INFLUENCE OF RUNNING CONDITIONS ON RESONANT OSCILLATIONS IN FRESH-AIR VENTILATOR BLADES USED IN THERMAL POWER PLANTS

by

Milan B. TASIĆ, Radivoje M. MITROVIĆ, Predrag S. POPOVIĆ, and Marko M. TASIĆ

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High frequency cyclic load of fresh air supply to ventilator blades in thermo energetic facilities can cause the occurrence of fretting in the pressed overlap of ventilator shaft and socket. These loads can be generated by the resonant oscillations of ventilator blades and thermal residual stress due to welding. To prevent running in resonant conditions, the manufacturer of the ventilator defined a procedure of adjusting blades natural frequency in the process of production, as well as period control during exploitation period. The numerical simulations and the accelerations measured and presented in this paper, enabling analysis of mass changes and rotation rate effects on resonant oscillations occurrence in fresh air ventilator.

Key words: *ventilator, bedding, resonance, fretting*

Introduction

Thermo energetic facilities of thermal power plants use up about 10 to 15% of the produced electric power for the drive of electric motors of their belonging auxiliary devices (transporters, pumps, ventilators, mills, and similar). A 600 MW boiler, depending on the coal quality, can serve 6 to 8 ventilator mills of 1.3 MW each. The total power of just these devices uses up 1.7% of the thermal power plant's block capacity.

The boiler's continual operation is especially sensitive to reliable operation of the ventilator for fresh air supply and exhaust gases elimination. One boiler unit is served by two ventilators which in joint operation can provide fresh air amount higher by 20% than the nominal one, for the given boiler capacity. In case of one ventilator failure, the fresh air supply drops to 60%, which diminishes the boiler capacity by 40%.

Blades resonant oscillations can be the cause of a ventilator bedding breakdown. Measurements of blades natural frequencies at each stoppage in the course of regular annual boiler repair, as well as numerical simulations and possible adjustments of blades own frequencies at the facility itself, can significantly contribute to precise prediction of the ventilator operating life. Knowledge of the operating life would, on the one hand, enable preventing ventilator breakdown, while, on the other hand, it would enable the ventilator circuit to be replaced in the planned manner within the regular repair operation.

Beddings of boiler's auxiliary devices in thermo power plaints, such as ventilators for fresh air supply or emission gases, should enable secure and reliable running in all conditions.

However, extreme running conditions, such as contamination of fresh air with land or coal dust, often disable beddings to fulfill their basic function.

As the consequence of inappropriate running conditions, failure of internal bedding may occur. In the worst case, bearing blockage leads to overheating of the assembly, collapse of the material mechanical characteristics and excessive shaft journal bending [1]. This leads to the bending which exceeds the allowed limit, causing contact between ventilator blades and case. Collision between blades and case causes damage of ventilator assembly parts. The process occurs at very high speed, so the existing temperature supervision systems are unable to detect the damage, leading to melting of the inner bearing ring, socket, and shaft journal. Cross-sections of the bedding are shown in fig. 1.

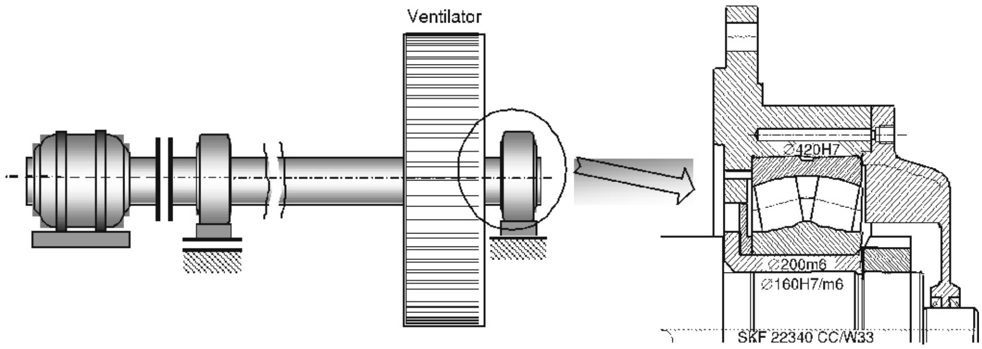

Figure 1. Cross-sections of the bearing bedding SKF 22340 CC/W33

Bearing bedding failure hypotheses

According to the studies published in papers [2-8], potential causes of the breakdown include, among others, the following influences.

