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THE LONG-PITCH CORRUGATION DEVELOPMENT IN SMALL RADII CURVES

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Abstract. The paper deals with the phenomenon of long-pitch corrugation in curves of the small radii and also the effects that accelerate or slow down its development. The paper presents data from sections of railway track measured for new rails, rails before and after grinding or replacement. The effect of train speeds running through the curves and the associated cant deficiency or excess were studied. The tendencies of long-pitch corrugation development are described, which can be used to estimate when maintenance action or rail replacement will be necessary.

Keywords: Cant defeciency, cant excess, long-pitch corrugation, speed, track, train.

1. Introduction

Various technologies to remove rail defects such as the long-pitch corrugation are present. The spectrum starts with the preventive grinding and spans all the way to a complete replacement of the rails. To understand which technology is for the track section or even for the specific curve at the time the most durable, a broad microgeometry data collection is necessary. Based on the data history it is then possible to predict the further defect development and to lay down the maintenance guidelines in order to improve the possessions plan and to minimize negative effects on the railway operation.

Although there are procedures and methods to measure a microgeometry of rails, in most cases these applications are simplified for practical use in the track record, for compiling substantial amounts of data, or for the "Rail reprofiling reception" [1]. The evaluation for the purposes of the development of the long-pitch corrugation then happens only based on line manager requests.

For the purposes of measuring and monitoring the defects are categorized according to ČSN EN 13231 3 [1] into four wavelength ranges:

- 10 – 30 mm,
- 30 – 100 mm,
- 100 – 300 mm,
- 300 – 1000 mm.

According to [2], wavelengths in the range 100–300 mm are considered as long-pith corrugation (corrugation primarily on the surface of inner rails in curves).

The categorization mentioned above is not very suitable for the long-pitch corrugation monitoring, hence the length of the waves could be even shorter than 100 mm [3, 4], especially in the curves of small radii. Following [5], based on the long-pitch corrugation creation theory, own measurements, and data comparison, it could be concluded, that for the long-pitch corrugation monitoring the range 30-100 mm and the range 100-300 mm may be merged, since wave amplitudes in both ranges usually reach similar or even same values.

Therefore, according to the above stated, for the rail long-pitch corrugation in particular the ranges 30-100 mm a 100-300 mm are to be monitored.

2. The Long-Pitch Corrugation Development

Monitoring, evaluation, and data quantification of the measured data were conducted using the RMS and P2P calculations. The assessment originates from the 2006 standard ČSN 13231-3:2006 [6], and not from the actual 2012 standard ČSN 13231-3:2012 [1] due to the exclusion of the RMS method. To be able to use the data measured before the acceptance of the 2012 standard, older standard was used.

All the measurements were conducted on the railway line No. 326 (Brno – Česká Třebová) between traffic point Brno – Maloměřice St. 6 and railway station Adamov. Own measurements took place in sections called Hady (HA1.1 and HA1.2 to HA1.4), Bílovice (BV1.1 and BV1.2) and Babice (BS1.2), the track recording car data were used for the section Adamov (AD1.1).

Once the calculated values RMS and P2P are inserted into the graphs, the development speed gradient of the monitored magnitude could be obtained. Examples of the graphs for measuring places in section Hady are shown in Figure 2 and Figure 3.

The line-up of the measuring places according to the gradient is shown in Table 1. The steeper gradients are positioned lower. The consecutive order is also affected by the wavelength range.

When the weighted cant deficiency (or cant excess

Figure 1. Placement of the sections on the railway line No. 326 (Brno – Česká Třebová).

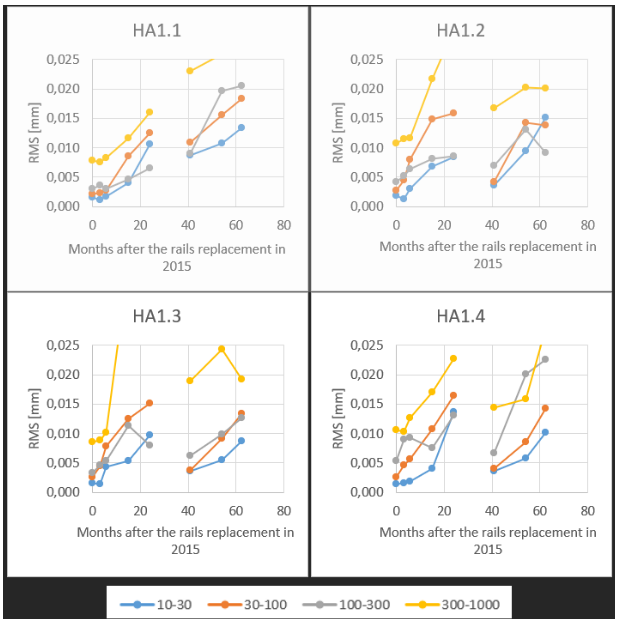

Figure 2. RMS progression in time for section Hády.

respectively) is calculated for each measuring place (curve) as shown in Table 2, the rank of the values in comparison with the Tab. 1 matches the wavelength range 100-300 mm.

