BLADE GROUP RESONANT STRESSES FEM SIMULATIONS

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Abstract: *This paper presents the results of the simulations of the resonant stresses in a FE environment. Numerical calculation for determination of natural frequencies, mode shapes and dynamic stresses, based on FEM and NISA package is used. Analysis are made on the blade group with three blades with rectangular cross section and typical turbine blades with taper, pretwist and asymmetric airfoil as well. The influence of the position of the lacing wire on the resonant stresses is analysed. Three-dimensional finite element models of the blade group are made by using of twenty node isoparametric solid elements. The number of degrees of freedom is different for each model (more than 30000 DOF). The results of the investigation are given in tables and graphics.*

Keywords: RESONANT STRESS, BLADE GROUP, FEA

1. Introduction

Operating practice of steam turbine shows that damages to blades constitute a considerable proportion of all the damages to steam turbine, therefore dynamic analysis of blades or blade groups is of great significance. The main reason for blade failures due to a fatique is vibration. The dynamic loads on the blades arise from many sources. The main source is the change of forces due to a blade passing across the nozzles of the stator with a frequency given by the number of nozzles multiplied by the speed of the machine. For LP blades, whose natural frequencies are low, the engine order excitation due to a non-uniform spacing of the diaphragms is important [1] and [2].

The work presented in this paper is a part of a project that should contains an investigations connected with turbine blade fatigue behavior under static and dynamic stress fields especially in the zone of high stress, during the critical condition of blade operating, where fatigue crack usually initiates.

This paper is showing a results of investigation of the dynamic behavior, resonant stresses calculation during the start up of the turbine, for a blade group with the lacing wire. Generally, the influence of the position of the lacing wire on the blade on the resonant stresses is simulated. Analysis are made on the blade group with three blades with rectangular cross section and typical turbine blades with taper, pretwist and asymmetric airfoil as well. First three tangential bending natural frequencies and mode shapes and influence of the lacing wire on them are discussed in this paper.

2. Critical Spids and Resonant Stresses

2.1. Blade Group Natural Frequencies

A blade group exhibits more complex dynamic behavior than a free-standing blade. The cantilever mode frequencies are influenced by the nearest blades, the shroud and lacing wires mass and elasticity. In addition to the cantilever modes, fixed-pinned modes appear in groups between the cantilever modes. For the purpose of resonant stress calculation, the influence of the first three bending modes in tangential direction are included [3] and [4].

The numerical calculation of the natural frequencies is done by using a complex program package NISA which is based on Finite Element Analysis method. We choose this software because it content great number of modulus that are helping during the generating the mesh of the system's model, and it is giving opportunities of detail structure analysis. These programs during the dynamic system analysis are using standard FEA model:

$$[\,\mathbf{K}\,]\,[\,\mathbf{D}\,] = [\,\mathbf{M}\,]\,[\,\mathbf{D}\,]\,[\,\mathbf{W}\,]^2$$

where [**K**] is stiffness matrix, [**M**] - mass matrix, [**D**] - displacement matrix (mode shapes), [**W**]^2 - diagonal matrix containing eigenvalues (natural frequencies).

The results of the calculations of the natural frequencies for the first three bending modes for different models of blade groups:

- blade group with one lacing wire located on various places on the blade (1xH÷0,5H),
- blade group with two lacing wires with different position of the second wire (1xH÷0,5H),

are used in forming of the Campbell diagrams for each different model. On figure 1 and figure 2 the first bending modes for different models of blade groups are given.

