# EXPERIMENTAL RESEARCH ON THE RESPONSES OF SHIP SHAFT UNDER LOADINGS ON BEARINGS

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With the development of the large-scale ships, the power and size parameters of ship shaft are increasing apparently. As a result, the problems caused by the coupling effects between hull and shaft via bearing structure are prominent. Based on the characteristics of dynamic excitations for the ship shaft, a reasonable experiment plan is designed. In this experiment, transversal, vertical, longitudinal loads are considered on the intermediate bearing and the stern bearing to simulate hull excitations on the bearings. Different rotational speed is also considered. The characteristics of transversal, longitudinal and rotational vibration of propulsion shaft are studied. The coupling effects are discussed.

Keywords: ship shaft, experimental research, hull deformation, coupling effects

## 1. Introduction

Recent years, the proportion of large or ultra-large ships of the total number of world ocean ship is increasing. Large-scale development of the ship is not only an urgent demand for marine economic development, but also a product supported by frontier ship basic theory and the advanced shipbuilding technology. The study of condition monitoring theory and method of large marine propulsion shafting is still a problem that has not been completely overcome. It has theoretical guiding significance and practical value to the safety of marine navigation [1-2]. Egan, Brownel and Murray investigated the relationships for the propulsion thrust and efficiency performance using a flexible hydrodynamic foil to gain a better understanding of the dynamic interaction with the surrounding fluid [3]. Torsional vibration is a characteristic of propulsion systems and is strongly related to their natural frequency. Differences between measured and analytically predicted torsional vibration could be caused by variation of parameters related to natural frequency such as stiffness, damping, and components' inertial masses [4-5]. H.S. Han used the Newmark method for the transient response analysis of the whole system. In the particular, the transient impact torque and excessive vibratory torque originating from diesel engine were interpreted and the resonant points identified through theoretical analysis [6-7]. Tan Di, Lu Chao developed 11-degree-of-freedom dynamics model to study the magnetic force influence on vehicle vertical and lateral coupling dynamics [8].

Based on existed references and the characteristics of dynamic excitations for ship propulsion shaft in navigation in the sea, in this paper, experimental tests about propulsion shaft vibration under transversal, vertical and longitudinal excitations on intermediate and stern bearings are designed. Different rotational speed is also considered. The characteristics the vibration of propulsion shaft are studied. The coupling effects are discussed.

## 2. Experimental System

The ship shaft dynamic characteristic experimental system has been designed and established. The experimental system is constituted by motor, shaft coupling, bent axle simulating set, intermediate shaft and bearing, stern shaft and bearing, hydraulic loading system, which are shown in Fig. 1. The parameters of main components are listed in Table 1.

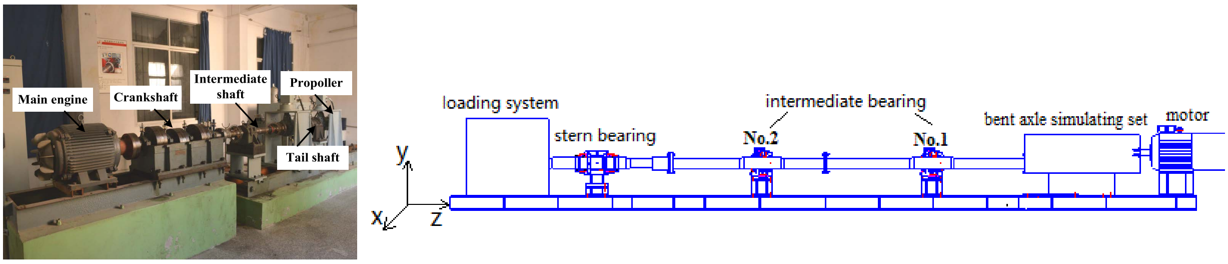



Figure 1： Experimental system

Table 1: Parameters of main components

| Component | Parameter/m |
|---|---|
| Diameter of intermediate shaft | 0.08 |
| Length of intermediate shaft | 1.37 |
| Length of No.1 intermediate bearing | 0.11 |
| Diameter of No.1 intermediate bearing | 0.13 |
| Length of No.2 intermediate bearing | 0.08 |
| Diameter of No.2 intermediate bearing | 0.18 |
| Length of stern shaft | 1.22 |
| Diameter of stern shaft | 0.09 |
| Length of stern bearing | 0.22 |
| Diameter of stern bearing | 0.18 |

