Research on squeal noise of tread brake system in rail freight vehicle

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Abstract. Brake squeal is a result of an unstable flutter from brake system, it results to the noise pollution in railway side and excessive wear of wheel tread. A finite element model of brake system for rail freight vehicle is set up, the contact and friction between the brake shoe and wheel tread is considered, the complex modals of brake system are calculated, the possibility of happening chatter and squeal noise are analyzed. The results show that the pressure angle or the brake force direction have an important influence on the unstable chatter and squeal noise, the more greater the pressure angle deviates from the wheel center, the more greater the possibility of happening chatter and squeal noise is, and the possibility of happening chatter and squeal noise is also increased along with the addition of friction factor.

1. Introduction

The thread brake is widely used because of simple structure, lower cost of manufacture and convenient control in rail freight vehicle, currently, the overwhelming majority of rail freight vehicle use the thread brake, it is that the brake force is directly acted on the wheel thread\cite{1-2}. The thread brake is same as the disc brake, if the structure is designed unreasonably or running condition is poor, the unstable chatter and squeal noise may be induced\cite{3-5}. The unstable chatter not only induce the high frequency squeal noise, produce the noise pollution in road side, but also cause excessive wear of wheels, wheel tread scratch and polygon wheel, this will seriously influence on the vehicle stability and steady in running\cite{6}. The research show that the frequency domain of squeal noise produced by brake are wide, the noise is named the chatter noise if its frequency is below the 500Hz, in contrast the noise is named the high frequency squeal noise if its frequency is above 500 Hz. The high frequency squeal noise is a research focus and is difficulty in control\cite{7}. Currently, the basic method of forecasting the instability chatter and squeal noise of brake system is to calculate complex modal of brake system, if real parts of complex modals exist any positive values, then the brake system has a lager possibility to happen the chatter and squeal noise\cite{8-9}. The chatter and squeal noise of brake system is related with the friction state\cite{10}, the possibility of inducing chatter and squeal noise can be depressed by improving the friction condition between the brake shoe and wheel tread, or improving the structure shape of brake system\cite{11-12}. Moreover, the state of brake force is also major factor to influence on the chatter and squeal noise of brake system\cite{13}.

In this paper, the finite element model of brake system for rail freight vehicle is built, its complex modal is calculated, the effect of pressure angle and friction factor on squeal noise of brake system are analysed.

2. The analysis theory of complex modal
The brake noise belongs to frictional noise, the mechanism includes glue-sliding, friction-velocity negative slope and modal coupling, etc. The researches show that the squeal noise is accompanied by a vibration with a same frequency, this means that the squeal noise is induced by an unstable vibration because of friction. The method of researching squeal noise is that the whole brake system is chosen as a object, its finite element model of brake system considering the friction and contact is set up, then its complex modales are calculated, the complex eigenvalues are used to forecast that if the unstable vibration may be induced or the squeal noise may be aroused, the corresponding frequency is just right the squeal frequency. In practical application, the real parts of complex eigenvalues are used to estimate the possibility of squeal noise, if any real parts are positive or greater than zero, then brake system is considered as potentially instability and the possibility of happening squeal noise is more greater. The equation of calculating system complex modals is shown as follows

\[(M \lambda^2 + C \lambda + K \lambda)\phi = 0\]  \hspace{1cm} (1)

where \(M\), \(C\), \(K\) are mass matrix, damping matrix and stiffness matrix, respectively, \(\phi\) is the eigenvector, \(\lambda\) is complex eigenvalue. If \(\lambda_i\) is a complex eigenvalue as order \(i\), then \(\lambda_i\) may be expressed as follows

\[\lambda_i = \beta_i + j\omega_i\]  \hspace{1cm} (2)

where \(\beta_i\), \(\omega_i\) are the real parts and imaginary parts, respectively, and the imaginary parts \(\omega_i\) is just right the frequency of complex modal as order \(i\).

