System for measurement of interaction forces between wheel and rail for railway vehicles

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Abstract. Determination of the interaction forces between wheel and rail of railway vehicles is essential for assessment of the vehicle dynamic characteristics from point of view of running safety and rail loading as well as for approval the vehicle and alignment them to the Technical Specification for Interoperability. The direct measurement of transverse and vertical interaction forces using the existing full-disk wheel is practical impossible due to the impossibility of separating the two types of forces. To avoid this impediment it was realized a measuring wheelset fitted with 12 spokes achieved as force transducers for measurement of the vertical forces and 12 spokes achieved as force transducers for measurement of the transverse forces. The measuring wheelset was calibrated as a force transducer and was used to determine the wheel and rail interaction forces for LE-MA 6000kW electric locomotive made by Softronic Craiova. The article presents the measuring wheelset, the calibration principle and the calibration characteristics as well as some time history of the main parameters which characterize the running safety and rail loading, determined in the on-track tests.

1 Introduction

All new or modified railway vehicles shall be certified from the point of view of their dynamic characteristics. The methodology for carrying out the tests to determine the dynamic behaviour and to validate the compliance with international norms in terms of running safety and rail loading is established by norms EN 14363:2005 [1, 2] and UIC 518:2009 [3].

Determination of the running characteristics can be made by tests or by numerical simulation. Determination by tests uses one from the two different types of, complete or partial on-track tests, each of which can be achieved using one of the two different methods, normal measuring method or simplified measuring method.

On-track tests by normal measuring method require assessment of running safety and rail loading of rail vehicle by direct measurement of interaction forces between wheel and rail.

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Assessment parameters for running behaviour are either directly measured or derived from other measured parameters. The following parameters generally used for assessment by test of the running behaviour are the following:
• Guiding force, Y, lateral measuring direction;
• Wheel force, Q, vertical measuring direction;
• Sum of guiding forces, ΣY, of a wheelset;
• Quotient, Y/Q, of guiding force/wheel force.

The derived parameters, ΣY, and Y/Q, are the criteria for running safety. They are considered as safety-critical assessment parameters. ΣY is used for the vehicle assessing with regard to the safety against the rail shifting. The quotient Y/Q of the leading wheel is the criterion for safety against the derailment resulting from the climbing of the wheel flange onto the rail.

The guiding force Y and the wheel force Q form the basis for the assessment of lateral and vertical track loading.

On-track tests for assessment of running behaviour are carried out in the four different test zones: in straight track and curves with very large radius, in medium radius curves (600 m ≤ R ≤ 900 m), in small radius curves (400 m ≤ R ≤ 600 m), in very small radius curves (250 m ≤ R < 400 m).

In order to measure the interaction forces between the wheel and rail, one of the following methods can be used:
• on a standardized railway which correspond in terms of: gauge, cant deficiency, radius curves and running speed, provided with rail sections with built-in force transducers for measurement of vertical and transverse forces;
• using a measuring wheelset equipped with sensors for measurement of the two types of forces, lateral guiding force, Y and vertical wheel force, Q.

Approaching the second measurement method requires the use of a measuring wheelset that very well matches to the wheelset used on the vehicle.

Article presents a measuring wheelset realized for Romanian electric locomotive LE-MA 6000kW, the calibration principle and the calibration characteristics as well as the time history parameters characterizing the wheel and rail interaction forces, determined in the on-track tests, according to the normal measuring method recommended by EN 14363:2005.

2 Measuring wheelset for the measurement of the wheel and rail interaction forces

Measurement of the wheel and rail interaction forces, Y and Q, using a full-disk drive wheels is a very difficult problem because it is practically impossible to delimit areas where can be possible to separate the two types of forces.

