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Research On The Diagnosis And Treatment Methods Of Rotating Mechanical Vibration In Nuclear Power Plant Commissioning Period

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Abstract:
During the commissioning period of nuclear power plants, vibration problems occurred frequently. In this paper, a certain nuclear power plant was taken as the analysis object. It was found that adopting reasonable vibration diagnosis and treatment methods is conducive to accurately locating and solving vibration problems of rotating machinery, such as false feet, insufficient stiffness, resonance, and misalignment, with less economic and time investment, thereby ensuring the safe operation of nuclear power plants.

Keywords: *Vibration diagnosis, Nuclear power plant, Rotating machinery*

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I. Introduction

In the research on rotating machinery vibration problems, it has gradually shifted from theoretical analysis to practical application, and a rather comprehensive set of standards and norms has been established, providing guidance for the design, manufacture, installation, and operation of rotating machinery and helping to reduce the occurrence of vibration problems. Many researchers have put forward solutions to specific problems through case studies. For instance, Mao Qiuaohua and others have proposed increasing the online monitoring systems for important rotating mechanical equipment by summarizing the actual situation of the vibration monitoring system for rotating machinery at Tianwan Nuclear Power Plant[1]. Lu Zhongxuan investigated the special type of vibration fault called "thumping", analyzed its causes and proposed solutions [2]. Regarding the vibration problems during the commissioning period of nuclear power plants, scholars have also proposed various diagnostic and treatment methods, including the handling of the "empty foot" problem, the solution to the problems of insufficient static stiffness and resonance, and the adjustment of misalignment.

The nuclear power industry has been constantly dedicated to uncovering potential issues of equipment through vibration diagnosis, eradicating latent risks, and averting potential economic losses caused by equipment damage. The equipment failure curve proposed by Milton Roy indicates that the early stage of the equipment life cycle is also a period with a relatively high failure rate [3]. As depicted in Figure 1, during the commissioning period of a nuclear power plant, the equipment is in the early failure period, which simultaneously is a period with a high occurrence of vibration problems for rotating equipment. Excessive vibration has become a key factor restricting the commissioning progress of nuclear power plants. This paper aims to provide guidance for handling vibration problems during the commissioning period of nuclear power plants by summarizing the types and treatment methods of common vibration problems.

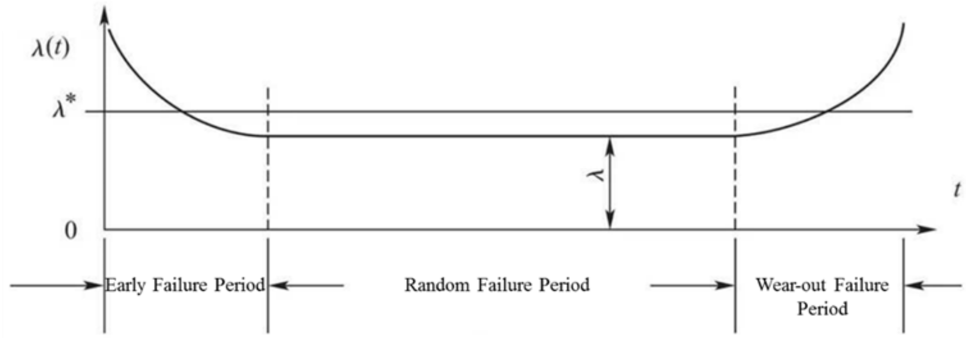


Figure 1. Equipment Failure Curve

II. Categories Of Common Vibration Issues

Hollow-Foot Issue

During the commissioning period of nuclear power plants, the problem of excessive vibration caused by the hollow-foot is widespread. When the fixing bolts of the machine's base or frame are loosened, a significant deflection occurs at the machine's foot, and an excessive elevation takes place at the base. This phenomenon is known as the hollow-foot. When the contact surface is uneven, tightening the bolts to force the contact surface to adhere will lead to the deformation of the equipment shell, exert a considerable influence on the alignment of the equipment or the concentricity of the motor air gap, and cause a distinct increase in vibration [4]. However, the occurrence of the hollow-foot in equipment does not always appear at the anchor bolts of rotating machinery. Misalignment of the pump outlet pipeline, deformation of the coupling, and loosening of the bolts of the water pump mechanical seal, etc., can all be regarded as hollow-foot issues.

The hollow-shaft problem often leads to the motor running at double frequency and the pump impeller passing frequency increasing, with the size of some bolt torque or the state of the isolator having a significant impact on the amplitude of vibration.

