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# Compilation and Verification of FatigueLoad Spectrum ofHighSpeed Maglev VehicleSwing Rod

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**Abstract:**The purpose of this study was to construct the fatigue test load spectrum for use in the high speed maglev vehicleswing rod.Based on the measured load spectrum of the high speed maglev vehicle running gear,the relatively poor condition and location of the swing rod was determined, according to the statistics and analysis the load data of swing rod. With the rain-flow cycle quantile extrapolation, a high degree confidence load spectrum was obtained in view of the differential damage among the different tests. The eight level one-dimensional load spectrum after mean equivalent processing was established, by applying the Goodman to correct mean stress effect on the fatigue strength and life; The stresses under the loadswere calculated using the ANSYSsimulation.The fatigue life obtained from the programmed load spectrum is compared with that calculated from measured load data using Miner theory，and the accuracy and validation of the programmed load spectrum for thehigh speed maglev vehicleswing rodwere verified.

**Key words:**swing rod; load spectrum; rain-flow cycle quantile extrapolation; fatigue life;

## I. INTRODUCTION

The mechanical structure of Germany TR08high speed maglev vehicleconsists of car body and moving machine in two parts [1].As a connection key to body and suspension components, it bears complex and alternating loads under car body and moving machine at high speed,and it plays a very important role in the moving machine. The fatigue life of swing rod is directly related to the safe operation of the vehicle. However, the fatigue strength and test standard[2]-[3] of high speed maglev vehiclehas not yet formed a specification. Therefore, it is necessary to study on the load spectrum for the key components of high speed maglev vehicle, and it is of great significance to the development of the highspeed maglev vehicle.

How to compile scientific and effective load spectrum is a key factor according with realistic fatigue test. At present, the method of rain-flow counting[4]generally is used to process the complex alternating load in the fatigue test. The method of rainflow counting is in accord withthe count of elastic-plastic stress-strain hysteresis loop. Because it has a solid mechanics foundation, thus it is widely used. Due to the differences between the different test data, the differences can cause differentialdamage.With the method of the rain-flow cycle quantile extrapolation[5], multiple sets of measured dataisextrapolatedto obtain a high degree confidence load spectrum. The tests for the high speed maglev vehicle are generally carried out in a limited range, so themethod of parameter is used to obtainthe whole life load spectrum.

Based on the measured load spectrum of the high speed maglev vehicle running gear, the relatively poor condition and location of the swing rod was determined, according to the statistics and analysis the load data of swing rod.Considering the differential damage among the different tests and the effect of mean stress on the fatigue strength and life, the one-dimensional load spectrum with high confidence after mean equivalent processing was established. Finally, the accuracy and validation[6]-[7] of the programmed load spectrum for the high speed maglev vehicleswing rod were verified using the nominal stress method and Miner theory.

## II. DATA ACQUISITION AND ANALYSIS

### 2.1 Data acquisition

The secondary system of the high speed maglev vehicleis dangling types structure, as shown in figure 1, due to the structure consisting of swing rod and separatedrollpillowmakes the suspension frame has lateral freedom of motion relative to the car body, and not sticks to its vertical motion. According to the hinged connection mode of swing rod, swing rod only bears axial load.

Based on the high-speed maglev line in Shanghai, the strain gauge were pasted in the middle of swing rod to measure the strain ofsixteenswing rod of the high speed maglev vehicle by the type of full bridge, as shown in Figure 2. Test equipment using DH5929 analysis of the dynamic stress-strain testing system, sampling frequency for the 1000Hz, mainly measured end 16 swing vehicles in the line up and running 300km/h, and 430km/h Speed data.

