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METROLOGICAL CONFIRMATION OF THE TRACK GEOMETRY MEASURING SYSTEMS BY THE DB NETZ AG

METROLOGICKÉ SKÚŠKY SYSTÉMOV NA MERANIE GEOMETRIE TRATE U DB NETZ AG

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1 INTRODUCTION

Among other things, the quality of the track and in particular good track geometry is indispensable for safe and reliable railway operation. As part of quality assurance and the legal requirements resulting from the national railway regulations, the railway network must be regularly inspected and maintained. To obtain information about the current track condition as quickly and effectively as possible, DB Netz AG uses several different track recording vehicles equipped with highly complex different measuring systems. However, before such measuring vehicles can be used, the measuring and evaluation technology must be tested in advance against the DB requirements.

2 MEASUREMENT OF TRACK GEOMETRY

The principal parameters describing the track geometry such as track gauge, longitudinal level, alignment, cross level, and twist are defined in the European Standard EN 13848 - 1 [1]. This document also specified the minimum requirements for measurement and analysis procedures. The main goal of this standardization is to ensure the comparability of results between different measuring systems.

2.1 Testing of track geometry recording systems according to EN 13848-2

The requirements for track geometry measuring systems are described in different parts of EN 13848. For the track recording vehicles used for regular inspection of the track geometry quality, the procedure defined in Part 2 of EN 13848 [2] is relevant.

To ensure effective and correct operation of the measuring equipment and the corresponding processing system, the measuring system and the entire measuring process must be tested regularly. This includes calibration and adjustment of the sensors as well as validation by static and dynamic tests.

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Static tests mainly concern gauge and cross level measurements. As a rule, the measured value is compared with a defined reference. As a reference high-precision hand-held measuring devices can be used.

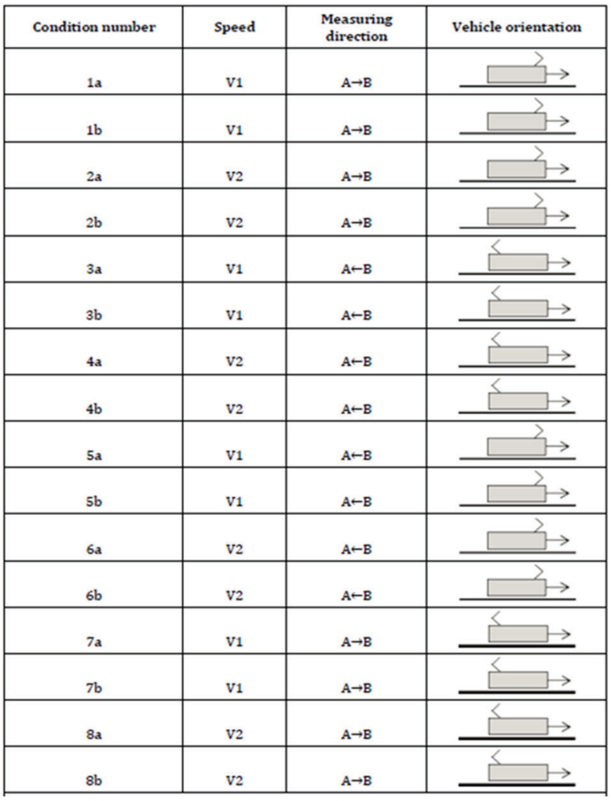
The dynamic tests concern all parameters of the track geometry according to EN 13848-1. The measurement outputs of successive test runs recorded under the same or changing measurement conditions are compared together. The test conditions shall represents the normal operation of the track recording vehicle at different speeds, measurement directions and measurement orientations of the vehicle.

For use on conventional lines, the track geometry recording system must be validated in a wide range of track design features, such as curves with different radii and directions, significant cant, frequent alternation of curves and straight lines.

The track geometry quality of the test track should preferably include standard deviations from class A to class C according to EN 13848 – 6 [3] for a speed range of 120 to 160 km/h.

2.2 Validation method

The validation method according EN 13848-2 preferred for track recording cars is based on comparisons of runs for the same vehicle. An example of the test configuration required in EN 13848- 2 is shown in ***fig. 1***.



