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Original scientific paper

# Study on Dynamic Creep Characteristics of Conical Rubber Primary Springs in Rail Vehicles

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**Abstract:** The bogie is an important guarantee for the safe operation of the train, and the primary suspension device is an important component of the bogie, connecting the wheel axle device and the frame, transmitting the vertical force of the train, absorbing the vertical vibration energy during train operation, and ensuring the smoothness of train operation. As an important form of suspension system for subway vehicles, conical rubber springs are prone to dynamic creep under repeated vertical forces during long-term use. This article adopts the method of real vehicle testing to regularly measure the height of a series of rubber springs on two selected test trains for a period of 39 months. The dynamic creep of the conical rubber springs is found to be between 0.17-0.18 cm/$10^3$ km. This conclusion provides a reference for railway departments to choose the timing of cushion work and determine the reserved amount for height adjustment, further ensuring the safety of train operation.

**Keywords:** dynamic creep; primary suspension; rubber springs; subway vehicles

## 1 INTRODUCTION

At present, the viscoelasticity of rubber is widely used in the design of urban rail vehicles to achieve functions such as vibration isolation, buffering, and noise reduction. Among them, the conical laminated rubber primary spring has been widely used in the design of running gear due to its simple production, compact structure, and ability to achieve linear low stiffness under low loads. However, the conical laminated rubber spring also has its own inherent disadvantages, especially in terms of the dynamic and static creep performance of the rubber spring, which needs to be paid attention to during use because its creep amount is large, and it is difficult to grasp all the performance in design and testing. Improper parameter selection can easily lead to reverse S-curves or an increase in derailment coefficient when the curve passes through due to creep affecting the suspension height of the system. The appearance of the conical rubber spring is shown in Fig. 1.

**Figure 1** Conical rubber first series spring for subway vehicles

The *Railway Transportation - Primary Rubber Spring Suspension General Technical Requirement* defines the meaning of static creep, clarifies the static creep performance of a series of conical rubber springs, explains the static creep test method and stability judgment conditions. But there is no explanation or clarification on the dynamic creep of the conical rubber spring system [1]. The "Determination of Creep of Vulcanized Rubber in Compression or Shear States" introduces a measurement method for the creep of rubber in compression or shear states, but the first research object is not the rubber primary spring, and the dynamic working conditions of repeated vertical forces are not considered [2]. The General Technical Conditions for Rubber Elastic Components Used in Locomotives and Rolling Stock specifies the content of type tests for rubber elastic components, but does not explain the law of creep generation [3].

There is relatively little research conducted by domestic and foreign scholars on the vertical creep law of conical rubber primary springs, and most of them are simulation or experimental studies conducted under static conditions. Miao Huiyong et al. studied the causes and development laws of creep in metal rubber composite axle box springs. The results showed that 80% of the creep that occurred in the first two years of the use of conical rubber primary springs in rail vehicles was concentrated, and could reach about 6mm. Such creep may need to be compensated for by adding pads to the rubber springs. Miao Huiyong et al. also analyzed the impact of creep of conical rubber spring products on the operational quality of rail vehicles, and explored engineering methods and assembly measures to reduce product creep [4]. Rong Jigang et al. used finite element analysis technology to perform finite element calculations on the vertical stiffness characteristics and vertical creep of rubber axle box springs. The research results showed that the creep of a series of conical rubber springs increases with the increase of load and has a certain linear relationship [5]. Starting from the requirements of bogies and complete vehicles, Liu Jianxun introduced the characteristics and application of three suspension devices: V-shaped springs, conical springs, and a series of positioning nodes, and elaborated on their technical key points [6]. Nie Xianpeng et al. conducted research on the stiffness variation characteristics of a series of rubber springs, but did not further explore the creep characteristics [7]. Scholars have also conducted research on the performance and application problems of different types of primary springs [8].

This article studies the law of downward creep of conical primary springs under dynamic loads on running trains, providing reference for railway departments to determine the creep cycle of primary springs and make decisions on whether to add pads and the thickness of pads.

## 2 RESEARCH METHOD

### 2.1 Data Acquisition

This article adopts the research method of real vehicle testing, selects trains in practical use as the research object, and continuously tracks and measures the suspension height of a series of vehicles after they enter the warehouse, in order to explore the law of vertical creep.

In the study, it was found that the height maintained by rubber conical springs is a random height that stays within a certain range. The suspension height measured from this is a series of discrete values that cannot directly show the trend of change in time. In general, if it is necessary to measure the creep behavior of a conical rubber spring, it must be removed during bogie maintenance to measure the remaining height of the spring, that is, the free height of the spring after being compressed. However, for trains that have not yet reached the bogie maintenance cycle during operation, this approach is both cumbersome and uneconomical, and it will further increase the workload of the railway department.

In the research process of this article, a fixed two column rail transit vehicle was selected as the research object. Over a period of 39 months, the height of the suspension springs of the entire train series was continuously tracked and measured to obtain the original data for the study. The timing of data collection for the first test train is shown in Tab. 1, and the timing of data collection for the second test train is shown in Tab. 2.

