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[1.] Ioan S. SEBESAN, [2.] Marius-Ovidiu I. ENE

ASSESSMENT OF RUNNING BEHAVIOUR OF AN ELECTRIC MULTIPLE UNIT 1720 KW - MINIMUM LOAD CONDITION (RUNNING BEHAVIOR OF EMU - MINIMUM LOAD)

[1.] University "Politehnica" of Bucharest, Faculty of Transports, Department "Railway Vehicles", ROMANIA
[2.] Romanian Railway Authority, Rolling Stock Laboratory, ROMANIA

Abstract: The evaluation of running behavior for a railway vehicle is usually made on a testing railway center by direct determining the evaluation values, for instance accelerations or forces. These values are used in assessing the interaction between vehicle and track and mainly describe the wheel/rail system or are closely related to it. The running behavior of an electric multiple unit 1720 kW was studied on a rail sector in alignment, the vehicle being subject of minimum load conditions – namely without passengers, by analyzing the transverse and vertical accelerations that occur both in the bogie frame and car body of the vehicle.
Keywords: EMU, running behavior, „on-track" tests, transverse and vertical accelerations, minimum load

1. INTRODUCTION

Running behavior assessment of an electric multiple unit (EMU) is determined by analyzing the accelerations that occur on the bogie frame and on the car body, thus enabling the study of the dynamic behavior of a railway vehicle with regards to railway safety, this method being used in case that it is not possible to determine the wheel-rail interaction forces [1].

In order to assess the dynamic behavior of the vehicle, the simplified method for measuring partial tests "on-track" was used, as provided in EN 14363 [2]. Running behavior assessment for EMU is based on the measured values of vertical and transverse accelerations occurring in the car body. To this end, there have been used acceleration transducers placed in certain locations on the vehicle, so as to completely characterize the running dynamic behavior of the vehicle [3].

The running behavior evaluation of EMU's was performed by analysis of acceleration values determined in the car body and in the bogies as a result of the vehicle passing with constant speed of 173 km/h through a railway test section consisting of a tangent track, according to UIC 518 leaflet [4]. The tangent track test section of 1300 meters was chosen from 6^{th}+700 until 8^{th} kilometer stones of CTF – Faurei Testing Ring. Because the vehicle is a passenger transport vehicle, running safety analysis was performed for the case of "minimum load" charging, the case of "exceptional load" charging following to be analyzed separately [5].

» The maximum speed provided for EMU is: $v_{max} = 160$ km/h
» The testing limit speed, v_{lim}, as provided by UIC 518 leaflet, is: $v_{lim}=v_{max}\pm10\%\ v_{max}$
» Consequently, the tests were performed at testing limit speed, v_{lim} included in the prescribed range: $v_{lim} = 173$ km/h
» The length of the track sections, l, according to UIC 518, when v_{lim} is less than 220 km/h, is: $l = 250$ m
» Correspondingly, the number of sectors, N (>25) was established at: N=42
» The testing zone length results from summing the lengths of the track sections, after making 14 laps of the ring, according to UIC 518 ($L = N\cdot l \geq 10.000$ m) was: $L = 10.500$ m

The tests were carried out under dry rail track conditions.

For the running behavior evaluation, there were determined the maximum limit vertical and transverse accelerations in the car body ($\ddot{z}^*_{S\,max\,lim}$, $\ddot{y}^*_{S\,\max\,lim}$), (index s representing class filtering), the transverse accelerations at the bogie ($\ddot{y}^+_{max,lim}$), and to establish the instability criterion, there were determined the maximum limit of effective accelerations (RMS) on transverse direction of the bogie ($\ddot{y}^+_{rms,lim}$).

Because the EMU is symmetric, in order to determine the accelerations that occur in the vertical direction and transverse there were made measurements only on the first wagon motor car MD1 and on the subsequent one, that is the first trailer wagon TI1, namely on the first motor bogie BM1 and on the subsequent two trailer bogies, BT1 and BT2, as represented in Figure 1:

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The measurements were performed with data acquisition equipment provided with suitable software for processing the information, being performed simultaneously on the 16 acquisition equipment channels. There have been collected the signals of 15 acceleration transducers, using the sampling frequency corresponding to a frequency range of 1.6 kHz, as well as the signal provided by the 16th channel, reserved for the speed signal acquisition provided by a speed transducer. The recorded signals are filtered before processing according to measurement signals processing conditions, given by EN 14363.