Insufficient Static Stiffness and Resonance

During the operation of the rotating machinery, forced vibrations are generated under the action of the excitation force. The amplitude of the vibrations is directly proportional to the magnitude of the excitation force and inversely proportional to the dynamic stiffness [5]:

$$A = F / K \qquad (1)$$

Where, A is the amplitude, F denotes the excitation force and K is the dynamic stiffness of the component.

$$K = \kappa\sqrt{(1-\omega^2/\omega_n^2)^2 + (2\xi\omega/\omega_n)^2} \qquad (2)$$

$$\omega_n = \sqrt{\kappa / m} \qquad (3)$$

Where, κ is component static stiffness, ω is excitation force frequency, ξ is relative damping coefficient, ω_n is component natural frequency and m is participating mass.

From the above formula, it can be seen that when the static stiffness of the component is too small or the excitation force frequency is close to the natural frequency of the component (at which resonance occurs), the dynamic stiffness of the component decreases, causing the amplitude to increase.

The common characteristic of insufficient stiffness and resonance is that the amplitude is more sensitive to changes in stiffness at the working frequency. Unlike this, resonance is more sensitive to changes in the excitation force frequency [6]. In the process of field problem handling, the natural frequency can be judged by tapping test. If the natural frequency is within 10% of the working frequency, it can be considered that resonance occurs, and the resonance problem can be solved by changing the excitation force frequency or natural frequency [7].

Misalignment

Another common source of vibration problems during the commissioning period of a nuclear power plant is improper alignment, which is often caused by improper installation of coupling. Misalignment occurs due to improper installation of coupling, and it can be classified into parallel misalignment and angular misalignment, as shown in Figure 2. Parallel misalignment has the characteristics of high radial vibration, with the main frequencies being one and two times the working frequency, and the radial phase is opposite at both ends of the coupling; angular misalignment usually has higher one and two times the working frequency in the axial direction, and the axial phase is opposite at both ends of the coupling [8]. In actual work, both types of misalignment often exist simultaneously.

(a) Parallel misalignment (b)Misaligned angle

Figure 2 Types of misalignment

Unbalance

As shown by Equation (1), vibration increases as the exciting force increases. During the manufacturing process of equipment, vibration occurs due to high exciting force caused by imbalance of the shaft system (such as the existence of pores), which is called unbalance.

Unbalance causes vibration at the working frequency, and the method of reducing the exciting force by implementing fine dynamic balancing often yields good results.

III. Vibration Problem Handling

To reduce the time and economic costs of vibration problem handling, the analysis and handling of vibration problems during the commissioning period of nuclear power plants should follow an easy-to-difficult approach for gradual elimination.

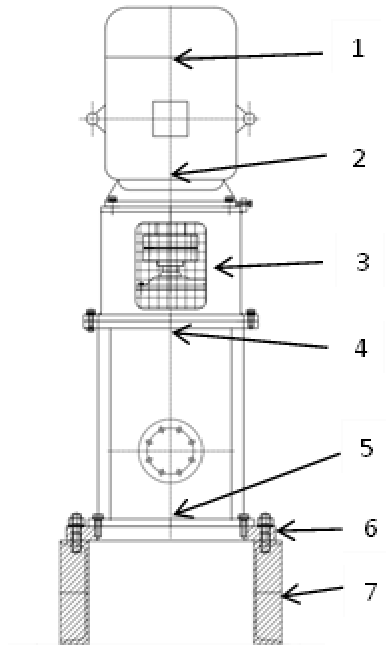


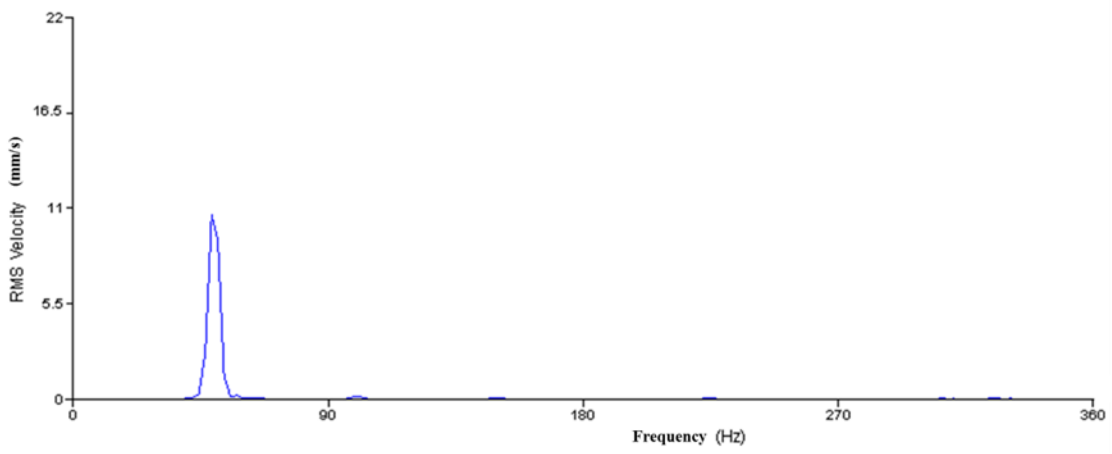
Figure 3. Vertical Long Shaft Pump Structure

