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## **MODELING BY FINITE ELEMENT METHODS OF IMPACT OF EROSION ON FREQUENCY OF NORMAL MODES OF L-0 BLADE**

### **ABSTRACT**

After some time of exploitation steam turbine rotors blades in energetic industry they are being eroded and also their frequency of normal modes is changed. Those changes can cause to unwanted shift of blades normal mode frequencies. It is necessary to find quick method of rating changes of frequency in connection of mass loss due erosion. The evaluation of this dependence was made by finite element modeling method using HyperWorks 8.0 software. Geometrical model of blade L-0 with mass of 22 kg and length of 74 cm was used. There were calculated frequencies of the first five modes in function of mass loss along the leading blade edge (up to mass loss of 1,2%). Small losses of weight (around 0,2%) cause similar changes in values (around 0,2%) for all modes but with different types of frequency change (decrease or increase). The frequency decreases for all modes except mode the 3rd. For bigger mass loss an monotonic decrease of frequency was observed in 1st, 2nd, 5th mode and maximum (around +1,5 %) for 3rd mode and minimum (- 0,5%) for 4th mode. For maximum mass loss (1,2%) maximal decrease of frequency was observed in 2nd mode around -2%. Results of this modeling can be used to estimate changes of frequencies caused by erosion in exploited blades when their mass loss is known.

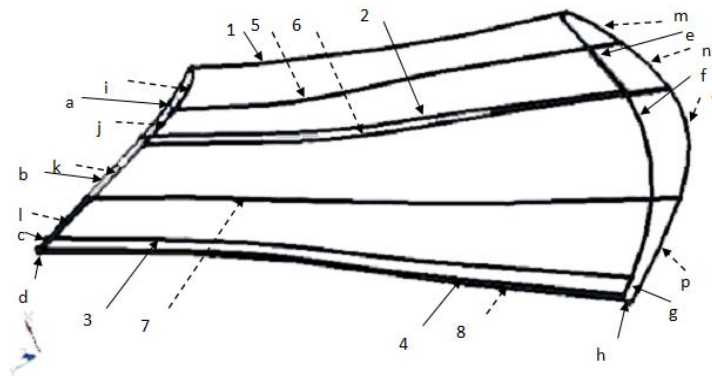
**Key words:** turbine blade, FEM, erosion, normal modes

### **INTRODUCTION**

Experience of using steam and gas turbines teach us the vibrations have big influence on properly working of turbine. World statistics inform about increasing power and speed of rotors of built turbines connect with increasing problems of free vibrations. Turbine rotors are built to minimize the problems with vibrations. Frequencies of normal modes should be different from frequencies of starting and working frequencies of rotor. Even small changes of frequencies of vibrations can lead to effect of resonance. Normal mode of blade depends on shape and mass of the given blade. Erosion on surface of lead edge decreases the mass of the blade and that leads to change of vibration frequency. The main goal of our work is evaluation dependence of the first five normal modes to mass loss along leading edge of the blade. For this evaluation we will used finite element method (FEM). [1,2]

## PARAMETERS OF CALCULATIONS

We used to simulation the blade shape presented on Figure 1 with sizes presented in Table 1. We got this blade shape from the Institute of Fluid-Flow Machinery of Polish Academy of Sciences. The edge with number 1 it is the lead edge.



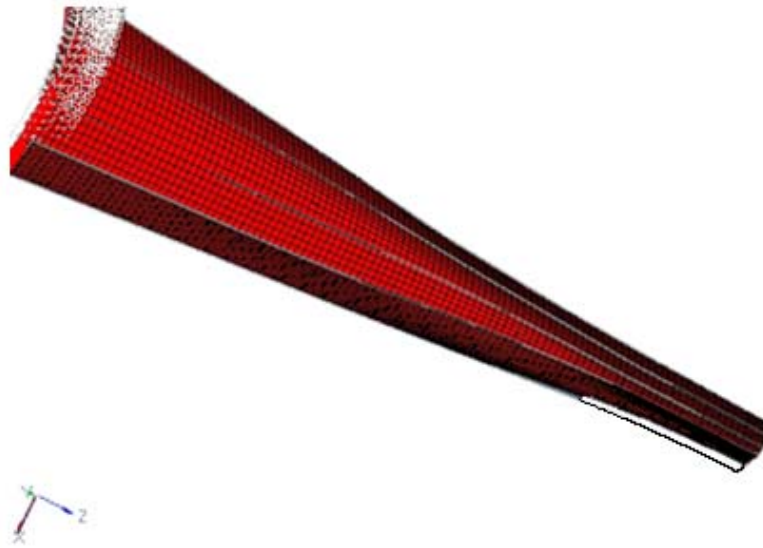
**Fig. 1.** Shape of the blade

**Table. 1.** Sizes of edges of the blade

1 – 747,24 mm	a – 55,28 mm	i – 32,61 mm
2 – 756,30 mm	b – 91,98 mm	j – 30,33 mm
3 – 775,49 mm	c – 9,34 mm	k – 49,54 mm
4 – 777,81 mm	d – 4,88mm	l – 50,08 mm
5 – 754,75 mm	e – 72,68 mm	m – 45,75 mm
6 – 760,22 mm	f – 126,62 mm	n – 45,34 mm
7 – 769,37 mm	g – 16,78 mm	o – 74,59 mm
8 – 779,631 mm	h – 11,89 mm	p – 76,14 mm

