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Indirect monitoring of Railway Bridges using the Continuous Track Monitoring System CTM2.0

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Abstract

Transportation vehicles and infrastructures, as part of the mobility sector, play a critical role in environmental protection, as they are responsible for significant amounts of gas emissions that lead to global warming. The railway system could contribute to this aspect, however, there is an urgent need to improve the reliability and availability of the railway network. Bridges are particularly important, as their renewal is time consuming, and their long-term shutting down can affect the entire infrastructure network. This paper investigates the possibility of identifying vibrating bridges using the Continuous Track Monitoring (CTM2.0) system, which enables the continuous monitoring of railway infrastructure by regularly scheduled trains. The paper deals with the analysis of 204 passages of the CTM train on two specific bridges in Germany to verify whether these bridges can be identified by the system based on their dynamic characteristics. The results show that CTM2.0 measurements can differentiate between the bridge structure and the rest of the track, giving the opportunity to collect information on the entire bridge stock across the railway network. However, further investigations are needed to reduce speed-dependent effects and to define the thresholds for detecting vibrating bridges.

Keywords: indirect monitoring, drive-by-monitoring, continuous track monitoring, bridge dynamics, field testing.

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1 INTRODUCTION

The transport, logistics, and mobility sectors play a crucial role in preventing environmental polution and limiting global warming. The railway system, which includes both passenger and freight transport, is particularly important in achieving these goals. However, the growing volume of rail traffic underscores the need to improve the reliability and availability of the entire railway network. Railway bridges are of particular importance, as their renewal is a time-consuming process and their closure can have far-reaching consequences for the entire infrastructure network.

DB Netz AG operates more than 25,700 railway bridges in Germany [1]. It is not feasible to implement a continuous monitoring system with sensors on the entire bridge network, therefore, it is necessary to develop a methodology to identify and prioritise the bridges that require monitoring. Bridges with pronounced resonance phenomena are of particular interest.

One possible strategy is to use simplified models of structures to assess the entire railway network [2].However, around 20 years ago, an alternative approach was proposed in [3] to determine the modal parameters of bridges based on measurements taken from a train, which could be used to evaluate the entire network. Since then, the field has evolved from the conceptual level and numerical investigations to the verification in field tests. For example, in [4] it was demonstrated that the identification of the resonant frequency of bridges is also possible under practical operating conditions and at high speeds. A detailed summary of recent developments and future challenges in the field of drive-by monitoring is provided in [5].

To the best of the authors' knowledge, only one study has been conducted in Japan [6] to identify resonant bridges using track irregularity measurements on both the first and last axle of the train, while the present study uses a system with only one measured axle and several bridge passages to identify resonant bridges. The system used is the Continuous Track Monitoring (CTM2.0) system developed by DB Systemtechnik GmbH, which enables the continuous monitoring of railway infrastructure by regularly scheduled trains. However, the present study investigates the possibility to use the system for the identification of However, further investigations are needed to reduce speed-dependent effects and to define the thresholds for detecting vibrating bridges and this is achieved through the analysis of 204 passages on two different bridges to verify, whether they can be identified by the CTM2.0 system. The first bridge is a single-track steel trough bridge with a span of 16.4 m and a ballasted superstructure, while the second bridge is a double-track tied arch bridge with a span of 77.5 m and a ballastless deck.

The paper is organized as follows: Section 2 provides a description of the CTM2.0 system. Section 3 comprises the analysis of bridge passages and it is divided into a separate subsection for each bridge. The paper concludes with section 4, which presents the findings and draws conclusions based on the analysis.

2 THE CONTINUOUS TRACK MONITORING SYSTEM CTM 2.0

Increasing rail traffic on existing infrastructure is a major challenge, as there is less time available for inspections and repairs. DB Systemtechnik GmbH has developed a solution in the form of the CTM measurement system, which has been used to monitor track quality for over two decades. The CTM system is installed on regularly scheduled trains and allows continuous monitoring of the infrastructure, which can lead to early detection of faults and better planning of repair work.

The CTM track measurement system has been improved over time, considering operational experience and feedback from infrastructure managers. The system has to meet a wide range of requirements from vehicle owners, measuring systems operators, and infrastructure managers. For vehicle owners, it is essential that the system does not affect the operation of the vehicle or require additional maintenance. For operators of the system, operation must be self-sufficient and fully autonomous, with automated monitoring reports and results provided for integration into existing maintenance databases. Infrastructure managers require valid and comparable results that can be assessed against infrastructure operator standards. [7]

The CTM2.0 measurement system consists of standard industrial components. It includes sensor boxes with sensors, measuring amplifiers, data recorders, positioning systems, and data transmission devices (Figure 1). The modular design of the system allows for individual components to be replaced or improved independently of each other. The second generation CTM2.0 transmits all data from the vehicle to the office, while the first generation CTM1.0 only transmits results. In addition to the raw sensor data, the vehicles also constantly record speed and location to match the results to the appropriate routes. Longitudinal track irregularities are calculated in the office using accelerations measured at the axle boxes and limited to wavelengths according to the European standard EN13848. The exact location of each measurement point is determined and the results can be directly compared with those of other inspection vehicles (Figure 2). [8]

