Defect Signal Detection Within Rail Junction of Railway Tracks

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Summary
The method of signal detection from transverse crack within rails joint is presented in the article. Using of correlation analysis of this signal after subtraction of averaged rails joint signal from it is proposed. The signal alignment for averaging is based on the mean value crossing point.

Keywords: railway diagnostic, defect, joint

1. Introduction

Defects in the railway rails are serious threat for traffic safety. In particular transverse crack in the rail head can cause significant economical losses. This defect can be detected only with special diagnostic equipment which efficiency depends on qualification of operators. Particularly difficult to detect a defect within the rail joint [1, 7].

The system used on the crack detector wagon of Lviv railway data acquisition is performed with fixed sampling frequency of 5 kHz. However depending on current wagon running speed the acquired data is resampled in the way to get samples with 1 cm step along the rail. Such characteristics are considered satisfactory for signal visualization and defect detection by operators.

On Fig. 1 the fragment of defectogram recorded with defect detector cart at Lviv railway is presented. Operators observe the defectogram in a similar view when performing analysis. The abscissa axis is the order numbers of samples, ordinate axis is amplitude of the signal in the values of analog to digital converter.

On presented defectogram on the background of near periodical signal from rail holding elements 1, signal from transverse crack 2 and typical high amplitude signal from rail joint 3 are clearly visible. Also the signal of negative polarity coming from the beginning of fishplate 4 and signal of positive polarity coming from the end of the same fishplate. Length of the fishplate is 80 cm, which allows determine the mutual placement of inhomogeneity of the railway.

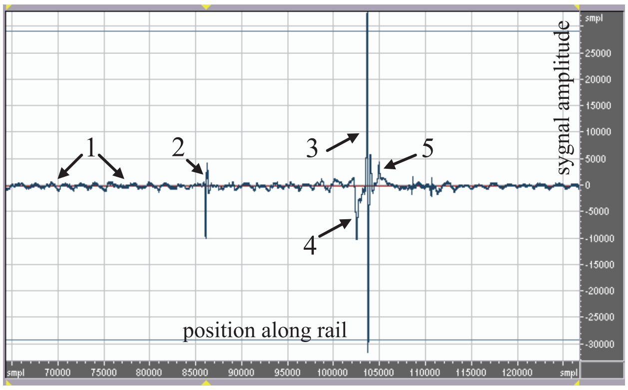

Fig. 1. Fragment of defectogram with transverse crack defect

As it can be seen from defectogram, rail joints form the signal which amplitude and time characteristic is similar to the transverse crack signal. This can mask and distort signal of the real defect if it is placed within rail joint. Solving the problem of automatic defect detection within the rail joint is an urgent task as it is aimed to help operators with defect identifying [5].

2. Problem definition and research methodology

The signal induced in the sensor of running defect detector wagon is time domain visualization of the spatial distribution magnetic field disturbances caused by inhomogeneity of the railway, in particular

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by defects. When using inductive sensors, as it is on the Lviv railway defect detector wagon, signal corresponds to the derivative of the spatial distribution of the magnetic field disturbance. Also as it was written above, defectoscopic data is stored with survey to the railway with interval of 1 cm. That is why it is more convenient to implement spatial processing of defectoscopic data instead of time domain processing.

Let ***y*** be the running coordinate along the railway. Then all investigated dependencies will be functions of the argument ***y***. Let's introduce the following denotation of spatial signals:

$S_i(y)$ – signal from *i-th* rail joint;
$S_D(y)$ – signal from the defect.

All signals from rail joints are aligned along ***y*** axis to form average signal from rail joint:

$$S_0\left(y\right)=\frac{1}{N}\sum_{i=1}^{N}S_i\left(y\right), \qquad (1)$$

where: N – number of signal records from rail joints used for analysis.

For performing modelling let's form a set of signals from each rail joint with defect:

$$SD_i(y) = S_i(y) + S_D(y). \qquad (2)$$

Then we can perform correlation processing of the signals. By analogy with the notation of cross correlation function for time domain signals, [2] such function can be defined by expression (3).

$$KD_i\left(Y\right)=\int_{-Ym}^{Ym}SD_i\left(y\right)\cdot S_D\left(y+Y\right)dy, \qquad (3)$$

where: Ym – integration range. Considering duration of rail joint signal is limited, it is enough to use reduced range for integration of $Ym = \pm 100$ cm.

