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THE IDENTIFICATION OF MEASUREMENT UNCERTAINTY SOURCE IN DETERMINING WAGON BRAKED WEIGHT BY MEANS OF TESTS

Abstract: *A management system of accredited laboratory shall efectively respond to the requirement for determining of measurement uncertainty and its expression in the test reports aimed for users. The precision of determining of wagon braked weight, as the key parameter of wagon brake system, plays the significant role in overall safety of passengers and wagon crew. Railway standards define the procedure of determining wagon braked weight and such tests are carried out on the main railways selected by test results users. However, the measurement uncertainty deriving from performanse of the test is not defined by the standards and appears to be a complex task. Ostensibly, there is a remarkable number of influencing varibles; some of them being dependent on laboratory equipment and peronnel skill, and remaining ones depending on the user and the environment. The paper discusses the issues of identification and evaluation of variables and parameters that affect measurement uncertainty in this test. The detailed analysis of influencing factors during test preparing and performing, as well as, the experience in performing such a test provide a good ground for measurement uncertainty evaluation.*

Keywords: *uncertainty, railway vehicles, braked weight*

1. INTRODUCTION

The determination of wagon braked weight of rolling stock by testing appears to be a complex process requiring numerous participants. Due to complexityspecific skill and developing proper testing procedure is needed irrespedtive of the fact that methods, conditions and acceptibility criteria are defined in Leaflet UIC 544-1, [1], for all rolling stocks and in TSI Appendix S 1.3 [2] particularly for passanger coaches and freight wagons

In railway vehicles a multitude of air-brakes may be encountered differing in design, application, efficiency etc. Consquently, different vehicles will not have the same braking distance regardless of being the same type and submitted to equal running conditions. To provide assurance in safe train stop in all running regimes International union of Railways establishes Leaflet 544-1 in which braking power is identified by *braked weight* aimed to express the effect of braking via attaining specific braking distance.

The braking distance is denoted by B and measured in tonnes. It shall be noted that one braked weight tonne is not equal with train weight since it is the unit for expressing train capability to result in certain braking distance only. „Tonne“ is selected to express such characteristic (aside of more expected: meters for braking distance or seconds for braking time) because it appears easy to handle. By means of specific tables it is ease to compare and calculate whether a traqin under certain runing condition will stop for certain.

Since train weight is expressed in tonnes the brake weight (also expressed in tonnes) may be used to calculate the percentage sfficient to provide effective train stop on a defined braking distance. This percentage is named *braked weight percentage* and denote by λ, [3].

The braked weights assigned to the individual vehicles or vehicle segments shall normally be marked on the outside of the vehicles in accordance with UIC regulations, [1].

2. MEASUREMENT UNCERTAINTY

Following EA-4/02 instruction, [4], measurement uncertainty is a poaremeter allied with testing results, aimed to define results dissipation which may be reasonably attributed to measured value.

Determination of measurement uncertainty may simply be carried out in four steps, [4, 5, 8]:

1. Define measured value. Identify and record what is measured, along with the relationship between measured values and influencing parameters. Also, it is needed to identify systematic errors and infromation from spacifications given in standard operating procedures.
2. Identify measurement uncertainty sources, i.e. list all possible measurement uncertainty sources. This step is of major importance and requires a sound knowledge of measuring equipment, testing methods and their application, including the impact of environment on test results,
3. Quantify measurement uncertainty contributors. First calculate measurement uncertainty of grouped factors, then remaninig factors and finally derive standard deviation for all factors
Uncertainty contributions are expressed as standard deviations on the ground statistical calculations for the measurements where more than 10 repetitive tests may be operated – Measurement uncertainty evaluation method – type A.
When such repetitive test are not feasible for each measurement uncertainty source Measurement uncertainty evaluation methods - Type B are used (E.g. using data from certificates, technical documentation, technical specifications, calibration records, manufacturers measuring units or by assessment method).
4. Calculate combined measurement uncertainty and at the end reckon extended measurement uncertainty.

The final goal is to obtain measuring results in the form $Y = y \pm U$.

3. BRAKED WEIGHT DETERMINATION BY TESTS

Following fomulae are used to determine braked weight and braked weight persentage, respectively:

$$B = \frac{\lambda \cdot m}{100} \qquad (1)$$

$$\lambda = \frac{C}{s} - D \qquad (2)$$

where:
s[m] – braking distance,
C, D – empiric factors obtained from extensive tests on plain and strait railway with variations of brake positions and initial train speed..