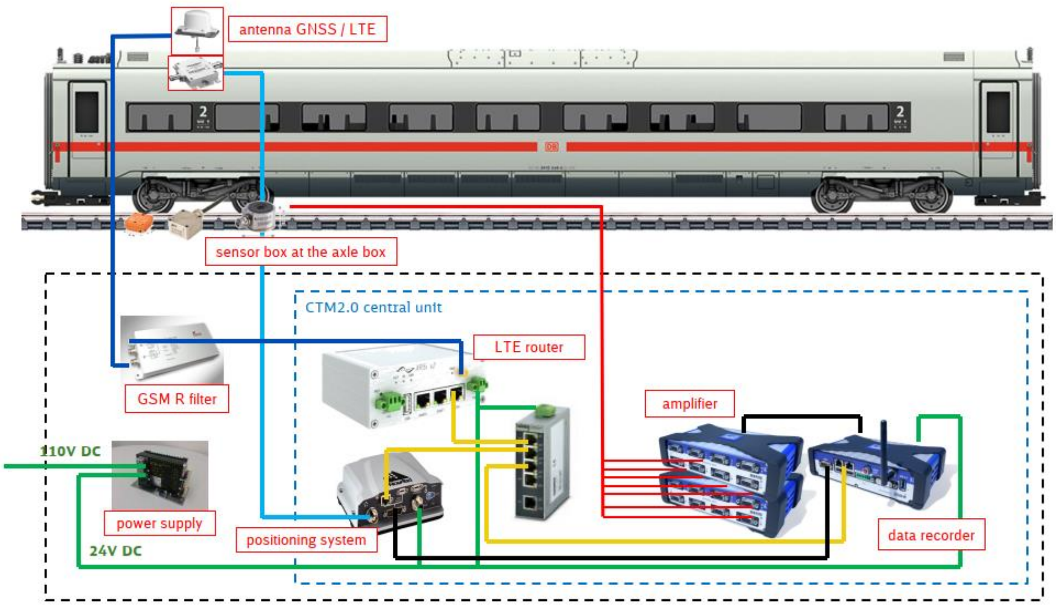

Figure 1 Principle of the CTM 2.0 measuring system [9]

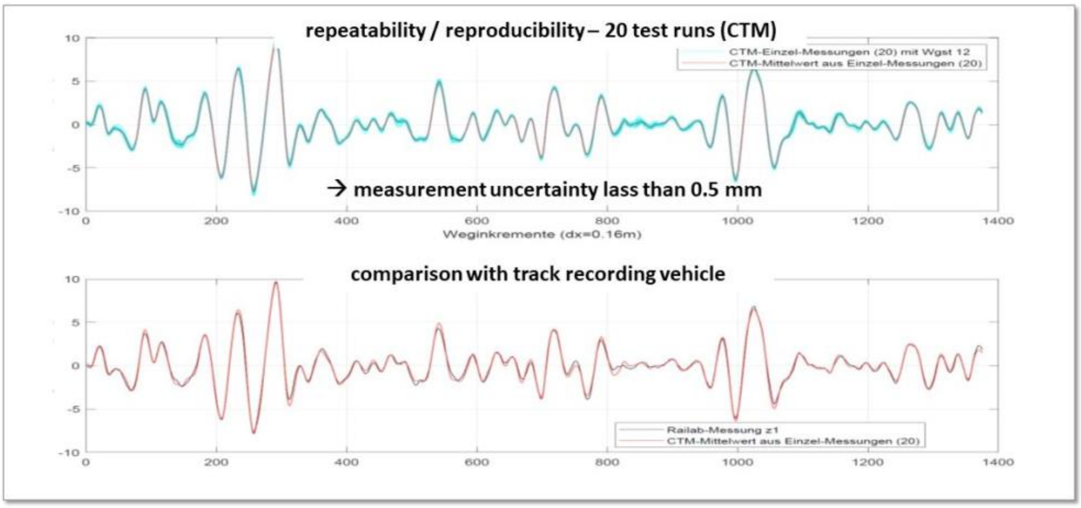

Figure 2 Validation of the CTM 2.0 results [8]

DB Netz AG currently has four first-generation (CTM1.0) and seven second-generation (CTM2.0) CTM measuring systems in operation, with two more to be added by the end of 2023.

On behalf of DB Netz AG, DB Systemtechnik GmbH is responsible for monitoring more than 5,000 kilometres of railway track in Germany using the CTM track measurement system, with the aim is to reach 9,000 kilometres by the end of 2023. The results obtained are regularly provided to the infrastructure managers of DB Netz AG on a weekly basis to help improve infrastructure maintenance. The monitoring data enable early detection of faults, facilitate specific planning of repair work, and allow the quality and sustainability of repairs to be checked. Figure 3 shows the lines operated by DB Netz AG that are continuously monitored with CTM track measurement systems.

Figure 3 Map of the lines operated by DB Netz AG that are continuously monitored with CTM track measurement systems [7]

3 EVALUATION OF THE CTM 2.0 MEASUREMENTS AT THE BRIDGES

In this section, the acceleration measurements of the CTM 2.0 and the calculated track longitudinal irregularities recorded during passages of two specific bridge structures within the monitored network are examined. The two bridges are equipped with a permanently installed monitoring system as part of the ZEKISS research project funded by the German Federal Ministry for Digital and Transport.

3.1 Ballasted single track steel trough bridge

The first bridge structure, for which CTM2.0 recorded passages were analysed, is a single-track steel trough bridge with a span of 16.4 m and a ballasted superstructure. The directional track and the opposite directional track of the line are located on two structurally separate bridges of the same design (Figure 4). The bridge is located on a highly frequented long-distance line.

Figure 4 View of the track and superstructure against the direction of travel (left). View of the bridge from the side with the walkway (right)

The bridge's monitoring system consists of 9 uniaxial accelerometers and 8 uniaxial strain gauges installed on the two main girders of the structure. To trigger the recordings and detect the axles, two pairs of rosette strain gauges are placed on the tracks [10] at two locations that are 14.40 metres apart (Figure 5). The decay phase acceleration signals were used to perform Stochastic Subspace Identification (SSI) automatically using the code from [11]. The time points when the trains left the bridge were determined by analysing the signals from the rosette strain gauges on the tracks. The results show that there is a clear dependence of the frequency on the amplitude, which means that the system has a mechanically nonlinear behavior (Figure 6).

