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Study on Abnormal Vibration Cause and Blade Damage Fractal of Induced Draft Fan Burning Low-quality Coal

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Abstract: With increasingly fierce competition in the electricity market and the gradual recovery of coal prices, the co-firing of low-quality coal is becoming increasingly popular among large-capacity thermal power units as a means to reduce fuel costs and improve economic efficiency. This study first conducted an abnormal vibration analysis of the induced draft fan blades in a thermal power plant that follows the principles of low-quality coal blending. The results are as follows: By recording vibration data inside the bearing housing during operation, it was found that severe bearing looseness caused excessive vibration. Upon disassembling the induced draft fan and inspecting its condition, it was discovered that, due to the high silicon and sulfur content in the low-quality coal, a significant amount of ammonium bisulfate crystals had formed on the hub. Additionally, the blades exhibited severe corrosion and wear, ultimately leading to dynamic imbalance and resulting vibration. Next, fractal theory was applied. Threshold segmentation was performed using ImageJ software to identify areas of pitting, wear, and microcracks in the segmented images. Fractal dimensions were calculated at different locations on the blades to determine their specific damage states and priority maintenance areas. Finally, corresponding measures to prevent excessive induced draft fan vibration were proposed for operating and maintenance personnel at power plants burning low-quality coal.

Keywords: Low-quality coal, induced draft fan, fractal theory.

1. Introduction

My country's power industry can be divided into thermal power, wind power, hydropower, photovoltaic and other forms, and with the clean and renewable energy generation of science and technology, it has gradually become the main power supply body of society. In this case, coal power companies are facing two operating pressures. On the one hand, new energy power generation is given priority, and coal power companies need power generation. On the other hand, electricity prices and high-quality coal market prices are high. Due to the economic benefits of coal power companies, some companies have to blend low-quality coal raw materials. The high content of silicon and sulfur in low-quality coal, coupled with the addition of limestone, generates flue gas that is more corrosive, which directly threatens the service life of the blades of the boiler induced draft fan, leading to abnormal vibration of the blades in the rotating parts, and eventually causing greater economic losses. In this paper, the fundamental and indirect causes of blade vibration are analyzed. The fractal theory is used to calculate the normal blades and pitting blades, and the relevant measures to prevent blade failure are put forward.

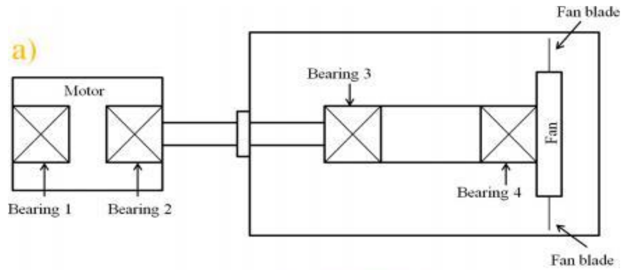
2. Vibration Monitoring Before Equipment Failure

In this paper, the actual operating conditions of a power plant are used as an example. The following is the operating status of the induced draft fan in the coal power plant after 10000 hours of operation. (See Table 1)

Table 1. Operating status of internal fan for 100, 000 hours

Parameter	Value	Unit
Flue Gas Flow Rate	225	m^3/s
Exhausting air pressure	355	mmwc
Flue Gas Temperature	141	℃
Number of Boilers	01	——
Rotational Speed	750	rpm
Motor Power	1100	kW

In the operation process, the vibration was measured under no-load condition and load operation condition of the whole plant respectively. The overall schematic diagram of the induced draft fan is shown in Fig. 1a, and the schematic diagram of the disassembled structure is shown in Fig. 1b. The vibration measurement range is all bearing positions (bearing1-bearing4 in Fig. 1a), and the vibration spectrum of the housing surface at the bearing 3 position is analyzed below as an example.