For vehicle speed les than 200 km/h, according to Leaflet UIC 544-1, [1], braked weight is determined by tests using following methods:

1. Tests with a single vehicle:

- Passenger coaches up to 160km/h,
- Passenger coaches passenger coaches that may operate up to 200km/h thath have a constant level of braking power regardless of speed,
- Freight wagons not exceeding 120km/h,
- Freiht wagons with maximum speed ithe range 120 - 160km/h.

2. Test with train length of 400m:
- Passenger coaches with maximum speed exceeding 120km/h.

3. Tests with train length of 500m:
- Freight wagons not exceeding 120km/h,
- Freiht wagons with maximum speed ithe range 120 - 160km/h.

4. Locomotive tests.
5. Multiple units tests.

General testing conditions defined in Leflet UIC 544-1, [1 include>

- Tested train/single vehicle speed up to the initial braking speed. At the speed, on plain and straight (inclination less than 3‰), activate rapid brake, whereby pulling power is turned off or a single vehicle uncoupled. In every test, the braking distance is measured from the point at which the rapid brake application was initiated.
- Atmospheric condition: In order to avoid bad atmosferic conditions compromise test results test shall be carried out on dry rails and at least possible wind.
- Tests are operated on straight and plain railway (inclination less than 3‰)
- Measurement results may be accepted once the difference between measured and nominal speed does not exceed 4km/h.

$$\left|V_{jizm} - V_{jnom}\right| \leq 4km/h \qquad (3)$$

- Number of tests> To calculate mean value Za izračunavanje srednjih vrednosti, four or more tests are needed. All breaking distances are to be corrected following the method described in Appendix F c.F2.1UIC 544-1. To make the obtained value acceptable, two following criteria are to be met:

Criterium 1:

$$\frac{\sigma_n}{\overline{s}} \leq 3\% \qquad (4)$$

Criterium 2:

$$|s_e - \overline{s}| \leq 1,95 \cdot \sigma_n \qquad (5)$$

where:
σ_n - denotes standard deviation [m]
$\overline{s}$ - mean braking distance [m]
s_e - braking distance furthest from the mean [m]

- Remaning conditions: Before the start of the tests, the friction components (brake pads/shoes) shall be run-in to give at least 70% coverage, what is visually checked before test starts. Also it is required that the initial temperature of the wheels/brake discs should be between 50 and 60°C.

Following values are measured in the test: speed [km/h] and braking distance [m], while values like: wheel/disc temperature [°C], brake cylinder and brake pipe presure [bar] age only checked.

Corrected braking distrance is reckoned by

$$\overline{s}_{jkor} = \frac{3,99 \cdot \rho \cdot V_{jnom}^2}{3,99 \cdot \rho \cdot V_{jizm}^2 - i_m \cdot s_{jizm}} \cdot s_{jizm} \qquad (6)$$

where :
$\overline{s}_{jkor}$[m] - corrected braking distance which corresponds to the nominal speed in the test j,
V_{jizm} [km/h] - nominal initial speed in test j,
V_{jnom}[km/h] - initial speed measured in test j,
s_{jizm} [m] - braking distance measured in test j,
ρ[-] - coeffcient of inertia of the rotating masses, which is defined as follows:

$$\rho = 1 + \frac{m_r}{m}$$

m[kg] - mass of the test train or test vehicle,
m_r [kg] - equivalent mass of the rotating components
i_m[‰] - mean gradient over s_{jizm} of the test track.

4. TEST RESULTS

Table 1 and 2 provide results of a brake test on diesel-engin multiple unit DMV711. The experiment included five tests. Upon calculating mean braking distance (previously corrected by (6)) braking weight percentage is determined on the ground of the diagram (UIC544-1), [1], and braking weight is calculated sing fomula (1). The obtained value may be accepted since they meet criteria (4) i (5) - Table 2.

It may be noticed that braking weight is expressed as B=161 t, and not in form of B=161+U [t].