However direct correlation processing of the signals $SD_i(y)$ will not be effective, since signal level of any rail joint (Fig. 1) is much higher than signal level from the defect. That is why the following methodology is proposed and used in the work. The averaged signal from rail joints is subtracted from each rail joint:

$$S_{\Delta i}\left(y\right)=SD_i\left(y\right)-S_0\left(y\right). \qquad (4)$$

Then let's build cross correlation function between expression (4) and defect signal $S_D(y)$ which position along ***y*** axis is considered known.

$$K_i\left(Y\right)=\int_{-Ym}^{Ym}S_{\Delta i}\left(y\right)\cdot S_D\left(y+Y\right)dy. \qquad (5)$$

Conclusion about defect presence within rail joint can be made if the maximum of correlation function corresponds to zero of its argument.

3. Results of experimental research

Often when performing experimental research mathematical models of defectscopic signals are used [4, 6]. This allows solving some part of problems without expenses on hardware and equipment. However models are not always taking into consideration all features of real signals. That is why experimental verification of proposed method performed by procesing and analyzis of real rail inspection signals recorded with defect detector cart at Lviv railway. The fragment of defectogram used by authors included 143 signals from rail joints and one signal from transverse crack defect.

For example aligned signals from randomly chosen two neighbors rail joints are shown on Fig. 2. They are $S_{48}(y)$ shown with solid line and $S_{49}(y)$ shown with dotted line. Signal visualization is done using Mathcad software [3].

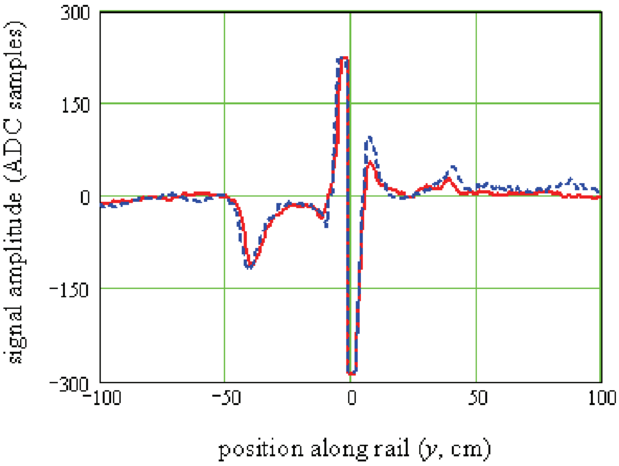

Fig. 2. Aligned signals from two neighbors rail joints

Along ***y*** axis signals are represented on interval ±100 cm, which allows better identify all signal features and characteristic. Amplitude values correspond to the data from analog to digital converter (ADC) of the defect detector. All 143 signals from rail joints are aligned on the point of crossing their mean value.

It can be seen from Fig. 2 that signals from even neighbor signals can be considerable different from each other. Main reasons for this are technological deviation of rail joint elements size. In particular gap between the joined rails, different detrition. For example photo of two rail joints is shown on Fig. 3.

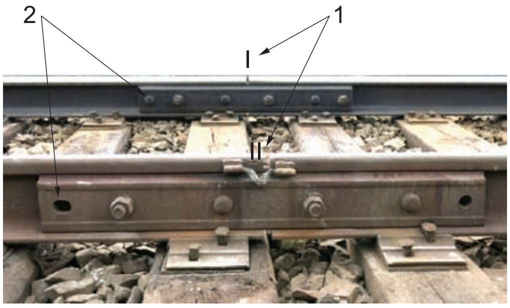

Fig. 3. Difference of rail joints

Their air gap differs by two times (1). Also fishplates of the near joint are mounted with four bolts and on the far joint fishplates are mounted with six bolts (2). Bolts are pretty massive and can make their contribution into the magnetic field scattering. In addition differences of signal shape can be caused with random displacement of the sensor due to vibration.

If there is no information about particular rail joint in the memory of defect detection system for the area of possible defect the question of forming hypothetic signal. This can be averaged signal from rail joints $S_0(y)$ obtained from expression (1). This signal is presented on Fig. 4.

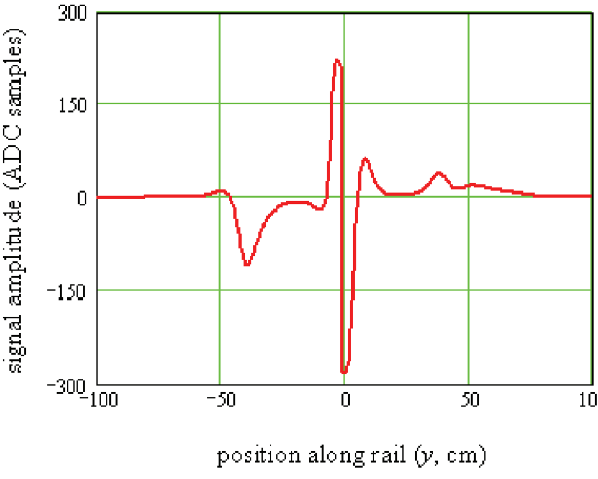

Fig. 4. Averaged signal from rail joints

By averaging 143 signals fluctuations caused by the influence of substrate sleeper and noise are significantly smoothed, clearly visible signal of the beginning and the end of fishplates, the distance between them is about 80 cm.

