Development of Track Superelevation Simulation Testing System

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Abstract: This paper first discusses the standard requirements and the existing test method for the coefficient of flexibility of the existing metro vehicle. The existing method has the disadvantages of manpower cost, insufficient accuracy of track lifting, different lifting speed of jacks under axle boxes. There are also safety hazards of the vehicle capsizing and the jack sliding. This paper introduces a set of simulation testing system based on hydraulic principle for these problems, measuring track superelevation accurately, reading and controlling the height of vehicle body and the track, thus realizing measuring the coefficient of flexibility. This system has the advantages of simple structure, easy installation, convenient operation and high measuring precision. The track distance, wheelbase and biaxial distance are all variable. It also saves manpower and effectively eliminate safety hazards.

1. Introduction

According to the IEC 61133-2006 "Railway applications – Rolling stock – Testing of rolling stock on completion of construction and before entry into service ", the measurement of coefficient of flexibility is required on the assembled vehicle to verify whether it meets the standard requirements of the UIC505-5-1997 "Railway transport vehicle limit – Notes on the preparation and provisions of these Leaflets ".

The routine of coefficient testing of flexibility: When the locomotive vehicle is parked on the track of a certain superelevation D, under the premise of eliminating the influence of asymmetry and suspension elements, the tilt angle of the vehicle relative to the track line is \( \eta \), the tilt angle of the track line relative to the water level is \( \delta \), the ratio is called the coefficient of flexibility. According to UIC 505 standard, the coefficient of flexibility is measured in the following steps: Place the vehicle on the straight track, four axle boxes on one side of the vehicle are lifted by jacks, which makes the distance between vehicle and track is the same height D (Simulate the maximum superelevation D, but the maximum value is determined in the process). Then measure the tilt angle \( (\eta+\delta) \) of the vehicle by track superelevation measuring ruler. The principle diagram is shown in figure 1.
Figure 1. Principle diagram of coefficient of flexibility

The tilt angles, $\eta$ and $\delta$ are minimal, which are approximately equal to the tangent of them. Set the value measured by the superelevation measuring ruler is $E$ mm, the tilt angle of the vehicle $(\eta + \delta) \approx E/1500$ radian, the tilt angle of track line $\delta = D/1435$ radian. The carbody and center line perpendicular to the plane of the track form angle $\eta$, see formula (2). So, in different $D$ cases, reading $E$ value can get $\eta$ and $\delta'$. The coefficient of flexibility $S$ is calculated according to the minimum squares method in UIC505 ($h_2 = E$, $h_1 = D$ in figure 1):

\[
s = \frac{\eta_1 \delta_1 + \eta_2 \delta_2 + \ldots - (\eta_1 + \eta_2 + \ldots)(\delta_1 + \delta_2 + \ldots)}{\delta_1^2 + \delta_2^2 + \ldots - (\delta_1 + \delta_2 + \ldots)^2}
\]

\[
\eta = \frac{E}{1435} - \frac{D}{1500}
\]

Note: 1435 is the length of the superelevation measuring ruler, and 1500 is the rolling distance between two wheels on one axle.

There are some disadvantages to the conventional test method: 1. It takes a lot of manpower on controlling jacks under four axles at the same time, cushion under the wheel, reading values from the superelevation measuring ruler and safety protection and so on. 2. The accuracy of the track lifting is not enough. The testing results will be affected by process of lifting over the target height and then pullback. 3. The lifting speed of four jacks under axles is hard to keep pace. 4. In the process of the testing, there are safety hazards of vehicle capsizing and jack sliding.

In order to solve above problems, a high precision track superelevation simulation testing system is developed.

2. The purpose of system development

A high precision track superelevation simulation testing system is provided to ensure the system highly automated, to save manpower, to simulate the track superelevation state, and to realize the synchronization of lifting each wheel position, so that guarantee the high precision of testing. It can also avoid safety hazards of vehicle capsizing and the jack sliding. In addition, the system can meet the requirements of track distance, wheelbase and biaxial distance.

3. Technical route and implementation plan

Through the track superelevation simulation testing system, the vehicle is rotated relative to the outside of the other side of the track combined with bogies and track, accurately simulate the
superelevation state of track. Wheels on the same side can be lifted synchronously or partially. Load sensors are set to measure the wheel weight and the axle weight. Ranging sensors are set under the track, which can measure the superelevation. Each wheel location is equipped with wheel safety protection to prevent capsizing during the testing. The track distance is variable, so as the wheelbase and biaxial distance, the positioning is precise. It can be used in many different types of vehicles.

