Analysis of Stability and Vibration Transmission Law of Type A Metro Vehicles

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Abstract. In this paper, a dynamics test is carried out on the 120km/h type A metro vehicle, and the vibration characteristics of the car body, the bogie frame, the motor and the gearbox are respectively monitored at different speed levels of the motor car and trailer. Vibration acceleration sampling was conducted according to GB/T 5599-2019 to obtain the vehicle body's stability index and analyze the vehicle body's vibration characteristics. According to UIC518-2005, the root mean square (RMS) value of the frame lateral acceleration is used as an index to analyze the vibration characteristics of the frame. By sampling and analyzing the vibration acceleration of the motor and gear box, the rotation frequency of the motor at 95km/h and the vibration transmission frequency of the transmission system in three directions are obtained.

1. Introduction
Vibration is a cause of partial failures and component damage of rail vehicles, shortening the service life of the vehicles and thus affecting the operational effectiveness of rail transit[1]. Carrying out vibration characteristic analysis and dynamic performance analysis of the vehicle can comprehensively study the dynamic characteristics of railway vehicles[2]. Therefore, it is very necessary to monitor the vibration characteristics of the subway car body, frame, motor and gearbox before the subway is officially put into operation.

The test data collector uses the German HBM SomateDaq data acquisition system, the number of effective data channels for a single data acquisition terminal is 128, the sampling between channels is strictly synchronized, and the vibration acceleration sampling frequency is 5kHz. The stability index and the root mean square value of the acceleration are used to measure the stability of the car body and the frame[4,5]. By monitoring the vibration acceleration of the gearbox and the motor's far and near couplings, the vibration characteristics and vibration transmission rules are analyzed.

There are many vibration signal processing methods, which can be roughly divided into two categories: one is the traditional method, the typical ones include amplitude domain analysis, Fourier transform and correlation analysis. The other is modern methods, the typical ones of which include Wigner-Ville distribution, spectrum analysis, wavelet analysis[3]. This paper mainly uses Fourier transform and ‘2 meters smoothing’ data processing method to process and smooth the obtained data. The basic processing principle of the ‘2 meters smooth’ data processing method is: the data window is 2 meters long, and the vehicle vibration data within x to x+2 meters is processed as the vibration characteristic value of the vehicle at x meters.
2. Vibration Characteristics of the Car Body

The vibration acceleration sampling frequency is 2kHz. The stability index of the car body is an important index to evaluate the vibration of the car body. The calculation method of stability index and the selection of measuring point position in this paper are based on GB 5599-2019[5]. The motor car is represented by MP01, and the trailer is TC01.

Take tc01-1 measuring point and compare the lateral and vertical stability indexes of car body under different line conditions under AW0 (AW0 means “no load”) working condition, as shown in Fig. 1 and Fig. 2. When the running speed is the same, the smaller the radius of the line curve is, the larger the vehicle body's lateral and vertical stability index is; under a certain line condition, the faster the vehicle runs, the larger the vehicle body's lateral and vertical stability index is.

Take tc01-1 measuring point and compare the differences of transverse and vertical stability indexes of car body under AW0 and AW3 load in straight line condition, as shown in Fig. 3 and Fig. 4. It can be seen from the figures that under different loads, the lateral and vertical stability indicators increase with the increase of the speed; when the speed is the same, the lateral stability index under AW0 load is larger than the AW3 load, while the vertical stability index is in contrast.

3. Characteristics of Frame Vibration

The sampling frequency of the vibration acceleration signal at the end of the frame is 2000 Hz. According to UIC518-2005[4], this paper uses the RMS value of frame lateral vibration acceleration to
measure the characteristics of frame lateral vibration, and the measuring point is at the end of the frame. The RMS value of the frame lateral acceleration shall not exceed the limit:

\[ s_{Ys} < 6 \frac{M_b}{10} \]  \hspace{1cm} (1)

Where \( M_b \) is the mass of the bogie (t). When the RMS value of acceleration exceeds the limit value, the vehicle system is considered unstable.

In this paper, \( M_{bTC} = 5.270t \), \( M_{bMP} = 5.428t \). According to formula (1), the lateral acceleration limit value of TC01 vehicle frame is calculated as: \( [s_{Ys}]_{limTC} = 0.730m/s^2 \), and the lateral acceleration limit value of the MP01 vehicle frame is calculated as: \( [s_{Ys}]_{limMP} = 0.572m/s^2 \). Under the load of AW0 and AW3, the RMS of the frame lateral acceleration of the TC01 car and MP01 car under each line condition did not exceed the limit value, as a result, the frame did not appear lateral instability in this test.

The comparison of vibration characteristics of the frame under different line conditions shows in Fig.5. When the vehicle speed is the same, the smaller the radius of the line curve is, the greater the RMS value of the frame's lateral acceleration is; under a certain line condition, the faster the vehicle runs is, the greater the RMS value of the frame's lateral acceleration is.