Condition number	Speed	Measuring direction	Vehicle orientation
1a	V1	A→B	
1b	V1	A→B	
2a	V2	A→B	
2b	V2	A→B	
3a	V1	A←B	
3b	V1	A←B	
4a	V2	A←B	
4b	V2	A←B	
5a	V1	A←B	
5b	V1	A←B	
6a	V2	A←B	
6b	V2	A←B	
7a	V1	A→B	
7b	V1	A→B	
8a	V2	A→B	
8b	V2	A→B	

Fig. 1 *Required test conditions according EN 13848-2*

Obr. 1 *Požadované testovacie podmienky podľa normy EN 13848 - 2*

For each specified test configuration, a run with the assessed vehicle has to be made on a predefined test track.

In EN 13848-2, the assessment of the performance of measuring systems is based on the evaluation of repeatability and reproducibility. For this purpose, predefined runs are compared in pairs and the differences between these runs are statistically evaluated. The 95% quantile of the distribution of the calculated differences must not exceed the specified limits.

2.3 Disadvantages of normative validation of track geometry measuring systems

Even though the method described above for the validation of measuring systems is widely used in Europe, some deficits can be identified. The normative validation method is based on the recorded data of the same vehicle, a comparison with a standard or a reference measuring system is not required. In addition, due to the small number of measurement series required and the paired comparison of two measurements under the same conditions, it is not possible to detect a systematic error in the measurement process. Furthermore, the evaluation criteria of reproducibility and repeatability are not correlated with the characteristic tolerances of the individual track geometry parameters.

With the increasing number of different measuring systems at DB Netz AG, the methodology of system testing and validation has also developed further. It is largely based on the methods of modern quality management and includes the complete chain from the definition of the measured quantity, through the characteristic tolerances to the complete measurement result, including all metrological information for determining the measurement uncertainty.

3 METROLOGY AND CONFIRMATION OF TRACK GEOMETRY MEASURING SYSTEMS BY THE DB NETZ

When reporting the result of a measurement, quantitative indication of the quality of the result should be given to assess its reliability. Without such an indication, measurement results cannot be compared, either among themselves or with reference values given in a specification or a standard.

According to EN ISO 10012:2003 [4], an effective measurement management system must ensure that measuring equipment and measurement processes are fit for their intended use. An important part of the measurement management system is the metrological confirmation including estimation of measurement uncertainty. The commonly used method for the estimation of measurement uncertainty is described in ISO/IEC Guide 98-3 (previous GUM - Guide to the Expression of Uncertainty in Measurement) [5].

3.1 Measurement uncertainty

The measurement uncertainty is a parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand. Measurement uncertainty generally comprises many components. Some of these components can be assessed from the statistical distribution of the results of measurement series and can be characterized by experimental standard deviations. The other components, which can also be characterized by standard deviations, are assessed from assumed probability distributions based on experience or other information.

Regarding the measurement uncertainty in track geometry measurement, the measurement result is influenced by various factors. The correlations between the measured variable and the measurement result can be represented in a simplified way by a model of the measurement, the so-called Ishikawa or cause-effect diagram, see ***fig. 2***.