Bearings are assumed as the connections between hull and propulsion shaft to transmit hull deformation excitations. Thus, hydraulic transversal and vertical vibration generators are set on the No. 2 intermediate bearing to simulate the hull deformation excitation. Hydraulic vibration generators in transversal, vertical and longitudinal directions are set on the stern bearing to simulate loadings on the stern from hull deformation and propellers. In this way, there are 5 routs of hydraulic loading to constitute the whole loading system. Also, the speed of shaft is changed to exert various rotational forces. The vibration results are gained by sensors and test system. The observed point is located at the intermediate bearing.

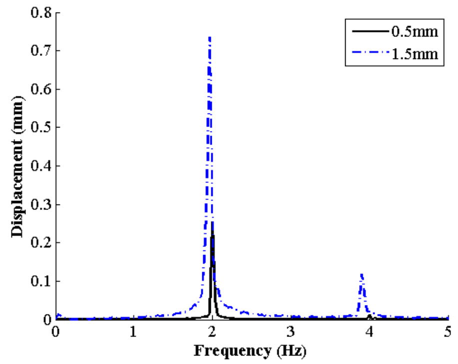
## 3. Results and Discussion

### 3.1 The Responses of ship shaft under transversal loading

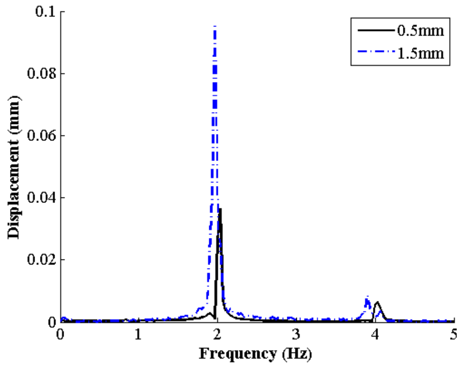
This part discusses the characteristics ship shaft under transversal loading in X direction.  Three cases are considered, which are transversal loading setting at No. 2 intermediate bearing (case 1), at stern bearing (case 2) and at both 2 bearings (case 3). The amplitudes of the dynamic excitations in case 1-3 are 0.5mm/1,5mm, 0.1mm/0.5mm and 0.5mm.  The responses of transversal vibration (in X and Y direction), longitudinal vibration (in Z direction) and rotational vibration for case 1, 2 and

3 are shown in Fig. 2-4, respectively. In Section 3.1 – Section 3.3, rotation speed 120r/min is chosen and the frequency for all dynamic excitations is 2Hz.

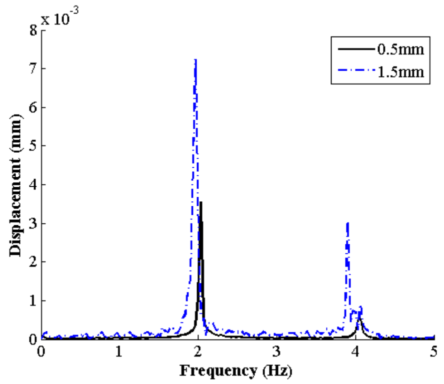
It can be seen from Fig. 2 and Fig.3, under transversal excitation in X direction, although UX is largest, the displacements in Y and Z direction are also evident, due to the coupling effects between different vibration. However, UY is much larger than UZ, as vibration in X and Y are both transversal vibration and interact with each other during shaft rotation. Moreover, the amplitude of transversal excitation has more effects on UY and UZ, when it is applied on intermediate bearing than when it is on the stern bearing. In case 1, the largest UX is about 8 times of the largest UY, while in case 2, the largest UX is only about 2 times of the largest UY. It is because the observed response point is at intermediate bearing and is more easily effected by the excitation at this point and the coupling effect is also more evident. The amplitude and location of transversal excitation both has few effect on rotational vibration.



