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Structural Intensity Simulation of Bolt Joints in Vibration Environment

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Abstract

The paper a nonlinear model of bolt joints structure in vibration environment is built, including the friction, contact and so on complex nonlinear factors. Structure Intensity (SI) of it is calculated by Finite Element Method (FEM) as an approach for the state identification of bolts joints structure in vibration environment. The plots of the structure intensity vector under different tightening torque were obtained and showed the SI changes of bolt joints structure with different tightening torque, and showed the energy distribution and transmission at different tightening torque.In order to compare, The SI maps of of rigid connected beam at different tightening torque also were obtained.

Keywords*: structural intensity, bolt joints, finite element, power flow, vibration environment*

1. Introduction

The joints form of mechanical assembly is so various, including the section of the degree of joints, bolt joints, Pin joints, welding, cementation and so on. The bolt joints is one multi-scale nonlinear problem among all of the joints above. The discontinuous of the structure's local stiffness and damping is caused by the existence of joints. The relative sliding on tangential of the joints and the gap separation and impact on the normal may arise in Vibration conditions. Friction and clearance are the two typical nonlinear outcomes of bolt joints, once it's in vibration environmental. Under the domination of these behaviors, abundant and intricate nonlinear phenomenon will occur in the dynamic response of the bolt joints [1]. Many scholars studied the characteristics of the bolt joints in recent years. The definition and constructor methods of nonlinear model have been proposed by Pesheck and Pierre [2], and they also did a primary study on the nonlinear modal analysis by the way of The finite element method, and this method is promoted to piecewise-linear system by Jiang [3]. In order to find out the statistic feature for the warning of the failure of bolt joints, the method of combining the numerical simulation and experiment is adopted by DengFeng Zhao. The effects of the nonlinear characteristics of bolt joints on the vibration response parameters are deeply researched by XueQian Chen and others.

As for the elongated structure, the propagation of wave is an important form of moveme nt under excitation, and it will been changed by the new crack in the structure which carried ene rgy through vibration wave in dissemination. So the distribution and transmission of vibration en ergy have been changed. Therefore, the vibration power flow characteristics of damaged structu re can be studied through the propagation of vibration energy, and then the position and size of damaged structure can be diagnosed. Because of the advantages of the structure vibration in p ower flow method, it is more and more widely used in engineering practice. The power flow met hod is used as analysis tool in vibration control research since its theory was created by H.G.D. Goyder and R.G.White [4-6] in 1980. By measuring the transfer function is not enough to provide sufficient information to determine the transfer pathway when a continuous structure vibration transmission from point to point was studied. In order to take effective measures to improve the vibration control, the power flow were studied widely in recent years. The main advantages of power flow method are that the force and the speed in the struct ure have been considered, so does the impedance characteristic in the structure. Power is a single value which can give an absolute measure of vibration transmission.

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2. Computational Methods of *S*tructural Intensity [7]

The concept of structural intensity was introduced in 1970 to the structure acoustic fiddle [8-9] and Pavic developed SI formula [10]. The SI focus on the structure internal stress and the particle motion. SI was defined as power per unit width in a specified direction of flow. The SI can as the power flow density, which is a vector and shows the energy's magnitude and direction of a point on the structure. The SI of three-dimensional structure is vector of time under normal circumstances, which is equal to the power flow per unit area of the vibration structure and its matrix form is:

$$\begin{pmatrix} i_x \\ i_y \\ i_z \end{pmatrix} = \begin{pmatrix} \sigma_x(t) & \tau_{xy}(t) & \tau_{xz}(t) \\ \tau_{yx}(t) & \sigma_y(t) & \tau_{yz}(t) \\ \tau_{zx}(t) & \tau_{zy}(t) & \sigma_z(t) \end{pmatrix} \begin{pmatrix} v_x(t) \\ v_y(t) \\ y_z(t) \end{pmatrix} \quad (1)$$

Where σl(t)、τnl(t)and vl(t)are the velocity and stress respectively at time t.