Features of this system: Consists of hydraulic control system, mechanical execution system and safety device. The hydraulic control system is mainly composed of two-way motor, flow control valve, manual direction control valve, overflow valve, pressure gauge, direction interlock check valve and hydraulic arm. The hydraulic arm is connected to the execution lifting device, which is made up of beam, support, track and infrared ranging sensor. In order to achieve a variable gauge, the installation of the railway and the foundation is implemented through the cross groove. In order to eliminate the safety hazard of capsizing, it also equipped with the safety chain by the lifting side and safety belt beside the bogies.

3.1. Hydraulic control system design

3.1.1. Function.
The function of the hydraulic control system: First, to realize lifting and falling of the whole system; Second, maintain the height and ensure safety during lifting and falling process.

Based on the above functions, the hydraulic control system element is composed of hydraulic tank, two-way motor, flow control valve, manual direction control valve, overflow valve, pressure gauge, directional interlock valve and hydraulic arm, each component functions as follows:

Two-way motor: Ensure to output torque in both directions at any time;
Flow control valve: Control lifting speed;
Manual direction control valve: Manual control lifting and falling;
Overflow valve: Safety protection, overpressure protection;
Pressure gauge: Monitoring pressure change;
Directional interlock valve: Guarantee that only one direction can be used at a moment;
Hydraulic arm: Hydraulically operate lifting and falling;

3.1.2. Principle.
The principle diagram is shown in figure 2:

![Figure 2. The hydraulic principle diagram](image)

Control lifting and falling of hydraulic arm (12) through two-way hydraulic motor (2) and manual direction control valve (4). Control the lifting or falling speed through flow control valve (3). Control the lifting force through flow control valve (3) and overflow valve (5). The system pressure is displayed by the pressure gauge (6).
The directional interlock valve (7) is to ensure that only lifting or falling can be operated. When the motor starts, the hydraulic arm extends, which makes the vehicle (8) rotated relative to the fixed pivot combined with bogies and track (9). During the rotation, the height of the vehicle (8) and bogie (9) is different due to the presence of coefficient of flexibility. The height is measured by the superelevation measuring ruler on the floor and the infrared ranging sensor under the beam.

### 3.1.3 Parameter design.

#### 3.1.3.1 Open and closed system determination.
Consider the system has single function and relatively simple, it doesn’t conduct frequent reversing operations, and the open system is conducive to heat dissipation, so it adopts open system.

#### 3.1.3.2 Composition and calculation of load.
In the detailed design phase of the hydraulic control system, the selection of hydraulic components is based on pressure and flow of the system, and considering the operating condition and execution plan of the whole system. So, the most fundamental thing is to determine the pressure and flow of the system.

#### 3.1.3.2.1 Pressure calculation.
The system plans to use four hydraulic cylinders. The external load on each piston rod includes working load $F_w$, the friction of guide $F_f$ and inertial forces $F_a$ caused by the change of speed.

$$ F_w = G / 2 $$

In the form, $G$ is a quarter of total weight of vehicle body, bogies and the track, take 40t for example.

$$ F_f = \mu (G + F_a) $$

$\mu$ is the friction coefficient, 0.05-0.08.

The positive pressure (N) is external load $F_w$ acts on the piston rod

$$ F_w = \frac{G \Delta v}{g \Delta t} $$

Average=0.5~1.5 $m / s^2$.

Calculate the external load of the hydraulic cylinder according to the above

$$ F_w = F_g + F_f + F_a \approx 55KN $$

| Load/KN | Working pressure/MPa | Load/KN | Working pressure/MPa |
|---------|----------------------|---------|----------------------|
| <5      | <0.8-1               | 10-20   | 2.5-3                |
| 5-10    | 1.5-2                | 20-30   | 3-4                  |
| 30-50   | 4-5                  | >50     | >5                   |

According to table 1, the system working pressure is selected 5mpa.

#### 3.1.3.2.2 Flow calculation.
According to the system working pressure 5MPa, select $d/D=0.62$ $d=99.2$ $D=160mm$, flow calculated:
\[ Q_{\text{max}} = A \cdot V_{\text{max}} = \pi \left( \frac{D}{2} \right)^2 \cdot V_{\text{max}} \]  

(7)

In order to ensure the safety and stability of the testing, the value of \( V_{\text{max}} \) is 0.001 m/s, so that \( Q_{\text{max}} = 0.2 \times 10^{-3} \text{m}^3/\text{s} \). In total, the hydraulic component can be selected based on working pressure and flow of the system, which is no longer detailed here.