Having averaged signal of rail junction we can assess the similarity of signals from rail joints using for example Pearson's correlation coefficient. In Mathcad these coefficients can be calculated by using the built-in $r_{0,i} = corr(S_0, S_i)$ [3]. Distribution of Pearson correlation coefficients for the studied rail joints presented in Fig. 5. The median value of the correlation coefficient for this sample is 0.97. It should be noted that the signals from rail joints where the correlation coefficient is less than 0.9 are visually very different.

There are six such signals $S_{16}(y)$, $S_{49}(y)$, $S_{71}(y)$, $S_{87}(y)$, $S_{92}(y)$ and $S_{130}(y)$. For example, the signals presented in Fig. 2 correlation coefficient is 0.978 for the sygnal $S_{48}(y)$ and 0.86 for the signal $S_{49}(y)$. The low value of the correlation coefficient between the signal on the specific rail junction and averaged signal from rail joints may make detection of the defect more difficult.

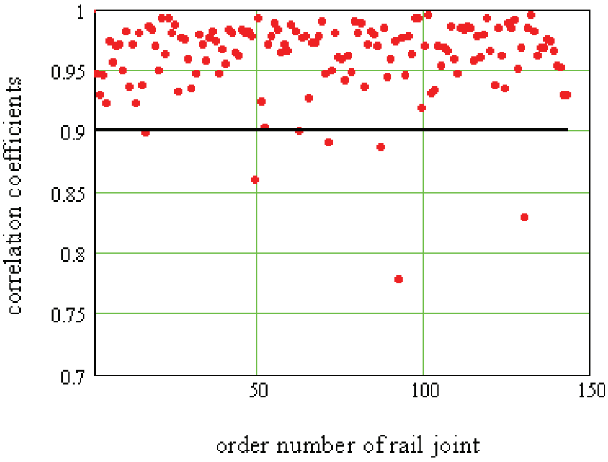

Fig. 5. Pearson's correlation coefficient for rail joints

The signal from the defect – transverse cracks from the same defectogram is shown in Fig. 6.

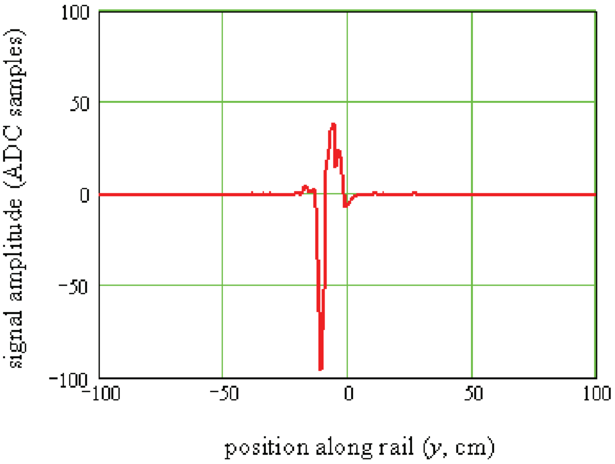

Fig. 6. Signal from the transverse crack defect

Root mean square value of detected signal from the defect was about 17 dB below the signal of averaged rail junction. To better reflection its amplitude scale changed three times. The graph shows a slight distortion of the signal caused by low sample rate while saving signals. Beyond its existence array of numerical data from the defect signal is supplemented with zeros, this assured of same dimension and consistency for the duration of signals from arrays rail joints.

The next step was the addition of the defect signal to each of the signals from the rail joints, according to the expression (2). This operation realized a simulation signal from the rail junction with the defect. Its result for the signal $SD_{48}(y)$ is shown in Fig. 7.