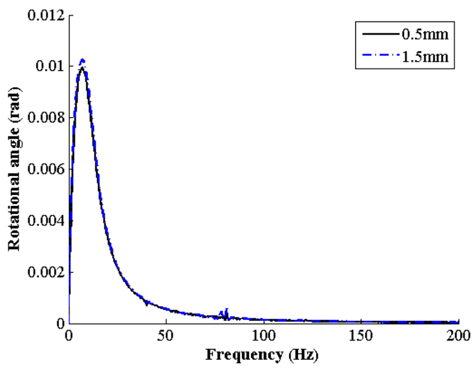

(a) UX




(b) UY

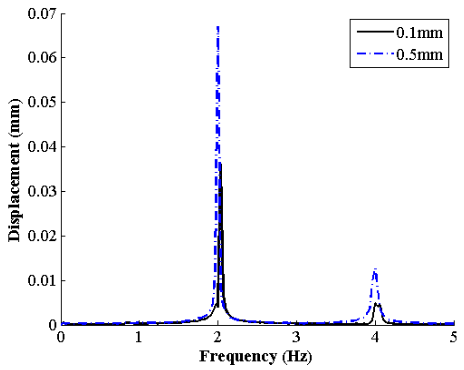



(c) UZ

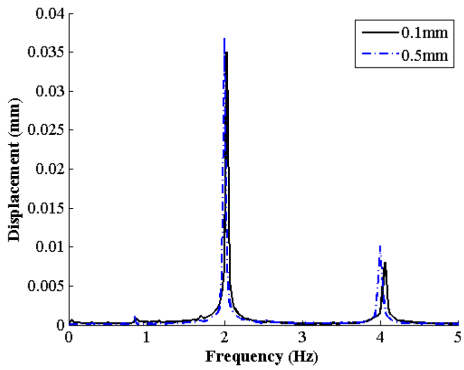



(d) Rotational angle

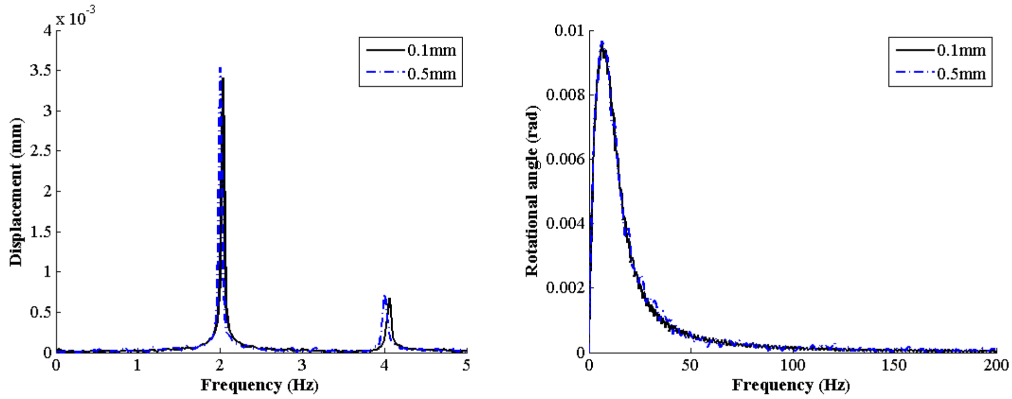
Figure 2: Displacements of shaft under transversal excitation (Case 1)