![Fig.5. RMS value of lateral acceleration of TC01 frame_AW0](image)

The RMS value of the lateral acceleration of the motor car and the trailer frame under the different line conditions of AW0 load is taken, as shown in Table 1-3. It can be seen from Table 1-3 that under the same working conditions, the RMS values of the lateral acceleration of the motor car and the trailer frame are equal, that is, the vibration amplitudes of the motor car and the trailer frames are close.

| Speed | 70 | 80 | 90 | 100 | 110 |
|-------|----|----|----|-----|-----|
| TC01  | 0.17 | 0.19 | 0.23 | 0.27 | 0.29 |
| MP01  | 0.17 | 0.19 | 0.23 | 0.27 | 0.29 |

| Speed | 40 | 50 | 60 | 70 | 75 |
|-------|----|----|----|----|----|
| TC01  | 0.16 | 0.2 | 0.25 | 0.3 | 0.34 |
| MP01  | 0.16 | 0.2 | 0.25 | 0.3 | 0.34 |
Table 3 The RMS value of the lateral acceleration of the frame on 350-meter radius curve

| Speed | 50  | 60  | 70  | 80  | 82  |
|-------|-----|-----|-----|-----|-----|
| TC01  | 0.22| 0.28| 0.33| 0.44| 0.44|
| MP01  | 0.22| 0.28| 0.33| 0.44| 0.44|

4. Vibration Characteristics and Vibration Transmission of Motors and Gearboxes

The motor and gearbox are important components of the vehicle power and transmission system, so the normal operation of the two is very important to the normal operation of the vehicle. Monitoring the vibration of the motor and gearbox and mastering the law of vibration transmission between the motor and the gearbox will help identify abnormal vibrations of the motor and gearbox and perform fault diagnosis.

4.1 Vibration characteristics of motors and gearboxes

Vibration acceleration signals of the gear box of TC01 were sampled under AW0 load. The measuring point was directly above the gear box of axis 1, and the sampling frequency was 5000Hz. As shown in Fig.6, the amplitude of lateral vibration acceleration is greater than that of vertical and longitudinal vibration. The amplitude of lateral vibration acceleration is generally distributed within 30g, and there is impact vibration in local sections, with the maximum amplitude exceeding 40g. The amplitude of vertical and longitudinal vibration acceleration is within 20g.
In order to analyze the vibration frequency characteristics of the gearbox, this article mainly discusses the gearbox lateral vibration acceleration, as shown in the time-frequency diagram of Figure 7. The time-frequency diagram can more intuitively reflect the strength and weakness changes of various frequency signals in time.

The amplitude of lateral vibration acceleration within the frequency range of 60-100Hz is relatively large and does not change with time. Therefore, it is judged that the natural frequency of lateral vibration of the gearbox is within this frequency range. The frequency of 800-1300Hz varies with the running speed of the vehicle. There are obvious discontinuous and large vibration acceleration amplitudes in the time domain near the frequencies of 1400Hz and 850Hz, which correspond to the frequency peaks of the above-mentioned curve. It is judged that the gearbox is generated by shock vibration when the vehicle is running at a high speed.

The sampling frequency of the vibration acceleration signal of the motor is 5000Hz, and the measuring points are located at the far and near coupling of the motor respectively. Excluding the interference of electrical signals, the vertical vibration amplitude of the motor is within 5g, and the horizontal and longitudinal vibration amplitude are both within 2.5g (Fig.8).

There is little difference in the vibration acceleration between the motor's near coupling and far coupling. As shown in Fig.9, the root-mean-square amplitude of the near coupling of the motor near 60Hz is very close, so 60Hz is the motor rotation frequency when the speed is 95km/h.

4.2 Vibration Transmission of Motor and Gearbox

As the motor, gear box and axle box are structurally connected, the transmission system will produce vibration transmission when the vehicle is running, and the vibration of the three parts will affect each other. As shown in Fig.10, the vibration characteristics of the motor's near coupling and far coupling are not much different. The vertical vibration frequency of the three parts has an obvious transmission relationship around 60 Hz; the longitudinal vibration frequency of the three parts has an obvious transmission relationship around 30 Hz and 60 Hz. The motor has obvious main frequency vibration with a frequency around 60 Hz in three directions.

The speed corresponding to vibration transmission analyzed above is 95km/h, and the
corresponding wheel rotation frequency is 10Hz, motor rotation frequency is 61.1Hz, and gear box
meshing frequency is 1160Hz.

Fig.10. Vibration transmission of the transmission system

5. Conclusion
When vehicles are running at the same speed, the smaller the radius of the line curve, the greater the
vehicle body's lateral and vertical stability index; under certain line conditions, the faster the vehicle
runs, the greater the vehicle body's lateral and vertical stability index is. There is little difference in the
lateral and vertical stability indexes of the motor car and the trailer at different measuring points.

When the vehicle runs at the same speed, the smaller the radius of the line curve is, the greater the
rms value of the lateral acceleration of the frame is; under certain line conditions, the higher the
vehicle runs, the greater the rms value of the lateral acceleration of the frame is. The vibration
amplitude of the frame of the motor car and the trailer is close to each other.

The lateral natural vibration frequency of the gearbox is in the frequency range of 60-100Hz. There
is little difference between the vibration characteristics of the motor near coupling and far coupling.
61.1Hz is the motor rotation frequency at 95km/h. The longitudinal and vertical vibration frequencies
of the motor, gearbox and axle box have an obvious transmission near the motor rotation frequency;
the longitudinal vibration frequency has an obvious transmission relationship near 30 Hz.

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