**Table 1** Timing of data collection for 1st test train

| **Measurement sequence** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| **Operating mileage / $10^3$ km** | 8.219 | 10.539 | 17.906 | 21.673 | 27.537 | 37.972 | 46.308 | 61.163 |
| **Measurement sequence** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| **Operating mileage / $10^3$ km** | 76.212 | 91.027 | 104.589 | 119.291 | 134.022 | 150.460 | 163.502 | 179.306 |
| **Measurement sequence** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** |
| **Operating mileage / $10^3$ km** | 193.423 | 205.009 | 218.650 | 236.959 | 254.242 | 271.443 | 287.291 | 298.276 |

**Table 2** Timing of data collection for 2ndtest train

| **Measurement sequence** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| **Operating mileage / $10^3$ km** | 15.070 | 27.500 | 33.761 | 44.576 | 49.589 | 52.824 | 59.180 | 73.743 |
| **Measurement sequence** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| **Operating mileage / $10^3$ km** | 88.788 | 103.576 | 115.988 | 129.397 | 143.210 | 159.747 | 173.202 | 182.906 |
| **Measurement sequence** | **17** | **18** | **19** | **20** | **21** | **22** | | |
| **Operating mileage / $10^3$ km** | 187.669 | 214.567 | 230.471 | 243.540 | 260.824 | 276.001 | | |

### 2.2 Data Processing Methods

To address the impact of random vehicle parking on the study of vertical creep laws, this paper uses the least squares method to handle the errors in the calculation results. Firstly, choose two methods: linear fitting and hyperbolic fitting, compare the data processing results, and then select the method that is more conducive to result analysis for subsequent research.

(1) Linear fitting

The straight line fitting method is as follows:

$$H_i = \frac{x_i\left(\sum_{i=1}^{n} x_i \cdot \sum_{i=1}^{n} y_i - n \cdot \sum_{i=1}^{n} x_i y_i\right)}{\left(\sum_{i=1}^{n} x_i\right)^2 - n \cdot \sum_{i=1}^{n} x_i^2} + \frac{\sum_{i=1}^{n} x_i \cdot \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i^2 \cdot \sum_{i=1}^{n} y_i}{\left(\sum_{i=1}^{n} x_i\right)^2 - n \cdot \sum_{i=1}^{n} x_i^2}$$

Among them, $x$ is the measurement order, n is the maximum number of measurements. In this study, the first train was measured 24 times, so $n = 24$, and the second train was measured 22 times, so $n = 22$. $y$ is the measured data, and $H_i$ represents the suspension height of the first series after reducing the impact of random vehicle stops on vertical height, which is the research object of this paper.

(2) Hyperbolic fitting

The hyperbolic fitting method is as follows:

$$H_i = e^b t_i^k$$

$$b = \frac{\sum_{i=1}^{n} y_i - k \cdot \sum_{i=1}^{n} x_i}{n}$$

$$k = \frac{\sum_{i=1}^{n} y_i - k \cdot \sum_{i=1}^{n} x_i}{\sum_{i=1}^{n} x_1^2 - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n}}$$

The $t_i$ in the above equation is the measurement order, and the two trains have different measurement times, so the maximum values of $t_i$ are also different, which are 24 and 22, respectively. The meanings represented by $x$ and $y$ are the same as when fitting a straight line.

### 2.3 Measurement Point Setting

In this study, any two columns of a certain type of rail vehicle are selected as the research objects. Over a period of 39 months, the height of the suspension springs of the two trains was continuously tracked and measured. Both trains were composed of six cars, with two bogies per car and four suspension springs per bogie. There were a total of 48 suspension springs per train, and a total of 96 measurement points were included in the study.

For the convenience of research, the measuring points are uniformly numbered according to the train direction. Firstly, the measuring points of test train 1 are numbered from car 1 to car 6, from the 1st end to the 2nd end, and from the 1st side to the 2nd side. Then, the measuring points of test train 2 are consecutively numbered using the same method. Fig. 2 shows a schematic diagram of the numbering rules for measuring points of one vehicle. The correspondence between the measuring point numbers and their locations is shown in Tab. 3.

