Development of a system to detect malfunction by the monitoring of the air spring pressure

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A commuter train derailed at the Sagamiko station on the JR East Chuo line in September 2013, the main cause being increased wheel load unbalance caused by an automatic air spring level controlling device damaged from human contact. The railcar had been used with the damage gone undetected, and where greater vertical force unbalance occurred on a transition curve, the wheel flange climbed on the rail, and finally derailed.

To counter such accidents, authors developed of a system to detect malfunction by the monitoring of the air spring pressure. Currently, this system is installed in JR East's newer models for actual introduction, and this system has been verified by monitoring run.

keywords : wheel load unbalance, detecting malfunction, air spring pressure, diagonal unbalance, lateral unbalance

1. Introduction

A commuter train derailed at the Sagamiko station on the JR East Chuo line in September 2013, the main cause being increased wheel load (hereafter "vertical force") unbalance caused by an automatic air spring level controlling device (hereafter "air spring device") damaged from human contact. The railcar had been used with the damage gone undetected, and when greater vertical force unbalance occurred on a transition curve, the wheel flange climbed on the rail, and finally derailed. (1)

To counter such accidents, we need to introduce a system to detect air spring device malfunction in railcars, and conducted a test reproducing railcar conditions of the above mentioned accident. Through this test, we learned that diagonal unbalance occurs in air spring pressure (hereafter pressure) when an air spring device is damaged.

Therefore, we devised a method to detect air spring device malfunction by diagonal unbalance in pressure (patent applied).

Because we intend to introduce this system in newer JR East car designs, we measured and analyzed pressure, etc. from various operating trains on different lines, to determine the threshold necessary for judgment and verified the judgment algorithm.

2. Study of malfunction detection method

2･1 Air spring device Fig. 2-1 shows an outline of the automatic air spring device leveling. Normally, as load increases with number of passengers, an air spring is compressed and the car body lowers, compressed air is supplied to the air spring, and the car body rises.

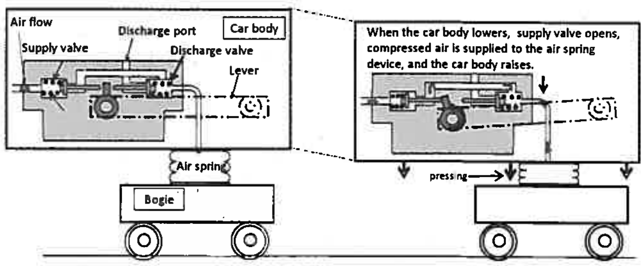

Fig. 2-1 Automatic air spring device leveling

2･2 Reproducing railcar conditions

We conducted a test reproducing railcar conditions using the railcar of the accident (see Fig. 2-2) in order to ascertain railcar conditions when the derailment accident occurs. In this accident, the air spring device on the rear bogie outer rail side (first position) of the rearmost railcar was damaged from human contact, and the following situation was brought about.

① Compressed air was supplied to the first air spring even though the car body had not lowered.

② Vertical force (hereafter "V") of the outer rail side of the rear bogie and the inner rail side of the front bogie increase because the level of the air spring at first position rose notably. (V of the inner rail side of the rear bogie and the outer rail side of the front bogie was reduced.)

③ The pressure at first position (AS1 in Fig. 2-2) and the inner rail side of the front bogie (AS4) rose. (The pressure at inner rail side of the rear bogie (AS2) and the outer rail side of the front bogie (AS3) lowered.)

For testing, we installed an air spring device on the railcar of the accident at the first position as it had been at the time, ran it at low speed along a straight section on a track in our company's General Rolling Stock Center, and measured the air spring level, pressure, V of the front bogie (3rd and 4th axels). Changes from normal conditions are shown in Table 2-1.

The level of the air spring at first position had risen considerably, and AS1 and AS4 were higher, and AS2 and AS3 were lower. (Diagonal unbalance occurred.)

In addition, since the change rate of V balance was about 40% for both the 3rd and 4th axels, we judged that railcar conditions at the time of the derailment had been the same as in this test.