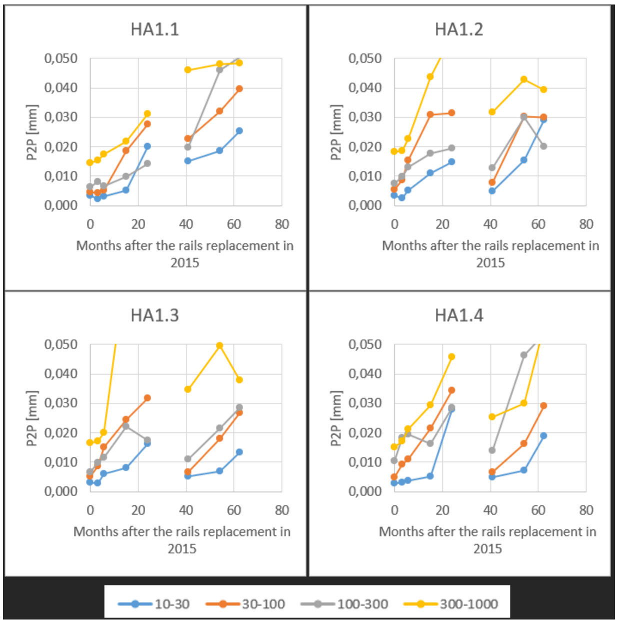

Figure 3. P2P progression in time for section Hády.

30-100 mm	100-300 mm
BS1.2	BS1.2
BV1.2	HA1.1
BV1.1	BV1.2
HA1.1	HA1.2-4
HA1.2-4	BV1.1

Table 1. Measuring places line-up according to gradient.

Curve	$l_{weighted}$ [mm]
BS1.2	21.0
HA1.1	46.1
BV1.2	67.6
HA1.2-4	73.8
BV1.1	87.0

Table 2. Weighted cant deficiencies in curves for all recorded trains (not rounded).

3. Development Prediction

3.1. Prediction Based on the Previous Defect Progression

Sections Hády and Bílovice

Using the gradients, the timeframes required for reaching the RMS and P2P values were calculated for the purposes of the prediction of the future defect development. The timeframes respect the replacement works, or the rail grinding according to the particular place or section.

The timeframe size differs significantly according to

Section		Hady								Bílovice
Measuring place		1.1		1.2		1.3		1.4		1.2
Number of years from timeframe		0 – 24	40 – 63	0 – 24	40 – 63	0 – 24	40 – 63	0 – 24	40 – 63	
30-100	RMS	5.1	6.9	4.1	5.1	4.9	5.7	3.6	4.5	5.0
	P2P	4.7	6.3	4.0	4.2	4.7	5.6	3.4	5.3	5.1
100-300	RMS	22.0	5.6	28.3	37.0	21.0	17.4	49.7	14.2	4.7
	P2P	23.0	4.9	26.1	30.3	23.3	14.9	47.7	13.7	3.9

Table 3. Weighted cant deficiencies in curves for all recorded trains (not rounded).

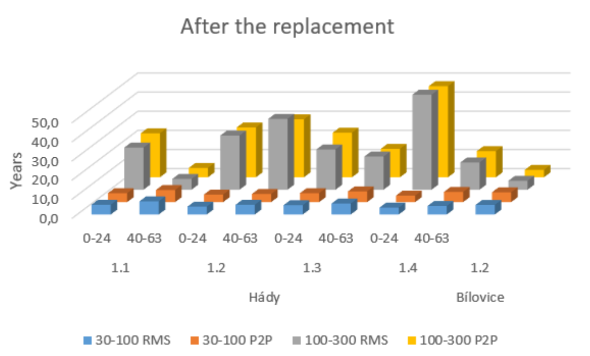

Figure 4. Number of years needed to reach the wave defect progression of the same level as before the rails replacement.

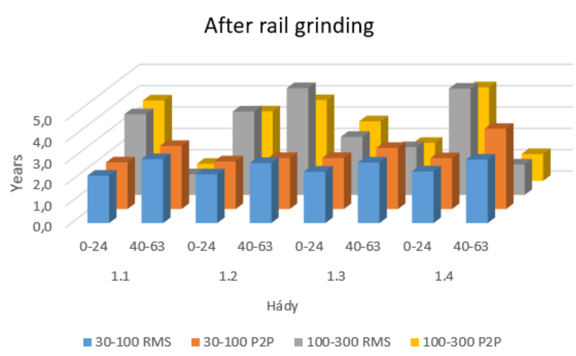

Figure 5. Number of years needed to reach the wave defect progression of the same level as before the rail grinding.

the wavelength range. Whilst the wavelength range of 30-100 mm indicates the timeframe in years, the wavelength range of 100-300 mm reaches tens of years in timeframe estimation. The interval of 17 to 19 years could be associated with the essential modernization of the railway line at the end of the 1990s, where the sections are placed. On the other hand, to assume that the defect development lasts for two decades would not be right, since major maintenance efforts such as rail grinding took place a number of times.