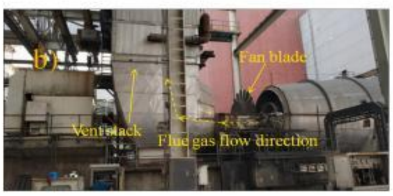


Figure 1. The overall schematic diagram of the induced draft fan is shown in Fig. 1a, and the schematic diagram of the disassembled structure is shown in Fig. 1b

The acceleration signal is collected by VIBXpert instrument, the sampling is 4096 Hz, the sensitivity of the acceleration sensor is 100 mV/g, and the vibration spectrum of the horizontal, vertical and axial directions of the bearing 3 position is shown in Figure 2. It is found that the overall vibration level in the axial direction of the bearing is higher than that in the horizontal direction and vertical direction. When the speed of bearing C is 750 rpm at full load, the operation of the fan blade is 12.5 Hz (750 rpm), and there are many peaks at the harmonics, and the phase presents unsteady characteristics; The presence of these harmonics indicates the existence of rotational loosening. An increase in vibration clearance is then observed at the bearing housing. This kind of vibration results in a significant increase in the blade vibration spectrum.

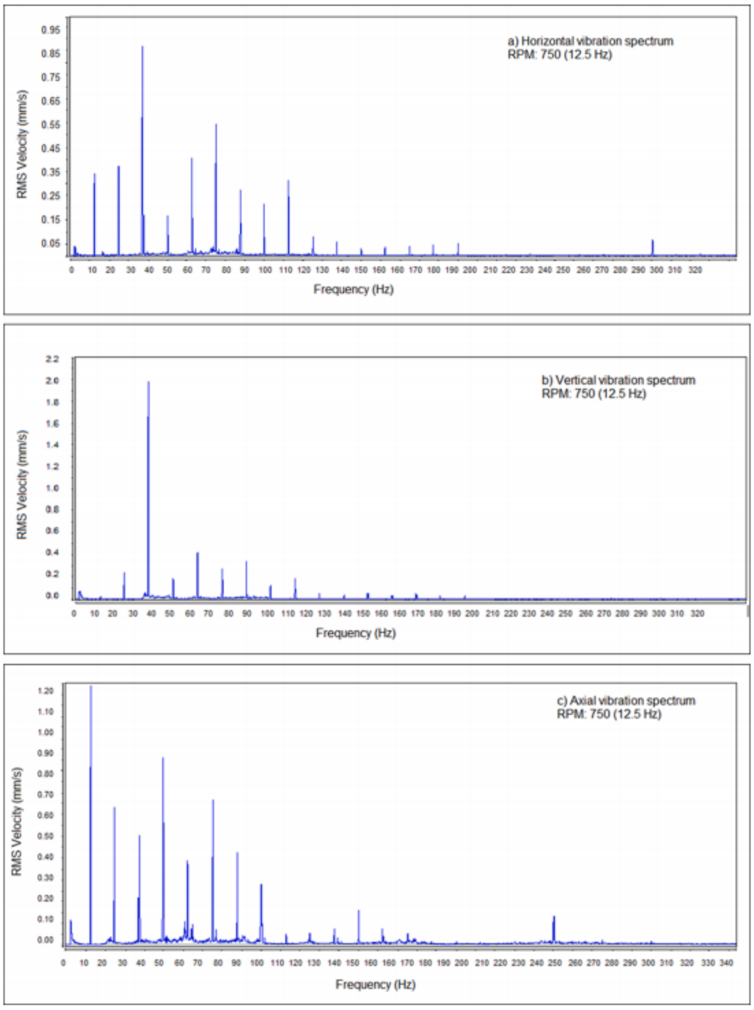


Figure 2. Vibration spectrum of bearing 3 in horizontal, vertical and axial directions

3. Analysis of Vibration Causes of Induced Draft Fan

Direct Causes In order to improve economic benefits, thermal power plants have adopted the principle of blending low-quality coal. Low-quality coal itself contains high silicon and sulfur components. When burning, it will produce sulfur dioxide, sulfur trioxide and other sulfur oxide acidic flue gas, and at the same time generate coal ash with high silica content. The induced draft fan is directly mechanically connected to the ash removal and dust removal, and the smoke temperature at the location reaches 135-150 °C. When the ash removal and dust removal effect is poor, it will inevitably be worn by dust and corroded by smoke. By analyzing the specific working conditions, due to the escape of ammonia in the out-of-stock reaction, NH3 that did not participate in the reduction reaction combines with sulfur trioxide in the flue gas to form ammonium bisulfate, ammonium sulfate, ammonium chloride, etc. Some crystals are adsorbed on the surface of the induced draft fan hub, and some impact Blades cause blade corrosion and wear. After long-term operation, the hardness of the blade and the weight of the hub change, and the dynamic balance exceeds the standard.