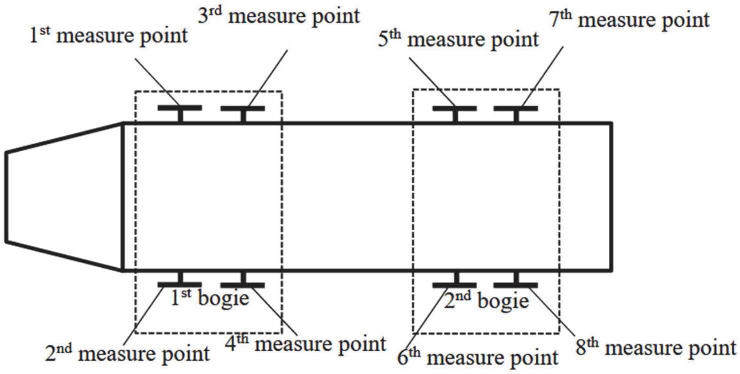



**Figure 2** Schematic diagram of the 1st vehicle measurement point numbering rule for the 1st test train

**Table 3** Correspondence between measurement point number and location

| 1st test train | 1st vehicle | | 2nd vehicle | | 3rd vehicle | |
|---|---|---|---|---|---|---|
| **Bogie number** | **1st bogie** | **2nd bogie** | **1st bogie** | **2nd bogie** | **1st bogie** | **2nd bogie** |
| **Measurement point number** | 1-4 | 5-8 | 9-12 | 13-16 | 17-20 | 21-24 |
| **1st test train** | **4th vehicle** | | **5th vehicle** | | **6th vehicle** | |
| **Bogie number** | **1st bogie** | **2nd bogie** | **1st bogie** | **2nd bogie** | **1st bogie** | **2nd bogie** |
| **Measurement point number** | 25-28 | 29-32 | 33-36 | 37-40 | 41-44 | 45-48 |
| **2nd test train** | **1st vehicle** | | **2nd vehicle** | | **3rd vehicle** | |
| **Bogie number** | **1st bogie** | **2nd bogie** | **1st bogie** | **2nd bogie** | **1st bogie** | **2nd bogie** |
| **Measurement point number** | 49-52 | 53-56 | 57-60 | 61-64 | 65-68 | 69=72 |
| **2nd test train** | **4th vehicle** | | **5th vehicle** | | **6th vehicle** | |
| **Bogie number** | **1st bogie** | **2nd bogie** | **1st bogie** | **2nd bogie** | **1st bogie** | **2nd bogie** |
| **Measurement point number** | 73-76 | 77-80 | 81-84 | 85-88 | 89-92 | 93-96 |

## 3 RESULT ANALYSIS
### 3.1 Measurements

Due to the large amount of measurement data, this article only displays some actual measurement data. Tabs. 4 and 5 show the actual measurement data of the 1st bogie and 2nd bogie suspension spring heights for the 1st vehicle of the 1st test train.

Tabs. 6 and 7 show the actual measurement data of the 1st bogie and 2nd bogie suspension spring heights for the 1st vehicle of the 2nd test train. As can be seen from the data, the measurement results are a series of discrete values.

**Table 4** Actual measurement data of suspension spring height at each axle of the 1st bogie of the 1st vehicle in the 1st test train (unit: cm)

| **Measurement sequence / Axis position** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 49 | 51 | 55 | 53 | 54 | 54 | 52 | 51 | 51 | 51 | 52 | 55 |
| 2 | 54 | 55 | 52 | 53 | 53 | 55 | 52 | 53 | 51 | 55 | 53 | 53 |
| 3 | 48 | 53 | 52 | 52 | 54 | 53 | 51 | 52 | 53 | 51 | 54 | 55 |
| 4 | 54 | 53 | 54 | 54 | 53 | 54 | 52 | 54 | 51 | 52 | 52 | 51 |
| **Measurement sequence / Axis position** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** |
| 1 | 53 | 48 | 52 | 48 | 50 | 54 | 53 | 50 | 50 | 53 | 52 | 50 |
| 2 | 54 | 48 | 49 | 50 | 50 | 53 | 53 | 50 | 51 | 51 | 54 | 51 |
| 3 | 53 | 49 | 50 | 51 | 52 | 52 | 51 | 54 | 50 | 51 | 51 | 50 |
| 4 | 54 | 50 | 51 | 50 | 50 | 53 | 51 | 51 | 51 | 51 | 53 | 50 |

**Table 5** Actual measurement data of suspension spring height at each axle of the 2nd bogie of the 1st vehicle in the 1st test train (unit: cm)

| **Measurement sequence / Axis position** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 50 | 52 | 51 | 53 | 55 | 53 | 52 | 50 | 50 | 52 | 52 | 54 |
| 6 | 50 | 51 | 50 | 52 | 53 | 53 | 50 | 52 | 49 | 54 | 50 | 54 |
| 7 | 51 | 52 | 52 | 52 | 52 | 54 | 51 | 51 | 51 | 51 | 52 | 55 |
| 8 | 52 | 53 | 51 | 52 | 51 | 53 | 51 | 54 | 49 | 51 | 51 | 53 |
| **Measurement sequence / Axis position** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** |
| 5 | 53 | 48 | 52 | 49 | 51 | 52 | 51 | 53 | 49 | 52 | 51 | 51 |
| 6 | 54 | 49 | 53 | 50 | 50 | 53 | 51 | 56 | 50 | 49 | 52 | 51 |
| 7 | 53 | 48 | 53 | 49 | 50 | 53 | 50 | 54 | 51 | 50 | 51 | 51 |
| 8 | 53 | 47 | 51 | 48 | 50 | 53 | 50 | 52 | 50 | 48 | 52 | 52 |

**Table 6** Actual measurement data of suspension spring height at each axle of the 1st bogie of the 1st vehicle in the 2nd test train (unit: cm)

| Measurement sequence / Axis position | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 53 | 54 | 54 | 54 | 55 | 53 | 53 | 51 | 51 | 53 | 54 |
| 2 | 53 | 51 | 51 | 53 | 54 | 54 | 53 | 51 | 51 | 54 | 54 |
| 3 | 55 | 55 | 54 | 53 | 55 | 56 | 55 | 50 | 54 | 52 | 56 |
| 4 | 53 | 52 | 53 | 54 | 54 | 56 | 55 | 51 | 51 | 54 | 54 |
| **Measurement sequence / Axis position** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** |
| 1 | 53 | 52 | 49 | 49 | 51 | 51 | 50 | 53 | 51 | 49 | 51 |
| 2 | 53 | 53 | 50 | 51 | 52 | 50 | 51 | 56 | 54 | 47 | 52 |
| 3 | 54 | 52 | 51 | 50 | 54 | 52 | 52 | 54 | 51 | 49 | 52 |
| 4 | 53 | 53 | 52 | 51 | 52 | 51 | 51 | 54 | 54 | 48 | 52 |

