Analysis of influence of rubber support structure on vibration characteristics of ship pipeline

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Abstract. In high performance ships, especially luxury cruise ships, people have higher and higher requirements on ride comfort. Pipeline system is an important source of vibration in Marine power plant. In order to reduce the transmission of vibration energy from pipeline system to bulkhead, more and more rubber structures are used to connect pipeline and bulkhead, especially through the connecting base of bulkhead. The difference of vibration transfer characteristics between rubber base and steel base is analyzed by finite element method. The analysis results show that the rubber material has good application performance in ship pipeline.

1. Introduction
Compared with ordinary metal materials, rubber materials have the characteristics of super-elasticity and viscoelasticity, and have good vibration isolation and noise reduction performance, so they are widely used in mechanical systems. The super-elastic characteristics of rubber are as follows: if you apply a small external force on rubber, it can produce a large deformation, and in the removal of external force, it can quickly recover. In the state of tension, the maximum elongation of rubber is usually between 500% and 1000%, and such deformation is still reversible, in contrast, the metal material shape variable is generally less than 1%. The viscoelastic properties of rubber are as follows: under cyclic alternating loading, the strain of rubber material lags the stress [1]. This phenomenon is mainly due to the effect of external force, the relative slip occurs between the rubber molecular chain, because there is internal friction between the molecular chain, during the slip process, to overcome this internal friction there generate heat, thereby consuming energy, macro performance is nonlinear viscoelasticity [2, 3]. Based on the nonlinear finite element software ABAQUS, the vibration transfer characteristics of the pipe connecting base of rubber and copper alloy isolators are compared and analyzed. Through comparative analysis, it is found that the rubber isolator has a good potential in vibration and noise reduction in this kind of structure [4].

2. Establishment of finite element model of pipe penetration connection base
The finite element analysis method is adopted to analyze the vibration transfer characteristics of the transom structure as follows: (1) using software including CATIA to build detailed 3D geometric models; (2) import the model into the Hypermesh software; (3) establish the finite element model in the Hypermesh software; (4) apply the load and constraint conditions (according to the actual working
conditions); (5) solve with ABAQUS software; (6) review the results and prepare the analysis report. The main steps can be summarized as shown in Fig. 1.

![Diagram of finite element analysis process](image)

**Fig. 1** Finite element analysis of vibration transfer characteristics of cabin penetrating structure flow chart

### 2.1. Establishment of finite element model

Figs. 2-6 show the finite element mesh model of the structure, which also includes four parts: fixed base, welded ring, elastomer and flow pipe. The finite element model of the whole structure includes 127,209 nodes and 105,595 elements, of which 101,395 are hexahedral elements, accounting for 96.02% of the total number of units, and 4,200 are transitional pentahedral elements, accounting for 3.98% of the total number of units.

![Finite element mesh models](image)

**Fig. 2** Finite element mesh model of fixed base  **Fig. 3** Finite element mesh model of overcurrent pipe

**Fig. 4** Finite element mesh model of Welding ring  **Fig. 5** Finite element mesh model of elastomer
2.2. Material parameters

(1) the material used for fixing the base, welding ring and flow pipe is steel. When calculating, take:
Young's modulus of elasticity $E=206000$ MPa; Poisson ratio $\mu=0.3$;
mass density $=7.849 \times 10^{-6}$ Kg/mm$^3$;

(2) elastomer material is rubber

A. Hyperplastic

Rubber is a hyperplastic material, and its stress-strain constitutive relation is expressed by the
derivative of strain energy potential function with strain invariant. Ogden constitutive model is adopted
in this project. Take three main elongation $\lambda_1$, $\lambda_2$ and $\lambda_3$ as variables of the Ogden strain energy. In
finite element software ABAQUS, the form of strain energy is:

$$U = \sum_{i=1}^{N} \frac{2\mu_i}{\alpha_i} \left( \lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3 \right) + \sum_{i=1}^{N} \frac{1}{D_i} \left( \sqrt{I_3} - 1 \right)^{2i}$$

Where, $\mu_i$, $\alpha_i$ and $D_i$ are the material constants determined according to the material test data. It
can be obtained by numerical fitting. The parameters of the rubber material constitutive model used in
this project are shown in Table 1.