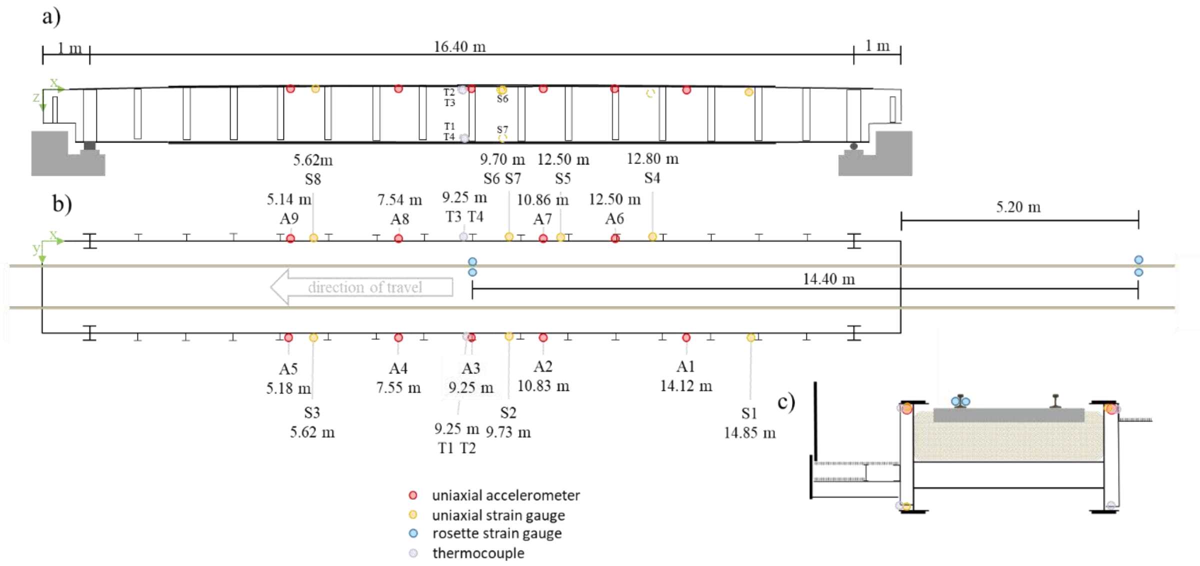

Figure 5 Monitoring setup attached to the bridge: a) side view b) top view c) cross-section

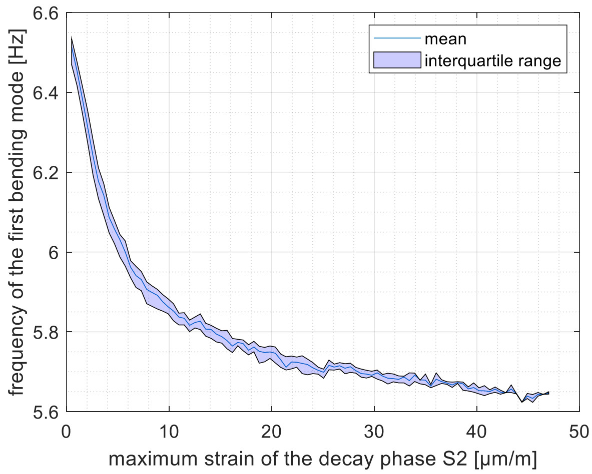

Figure 6 First bending frequency determined by SSI from the decay phases as a function of the maximum absolute values of the strain in the centre of the bridge span.

A total of 17 passages between the dates of 07/02/2020 and 02/23/2022, were evaluated, with speeds ranging from 102 km/h to 162 km/h. The signal section used for evaluation spanned from 250 m before the start to 250 m after the end of the bridge. The acceleration measurements were filtered based on the bridge frequency, as a function of the average speed v_{mean} in the spatial domain, with a wave number of $\Omega = \frac{F_{\mathrm{c}}}{v_{\mathrm{mean}}}$. A 4th order Butterworth low pass filter [12] was employed with a cut-off frequency of F_{c}= 8 Hz. The calculated track positions were then evaluated within the wavelength range D1[13] (3 m<λ≤25 m).

When comparing all measurements from this period, two distinct groups of signals can be identified (Figure 7 and Figure 8). In all figures, the vertical red dashed lines indicate the beginning and the end of the bridge structure on the track route. The distinctive parameter was presumably the tamping of the track ballast, with up to 7 measurements falling into group 1 and 6 into group 2, before and after the tamping, respectively. To ensure that the bridge was excited in the same way, only the passages where the train had the same direction of travel were used for comparison, excluding 3 of the 17 passages. The variance of the two groups differs significantly, with the measured and calculated track positions showing a significantly larger variance prior to tamping.

