Diagnosis method of turbine blade loosening

Qingliang Niu\textsuperscript{1a*}, Yuli Gong\textsuperscript{2b}, Guocheng Tian\textsuperscript{1c}, Chuanling Liu\textsuperscript{1d}

\textsuperscript{1}Shandong Branch, Huadian Electric Power Research Institute Co., LTD, Jinan, shandong, China
\textsuperscript{2}Cnooc Petrochemical Engineering Co., LTD, Jinan, shandong, China
\textsuperscript{b}email: gongyuli123@163.com, \textsuperscript{c}email: guocheng-tian@chder.com, \textsuperscript{d}email: chuanling-liu@chder.com

*corresponding author: \textsuperscript{a}email: qingliang-niu@chder.com

Abstract. Abnormal vibration of low-pressure rotor occurred after low-pressure cylinder cutting transformation of 330MW steam turbine generator unit in a power plant. Through the analysis of vibration data, the vibration spectrum was mainly manifested as low-frequency component of 18Hz, which fluctuates with time cycle, and it was judged that it might be related to the loosening of low-pressure rotor blades. After 6 months of operation, routine inspection after cylinder cutting showed that there were three loose roots and worn top steam seals on the secondary last stage blades of low pressure rotor. After repairing the blades, the abnormal vibration problem of the low pressure rotor of the turbine generator set was successfully solved.

1. Introduction
In the process of thermal power unit operation, the blade is an important part of the turbine energy conversion, which works in high temperature, high pressure, high speed and other bad environment, standing the centrifugal force, steam force, steam exciting force, corrosion, vibration and cavitation. In addition, it is difficult to avoid the design, manufacturing, installation, operation and maintenance of adverse factors, the blade often appear damage \cite{1}. Once the blade damage occurs, it will cause abnormal vibration of the turbine rotor, and it will cause non-stop and sweeping accidents. Therefore, the safety of turbine blade is directly related to the safety and economy of power generation.

There are two kinds of faults in turbine blades: (1) blade damage, the main forms of erosion cavitation, honeycombs pitting, corrosion, loosening and abrasion, thereby reducing economic performance and causing safety risks. (2) Blade damage, the main forms of crack, fracture, bending, strip off, rib open welding, loss of its basic functions, and produce a huge damage.

The location of blade damage is from shroud to blade root. In addition, the damage chance of turbine blades at all levels is uneven. According to the statistics of the United States, almost all blade accidents occurred on the low pressure rotor, of which the last stage accounts for 20%, and the second last stage accounts for 58%. According to the statistics of Japan, 20% of accidents also happened here \cite{2}.

The problem of operation and maintenance was the main cause of blade damage in the near future. The last stage blades of many large units had been designed according to the conventional basic load, without considering the needs of peak load regulation and high back pressure operation, so it was difficult to determine the long-term operation performance and its impact on life loss under small
volume flow. With a large number of new steam turbines put into operation or the imbalance of power supply and demand, when the steam turbine deviates from the design condition for a long time, the blade faults caused by design, manufacturing, installation, maintenance and improper operation would be exposed. In China, the installed capacity of large-scale thermal power turbines have increased rapidly for more than 20 years and new energy sources have increased rapidly. Many large-scale thermal power units have been operating at low load for a long time. Therefore, it is very necessary to investigate, analyze and summarize all kinds of damage of blades, especially the last stage and regulating stage blades, and find out the rules, and formulate preventive and improvement measures to avoid large losses.

In this paper, aiming at the abnormal vibration problem of low-pressure rotor of 330MW steam turbine generator unit after cylinder cutting transformation in a power plant, combined with the vibration change period, spectrum characteristics and equipment maintenance situation, the blade looseness fault was diagnosed. After blade repaired, the abnormal vibration problem was successfully solved, which provided reference for similar units.

2. Low pressure rotor vibration failure

The vibration forms of blades are different under different external forces. According to the characteristics of blade excitation force, blade vibration can be divided into three main forms: free vibration, forced vibration and self-excited vibration [3]. Forced vibration of blade is the vibration of blade under the action of external periodic alternating load. The forced vibration is excited by external exciting force, and the frequency of blade vibration is the same as that of exciting force. When the frequency of the external excitation force is equal to the natural frequency of the blade, the blade would produce strong vibration, that is, the resonance phenomenon of the blade.

The self-excited vibration of blade refers to the vibration produced by the self-excited force of blade, which has nothing to do with the external excitation force. It is maintained by the energy provided by the movement of blade itself. Blade flutter is a kind of self-excited vibration. When the mechanical damping of the blade is not enough to consume the mechanical energy of the blade, the vibration amplitude of the blade will be larger and larger, and the stress on the blade will also increase sharply, and the crack, fracture and other faults will appear soon due to the vibration fatigue of the blade.

The steam turbine of 335 MW unit in a power generation enterprise. The equipment condition is as follows:

It is a subcritical, reactionary, single shaft, one intermediate reheat, two cylinders and two exhausts, with one stage adjustment extraction steam condensing heat supply unit. The steam turbine has four radial bearings, two rotors for high and low pressure. The shafting structure was shown in figure1.