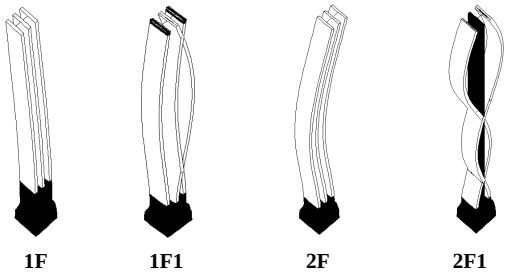

Fig. 1 *Bending mode shapes of blade group with one lacing wire*

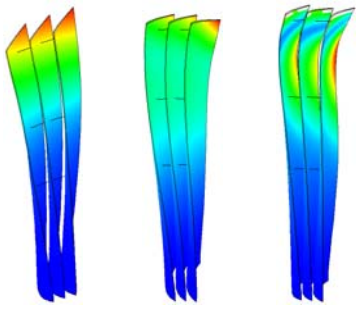

Fig. 2 *Bending mode shapes of blade group with three lacing wires*

2.2. Critical spids and Resonant Forces

The process of resonant stresses calculations during start up of turbine is connected with resonant frequencies determination according to the Campbell diagrams, e.g. interaction of the first three bending modes of vibration with the first six harmonics of the rotational speed. An example of the Campbell diagram for one of the investigated models is shown on figure 3.

The force that arise when a rotor blade passes across the nozzles of a stator, which experiences fluctuating lift and moment forces repeatedly at a nozzle passing frequency is given in equation (2.1), and engine order excitation due to a non-uniform spacing of the diaphragms is given in equation (2.2).

$$F = F_0 + \sum_{K=1}^{\infty} \mathrm{F_K} \cos K\left(2\pi \mathrm{mzt} + \beta_{\mathrm{K}}\right) \qquad (2.1)$$

$$F = F_0 + \sum_{K=1}^{\infty} \mathrm{F_K} \cos K\left(2\pi \mathrm{nt} + \beta_{\mathrm{K}}\right) \qquad (2.2)$$

where:
z – number of diaphragms,
β - phase,
F_0 – static force of the pressure,
$F_K cosK(2\pi nzt+\beta_K)$ – dynamic force-K-th harmonic.

Because of the complex and nonlinear damping mechanisms (friction from slipping surfaces, material damping and aerodynamic damping), the equivalent viscous damping effect is used to estimate the resonant stresses with damping ratio of 0,02 [1], [2].

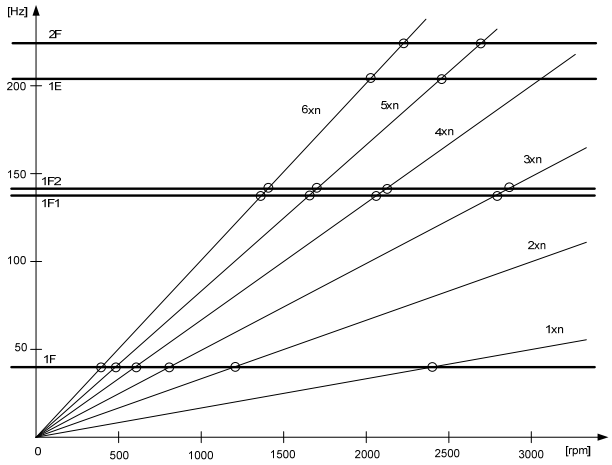

Fig. 3 *Campbell diagram*

The results of resonant stresses calculations during start up of the turbine for interaction of the I, II and III harmonics with the bending modes of vibration are shown on Fig. 4 to 6.