The drain pump group of a nuclear power plant is a vertical pump group, with the motor being a three-phase asynchronous motor with a rated power of 15KW and a rated speed of 2930r/min. The motor drive end and non-drive end are both supported by rolling bearing, with the model being a deep groove ball bearing 6309. The entire equipment is placed on a flat plate on the upper part of the suspended steel structure. The maximum allowable speed of the motor under no-load operation is V≤2.3mm/s (RMS), and the maximum allowable speed of the motor under load operation is V≤2.8mm/s (RMS), and the maximum allowable speed of the pump is V≤1.8mm/s (RMS). The structure and vibration measurement location of the pump group are shown in Figure 3, where 1, 2, 4, and 5 represent the measurement points at the non-driving end of the motor, the driving end of the motor, the driving end of the pump, and the non-driving end of the pump, respectively. Each measurement point is divided into three measurement directions of east-west, north-south, and axial; 3, 6, and 7 represent the lower support cylinder of the motor, the bottom steel plate of the pump group, and the bottom steel structure of the pump group, respectively.

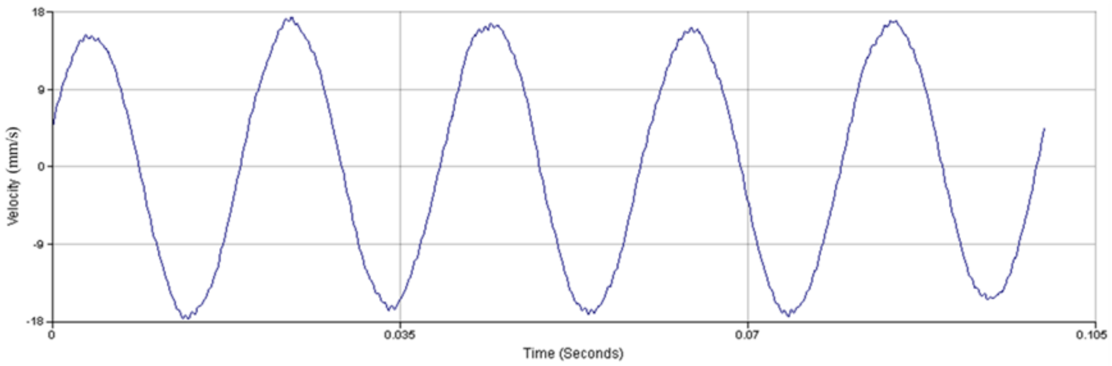
Since the pump group was installed, there has been a problem of vibration exceeding the standard. The initial vibration data measured with load are shown in Table 1. The spectral components are all dominated by the first harmonic, and the vibration spectrum and waveform are shown in Figure 4.

Table 1 Initial vibration data of the pump group

Measuring Point	East-west direction	North-south direction	Axial direction
The non-driving end of the motor	11.73	6.39	1.42
The driving end of the motor	8.69	4.07	1.24
The driving end of the pump	8.39	3.68	1.09
The non-driving end of the pump	5.13	2.93	1.99



(a) Spectrum



(b) Waveform

Figure 4. Spectrum and waveform of east-west vibration of motor non-drive end

The commissioning personnel first took the adjustment of the foundation bolts as a means of checking the problem of hollow feet, and found that the vibration change was not obvious after adjusting the foundation bolts. During the inspection, they found that the vibration at the outlet pipe of the pump was as high as 6.5 mm/s, suspecting that the pump body was deformed due to the misalignment of the flange at the outlet. After further inspection, they found that the flange at the outlet of the pump was not parallel to the pipe connection, the bolts were tilted and subjected to force, and the pump outlet pipe lacked support and restraint. After removing the bolts, they found that the flange had a serious misalignment. Subsequently, a support was added to the pipe at the location, and the pipe position was rectified to eliminate the flange misalignment. The vibration was significantly reduced, but still exceeded the vibration limit value. The vibration data is shown in Table 2.

Table 2 Vibration Data After Eliminating Misalignment

Measuring Point	East-west direction	North-south direction	Axial direction
The non-driving end of the motor	2.59	3.45	1.31
The driving end of the motor	2.26	2.33	1.24
The driving end of the pump	1.55	1.19	1.98
The non-driving end of the pump	1.07	1.14	1.90

Subsequent vibration treatment personnel learned that there may have been installation problems during the installation process. The pump group was disassembled, and the gap between the bottom steel plate and the steel structure was adjusted. The horizontal degree of the bottom steel plate was measured, and finally, the horizontal degree was ensured to be within 0.05mm/m. After reinstallation, a motor empty test was conducted, and it was found that the vibration exceeded the standard. The vibration data is shown in Table 3.