Lastly, the considerably longer timeframe for the defect progression for the measuring place HA1.4 is not the result of the slow development of the defects, but the reason probably is the significantly worse state of the rails before their replacement in 2015.

When calculating the timeframe required for reaching the defect progression of the same level as before rail grinding, the results are shorter. The reason is given by the lesser absolute values to be reached on one hand, but also by the initial state of rails on the other, hence the state of rails after grinding does not necessarily have to be equal to new rails.

Unfortunately, for the measuring places Bílovice 1.1, Babice 1.1, and 1.2 the initial state before the replacement of the rails in 2016 was not documented.

Section Adamov

The same principles of the development prediction were applied to the data from the Track recording car in the section Adamov.

The P2P from the Track recording car is simplified just to values in 0.25 m steps, where all 4 values representing one meter of the rail are given the same value. These values are for the purposes of this paper signed as P2P modified (P2Pm). Furthermore, when all the values for the measuring place are summarized, the P2P modified sum is obtained (P2Pms). This simplification regrettably brings the loss of information about the development progress, on the other hand, it helps to reduce local inaccuracies.

When the P2Pms values are drawn into the chart, the gradient could be assessed. The drawn values are referred to the initial state of the new rails, i.e. after the rail replacement. Together with the known P2Pms values before the rail replacement, it is then possible (by extrapolating the gradients) to search for the time, when the P2Pms reaches the same value as it was before the rail replacement.

This search is practically possible to be conducted on all the four wavelengths, however, the soundest ranges to be examined are the 30-100 mm and the 100-300 mm. To clarify: the wavelength range 10-30 mm, which is embodying the non-periodical rail defects, could show locally randomized development progress. Contrariwise, the wavelength range 300-1000 mm represents more the defects of the track or even the defects of the whole substructure and do not reflect the maintenance done on the superstructure.

The referential value of the developed defect for

Section		Hady							
Measuring place		1.1		1.2		1.3		1.4	
Number of years from timeframe		0 – 24	40 – 63	0 – 24	40 – 63	0 – 24	40 – 63	0 – 24	40 – 63
30-100	RMS	2.2	3.0	2.3	2.8	2.4	2.8	2.4	3.0
	P2P	2.2	3.0	2.2	2.4	2.4	2.9	2.4	3.8
100-300	RMS	3.8	1.0	3.9	5.1	2.7	2.2	5.0	1.4
	P2P	3.8	0.8	3.3	3.8	2.8	1.8	4.4	1.3

TABLE 4. Number of years needed to reach the wave defect progression of the same level as before the rails were ground.

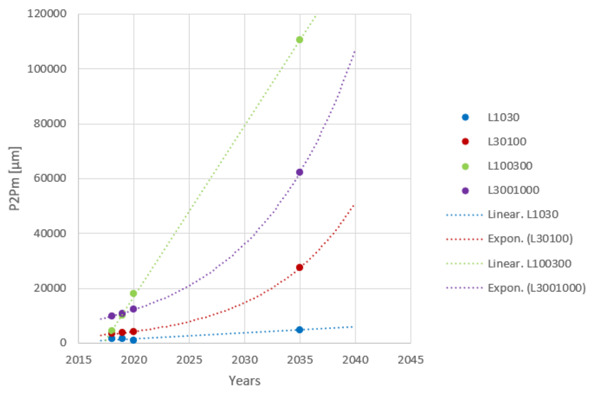

FIGURE 6. Wave defects development prediction based on the previous measurements done by the Track recording car.

the measuring place Adamov 1.1 was taken from the measurement in 2016. Maintenance works were carried out in 2018 (the values for the gradient obtention were from 2018, 2019, and 2020). The type of the regression curve (linear, exponential, ...) is based on the coefficient of determination so that its value is as close to 1.0 as possible.

The P2Pms value corresponding with the initial state before the maintenance works was for the measuring place Adamov 1.1 found in 2035, which represents the progression of the defect for 17 years. It is interesting that this figure is comparable with the progression between 1999 (the newly modernized railway line put into service [7]) and the maintenance works in 2018.

The development prediction, however, could not reflect some minor maintenance works, and also due to not very rich set of measured values, it is burdened with some uncertainty. Moreover, the maintenance works in 2018 were of much lesser scale in comparison with the complex modernization in 1999. That is why the future timeframe still remains to be misty (see Figure 6).