It is not convenient to use the form B=161+ U [t]. In order to comply with both perspectives: practical issues and EA-4/02, [4], International union of Railways introduced criteria (4) i (5) in latest revisions of Leaflet UIC544-1. In this document braking weight is not expressed in form of $Y = y \pm U$. However, when designation B=161t is put on the outer surface of train DMV711, grounding on test results, it means that brake on that train secures (in R regime) safe train stop in the range 395.8 ±17,4m, what is presented on Figure 1.

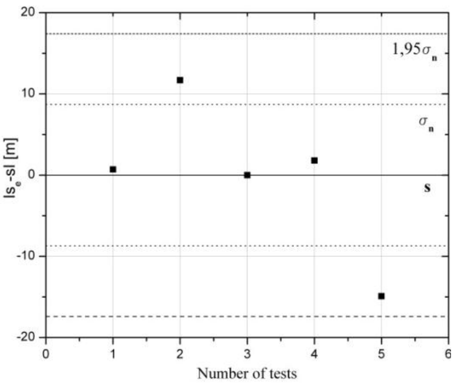

***Figure 1 –** Meeting criterium from equation (5) for multiple unit DMV711*

Table 1 – Test results DMV711

No.	Braking mode	m	V_{nom}	V_{izm}	p_{maxKC}^{001} / p_{maxKC}^{101}	s_{izm}	t_K	T^{001} / T^{101}	s_{kor}	λ
		[t]	*[km/h]*	*[km/h]*	*[bar]*	*[m]*	*[s]*	*[˚C]*	*[m]*	*[%]*
1	*R*	110.05	100	100.5	3.50 / 3.52	406	25.5	45.1 / 41.1	396.5	145.8
2	*R*	110.05	100	100.9	3.53 / 3.53	411	25.9	59.4 / 39.9	408.2	141.3
3	*R*	110.05	100	99.6	3.54 / 3.52	398	25.2	61.5 / 52.3	395.8	146.0
4	*R*	110.05	100	101.1	3.55 / 3.52	402	25.3	60.2 / 57.4	397.6	145.3
5	*R*	110.05	100	101.3	3.57 / 3.51	396	25.0	61.9 / 49.9	380.9	152.0

Table 2 – Checking acceptability of test results following UIC544-1 Appendix F

V *[km/h]*	Braking mode	m *[t]*	$\bar{s}$ *[m]*	λ *[%]*	B *[t]*	σ_n *[m]*	$\frac{\sigma_n}{\bar{s}}$ -	$\lvert s_e - \bar{s} \rvert$ *[m]*	$1{,}95 \cdot \sigma_n$ *[m]*
100	R	110.05	395.8	146	161	8.70	0.022	14,9	17.4

5. MEASUREMENT UNCERTAINTY SOURCES IDENTIFICATION

In spite of the fact that Leaflet UIC544-1, [1], virtually includes measurement uncertainty issue through criteria (4, 5), it is necessary to identify the sources of measuremnet uncertainty [5, 6, 7], thus to be uble to mitigate their impact on test results.

Grounding on test experience and measurements and by using the expression for corrected braking distance (6) and test conditions, sources of measurement uncertainty may be traced, Fig. 2.