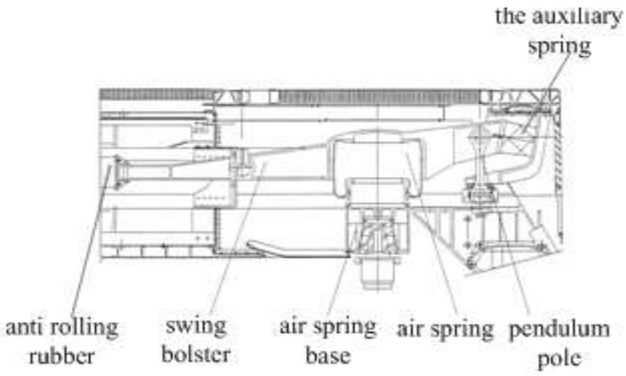
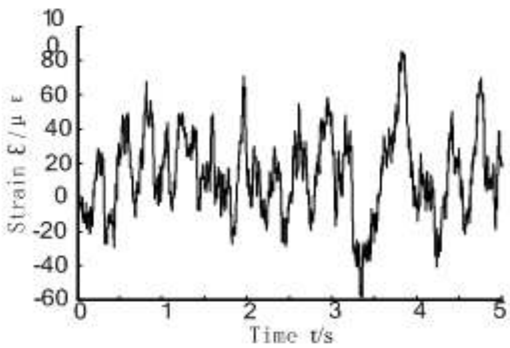



Fig.1The secondary system of the high speed maglev vehicleFig.2Arrangement of measuring points

### 2.2 Data analysis

The strains of swing rodware gained by the data acquisition system. However, due to the shielding effect of device and the influence of zero drift, the measured data often mix with a lot of noise,asshown in figure 3. To get real signal reflecting the load changes of high speed maglev vehicleswing rod, the measured data should be pretreated before data analysis. The effect of temperature on strain was eliminated by the type of full bridge.Some of data preprocessing methods were used before data analysis,such as thehigh-pass filtertoeliminatedthe zero drift trend, five point three timestoremove singular items, andunder 30Hz low pass filter to eliminate noise, after data preprocessing as shown in figure 4.



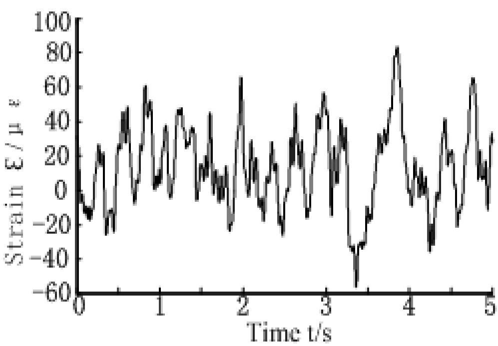




Fig.3The measured strain signal Fig.4 The strain signal after data preprocessing

## III. LOAD SPECTRUM COMPILATION

### 3.1The rain-flow cycle quantile extrapolation

The rain-flow cycle quantile extrapolation examines the difference of large amplitude load lead to the different damage among the different tests. It predicts the large load distribution in original data,according to the data set composed of small sample test data. It further improves the rain flow circulation extrapolation.

The method of rain flow count developed from the stress-strain hysteresis countwhichmakesalink between load statistical process and material fatigue characteristics, and it has apparent mechanical basis. Its main function is to simplifythe measured load to a number of load cyclesfor fatigue life estimation and load spectrumcompilation. The rain-flow counting considering the amplitude and the mean of the load,it is in accord with the inherent characteristics of the fatigue load. Because not all of the load effect on structure damage, five percent of range (maximum-minimum) of the load will be compressed by the rain-flow counting.

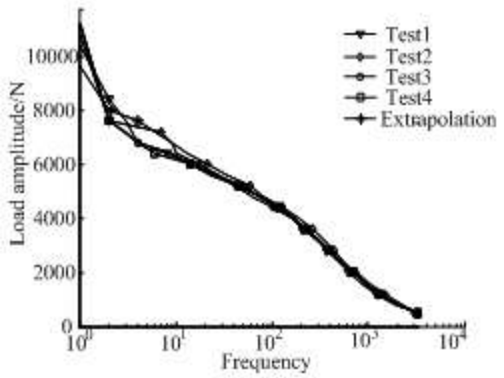
Firstly, the mean matrix *M*and the relative variance matrix *D*of the different test was calculated by the rain-flow cycle quantile extrapolation:

$$M(i,j) = \frac{1}{t}\sum_{n=1}^{t} R(i,j) \quad (1)$$

$$D = \frac{1}{M(i,j)}\sqrt{\frac{1}{t-1}\sum_{n=1}^{t}[R(i,j) - \bar{M}(i,j)]} \quad (2)$$