To avoid this impediment, a measuring wheelset with spokes was realized to measure the interaction forces with rail of the LE-MA electric locomotive. The spokes of the measuring wheelset were equipped with strain gauges, in full-bridge configuration, being transformed into measuring transducers for Y and Q forces, and were calibrated as measuring transducers as such. Each wheel is equipped with 24 spokes, of which 12 are designed as transducers for transverse forces, Y, and 12 as transducers for vertical forces, Q. The spokes for measurement of Y forces have an elliptical-shapes with the large axis oriented perpendicular to the axis. The spokes for measurement of Q forces are thinner and have a round-shapes.

To select the place for application of the strain gauges on the spokes for transverse forces it was used the ANSYS 15 program.

To increase the sensitivity of the transducers so made, the successive spokes Q were connected in the antiphase and the successive Y spokes were connected in phase. In this way, when running a full wheel length under constant vertical and horizontal loads, the voltage signal supplied by the vertical spokes has an almost sinusoidal shape, and the voltage signal provided by the horizontal spokes has an almost constant shape.

To be used as a transducer for the measurement of independent Y and Q forces, the measuring wheelset was calibrated on a stand allowing successive and independent application of the vertical and transverse forces on each spoke. Loading on the spokes was carried out with a 150kN hydraulic cylinder and the force was measured with an etalon cell.

Figure 1 shows the calibration stand with the wheelset mounted for calibration procedure.

Figure 2 presents a typical calibration chart obtained for Q force applied on spoke 1 of wheel 1. The same calibration charts are obtained for all spokes. It can be seen that the measuring wheelset behaves like a linear transducer.

Fig. 1. Calibration stand with measuring wheelset mounted for the calibration procedure

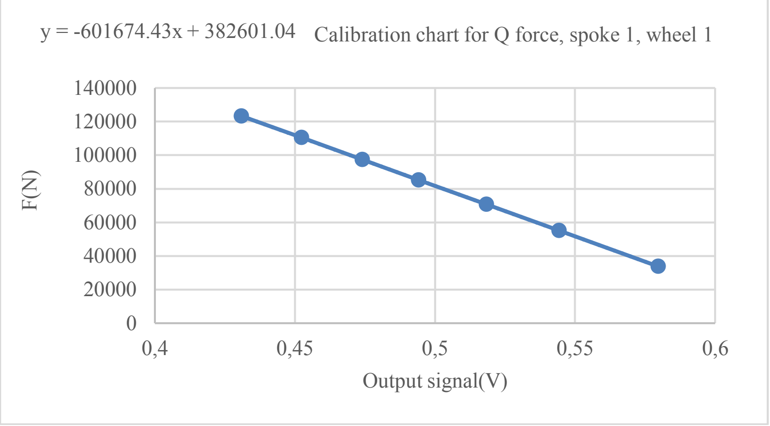

Fig. 2. Calibration chart of measuring wheelset for Q force applied on spoke 1 of wheel 1

The interpolation factors, A and B, were determined for each spoke, in table 1 being represented the interpolation factors for all spokes of the measuring wheelset. From the table it can be seen the need of measurement of angle of the measuring wheelset with the vertical direction for all the moments when the spokes are in the vertical position and they exert the maximum force on the track.

The main characteristics of the measuring wheelset are: gauge: 1 435 mm; diameter: 1250 mm; equivalent conicity: $\tan \gamma_e$ =0.49.

Table 1. Linear interpolation factors, A and B, of the measuring wheelset.