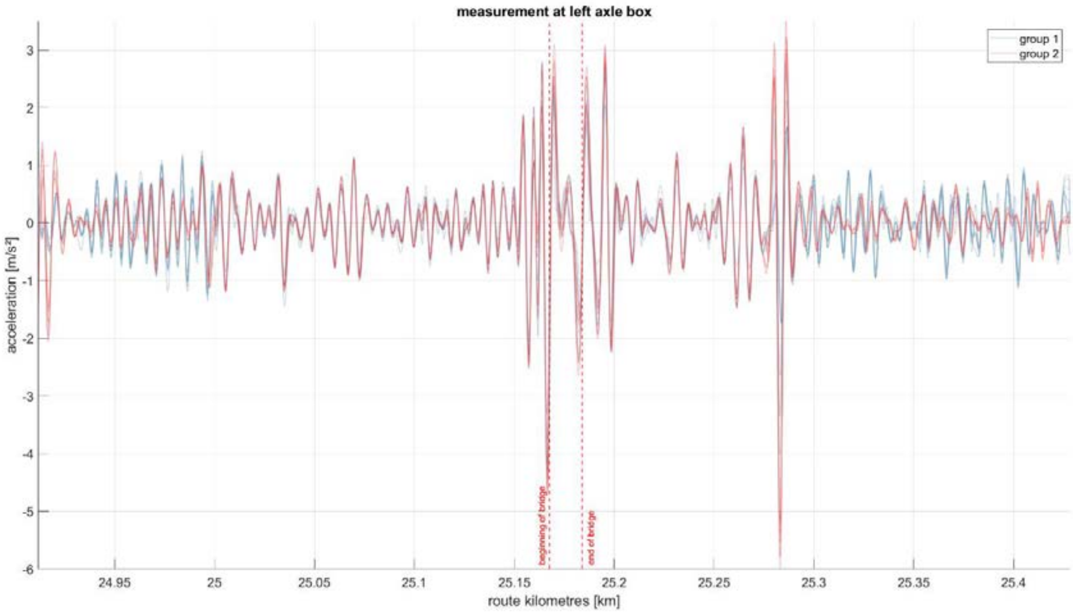

Figure 7 Acceleration signals recorded at the left axle box 250 m before to 250 m after the bridge. Group 1 before and group 2 after tamping the tracks.

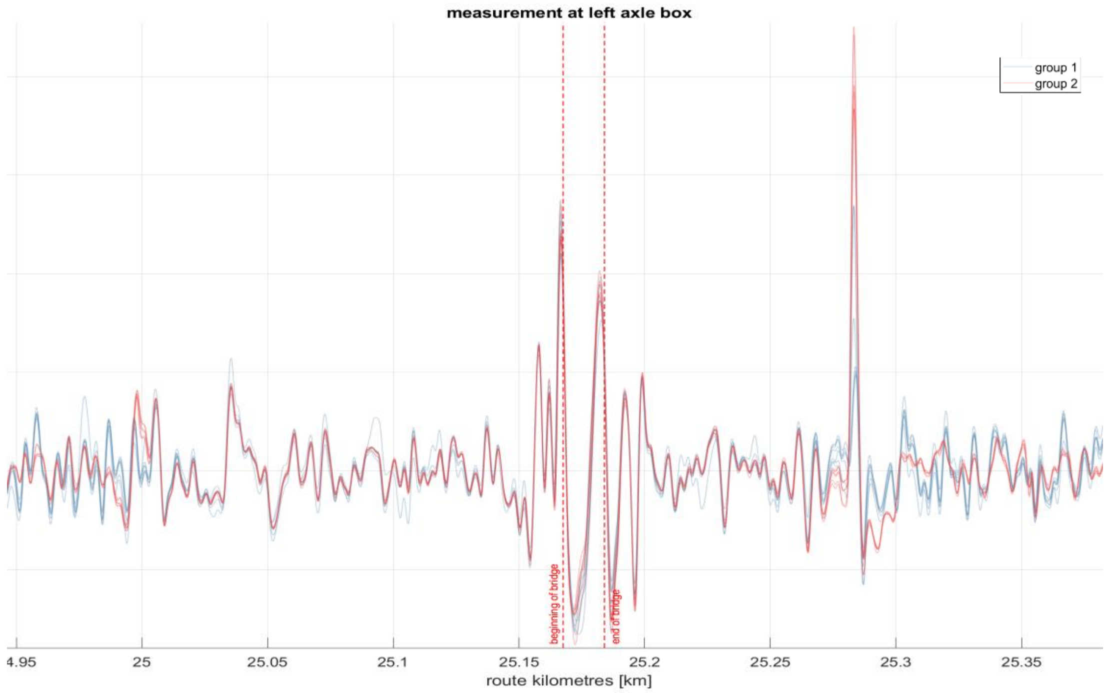

Figure 8 Calculated track irregularities (D1) at the left rail 250 m before to 250 m after the bridge. Group 1 before and group 2 after tamping the tracks.

Presumably, the empirical variance of these signals can be used to detect vibrating bridges or imperfections in the superstructure. Figure 9 shows the sample variances of the acceleration signals for groups 1 and 2 on both rails. To identify outliers in the sequence, a percentile value is defined and a sequence length is chosen in relation to the bridge length on which the percentile value should be exceeded. If a percentile value of 50 is used with a sequence length equal to the bridge length, the bridge is clearly distinguishable. Using these settings, an imperfection on the right side outside the bridge is also detected during the post-tamping period. Figure 10 shows the sample variance of the calculated track irregularity (D1). By defining an outlier with a percentile value of 80 and a sequence length equal to the bridge length, the bridge can be distinguished from the rest of the track, similar to the results obtained with the acceleration signals, including also the identification of the imperfection on the right side of the bridge (see Fig. 10 bottom left). The imperfection detected is below the intervention thresholds of the maintenance planning according to DB-Ril821.2001 (SRA)[14].

