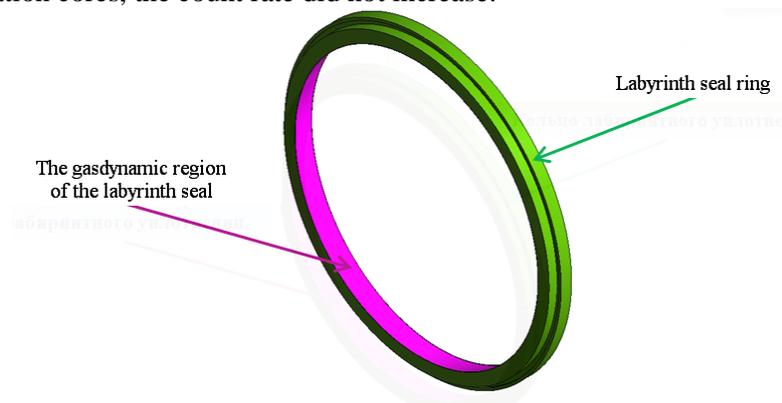
Figure 1. Solid-state model of the 2FSI subsystem of the LS CC GTU.

3. The mesh model
The minimum size of the finite elements of the mesh models of the LS ring and the gas-dynamic gap of the LS is 3.75 mm, the element type is hexahedral (Figure 2). For the feasibility of 2FSI calculations in the construction of mesh models of the gas dynamic region and durability region, it was ensured that the corresponding network elements coincide at the data transfer boundary from one type of analysis to another.
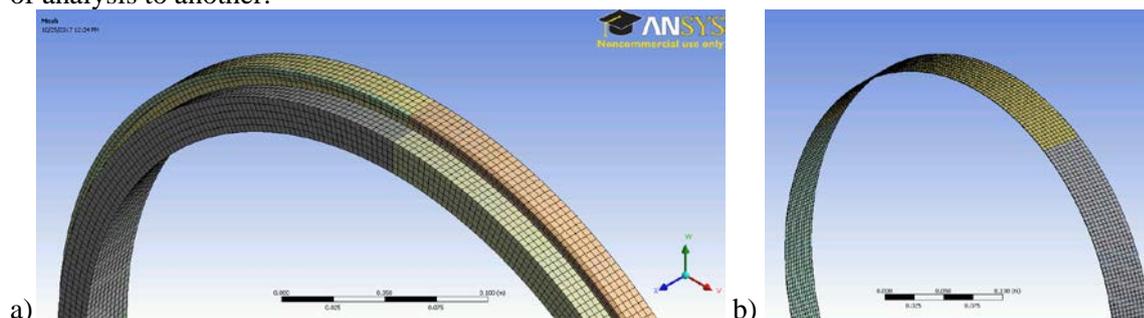
Figure 2. The mesh model of the 2FSI subsystem of the LS CC GTU: (a) - mesh model of the labyrinth seal ring; (b) - mesh model of the gas-dynamic region of the labyrinth seal