The response of system may be expressed as follows

\[u(t) = \sum \phi_i \exp(\beta_i + j\omega_i) t\]  \hspace{1cm} (3)

The equation (3) show that if any real pars of complex modals is greater than zero, then the response \(u(t)\) is added persistently along with the time, that means the system is unstable and the squeal noise may be induced.

3. Finite element model of tread brake system

Finite element model of brake system is shown in Figure 1, it is comprised of wheel, brake shoe, brake shoe salver and brake beam. The each components are partitioned by use of the hexahedron and pentahedron element, the numbers of total elements are 47082. A contact of surface to surface is defined between the wheel surface and brake shoe surface, the coulumb friction model is used; the tied constrains are imposed between the brake shoe and brake shoe salve and between the brake shoe salve and the beam, respectively; the fixed constraints are imposed at the axel hole of wheel. When the braking is required, a pressure is produced between the brake shoe and the wheel because of a braking force acting on the brake beam, and therefore the braking will be achieved. The material property are listed in Table 1.

![Figure 1. Finite element model of brake system.](image-url)
Table 1. Material property

| component       | material | elasticity modulus (MPa) | Poisson ratio | density Kg/m3 |
|-----------------|----------|--------------------------|---------------|---------------|
| wheel           | steel    | 2.1e11                   | 0.3           | 7800          |
| Brake shoe      | complex  | 8.0e8                    | 0.4           | 1800          |
| Brake shoe salve| steel    | 2.0e11                   | 0.3           | 7800          |
| Brake beam      | steel    | 2.0e11                   | 0.3           | 7600          |

4. Computing results and analysis
The complex modal of the above finite element model are computed by using of the ABAQUS software, the effect of both the pressure angle of brake assemble and the friction factor on the complex modal are analysed.

4.1. The initial analysis
The initial state of the braking is follows: the brake force is 25.3kN, the direction of brake force is point to the wheel center, it means $\alpha=0$, it is shown Figure 2; the running speed of railway freight is 8.28km/H; it means that the angle speed of wheel is 5rad/s, the friction factor of between the wheel surface and brake shoe is 0.3. The front 200 complex modal are computed, the vibration modal of complex modal foe 135 order is shown Figure 3. The real parts of frequencies of complex modal computed are all zero, this means that the brake system is stable, the possibility of bringing brake squeal is lesser.

Figure 2. Pressure angle of brake system.

Figure 3. The 125th complex modal with a Frequency of 2635.1Hz.

4.2. The effect of pressure angle on the Squeal Noise
In running process of railway freight, the direction of braking force may be changed because the poor design, poor operation condition and various vibration, this can results that the direction of braking force is not point to the wheel center. When the pressure angles are both $\alpha=7^0$ and $\alpha=14^0$, the complex modal of brake system are computed, respectively, the real parts and imaginary parts are shown in Figure 4 and Figure 5, respectively. The Figure 4 and Figure 5 show that the possibility of bringing brake squeal are added when the brake force is not point to the wheel center, the real parts of three and six complex modal are positive values for $\alpha=7^0$ and $\alpha=14^0$, respectively, and in case of $\alpha=14^0$ the number of the real parts with the positive values are two times as $\alpha=7^0$, the most value of real part is also much bigger than that of $\alpha=7^0$. This shows that the instability of brake system are deteriorated with the increasing of pressure angle.
4.3. The effect of friction factor on the Squeal Noise

In case of $\alpha=7^0$, the complex modals of brake system with the 0.35 and 0.4 for friction factor are computed, the results show that the number of complex modals with a positive values for real parts are added than original one , and most values of real parts with a positive values are added, this means that the possibility of bringing brake squeal are added with along the addition of friction factor. Therefore, in order to increase the stability and reduce the possibility of bringing brake squeal, the friction factor should be properly chosen.

5. Conclusions

The pressure angle or the direction of brake force have the important influence on the stability and squeal noise of brake system, the direction of brake force deviating from the wheel center may be induced because of poor running condition. The more greater the pressure angle is deviated from the wheel center is, the instability of brake system is higher, the more greater the possibility of bringing brake squeal is. The possibility of bringing brake squeal are added with along the addition of friction factor.

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