3.2. Mechanical execution system design and safety device design

The function of mechanical execution and safety device is to realize lifting and falling of vehicle body, bogies and tracks, and ensure safety. Based on the above functions, the mechanical system is shown in figure 3.

When lifting, the hydraulic arm (7) extends, the track (5) combined with beam support (6) below rotated together relative to the fixed pivot (A). In the process of rotation, the vehicle body (2) and the bogies (3) are also be lifted. The height of the vehicle (2) and bogies (3) is different due to the presence of coefficient of flexibility. It is measured by the superelevation measuring ruler on the floor and the infrared ranging sensor (8) under the beam. In order to eliminate the safety hazards of car capsizing, the safety device ring (9), safety device chain (10) and bogie safety belt (11) are installed specially. Put bogie safety belt (11) on the lifting side of four axles of the bogie before lifting, through the ring on the bottom of the beam (5) and lock it, then one end of the safety chain (10) is fixed in the safety device ring, the other end fixed on the ground. The safety allowance is determined by the lifting height.

![Figure 3. Mechanical execution system and safety](image)

The variable gauge can be solved by the installation of track and foundation, which is implemented through the cross groove.

4. Test contrast

Take a railway vehicle project as example, according to the test method using the original test device, the test site as shown in figure 4 and figure 5, and the results are shown in table 3.
Figure 4. Original test method (1)

Figure 5. Original test method (2)

Table 2. Results of original test method

| Case | Simulate superelevaion D(mm) | Value from track superelevation measuring ruler E(mm) | $\delta$(rad) | $\eta$(rad) |
|------|------------------------------|--------------------------------------------------------|--------------|------------|
| 0    | ---                          | ---                                                    | ---          | ---        |
| AW0  | 50                           | 51                                                     | 0.0333       | 0.0036     |
|      | 75                           | 87                                                     | 0.0500       | 0.0120     |
|      | 100                          | 112                                                    | 0.0667       | 0.0128     |

$$S = \sum_{i=1}^{n} \eta_i \delta_i = \frac{\sum_{i=1}^{n} \eta_i \sum_{i=1}^{n} \delta_i}{n}$$

$$\sum_{i=1}^{n} \delta_i^2 = \frac{(\sum_{i=1}^{n} \delta_i)^2}{n}$$
| Case | Simulate superelevation D(mm) | Infrared ranging sensor \( h_1 \) (lifting side) | Infrared ranging sensor \( h_2 \) | \( \delta \) (rad) | \( \eta \) (rad) |
|------|-----------------------------|-----------------------------------------------|---------------------------------|-----------------|-----------------|
| 0    | —                           | —                                             | —                               | —               | —               |
| 50   | —                           | —                                             | —                               | 0.0333          | 0.0036          |
| 75   | —                           | —                                             | —                               | 0.0500          | 0.0120          |
| 100  | —                           | —                                             | —                               | 0.0667          | 0.0128          |
| 120  | —                           | —                                             | —                               | 0.0800          | 0.0148          |
| AW0  | 100                         | —                                             | —                               | 0.0667          | 0.0114          | 0.213           |
| 75   | —                           | —                                             | —                               | 0.0500          | 0.0106          |
| 50   | —                           | —                                             | —                               | 0.0333          | 0.0050          |
| 0    | —                           | —                                             | —                               | —               | —               |

\[
\sum_{i=1}^{n} \delta_i = \sum_{i=1}^{n} \eta_i \delta_i \left( \sum_{i=1}^{n} \eta_i \right)^2 - \left( \sum_{i=1}^{n} \delta_i \right)^2 \frac{1}{n}
\]

| \( \sum_{i=1}^{n} \) | — | — | 0.3800 | 0.0702 |
5. Conclusion
The system achieves the simulation of track superelevation by making the hydraulic system and mechanical system integrated. $h_1$ in figure 1 is equal to the value of infrared ranging sensors (8) in figure 3, $h_2$ also use value E from superelevation measuring ruler, calculate the coefficient of flexibility based on Formula (1). This paper mainly introduces the new developed system after considering the risks of the original test method. In addition to the result of coefficient of flexibility, the system also has the advantages of simple structure, easy installation, convenient operation and high measuring precision. The track distance, wheelbase and biaxial distance are all variable. It also saves manpower and effectively eliminates safety hazards.

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