Table 3 Vibration Data of the Motor in Empty State after Reinstallation

Measuring Point	East-west direction	North-south direction	Axial direction
The non-driving end of the motor	6.35	5.10	1.20
The driving end of the motor	4.15	3.08	0.69

In this regard, the vibration treatment personnel suspected the occurrence of resonance. Thus, the third-order natural frequency of the motor under no-load conditions was measured, as shown in Table 4. It can be observed from the knocking test data of the motor body after installation that the first-order natural frequencies of both the non-driven and driven ends of the motor and the motor support frame are all within the range of 46 to 48.5, with a difference of less than 10% from the motor rotational speed frequency of 49.5 Hz. It can be determined that the natural frequencies in all directions have decreased significantly after the motor is installed, resulting in resonance.

Table 4 Natural frequencies of the motor without shaft connection

Measuring Point	Natural frequency		
	First-order	Second-order	Third-order
The non-driving end of the motor (east-west)	46.5	107	196
The non-driving end of the motor (north-south)	48.5	107.5	136.5
The driving end of the motor (east-west)	48.5	160	236
The driving end of the motor (north-south)	46	135	172.5

To enhance the stiffness and avoid the occurrence of resonance, the vibration treatment personnel decided to install four threaded rods, respectively, at the east-west and north-south directions between the wall and the non-driven end and the driven end of the motor, in order to increase the stiffness at the motor location and conduct natural frequency measurements. It was discovered that the first-order natural frequencies at each position were no lower than 88 Hz. After restarting the machine and obtaining qualified results for the no-load vibration measurement, the measurement of the loaded data with the pump connected was also qualified. Considering the risk of the threaded rods falling off, they could only serve as a temporary measure. Subsequently, a permanent support was installed on the wall to replace the threaded rods for supporting the motor. The final data is presented as follows.

Table 5 Vibration Data of Pump Set with Added Support Structure

Measuring Point	East-west direction	North-south direction	Axial direction
The non-driving end of the motor	2.36	2.41	0.97

The driving end of the motor	1.69	1.84	0.80
The driving end of the pump	1.83	1.47	0.85
The non-driving end of the pump	0.54	1.42	0.63

IV. Conclusions

The commissioning period of a nuclear power plant is a period with a high incidence of vibration issues. This paper briefly introduces several of the most common vibration problems of rotating mechanical equipment during the commissioning period of a nuclear power plant. Considering the reduction of time and economic costs for handling vibration problems, it proposes treatment methods for vibration issues. The aim is to quickly and accurately determine the type of vibration problem using a reasonable approach and solve the vibration problems of rotating equipment. This research is of great significance for reducing economic and time costs during the commissioning process and ensuring the safe commissioning and operation of nuclear power plants.

Reference

[1] Qiuhua Mao, Qin Ouyang, Zhengping Zhou, Linlin Chen. Vibration Management Of Rotating Equipment At Tianwan Nuclear Power Plant[J]. Energy Technology And Management, 2014, 39(02):122-124.

[2] Zhongxuan Lu. Analysis And Management Of Rotating Equipment Vibration Problems In Nuclear Power Plants[J]. China Nuclear Power, 2023,16(03):461-466.

[3] Donald E.Bently, Charles T.Hatch. Fundamental Of Rotating Machinery Diagnostics[M]. Mechanical Industry Press, 2014.

[4] Wen Zhu, Mulei Lin. Analysis Of Causes And Solutions For Vibration In Vertical Pumps[J]. Plant Maintenance Engineering, 2024(9):82-84.

[5] Zimeng Chen, Wei Liu. Treatment Of Motor Vibration In Long-Shaft Liquid-Submersed Pumps At Nuclear Power Plants[J]. China Nuclear Power,2023,16(6):828-831.

[6] Bo Ma, Minze He, Ganghao He. Diagnosis And Treatment Of Vertical Shaft Pump Motor Vibration In Nuclear Power Plant[J]. Electrical Engineering Technology,2021,10:177-178+181.

[7] Mingli Liu, Jiangyong Fu, Xingjun Fu, Xinyang Wang, Huiren Zhang. Research And Management Of Structural Resonance In The Same Type Of Pump Set[J]. Nuclear Science And Engineering, 2023, 43(1):97-103.

[8] Zhansheng Liu, Guang Zhao, Xin Long. A Review Of Unbalanced Coupling In Rotor Systems[J]. Turbine Technology, 2007,49(005):321-325.