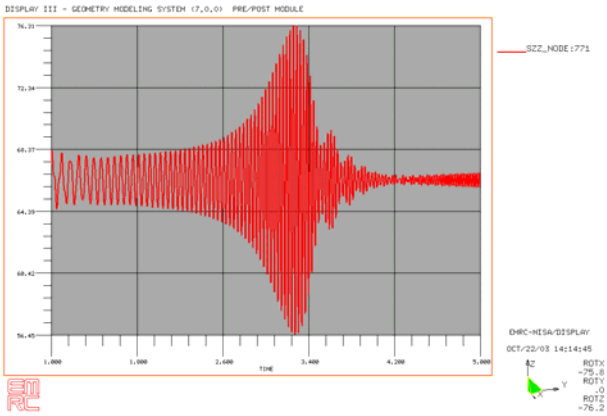

Fig. 4 *Resonant stresses due to a first harmonic*

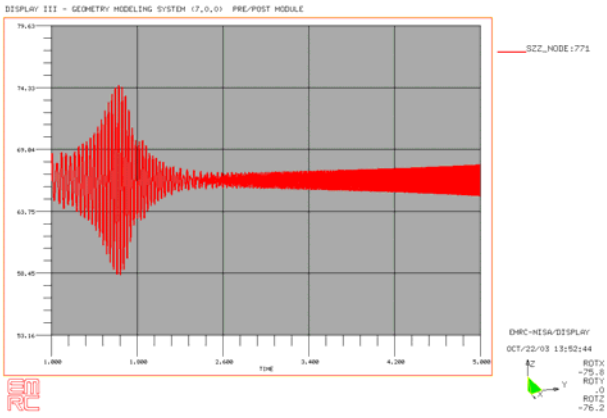

Fig. 5 *Resonant stresses due to a second harmonic*

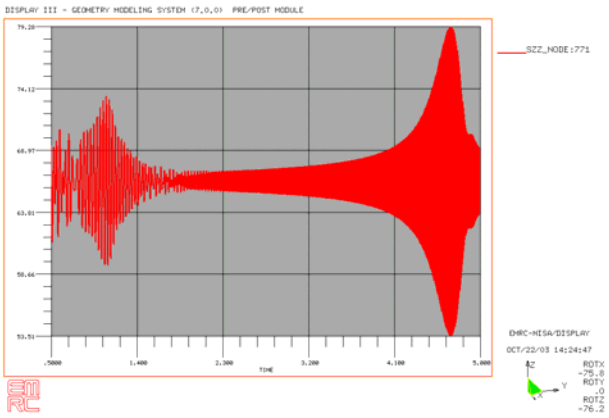

Fig. 6 *Resonant stresses due to a third harmonic*

The results of resonant stresses calculations due to a I harmonic for the model of blade group with three blades, and a change of position of the lacing wire (1xH÷0,56H) are shown on Fig.7 to 12.