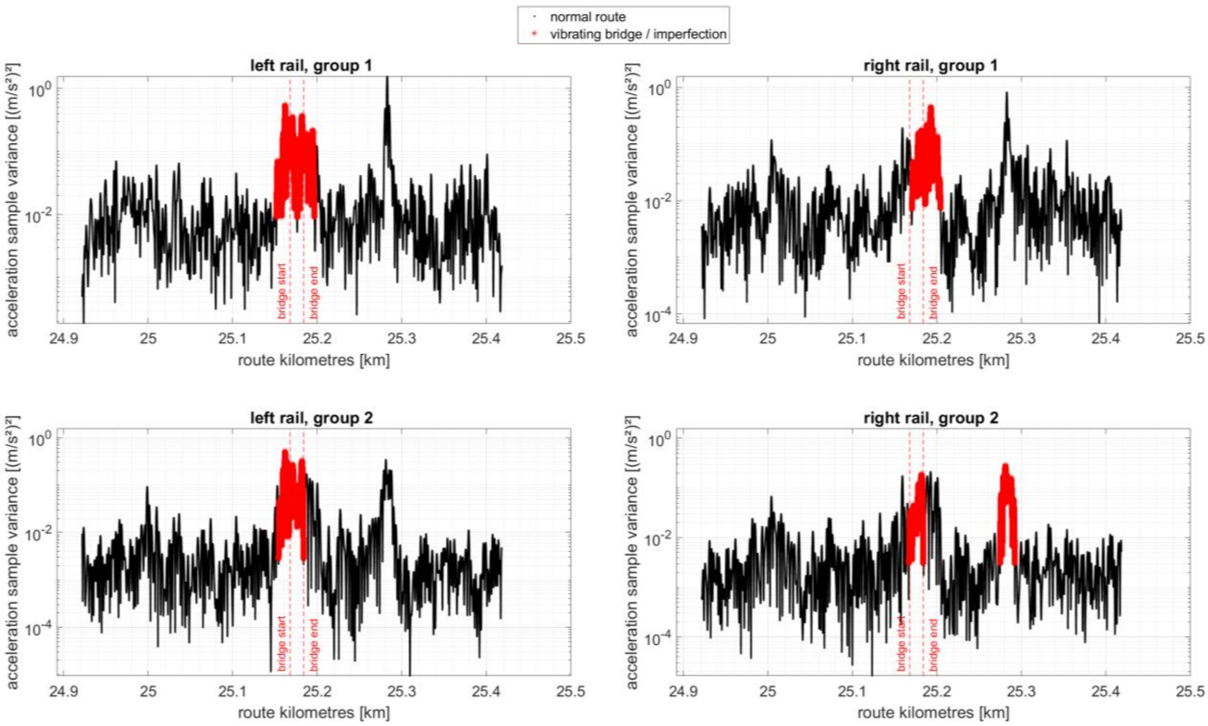

Figure 9 Sample variance of acceleration signals 250 m before to 250 m after the bridge. Group 1 before tamping (top), group 2 after tamping (bottom). Outlier definition percentile 50, length of sequence: 100 % of the bridge length

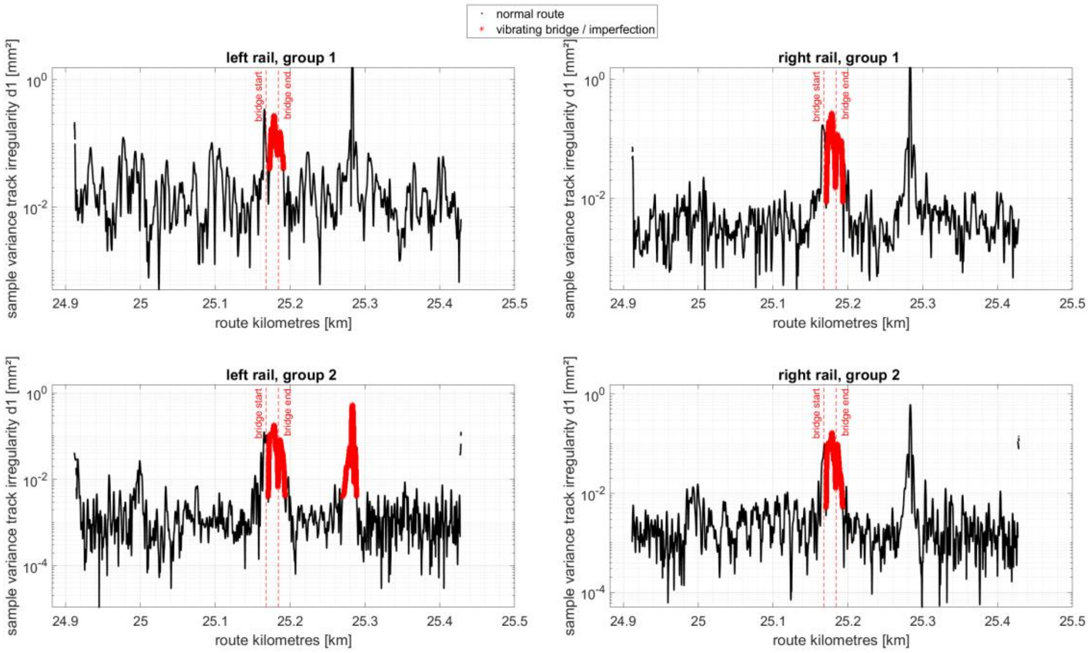

Figure 10 Sample variance of calculated track irregularities (D1) 250 m before to 250 m after the bridge. Group 1 before tamping (top), group 2 after tamping (bottom). Outlier definition percentile 80, length of sequence: 100 % of the bridge length

3.2 Ballastless double track tied arch bridge

The second bridge analyzed in this study is a ballastless double-track tied arch bridge with a span of 77.5 m (Figure 11 and Figure 12). The monitoring system for the ZEKISS research project installed on the bridge includes 8 uniaxial strain gauges, 6 uniaxial accelerometers, and 10 temperature sensors. The dominant bending mode is the antisymmetric mode with two sinusoidal half-waves at 2.74 Hz, while the bending mode with one sinusoidal half-wave occurs at 3.30 Hz. [15] The frequency shows no recognisable dependence on the amplitude, which indicates a mechanically linear system behaviour. From the period from 07/04/2020 to 28/03/2022, 108 runs over the directional track and 79 runs over the opposite directional track were analysed. In the following, the analyses are presented separately for both directions. The procedure is the same as for the bridge described above, except that the filter is adjusted to $F_c = 4$ Hz according to the second bridge's frequency.