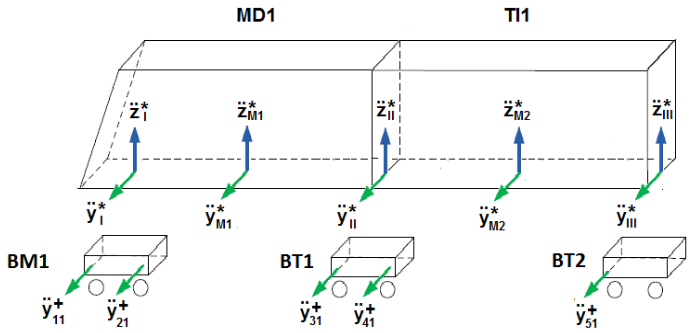

Figure 1: The acceleration transducers location

For each testing zone and recording section, there were selected the channels corresponding to accelerations in the bogie frame and in the car body, the following references being used:

» $\ddot{y}^{+}_{11}$ = T Rama BM1_1 (m/s^2) –transverse acceleration in the motor bogie frame BM1, wheelset 1, left side wheel;
» $\ddot{y}^{+}_{21}$ = T Rama BM1_2 (m/s^2) - transverse acceleration in the motor bogie frame BM1, wheelset 2, left side wheel;
» $\ddot{y}^{+}_{31}$ = T Rama BT1_1 (m/s^2) - transverse acceleration in the trailer bogie frame TI1, wheelset 1, left side wheel;
» $\ddot{y}^{+}_{41}$ = T Rama BT1_2 (m/s^2) - transverse acceleration in the trailer bogie frame TI1, wheelset 2, left side wheel;
» $\ddot{y}^{+}_{51}$ = T Rama BT2_1 (m/s^2) - transverse acceleration in the trailer bogie frame TI2, wheelset 1, left side wheel;
» $\ddot{z}^{*}_{I}$ = V Cab Motor BM (m/s^2) – vertical acceleration in the front part of the motor wagon MD1 car body (floor level), above the center of the motor bogie BM1;
» $\ddot{y}^{*}_{I}$ = T Cab Motor BM (m/s^2) – transverse acceleration in the front part of the motor wagon MD1 car body (floor level), above the center of the motor bogie BM1;
» $\ddot{z}^{*}_{M1}$ = V Cab Motor Mij (m/s^2) – vertical acceleration in the middle zone of the motor wagon MD1 car body (floor level);
» $\ddot{y}^{*}_{M1}$ = T Cab Motor Mij (m/s^2) – transverse acceleration in the middle zone of the motor wagon MD1 car body (floor level);
» $\ddot{z}^{*}_{II}$ = V Cab Motor BT (m/s^2) – vertical acceleration above the center of the trailer bogie BT1 car body (floor level);
» $\ddot{y}^{*}_{II}$ = T Cab Motor BT (m/s^2) – transverse acceleration above the center of the trailer bogie BT1 car body (floor level);
» $\ddot{z}^{*}_{M2}$ = V Cab Trailer 1 Mij (m/s^2) – vertical acceleration in the center of the trailer wagon TI1 car body (floor level);
» $\ddot{y}^{*}_{M2}$ = T Cab Trailer 1 Mij (m/s^2) – transverse acceleration in the center of the trailer wagon TI1 car body (floor level);
» $\ddot{z}^{*}_{III}$ = V Cab Trailer1 BT2 (m/s^2) – vertical acceleration above the center of the trailer bogie BT2 car body (floor level);
» $\ddot{y}^{*}_{III}$ = T Cab Trailer1 BT2 (m/s^2) – transverse acceleration above the center of the trailer bogie BT2 car body (floor level).

