Dynamic Analysis of Torsional Vibration of Reed Damper of Diesel Engine

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Abstract. During the operation of diesel engine, there are many kinds of vibration modes in its shafting motion. Now the main explanation is torsional vibration. This kind of vibration may lead to the increase of shaft wear, even the fatigue damage of the shaft system or the damage of the diesel engine. During the operation of spring shock absorber, its components shear oil film continuously and interact with lubricating oil, which affects the change of fluid damping of the shock absorber, so as to better select effective methods to cope with the change. The fluid-solid coupling method is used to simulate the effect of lubricating oil and analyze the vibration absorption performance of shock absorber. Therefore, choosing elastic damped spring damper can respond to fluid-structure coupling analysis, through dynamic analysis, reduce torsional vibration of shafting and improve the safety of ship navigation, which has important significance and value.

Keywords: diesel engine; reed; shock absorber; torsional vibration; dynamics.

1. Introduction

The internal shock absorber of diesel engine is a widely used structural component. It is mostly used for structural vibration reduction and isolation in engineering, such as ground vehicle suspension system and gas turbine in naval vessel [1, 2]. The working principle of the shock absorber in use is to select the appropriate damping and stiffness to resist the system vibration caused by the change of external force or sudden increase of load, so as to better ensure comfort, reduce noise and reduce the damage of accuracy and sensitivity of the system in work [3, 4].

For example, in the operation of marine power system, its diesel engine is in a high turbocharging and efficient environment, requiring higher output efficiency per unit volume of equipment, which intensifies the torsional vibration degree of the shafting. Therefore, installing a spring shock absorber at the free end of the crankshaft of the diesel engine can effectively reduce the torsional vibration of the marine propulsion shafting and reduce wear and tear [5, 6].

Reed shock absorber is mainly composed of two parts. One is internal component and the other one is external component. They are connected by spring blade group, and lubricating oil is rushed into the middle block to ensure the normal use of components [7]. When the diesel engine crankshaft torsional vibration, the spring shock absorber can adjust the damping through its internal lubricant. In view of the relative use of the spring shock absorber, it can reduce the friction between the components, protect the crankshaft, the intermediate shaft and the propeller shaft, and reduce the probability of forbidden speed through its natural frequency [8].
2. Crankshaft system of diesel engine reed shock absorber

The propeller shafting should be selected to transmit power to the propeller in order to ensure that the propeller can rotate continuously in water and generate thrust, and gradually transmit thrust to the hull. During the course of the ship's moving, the shafting system undergoes various complex excitations, and there will be different forms of vibration, such as torsional vibration. This vibration form of noise is relatively large. In the process of appearing, it will continue to increase the wear of parts, which leads to the diesel engine cannot work properly. More serious will lead to diesel engine shafting damage. Therefore, in the torsional vibration of diesel engine shafting, the calculation of components is of great value. The common method of vibration reduction is to install damped torsional dampers at the free end of the crankshaft, such as silicone oil dampers and rubber dampers.

The selected model is 5S60MC, which is a two-stroke five-cylinder diesel engine. The model of elastic damper spring absorber used here is D260*20-1364. According to the analysis of its vibration situation, its shock absorber can establish a matching dynamic model, so as to better calculate the dynamic performance of the shock absorber under load.

Damping of the shock absorber is measured by the factory. It remains unchanged in a wide range of rotational speed and its parameters are more accurate. The rated speed of the diesel engine is 105 r/min, the rated power is 10260 kW, and the working speed is 20-110 r/min. In the multi-mass equivalent system model of diesel engine shafting, the names and parameters of each mass point and section are shown in table 1.