(a) UX

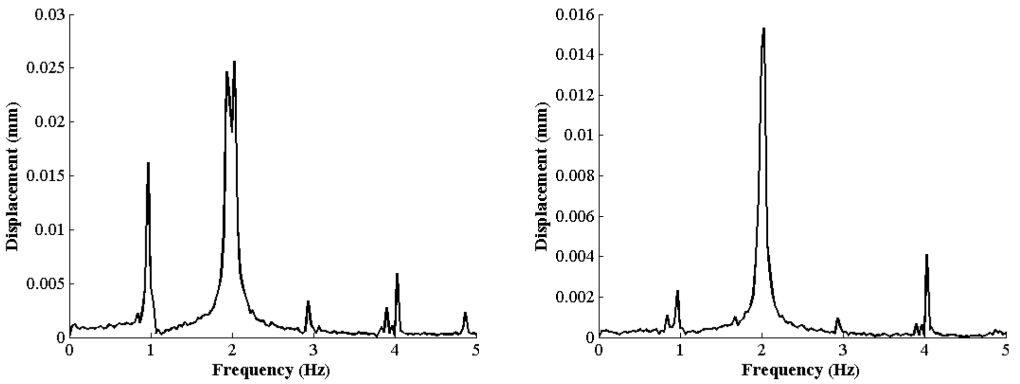



(b) UY

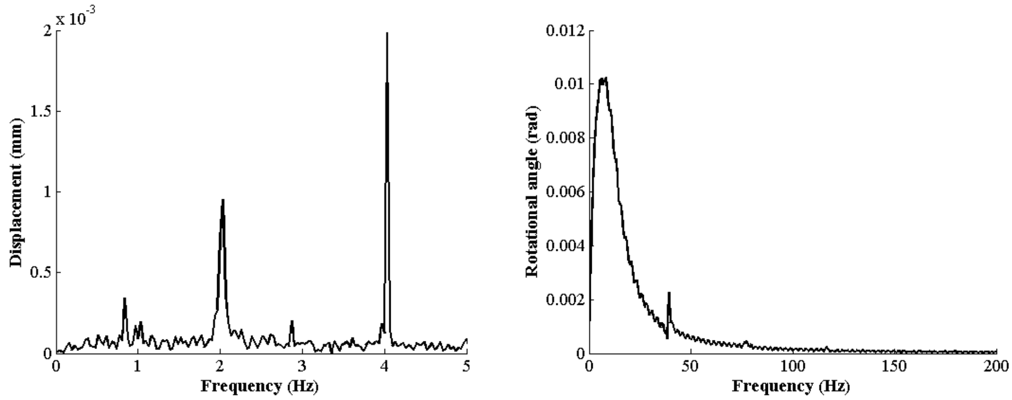



(c) UZ (d) Rotational angle

Figure 3： Displacements of shaft under transversal excitation (Case 2)




(a) UX (b) UY




(c) UZ (d) Rotational angle

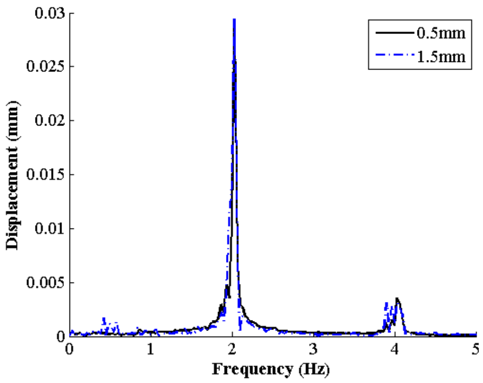
Figure 4： Displacements of shaft under transversal excitation (Case 3)

It is shown in Fig. 4 that under transversal excitations on both intermediate and stern bearing, the peaks of transversal and longitudinal vibration become more, comparing to the number of peaks in case 1 and case 2. It is because of the coupling effects between transversal excitation at different location.