Table 1. Parameters of the rubber material constitutive model

| $\mu_i$ | $\alpha_i$ | $D_i$ |
|--------|-----------|-------|
| 0.372301454 | 1.54482338 | 9.897580391e-3 |
| 6.56215274e-4 | 5.84632117 | -1.285048945e-2 |
| 1.703590401e-2 | -1.83456548 | 4.778882726e-4 |

The comparison of stress-strain relationship between the test curve and the fitting curve of Ogden
constitutive model ($N=3$) are show in Figs. 7-10. The comparison results show that the proposed
hyperelastic constitutive model has good simulation accuracy.
**Fig. 7** Single shaft tensile test fitting curve

**Fig. 8** Double shafts tensile test fitting curve
B. Viscoelastic

Under the action of periodic alternating load, the strain of rubber material will lag the stress, which is called viscoelasticity. The third-order Prony constitutive model is adopted, whose specific parameters are shown in table 2.

| i  | gi  | ki  | ri  |
|----|-----|-----|-----|
| 1  | 0.1954 | 0.0401 | 0.5737 |
| 2  | 0.14  | 0.0035 | 0.019  |
| 3  | 0.0604 | 0.004  | 0.000203 |
3. Frequency response analysis results

3.1. Frequency response analysis model
The adopted model of frequency response analysis is shown in Fig 11. The constraint is applied at the bottom of the fixed base, the unit excitation force is applied at the center of the end face of the flow tube, and the excitation force direction is Z direction (as shown in the coordinate system). The acceleration measurement point is selected at the top corner point of the fixed base. The constraint reaction force is another measurement point, and is the resultant force of all nodes on the constraint surface [5]. The resultant action point is located at the center of the constraint surface. Since rubber material is a nonlinear material, the direct integral dynamics method is used to solve the dynamic model.

![Fig. 11 Boundary conditions and excitation force diagram of the model](image)

3.2. Frequency response analysis results
Fig. 12 shows the acceleration result in the X direction at the acceleration measurement point. The X direction is perpendicular to the plane of the vertical plate of the fixed base, and the stiffness in this direction is the minimum. It is the main direction that may cause vibration, which needs to be considered. The blue curve is the result of rigid connection and the red curve is the result of elastic rubber connection. As can be seen from the figure, when rigidly connected, the blue curve has multiple acceleration spikes. These peaks are all located near the natural mode of a certain order of the structure. In comparison, the elastic rubber connection represented by the red curve has a much smaller peak acceleration due to the elastic vibration isolation and damping effect, with a gap of three orders of magnitude. Logarithm of the acceleration can be seen more clearly on the order of magnitude (Fig. 12b). The vibration reduction effect of rubber material is obvious on the whole structure.
To further illustrate the difference in vibration transfer between the two structures, the vibration of the peak points of the vibration was compared (four typical peak points were taken). The vibration displacement cloud diagram when the excitation frequency $f = 73.11$Hz is shown in Fig. 13. As can be seen from the figure, at this time, the second-order bending mode of the fixed base in the rigid connection structure is excited, which causes a large vibration of the vertical plate. However, when the rubber elastomer is connected, the vibration is well isolated. The vibration is mainly concentrated on the rigid body mode of the flow tube itself, and the vibration transferred to the fixed base is very small. The results show that the elastomer structure has better vibration isolation effect at this frequency.

**Fig. 12** Comparison of x-direction acceleration at the output point
Fig. 13 When $f = 73.11\text{Hz}$, the vibration displacement cloud diagram of the two connection modes (left: rigid connection; Right: elastomer connection)

The vibration displacement of other peak points of vibration is shown in Fig. 14 to Fig. 17, and the same conclusion can be seen from the figures. At this point, the bending mode of the fixed base in the rigid connection structure is excited, which causes the large vibration of the vertical plate. However, when the rubber elastomer is connected, the vibration is well isolated. The vibration is mainly concentrated on the rigid body mode of the flow tube itself, and the vibration transferred to the fixed base is very small. From the analysis results, it can be seen that the elastomer structure has a good vibration isolation effect under these frequencies and can significantly reduce the vibration peak.