4. Preparation and carrying out calculations on estimation of influence of LS geometrical characteristics on circumferential oscillations in 2FSI subsystem LS CC GTU
In accordance with the plan, the influence of the LS geometric characteristics on circumferential oscillations in the 2FSI subsystem of the LS GTU is investigated. Time dependences of pressure, gas dynamic force, work of gas dynamic force and total displacements in the LS ring LU on the rotor diameter are obtained (Figure 3).
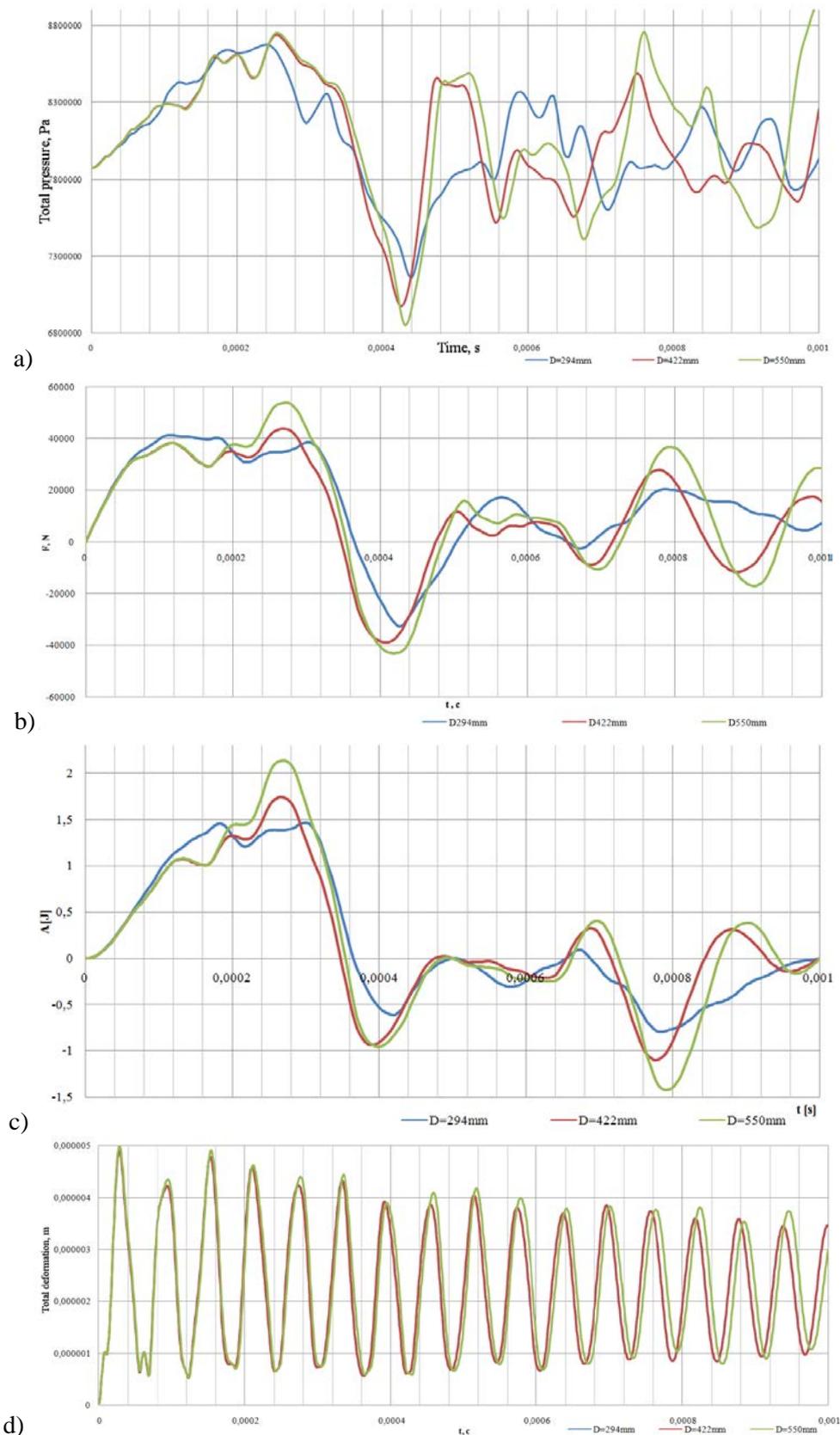
Figure 3. Time dependences of the 2FSI parameters of the LS CC GTU subsystem on the rotor diameter: (a) pressure in the LS gas-dynamic gap; (b) gas-dynamic force; (c) work of the gas dynamic force; (d) total displacements in the LS ring.
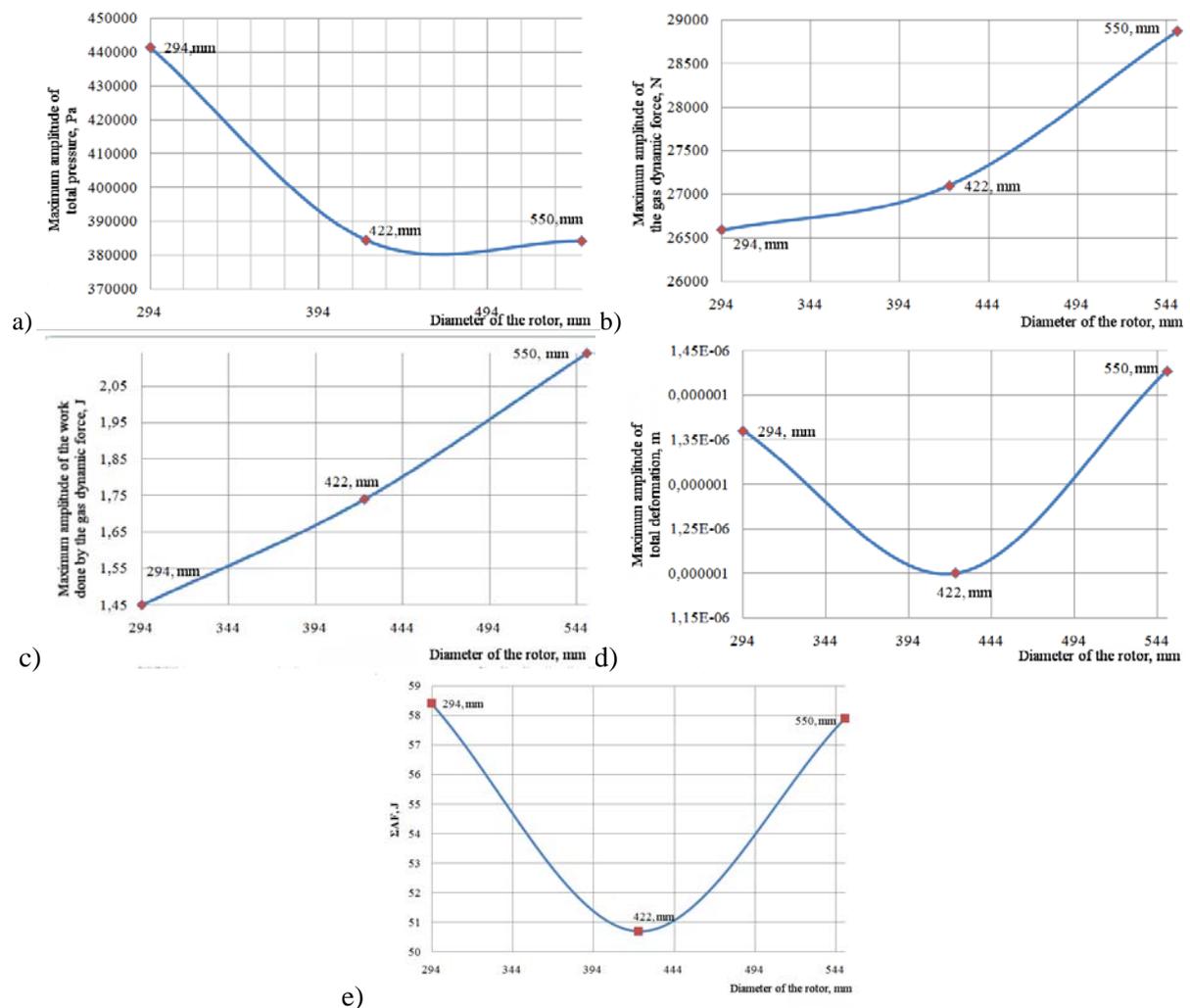
Figure 4. Analysis of the time dependences of the LS subsystem 2FSI parameters CC GTU on the rotor diameter: (a) - maximum amplitude of the braking pressure; (b) - maximum amplitude of the gas dynamic force; (c) - maximum amplitude of the gas dynamic force; (d) - maximum amplitude of the total displacements; (e) - total work of the gas dynamical force.