3.2. PREDICTION BASED ON THE GIVEN LIMITS

The most suitable method for prediction is to use the gradients for calculation of RMS and P2P into the values Table 17 (ČSN 13231-3:2006 [6]).

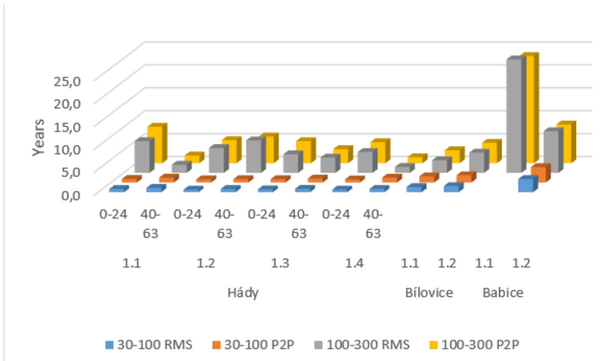

FIGURE 7. Timeframe needed for the defect progression according to Table 17 (ČSN 13231-3:2006 [6]).

The same applies to the standard SŽDC S2/4 [8] for the level 0.1 mm.

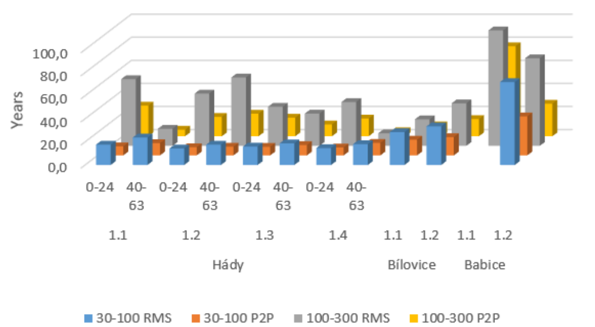

FIGURE 8. Timeframe needed for the defect progression according to standard SŽDC S2/4 [8] for the level 0.1 mm.

The longest timeframe for the defect progression or development appears to be in Babice, although there were some negative gradients for the wavelength range 30-100 mm excluded from the assessment, and also the RMS value for the wavelength range 100-300 mm is cropped.

4. Conclusions

Based on the measurements of the actual state there is the possibility to predict the speed of the further development of the long-pitch corrugation in curves of small radii. Simultaneously, there is a possibility by monitoring weighted cant deficiencies (respectively cant excesses) to estimate in advance in which curves the progression of the defect will be faster.

Currently, a spectrum of measures exists to suppress the development of the long-pitch corrugation: starting with the methods aiming to prevent or slow down the defect progression and concluding with the measures designed to remove already developed defects. It is thus possible to use elastically enhanced superstructure or to grind off the defects extensively. That is why infrastructure managers face the difficult decision of which of the methods would be most suitable for their respective cases. Once they had some appropriate tool to predict the defects progression, they can easily, based on the previously conducted measurements, decide for the actions generating lesser expenses or minimize the track possessions.

Performed measurements have also shown, that long-pitch corrugation monitoring via the P2P values is the most suitable way. Assessments have additionally proven, that such monitoring should not be conducted without observation of other factors and parameters as well, hence the long-pitch corrugation is the result of the processes happening in an interconnected system infrastructure – vehicle – traffic. Some parameters change over time very dynamically (rail wear, composition of trains), others are consistent (such as curve radii). Long-term monitoring shows, that even in sections, appearing for the first sight as homogeneous, where unified construction and parameters take place, still some anomalies are present with different properties. These could be not only of the construction type (like the superstructure composition), but also even historical (previous actions not just to the infrastructure itself, but to the entire system infrastructure – vehicle – track). That amplifies the need for the selection of the appropriate parameters for the monitoring.

Regarding the current state, where the tracks are regularly diagnosed by the track recording car for the superstructure, there is no lack of high-quality data. In the case of the national line corridors, this means consistently three times during one year to obtain such data. Naturally therefore there should be the drive to assess the data not only for the backward analysis but also for the defect development prediction. In the modern era, where powerful hardware and neural networks are present, data analysis is even easier.

There is also the need for defect progression prediction on the designer side. The current state of the general knowledge of track designers is not overly broad: the usual conclusion is that the usage of curves of small radii is wrong, and it will eventually lead to long-pitch corrugation development. This is the space, where quality information about the parameters affecting the progression of long-pitch corrugation could be used most. Track designers like to use guidelines and therefore some kind of a handbook, where the significant parameters, superstructure choices, and other crucial aspects would be summarised, would eventually lead to a significant decrease in the construction and maintenance costs and also in the number of possessions.

As a result, society would obtain superior, safer, more dependable, and a neighbourly conscious railway track.

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