MODAL ANALYSIS OF A STEAM TURBINE BLADED DISK TO INVESTIGATE BLADE DAMAGE

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Abstract. This work is the first stage of the root-cause investigation of the blade damage in a steam turbine bladed disk of a thermoelectric power plant. The purpose of this work is to determine the natural frequencies and the associated modes of vibrations of a disk formed by several blade groups. Each group is an assembly of four or five blades, connected by elements named *shroud* and *tie-wire.* Initially, a numerical/experimental modal analysis is made on a single blade in a free-free condition. Furthermore, a numerical/experimental modal analysis is made on a five blades group in a clamped-free condition. The results obtained from the mathematical model, using a finite element code, have shown to be in a very good agreement with the experimental modal analysis measurements.

Keywords: Steam turbine, blade, damage, modal analysis, finite element modeling.

1. INTRODUCTION

This paper presents the first stage of the root-cause investigation of the blade damage in a steam turbine bladed disk, operating in a thermoelectric power plant. This turbine is a part of a turbogenerator that generates 320 MW in a power plant, situated in the Santa Catarina state, Brazil, as shown in Fig. (1).

Recently, after a careful site inspection was identified that one blade was broken and several others were in a cracking process, in one disk of the low-pressure turbine stage. For the investigation of the root-cause of the blade damage one proposes to determine the vibratory stress due to the flow-induced vibrations on the bladed disk in order to compare with the fatigue limit of the material, Fleeter (1998), Chyou (2000) and Castilho *et al.* (1998). A preliminary metallurgical examination of the fractured component showed beach marks, which is characteristic of a fatigue failure.

The computational mechanics procedure used in this work was firstly to digitize a single blade for obtaining a file with the geometric dimensions and, secondly, to build a solid CAD model of the blade. The CAD model was verified by comparing the calculated and measured blade weight. This file was read and analysed using a finite element code in order to obtain the natural frequencies and the associated vibration modes of a single blade in a free-free condition. A modal testing was performed and the numerical/experimental comparison was used to adjust the material properties and the geometric dimensions.

Figure 1. Overall view of the steam turbine

In addition, a five blades group was modeled considering the *tie-wire* and the *shroud* as the elements used to connect the blades. In this case, another modal testing was performed and the numerical/experimental comparison was used to adjust the material properties introduced in the computational model with the objective of simulating the contact between the blade and the *tie-wire* and the blades and the *shroud.* As shown in several papers and reports, these elements can play a very important role in this type of analysis. A combination of modal testing and finite element analysis are the current procedure to accurately predict the dynamic response of bladed disk in turbomachinery, Orsagh *et al*. (1994).

2. MODAL ANALYSIS ON A SINGLE BLADE

The purpose of this analysis is to adjust the material properties and the geometric dimensions of the blade, in the numerical model, in order to fit the modal testing measurements. Figure 2 shows the numerical model in which the medium size of the elements is 10 mm and the total number of elements is 14 313.

Figure 3 shows the blade configuration for the modal testing in a free-free condition. The instruments used for this purpose were a force transducer B&K 8200, a shock hammer (coupled to the force transducer), an accelerometer B&K 4344 and LMS SCADAS III with a Fourier analysis software. For the identification of the mode, accelerations were obtained at 105 points of the blade.

Table 1 presents the numerical/experimental results of the first ten modes of the modal analysis of a single blade in a free-free condition.

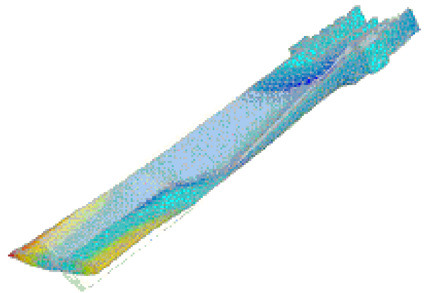

Figure 2. Finite element mesh of a single blade

Figure 3. Experimental set for the modal testing of a single blade in a free-free condition

Table 1 – Numerical/experimental results on a single blade.

