Dynamic modelling and simulation of 9.0 m double-tamper mechanism for asphalt paver

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Abstract. Compound motion of double-tamper mechanism has impact force on the ironing plane frame, which affects the quality of the load when the Asphalt Paver running. The dynamic model of the double-tamper mechanism is established by adopting multi-body dynamics, the virtual prototype model of 9.0m Asphalt Paver is established and simulated through the analysis of the principle of the Asphalt Paver. The impact regularity of the vibrating beam inertia force and moment is obtained, and that could provide a reference for the design of double-tamper mechanism for asphalt paver and the adjustment of construction parameters.

1. Introduction
The screed is the main device of the asphalt paver which plays a very important role in the construction. It achieves modeling, leveling and compaction of paving roads [1]. The screed with double-tamper mechanism has been widely applied in the market due to the characteristics of high level, high density and high operating efficiency. The double-tamper Mechanism in the front of the screed is driven by the rotation of the vibrating beams, and its rotational frequency is commonly 0 ~ 25 Hz. The inertia force impacting on the screed is very large. In some early researches, the movement of the tamper mechanism is simplified as simple harmonic vibration which didn’t take the vibration of the vibrating beams into account[2]. Few studies [3] have investigated the theoretical calculation based on the method of complex vector. The process of this method is trivial and only the movement parameters of the tamper mechanism can be calculated. This paper established the dynamics model and the virtual prototype model of the double-tamper according to the analysis of the Structure and principle of the double-tamper Mechanism. The impact regularity of the vibrating beam inertia force and moment is obtained which could provide a reference for the design of double-tamper mechanism for asphalt paver and the adjustment of construction parameters.

2. Work principle of double-tamper mechanism
The first paragraph after a heading is not indented. Double-tamper mechanism for asphalt paver mainly composed of the eccentric shaft, eccentric sleeve, main vibrating beam and auxiliary vibrating beam. Eccentric shaft is supported on the frame by the bearings and driven by a hydraulic motor. The initial compaction of the paving mixture is realized through the vibration beam move up and down which is caused by the rotation of the eccentric shaft. The main and auxiliary vibrating beams are considered as the slab and girder structure. The top of the beams is grid, and the beams are hanged on
the eccentric shaft, the structure is shown as shown in figure 1. There are only some extended parts which are parts of the double-tamper mechanism in the figure 1.

![Figure 1. Structure type of double-tamper mechanism](image)

The eccentricity between the eccentric part of the eccentric shaft and the rotating center of the mechanism is $e_1$, and the eccentric sleeve is installed on the eccentric shaft. The eccentricity between the outer circle of the eccentric sleeve and the inner hole center of the eccentric sleeve is $e_2$. The total eccentricity $e$ is the vector sum of the shaft and sleeve eccentricity, which is calculated by the following formula [4].

$$e = \overrightarrow{OP} = \sqrt{e_1^2 + e_2^2 - 2e_1e_2 \cos \alpha}$$  \hspace{1cm} (1)

Where $e_1$ is eccentricity of eccentric shaft, $e_2$ is eccentricity of eccentric sleeve, $\alpha$ is rotation angle of eccentric sleeve relative to the eccentric shaft.

A variety of different combinations of amplitudes can be obtained by adjusting the eccentricity of the eccentric shaft and eccentric sleeve, also different phase difference between the vibrating of the main and auxiliary vibrating beams. Thus a better inertia force can act on the flatiron-box which can better improve the road paving quality [5].

3. Simulation model establishment of double-tamper mechanism

In this article, Adams is used to build a virtual prototype model of 9.0m double-tamper mechanism for simulation analysis. At present, ADAMS is widely used in simulation analysis of mechanical system, including powerful constraint database, force database and machine part database, and powerful solver with numerical analysis function. Based on Lagrange equation in Dynamics of Multi-body System, ADAMS can automatically establish dynamic equation of mechanical system, quickly and accurately solve various kinematics and dynamics problems of mechanical system. The results of simulation analysis can be displayed in the form of curve and graph [6].

3.1. Fundamental theory

Adams can use the method of Lagrange equation according to mechanism model, use Cartesian coordinates of center of mass of rigid body $i$ and the Euler angles of the position of rigid body as generalized coordinates, which expressed as an equation is $q_i = [x, y, z, \psi, \theta, \phi]^T$, $q = [q_1^T, q_2^T, \ldots, q_n^T]^T$. To each rigid body is described by six generalized coordinates. The algebraic equation of constraint, external force equation and self-defined Differential-Algebraic Equations of the system are as follows.
\[ \begin{align*}
\phi(\dot{q}, q, t) &= 0 \\
F(\ddot{u}, u, q, f, t) &= 0 \\
diff(\dot{u}, u, q, f, t) &= 0
\end{align*} \quad (2) \]

Where \( q \) is generalized coordinates, \( u \) is differentiation of each generalized coordinates, \( f \) is external force of system and constraint.