Here, there is a probability distribution corresponding toeach load level ( i, j). Generally, the load distribution is assumed to obey Weibull distribution, and the hypothesesneed be checked for each load level. Eventually the rani flow matrix R is extrapolated by the method of the extrapolation.

The paper aming at four test dataatthe speed 430km/h,the result of extrapolation is shown in figure 5 by the 95% quantile rain flow extrapolation.Theresultreflectsthe frequency of a minor load that has littleeffecton fatigue life is fewer changes and the frequency of a major load that has much effect on fatigue life is rather changeable. The result meetsthe differences of the major load distribution among different test. By the 95% quantile rain flow extrapolation, the result of distribution after extrapolation is shown in figure 6.



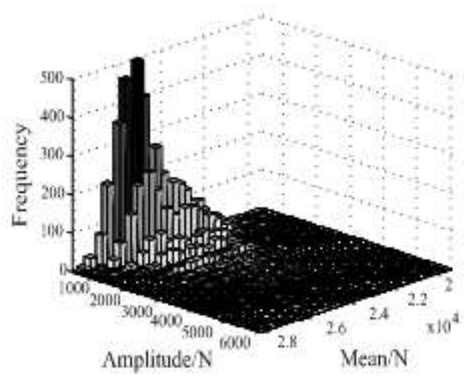




Fig.5the result of extrapolationFig.6 the result of distribution after extrapolation

### 3.2The average equivalent processing

It has an important effect on cumulative damageaccording to the research, so at the time of load spectrum compilation, the mean value need to processing by equivalent treating method to gain a high degree confidence load spectrum.The Fatigue empirical formula, Goodman, it can eliminate the effect of mean value on fatigue life.The mean stress for $S_m$ is converted to stress cycle with zero means, in accordance withGoodmanrule, the equivalent stress formula can be gained, as shown in formula 3.

$$S_i = \frac{\sigma_b S_{ai}}{\sigma_b - |S_{mi}|} (3)$$

Where $\sigma_b$isthetensile strength, $S_i$ is the equivalent stress of point i, $S_{ai}$ is the stress amplitude of point i,$S_{mi}$ is the stress mean of point i;

The material of swing rodis 6082aluminum alloy, and $\sigma_b$ is 205MPa, E is 70GPa.The formula 5can be acquired by the the formula 3 and the calibration formula4.

$$F(t) = 34.66\varepsilon(t) \quad (4)$$

$$F_i = \frac{\sigma_b F_{ai}}{\sigma_b - |(EF_{mi})/34.66|} \quad (5)$$

Where $F_i$ the equivalent load of point i, $F_{ai}$ is the load amplitude of point i,$F_{mi}$ is the load mean of point i;

The equivalent load can be obtained by the formula 5 with load amplitude and mean. The statistical results of the average equivalent processing for swing rod are shown in table 1.

Table 1 The statistical results of the average equivalent processing

| Load amplitude | Frequency | Load amplitude | Frequency |
|---|---|---|---|
| 749.4 | 4535 | 4562.8 | 5 |
| 1392.8 | 471.5 | 5234.9 | 3.5 |
| 2002.6 | 249 | 5920.6 | 0 |
| 2624.2 | 165 | 6620.3 | 0 |
| 3257.8 | 90.5 | 7334.4 | 0.5 |
| 3903.9 | 66 | 8063.5 | 0.5 |