Spoke	Angle	A_{W1_V}	B_{W1_V}	A_{W1_OT}	B_{W1_OT}	A_{W2_V}	B_{W2_V}	A_{W2_OT}	B_{W2_OT}
	(degree)	(kN/V)	(kN)	(kN/V)	(kN)	(kN/V)	(kN)	(kN/V)	(kN)
1	196.9	-601.895	382.649	428.669	234.476	678.128	116.670	440.733	19.485
3	225.7	652.412	-415.721	426.405	233.306	-541.601	-92.720	441.377	19.428
5	255.4	-760.080	483.984	419.512	229.490	635.833	109.542	441.948	19.537
7	284.1	711.484	-454.243	408.377	223.429	-603.775	-104.091	431.795	19.172
9	315.3	-578.033	369.161	402.486	220.075	664.713	114.838	402.063	17.941
11	345	686.146	-440.387	400.337	218.959	-725.561	-126.487	375.194	16.735
13	14.6	-726.165	464.996	400.500	219.062	689.191	120.050	369.188	16.462
15	46.7	651.292	-414.920	400.227	218.971	-704.265	-123.268	381.137	16.954
17	75.7	-695.433	442.849	403.567	220.755	705.218	123.562	404.013	17.968
19	107.1	650.879	-414.818	407.705	223.002	-752.666	-131.244	422.611	18.777
21	137.2	-713.541	453.918	414.363	226.652	662.647	115.550	429.914	19.087
23	165.6	592.151	-377.250	423.745	231.719	-593.637	-102.842	438.076	19.403

3 ON-TRACK determination of wheel and rail interaction forces

Have been carried out complete on-track tests using the normal measuring method for approval of LE-MA 6000kW electric locomotive from point of view of running safety, rail loading and ride characteristics (Figure 3). Assessment from point of view of ride characteristics is not the subject of this article and will not be discussed.

A number of critical problems appear during the measurement of Y and Q forces: the measuring wheelset is in rotation motion; the area is heavily electromagnetically disturbed; the space between the axle of measuring wheelset and the traction motor is very limited and does not allows the positioning of wireless transmission modules, etc. Due to these reasons, it was realized two devices containing each two galvanic isolated modules type MB 38 for strain gauge, in full bridge configuration, powered by supercapacitor battery, mounted on a wheel.

Each module supplies the measuring full bridge strain gauge configuration, mounted on a wheel and it is, in fact, an interface that provides both supplying of strain gauge and protection against electromagnetic disturbances and mechanical shocks.

During the tests, were used the following equipment and software:

• Data acquisition system, including: LAN-XI 3053 B-120, Bruel & Kjaer, 12 input channels, 24 kHz, 24bit, 105789 series and LAN-XI 3160 A-042, series 105628, CE 01.03-346/2015;

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Fig. 3. LE-MA 26 equipped with the measuring wheelset during the on-track tests

• Measuring Wheelset type LE: gauge 1 435 mm; diameter: 1250 mm; equivalent conicity: $\tan\gamma_e$ =0.49;
• Locomotive Speed Measuring and Recording Equipment, type IVMS;
• Multifunction calibrator, CALYs75-AOIPsas, series 0306 A11 0994A, CE 0306 A11 0994;
• Piezoelectric accelerometers;
• Microphone (for comments);
• Laptop Dell Precision M6800: 32GB RAM, Processor i7-4930MX;
• PulseLabshop, Bruel & Kjaer, 29B5FCFA series: real-time data acquisition software;
• PulseReflex, Bruel & Kjaer, 29B5FCFA series: post-processing software;
• TestPoint, post-processing software.

During the tests, were determined and calculated the following parameters:
• Guiding force of wheels 1/2: $Y_{1/2}$ (N);
• Vertical wheel forces on 1/2: $Q_{1/2}$ (N);
• Locomotive speed: Speed (km/h);
• Wheel angle: Angle (degrees);
• Accelerations of bogie frame and in the body in vertical and transverse directions;
• Sum of guiding forces, ΣY, on a wheelset;
• Quotient, $Y_{1/2}/Q_{1/2}$, of guiding force / wheel force;

Given the particularities of the Y/Q force measurement system, in the TestPoint programming environment, was developed a program to process the data acquired during the tests in view to determine the above mentioned parameters. The program performs:
• Following the recorded signals, determines the maxima and minima for voltage signals recorded from the vertical spokes, for both wheels R1 and R2;
• For each determined maximum or minimum, read the wheelset angle and determine the spoke who interact with the track. Correspondingly, using the interpolation table 1, determines the parameters A and B for both, vertical and the adjacent horizontal spokes;
• By linear interpolation determines the value of the forces Y and Q;
• Determine the sum of guiding forces, ΣY, on a wheelset and quotients $Y_{1/2}/Q_{1/2}$, of guiding force/wheel force.

