Research on mining truck vibration control based on particle damping

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\textbf{Abstract:} More and more attentions were got by people about the research on mining truck driving comfort. As the vibration transfer terminal, cab is one of the important part of mining truck vibration control. In this paper, based on particle damping technology and its application characteristics, through the discrete element modeling, DEM & FEM coupling simulation and analysis, lab test verification and actual test in the truck, particle damping technology was successfully used in driver’s seat base of mining truck, cab vibration was reduced obviously, meanwhile applied research and method of particle damping technology in mining truck vibration control were provided.

1. Introduction
Mining truck is a kind of special transport vehicles, because of the product particularity and bad working condition, research on mining truck vibration control are still in a primary stage, which can only meet the minimum requirements of industry standards. With the development of mining truck technology and improvement of environment, health and safety awareness, more and more attentions were got about the research on mining truck driving comfort. Driver’s seat is the mining truck vibration transfer terminal, it’s also direct feeling source of driving comfort to driver. In this paper, particle damping technology was used in driver’s seat base of mining truck, through discrete element modeling, DEM & FEM coupling analysis, lab test verification and actual test on the vehicle, cab vibration was reduced, meanwhile method of particle damping technology in mining truck vibration control were provided.

2. Theoretical basis

2.1. Particle damping technology
Particle damping technology is also called micro particle damping technology, which is a kind of vibration control technology in the 1990s. Filling a certain number of small particles in the closed space of vibrating body, Particle damping technology is a passive vibration control technology, which
is based on the theory of energy dissipation mechanism. Damping effect is mainly caused by the friction and collision between particles filled in the cavity or between the particle and the damper wall, to realize mechanical structural vibration reduction by energy conversion.

2.2. Discrete element method
As a type of granular, particle is another physical form relative to gas, solid and liquid. For this kind of discontinuity, motion equations cannot be established similar to the solid’s or fluid’s, which movement is mainly controlled by the contact effect between particles. So there is a new numerical method, called discrete element method (DEM), which can solve the discontinuous medium problems. According to DEM, the interaction between particles is considered as a continuous dynamic process into balance. If the time step selected smaller enough, in every single time step, movement of a particle is only depends on itself and the particle direct contact with it. Contact constitutive relation and Newton's second law are applied in the DEM calculation, contact constitutive relation is used to get contact force and relative displacement between particles, Newton's second law is used to calculate the movement caused by contact and the mass.

2.3. Particles motion equations
Take, for instance, particle i and j contact, according to the Newton's second law, through the calculation of resultant force and torque of particle i mass center, the particles equations of motion in time t can be get as follows.

\[
\begin{align*}
\ddot{u}_i^{(t)} &= \frac{\sum_{j \neq i} F_{ij}^{(t)}}{m_i} \\
\ddot{\theta}_i^{(t)} I_i &= \sum_{j \neq i} \frac{M_{ij}^{(t)}}{I_i}
\end{align*}
\]

Where \( \ddot{u}_i^{(t)} \) and \( \ddot{\theta}_i^{(t)} \) are the acceleration and the angular acceleration of particle i, \( m_i \) and \( I_i \) are the mass and the moment of particle i.

In calculation, the new location of particle can be obtained by central difference method.

\[
\begin{align*}
\ddot{u}_i^{(t+\Delta t)} &= \ddot{u}_i^{(t)} + \ddot{u}_i^{(t+\Delta t/2)} \Delta t \\
\ddot{\theta}_i^{(t+\Delta t)} &= \ddot{\theta}_i^{(t)} + \ddot{\theta}_i^{(t+\Delta t/2)} \Delta t
\end{align*}
\]

Where \( \Delta t \) is time step.

3. Simulation and analysis of seat base
In general, finite element method (FEM) can be used in mechanical structure analysis and calculation, but for the issues related to particle movement, it is necessary to combine the DEM and FEM, that is DEM & FEM coupling analysis method. Particle movement characteristics were calculated in DEM, then the action of particles on damper wall in DEM can be passed into FEM model by coupling interface, to calculate influence of particles on structure. The DEM & FEM coupling analysis method process is shown in Fig. 3.1.
3.1. Seat base modeling
According to the seat base structural characteristics, simplified and established the 3D model. Considering the element size and quality factors, meshed with hexahedral element. Fig. 3.2 shows the finite element mesh model.