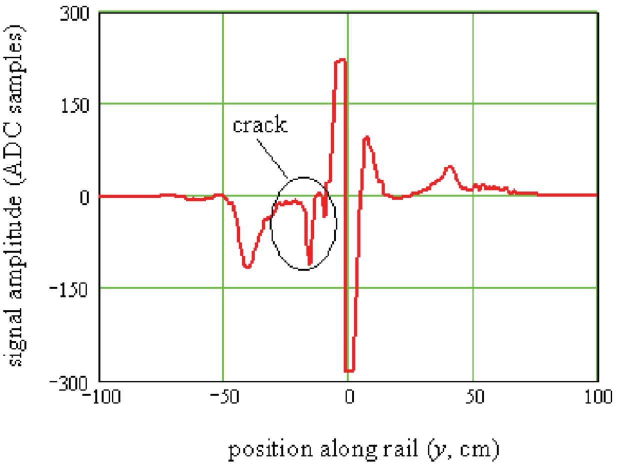

Fig. 7. Simulation of signal from rail joint with transverse crack defect

Because at this stage of the study defect position is considered as known, the maximum correlation function is expected at zero of the argument and it should be positive. The result of direct correlation function calculation by the expression (3), presented in Fig. 8 showed the following.

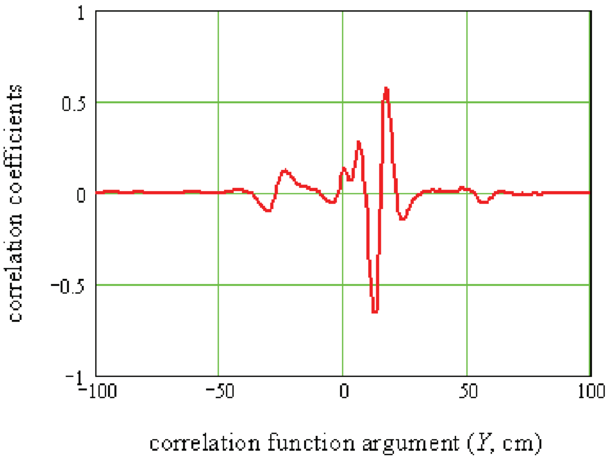

Fig. 8. Correlation function of signal from rail joint with defect with signal from defect

The correlation coefficient with $Y = 0$ is very low and is merely 0.139. Side maximums of correlation function show similarities of fragments of rail junction signal with the signal of the defect, which greatly complicates the task. The subtraction operation of signal averaged rail junction signals on the signal from the rail junction with the defect, according to the expression (4) made it possible to get the difference signal shown in Fig. 9.

The graph shows clearly visible signal of the defect, but there are adverse deviation of the signal waveforms caused by mismatch on the specific rail junction and averaged rail junction signal.

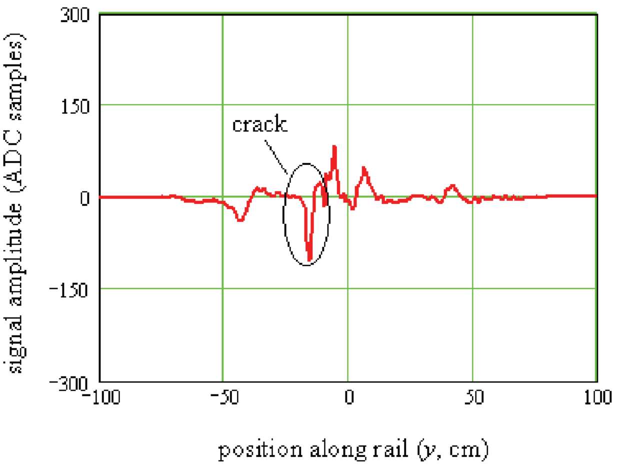

Fig. 9. Result of subtracting the averaged rail junction signal from the rail junction signal with defect

The result of the calculation of the correlation function in this case is the expression (5) shown in Fig. 10.

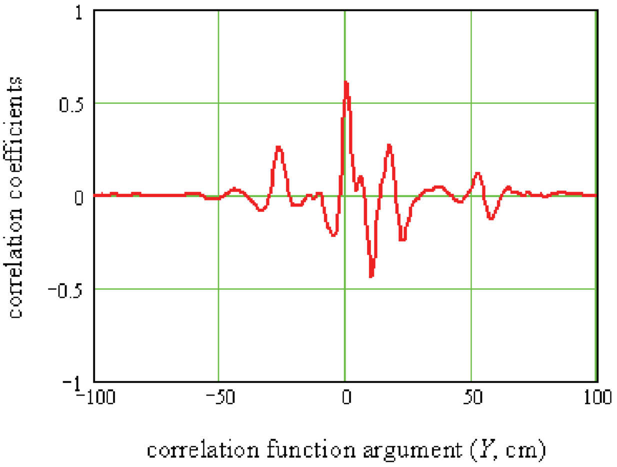

Fig. 10. Correlation function of difference signal with signal from defect

As you would expect the correlation coefficient with $Y = 0$ has increased significantly and is 0.613. It is the greatest of all positive deviations of the correlation function. In practice, this result should attract the attention of the operator defectoscop wagon for a more detailed analysis of the signal from such junction.