There are given the values of the quantities used for modeling: mass of the blade - 22,65 kg (m); Young's modulus -  $2,1 \times 10^5 \text{ N/mm}^2$ ; Poisson factor - 0,3; density -  $8 \times 10^{-6} \text{ kg/mm}^3$ . Blade was divided into 38913 finite elements; 34008 CHEXA elements (CHEXA - solid element composed of 6 quadrilateral faces with 8 grid points) and 4905 CPENTA elements (CPENTA - solid element composed of 3 quadrilateral and 2 triangular faces with 6 grid points). The erosion model could be accurately described by deleting some finite elements. Erosion is starting from the end of blade on leading edge (the end is shown on left side of Figure 1). For first simulation with effect of erosion we delete there some elements what change the mass of the blade for few grams ( $\Delta m$ ). Than we continue deleting them through this edge and into depth for each simulation erosion was attacking the edge on the longer distance than last one. By the whole time the biggest depth of deleted elements was on the end of the blade and the smallest in the central part of this edge where was finishing erosion. The biggest effect of erosion was made to half of the length and with maximum

depth around 3 cm. We tried to propagate them so in order to make them analogue as much as possible to the observed erosion on the exploited blades[3]. The model with ‘eroded’ edge shown in Fig. 2. The relative mass losses used for simulation are given in Table 2.



**Fig. 2.** Blade with deleted elements for erosion simulation (white part)

**Table 2.** Labels and relative mass loss applied for each simulation

Number of simulation	$\Delta m/m$ of blade. [%]
A1	0,000%
A2	0,052%
A3	0,060%
A4	0,068%
A5	0,079%
A6	0,109%
A7	0,144%
A8	0,151%
A9	0,171%
A10	0,208%
A11	0,245%
A12	0,273%
A13	0,321%
A14	0,405%
A15	0,466%
A16	0,627%
A17	0,820%
A18	1,173%

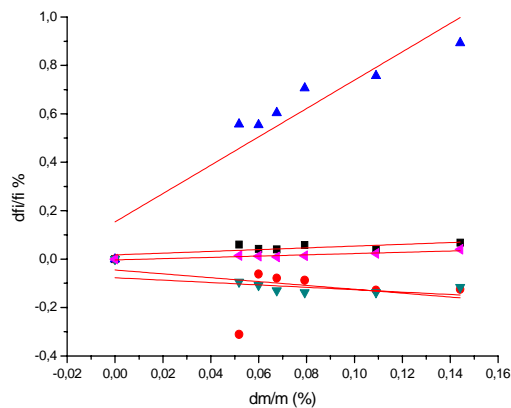
**Table 3.** Frequencies of normal modes of the not eroded blade

Mode	Frequency (Hz)
1	9,7323E+01
2	1,8890E+02
3	3,2918E+02
4	3,8109E+02
5	5,4615E+02

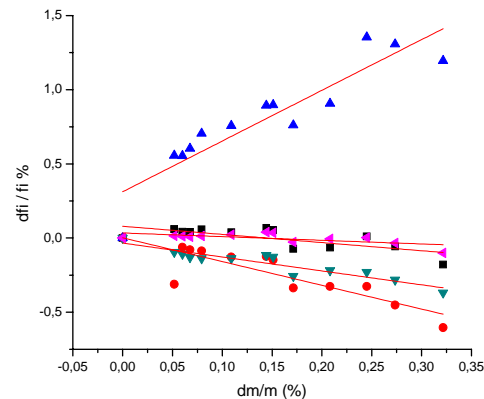
## RESULTS OF SIMULATIONS

For each mode we got different effects of frequency dependence on mass loss. These dependencies are presented on graphs below. In table 3 we presented the frequencies of first five modes before we started deleting some elements from blade (A1 simulation). Those frequencies are very similar to empirical research [4,5], or to simulations founded in other publications with similar L-0 blades [6].

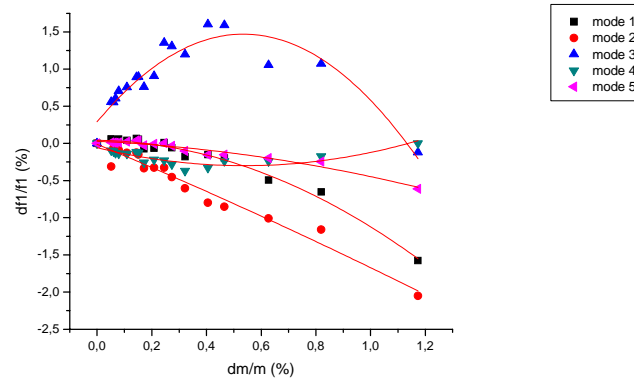
1)



2)



3)