Design

- Decreased axial gap between the cage and internal ring of the bearing due to the assembly tightening and warming up, resulting from the friction;
- Inappropriate modular gap and inexistence of a security mechanism to prevent rotation of the socket with respect to shaft journal.

Exploitation conditions

- Presence of pollution in the grease;
- Increased friction in the bearing due to steel particles from the steel cage (brass cage was replaced with steel cage by the manufacturer);
- Axial vibrations in the bearing caused by ventilator blades resonant oscillations.

Presented parameters support the hypothesis that failure of the bedding is the consequence of slipping of the pressed overlap between the shaft journal and internal bearing ring socket. The modular gap increased due to temperature rise.

Friction coefficient changed as the consequence of fretting, among other reasons, due to high-frequency cyclic load. Fretting has been the cause of countless failures of the machinery components. One definition describes fretting as: "A special wear process that occurs at the contact area between two materials under load, which are exposed to relative motion by vibration or some other force" [5, 9].

When two pieces of material, pressed together by an external static load (for example, press fits or bolted flanges) are subjected to transverse cyclic loading, so that one contacting face is relatively displaced, parallel to the other face in the presence of high contact stress, wear on the mating surfaces occurs. If the displacement magnitude is less then about 50 mm, the wear is termed "fretting", fig. 2.

Figure 2. Damaged journal surface caused by fretting

Fretting wear can be reduced by eliminating the contacting surfaces' oscillatory movement:
– by increasing of friction, and
– by strengthening surface of the material (coatings, heat treatment, laser).

In this paper the blades resonant oscillations and possibilities for their reducing are analysed, because of its crucial influence on reliability and duration of the ventilator life. Usually, the first step of resonant analysis is determination of natural frequencies of all significant assembly parts. In this case, this is analytical and experimental determination of natural frequencies of the ventilator blades.

Adjustment of blades natural frequency

The ventilator is welded assembly. Their rotary part consists of ventilator body and blades. The body front part is produced by deep pressing and rear part is made of steel sheet. The blades are produced by forging. The tolerances of the shape and dimensions of all parts are defined according to rational and inexpensive fabrication. Used tolerances values cover common expected instability in deep pressing and forging processes. Allowed values of the tolerances can produce locally different shape of the ventilators body segments and between the blades.

Blades are placed into proper position and partially welded by a special tool. In the end, complete welding of blades root is performed on the rotary positioning device, used for the purpose of putting the ventilator into optimal welding position, fig. 3. This process can also put some allowed errors in real shape of the ventilator. That geometry imperfections cause unbalanced centrifugal forces and different natural frequencies of the body segments and all blades.

Figure 3. Ventilator production – welding of blades

The effect of thermal residual stresses in the material, as the consequence of welding, also presents a problem for natural frequencies. Namely, the welding process applied here was manual arc welding with covered electrodes, typical for relatively large thermal gradients during heating and cooling of welded joint. As the consequence thermal residual stresses are generated in blade root, affecting the natural frequencies of a blade. It is even possible to adjust the natural frequencies by additional surface welding of the critical region in blade root. Due to all of this, it is essential to perform heat treatment of the welded structure in order to decrease the residual stresses in the material. Such a heat treatment is complicated process, which is performed without precise control of temperature history. Thus, one should not neglect possible influence

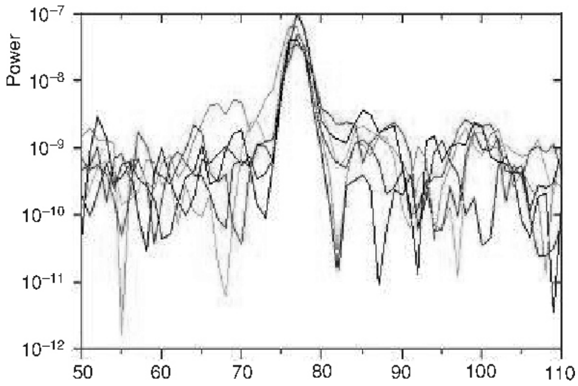

Figure 4. Area of the first natural-frequency mode

of heating and cooling processes during welding and post weld heat treatment on blade natural frequencies and operational behaviour.

