Effect of Dynamic Balance Parameters on Vibration of Vertical and Horizontal Rotor System

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Abstract. In this paper, a rotor test device for vertical-horizontal conversion is designed. The effects of unbalanced mass, dynamic balance position and other dynamic balance parameters on the vibration response of the rotor system are experimentally analyzed, and the difference of the vibration response of the rotor system between vertical and horizontal states is compared. The test results show that the vibration of the bearing base foot will increase after the dynamic balancing rotor is installed in the vertical shafting in the horizontal state; in order to ensure the dynamic balancing accuracy, the dynamic balancing of the vertical rotor system should be carried out on the vertical system as far as possible, and the aggravation should be carried out far away from the driving end. The research results in this paper can provide necessary support for the determination of dynamic balancing process and the study of dynamic characteristics of vertical rotors.

1. Introduction
Vertical rotor system is widely used in marine auxiliary equipment, such as fuel pump, lube pump, fire pump, condensate booster pump and so on. However, due to the difference of layout and load-bearing conditions, the design calculation and test methods of horizontal rotor system can not be applied to vertical structure [1,2].

In engineering practice, the dynamic balancing of the vertical rotor is completed in the horizontal state, which results in a large deviation between the vibration response of the vertical rotor system and the theoretical value [3]. In this paper, a rotor test-bed for vertical-horizontal conversion is tested, the difference of vibration response between vertical and horizontal rotor systems is analyzed, and the relationship of vibration response between horizontal and vertical conversion process is established to provide necessary support for the study of dynamic characteristics, state assessment, fault diagnosis and life prediction of vertical rotor systems.

2. Difference of Vertical and Horizontal Rotors
For the vertical single-stage cantilever pump, the dynamic model of the rotor-bearing system can be established as follows (without considering the axial vibration of the rotor)[4,5].

\[
[M][\dot{U}]+[G][U]+[C][\dot{U}]+[K][U]=[F] \quad (1)
\]

Among them, [M] and [K] are mass matrix and stiffness matrix, [G] is rotation matrix, [C] is damping matrix, \{F\} is system force, for vertical rotor system, \{F\} = \{Fe\} + \{Ft\}, for horizontal rotor system, \{F\} = \{Fe\} + \{Ft\} + \{W\}, where \{W\} is rotor gravity, \{Fe\} is unbalanced force and \{Ft\} is fluid exciting force.
It can be seen from the above formula that the most obvious difference between vertical and horizontal rotors lies in the difference of system forces, that is, the gravity in horizontal rotors plays a dominant role in the rotor forces, while the unbalanced force and fluid-induced force have less influence; while for vertical rotors, the influence factors of gravity can be neglected, and the unbalanced force and fluid-induced force play a dominant role in the rotor system.

These differences make the vibration responses of vertical and horizontal rotors significantly different under the same unbalanced excitation, and the vibration response characteristics are the basis for calculating the unbalanced state in the dynamic balancing process. Therefore, the fundamental improvement of the dynamic balancing process of vertical rotors lies in the analysis of the dynamic characteristics of the rotor bearing system under the same unbalanced excitation.

3. Design of Vertical and Horizontal Conversion Test Device

In order to analyze the difference of vibration response between two rotor systems from the point of view of experiment, a kind of rotor test bench which can be used for vertical-horizontal conversion is designed. Vertical and horizontal conversion test-bed is mainly composed of driving motor, coupling, aligning roller bearing, simulation shaft, adjustable bearing seat, support, adjustable base, test system and hydraulic lifting system. The bearing-rotor system of the model vertical pump is taken as the model of the test-bed, and the geometric dimensions and relevant operating parameters of the test-bed are determined according to the similarity criterion. The structure sketch is shown in Figure 1.

The test device has the following characteristics: (1) the parameters of the test-bed can be adjusted to meet the vibration response test and analysis of the rotor system under different working speeds, different balancing conditions, different support stiffness and non-span conditions; (2) the installation mode of the test-bed can be adjusted, and the vertical and horizontal conversion of the test-bed can be achieved through the hydraulic device at the base; (3) the installation and disassembly is convenient and the positioning is reliable.

The dynamic analysis of the rotor system shows that the first-order critical speed of the rotor is 3218 r/min and the second-order critical speed is 9468 r/min, which can meet the operation requirements of the test-bed. The calculation model and the Campbell diagram of the rotor system are shown in Figure 2 and Figure 3.
Comparison of Vibration of Vertical and Horizontal Rotors under Unbalanced Excitation

The influence of unbalance on the vibration of the bench was tested on a typical test bench of vertical pump. By adding bolts of different mass on the balance plate, the influence of unbalance on the fundamental frequency vibration of the bearing base was analyzed, and the characteristics of the bench under different rotational speeds were compared and analyzed. According to the characteristics of the bench, four kinds of unbalanced mass are set up, which are 0.8g, 6.8g, 12.4g and 24.6g, respectively. The rotational speed of the bench is 1200 r/min. The test results are shown in Figure 4.

It can be seen from the test results that: (1) in the ideal unbalanced state (unbalanced mass 0.8g), the vibration at the foot of the vertical bearing is higher than that at the horizontal state. With the deterioration of the balance state, when the unbalanced amount increases to 12.4g, the vibration at the foot of the vertical bearing is obviously lower than that at the horizontal state; (2) in the horizontal state, the vibration at the front and rear bearing seats is all along with the unbalanced amount. The vibration of bearing seat increases linearly with the increase of unbalance, but the gradient of variation decreases obviously when the bench changes from horizontal to vertical.

The test data show that the vibration of the bearing base foot will increase after the dynamic balancing rotor is installed in the vertical shafting under the influence of support stiffness and installation conditions. When the unbalance of the rotor increases after the operation of the vertical
shafting, the vibration of the bearing seat will increase, but the increase is less than that of the horizontal shafting.

5. Analysis of the Effect of Balanced Position on Vibration
The influence of uneven position on the vibration of the test bench is tested on a typical test bench of vertical pump. By applying the same unbalanced counterweight blocks at five different positions of the test rotor shafting, the influence of the unbalanced mass loading position of the vertical rotor on the vibration characteristics of the shafting is studied. The aggravating position is shown in Figure 5. Starting from the side of the cantilever rotor, the test is marked as position 1 to position 5, respectively. The weights are 12.4 g and the working speed is 1200 r/min. The test results are shown in Figure 6.

![Figure 5](image)

**Figure 5.** Schematic diagram of unbalanced mass applied position

![Figure 6](image)

**Figure 6.** Influence of unbalanced position on vibration

From the test data, it can be seen that in the horizontal state, the aggravating position of dynamic balance is close to the whole drive, the smaller the vibration of the bearing seat, and in the vertical state, the closer the processing position is to the driving end, the greater the vibration of the bearing seat. The test data show that the dynamic balancing of the horizontal rotor system should be carried out near the driving end, and the dynamic balancing of the vertical rotor system should be carried out far away from the driving end.

6. Conclusion
In this paper, the effects of unbalanced mass, dynamic balance position and other dynamic balance parameters on the vibration response of the rotor system are experimentally analyzed on a rotor test device capable of vertical-horizontal conversion. The following conclusions are drawn:

(1) When the dynamic balancing rotor is installed in the vertical shafting, the vibration of the bearing base foot will increase.

(2) In order to ensure the accuracy of dynamic balancing, the dynamic balancing of the vertical rotor system should be carried out on the vertical system as far as possible.
(3) The aggravation of dynamic balance of vertical rotor system should be carried out far away from the driving end.

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