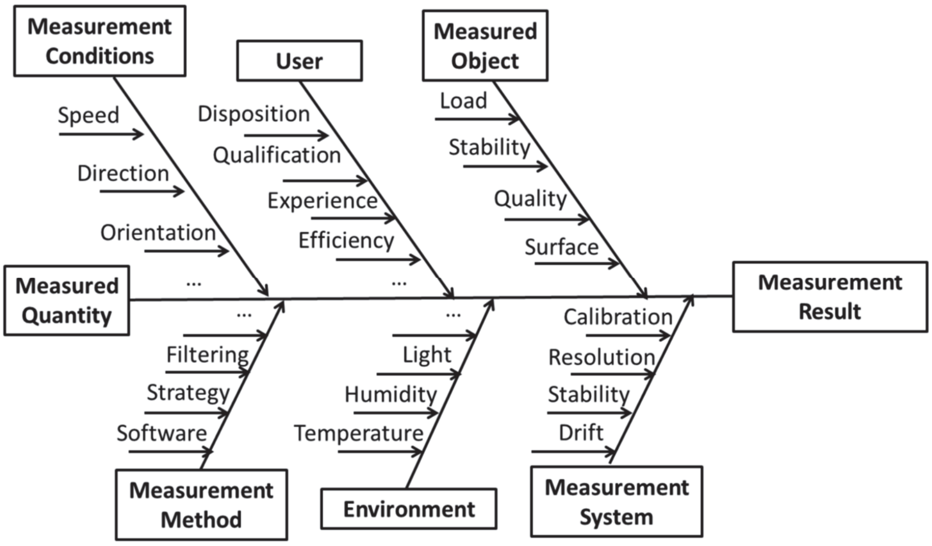


Fig. 2 *Metrological model of track geometry measurement*

Obr. 2 *Metrologický model merania geometrie trate*

The most important influences that contribute to the measurement uncertainty in track geometry measurement should always be considered when validating the measuring systems. These include the measuring system itself, especially the calibration of the individual sensors and their adjustment, data processing such as filtering and positioning, but also the measurement conditions and the measured object.

3.2 Measurement campaign

The validation of new measuring systems as well as the annual repeat testing of all measuring systems at DB is carried out on two defined reference lines that fulfil all normative requirements for track layout and track geometry quality.

A high number of measurements under varying measurement conditions is required in order to conduct well-founded statistical analysis of the measured data. The measurements take place in a narrow time frame so that the measured object does not change significantly during the campaign. ***Fig. 3*** provides an example of the RAILab 3 measurement campaign provided on one of the reference tracks.

For the assessment of the measuring system performed on the reference track, relevant track sections are used. The total length of these reference sections is more than 18 km, at a sampling rate of 16 cm this results in at least 112500 measuring points per recorded quantity, at which the reproducibility of the measurement is evaluated. The standard deviation of the measured values is calculated at each measuring point.

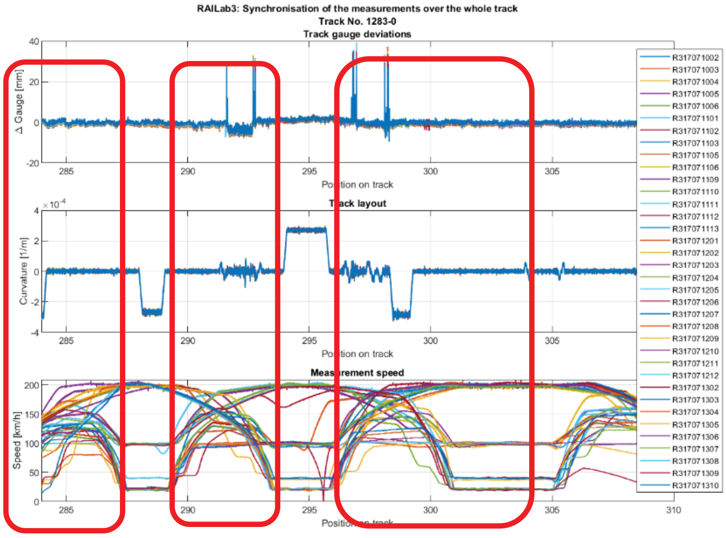


***Fig. 3** Example of a RAILab3 validation campaign on one selected reference track*

***Obr. 3** Príklad validačnej kampane systému RAILab3 na jednej vybranej referenčnej trati*

In order to perform a correct evaluation, an exact synchronisation of the measurement data must first be carried out. This requires a division of the evaluation routes into shorter subsections of around 200 m length, where the odometer wheel shift and slip are negligible. The track gauge is used as a suitable parameter for synchronisation. An example of the synchronised evaluation in a 200 m subsection is shown in ***fig. 4***.