Since the signals from the studied rail joints are significantly different, then it is expected that a significant number of considered signal correlation coefficients are lower. By analogy with the calculation of correlation coefficients for rail joints, which result is shown in Fig. 5, the calculation of correlation coefficients for all investigated signal with the signal from the defect was performed. The results are shown in Fig. 11. Each point on the graph corresponds to a value of the correlation coefficient for a particular rail junction, which is investigated.

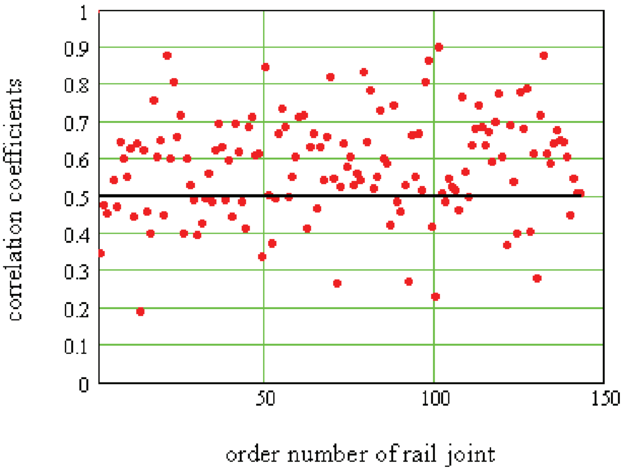

Fig. 11. Correlation coefficients of difference signal with signal from defect

Despite the fact that all the investigated samples of signals include defect, correlation coefficient is not high, because of the significant difference in signals from rail joints, which were available to the authors. That is why correlation coefficient greater than 0.5 is defined as a criterion for the assertion of the defect.

It is found that studied 143 signals in 41 event had correlation coefficient less than 0.5. This means that 28.7% of joints with defects were missed. For the remaining 102 signals which are 71.3%, this ratio was greater than the defined level, and its maximum placed at zero of argument, indicates the presence of a defect. So described technique can be adopted as the basis for the criteria for automatic detection of defects within the rail joints.

The difference waveforms of adjacent rail joints is the reason that the result of subtracting them from the average signal from the rail junction formed difference signal fragments which may be similar to the signal from the defect. This can lead to the formation of additional peaks in the correlation function of other values of the argument.

As mentioned above, the difference signals from rail joints affecting technological dimensions of the deviation of the rail joints, particularly the gap between the rails, uneven wear and possible sensor displacement. An additional reason for the author's opinion, is the lack of spatial sampling investigated defectoscopic signals.

For example, a signal from a defect in negative values area, where is the maximum change includes only four counts, and the signal from the rail junction in the transition through zero has no intermediate values. Such a resolution is sufficient for defectoscop wagon operators to visualize and detect signals. However, the construction of the automatic defects detection system, the sampling step should be reduced by increasing the sampling rate of defectoscopic system that is not problematic for modern electronic means.

4. Conclusion

1. Proposed method allows detecting signals from defect within rails joints using maximum of correlation function in automatic mode. 71.3% of joints with defects were found. It will be used for the construction of the automatic detection of defects within the rail joints.
2. The reason of significant deviation of correlation coefficients during experimental research is deviation of real signals from rails joints which were taken for making average signal.
3. For increasing performance of this method the quality of signals should be improved, in particular the sampling rate should be increased.

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Wykrywanie wad sygnału na złączu szynowym

Streszczenie

W artykule przeanalizowano sposób identyfikacji sygnału pochodzącego od pęknięcia poprzecznego w obszarze złącza szynowego. Zaproponowano wykorzystanie analizy korelacji tego sygnału po odjęciu uśrednionego sygnału pochodzącego od luzu pomiędzy szynami. Analizowane sygnały znajdują się dokładnie w punkcie przejścia przez ich wartość średnią.

Słowa kluczowe: diagnostyka toru kolejowego, wada, złącze szynowe

Обнаружение дефектов сигнала на рельсовом стыке

Резюме

В работе проанализирован способ идентификации сигнала происходящего от поперечной трещины в районе рельсового стыка. Было предложено использование корреляционной обработки этого сигнала после отнятия усредненного сигнала из стыкового зазора. Анализированные сигналы выступают точно в пункте пересечения их среднего значения.

Ключевые слова: диагностика железнодорожных рельсов, дефект, рельсовой стык