### Table 1. Multi-mass equivalent system parameter table

| Equivalent mass point | Moment of inertia/(kg·m²) | Component name | Shaft segment | Torsional stiffness (MN·m/rad) | Name of shaft segment |
|-----------------------|----------------------------|----------------|---------------|-------------------------------|---------------------|
| 1                     | 28870                      | Propeller      | 1-2           | 106.5                         | Propeller shaft      |
| 2                     | 485.2                      | Coupling       | 2-3           | 49.8                          | Intermediate shaft   |
| 3                     | 20230                      | Free wheel     | 3-4           | 2739.7                        |                     |
| 4                     | 1667                       | Rear tail shaft| 4-5           | 0                             |                     |
| 5                     | 3608                       | Cam            | 5-6           | 1865.7                        |                     |
| 6                     | 10990                      | Fifth cylinder | 6-7           | 1443                          | Crank shaft          |
| 7                     | 10990                      | Fourth cylinder| 7-8           | 1356.9                        | Crank shaft          |
| 8                     | 10990                      | Third cylinder | 8-9           | 1366.1                        | Crank shaft          |
| 9                     | 10990                      | Second cylinder| 9-10          | 1385                          | Crank shaft          |
| 10                    | 10990                      | First cylinder | 10-11         | 1677.9                        |                     |
| 11                    | 2787                       | Front tail shaft| 11-12         | 10°                           |                     |
| 12                    | 546                        | Flange         | 12-13         | 0                             |                     |
| 13                    | 778                        | Spline shaft   | 13-14         | 39                            |                     |
| 14                    | 18500                      | External components | 14 | | |

3. Transient dynamics analysis of shock absorber

3.1. Basic equation of dynamics

Through dynamic analysis, the transient dynamic characteristics of the shock absorber are determined, and the structural dynamic characteristics are mastered by combining damping and inertia. In this case, the dynamic equation needs to understand the modal, response spectrum analysis and transient response analysis. In the role of shock absorber, when the structure bears external dynamic load, it not only generates in the elastic interior corresponding to the load, but also needs the corresponding inertial force and damping force. But these forces will change according to the time. In the finite element analysis of China, the structure is discretized. To master the relationship between displacement, load and node array, the structural dynamic equilibrium equation is as follows:
In the formula, \( F_i \) represents inertial force vector, \( F_d \) represents damping force vector, \( P \) represents dynamic load vector, and \( F_e \) represents elastic force vector.

According to the principle of D’Alembert, the inertial force is expressed by mass matrix and node acceleration. The formulas are as follows:

\[
F_i = M \ddot{u}
\]

In the formula, \( M \) represents the mass matrix and represents the acceleration vector of the node.

### 3.2. Dynamic simulation analysis of spring damper

The analysis of non-linear transient process is similar to that of linear static or quasi-static analysis. The program is loaded incrementally step by step, and the equilibrium iteration is carried out in each step. The main difference between static and transient processing is to activate the time integral effect in transient process analysis, so time always represents the actual time sequence in transient process analysis.

#### Dynamic computing model:

The solid model of spring damper with elastic damping is established in UG, as shown in figure 1. Bolts, holes and chamfers in the actual structure are omitted in the solid model.

#### Table 2. Parameter setting of finite element model

| Serial number | Building name         | Material serial number | Cell type   | Number of grids |
|---------------|-----------------------|------------------------|-------------|-----------------|
| 1             | Bronze gasket         | 3                      | Solid164    | 14363           |
| 2             | Spline shaft          | 4                      | Solid164    | 20699           |
| 3             | Main reed             | 1                      | Solid164    | 36251           |
| 4             | Cover plate           | 2                      | Solid164    | 27843           |
| 5             | Tightening ring       | 5                      | Solid164    | 16139           |
| 6             | Intermediate block    | 6                      | Solid164    | 27037           |

Contacts are created and constraints are imposed.

A total of 272 pairs of contact pairs are created on the contact surfaces of 24 groups of reeds and other components in the process of rotation. Static and dynamic friction coefficients are set, and the automatic contact form between surfaces is selected. Distribution of contact pairs around each spring of spring damper is shown in figure 3 and 4. Contact pairs can be divided into five types.

The first one is the contact surface between the bronze gasket and the fastening ring. The second one is the contact surface between the main reed and the fastening ring. The third one is the contact surface between the main reed and the middle block. The fourth one is the contact surface between the main reed and the bronze gasket. The fifth one is the contact surface between the main reed and the spline...
shaft. In dynamic simulation, only structural damping is added to the system, and the value of structural damping is 0.05. At the same time, a rotating pair is added to the cylindrical surface of the inner ring of the spline shaft in order to apply input excitation. Constraints are imposed on the spring damper, leaving only the degree of freedom of rotation around the axis in cylindrical coordinates.