**3.3 program load spectrum compilation**

In General, $10^6$cycles containthe worst loads that occur rarely. The frequency of load should be extrapolated to $10^6$by the parametric method.Generally, the amplitude of load obeys the three-parameter Weibull distribution.Firstly,the least squares parameter estimates and K-S testing will be applied to calculate for the amplitude of load, using the formula 6 of three parameter Weibull probability density function.The maximum load can be calculated by the formula 7 of Weibull distribution function,.

$$f(x_a) = \frac{\alpha}{\beta}\left(\frac{x_a-\varepsilon}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x_a-\varepsilon}{\beta}\right)^{\alpha}}, x_a \geq \varepsilon$$

Where $\varepsilon$isthe location parameter, $\alpha$is the scale parameter,$\beta$is the shape parameter;

$$F(x_{amax}) = \int_{x_{amax}}^{\infty} \frac{\alpha}{\beta}\left(\frac{x_a-\varepsilon}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x_a-\varepsilon}{\beta}\right)^{\alpha}} dx_a \quad (7)$$

$$x_{amax} = \varepsilon + 13.816^{\frac{1}{\alpha}}\beta \quad (8)$$

According to the statistics result of amplitude frequency, as shown in table 2. The location parameterε、scale parameters $\alpha$and shape parameters $\beta$ is 720.13、0.88、531.49respectively,which were calculated by the least squares parameter estimation and K-Stest. The maximum load is 10293.94N, which was calculated using formula 8.

Random load spectrum is simplied into eight level program load spectrumby the method of unequal interval,and the eight level program load spectrum is shown in table 2.

Table 2 The eight level program load spectrum

| Level | Load amplitude | Frequency | cumulative frequency |
|---|---|---|---|
| 1 | 1286.74 | 653400 | 1.0000E00 |
| 2 | 4374.92 | 342600 | 3.4660E-01 |
| 3 | 5919.02 | 3482 | 4.0000E-03 |
| 4 | 7463.11 | 445 | 5.1868E-04 |
| 5 | 8328.29 | 48 | 7.2900E-05 |
| 6 | 8749.85 | 11 | 2.4842E-05 |
| 7 | 9778.73 | 10 | 1.4778E-05 |
| 8 | 10293.94 | 4 | 4.2119E-06 |

**3.4 load spectrum validation**

Thefinite element model of swing rod was built using finite element analysis software ANSYS, and it has 15143 elements and 15978 nodes. The boundary conditions and measured and programmed load spectrum were defined using finite element analysis software. The stress-time history of the swing rod was calculated by ANSYS.

The fatigue life obtained from the programmed load spectrum is compared with that calculated from measured load data using Miner theory and nominal stress method，and the result of fatigue life is shown in table 3.

Table 3 the result of fatigue life

| Load type | Time | damage | Life |
|---|---|---|---|
| Measured load spectrum | 400s | 2.01e7 | 253years |
| Programmed loadspectrum | 2000s | 3.15e6 | 199 years |

The relative error of the fatigue life calculated by measured loadspectrumand the programmed load spectrum is 21.3 percent.Meetingthe demands of load spectrum compiling error. The fatigue life calculated by measured load spectrum is shorter than the fatigue life calculated by the programmed load spectrum, butthe programmed load spectrum can be easily applied to fatigue test, and it can substitute the actual load spectrum in actual fatigue test.

## IV. CONCLUSION

The paper studies to establish a high confidence level program load spectrum for high speed maglev vehicleswing rod, based on the measured load data of the highspeed Maglev vehicle. The main conclusions as follows:

1) According to the quantile extrapolation found that the frequency of a minor load that has little effect on fatigue life is fewer changes and the frequency of a major load that has much effect on fatigue life is rather changeable. A high degree confidence load spectrum was obtained by the 95% quantile rain flow extrapolation;

2) Considering the differential damage among the different tests and the effect of mean stress on the fatigue strength and life, the one-dimensional load spectrum with high confidence after mean equivalent processing was established by the fatigue empirical;
3) The validation of the equivalent load spectrum for the high speed maglev vehicle swing rod is verified using finite element analysis software ANSYS.

## V. ACKNOWLEDGEMENTS

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