DYNAMIC CHARACTERISTICS STUDY
AND VIBRATION CONTROL OF
MODERN TRAM TRACK SYSTEM

Zheyu Zhang, Anbin Wang,
Jian Bai, Zhiqiang Wang

Luoyang Ship Material Research Institute
1、Introduction

Modern Tram System

- energy saving (about 1/3 of the subway)
- short construction period
- low cost (about 1/3 of the subway)

Compared with
subway

- sharing roads with other transportation vehicles
- adapting to a smaller bend radius
- close to the residential areas

Compared with
traditional tram

- safe operation
- vibration and noise reduction

Requirements
1、Introduction

Work Done Flow

Structure design → Safety evaluation → parameters optimized → dynamic performance analysis

- Stress, displacement
  - Nastran
- Nature frequency
  - Simpack
- Derailment coefficient
  - Simpack
2. Structure of The Track System

- Protection of rails
- Increasing line density
- Prevent corrosion problems and damage during maintenance
3、Safety Evaluations

3.1 Numerical model

Beam element

Solid element

Tetrahedral elements

hexahedral elements
3、Safety Evaluations

3.2 Tram operating conditions

<table>
<thead>
<tr>
<th>Structure parameters</th>
<th>value</th>
<th>Structure parameters</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail Young’s Modulus(GPa)</td>
<td>210</td>
<td>Rail sectional area(m²)</td>
<td>76.52E-4</td>
</tr>
<tr>
<td>Rail passion ratio</td>
<td>0.3</td>
<td>Rail pad stiffness(kN/mm)</td>
<td>20</td>
</tr>
<tr>
<td>Rail moment of inertia(m⁴)</td>
<td>3.302E-5</td>
<td>Sleeper spacing(m)</td>
<td>0.625</td>
</tr>
</tbody>
</table>

- Maximum rail lateral displacement is 0.97mm (6mm)
- Maximum stress is 214MPa (457Mpa)

Refer to the class I dynamic rail gauge maintenance standard of the "Railway Line Maintenance Rules"
3、Safety Evaluations

3.3 Road vehicle rolling conditions

The relationship between vertical displacement and wheel radius

\[ \Delta l = R - h = R - \sqrt{R^2 - \left(\frac{b}{2}\right)^2} \]

Force is hard to determine, **DISPLACEMENT** is adopted.
3、Safety Evaluations

3.3 Road vehicle rolling conditions

\[ \Delta l = R - h = R - \sqrt{R^2 - \left(\frac{b}{2}\right)^2} \]

worst condition: the maximum vertical displacement effecting on the maximum contact area

The maximum stress is 0.063MPa
Safety Factor is about 16
4、The dynamic performance

4.1 Numerical model of the track system

Avoid the process of solving the four order partial differential equations of rail dynamics
Equivalent calculation

The mass conversion requires the kinetic energy is constant.

**Taking mass conversion of rails as an example**

Under load $P_0 e^{i\omega t}$ the kinetic energy of the rail is

$$T = \frac{3}{4\beta} m_r Z_0^2(t) \quad \text{(Continuous system);} \quad T = \frac{1}{2} M_r Z_0^2(t) \quad \text{(Equivalent lumped system)}$$

So

$$M_r = (3/2\beta)m_r$$

Mass conversion above also applies to the track system under rails

$$M_s = \frac{3}{2\beta} m_s \quad \quad M_b = \frac{3}{2\beta} m_b$$

Where

$$k_p = \frac{K_{pi}}{l_s} \quad k_b = \frac{K_{bi}}{l_s} \quad k_f = \frac{K_{fi}}{l_s}$$

$$\frac{1}{k_i} = \frac{1}{k_b} + \frac{1}{k_f} + \frac{1}{k_p} \quad \quad \beta = \left(\frac{k_i}{4EI}\right)^{1/4}$$
Equivalent calculation

The stiffness conversion requires the deflection is constant.

Taking stiffness conversion of rails as an example

Under load $P_0 e^{i\omega t}$ the deflection of the rail is

$$Z_0(t) = \frac{\beta}{2k_t} P_0 e^{i\omega t} \quad \text{Continuous system} \quad Z_0(t) = \frac{1}{K_t} P_0 e^{i\omega t} \quad \text{Lumped equivalent system}$$

So

$$K_t = \frac{2}{\beta} k_t$$

Stiffness conversion above also applies to the track system under rails

$$K_p = \frac{2}{\beta} k_p \quad K_b = \frac{2}{\beta} k_b \quad K_f = \frac{2}{\beta} k_f$$

Where

$$\begin{cases} k_p = K_{pi} / l_s \\ k_b = K_{bi} / l_s \\ k_f = K_{fi} / l_s \end{cases} \quad \frac{1}{k_i} = \frac{1}{k_b} + \frac{1}{k_f} + \frac{1}{k_p} \quad \beta = \left( \frac{k_i}{4EI} \right)^{1/4}$$
4. The dynamic performance

4.2 System parameters optimized

- Rail line mass:
  - 60kg/m (original line density)
  - 80kg/m (With rubber casings)

- Stiffness:
  - 20kN/mm
  - 60kN/mm
  - 100kN/mm
rail line mass: 80kg/m

Stiffness: 20kN/mm
4、The dynamic performance

4.3 Analysis of the dynamic performance

Traditional road construction

<table>
<thead>
<tr>
<th>Item</th>
<th>Traditional track system</th>
<th>Modern track system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail mass</td>
<td>67.98kg</td>
<td>116.85kg</td>
</tr>
<tr>
<td>Sleeper mass</td>
<td>144.31kg</td>
<td>183.3kg</td>
</tr>
<tr>
<td>Dispersed ballast block mass</td>
<td>758.94kg</td>
<td>963.97kg</td>
</tr>
<tr>
<td>Sleeper space</td>
<td>0.625m</td>
<td>0.625m</td>
</tr>
<tr>
<td>Rail pad vertical stiffness</td>
<td>613.2 E6N/m</td>
<td>62.3 E6N/m</td>
</tr>
<tr>
<td>Ballast block vertical stiffness</td>
<td>588.7 E6N/m</td>
<td>747.8 E6N/m</td>
</tr>
<tr>
<td>Foundation vertical stiffness</td>
<td>10E10N/m</td>
<td>10E10N/m</td>
</tr>
</tbody>
</table>

High fastener stiffness: 200kN/mm

VS

Fastener stiffness of the modern tram system: 20kN/mm
Dynamic Characteristics Study and Vibration Control of Modern Tram Track System

Vertical wheel-rail forces

Vertical wheel-rail forces (with AAR 5)

Derailment coefficients

Derailment coefficients (with AAR 5)
## Reduction of modern tram compared to traditional system

<table>
<thead>
<tr>
<th></th>
<th>vertical force discrepancy</th>
<th>derailment coefficient</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Without excitation</td>
<td>8.5kN</td>
<td>0.1</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>16%</td>
</tr>
<tr>
<td>With AAR5</td>
<td>12kN</td>
<td>0.6</td>
<td>36%</td>
</tr>
</tbody>
</table>
5、 Conclusions

1) The modern tram track system is safe in tram normal operation and road vehicle rolling conditions, with sufficient security (the lateral displacement of a rail head is less than 1.9mm, the stress 214MPa), and the rail system components are not destroyed (two rubber blocks maximum stress 0.063MPa).

2) The natural frequency of the track system and the amplitude of wheel-rail force decrease with either the rail pad stiffness decreases, or the rail line mass increases.

3) Compared with the traditional track system, the modern tram track system can obviously reduce the vertical force discrepancy and derailment coefficient on the curve line.
Thank You!