Fig. 14 When $f=557.8\text{Hz}$, the vibration displacement cloud diagram of the two connection modes (left: rigid connection; Right: elastomer connection)
Fig. 15 When $f=766.1\text{Hz}$, the vibration displacement cloud diagram of the two connection modes (left: rigid connection; Right: elastomer connection)

Fig. 16 When $f=1119\text{Hz}$, the vibration displacement cloud diagram of the two connection modes (left: rigid connection; Right: elastomer connection)
Fig. 17 When $f=1575\text{Hz}$, the vibration displacement cloud diagram of the two connection modes (left: rigid connection; Right: elastomer connection)

The resonance peak when the elastomer is connected is shown in Fig. 18 to Fig. 5-22. At this point, the vibration is not completely isolated on the flow tube, but activates a certain mode of the whole fixed base plate. However, when rubber elastomer is connected, due to the damping effect, the peak value of vibration is well controlled and the overall vibration isolation effect is good.

Fig. 18 When $f=49.07\text{Hz}$, the vibration displacement cloud diagram of the two connection modes (left: rigid connection; Right: elastomer connection)
Fig. 19 When $f=61.09\text{Hz}$, the vibration displacement cloud diagram of the two connection modes (left: rigid connection; Right: elastomer connection)

Fig. 20 When $f=101.2\text{Hz}$, the vibration displacement cloud diagram of the two connection modes (left: rigid connection; Right: elastomer connection)
Fig. 21 When f=694Hz, the vibration displacement cloud diagram of the two connection modes (left: rigid connection; Right: elastomer connection)

Fig. 22 When f=930.4Hz, the vibration displacement cloud diagram of the two connection modes (left: rigid connection; Right: elastomer connection)

The y-direction acceleration result at the acceleration measurement point is shown in Fig. 23, and the y-direction is the direction parallel to the plane of the fixed base slab, which makes it difficult to excite vibration. It can also be seen from the figure that the number of vibration peaks is small, which also supports this inference. As can be seen from the figure, the resonance peak is greatly reduced when the elastomer is connected. Vibration isolation effect is obvious. As for the comparison of peak vibration, it is not the main direction of vibration and is limited to the space, so it is not explained in detail here. The specific analysis results can be viewed in the Abaqus software results file.
The z-direction acceleration result at the acceleration measurement point is shown in Fig. 24, and the z-direction is the direction parallel to the plane of the fixed base slab, so it is difficult to excite vibration. It can also be seen from the figure that the number of vibration peaks is small, which also supports this inference. As can be seen from the figure, the resonance peak is greatly reduced when the elastomer is connected. Vibration isolation effect is obvious. As for the comparison of peak vibration, it is not the main direction of vibration and is limited to the space, so it is not explained in detail here. The specific analysis results can be viewed in the Abaqus software results file.
Fig. 24 comparison of z-direction acceleration at the output point

The excitation forces $F_x$, $F_y$, $F_z$ and excitation moments $M_x$, $M_y$ and $M_z$ transferred to the fixed base are shown in Fig. 25 to Fig. 30. The blue curve is the result of rigid connection and the red curve is the result of elastic rubber connection. As can be seen from the figure, the excitation force transferred to the base has been greatly reduced to several orders of magnitude, so it can be clearly seen from the logarithm of excitation force. The reduction of the force transferred to the base can effectively reduce the transfer of transverse (radial) vibration of the flow pipe to the fixed base.
Fig. 25 The excitation force (Fx) transferred to the bottom of fixed base
Fig. 26 The excitation force (Fy) transferred to the bottom of fixed base
Fig. 27 The excitation force (Fz) transferred to the bottom of fixed base
Fig. 28 The excitation force (Mx) transferred to the bottom of fixed base
Fig. 29 The excitation force (My) transferred to the bottom of fixed base
4. Conclusion
The finite element model of cabin piercing structure with inner diameter of 200mm was established by finite element method. The frequency response analysis of the structure with rigid connection and rubber elastic connection is compared. It can be seen from the comparison results that the use of rubber elastomer structure can effectively reduce the vibration peak of the structure, and at the same time greatly reduce the excitation force transferred to the bottom of the fixed base, the vibration isolation effect is obvious.

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