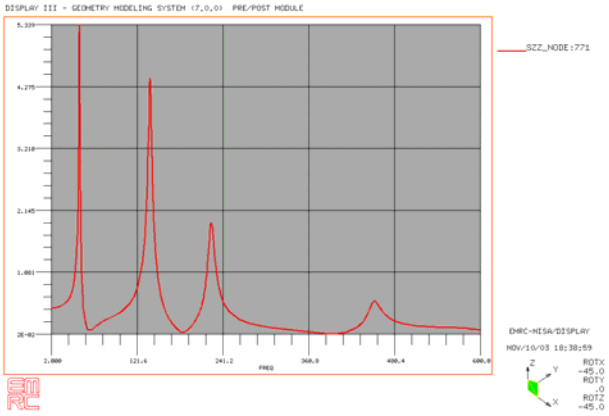

Fig. 7 *Resonant stresses due to a first harmonic-lacing wire on 1xH*

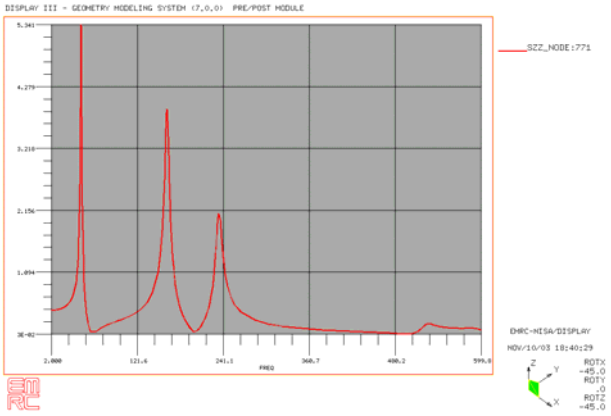

Fig. 8 *Resonant stresses due to a first harmonic-lacing wire on 0,92xH*

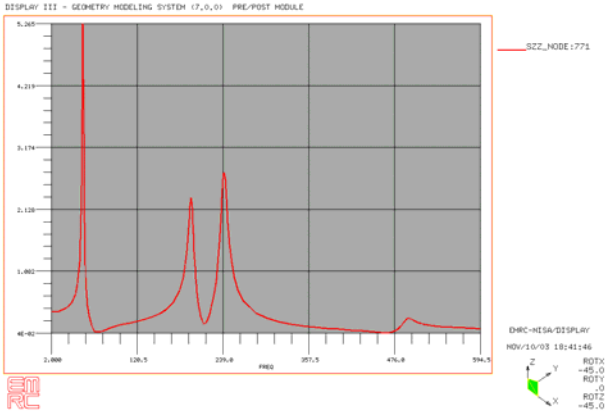

Fig. 9 *Resonant stresses due to a first harmonic-lacing wire on 0,81xH*

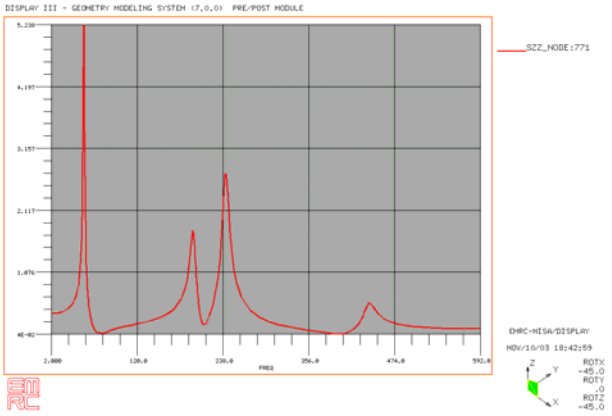

Fig. 10 *Resonant stresses due to a first harmonic-lacing wire on 0,78xH*

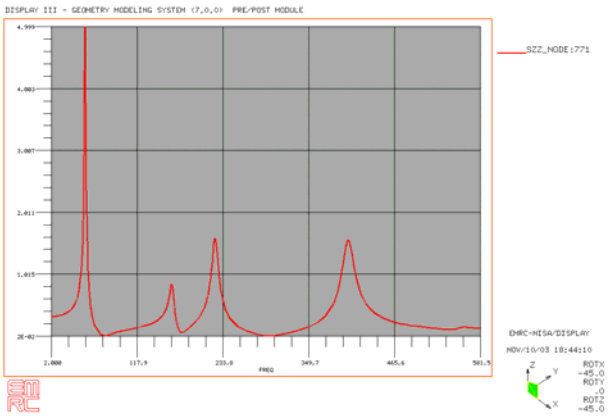

Fig. 11 *Resonant stresses due to a first harmonic-lacing wire on 0,69xH*

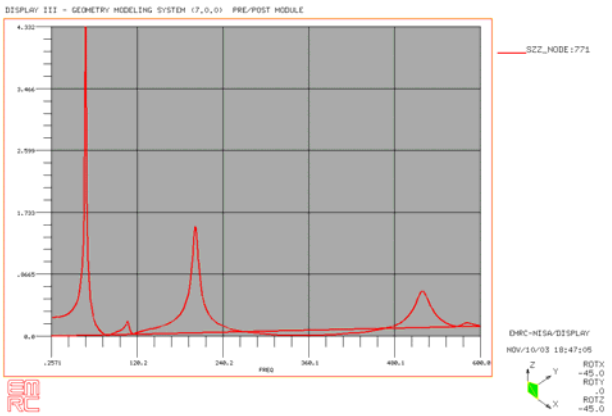

Fig. 12 *Resonant stresses due to a first harmonic-lacing wire on 0,56xH*

Resonant stresses calculations due to a I harmonic for the model with two lacing wires, and a change of position of the second lacing wire (1xH÷0,56H) are shown on Fig.13 to 17.