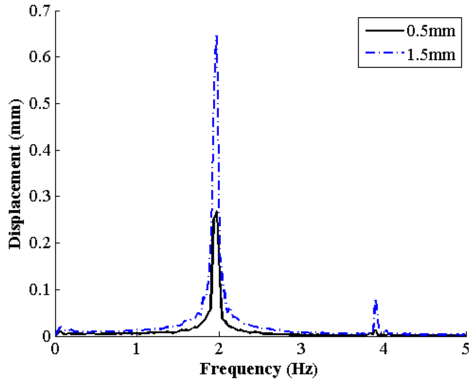
### 3.2 The Responses of ship shaft under vertical loading

This part discusses the characteristics ship shaft under vertical loading in Y direction. Similarly, three cases are considered, which are vertical loading setting at No. 2 intermediate bearing (case 1), at stern bearing (case 2) and at both 2 bearings (case 3). The amplitudes of the dynamic excitations in case 1-3 are 0.5mm/1,5mm, 0.1mm/0.5mm and 0.5mm. The response of transversal vibration (in

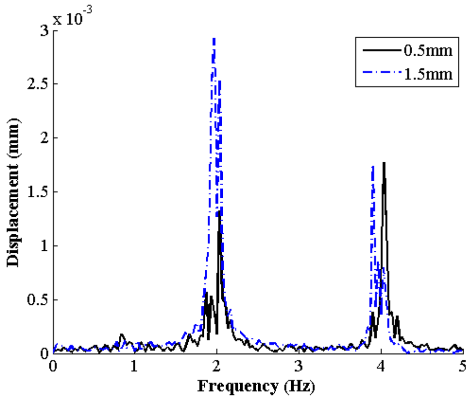
X and Y direction), longitudinal vibration (in Z direction) and rotational vibration for case 1, 2 and 3 are shown in Fig. 5-7, respectively.



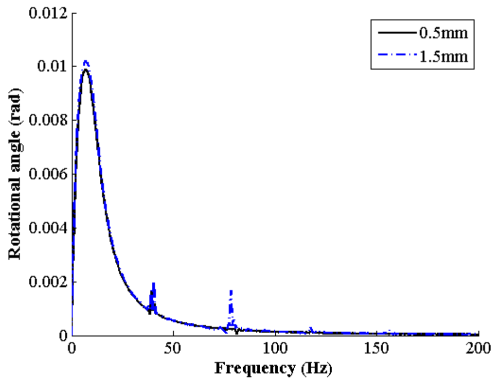

(a) UX




(b) UY

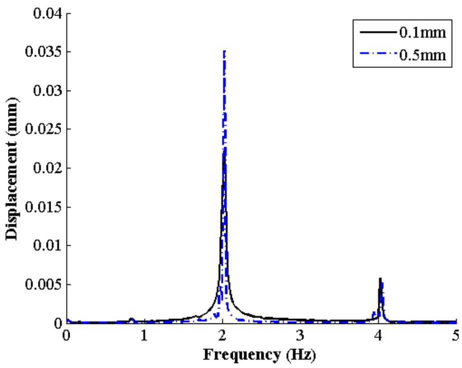



(c) UZ

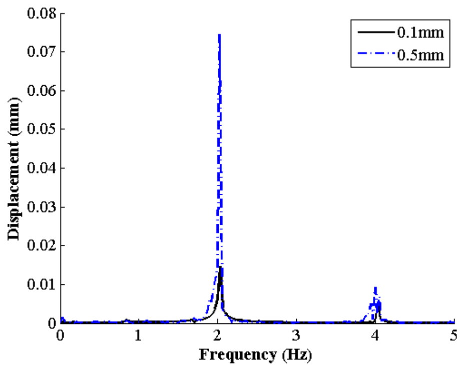



(d) Rotational angle

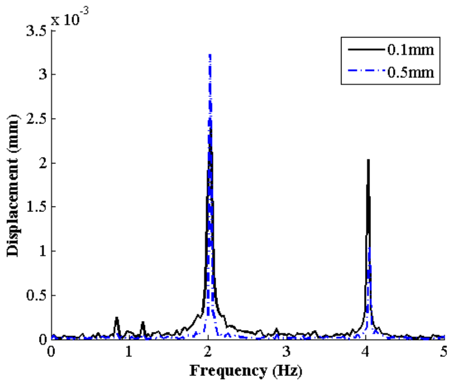
Figure 5： Displacements of shaft under vertical excitation (Case 1)