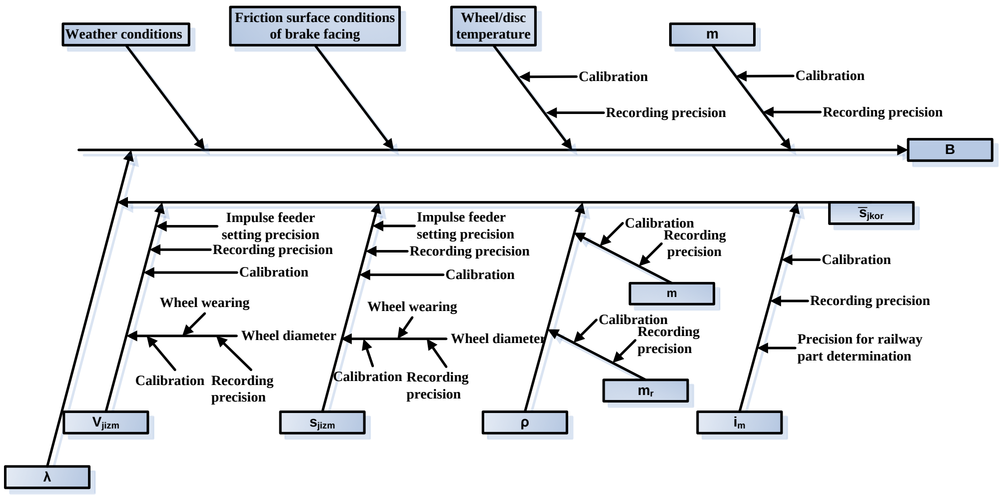

***Figure 2** – Factors contributing measurement uncertainty in experimental determination of braked weight*

Figure 2, shows that major measurement uncertainty sources for determination of railway vehicle braked weight are: weather conditions, condition of friction surface of brake facings, wheel/disc temperature, vehicle mass, initial speed, measured braking distance, railway slope and momentum of rotating mass.

Simply by obeying prescribed weather conditions for conduting tests their contribution to overall measurement uncertainty may be regarded negligible.

Data on vehicle mass and rotating parts a laboratory may easily obtain from railway authority or from vehicle manufacturer which perform measurements on weighbridges.

Speed and braking distance of railway vehicles is recorded by means of RPM impuls feeder. Based on measured frequency and using expressions (7) and (8) speed and breaking distance may be reckoned, respectively:

$$V_{izm} = \frac{f \cdot D_t \cdot \pi \cdot 3600}{z} \qquad (7)$$

$$s_{izm} = \frac{n_i}{z} \cdot D_t \cdot \pi \qquad (8)$$

where:

f denotes frequency,

z – gear teeth number oif RPM impuls feeder,

D_t – vehicle wheel diameter,

n_i – impulse number recorded by impulse feeder.

Expression (7) and (8) show that real sources of measurement uncertainty in speed and breaking distance measurment are: wheel diameter measurement (calibration of unit for measuring wheel diameter, precision of anlogue equipment), wheel wearing during the test (diameter from test beginning is used in calculations), precision in the impulse feeder positioning and precision in speed/breaking distance recording (selection of the moment when braking proces has started and reading from diagram corresponding initial speed).

Data on railway slope may be read from the signs aside the track (containing „+“ for uphill and „-„ for downhill. Railway authority timely examines the conditions of the rails, inluding wether the slope is maintained. The source of measurement uncertainty for braked mass determination lies in precision of defining the railway part where j[th] braking distance measurement actually took place.

Based on consideration and grouping of all relevant measurement uncertainty (Fig 2), the following diagram is obtained (Fig. 3).

I may be inferred that major souces of measurement uncertainty lie in folllowing activities:

- Measurement of vehicle mass and rotatin parts,
- Wheel diameter measurement
- Railway slope measurement,
- Frequency measurement, and
- Impulse rate measurement.

Above values may be determined using the data of measuring equipment and corresponding calibration certificates if evaluation method Type B is selected

Aside of major sources, remaining sources of measurement uncertainty that are to be taken into account are:

- Precision in RPM impulse feeder positioning (following manufacturer’s recommendation)
- Precision of defining the railway part where j[th] braking distance measurement actually took place (link to data of Railway Authority possessing updated records)
- Precision in speed/breaking distance recording – selection of the moment when braking proces has started and reading from diagram corresponding initial speed/braking distance in j[th] test.

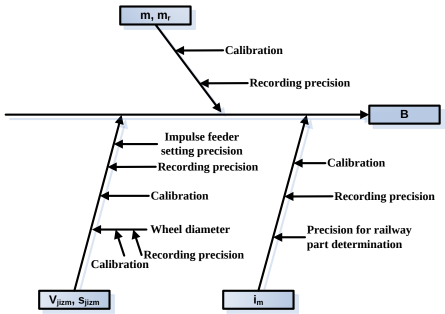

Figure 3 – *Reduced diagram of uncertainty measurement source in experimental brake mass determination*

These sources of easurement uncertainty cannot be quatified, but attention must be paid during the test that their contribution to measurment uncertainty is the least possible.

6. CONCLUSION

The paper arose from proper research conducted to define measurement uncertainty in experimental determination of railway vehicle brake weight

Particular attention is paid to identification of parameters influencing measurement uncertainty in such a complex laboratory testing.

The elaborated procedure of influencing parameters identification is the result of experience drawn from authors’ participation in above mentioned testing as well as in processing of test results following the new requirements contained in EA-4/02 Expression of the Uncertainty of Measurement in Calibration.

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