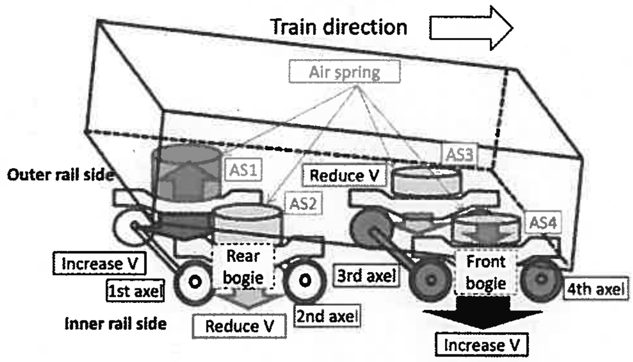

Fig. 2-2 Test reproducing railcar conditions

Table 2-1 Result of test

	1st(rear) bogie		2nd (front) bogie	
	No.1 (Outer rail side)	No.2 (Inner rail side)	No.3 (Outer rail side)	No.4 (Inner rail side)
Level change of air spring device(mm)	43	12	3	-2
Change rate of pressure	35.8%	-21.1%	-33.6%	38.8%
Axial position			3rd (rear) axel	4th (front) axel
Change rate of V balance			44.4%	41.2%

〈2・3〉 Devising index As a result of the test reproducing railcar conditions, it was found that when an air spring device is damaged, significant diagonal unbalance appears in V and pressure. It is generally difficult to monitor V, so we considered developing a method in which air spring device malfunction is found by diagonal unbalance as detected through pressure.

First, we devised "DU" as an index of diagonal unbalance (Formula (1)).

$$DU = \frac{|(AS1+AS4)-(AS2+AS3)|}{AS1+AS2+AS3+AS4} \quad \cdots \quad (1)$$

When DU is calculated in the reproducing test from formula (1), it was 0.06 in normal condition and 0.24 in the accident reproducing. From this result, it was confirmed that if an air spring device is damaged, DU changes significantly. In addition, DU calculated from the pressure recorded in the railcar of the accident was more than 0.3. Provisional threshold is set at 0.2 so that these values can be detected, and we measured pressure in operating trains. If an air spring device is damaged, we assume that the value will continue to be DU>0.2, so we believed that we could detect malfunction by grasping change of DU in normal conditions. Incidentally, we measured the pressure on 10 railcars of 4 different types.

3. Malfunction evaluation

3・1 Measurement results of operating trains As a result of measuring the pressure of operating trains, sections in which DU> 0.2 were observed in sections where the train seemed to be passing along a transition curve at low speed or when stopped.

Since car is theoretically supported at three points as it passes over a transition curve, V unbalance occurs even if normal conditions.

Transition curve where the left side in the direction of travel is on the outer rail side and the cant gradually becomes smaller is the same condition as in the reproducing test (see Fig. 2-2), and it can be assumed that DU> 0.2, but there were sections where that condition continued over long periods.

Among these, the measurement sample where the longest DU> 0.2 continued is shown in Fig. 3-1.

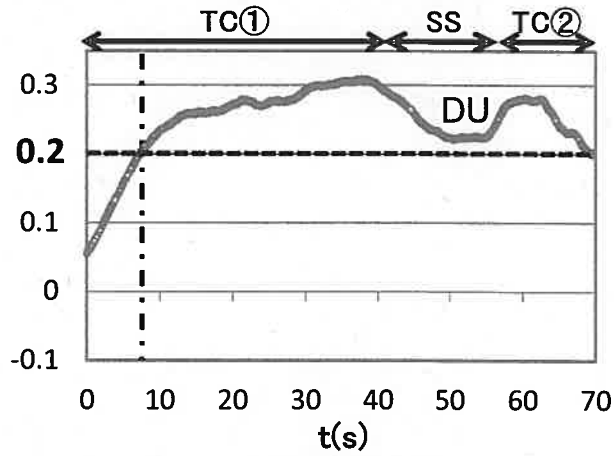

Fig.3-1 Measurement result with the longest continuation of DU> 0.2

This example is the result of the train passing over a transition curve ①(TC ①) → straight section (SS) → transition curve ②(TC ②) at low speed, where DU> 0.2 continued for about 60 seconds. From this result, it was found that change in the pressure due to the transition curve may continue even after the train has passed it.