Various state variables are the harmonic vibration at the same frequency in the analysis of harmonic response, which is expressed as a plural form. The SI in the frequency domain is divided into two parts. One part is a constant value, the section of which is unchanged. If damping is zero, then that part is also zero. Another part is the amount of changes with two times of harmonic frequencies and direction. The SI in the frequency domain can be defined as follows:

$$\begin{pmatrix} I_x \\ I_y \\ I_z \end{pmatrix} = \frac{1}{2}\mathrm{Re}\left(\begin{pmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{pmatrix} \begin{pmatrix} v_x \\ v_y \\ y_z \end{pmatrix} \right) \quad (2)$$

$$\begin{pmatrix} I_x \\ I_y \\ I_z \end{pmatrix} = \frac{1}{2}\mathrm{Re}\left(\begin{pmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{pmatrix} \begin{pmatrix} v_x^* \\ v_y^* \\ y_z^* \end{pmatrix} \right) \quad (3)$$

Where the Equation (2) is changing part, Equation (3) is a constant value portion, σl, τnl is multiplexing stress as frequency domain, vl* is the conjugate of the speed and Re represents the selection of the real part of complex numbers.

3. Finite Element Model

3.1. Model Introduction.

The simplification and mesh model is an important step in finite element modeling, will directly affect the accuracy and the computational scale results. In the paper, the model is composed of a pair of beams and two bolts of M6×25. The bolt screw and structural chamfer are ignored, the nut and bolt as an organic whole, and shown in Figure 1. In order to reflect the nonlinear behavior of bolt joints structure of the contact and friction, use the contact model of finite element analysis by establishing contact pairs between connected pieces, nut and connected. The friction between the contact surfaces must be taken into account. At last, the Coulomb friction model of simple and applicable is taken. The model mesh is shown in Figure 2.

In order to study comparing with lap joint structure with bolts, this paper has established the finite element model of rigid connected beam. And the difference with bolt connection structure finite element model is that there is no friction between a pair of beam, instead of using the adhesive (that is, a pair of form the combination).

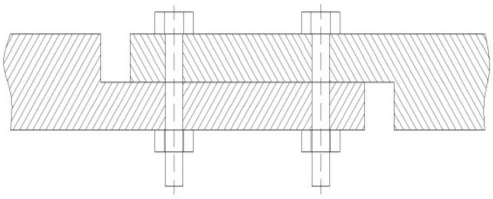

Figure 1. The Model of the Bolt Joints Structure

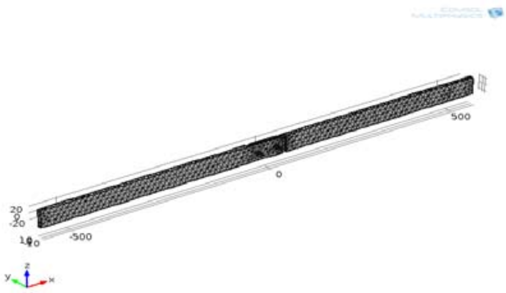

Figure 2. The Finite Element Model

3.2. Model Material and Boundary Conditions.

The relevant material constants are shown in Table 1 , and bolts are M6 × 25 standard steel bolts. External load is: lap beam fixed at one end, and the other end of the applied force of 10N and 500Hz sine excitation, which the position is point 1 in Figure 6.

Table 1. The Material Constants

materia	Young's modulus (Gpa)	Poisson's ratio	Density (kg/ m^3)	Damping
steel	210	0.23	7850	0.0002

3.3. The Bolt Tightening Torque Simulated by Prestrain

Bolt tightening torque is tightened the bolt occurs during the stretching force generated by the deformation. In general use of finite element software perload element method, cooling method, penetration contact method to simulate bolt tightening torque. In this paper finite element caculations, the bolt tightening torque to describe the use of prestrain, the calculation required for the torque converter bolts prestrain applied to the bolt.

4. Result

The SI maps of bolt joints structure at 500Hz when the tightening torque is 0Nm, 1Nm and 2Nm are respectively showed in Figure 3, Figure 4, Figure 5. The SI value is large influenced by tightening torque at bolt joints. So the both ends of lap beam are studied and the connections are ignored.

In Figure 3, the source of excitation and the flow of energy in the bolt joints structure is shown clearly and the SI value is very little. So the energy transmitted to the other end by blots joints is so small. The reason why can clearly show the flow of energy and the excitation source, according to the wave theory is reflecting energy at incentive points.