**Table 7** Actual measurement data of suspension spring height at each axle of the 2nd bogie of the 1st vehicle in the 2nd test train (unit: cm)

| Measurement sequence / Axis position | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 52 | 51 | 51 | 56 | 54 | 54 | 53 | 51 | 51 | 52 | 54 |
| 6 | 55 | 54 | 50 | 55 | 56 | 54 | 54 | 51 | 52 | 51 | 55 |
| 7 | 52 | 52 | 52 | 55 | 53 | 55 | 53 | 51 | 52 | 51 | 54 |
| 8 | 55 | 55 | 50 | 55 | 55 | 55 | 52 | 51 | 52 | 50 | 55 |
| **Measurement sequence / Axis position** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** |
| 5 | 52 | 52 | 49 | 49 | 50 | 50 | 50 | 53 | 50 | 49 | 51 |
| 6 | 53 | 51 | 52 | 49 | 52 | 51 | 50 | 54 | 51 | 50 | 51 |
| 7 | 51 | 51 | 50 | 50 | 51 | 51 | 51 | 53 | 52 | 48 | 52 |
| 8 | 52 | 51 | 53 | 50 | 51 | 52 | 51 | 56 | 52 | 50 | 52 |

The main reasons for the random distribution of suspension height measurement values in this series are as follows:

(1) Due to the high viscoelasticity and small elastic modulus of rubber constitutive characteristics, it undergoes significant deformation compared to metal materials when subjected to loads. When the load changes, the rubber deformation that follows the load changes has a certain lag. From a macroscopic perspective, it is manifested as large viscous damping within the rubber component and deformation changing over time after unloading, resulting in varying suspension heights. This is also the reason why rubber elastic components can effectively isolate and reduce noise.

(2) Due to the differences in vibration and changing loads during the operation of rail vehicles, such as curve passing, uneven tracks, temperature changes, etc., the first series of rubber springs in the four axle boxes of the bogie are at different heights when the vehicle stops running.

(3) Determined by the operational and structural characteristics of rail vehicles, such as differences in the load transmitted to the bogie frame through secondary suspension, uneven weight distribution of the vehicle body, differences in the effect of braking on the wheelset, and significant differences in the load of each conical rubber spring in the three directions of the primary suspension, the height of the primary suspension varies from measurement to measurement.

Therefore, without disassembling the vehicle, the measurement value of the suspension height of the first series is subject to various influencing factors and has a certain degree of randomness. By measuring the height of a suspension system, it is not possible to intuitively determine the changes in creep. However, due to the direct influence of the height of the primary cone spring on this value, there is a high correlation with it. Through appropriate data processing, trends and values reflecting changes in creep can be obtained.

### 3.1 Method Select

Fig. 3 shows the comparison between the actual measurement values of the 4th Axis position of the 1st vehicle in the 1st test train and the fitted curve. As can be seen from the figure, the straight line fitting shows good linearity, but the curve fitting cannot fully demonstrate the curve performance.

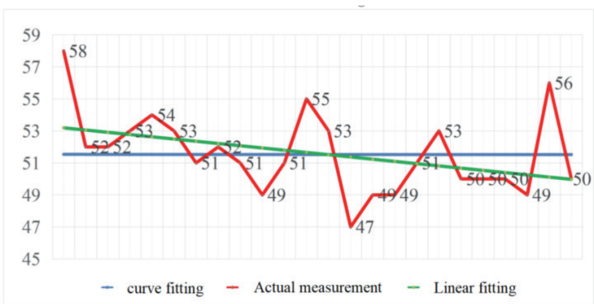



**Figure 3** Comparison between the 4th axis position measurement and fitting curve of the 1st vehicle in the 1st test train

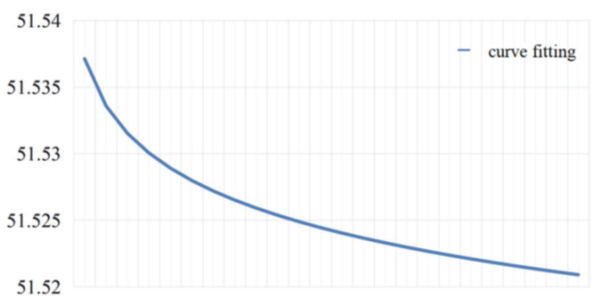



**Figure 4** Fitting diagram of the 4th axis curve of the 1st vehicle during the 1st test train

To better observe the curve fitting results, the curve fitting image was enlarged separately, as shown in Fig. 4. As shown in the figure, there is a clear curve characteristic throughout the entire measurement cycle, but the longitudinal amplitude is small. The fitted data is between 51.52-51.54 cm, and the trend of change is not obvious, which is not conducive to data analysis. The analysis results have little guiding significance for railway field.

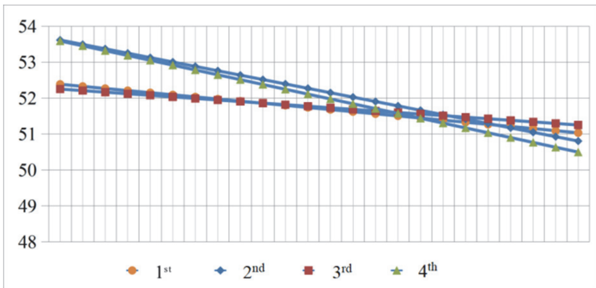
In summary, in this study, the linear fitting method was used to investigate the dynamic creep behavior of a series of springs.