4. Indirect Causes

4.1. Stall and Surge Effects

Unstable combustion of low-quality coal will cause negative pressure disturbance in the furnace, and the induced draft fan enters stalling and surging conditions. In addition, the operator cannot measure the opening and closing angles of the blades step by step in the actual operating plate, and the blades are subject to strong impact due to sudden changes in the adjustment range. Wind pressure, wind pressure fluctuates periodically, the blades bear alternating impact loads, and the vibration is directly transmitted to the hydraulic rod through the adjustment connecting rod, resulting in wear of the thrust rod and bushing and the shaking of the hydraulic cylinder. The vibration is directly transmitted to the primary and secondary impellers of the induced draft fan. The impeller, which should have a stable rotation trajectory, produces irregular unbalanced displacement along the ring direction (that is, the circumferential direction) and the axial direction (that is, the axis direction) when running at high speed The sloshing of the hydraulic cylinder is directly transmitted to the primary and secondary impellers of the induced draft fan through the mechanical connection structure, so that when the impellers with a stable rotation trajectory run at high speed, they have irregular unbalanced displacements along the circumferential direction (that is, the circumferential direction) and the axial direction (that is, the axis direction).

4.2. Impeller Ash Accumulation Causes Dynamic Balance to Exceed the Standard

The blending of low-quality coal in the unit caused ash accumulation in the impeller of the induced draft fan (see Figure 3). It can be observed in the picture that the thickness of the ash accumulation has exceeded 1mm. Moreover, the thickness of ash accumulation in the left area is quite different from that in the middle area, forming an obvious raised area. Low-quality coal generally has low calorific value, large ash content, and poor combustion efficiency. During the combustion process, a large amount of fine fly ash that is not completely burned out will flow through the impeller of the induced draft fan with the high-temperature flue gas. During the continuous operation of the fan, fly ash will gradually accumulate on the surface of each blade of the impeller, and due to the influence of flue gas deflection, blade wear differences, and fluctuations in combustion conditions, the thickness and distribution of ash accumulation are extremely uneven, and some blades have thick ash accumulation. Some blades accumulate less ash or even fall off locally, and the original precise dynamic balance state of the direct impeller. As a specific example (see Figure 3), with the duration of operation, the amount of ash accumulation accumulates, and the eccentricity difference of the impeller continues to increase, which eventually leads to the dynamic balance value of the fan rotor seriously exceeding the standard. After the dynamic balance exceeds the standard, there will be periodic abnormal vibration during the operation of the fan, which will not only aggravate the fatigue loss of the impeller, bearing, main shaft and hydraulic adjustment mechanism, cause uneven force on the blade, increase the impact load of the hydraulic rod, but also cause the temperature of the bearing. Problems such as rising and loosening of equipment fasteners further amplify the vibration defects and seriously threaten the safe and stable operation of the induced draft fan.

Figure 3. Impeller ash accumulation

5. Fractal Study on Blade Damage

5.1. Fractal Theory

Blade maintenance and inspection Usually, the power plant will carry out penetration inspection without damaging the blade body, spray red permeate liquid to stand and fully penetrate, unidirectionally remove the excess agent on the surface, and uniformly spray white imaging agent, and wait for red marks to ooze from the defect. Observe cracks, pinholes and other defects. This approach is a waste of time on the one hand, and has economic costs on the other. In this paper, fractal theory is adopted to avoid these defects. The main features of fractal theory are self-similarity and fractal dimension, which is an important measure to describe the complexity of images. The common fractal dimension calculation methods include box dimension method, fractal Brownian motion method, carpet covering method and so on. The box dimension method has been proposed by some scholars in the field of blades, and the calculation is relatively simple and the results are accurate. Therefore, this paper adopts the box dimension method for the distribution of cracks on the surface of blades under different corrosion degrees, and uses the box dimension calculation formula (1) in Image j software to conduct fractal dimension statistics and compare fractal dimensions.