Figure 11 IC2 (double-deck IC) passing the bridge

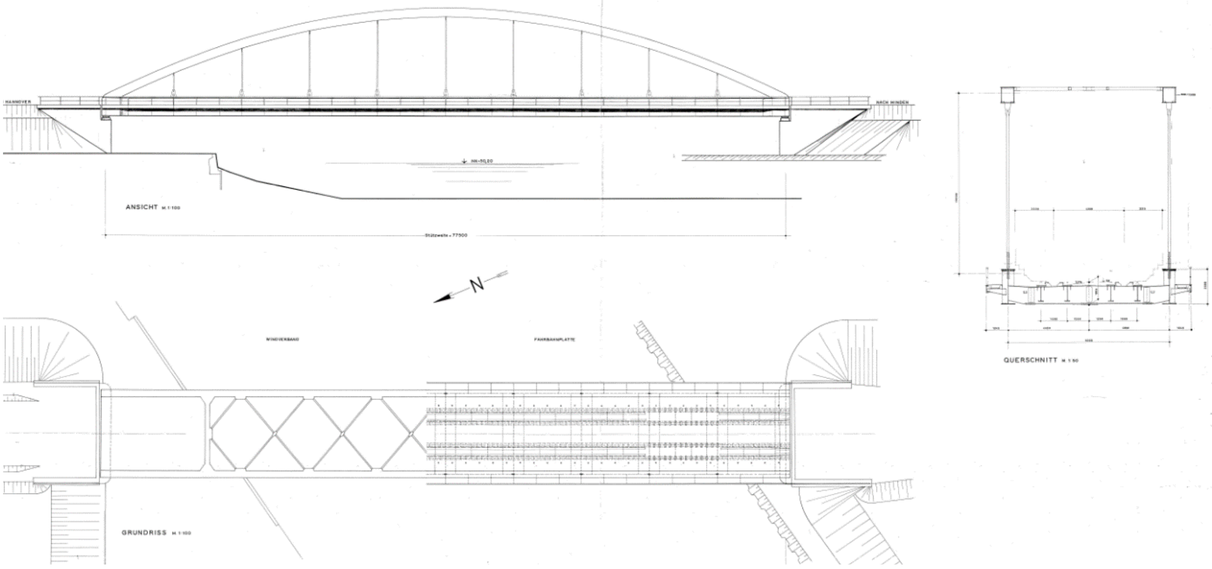

Figure 12 Blueprint of the bridge [16]

DIRECTION TRACK

Two groups per direction of travel were detected at this structure during the period studied, which is probably also due to tamping of the tracks before and after the bridge. However, unlike the previous investigation the signals evaluated after tamping the tracks (group 2) contain some outliers that require further investigation (Figure 13). This investigation is beyond the scope of this article. Therefore, only the variance of group 1 is presented below.

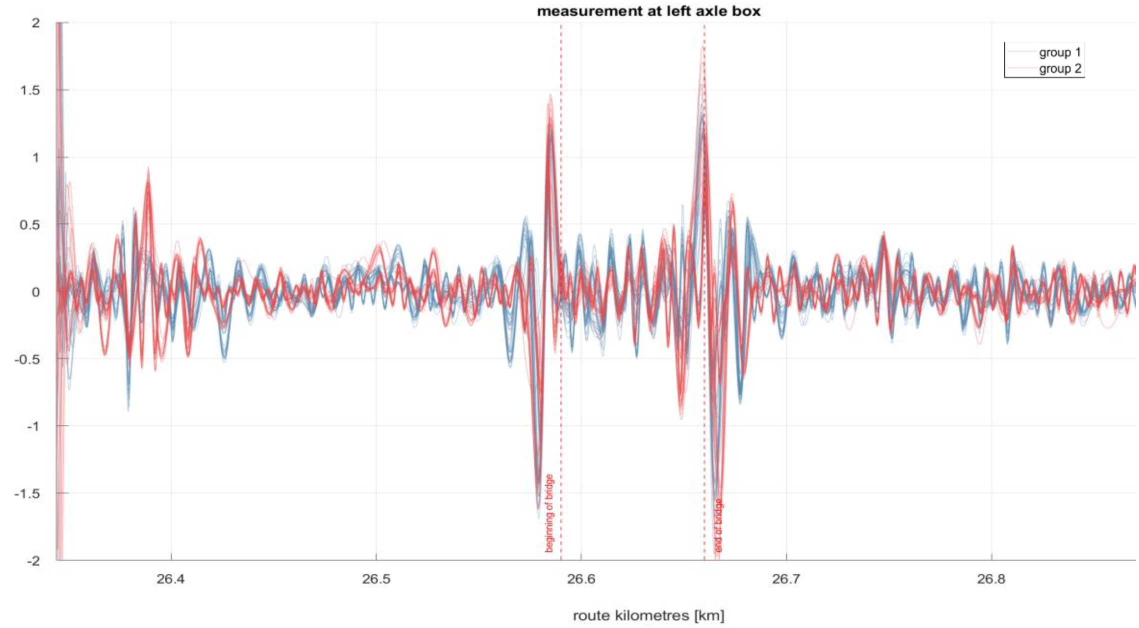

Figure 13 Acceleration signals recorded at the left axle box on the directional track, 250 m before to 250 m after the bridge. Group 1 before and group 2 after tamping the tracks.

Figure 14 and Figure 15 also show that for this structure a distinction of the structure from the rest of the track is possible, with an outside the bridge (on the left side) again being detected. The imperfection is also below the intervention thresholds [14].