Loading and solution of shock absorber:

Combined with the elastic damper spring of the shock absorber and the special function of the shock absorber installation, in the installation of the free end of the crankshaft system, the crankshaft rotates continuously with the rotation of the crankshaft. Therefore, in the dynamic analysis of spring shock absorber, there is no need to construct a crankshaft system with spring shock absorber and apply the crankshaft transmission speed in the inner ring of spline shaft. Through the elaboration model construction of the whole crankshaft system, the torsional angular velocity of the spline shaft can be obtained under the rotational speed by using the dynamic equation, and the angular velocity change can be recorded by changing the situation at any time.

**Figure 2.** Actual input angular velocity curve of the damper

4. Dynamic response analysis of torsional vibration of reed shock absorber

4.1. Dynamic contact force and stress of reed damper

By analyzing the working condition of the spring damper, the output torque produced by the cylinder of its diesel engine will be transmitted to the spline shaft of the shock absorber, which is also the external excitation of the shock absorber. Through the side of the spline shaft keyway, the force can be transferred to the free end of the bamboo spring, so that the spring components connected with it can drive the spring damper to rotate together.

Because the output torsion of the cylinder has torsional component, the whole crankshaft system will be twisted. The dynamic contact force between the key groove side of the spline shaft and the spring blade acts as the internal excitation of the spring damper and ensures that the damper plays its role.

Through the actual change curve of the shock absorber and the dynamic contact force between the left and right sides of the spline shaft keyway and the spring, it can be concluded that when the spring shock absorber rotates, the contact force between one of the two adjacent reeds and the side of the keyway increases, while the contact force between the other reed and the side of the keyway decreases gradually. During the operation, the spring assembly and the spline shaft are contacted repeatedly and alternately, and the dynamic contact force as an excitation is transmitted to the external component, which drives the movement of the external component. Under the excitation, there is also a large dynamic contact force between the reed assembly and the middle block.

The following figure shows the stress nephogram of the spring damper at different time during its operation. It can be seen from the graph that the maximum equivalent force at each time appears near the position where the spring assembly contacts the spline shaft in the working process of the shock absorber. The reason is that the external excitation of the shock absorber contains torsional vibration.
The spring assembly bears alternating loads and bends repeatedly. When the spring bends, the bending near the contact position is the most serious, resulting in larger bending stress. However, when the spring assembly is located near the equilibrium position in the bending process, the dynamic stress is small. When the spring is in the first 0.2 seconds, the sudden applied load makes the spring produce greater bending stress. After 0.2s, the motion of the shock absorber tends to be stable and the dynamic stress decreases.

![Stress nephogram of reed damper at different time during operation](image)

**Figure 3.** Stress nephogram of reed damper at different time during operation

4.2. Movement of external components of reed damper
The actual angular displacement and torsional angular displacement curves of the fastening ring of the external component of the spring damper under rated working conditions are given.

![The actual angular displacement of the fastening ring of the external member of the reed damper under rated working conditions](image)

**Figure 4.** The actual angular displacement of the fastening ring of the external member of the reed damper under rated working conditions

Because the torsional angular displacement of crankshaft system is smaller than the total angular displacement of crankshaft system under rated condition, the torsional vibration in the system cannot be
reflected in the overall angular displacement curve of fastening ring. At 1.0s, the motion of the spring damper has reached a relatively stable state. At this time, the angular displacement of the fastening ring in uniform motion can be removed from the total angular displacement curve, and the torsional angular displacement curve of the fastening ring can be obtained.

5. Conclusion
The time history of equivalent stress, maximum principal stress and minimum principal stress of the reed assembly is simulated and analyzed. Because the reed assembly is repeatedly bent and bears complex alternating loads during its working process, its equivalent stress curve fluctuates in a large range with a high frequency of change and its amplitude is 315 MPa. The maximum principal stress and minimum principal stress are 390 MPa and -350 MPa respectively. The damper spring assembly will not be damaged under input excitation. The variation of torsional angular displacement, angular velocity and angular acceleration of the fastening ring contacted with the outermost end of the spring assembly during the working process of the spring damper is calculated. The curve of torsional angular displacement fluctuates periodically with an amplitude of 10.2 mrad. Since only structural damping is considered in the system at this time, and the effect of viscous damping of lubricating oil is not considered, the relative damping value is smaller than the actual situation. The angular displacement amplitude of torsional vibration is slightly larger than the calculated value of lumped parameter model, which is 7.5mrad.

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