3.2. DEM simulation and analysis

3.2.1. Time step
Time step is one of key problems of DEM, which should be determined firstly when calculating particle movement by DEM according to particle parameters, to track the collision and friction between particles. A small time step will increase the amount of calculation, also a big time step will affect the result accuracy. Usually Rayleigh rated time step was used, which formula shown as follow:

$$T_R = \pi R \left( \frac{\rho}{G} \right)^{1/3} \left( 0.1631 + 0.8766 \right)^{-1}$$

Where R, ρ, G, ν are particle radius, particle density, shear modulus and Poisson's ratio. In general, 20% ~ 40% of the Rayleigh rated time step was selected as a DEM time step.

3.2.2. Particle motion analysis
According to DEM simulation, analyzing particle motion at the beginning of the vibration of seat base. As shown in Fig. 3.3, at first, with the seat base vibration, due to the action of friction and force from inner wall of seat base, the upper particles began to vibration, and downward through bouncing back collide with other particles, rebound and slow down until collisions with the bottom of the base. During the process, the energy of the seat base is transferred to particles. The vibration energy is converted to heat by the inelastic collision and friction of particles.

As shown in Fig. 3.4, damping force of particles on the seat base, it can be seen that vibration start at 0.2s, the particles start from static to dynamic, damping force appears and is biggest. With base motion...
tending to steady, because of collision between particle and base wall, damping force decrease and display periodic changes.

![Fig. 3.4 Damping force of particles](image)

![Fig. 3.5 Energy dissipation of particles](image)

### 3.2.3. Energy dissipation

Particles vibration caused by Seat base, through collision and friction between particles or between the particle and the damper wall, system vibration is reduced. As shown in Fig. 3.5, same with trends of damping force, the largest energy dissipation appear in vibration beginning, then display periodic changes. Through the simulation at engine speed 750rpm and 2200rpm, energy dissipation comparative analysis is shown in Fig. 3.6, the higher engine speed, the more energy dissipation, the more obvious vibration reduction.

![Fig. 3.6 Energy dissipation of particles](image)

![Fig. 3.7 Damped discrete element model](image)

### 3.3. FEM-DEM coupling analysis

Analyze the influence of damping particles on the seat base vibration by FEM-DEM coupling analysis method, input the damping force of DEM calculation to the FEM model, build the damped discrete element model, which as shown in Fig. 3.7.

Through sine sweep excitation, get the seat base response curves with particles and without particles. As shown in Fig. 3.78 and Fig. 3.9, the peak of structural response reduce from 1.8744m/s² to 0.469m/s² at 750rpm, and the peak of response reduce from 2.53m/s² to 1.54m/s² at 2200rpm. The results indicate that vibration reduction is obvious with particles damping.
4. lab simulation and test

As shown in Fig. 4.1, simulate seat base vibration at engine speed 750rpm and 2200rpm, obtain comparative test results with particles and without particles. From the results in Fig. 4.2 we can get conclusions: the vibration amplitude of seat base with particles reduced by nearly 30%, driving comfort is improved obviously; And, by comparing the vibration with particles at different engine speed, we can see that vibration reduction is more obvious at a higher speed, also the DEM simulation results are verified.

5. Actual test in the truck

Test in a truck with particles damper, select two points directly connected to seat base as the testing points, one is seat bottom (point 1) and another is cab floor (point 2), through vertical contrast test at different engine speed, analyze the effect of particles on vibration control.

As shown in Fig. 5.1 and Fig. 5.2 are the vertical vibration test results of point 1 at 750rpm and 2200rpm (where purple curve show results without particles, blue curve show results with particles, the same below.). Fig. 5.3 and Fig. 5.4 are the vertical vibration test results of point 2 at 750rpm and 2200rpm. According to the test results and data analysis, we can obtain: With the particle damping, the root mean square of acceleration decreased more than 30% at both point 1 and point 2, effect of cab vibration control is obvious; vibration reduction at 2200rpm are more better than 750rpm, verify the simulation results further.
Fig. 5.1 Test results of point 1 at 750rpm

Fig. 5.2 Test results of point 1 at 2200rpm

Fig. 5.3 Test results of point 2 at 750rpm

Fig. 5.4 Test results of point 2 at 2200rpm

6. Conclusion
With the development of mining truck technology, more and more attentions were got about the research on mining truck driving comfort. In this paper, based on particle damping technology and its application characteristics, through simulation and analysis, lab test verification and actual test in the truck, particle damping technology was successfully used in driver’s seat base of mining truck, cab vibration was reduced obviously, meanwhile applied research and method of particle damping technology in mining truck vibration control were provided.

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