Therefore, we considered a malfunction detection method that excludes transition curves and their area of influence.

3・2 Exclusion of transition curve influence from malfunction detection criteria As described in 3・1, it is necessary to exclude transition curves when judging malfunction by DU, but we cannot distinguish the tendencies in pressure while the train is passing over a transition curve at low speed, or stopped from when the cause is air spring device damage.

For this reason, we devised a method that uses the time taken to pass over the transition curve (hereafter "passing time") to exclude transition curves when judging malfunction by DU. Since passing time varies depending on train speed, we considered train speed range divided into 3 patterns of mid-high speed, low speed, and extremely low speed.

(1) Mid-high speed range

The mid-high speed range was set to 25 km/h or over. Passing time in the mid-high speed range is set taking into account the longest time to pass over a transition curve at 25 km/h or over, passing time is excluded when evaluating malfunction, even if DU> 0.2.

(2) Low speed range

The low speed range was set between 5 to 25 km/h. As in (1), passing time within this range is set and excluded when evaluating malfunction.

(3) Extremely low speed range

The extremely low speed range is set at 5 km/h or under, and excluded when evaluating malfunction.

Transition curves were excluded, according to the above criteria.

3・3 Exclusion of lateral unbalance When applying the method described above in 3.2, it was found that influence from transition curve continued over long periods when running on S-curves. In particular, in the case of the low speed range, this tendency appears conspicuously, and therefore, we considered a method of excluding sections where the influence of S-curves when evaluating malfunction.

Normally, if a train runs over curves at speed balanced with the cant, lateral balance of the pressure is maintained.

However, if a train is running at low speed, overtilting occurs as in Fig. 3-2, whereas at higher speeds there is a tendency of undertilting, in either case pressure will show a lateral unbalance.

Therefore, also on a transition curve, it is assumed that a lateral unbalance becomes greater when the train runs at low speed along the inner side of a circular curve, so we studied a method of excluding lateral unbalance when evaluating malfunction.

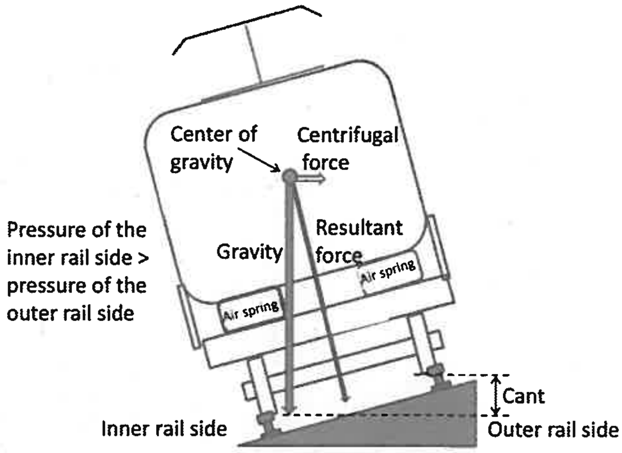

Fig. 3-2 Change in pressure (overtilt)

We devised "LU" as an index for lateral unbalance (Formula (2)).

$$LU = \frac{(AS1+AS3)-(AS2+AS4)}{AS1+AS2+AS3+AS4} \quad \cdots \quad (2)$$

An example of LU measurement is shown in Fig. 3-3.

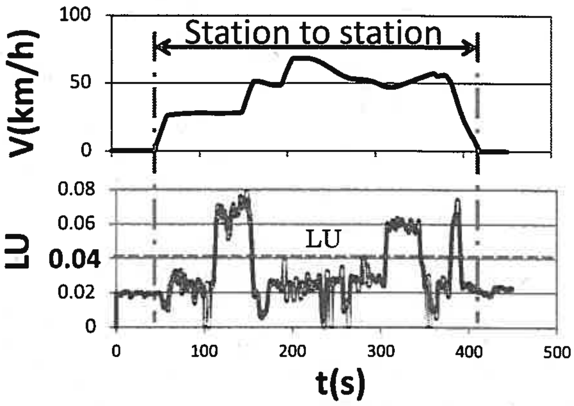

Fig. 3-3 lateral unbalance (LU)

Since |LU| is normally 0.04 or less, we decided to exclude sections where | LU |> 0.04 f when evaluating malfunction, even if DU> 0.2.