Let \( y = [q, u]^T \) be state vector, then the equation of the system can be expressed as

\[ G(y, \dot{y}, t) = 0 \quad (3) \]

### 3.2. Model establishment

In this paper, Pro / E is used to establish the three-dimensional digital model and entity assembly relationship of the double-tamper mechanism. Each quality parameters of each component are as table 1.

| Table 1. Parameters of System |
|-------------------------------|
| parameters of the base part   |
| \( r_1 / \text{mm} \)         | 2.5  | \( r_2 / \text{mm} \) | 3   |
| \( b_1 / \text{mm} \)         | 6.27 | \( b_2 / \text{mm} \) | 24  |
| \( m_1 / \text{kg} \)         | 5.1  | \( m_2 / \text{kg} \) | 90.07 |
| \( m_3 / \text{kg} \)         | 71.53 | \( m_4 / \text{kg} \) | 7.84 |
| \( J_2 / \text{kg.mm}^2 \)    | 3.55x10^6 | \( J_1 / \text{kg.mm}^2 \) | 2.68x10^6 |
| parameters of the added part  |
| \( m_1 / \text{kg} \)         | 5.1  | \( m_2 / \text{kg} \) | 75.04 |
| \( m_3 / \text{kg} \)         | 49.16 | \( m_4 / \text{kg} \) | 7.84 |
| \( J_2 / \text{kg.mm}^2 \)    | 3.01x10^6 | \( J_1 / \text{kg.mm}^2 \) | 1.94x10^6 |

By using the interface module MECHANANISM/Pro, the data transmission between Pro/E and ADAMS can be realized. Add the gravity restrain on the whole mechanism and the rotational restrain between the eccentric shaft and the main and auxiliary vibrating beams \(^7\). Then add the bushing retrain to imitate the elastic coupling. In practice, the main and auxiliary vibrating beams can be simplified as them to two planes fixed on the earth in the dynamic model by applying planar constraint between the vibrating beams and the panels. The dynamic model is shown in Fig.2.

**Figure 2.** Simulation model
4. Dynamic simulation of double-tamper mechanism

4.1. Analysis of inertia force under different vibration frequency

The inertial force and moment of inertia can be obtained by measuring the force of rotational constrain between the eccentric shaft and the bearing. Take the amplitude of the main vibrating beam as 5mm, the amplitude of the auxiliary vibrating beam as 6mm, the simulation is carried out at different vibration frequencies 10,15,20,25 Hz, and carry out the simulation.

4.2. The inertial force curve of the right base of the screed in x and y direction are shown as follows.

As shown in the figure, the frequency of tamper mechanism has a greater impact on inertia force. Take the inertial force in X direction for example. While the frequency is respectively 10Hz, 15HZ, 20HZ, 25HZ, the maximum of the inertial force in X direction is 275.7N, 622.2N, 1145.3N, 1827.6N.

It is shown that the inertia force of the vibrating beams increases greatly with increasing of the vibration frequency, and the inertia force approximately increases $k^2$ times when the vibration frequency increases $k$ times. The transverse inertia force is large, which will lead to transverse vibration of the flatiron-box. In the previous analysis, we only consider the vibration in the vertical direction, and neglect transverse vibration of the flatiron-box, that is not correct, it is not able to fully reflect the working status of the screed.
4.3. Plotting the effective value of the inertia force of each parts of the double-tamper mechanism

![Figure 5. Curve of the inertia force of the double-tamper mechanism at different frequency](image)

It is shown that the larger the speed the larger increasing extent of the inertia force and has a bad evenness. We should take low-frequency vibration in the precondition of meeting the pavement compaction conditions. The vibrating mechanism has a small effect on the screed at a low frequency. The vibrating mechanism has a significant effect on screed at a high frequency.

4.4. Analysis of inertia force under different vibration amplitudes

Take the amplitude of the main vibrating beam as 5mm, the amplitude values of the auxiliary vibrating beam are 0,3,6,9,12 mm, at the condition of different frequencies 5,10,15,20,25 Hz, take the maximum of the inertial force and moment to draw graphics, the results is shown as follow.

![Figure 6. Inertia force of right base part of the tamper mechanism](image)
As shown in the above figure, the change of the inertia force and the moment is small while the amplitude of the main vibrating beam is 5mm, the amplitude of the auxiliary vibrating beam changes from 3mm to 6mm. while the amplitude of the auxiliary vibrating beam is 9mm or 12mm, the inertia force and inertia moment is to the peak. The result of the simulation and theoretical analysis are in good agreement.

4.5. Analysis of inertia force under different phase angles between adjacent vibrating beams
This paper carries the simulation by Taking the phase difference \( \alpha \) between the left and right base part as 60° and the phase difference \( \beta \) between the base part and the added part as 0°, 60°, 90°, 150°, 180°. The result of inertial force of each part are shown as follows.

The mean value and variance of the value of each parts of the double-tamper mechanism are shown in table 2.

| Phase   | 0°   | 60°  | 90°  | 150° | 180° |
|---------|------|------|------|------|------|
| Mean value / N | 618.11 | 620.52 | 627.19 | 625.66 | 624.82 |
| Variance    | 23.03 | 22.42 | 24.49 | 23.07 | 23.92 |
The driven moment to maintain the rotation of the 9.0m double-tamper mechanism can be obtained by the measure of the added motor.

![Figure 9. driven moment with different phase](image)

It is shown that the inertia force is small and the while the phase \( \beta \) is 0° or 60°, the inertial force is larger and has small changes at 90°, 150° and 180°. The inertial force has a good evenness at 60°, however the inertial force has a bad evenness at 90° and 180°. The driven moment is small at 60°, but larger at 90° and 150°. In order to have a little effect on the screed, so we should set the phase between the base part and the added part as 60° in practice.

5. Conclusions
In this paper, the multi-body dynamic model of tampering mechanism of asphalt paver is established based on Pro/E and ADAMS. The dynamics characteristic of the mechanism is simulated. The virtual prototype model is established according to the real machinery, compared with previous simplified calculation model. This paper considers the space structure and mass distribution of each component, avoiding product the real machinery, and improving the design efficiency. This method is very suitable for the research on complex mechanism.

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