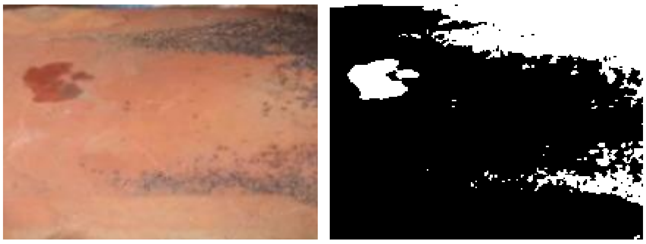
$$D = \lim_{r \to \infty} \frac{ln(Nr)}{ln(r)} \tag{1}$$

In the equation, r is the size of the square box, the entire pore and crack area is covered with boxes of the same size, and the minimum number of boxes required is defined as Nr. The natural logarithm is taken for the side length r and the total number of boxes Nr, respectively, as X coordinate and Y coordinate. The value of r is constantly changed, a series of coordinate points are determined and merged into the coordinate system, and the values are fitted linearly by the least square method. The slope obtained is the box dimension.

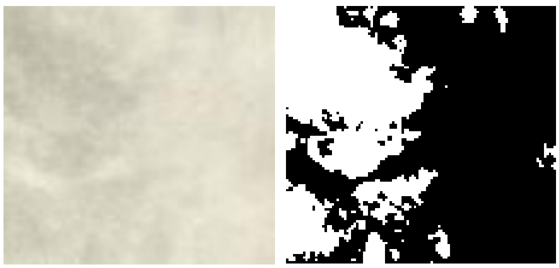
5.2. Fractal Calculation of Different Blades

Because the operating surface area of the induced draft fan of the boiler unit is seriously gray, it needs to be cleaned before fractal calculation of the blades. After the work is over, use Image j software to divide the image of the observed area of the blades into thresholds. The divided pictures show black and white. The black part represents the intact area of the blades, and the white part represents the severely corroded part. Now the threshold division of the blades in different states is shown in Figure 4. FIGS. 4 (A) and 4 (B) are pictures of the same blade taken in the case of severe pitting, 4 (A) belongs to the corrosion situation in the upper middle position of the blade, and 4 (B) belongs to the corrosion situation in the lower middle position of the blade. FIGS. 4 (C) and 4 (D) are pictures taken when the blade is in good operation condition, and 4 (C) belongs to. FIGS. 4 (a), 4 (b), 4 (c), and 4 (d) are corresponding region-divided pictures.

Blade (A) (a)



Blade (B) (b)



Blade (C) (c)

Blade (D) (d)

Figure 4. Threshold division under different blades

Observe that the pitting corrosion in Figure 4 (A) and Figure 4 (B) is more serious. Under normal circumstances, the maintenance personnel can observe the damage area of the blade with the naked eye. In the figure, obvious black and red areas are observed, and the black area is larger than the picture. Below is the pitting phenomenon caused by smoke corrosion of the blade. The red area at the top of the picture is due to the red rust layer formed by the corrosion of SO_2 and water vapor dew point in the flue gas. The difference between the two states is obvious, and the red domain is normal after the region is divided, which shows that the red rust layer is regarded as a normal region when calculating the box dimension, and only the pitting region is calculated. The overall threshold figure is consistent with the original figure. It shows that the pitting area can be clearly distinguished by using image j software. The wear conditions of FIGS. 4 (C) and 4 (D) are difficult to observe with the naked eye, wherein the blackened parts represent the areas worn by particles during blade rotation, and can be clearly distinguished after region division. The results show that the software threshold partition can distinguish the wear position effectively.