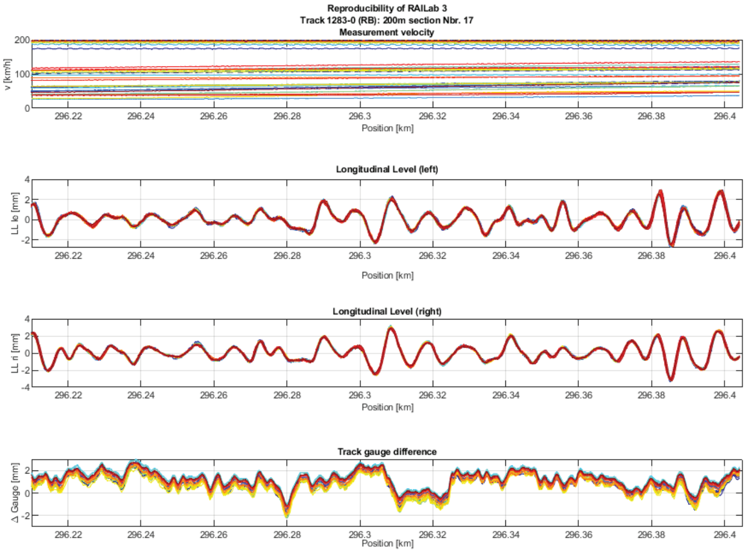


***Fig. 4** Example of a fine synchronised 200 m subsection*

***Obr. 4** Príklad presne synchronizovanej 200 m dlhej podsekcie*

After a successful fine synchronisation, standard deviations of the measured data are calculated at each measuring point over all subsections. Then the frequency distribution of the standard deviations is determined, see ***fig. 5***.

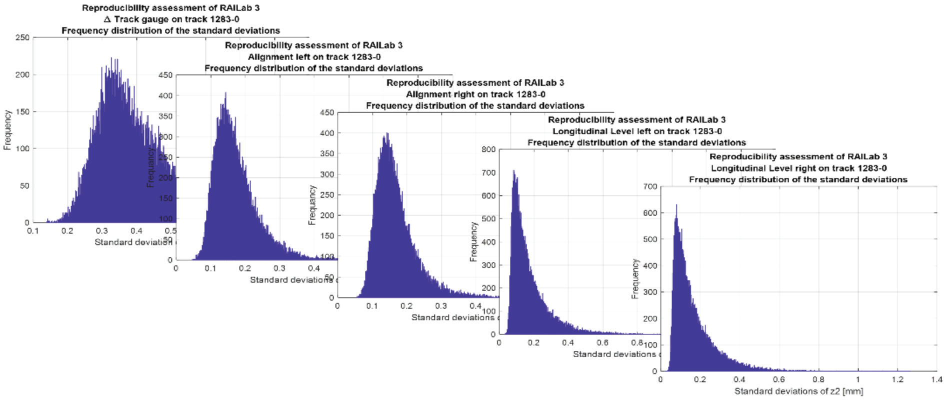


***Fig. 5** Frequency distribution of the standard deviation in track geometry measurement*

***Obr. 5** Rozdelenie početnosti štandardných odchýlok pri meraní geometrie trate*

Finally, the 95% quantile is calculated from the cumulative frequency as an estimate for the measurement uncertainty. These results are compared with the permissible measurement uncertainties.

3.3 Tolerances and permissible measurement uncertainty

The consideration of the measuring system capability would be meaningless without taking into account the tolerances of individual track geometry quantities. These tolerances result from the minimum distances between the Intervention Limit (SR_{100}) and the Immediate Action Limit (SR_{lim}). These are two important levels for assessment of track geometry specified in the DB regulation RIL 821.2001 [6]. The tolerances of the track geometry parameters and the permissible measurement uncertainties derived from them are listed in ***TABLE 1***.

***TABLE 1** Tolerances and permissible measurement uncertainty according RIL 821.2001*

***TAB. 1** Tolerancie a prípustná neistota merania podľa predpisu RIL 821.2001*

Track geometry quantity	**Tolerance [mm]**	**Permissible measurement uncertainty [mm]**
Track gauge	Not defined	0,5
Longitudinal level	2	0,5
Alignment	2	0,5
Cross level (filtered)	2	0,5
Cross level	5	1,25

4 COMPARABILITY OF TRACK RECORDING SYSTEMS

In the quality assurance of track geometry inspection is not only the ability of the individual measuring systems important, but also their comparability. During the annual metrological verification, all measuring systems of DB Netz AG are examined, if possible, simultaneously or at short period of time, see example in ***fig. 6***.