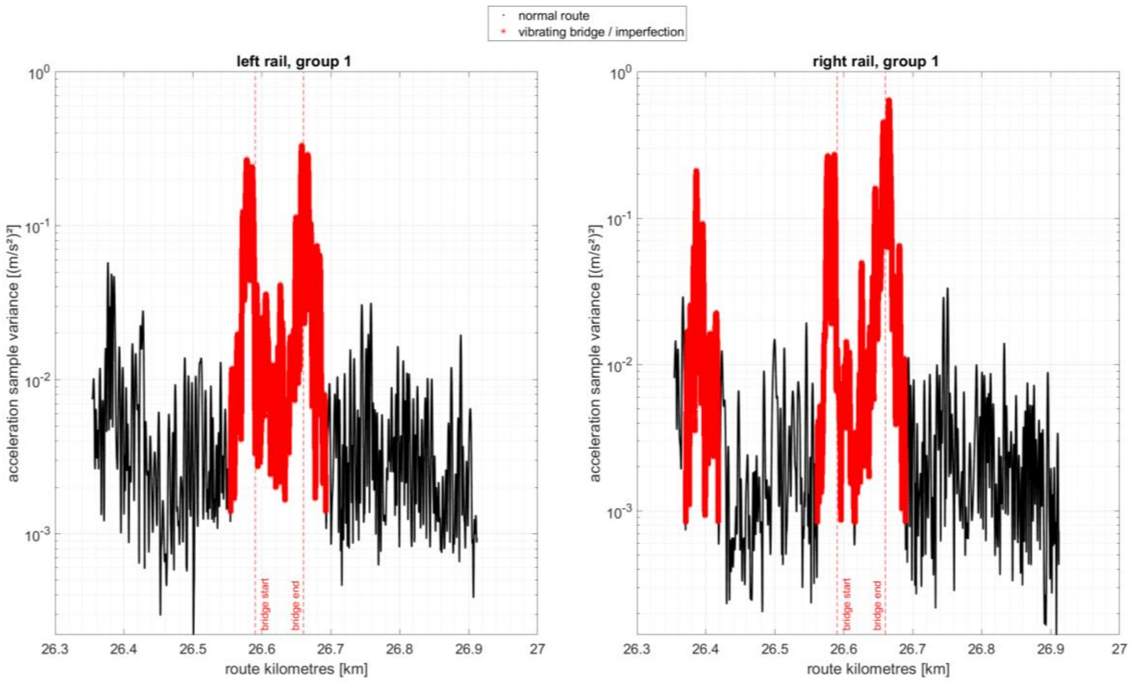

Figure 14 Sample variance of acceleration signals of the directional track, 250 m before to 250 m after the bridge. Group one before tamping. Outlier definition percentile 15, length of sequence: 50 % of the bridge length

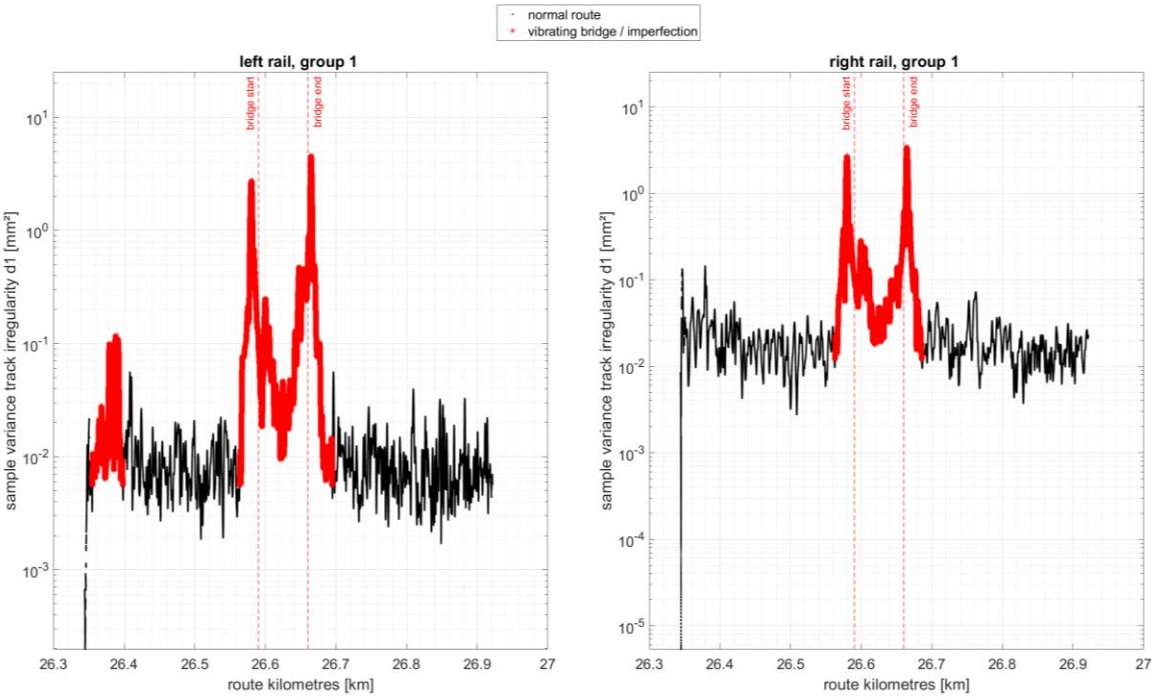

Figure 15 Sample variance of calculated track irregularities (D1) of the directional track 250 m before to 250 m after the bridge. Group one before tamping. Outlier definition percentile 15, length of sequence: 50 % of the bridge length

OPPOSITE DIRECTION TRACK

On the opposite direction track, the results are similar, however, the imperfection outside the bridge is not detected with the selected settings in that case, as presented in Figure 16 and Figure 17.