### 3.3 Research on Linear Fitting

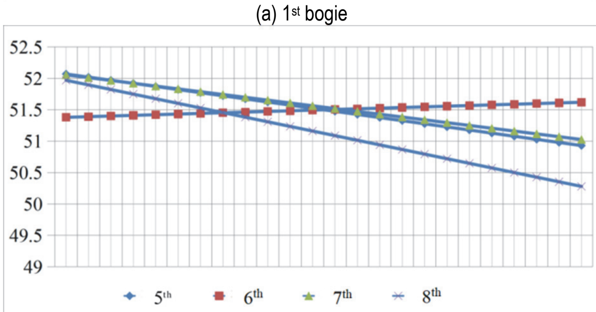
As mentioned earlier, there is a certain degree of randomness in the measurement values of suspension height. If the rail vehicle, measuring tools, and measuring personnel are regarded as a measuring system, based on the structural characteristics of the rail vehicle, the measurement values are superimposed with random factors such as the height variation of the spring under a certain load, creep, and the true value of the spring height at the time of measurement. The change trend of the measured value is consistent with the change trend of the creep deformation of the conical rubber spring. According to the analysis of the data fitting conditions, the fitting curve of the measured value can also be regarded as the change curve of the creep deformation of the conical rubber spring.

To this end, binomial line fitting is used to observe the trend of measurement data changes, followed by power exponential function curve fitting to compare and confirm the trend value of creep changes.

The binomial line fitting using the least squares method is shown in Figs. 5 to 16.