The Figure 4 showed that the distribution and size of power flow transmitting at lap beam when tightening torque is 1Nm. The energy transmitted to the other end by blots joints is larger than that at tightening torque is 0Nm.And the SI value at bolts joints is larger for the tightening torque. According to wave theory is due to t the energy transmission and reflection superposition at coupling boundary. In practical engineering structure, by external elastomer won't like ideal state immediately produce deformation and stress in the whole structure, but in the form of volatility carry energy transfer to the distance from the part of motivated. Carry energy and elastic wave including: longitudinal wave, torsional wave and flexural wave, these waves are plane wave. According to wave theory, the wave will encounter in the process of complex structure of relay discontinuous place, such as material, geometry shape or structure change, in this case, can produce reflex wave and transmission wave. And in some cases with incident waves of different types of wave is produced.

When the tightening torque is 2Nm, shown in Figure 5, the energy transferred the whole lap beam significantly enhanced, and more energy transferred to the other end by bolts joints. The SI of bolt connection structure is also larger, showing the energy reflection and superposition at the bolt joints is stronger.

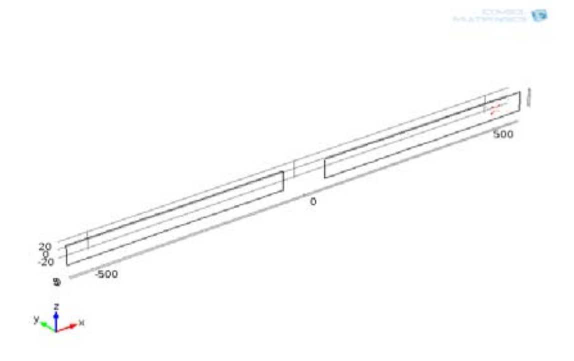

Figure 3. The SI Map of Bolt Joints Structure at Tightening Torque =0Nm

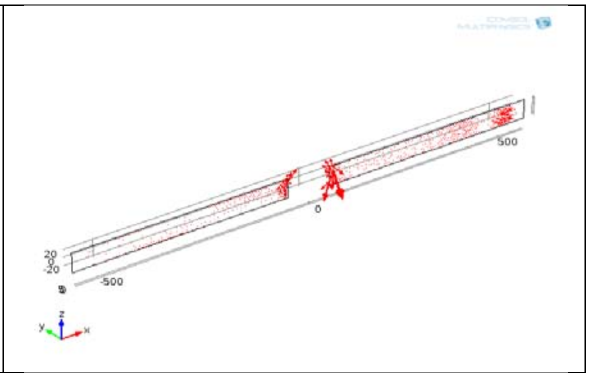

Figure 4. The SI Map of Bolt Joints Structure at Tightening Torque =1Nm

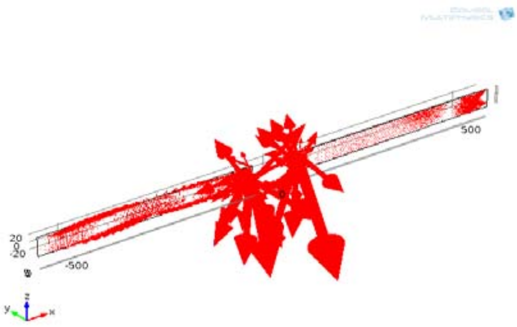

Figure 5. The SI Map of Bolt Joints Structure at Tightening Torque =2Nm

The 6 points selected on the lap beam, and the position as shown in Figure 6 (the excitation position is point 1). The SI value of each point are shown in Figure 7, and it increased quickly when the tightening torque changing form 0Nm to 2Nm.