![Figure1. Schematic diagram of shafting structure](image)

At 1:30 on November 13, 2019, unit 3 was started after cylinder cutting transformation, and severe friction vibration occurred during impulse starting. At 2:50, the speed raised to 1700r/min, 3x reached 300μm, 4x reached 270μm, which was dominated by power frequency vibration. When the rotating speed reaches 3000r/min, the vibration of No.3 and No.4 shafts return to normal, as shown in table 1.

| Bearing number | #3x | #3y | #4x | #4y |
|----------------|-----|-----|-----|-----|
| Direct frequency | 35  | 51  | 30  | 28  |
| power frequency  | 28  | 46  | 26  | 24  |

At 7:40 on April 6, 2020, the No.3 and No.4 axial vibrations appeared at 50μm-80μm, which fluctuated with load.
3. Vibration signal analysis
In order to further analyse the vibration and fluctuation of No. 3 and No. 4 shafts, Shaft vibration data and frequency spectrum of 240MW at 14:21 on April 6 and 300MW at 17:26 on April 6 were adjusted, as shown in table2~3.

Table2. Vibration data of No.3 and No.4 shafts under 240 MW load /μm

| Bearing number | #3x | #3y | #4x | #4y |
|----------------|-----|-----|-----|-----|
| Direct frequency | 90  | 68  | 80  | 44  |
| Power frequency  | 43  | 47  | 28  | 21  |

Table3. Vibration data of No.3 and No.4 shafts under 300 MW load /μm

| Bearing number | #3x | #3y | #4x | #4y |
|----------------|-----|-----|-----|-----|
| Direct frequency | 137 | 73  | 92  | 37  |
| Power frequency  | 38  | 16  | 19  | 18  |

In order to analyze the frequency spectrum, the axial vibration spectrums with a power of 300MW on 17:26, April 6 were selected, as shown in figure2~5 (the abscissa represents frequency in Hz and the ordinate represents amplitude in μm.)

4. Blade maintenance and effect
There are two main acting forces on turbine blades: one is that the blades are subjected to strong centrifugal force when rotating at high speed along the circumferential direction. The longer the blades are, the greater the diameter and speed of the rotor are, the greater the centrifugal force is. The second
is the steam flow impact when the steam flow passes through the cascade. The axial change or fluctuation of the steam flow is an unstable impact on the blade [4].

The force on the blade is transferred to the blade root and rotor groove. The structure of the blade root has many grooves, which can bear large centrifugal force. Machining and installation errors will lead to uneven bearing, resulting in blade loosening and damage. In addition, when the blade tip is subjected to severe friction vibration, it would also cause the blade to loose and damage.

On April 14, 2020, after the low pressure cylinder was removed, it was found that the secondary last stage blade of the low pressure rotor was loose and the root locking device moved freely, as shown in figure6, and the function of the fixed blade could not be started. Two blades on the No. 3 bearing side and one blade on the No. 4 bearing side of the low-pressure rotor became loose. The staff replaced the root lock and fixed the blade. On May 6, 2020, after the unit was started, the shaft vibration of No.3 and No.4 returned to normal. The vibration data at 12:30 under 260 MW load was shown in table4, and at 15:21 under 330 MW load was shown in table5. the axial vibration spectrums were selected, as shown in figure7~10 (the abscissa represents frequency in Hz and the ordinate represents amplitude in μm.)

**Table 4. Vibration data of No.3 and 4 shafts under 260MW load (after repair) /μm**

| Bearing number | #3x | #3y | #4x | #4y |
|---------------|-----|-----|-----|-----|
| Direct frequency | 38  | 53  | 31  | 34  |
| Power frequency    | 33  | 50  | 17  | 16  |

**Table 5. Vibration data of No.3 and 4 shafts under 330MW load (after repair) /μm**

| Bearing number | #3x | #3y | #4x | #4y |
|---------------|-----|-----|-----|-----|
| Direct frequency | 45  | 52  | 39  | 35  |
| Power frequency    | 42  | 48  | 24  | 20  |

**Figure 6. Loose blade**

**Figure 7. 3X spectrum (after repair)**

**Figure 8. 3Y spectrum (after repair)**
5. Conclusion
According to the theoretical analysis of vibration data of low pressure rotor and cylinder opening inspection, the problem of secondary last stage blade root loosening of low pressure rotor was found, which avoided major safety hazards and improves the safety factor and economic benefits of generator set.

The abnormal vibration of low pressure rotor was mainly caused by blade looseness. Therefore, when the unit will be running, it must strictly implement the operation procedures, and eliminate illegal operation, so as to avoid blade damage caused by improper operation. During maintenance, the inspection and maintenance of turbine blades shall be carried out according to the standard maintenance process.

The method of vibration signal analysis was very effective for blade fault diagnosis. Vibration signal is mainly produced in the process of blade movement, which is the most direct phenomenon in blade movement. In addition, the vibration signal is easy to obtain and diagnose. Using this method, the loose fault of low pressure rotor blade in a power plant was found, and the abnormal vibration problem was successfully solved after blade repair, which provided reference for similar units.

Acknowledgments
The research work of this topic was supported by Research and Application of Intelligent Protection System for All Working Conditions of Shafting Motion Pair of Steam Turbine Generator Unit.

References
[1] Xiao Z.H., Mao Y.L., Zhang R.Q., Wang Y., Huang C. (2006) Analyses the reason of the second last stage's blades were broken in thermal power plant. J. Mechanical design and manufacture, 12: 110-111.
[2] Luo J.B., Tan S.S., Yuan L.P. (2002) Cause analysis of large turbine blade accident. J. Power safety technology, 4: 11-12.
[3] Ou Y.T. (2011) Rotating Blade Vibration Detection and Parameters Identification Technique Using Blade Tip-Timing. D. Tianjin university.
[4] Qi F.H. (2003) Research and Application on the Method of Condition.Monitoring and Diagnosing for Steam Turbine Blade. D. North China Electric Power University.