MACHINERY VIBRATIONS INDUCED BY PROPELLER OF THE SHIP

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When propeller pushes ship forward, it also radiates noise and supply vibration. Exciting force resulted from propeller can cause vibration of itself and vibration of the parts linked to the propeller, including shaft vibration. This exciting force can even cause vibration of the entire ship. The noise generated by this kind of machinery vibration is called machinery noise. In the book “Principles of Underwater Sound”, Robert J. Urick addressed: “Propeller noise is a hybrid form of noise having features and an origin common to both machinery and hydrodynamic noise.” If you want to study propeller noise you will have to study machinery noise of propeller. In order to study the machinery noise created by the propellers, vibration from propellers should be studied first. In this article, the machinery vibration of the propeller rotation is analyzed, specifically that of the circumgyratetion. It is expected that this article should be helpful on controlling or eliminating the vibration along with the resulting noise.

1. Introduction

There are two major purposes that lead to study of machinery vibration. One is to prevent metal structure from fatigue; the other is to reduce noise caused by vibration. The subject developed in this paper is noise reduction. Machinery vibration is an object reciprocating motion with a balance point. It maybe radiates noise when machinery vibration takes place. This kind of noise is called machinery noise.

Due to damping, it requires power supply for the object to vibrate constantly. When marine propeller obtains machinery energy form engine to push ship, part of the machinery energy transforms into machinery vibration energy. Since vibration energy can be transmitted by wave propagation, this vibration energy may be transmitted to portions of the vessel and induce vessel vibration. In the book “Principles of Underwater Sound” Robert J. Urick pointed out that propeller noise has features and an origin common to both machinery and hydrodynamic noise [1]. Hence, besides the hydrodynamic noise (e.g., cavitations, singing), more focus should be put on the machinery noise in order to study propeller noise. And in order to study the property of machinery noise of propeller, properties of machinery vibration should be studied first.

As marine propulsor, propeller must be linked to the shaft as a propeller rotor with many of support points (Fig.1). Therefore machinery vibration of propeller must be related to the shaft and its bearings. This paper will present the mechanism of vibration caused by mass off-centre and circumgyratetion of the propeller rotor, it develops mechanism of friction between shaft and bearings.
too. Attention shall be paid mainly to circumgyration of propeller rotor and vibration excitation of propeller rotor circumgyration to the vessel will be analyzed.

![Schematic diagram of propeller rotor](image1)

**Figure 1.** Schematic diagram of propeller rotor

2. **Nomenclature:**

- $\omega$: Propeller rotation angular speed on its real shaft
- $\omega_n$: Propeller revolution angular speed on its ideal shaft
- $m_p$: Mass of propeller
- $J_p$: Polar moment of propeller
- $J_d$: Propeller moment on the radial shaft
- $\delta_w$: Shaft deflection at the propeller geometric center $O_p$ when unit force act on the propeller
- $\phi_w$: Shaft diversion angle at the propeller geometric center $O_p$ when unit force act on the propeller
- $\delta_m$: Shaft deflection at the propeller geometric center $O_p$ when unit torque act on the propeller
- $\phi_m$: Shaft diversion angle at the propeller geometric center $O_p$ when unit torque act on the propeller

3. **Exciting force induced by propeller rotor**

When marine propeller rotates on its real shaft it will revolution on its ideal shaft, as shown in Fig.2. There is divarication between real shaft and ideal shaft. The higher the speed on its real shaft, the smaller the divarication. Propeller rotor circumgyration is the revolution on its ideal shaft. And because propeller rotor is a large massive turning part, circumgyration propeller rotor will induce high exiting force $F$ on the bearings. Though mass off-centre of the propeller rotor may also induce exciting force, this exciting force can be negligible comparing to the exciting force induce by circumgyration of the propeller rotor at lower speed on its real shaft. The measurement result has proved that is true.

![Schematic diagram of rotation and circumgyration of propeller rotor](image2)

**Figure 2.** Schematic diagram of rotation and circumgyration of propeller rotor
In Fig.2, \( \omega \) is rotation angular speed of the propeller on its real shaft, \( \omega_n \) is revolution angular speed of propeller (circumgyratetion). When propeller rotates on its real shaft at higher speed, \( \omega > \omega_n \); on the other hand, while propeller rotates on its real shaft at lower speed, \( \omega < \omega_n \). For marine propeller in generation, \( \omega \) is usually smaller than \( \omega_n \). This is the characteristic of marine propeller rotor\(^{[2]}\).