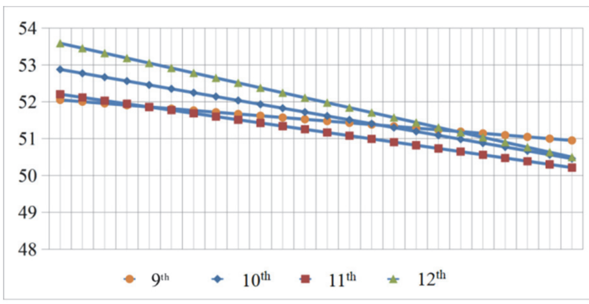



(a) 1st bogie

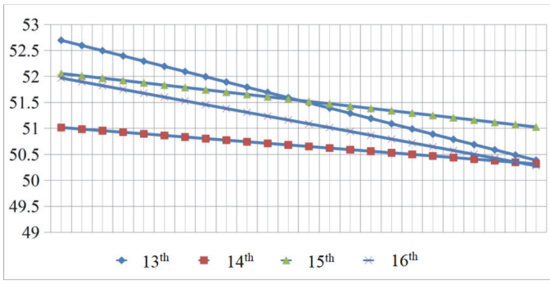



(b) 2nd bogie

**Figure 5** Line fitting of 1st vehicle measured values for the 1st test train

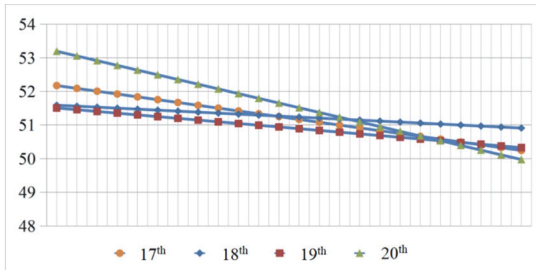



(a) 1st bogie

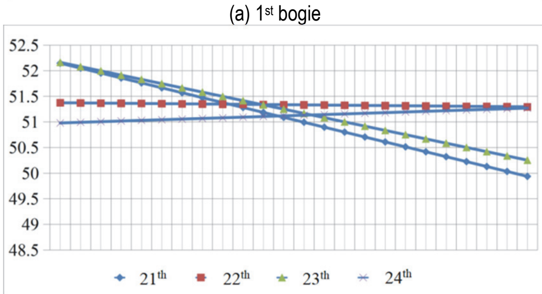



(b) 2nd bogie

**Figure 6** Line fitting of 2nd vehicle measured values for the 1st test train

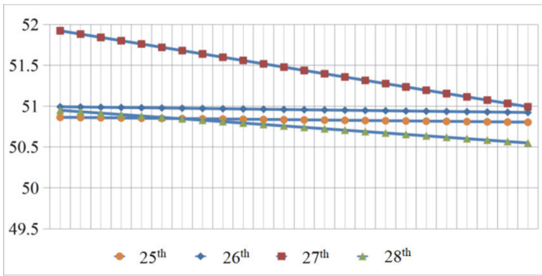



(a) 1st bogie

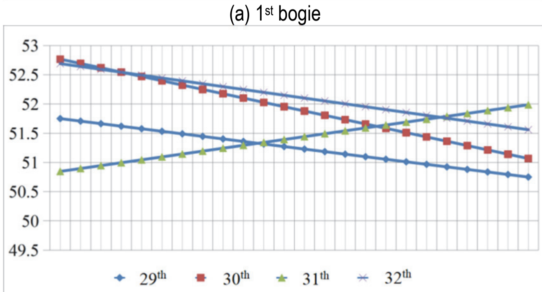



(b) 2nd bogie

**Figure 7** Line fitting of 3rd vehicle measured values for the 1st test train

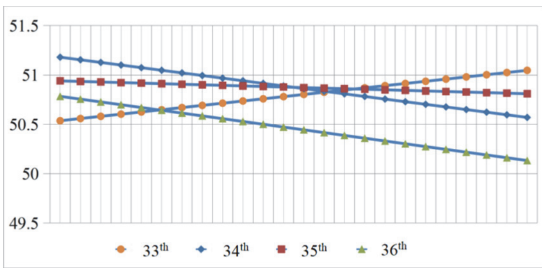



(a) 1st bogie

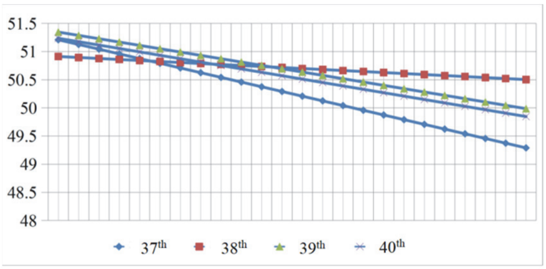



(b) 2nd bogie

**Figure 8** Line fitting of 4th vehicle measured values for the 1st test train

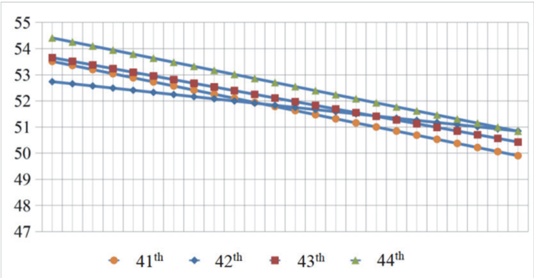



(a) 1st bogie

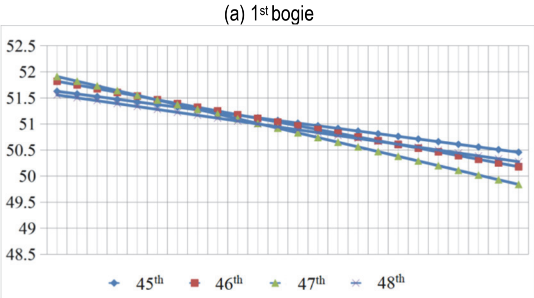



(b) 2nd bogie

**Figure 9** Line fitting of 5th vehicle measured values for the 1st test train

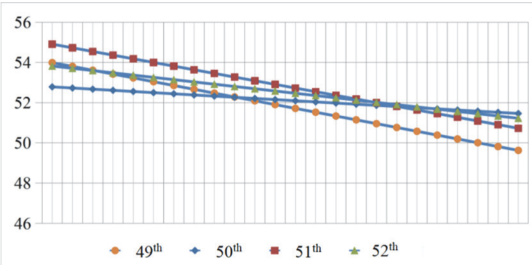



(a) 1st bogie

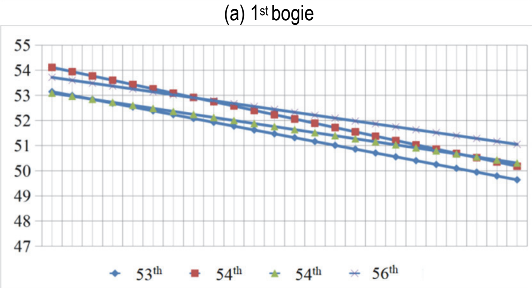



(b) 2nd bogie

**Figure 10** Line fitting of 6th vehicle measured values for the 1st test train

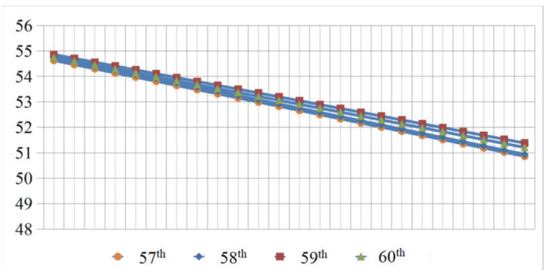



(a) 1st bogie

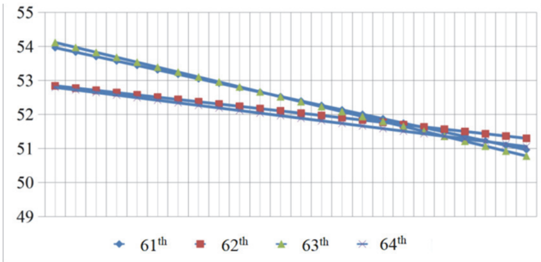



(b) 2nd bogie

**Figure 11** Line fitting of 1st vehicle measured values for the 2nd test train

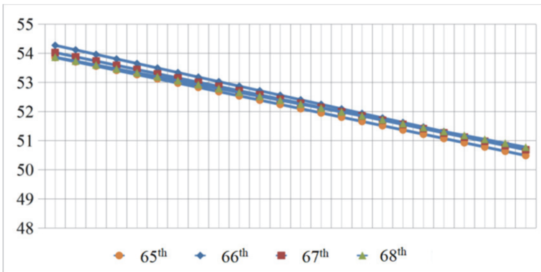



(a) 1st bogie