After dividing the threshold, the box dimension values of different blades are calculated and counted. In this paper, the lnr of 9 box sizes (2, 3, 4, 6, 8, 12, 16, 32, 64) and the corresponding lnNr values of each blade are listed. It is found that the calculated values of blade A and blade B are larger than those of blade C at 0.69315 (the number of boxes is 2), and smaller than those of blade C at 4.15888 (the number of boxes is 64). The overall slope of blade A and B is larger, which corresponds to the fractal dimension value of blade A (1.887). The results show that pitting corrosion is more serious than blade wear.

Table 2. Calculation results of different blade box dimensions

lnr	lnNr			
	Blade A	Blade B	Blade C	Blade D
0.69315	8.94259	8.17639	7.07918	7.58832
1.09861	8.15249	7.38709	6.39024	6.83626
1.38629	7.60688	6.84162	5.88332	6.34739
1.79176	6.83518	6.03309	5.22575	5.58725
2.07944	6.29711	5.48894	4.70953	5.0876
2.48491	5.52943	4.7362	3.98898	4.44265
2.77259	4.98361	4.21951	3.55535	3.91202
3.46574	3.71357	2.99573	2.63906	2.99573
4.15888	2.48491	1.79176	1.38629	2.19722

According to the statistics of the blade fractal dimension in the two cases, (see Table 3) the blade A fractal dimension value is 1.887 compared with the blade B0.024 (1.28%), and the blade C fractal dimension value is 1.528 compared with the blade D0.048 (3.2%). It shows that the pitting corrosion and wear of the upper and middle parts of the blade are more serious than those of the lower and middle parts of the blade under the same working conditions. Maintenance and inspection of the middle and upper parts of the blades should be strengthened when the unit is undergoing major or minor repairs.

Table 3. Fractal dimensions of different leaves

	Blade A	Blade B	Blade C	Blade D
D	1.887	1.863	1.528	1.480

6. Conclusions and Recommendations

6.1. Conclusions

In this paper, the induced draft fan mixed with low-quality coal boiler is studied first, and the various reasons causing the vibration of the induced draft fan are discussed. Then the fractal theory is proposed. Using the fractal theory, the specific conditions of blade damage and blade damage in different positions under different working conditions are discussed. Finally, the following conclusions are obtained.

1) In this paper, the bearing vibration was measured by VIBXpert instrument, and it was found that the high vibration of the blade was caused by the loosening of the bearing shell. After disintegration, it is found that the ash accumulation phenomenon is serious when the blade is observed.

2) The combustion of low-quality coal blended in the unit produces high content of sulfur dioxide and sulfur trioxide. And because ammonia escapes to generate ammonia bisulfate and other crystals, part of them are adsorbed on the surface of the hub, and the other part impacts the surface of the blade, causing wear and pitting. Eventually, the induced draft fan vibrates greatly.

3) Using image j software, the threshold value can be divided, and the wear and corrosion area of the blade can be judged, which can provide guidance for the follow-up maintenance of the blade. Compared with the box dimension value of the blade under the same working condition, the corrosion and pitting corrosion of the middle and upper parts of the blade are more serious than that of the middle and lower parts.

6.2. Suggestions

1) During the operation of the unit, first of all, the operator should proceed step by step when opening and closing the blade angle, so as to avoid the value being too large, resulting in excessive wind pressure impacting the blade. Secondly, during the destocking process, the dynamic amount of ammonia injection should be carried out according to the NOx concentration at the denitrification inlet, boiler load and flue gas temperature. Avoid the sudden increase of ammonia escape caused by the excessive amount of instantaneous ammonia injection. Finally, the operator should ensure that the cathode and anode plate rapping system operates normally and when the dust removal is stuck, eliminate the fault in time, dredge the lower ash pipe, and ensure the smooth discharge of ash.

2) Maintenance personnel need to correct the dynamic balance on site after shutdown for maintenance or after the induced draft fan returns to the factory to eliminate the imbalance caused by wear, ash accumulation or thermal deformation. Regularly check the wear of blades, and repair or replace worn and deformed blades in time; Check the wear and clearance of the blade adjustment mechanism (such as the adjustment slider and push disk) to ensure that the blade angle is consistent and eliminate the local imbalance of the power field.

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