Figure 4 shows the equipment used to perform the on-track tests and figure 5 presents a typical time history of the characteristic parameters for running safety and rail loading in successive enrolment in left and right curves on the track of LE-MA 26.

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On-track tests recordings are divided into zones of interest and then in sections with lengths imposed by EN 14363-2005, 250m for testing in straight rail and very large curves, 100m for large and small radius curves and 70m for very small radius curves.

From recorded signals are calculated the frequency values y(hj), according to the cumulative curve: y (h1), frequency of cumulative curve h1 = 0,15 %; y(h0), frequency of cumulative curve h0 = 50,0 %; y (h2), frequency of cumulative curve h2 = 99,85 %.

Figure 5 shows the following characteristics:

- Vertical forces on the right wheel, Q1dr (N), black upper trace, ass. with left ordinate;
- Vertical forces on the left wheel, Q2st (N), lt. red upper trace, ass. with left ordinate;
- Sum of guiding forces, ΣY2m (kN), blue trace, associated with left ordinate;
- Quotient, (Y1/Q1), green trace, associated with right ordinate;
- Quotient, (Y2/Q2), lt. magenta trace, associated with right ordinate;
- Position in the current line, Pos(m), red trace, associated with middle ordinate;
- Guiding force of the right wheel, Y1dr (N), black bottom trace, ass. with left ordinate;
- Guiding force of the left wheel, Y2st (N), lt. red bottom trace, ass. with left ordinate;
- Speed (km/h), blue trace, associated with left ordinate.

Fig. 4. Measurement equipment used in on-track tests by the normal measurement method

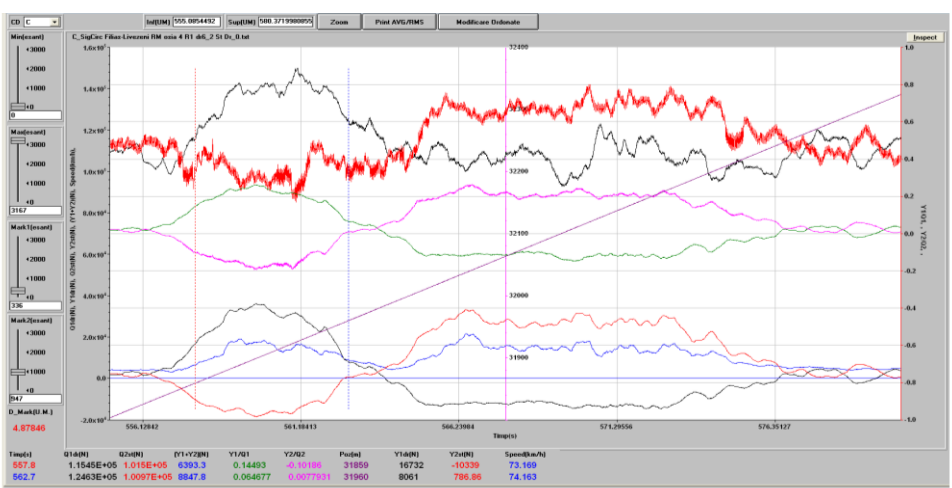

Fig. 5. Time history of characteristic parameters for running safety and rail loading in successive enrolment in left and right curves

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Conclusions

The article presents a measuring wheelset realized for determination of the interaction forces between wheel and rail of railway vehicles in view to assessment the running safety and rail loading for electric locomotive LE-MA 6000kW. It is presented the calibration principle and the calibration characteristics as well as the time history of characteristic parameters for wheel-rail interaction forces, determined in the on-track tests, according to EN 14363:2005.

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