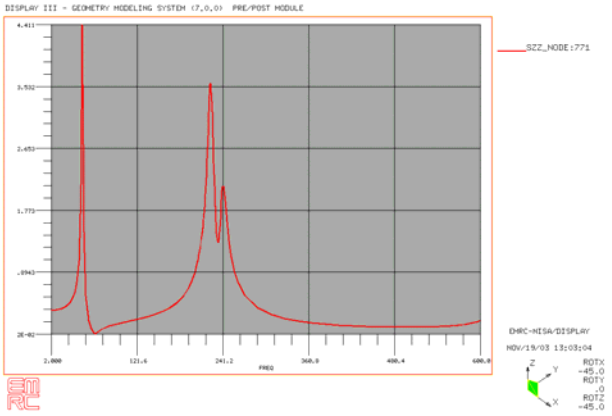

Fig. 13 *Resonant stresses due to a first harmonic-second wire on 0,92xH*

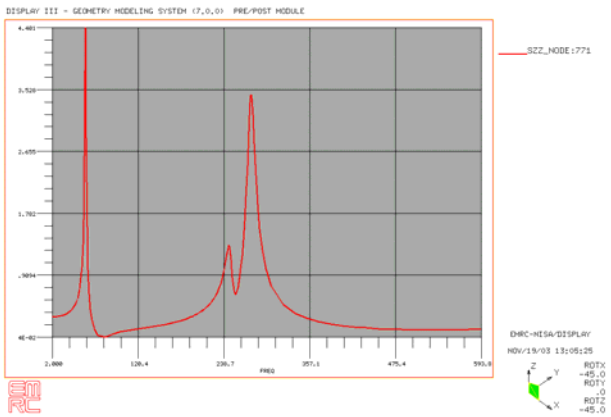

Fig. 14 *Resonant stresses due to a first harmonic-second wire on 0,81xH*

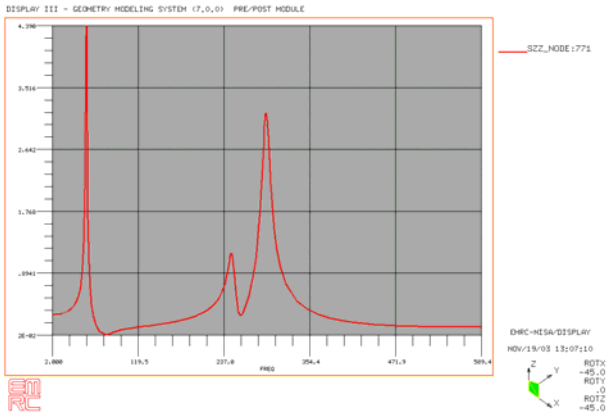

Fig. 15 *Resonant stresses due to a first harmonic-second wire on 0,78xH*

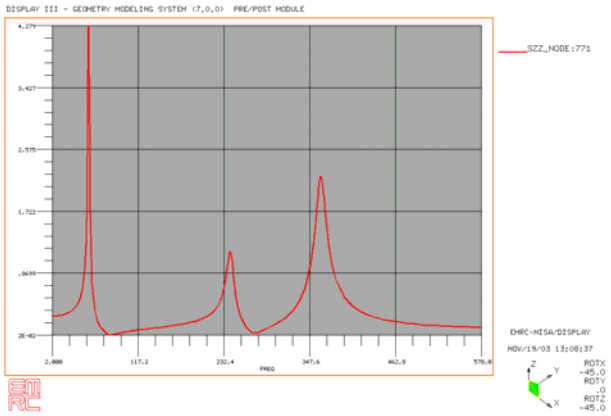

Fig. 16 *Resonant stresses due to a first harmonic-second wire on 0,68xH*

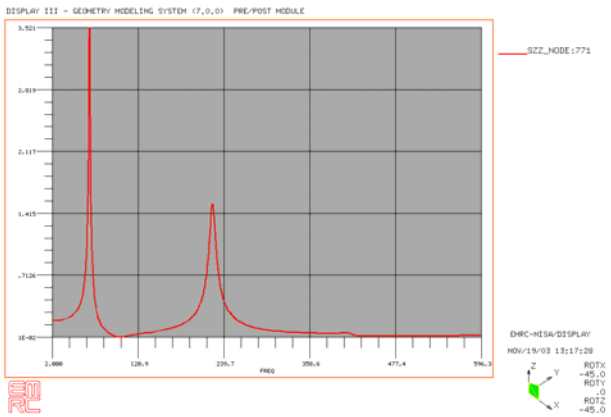

Fig. 17 *Resonant stresses due to a first harmonic-second wire on 0,56xH*

3. Resonant Stresses Analysis and Conclusion

During the simulations of the resonant stresses, a unit resonant force excitation is submitted. The results of the simulations of the resonant stresses changes for the models of blade group with one lacing wire mounted on different height of the blade is given in Table 1 and Fig.18.

It can be seen that when the lacing wire is mounted near node of the mode the resonant stresses are increased, and in the situation when the lacing wire is mounted near antinodes of the mode the resonant stresses are decreased.