Fig. 6 *Metrological assessment of track recording vehicles by DB Netz AG*

Obr. 6 *Metrologické posúdenie traťových meracích vozidiel spoločnosťou DB Netz AG*

4.1 Method of comparability assessment

During the measurement campaign, several data sets are recorded per each track recording vehicle. From all synchronised measurements of each vehicle, an average measurement is determined per parameter as an estimate for the true measured variable. ***Fig. 7*** shows an example for the comparison of alignment and longitudinal level measurement provided by different track recording vehicles.

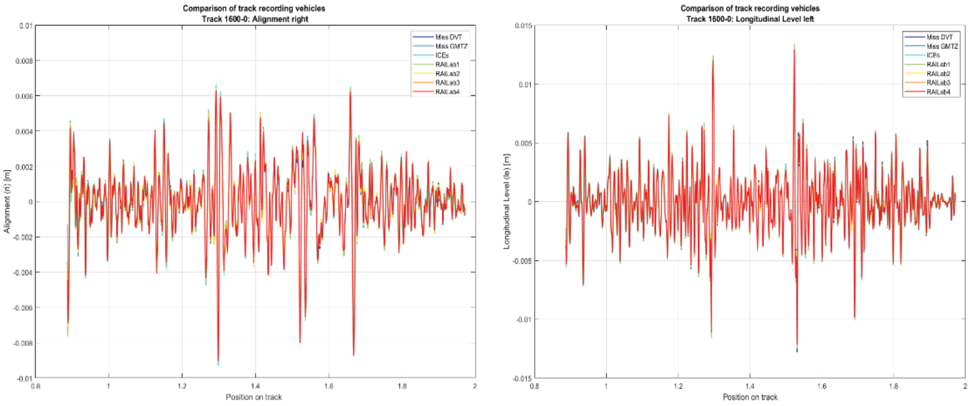


Fig. 7 *Comparability of track recording vehicles, example of alignment and longitudinal level measurement*

Obr. 7 *Porovnateľnosť traťových meracích vozidiel, príklad merania smeru a výšky.*

These average measurements of the vehicles are then statistically evaluated with each other. For this purpose, the difference to the mean value is calculated per vehicle. From the cumulative frequency of the differences, the 95% value serves as a key indicator for comparability.

The criteria for assessing comparability are also linked to the tolerances of the individual measured track geometry parameters. This ensures that the deviations between the measuring systems are within the range of the permissible measurement uncertainties.

5 CONCLUSION

Measuring systems must be metrologically verified in accordance with the standards of measurement quality management and the quality assurance processes of DB Netz AG.

Accordingly, an effective measurement management system ensures that measuring equipment and measurement procedures are suitable for the intended use. In addition, the quality objectives for the products can be better achieved and the risk of faulty measurement results can be better controlled.

Proof of the suitability of a measuring system is a prerequisite for metrological approval for track geometry testing in accordance with RIL 821.2001 in DB Netz AG.

The complex validation of the measuring systems at DB is not only carried out when new systems are introduced into operation; all measuring systems are validated annually. This is the only way to obtain high-quality data that serves as the basis for a proper assessment of the track condition. Maintenance measures derived from the recorded data enable a good quality of the track geometry and safe railway operation. High demands are also placed on data quality when using the measurement data for simulations and for the design of new rolling stock.

References

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Summary

The reliability and accuracy of the measured data provided by the track recording systems are important not only for the assessment of the track quality and the derivation of the necessary maintenance work. These data are also an important part in the design and homologation process of new rolling stock. Validation and confirmation of the capability of the measuring systems at DB is not only carried out when new systems are introduced into the service, but also as part of their annual evaluation. This article focuses on the procedure and criteria for this validation

Resumé

Spoľahlivosť a presnosť nameraných údajov, ktoré poskytujú traťové meracie systémy, sú dôležité nielen na posúdenie kvality trate a odvodenie potrebných údržbových prác. Tieto údaje sú tiež dôležitou súčasťou procesu navrhovania a homologizácie nových koľajových vozidiel. Validácia a potvrdenie spôsobilosti meracích systémov v DB sa vykonáva nielen pri zavádzaní nových systémov do prevádzky, ale aj v rámci ich každoročného prehodnocovania. Tento článok sa zameriava na postup a kritériá tohto overovania .