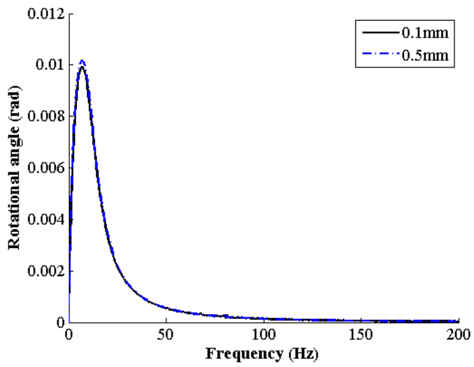



(a) UX




(b) UY

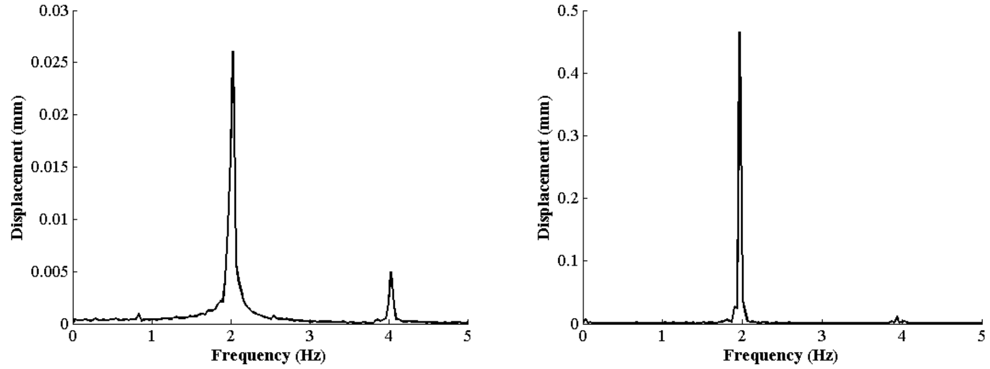


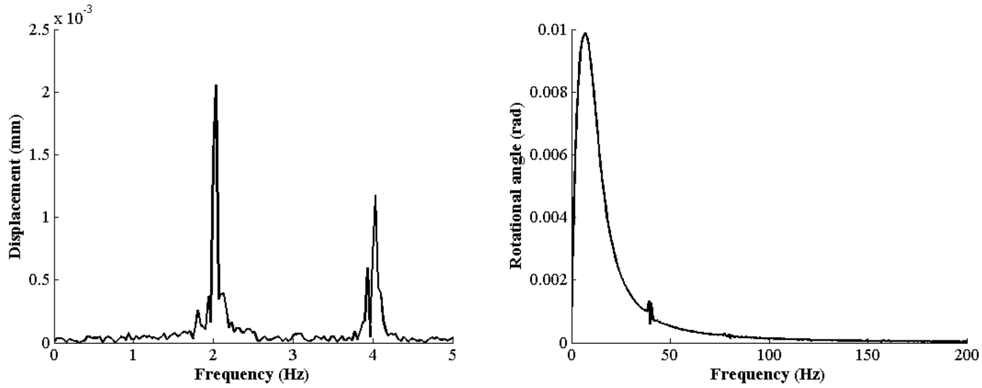
(c) UZ (d) Rotational angle

Figure 6： Displacements of shaft under vertical excitation (Case 2)

Similarly, it can be seen from Fig. 5 and Fig. 6 that under vertical loading in Y direction, UY is largest, but the displacements in X and Z direction are still evident, due to the coupling effects between different vibration. The amplitude and location of vertical excitation has few effect on rotational vibration. However, comparing to the results in the previous part, UY and UZ under transversal excitations is larger than UX and UZ under vertical excitations, especially for the case of excitation on the intermediate bearing. It shows that the coupling effects between different vibration is larger under transversal loading than vertical loading.