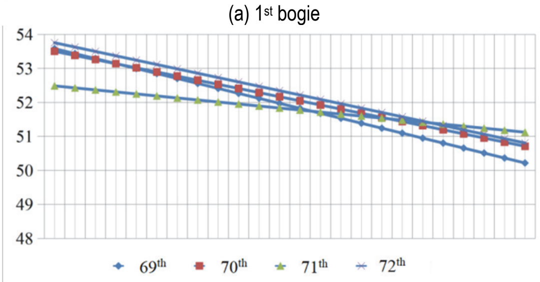



(b) 2nd bogie

**Figure 12** Line fitting of 2nd vehicle measured values for the 2nd test train

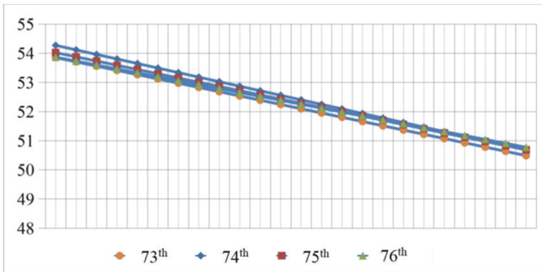



(a) 1st bogie

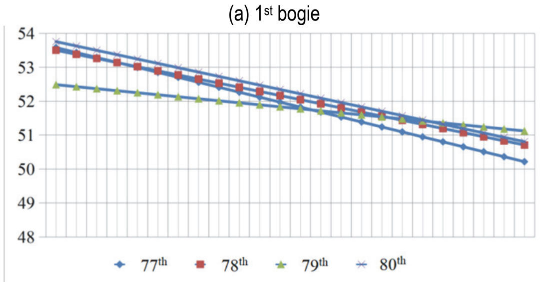



(b) 2nd bogie

Figure 13 Line fitting of 3rd vehicle measured values for the 2nd test train

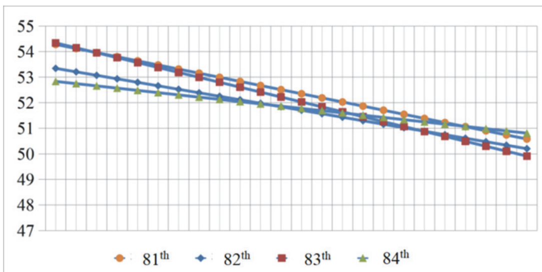



(a) 1st bogie

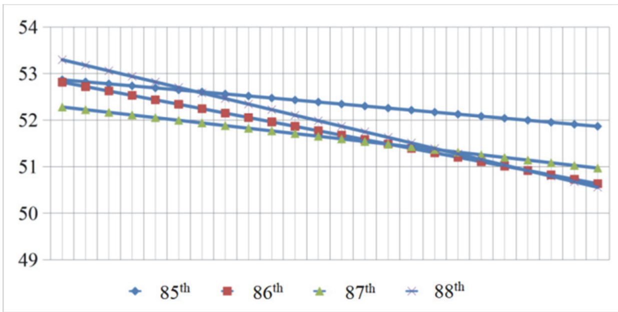



(b) 2nd bogie

**Figure 14** Line fitting of 4th vehicle measured values for the 2nd test train

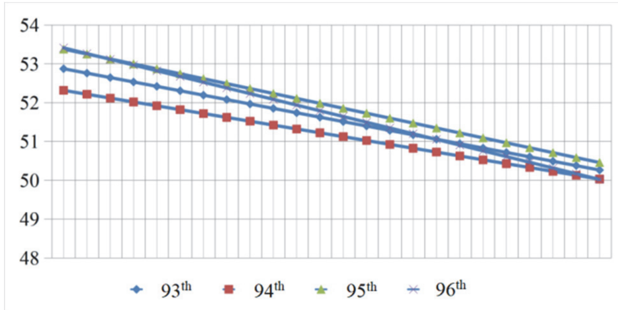



(a) 1st bogie



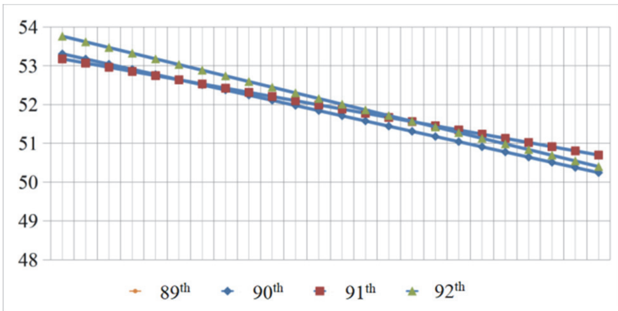

(b) 2nd bogie

**Figure 15** Line fitting of 5th vehicle measured values for the 2nd test train




(b) 2nd bogie

**Figure 16** Line fitting of 6th vehicle measured values for the 2nd test train




(a) 1st bogie

It can be seen that there is a significant trend in the measured values of the height suspension system:

(1) Overall, as the train running time increases, the height of the conical rubber primary spring gradually decreases;

(2) The height of a series of springs at the 6-position axle end of the 1-car 2-position bogie, the 7-position axle end of the 4-car 2-position bogie, and the 1-position axle end of the 5-car 1-position bogie gradually increases with the increase of train running time. The main reason for this phenomenon is the effect of dynamic loads during train operation.