Usual way to overcome this problem is experimental adjustment of unbalance and natural frequency. Due to possible running in resonate conditions, the blades natural frequency is adjusted by the producer prescribed procedure. Adjusting is performed by changing the blades mass. The modal analysis method is used for measuring and analytical determination of natural frequency.

The processed signal from several measurings, with isolated area of the first natural-value of the oscillation, is presented in fig. 4.

The diagram shows six consecutive measurings. Peak of the measured parameter in all cases matches the natural frequency of 78 Hz. The amplitudes are uneven on the left and right sides due to uneven hammer hits, which caused the measured oscillation.

Although all ventilator blades are manufactured against unique documentation, designed by the same manufacturer, the measurements show that there are differences in their natural-frequencies.

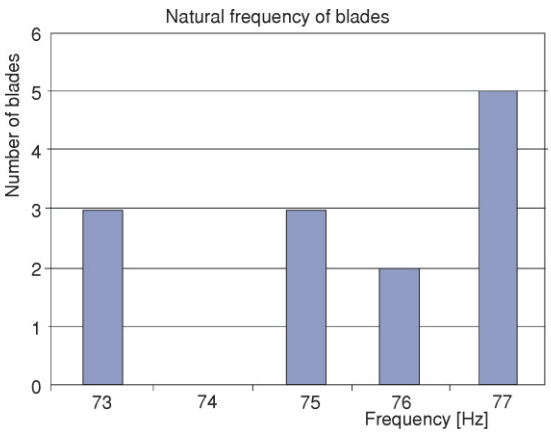

Figure 5. Measured values of blade's natural-frequencies

Figure 5 shows several ventilator blades with the same natural-frequency values. The measurements were done on one of the produced primary stage air ventilators.

The ventilator has 13 blades. Three of them have natural frequency of 73 Hz, other three 75 Hz, two 76 Hz, and five 77 Hz. This points out the importance that the final product – ventilator with controlled dynamic characteristics – can not be produces just according to technical drawings, prescribed welding technology and thermal treatment, but that it is essential to adjust the blades dynamical characteristics experimentally, adding or removing mass on top of the blades.

Field frequency control

During the exploitation time, erosion of the blades takes place, especially in the area with highest drift speed. Abrasion is performed by dust and sand, fig. 6.

Mass decrease on blade edges leads to increase of natural-frequency, so even already adjusted blade gets into the situation that its natural-frequency can match some harmonics of the ventilator electro-motor basic speed revolutions.

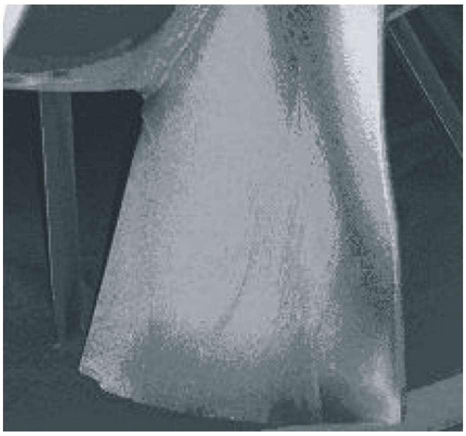

Figure 6. Damaged blade zones

Figure 7. Blade surface with attached layer of dirt

It is possible to perceive that the blade edge is damaged, especially on the top of aero profile front edge. The rear edge is missing a piece of the material.

Figure 7 shows appearance of the blade on the surface of which a layer of dirt is attached, increasing the mass and decreasing its natural frequency.

During periodical checking and overhaul of thermal power plants, cases with resonant running are noticed on ventilators used for some time, even though no vibrations were detected on regular check-ups on the check point standardized by the manufacturers. It means that strength of the blade was not directly endangered, but these vibrations were transmitted to other parts of the structure (such as bearing beddings) as micro vibrations. Such effect could be one of the crucial factors that cause fretting wear on the overlapped surfaces of the shaft journal and socket.

Modeling of the ventilator

This study pays special attention to journal and socket slipping caused by fretting. It examines the likelihood of periodic axial loads in journal socket assembly, caused by ventilator blades resonant oscillations. The finite element software, modal analysis package, was used for simulation of the 3-D blade models dynamic behavior. The numeric machine for 3-D measuring, located in the production facility of "21 May" company, was used to define the 3-D blade model. Original blade, manufactured by the "TLT" company from Germany, was used as a sample. Using the 3-D scanner, the coordinates of blade cross-sections were registered at each 20 mm, fig. 8. Based on these data, the blade profile cross-sections were defined. With the 3-D modeling software, these cross-sections were connected into one 3-D blade body. Ventilator body was modeled using the standard 2-D documentation and drawings.