(a) UX (b) UY




(c) UZ (d) Rotational angle

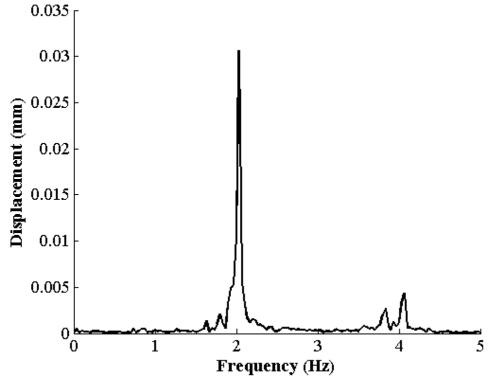
Figure 7： Displacements of shaft under vertical excitation (Case 3)

From Fig. 7, it can be seen that when vertical excitations are applied on intermediate and stern bearing at the same time, the location and number of peaks do not have evident changes, only the amplitude of case 3 is larger than case 1 and case 2. It means that the coupling effects of vertical excitations at different location is not evident.

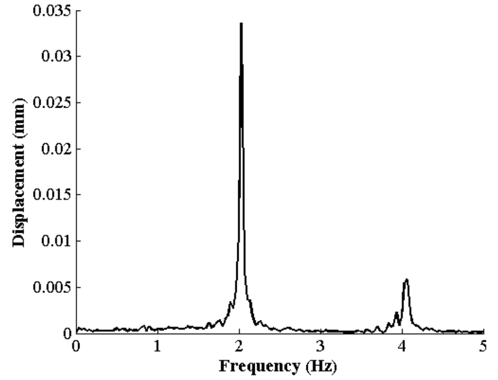
### 3.3 The Responses of ship shaft under longitudinal loading

This part discusses the characteristics ship shaft under longitudinal loading in X direction on stern bearing, as that is the only location to apply longitudinal in the experimental system. The response of transversal vibration (in X and Y direction), longitudinal vibration (in Z direction) and rotational vibration of the shaft under longitudinal loading is shown in Fig.8.

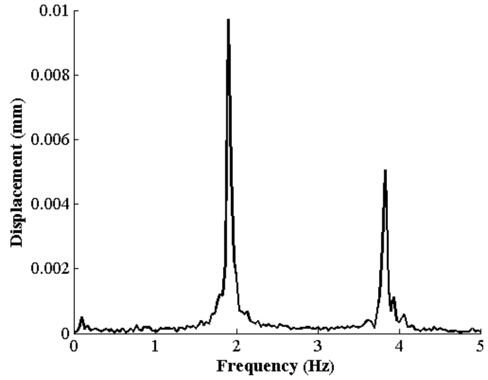
It can be seen from Fig. 8 that under longitudinal excitation, due to the coupling effects between different vibration, the displacements in X and Y direction are both evident and UX and UY have similar amplitudes. However, the amplitude of longitudinal vibration is not large under longitudinal excitation, comparing to the transversal vibration in X or Y direction under corresponding excitations. The reason is there is fewer space to vibration in longitudinal direction, due to the shaft structure. Also, the longitudinal loading has few effect on the rotational vibration.



