Research on Track Vibration Energy Recovery System for Vehicle Operation Based on Network System

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Abstract. With the continuous innovation and progress of vehicle rail transit technology, wireless sensors and radio frequency coils are gradually used in the signal system. In the past, these devices were battery powered. This kind of power supply not only increases the loss of cost, but also may pollute the environment. Therefore, we plan to use the energy of track vibration as a new type of energy to supply power for trackside equipment. In the process of field power supply, this technology provides power support and reduces the cost. In this paper, the collection method of vertical vibration energy of track is planned to provide power support for track side equipment, and the corresponding conclusions are finally obtained.

Keywords: Vehicle, Running Track, Vibration Energy

1. Introduction

The operation of automobile rail transit has become the most important mode of transportation in China[1]. It is called the lifeblood of national economic development. With the rapid economic progress of our society, people's demand for rail transit technology is higher and higher. Generally speaking, rail transit technology plays an important role in our daily life and work.

However, in some remote areas of our country, the operation of rail transit has been greatly limited due to the high cost of power use and the lack of reliable power resources. How to provide an economic and stable power supply for trackside equipment has become a difficulty in the scientific community. If we can absorb part of the energy from the track vibration process as the power supply, this situation will reduce the consumption of batteries and the cost of maintaining power equipment[2].

2. Development status of vibration energy of track

2.1. Inference of coupled vibration theory
Energy conversion is the basis of research on the recovery of track vibration energy. For a long time, the research of railway vehicle and track system is carried out separately. This leads to the formation of two relatively independent subject areas. Southwest Jiaotong University has carried out research on coupling dynamics from the perspective of vehicle and track\cite{3}. This research has great academic influence on the world. Electromagnetic track vibration device is shown as Figure 1.

![Electromagnetic track vibration device](image)

**Figure 1.** Electromagnetic track vibration device

### 2.2. Inference of mechanical vibration theory

At present, there are four methods to convert mechanical energy into electrical energy in the process of vibration. It includes electromagnetic conversion, electrostatic conversion, piezoelectric conversion and electrostriction\cite{4}. The structure of piezoelectric conversion is simple and reliable. It can convert very high voltage and does not need any transformer. The researchers found that using piezoelectric vibrator to recover the track vibration energy is a good way of power conversion.

### 2.3. Innovation in the application of piezoelectric vibrator

In order to improve the efficiency of piezoelectric vibrator. Researchers need to study the parameters that affect the efficiency of piezoelectric vibrator. On the basis of its normal use, the innovation optimization is carried out. The results show that thickness is the main factor affecting the output voltage of piezoelectric ceramics. The output power of piezoelectric vibrator is directly proportional to the electromechanical coupling coefficient and dielectric constant. In order to improve the efficiency of energy conversion. The energy acquisition system needs appropriate electromechanical coupling coefficient and mechanical quality coefficient. Mechanical quality coefficient is an important parameter to be optimized.

### 3. A random description of the geometric irregularities of a car's track

#### 3.1. The unevenness of car track

The height deviation of the center of the vertical upward point of the left and right rail surface from the design center of the line is called the height irregularity. It is also known as track vertical irregularity. The uneven track is the main cause of vertical vibration. It makes the car body float and nod. In this way, there is a large vertical force between wheel and rail\cite{5}.

#### 3.2. Uneven level of car track

The height difference between the left and right wheel rail contact surfaces of railway lines is called horizontal irregularity. In the process of calculating the level irregularity, technicians need to reduce the normal super elevation and elevation values (see Table 1). Horizontal irregularity will produce lateral vibration and roll of the vehicle. In this way, the vertical force of the side wheel rail is reduced or the
vertical force of the other side is increased.

| Parameter | Line level |
|-----------|------------|
|           | First stage | Level second | Level third | Level fourth |
| $A_v$     | 1.2107      | 1.0181       | 0.6816      | 0.2094       |
| $A_a$     | 3.3622      | 1.2101       | 0.4126      | 0.0762       |
| $\omega_c$ | 0.6011    | 0.9307       | 0.852       | 0.8209       |
| $\omega_a$ | 0.8245    | 0.8245       | 0.8245      | 0.8245       |
| $\delta_c$ | 16        | 40           | 64          | 128          |
| $\delta_a$ | 24        | 48           | 96          | 144          |

3.3. Distortion and unevenness of car track

The plane distortion of the car track is known as the triangle pit. It refers to the difference of the horizontal level of a certain distance and reflects the good and bad relationship of the track planarity. When the distortion of the car's track is very serious, it will lead to the suspension of the wheel rail. This way will cause great damage to the bogie.