**Table 8** Creep deformation of conical rubber primary spring at each measuring point / cm/10³ km

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measurement point number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| creep rate | −0.18 | −0.18 | −0.18 | −0.17 | −0.18 | −0.18 | −0.18 | −0.17 | −0.18 | −0.17 | −0.17 | −0.18 |
| Measurement point number | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| creep rate | −0.17 | −0.17 | −0.17 | −0.17 | −0.17 | −0.18 | −0.17 | −0.17 | −0.17 | −0.18 | −0.17 | −0.18 |
| Measurement point number | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
| creep rate | −0.18 | −0.18 | −0.18 | −0.17 | −0.17 | −0.18 | −0.18 | −0.18 | −0.18 | −0.17 | −0.18 | −0.17 |
| Measurement point number | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 |
| creep rate | −0.17 | −0.17 | −0.17 | −0.17 | −0.17 | −0.18 | −0.17 | −0.17 | −0.17 | −0.17 | −0.17 | −0.17 |
| Measurement point number | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 |
| creep rate | −0.17 | −0.18 | −0.18 | −0.18 | −0.18 | −0.17 | −0.17 | −0.18 | −0.18 | −0.18 | −0.18 | −0.18 |
| Measurement point number | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 |
| creep rate | −0.18 | −0.18 | −0.18 | −0.18 | −0.18 | −0.18 | −0.18 | −0.18 | −0.18 | −0.18 | −0.18 | −0.18 |
| Measurement point number | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 |
| creep rate | −0.18 | −0.18 | −0.18 | −0.18 | −0.17 | −0.18 | −0.18 | −0.18 | −0.18 | −0.17 | −0.17 | −0.18 |
| Measurement point number | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 |
| creep rate | −0.18 | −0.18 | −0.18 | −0.18 | −0.17 | −0.17 | −0.18 | −0.17 | −0.17 | −0.17 | −0.17 | −0.17 |

Extract the dynamic creep rate of a series of springs at each measuring point, as shown in Tab. 8.

As shown in Tab. 8, for every 1000 km of train operation, the creep amount of the conical rubber primary spring is approximately between 0.17-0.18 cm. The negative sign represents that the height variable of the conical rubber primary spring is negative, which means that as the train runs for more kilometers, the height of the conical rubber primary spring gradually decreases.

## 4 CONCLUSION

(1) The creep amount of the conical rubber primary spring is approximately 0.17-0.18 cm for every 1000 km of train operation.

(2) The creep deformation of a series of conical laminated rubber springs has an impact on safe operation. The creep situation can be determined by measuring the suspension height of the series. However, due to differences in operating status, loading history, temperature, and rubber constitutive characteristics, certain data processing is required on the measured values in order to obtain their changing trends and guiding values.

(3) In the comparison between straight line fitting and power exponential function fitting, it was found that the appearance of the curve fitting graph is closer to a straight line. The reason is that the first spring in use has already passed the initial stage of maximum deformation. Therefore, the power exponential function fitting graph is not much different from the straight line, but the slope

difference is large, which is consistent with the trend observed in multiple straight line fitting where the slope of the straight line gradually decreases.

(4) Under a certain load, the creep deformation of the conical rubber spring increases continuously over time, and the trend can be obtained by processing the measured values of the suspension height of the series. Based on this, during the maintenance process of rail vehicles, the trend and value of changes in the suspension height of a series of suspensions can be measured, and rubber springs that need to be padded can be selected for padding work, or corresponding specifications of spare parts can be prepared accordingly. There is no need to disassemble the rubber springs for measurement or blindly prepare accessory specifications, which effectively improves work efficiency.

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## 5 REFERENCES

[1] Standardization Administration of the People's Republic of China. (2018). *Railway transportation - Primary rubber spring suspension - General technical requirement* (GB/T 36375-2018).
[2] Standardization Administration of the People's Republic of China. (2003). *Rubber, vulcanized - Determination of creep in compression or shear* (GB/T 19242-2003).
[3] National Railway Administration of thePeople's Republic of China. (2015). *General technical requirement for rolling stock rubber to metal parts* (TB/T 2843-2015).
[4] Miao, H., Wang, M., Tian, Z., & Pan, W. (2011). Creepof metal rubber composite axle boxspring for rail vehicles. *Special Purpose Rubber Products*, *32*(5), 54-56. https://doi.org/10.16574/j.cnki.issn1005-4030.2011.05.002
[5] Rong, J., Huang, Y., Zhang, Y., & Liu, J. (2009). Research on the vertical stiffness and the creep of the primary spring. *Special Purpose Rubber Products*, *30*(2), 60-63. https://doi.org/10.16574/j.cnki.issn1005-4030.2009.02.013
[6] Liu, J. (2011). On primary suspension components for locomotive and rolling stock. *Urban Mass Transit*, *14*(1), 102-105. https://doi.org/10.16037/j.1007-869x.2011.01.019
[7] Li, L. & Long, Y. (2017). Design of axle boxspring for subway vehicle bogie. *Science and Technology Innovation Herald*, *14*(12), 35-36. https://doi.org/10.16660/j.cnki.1674-098X.2017.12.035
[8] Zhang, Y., Huang, Y., & Liu, J. (2010). Application of equivalent stress standard on optimization design of rubber component. *Electric Locomotives & Mass Transit Vehicles*, *33*(1), 32-34. https://doi.org/10.16212/j.cnki.1672-1187.2010.01.008

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