2. RUNNING BEHAVIOR EVALUATION

For the running behavior evaluation of the EMU, it is necessary to determine followings:

» the limit values of the maximum transverse accelerations in the bogie frame $\ddot{y}^{+}_{max,lim}$;
» the limit values of the maximum vertical and transverse accelerations in the vehicle car body $\ddot{z}^{*}_{S,max}$, $\ddot{y}^{*}_{S,max}$, s filtration grade
» instability criterion, by means of the limit RMS transverse accelerations values in the bogie frame $\ddot{y}^{+}_{rms,lim}$

Limit values:

✓ The limit value of the maximum transverse acceleration in the bogie frame:

Depending on the total weight of the fully equipped bogie, maximum lateral acceleration limit value is calculated using the following relationship:

$$\ddot{y}^{+}_{max,lim} = 12 - \frac{m^{+}}{5} \tag{7}$$

where m^{+} is the total weight in the bogie, in tones

Because the motor and trailer bogies weights are 9800 and 6500 kg, respectively, the maximum transverse accelerations limit at the bogie frames will be:

- $\ddot{y}^{+}_{max,lim} = 10,04 \frac{m}{s^2}$, for motor bogie frame;
- $\ddot{y}^{+}_{max,lim} = 10,70 \frac{m}{s^2}$, for trailer bogie frame.

✓ Instability criterion

$$\ddot{y}^{+}_{rms,lim} = \frac{\ddot{y}^{+}_{max,lim}}{2} \tag{8}$$

✓ The limit value of the maximum vertical and transverse accelerations in the vehicle car body $\ddot{y}^{*}_{S,max}$ and $\ddot{z}^{*}_{S,max}$

For multiple units, with dual suspension, such as the concerned EMU, maximum limit accelerations are as follows:

$$\ddot{z}^{*}_{S,max} = 3 \frac{m}{s^2} \tag{9}$$

$$\ddot{y}^{*}_{S,max} = 3 \frac{m}{s^2} \tag{10}$$

3. DETERMINATION OF TRANSVERSE ACCELERATIONS AT THE BOGIE FRAME AND THE INSTABILITY CRITERION EVALUATION FOR EMU 1720 KW

After performing the filtering "low pass" with a filter having a crossover frequency of 10 Hz, were determined percentiles F1 = 0.15% and F2 = 99.85%. It was calculated the absolute value of F1 = 0.15% percentile. After processing all values, there were determined the arithmetic mean values $\bar{\ddot{y}}$ and standard deviation s. With these values were also determined the statistical maximum values, $\hat{\ddot{y}}_{max}$, using the equation:

$$\hat{\ddot{y}}_{max} = \bar{\ddot{y}} + k \cdot s \tag{11}$$

where k = 3, according to EN 14363.

The maximum statistic values $\hat{\ddot{y}}_{max}$ were compared with the limit calculated values for motor and trailer bogies frames.

For assessing the instability conditions, for each measurement point and for each recording section, there were calculated RMS values of filtered accelerations, $\ddot{y}^{+}_{rms}$. The arithmetic means values are compared with the limit values set by the instability criterion:

$$\ddot{y}^{+}_{rms,lim} = \frac{\ddot{y}^{+}_{max,lim}}{2} \tag{12}$$

The final results obtained after processing records, including percentiles and RMS accelerations values, are shown in the table below, indicating the maximum statistical values and the limits for transverse accelerations in the bogie frames.

Also, the average values of RMS accelerations and the limits imposed by the instability criterion are presented in the Table 1.

Table 1. The maximum transverse accelerations and the transverse RMS accelerations in the vehicle bogies frames

	Maximum transvers accelerations in the vehicle bogies frames (m/s^2)					Transverse RMS accelerations in the vehicle bogies frames (m/s^2)				
	Frame BM1 wheelset 1	Frame BM1 wheelset 2	Frame TI1 wheelset 1	Frame TI1 wheelset 2	Frame TI2 wheelset 1	Frame BM1 wheelset 1	Frame BM1 wheelset 2	Frame TI1 wheelset 1	Frame TI1 wheelset 2	Frame TI2 wheelset 1
Statistical values	1.787	1.766	2.232	2.328	2.288	0.390	0.382	0.498	0.461	0.435
Imposed limits	10.04	10.04	10.70	10.70	10.70	Instability limit				
						5.02	5.02	5.35	5.35	5.35

The graphical representation of percentile values F1 = 0.15% and F2 = 99.85% and the limits for evaluating the transverse accelerations in the bogie frame is shown in Figure 2.