3・4 Passing time threshold We determined the passing time threshold for each speed range described in 3・2 as follows. We defined the time from the moment when DU> 0.2 and | LU |> 0.04 to the moment when DU> 0.2 and | LU | ≦ 0.04 as passing time.

As a result, passing time where DU > 0.2 was the longest (Fig. 3-1) was 28 seconds, as described later in 3・5. The passing time in the other sections is 8 seconds in the mid-high speed range and 16 seconds in the low speed range, and the passing time threshold is determined by adding the margin time.

3・5 Verification of exclusion methods

When applying the above-mentioned exclusion methods to the example of Fig. 3-1, it becomes as seen in Fig. 3-4.

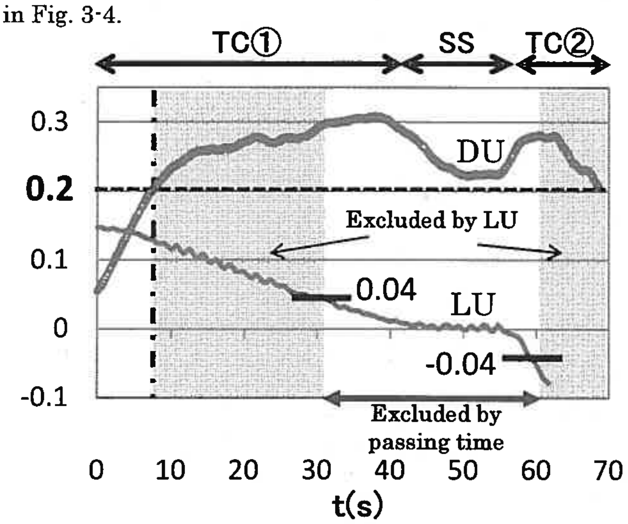

Fig. 3-4 Application of method to exclude from judgment

From Fig. 3-4, it was possible to exclude in the same way as in Fig. 3-1, so we decided that this exclusion method is valid.

〈3・6〉 Algorithms for malfunction detection Fig. 3-5 shows a flowchart for detecting malfunction of the air spring device considering 3・1 ~ 3・3.

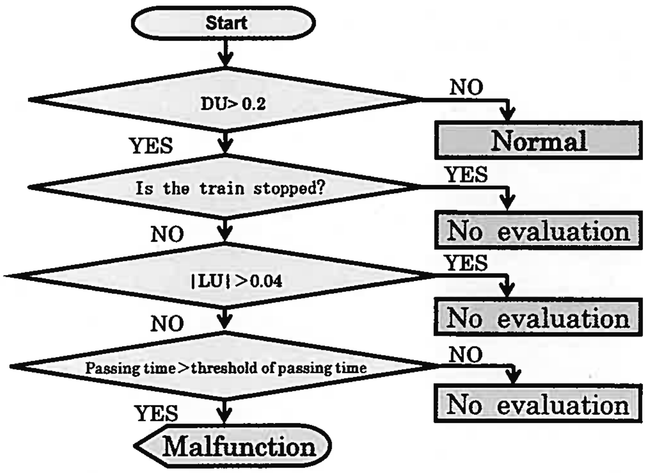

Fig.3-5 Flowchart for malfunction detection

4. Conclusion

We devised a method to detect malfunction in air spring devices by diagonal unbalance of monitoring air spring pressure, and verified it based on data of various operating trains. As a result, we obtained the following conclusions.

(1) Malfunction of an air spring device causing large wheel load unbalance (vertical force unbalance) can be detected by diagonal unbalance of air spring pressure.

(2) On a transition curve or a section where the influence of the transition curve remains, diagonal unbalance may have the same tendency as the malfunction of the air spring device. Therefore, we devised a method to exclude these sections from the judging malfunction by lateral unbalance and the time taken to pass over a transition curve according to the train speed range.

5. Postscript

Currently, this system is installed in JR East's newer models for actual introduction, and the threshold has been verified by monitoring run.

Reference:

(1) Japan Transport Safety Board, Railway Accident and Incident Report No. RA2015-5 [in Japanese] 2015.7.30