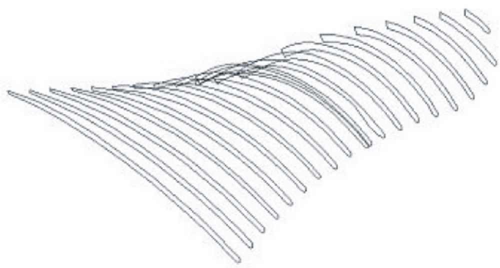

Figure 8. Blade cross-sections

The 3-D model of the ventilator, fig. 9, was imported into finite elements method (FEM) software for the calculation of natural frequency and natural mode shape oscillations.

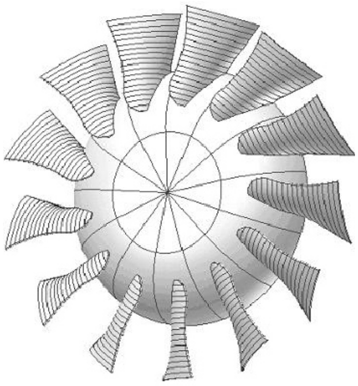

Figure 9. 3-D CAD model of the W33 air ventilator

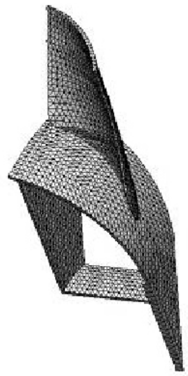

Figure 10. 3-D model of ventilator's periodic section

The actual structure is characterized by sector symmetry; therefore the mathematical model contains only one blade with its root constrained to the ventilator body, represented by one section. It is assumed that vibrations of other blades do not have influence on the result. This does not fully match the actual running conditions. Such idealization can be accepted because blades have higher slenderness than the spherical ventilator body. The ventilator mathematical model with segments is shown in fig. 10.

Influence of mass change on blades natural frequencies

Blade models with reduced mass were subject of the analysis, which was achieved by cutting off the material and blades with increased mass resulting from welding a material on the top.

As an example, cases of a standard blade are shown, fig. 11, and of a blade with reduced mass achieved by cutting off the top, fig.12. In both cases, the basic shape of oscillation is the one which bends the blade in its root, at the area where it is constrained by ventilator body. The figures depict the starting position (shaded) and final position of the blade. The standard blade's natural frequency was 51.4 Hz.

Change in mass results in change in natural frequency. The blade with reduced mass has natural frequency increased to 52.2 Hz. The models for which mass was added on the top (example is the triangle shaped top in fig. 9) resulted in the decrease of natural frequency value. Accord-

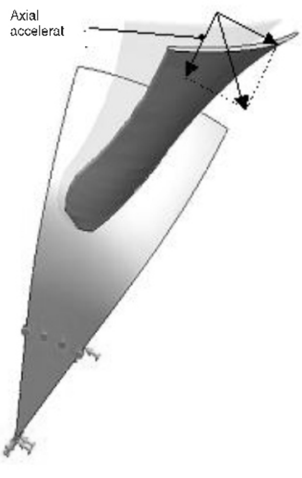

Figure 11. Natural frequency of standard blades – 51.4 Hz

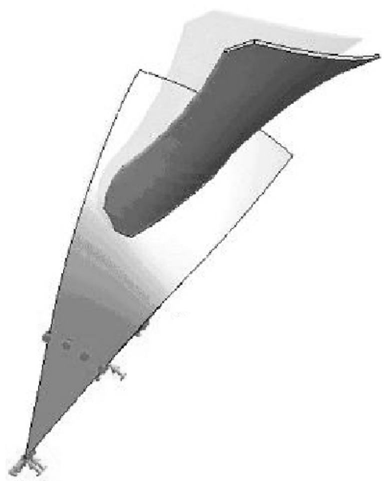

Figure 12. Blades frequency with reduced mass – 52.2 Hz

ing to the results [2], it is possible to define sensitivity of natural frequency change to mass change of the blade's top. This change is shown in fig. 13. It can be perceived that a relatively small mass change (ca. 200 g) of the blade, which has 50 kg in total mass (0.4%), changes the natural frequency by ca. 6% .