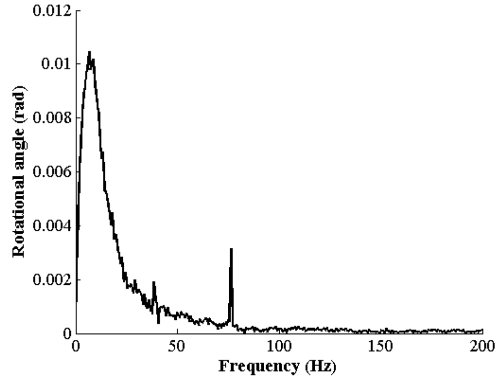

(a) UX




(b) UY




(c) UZ



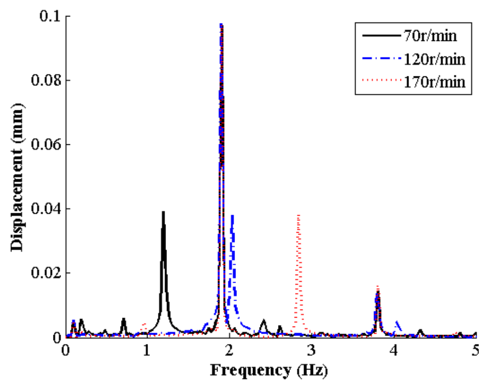

(d) Rotational angle

Figure 8： Displacements of shaft under longitudinal excitation

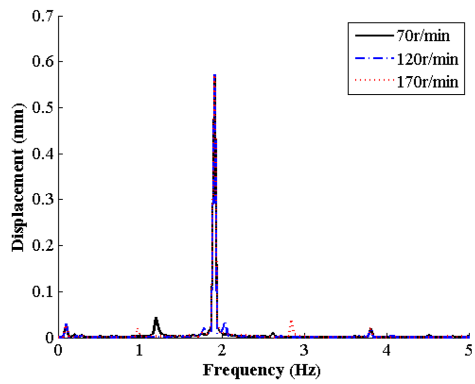
## 3.4 The Responses of ship shaft under different rotational speed

This part discusses the characteristics ship shaft under different rotational speed, which are 70r/min, 120r/min and 170r/min. Moreover, transversal excitation and vertical excitation on intermediate and stern bearings are all considered. The amplitude for all excitations is 0.5mm and the frequency is 2Hz. The response of transversal vibration (in X and Y direction), longitudinal vibration (in Z direction) and rotational vibration for case 1, 2 and 3 are shown in Fig 9.

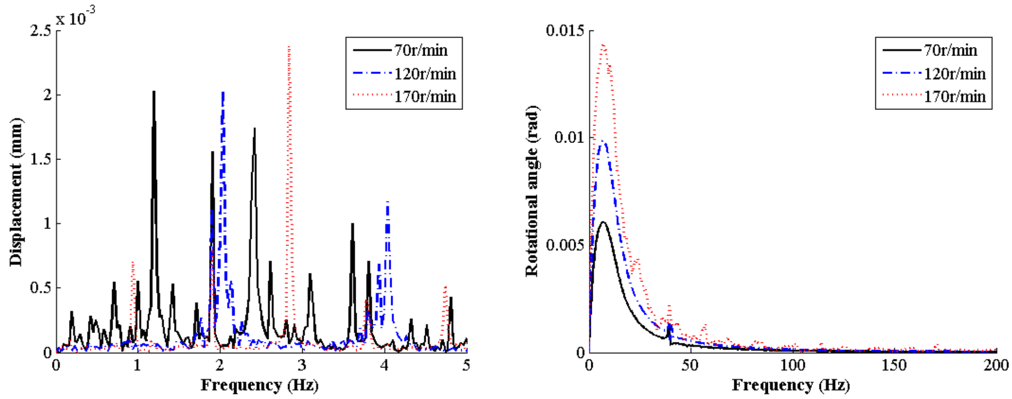
It can be seen from the Fig. 9, under different rotational speed, the location and amplitudes of UX and UZ curves changes but UY results have few difference. It means the rotational force has coupling effect on displacement in X and Z directions. Moreover, the rotational angle has larger amplitude under higher rotational speed, due to the larger rotational forces.




(a) UX




(b) UY




(c) UZ (d) Rotational angle

Figure 9： Displacements of shaft under different rotational speed

## 4. Conclusions

An experiment plan about propulsion shaft vibration under different rotational speed and transversal, vertical and longitudinal excitations on intermediate and stern bearings is designed in this paper to study the characteristics of propulsion shaft vibration under hull deformation excitation and stern excitation. The results show that under transversal and longitudinal excitations, the coupling effects between transversal and vertical vibration are existed. Transversal excitation on the intermediate bearing has more coupling effects than the case of stern bearing. The coupling effects between different vibration and between different excitations location under vertical loading are both not as evident as under transversal loading. However, under different rotational speed, the location and amplitudes of UX and UZ curves changes but UY results have few difference.

## 5. Acknowledgment

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