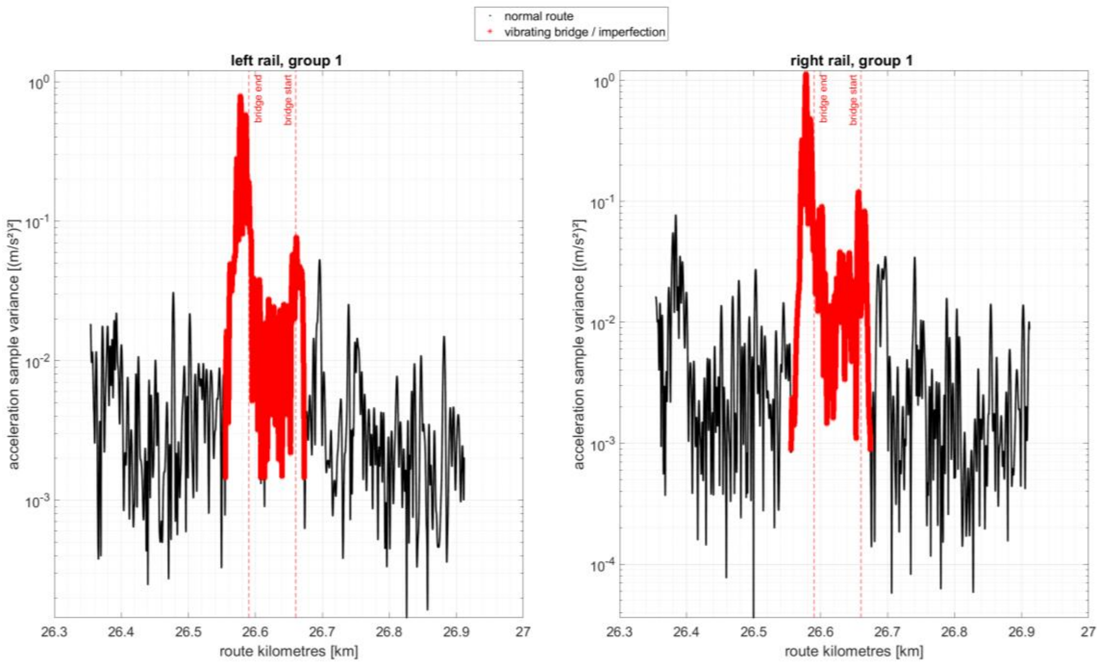

Figure 16 Sample variance of acceleration signals of the opposite direction track, 250 m before to 250 m after the bridge. Group one before tamping. Outlier definition percentile 18, length of sequence: 60 % of the bridge length

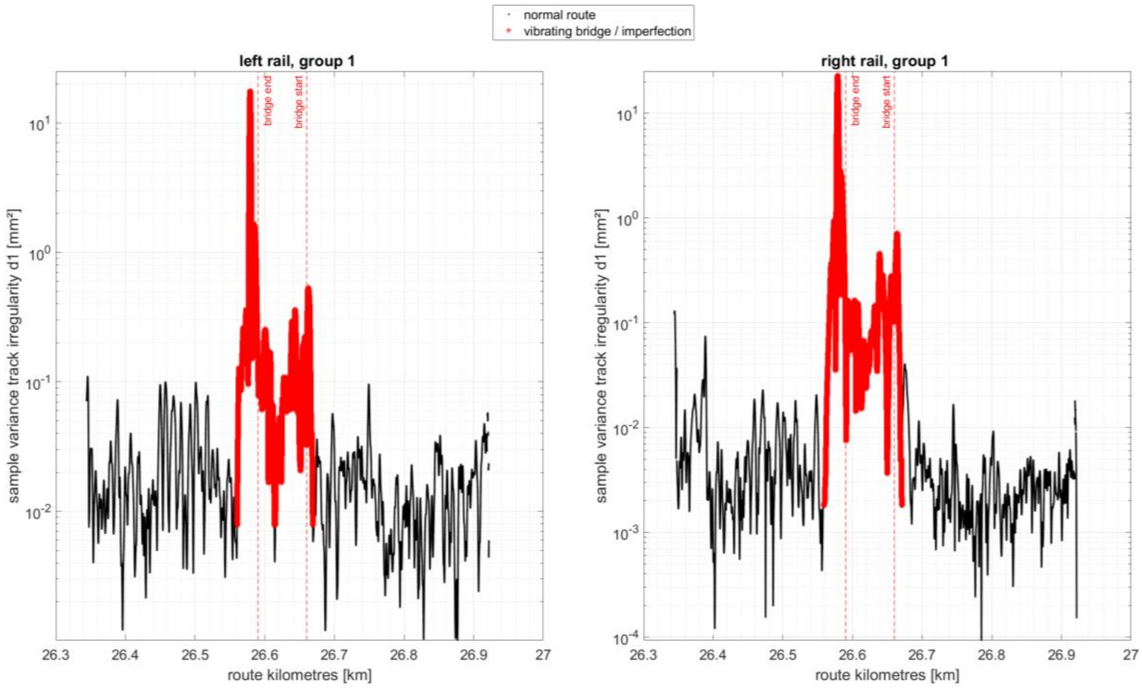

Figure 17 Sample variance of calculated track irregularities (D1) of the opposite direction track, 250 m before to 250 m after the bridge. Group one be-fore tamping. Outlier definition percentile 20, length of sequence: 50 % of the bridge length

4 CONCLUSION

We investigated the CTM 2.0 system from DB Systemtechnik, which can be installed on regularly scheduled trains, to verify the possibility to identify However, further investigations are needed to reduce speed-dependent effects and to define the thresholds for detecting vibrating bridges. For this purpose, we proposed to use the sample variance of the measurements around the bridge structures. The investigations on two bridge structures show that a differentiation from the rest of the track is possible. This applies both to the acceleration measurements and the track irregularities calculated from them.

In any case, the tamping of the tracks has to be considered for the procedure, as this results in a new distribution. The direction of travel of the train must also be taken into account, as the same excitations of the bridge should be compared. The definition of the thresholds for the detection of vibrating bridges requires a certain methodology however this needs to be further investigated on longer track sections and more bridge structures. Furthermore, the influence of the speed-dependent effects should be reduced in future investigations, for example by considering several runs at the same speed. This is particularly crucial for structures such as the first bridge with mechanically non-linear system behavior.

It can be concluded that the results indicate that the CTM 2.0 system can be used to collect information on the bridge stock across the entire network using regularly scheduled trains.

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