4. The establishment of the model of vehicle track and piezoelectric coupling dynamics

4.1. Brief introduction of vertical coupling model

The interaction between vehicle and track is a very complex dynamic process. They permeate and influence each other. Before studying the energy recovery of track vibration, we need to make clear the dynamic coupling relationship between vehicle and track. The determination of this relationship can help us to establish a vertical coupling model. Vertical coupling dynamic model of vehicle is shown as Figure 2[6].
Figure 2. Vertical coupling dynamic model of vehicle

4.2. Establishment of vertical coupling dynamic model

The piezoelectric vibrator will deform after being excited by the track vibration. This characteristic is called the vibration displacement of piezoelectric vibrator. In order to get the displacement value of piezoelectric vibrator accurately, it is necessary to establish the coupling vibration model.

4.3. Setting of the equations of the piezoelectric vertical coupling system of the vehicle

4.3.1. Vertical motion equation of car body

\[ M_t \ddot{Z}_c = M_g g + C_{sz}(\dot{Z}_{t1} + \dot{Z}_{t2} - 2\dot{Z}_c) + K_{sz}(Z_{t1} + Z_{t2} - 2Z_c) \]  

4.3.2. Nodal motion equation of car body

\[ J_c \ddot{\beta}_c = C_{sz} l_c (\dot{Z}_{t1} + 2l_c \dot{\beta}_c) + K_{sz}(Z_{t2} - Z_{t1} - 2l_c \dot{\beta}_c) \]  

4.3.3. Vertical movement of bogie

\[ M_{t1} \ddot{Z}_{t1} = M_{t1} g + C_{sz}(\dot{Z}_c - \dot{Z}_{t1} - l_c \dot{\beta}_c) + C_{pz}(\dot{Z}_{w1} + \dot{Z}_{w2} - 2\dot{Z}_{t1}) + K_{sz}(Z_{c} - Z_{t1} - l_c \dot{\beta}_c) + K_{pz}(Z_{w1} + Z_{w2} - 2Z_{t1}) \]  

4.3.4. Rail adopts Euler-Bernoulli equation. Suppose the vibration displacement of the rail is \( Z_r(x,t) \). The elastic modulus of rail is \( E \). Section inertia is \( I \). The vibration differential equation is:
\[ EI \frac{\partial^4 Z(x,t)}{\partial x^4} + m_v \frac{\partial^2 Z(x,t)}{\partial x^2} = - \sum_{i=1}^{N} F_{rsi(t)} \delta(x - x_i) + \sum_{j=1}^{N} P_j \delta(x - x_{wj}) \] (4)

4.3.5. Vibration equation of piezoelectric vibrator

\[ M_{pe} \ddot{Z}_{pe} + C_b \dot{Z}_{pe} + (K_{pe} + K_b)Z_{pe} - K_{pe}Z_s - C_{pe} \dot{Z}_{b} - K_b Z_b = 0 \] (5)

- \( M_c \) -- Body mass parameters
- \( M_t \) -- Frame quality parameters
- \( J_c \) -- Inertia parameter
- \( K_{sz} \) -- Secondary suspension stiffness
- \( C_{sz} \) -- Secondary suspension damping
- \( l_c \) -- Half of the vehicle distance

5. Research trend of vehicle track vibration

In this paper, the technology of dynamic coupling model of orbit is used for data simulation experiment. Designers can try to use other structures of piezoelectric vibrator for theoretical simulation and experimental research. The most suitable piezoelectric model can be selected by comparing the power generation effect of different structural vibrator. In addition, the design of energy recovery interface circuit and energy storage circuit can realize the decoupling between the oscillator and the circuit.

Based on the accurate parameter design model, we can build a simplified data model. This method can help the designer to optimize the system. The purpose of our research is very clear. There is no doubt that we need further efficient recovery of orbital vibration energy.

6. Conclusion

Through the simulation results, we find that the larger the vibration displacement of piezoelectric vibrator, the greater its power generation. In order to maximize the collected energy, the arrangement of piezoelectric vibrator should be reasonable. At the same time, the faster the vehicle speed, the greater the output energy of piezoelectric vibrator. Therefore, in order to improve the output power of piezoelectric vibrator, we can arrange it in the highway section.

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