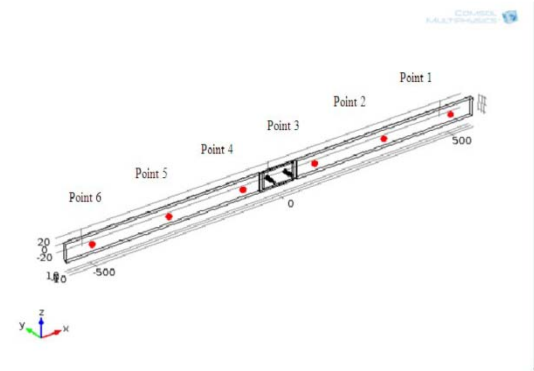

Figure 6. The Position of 6 Points Selected

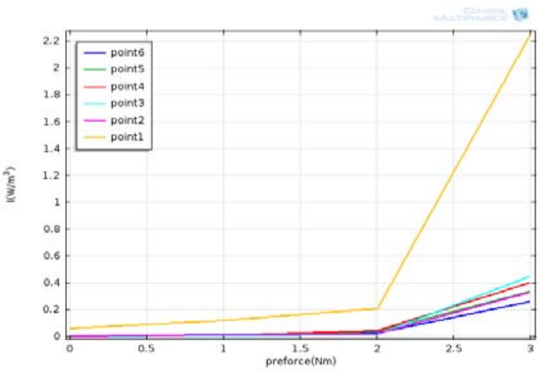

Figure 7. The SI Value of each Point

The SI map of of rigid connected beam at 500Hz when the tightening torque is 0Nm, 1Nm and 2Nm are respectively showed in Figure 8, Figure 9, Figure 10.

In Figure 8, the source of excitation and the flow of energy in the rigid connected beam is shown clearly and the SI value is very little. So the energy transmitted to the other end by blots joints is so small. But comparing with the Figure 3, it showed that the energy loss of through the bolt joints structure is larger than that through the rigid connection beam.

The Figure 9 and Figure 10 showed that the distribution and size of power flow transmitting at lap beam when tightening torque is 1Nm and 2Nm. The SI value of rigid connected beam is larger with the perforce growing. And because no longer connected by bolts, the energy transmission and reflection superposition is smaller at rigid connected boundary, the SI at this place is no that large comparing with the Figure 4 and Figure 5.

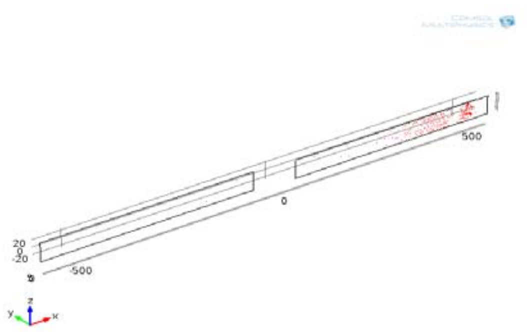

Figure 8. The SI Map of Rigid Connected Beam at Tightening Torque =0Nm

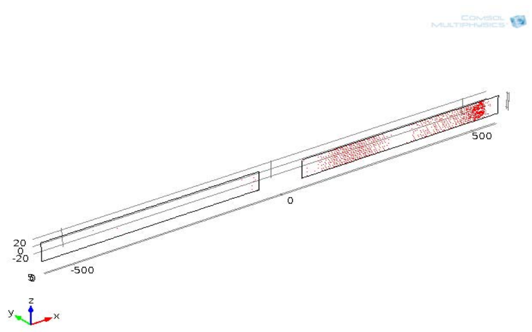

Figure 9. The SI Map of Rigid Connected Beam at Tightening Torque =1Nm

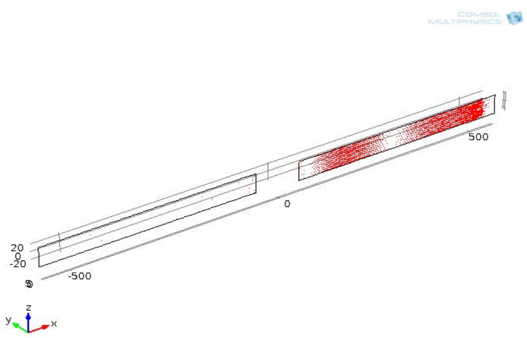

Figure 10. The SI Map of Rigid Connected Beam at Tightening Torque =2Nm

5. Conclusion

The lap beam model with bolts joints is built, including the friction, contact and so on complex nonlinear factors.

The SI at different tightening torque is calculated, and the SI map is plotted. The source of excitation the flow of energy in the bolt joints structure is shown clearly. At different tightening torque , the energy distribution and transmission are different.

As the energy transmission and reflection superposition at coupling boundary, the SI at bolt joints boundary is large. And the SI increases with the bolt tightening torque growing.

The SI value of each point at lap beam changed quickly when the tightening torque changing, and provide the basis for the state identification of bolts joints structure in vibration environment.

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