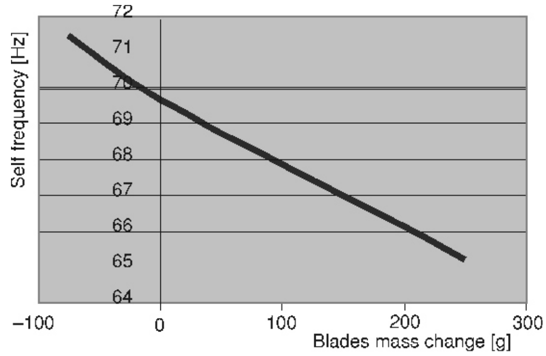

Figure 13. Influence of blades top mass change on its natural frequency

Influence of revolving speed on blades natural frequency

In addition to geometry and material characteristics, the strains in the structure also have significant influence on the natural frequency value. This means that the measured natural frequency of idle blades differs from the natural frequency in running conditions.

Strains increase in the direction of the blades top. Rotation simulations were performed to estimate this influence, with different revolving speed, starting from 0, 450, 740 up to 1000 per minute. Results are shown in the diagram on the fig. 14.

It is visible that the change in revolving speed has smaller influence on ventilator's natural frequency than the mass change. Change of the revolving speed by 21%, changes the natural frequency by 2 Hz (3.5%).

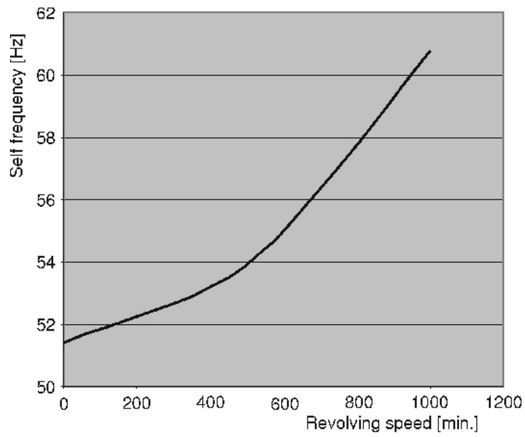

Figure 14. Influence of revolving speed

Conclusions

Perfectly precise blade geometry, constant revolving speed, and clean air are needed for constant values of natural frequencies. Allowed values of the tolerances can produce locally different shape of the ventilators body segments and between the blades. This changes their natural frequency.

The effect of thermal residual stresses in the material, as the consequence of welding, also presents a problem and changes blades natural frequencies.

In the case that blades natural frequency match some harmonics of the ventilator electro-motor basic speed revolutions, ventilator is running in resonate conditions. Such conditions can cause fretting wear in the overlaps in the bedding.

Blade natural frequency in actual running conditions is changeable and depends on fabrication tolerance, strains, layers of dirt, and erosion process. The influence of mass change on natural frequency is shown by numerical simulations. It has been confirmed by experiment that 0.4% of mass change on blades top changes natural frequency by 6%. Therefore, erosion or dirt layers during operation change blades natural frequencies and can cause resonant oscillations and fretting wear in the overlaps in the bedding.

It has also been confirmed that strain in blades, as the consequence of centrifugal forces, also has certain influence on the value of natural frequencies. Change of the revolving speed by 21% changes natural frequency by 3.5%. When blades are adjusted during production process, possible change of shaft revolving speed during operation has to be taken into consideration.

The inertial forces direction during resonant vibrations is partially axial, so it can cause fretting on the pressed overlaps in the bedding.

As the precaution measure to prevent resonant vibrations of the blades, periodical measuring and adjusting is suggested any time ventilator is shut down. In future, it will be essential to develop and define the methodology of natural frequency measuring for ventilator in running condition, because it would provide more accurate estimation of the possibility of ventilator running with resonant oscillations.

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Authors' affiliations:

M. B. Tasić (**corresponding author**)
College of Applied Sciences Tehnikum Taurunum
Belgrade, Serbia
E-mail: tasam@sezampro.yu

R. M. Mitrović
Mechanical Engineering Faculty, University of Belgrade
Belgrade, Serbia

P. S. Popović
Vin~a Institute of Nuclear Sciences
Belgrade, Serbia

M. M. Tasić
Mechanical Engineering Faculty, University of Belgrade
Belgrade, Serbia

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