4. DETERMINATION OF VERTICAL AND TRANSVERSE ACCELERATIONS IN THE CAR BODY OF EMU 1720 KW

After filtration "low pass" using a filter with a pass frequency of 6 Hz, for accelerations in the transverse direction and a filter "band-pass" with the bandwidth of 0.4 - 4 Hz, enabling the determination of percentiles F1 = 0.15% and F2 = 99.85%. It was calculated the absolute value of percentile F1 = 0.15%.

The statistical maximum values, $\hat{\hat{y}}_{max}$ were determined in vertical and transverse direction, being compared with the limit values, using the statistical method described above.

The final results are included in the Table 2, indicating the statistical maximum values and the limits for vertical and transverse accelerations in the center of first car body's front part, in the center of first car body's middle zone, in the center of the connection zone of MD1 and TI1 car bodies, in center of second car body's middle zone and in the center of the rear zone of TI1 car body.

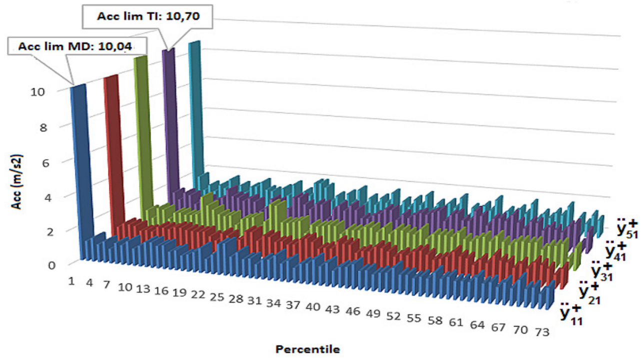

Figure 2: The transverse accelerations in the bogie frame

Table 2. The maximum transverse and vertical accelerations in vehicle car bodies

	Maximum transverse accelerations in vehicle car bodies (m/s^2)					Maximum vertical accelerations in vehicle car bodies (m/s^2)				
	In the front of MD1	In the front of TI1	In the middle of MD1	In the middle of TI1	In the rear of TI1	In the front of MD1	In the front of TI1	In the middle of MD1	In the middle of TI1	In the rear of TI1
Statistical values	0.636	1.024	0.382	0.644	1.334	0.624	0.740	0.494	0.413	0.681
Imposed limits	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000

The graphical representation of percentiles values F1 = 0.15% and F2 = 99.85 % and the limits for evaluating vertical and transverse accelerations on the floor of the car body is shown in the Figure 3.

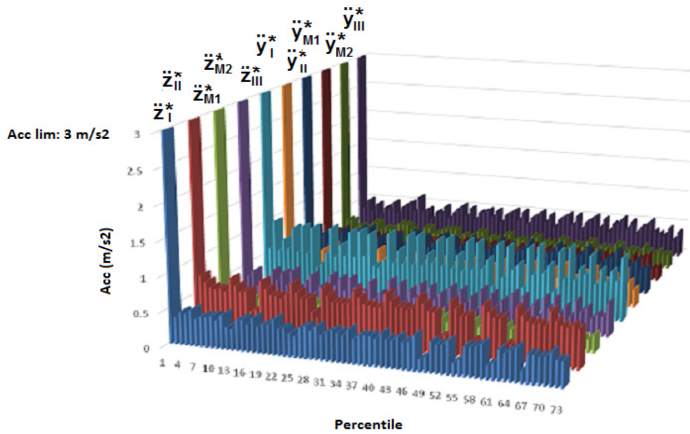

Figure 3: The transverse and vertical accelerations in the car body

5. CONCLUSIONS

With regard to the dynamics of EMU, on a tangent track section, it was observed that if the vehicle is running at maximum speed and at the minimum load capacity, corresponding to the running without passengers in traffic, the vertical and transverse accelerations that occur both in the bogie and in the car body are relatively small and can therefore be concluded that the above conditions of running confers a high reliability and also the running behavior is quite high.

Compared with maximum values imposed by EN 14363, the values obtained for instability criterion, are below 8%, for motor bogie, and roughly 9% for trailer bogie. The little higher percent obtained for the instability criterion values for the trailer bogie could be explained by the hunting oscillation of the railway vehicle, caused by the forward speed of the vehicle and by the wheel – rail interactive forces.

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