**Fig. 3.** Dependence of five modes of vibration in function of mass loss shown for three increasing scales of mass loss: 1) 0,16%; 2) 0,35; 3) 1,2%

Aim of our calculations was to find correlation between mass loss and change of frequencies of first five normal modes. The plots in Fig. 3 reveal that variation of the modes are very specific to each mode. By analyzing these plots we see at first some general feature – a decreasing of frequency with an increasing of mass loss of modes 1<sup>st</sup>, 2<sup>nd</sup>, 4<sup>th</sup> and 5<sup>th</sup> and an increase with extremum of mode 3<sup>rd</sup>. For mass loss below 0,15 % (similar to working blades erosion) (calculation A1-A7) we observe quite linear changes of frequencies of vibrations. Similar situation can be observed for results of the next five calculations (A8-

A12), as show plots in Fig. 3 ( part 2). In the third step (A13-A18) we done calculations for much bigger mass loss (beyond 0,3 %), bigger than mass erosion observed in practice. For those bigger changes of the mass (and hence geometry) we see that frequency of mode 3<sup>rd</sup> decreases while frequency of mode 4<sup>th</sup> increases. It's very high probability that the extremes in modes 3<sup>rd</sup> and 4<sup>th</sup> are effect of assembling higher harmonics.

We can state (analyzing Fig. 3) that the smallest changes of frequencies are very similar to linear like functions. Linear factors of approximations of these functions are presented in Table 4. For 1<sup>st</sup>, 2<sup>nd</sup>, and 5<sup>th</sup> mode frequency changes are smaller than 0,15Hz per lost 0,1% of mass. We can say also that they are oscillating around 0 level. In mode 4<sup>th</sup> change of frequency is double up and in 3<sup>rd</sup> mode frequency is much higher of about 2 Hz than frequency of the blade without mass losses.

When we expand our calculations to mass loss twice bigger than observed on exploited blades, our linear factors are changing but the functions are still close to linear. For 1<sup>st</sup> and 5<sup>th</sup> modes frequency changes are decreasing and still below 0,15 Hz per 0,1% mass loss. The plots for 2<sup>nd</sup> and 4<sup>th</sup> mode are showing decrease of frequency too, but on a little higher level, around 0,35 Hz per 0,1% of mass loss. In the case of the 3<sup>rd</sup> mode we observe a quick decrease of frequency of vibration.

Results of our calculations show that the frequency changes looks like linear only in close way but in fact they are not linear because factor is changing to much. Results of calculations for higher mass loss values show that all dependencies without that for the 2<sup>nd</sup> mode are not linear but parabolic. But still there are some changes on linear factor (in this simulation – 1,69) of the 2<sup>nd</sup> mode so we cannot be sure that it is linear. There is very important fact that 1<sup>st</sup>, 2<sup>nd</sup> and 5<sup>th</sup> mode are getting only smaller. The 3<sup>rd</sup> mode plot reveals the maximum in the range of middle values of mass loss scale. The 4<sup>th</sup> mode plot, however, reveals the minimum in this same range of mass loss changes.

**Table 4.** Linear factors and changes of frequency depended on scale of mass loss

	Range of changes of mass 0-0,16%		Range of changes of mass 0-0,3%		Range of changes of mass 0-1,2%
Mode	Linear factor	Changes in Hz per 0,1% of mass loss	Linear factor	Changes in Hz per 0,1% of mass loss	Changes in Hz per 0,1% of mass loss
Mode 1	0,364	0,03 Hz	-0,550	0,05 Hz	0,1 Hz
Mode 2	-0,493	-0,1 Hz	-1,601	0,3 Hz	0,3Hz
Mode 3	5,853	2 Hz	3,419	1,2 Hz	-
Mode 4	-0,044	-0,02 Hz	-0,938	0,35 Hz	-
Mode 5	0,263	0,15 Hz	-0,247	0,15 Hz	1Hz

Decreasing frequencies in modes with an increase of mass loss is unsuspected. It should be also stressed that for the highest mass losses, we change in fact the shape of the blade so our calculations shows that a shape of the blade is more important element of changing frequency than 'erosion' by itself.

## SUMMARY AND CONCLUSIONS

- We made the simulation by finite element method of impact of erosion on normal mode frequencies of the blade type L-0. Erosion was localized along leading edge.
- We have revealed specific dependence of normal mode frequency on mass loss within range from zero to 1,2 %: a monotonous decrease (down to - 2%) for 1<sup>st</sup>, 2<sup>nd</sup> and 5<sup>th</sup> modes and a maximum of frequency (up to + 1,5 %) and minimum (down to -0,5%) for 3<sup>rd</sup> mode and for 4<sup>th</sup>, respectively. It makes evident that erosion decrease frequency of two first normal modes of blade type L-0 which seem to be the most important for blade work when resonate frequencies of the turbine are in question.
- As the obtained erosion dependencies of normal modes may be used to estimate quickly the frequencies of eroded blades when their mass loss is known.
- This simulations should be verified experimentally in order to be fully applied for quick assessment of normal mode frequencies of exploited blades. Such assessment is desired during turbine blade service control.

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