When analyzing time dependences of the 2FSI subsystem of the LS CC GTU on the LS geometric parameters (Figure 4), it was revealed:

- with increase in the shaft diameter from 294 mm to 550 mm, the maximum amplitude of the gas dynamic force is observed at the diameter of 550 mm and equal to 28.9 kN, the minimum value of the gas dynamic force amplitude is observed at the diameter of 294 mm and equal to 26.6 kN;

- the maximum amplitude frequency of the gas dynamic force is constant and equal to 1.5 kHz for the considered range of diameters and is not equal to the frequency of the driving force (0.95 kHz);

- with an increase in diameter from 294 mm to 550 mm, the maximum amplitude of the oscillation of the braking pressure does not change;

- with increase in diameter from 294 mm to 550 mm, the maximum amplitude of total displacements does not change;

- with increase in diameter from 294 mm to 550 mm (by 1.9 times), increase in the maximum amplitude of the work done by gas dynamic force from 1.45 J to 2.14 J (1.5 times) is observed;

- in figure 4a, it is seen that at the diameter of 294 mm, the pressure oscillation amplitude is maximal. Spectral analysis showed that the diameter equal to 294 mm corresponds to an oscillatory process with a resonant frequency of 1800 Hz, which is multiple of the rotor oscillation frequency (2 times). It should be clarified that the rotor oscillation frequency was set equal to the blade frequency.

The labyrinth seals with diameters equal to 422 mm and 550 mm correspond to oscillatory processes with resonant frequencies of 1260 Hz and 720 Hz, respectively, which are not multiple of the exciting frequency. In this case, the pressure oscillation amplitude at these diameters is reduced (Figure 4a.)

5. Conclusions

1. The influence of the DN diameter on the character of the oscillatory process in the LS is revealed.

2. If the frequencies of oscillations of the rotor and gas coincide (in the circumferential direction), the maximum amplitude of the braking pressure in the LS is observed.

3. The total work of gas-dynamic forces is positive in the considered range of diameters, which indicates the possibility of "build-up" of the system (Figure 4e).

4. To reduce the amplitude of the oscillatory process, it is necessary to "detune" from the coincidence of the oscillation frequencies of the rotor and the gas dynamic volume of the LS by changing the diameter of the LS at the design stage.

6. References

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