There is an equation about angle speed of circumgyratetion and angle speed of propeller on its real shaft:

\[
m_p J_d (\delta_n \phi_m - \delta_m \phi_n) \omega_n^4 - m_p J_p (\delta_n \phi_m - \delta_m \phi_n) \omega \omega_n^3 \\
- (\delta_n m_p + \phi_m J_d) \omega_n^2 + \phi_m J_p \omega \omega_n + 1 = 0
\]

Equation (1) is a quartic equation as a function of \( \omega_n \). For any \( \omega \), it will have four solutions of \( \omega_n \). Two of them are positive and two are negative. If direction of circumgyratetion is same with propeller rotation, it will be positive, this kind of circumgyratetion is called positive circumgyratetion. Otherwise, it will be inverse circumgyratetion. Two positive solutions correspond to the first and second positive circumgyratetion; while the other negative solutions correspond to the first and second inverse circumgyratetion.

There is an example shown in Fig.3. For the convenience of analyzing, \( \omega_n \) is denoted as \( f_n \) with the unit of Hz, and \( \omega \) is denoted as \( n \) with the unit of rpm. During calculation, negative symbol of inverse circumgyratetion is canceled to show positive circumgyratetion and inverse circumgyratetion in same coordinate diagram. The lower picture of Fig.3 shows first positive circumgyratetion and inverse circumgyratetion. In lower picture, the solid line shows first positive circumgyratetion and the dash line shows first inverse circumgyratetion. The upper picture of Fig.3 shows second positive circumgyratetion and inverse circumgyratetion. In upper picture, the solid line shows second positive circumgyratetion and the dash line shows second inverse circumgyratetion.

Figure 3. An example of circumgyratetion

There are two circles in Fig.3. They are two noise spectrum frequencies at different rotation speeds of propeller. And it can be seen that calculating values correspond to all of measurement results perfectly.

As shown in Fig.3, two of noise spectrum frequencies of vessel at different propeller rotating speed correspond to first inverse circumgyratetion and to second positive circumgyratetion. Because there is no frequency of exciting force corresponding to the noise spectrum frequency of vessel, it
can be determined that exciting force induced by circumgyration is the source of vessel noise spectrum.

4. Friction

Friction is a special movement. Noise induced by friction may be detected in any common cases. For example, sound of music from violin can be produced by friction between string and bow. Similarly, intense noise caused by friction between shaft and bearing can also be detected.

The causation of radiating friction noise is that the ratio of variation of relative speed between two objects to the friction is negative sometimes. This negative friction forces the propeller rotor to vibrate and radiate noise \(^4\). The frequency of friction noise is same with the natural vibration frequency of the object, just like the natural frequency of string for violin. So the mechanism of ship friction noise can be developed that friction of shaft and bearing caused propeller rotor vibration, as a resonating cavity the portion of the ship amplifies and radiates the noise. All of the frequency of this friction noise and vibration are the natural frequency of the propeller rotor.

Because friction force is related with pressure on the friction surface, the heavier the pressure, the larger the friction force, so the value of friction force varies as a function of pressure. And the rotation and revolution of propeller rotor may cause the pressure to the bearing change. For circumgyration can make larger amount change of pressure between shaft and bearing, it can increase friction force and induce higher level of friction noise. In this case, the period of pressure variation is larger then the period of friction noise, so the friction noise which amplitude is change at a longer period then its noise's period can be measured. Moreover we can say that higher frequent friction noise is modulated by lower frequent circumgyration. Since modulation frequency of marine friction noise is usually same as the frequency of circumgyration, we can control friction noise through control the amplitude of circumgyration.

5. Conclusion

This article described two kinds of machinery vibration, including circumgyration and friction. It can be seen that circumgyration of propeller rotor is an important vibration exciting force source, it can result in low frequency noise of marine and friction noise of propulsion shaft and bearing.

REFERENCES