The results of the simulations of the resonant stresses changes for the models of blade group with two lacing wires with second wire mounted on different height of the blade is given in Table 2 and Fig.19.

The influence of the damping ratio changes on the resonant stresses is given in Table 3 and Fig. 20. It can be seen that the decrease of the damping ratio increase the resonant stresses on the blade group.

Table 1: *Influence of the position of the lacing wire on resonant stresses due to a I harmonic of excitation*

	σ_a [N/mm^2]			
	1F	1F1	2F	2F1
				
1.0xH	5.34	4.45	1.96	0.55
0.92xH	5.34	3.91	2.06	0.22
0.81xH	5.26	2.33	2.75	0.25
0.78xH	5.24	1.81	2.73	0.6
0.69xH	5	0.83	1.61	1.6
0.56xH	4.33	0.22	1.55	0.63
0.5xH	3.83	0.12	1.69	0.1

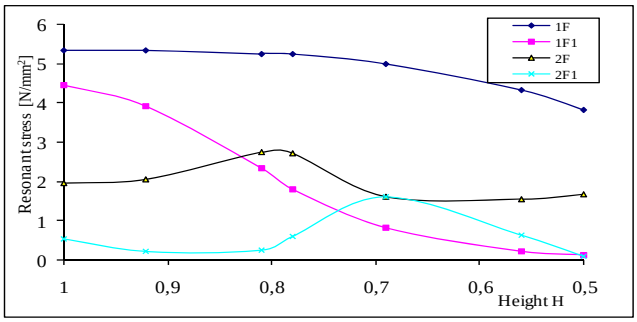

Fig. 18 *Resonant stresses due to change of position of the lacing wire*

Table 2: *Influence of the position of the second lacing wire on resonant stresses due to a I harmonic of excitation*

	σ_a [N/mm^2]		
	1F	1F1	2F
			
1.0xH	5.34	4.45	1.96
0.92xH	5.34	3.91	2.06
0.81xH	5.26	2.33	2.75
0.78xH	5.24	1.81	2.73
0.69xH	5	0.83	1.61
0.56xH	4.33	0.22	1.55
0.5xH	3.83	0.12	1.69

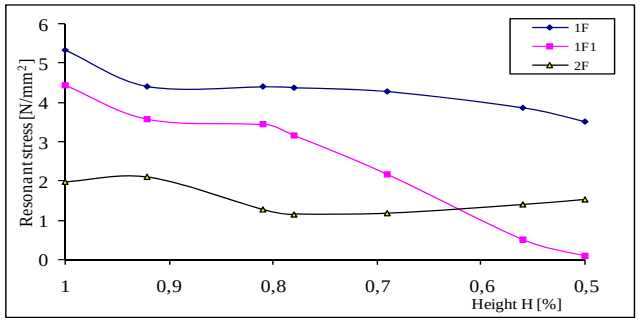

Fig. 19 *Resonant stresses due to change of position of the second lacing wire*

Table 3: *Influence of the damping ratio changes on resonant stresses*

	σ_a [N/mm^2]			
	1F	1F1	2F	2F1
				
0.02	5.34	4.45	1.96	0.55
0.018	5.93	4.92	2.14	0.62
0.016	6.67	5.6	2.4	0.7
0.014	7.62	6.35	2.75	0.84
0.012	8.88	7.42	3.2	0.98
0.01	10.6	8.94	3.84	1.2

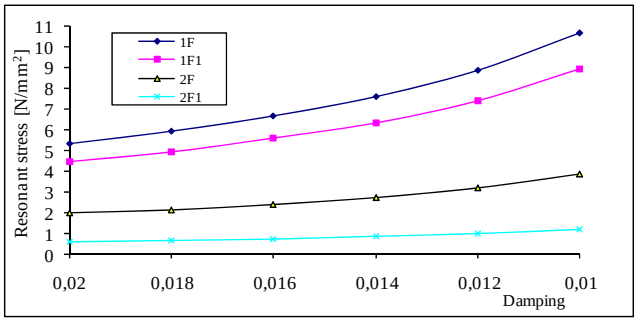

Fig. 20 *Resonant stresses due to change of damping ratio*

4. References

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