Mode	Numerical (Hz)	Experimental (Hz)	Type mode	Deviation (%)
1	162,8	166,9	bending	-2,5
2	442,3	451,7	bending	-2,8
3	524,6	547,2	torsion	-4,1
4	738,7	748,9	bending/torsion	-1,4
5	1.112,0	1.077,2	bending/torsion	3,2
6	1.212,0	1.166,1	bending-torsion	3,9
7	1.448,0	1.457,7	bending	-0,7

8	1.674,0	1.693,7	bending/torsion	-1,2
9	1.765,0	1.764,5	bending/torsion	0,0
10	1.848,0	1.850,9	bending of the root	-0,2

3. MODAL ANALYSIS ON A FIVE BLADES GROUP

A tie-wire and a shroud, as seen on Fig.(4), connect groups of four and five blades. The contact problem between the blade and the *tie-wire* and the blade and the *shroud* is analysed by using a soft material between them. So, the purpose of this analysis is to adjust the material properties, introduced in these regions in the numerical model, so that the numerical solution fits the experimental results.

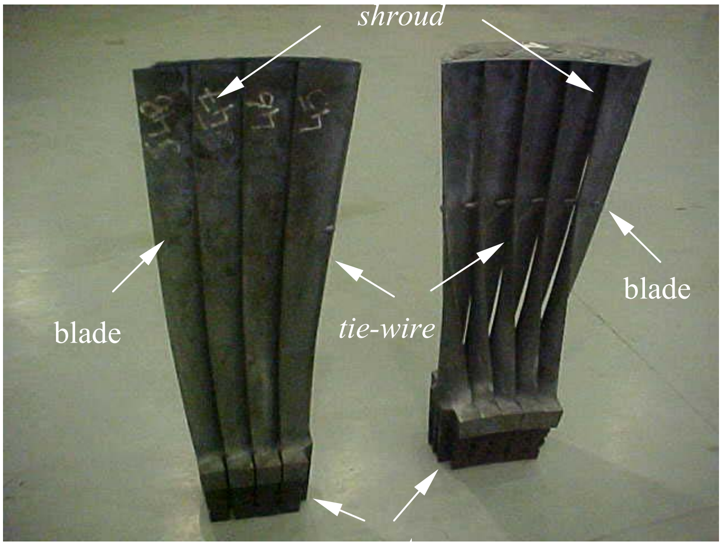

Figure 4. Four and five bladed groups

Figure 5 shows the numerical model in which de medium size of the elements is 7 mm on the blades, 4 mm on the *shroud*, 3 mm on the *tie-wire* and 2 mm on the material interface. The total number of elements used in the model is 98 184.

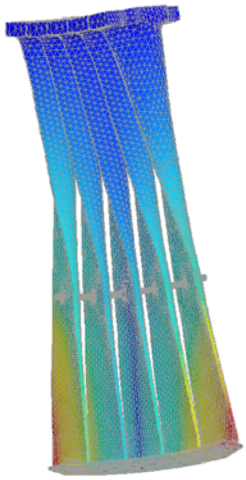

Figure 5. Finite element mesh of the five blades group

The experimental set for the modal testing of a five blades group is presented in Fig. (6). The instruments used for this purpose were the same used in the experimental setup in the modal testing of the single blade test.

Figure 6. Experimental setup for the modal testing of a five blades group in a clamped-free condition, showing selected impact point.

Table 2 presents the numerical/experimental results of the first ten modes of the modal analysis of a five blades group, in a clamped-free condition. Mode types are bending (B) or torsion (T).

Table 2 – Numerical/experimental results on a five blades group. Frequencies in Hz.

Numerical		**Experimental**		
Frequency	Mode	Frequency	Mode	Mode type
107,8	1	99,4	1	bending
-	-	142,3	2	bending/torsion
172,7	2	148,5	3	bending/torsion
213,6	3	210,7	4	bending/torsion
-	-	296,2	5	bending/torsion
395,2	4	336,4	6	bending/torsion
411,0	5	407,6	7	bending/torsion
499,1	6	479,4	8	bending/torsion
-	-	517,3	9	bending/torsion
548,4	7	538,8	10	bending/torsion

4. DISCUSSION AND CONCLUSION

The study proposed in this work is the first stage of the case-root investigation of the blade damage in a steam turbine bladed disk. From the results of the study cases, one can observe a good agreement of the numerical results with the modal testing measurements in the two models: the single blade and the five blades group. In the second case it is highlighted the importance of the investigation of the *tie-wire* and the *shroud* effect on the dynamic behavior of bladed disk. However, the experimental build up boundary condition wasn't very effective, and a better setup must be designed to obtain a closer agreement between numerical and experimental modal analysis data.

The next stage of this project is the modal analysis of the full disk including the centrifugal force due to rotation and the fatigue analysis considering the vibratory stress resulting from the flow-induced vibrations.

5. REFERENCES

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