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Design and fabrication of a non-destructive system to detect rail corrugation

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The present paper proposes a technique that is capable of inspecting the rail head for corrugation before and after the grinding process with high accuracy and repeatability. The heads of the rails, at certain places, are found not straight but corrugated i.e., with a wavy surface. This phenomenon is called corrugation. It is one of the common defects of railway lines that if it is not eliminated in time by grinding operations, could cause a lot of damage. Considering the importance of inspecting the issue of the railways, the application of nondestructive methods can be an effective step to detect the defects and, consequently, prevent irreparable damage to the railway industry. In this research, a device equipped with an accelerometer has been designed and fabricated to detect and measure corrugation. The proposed system generates an immediate qualitative and numerical report to predict a proper maintenance action or check the quality of the grinding. The implemented system is part of the RDD-S11 rail defect detector equipment and is currently in use in Mashhad Urban Railway Company.

1. Introduction

A railway system, like any other infrastructure, requires maintenance and repair operations and the occurrence of any problems in it could cause irreparable damage [1]. Therefore, the use of preventive maintenance methods is very important. The first step before any preventive operation is to identify possible defects because if not identified in a timely and reliable manner, it will not be possible to take effective preventive action. In recent years, various non-destructive methods have been used to detect and characterize discontinuities in railway lines [2, 3]. These defects include corrugation [4], lateral and vertical wear [5], and rolling contact fatigue (RCFs) cracks [6] that occur on busy railroad tracks and cause many of serious damage to these lines. Early detection of these rail defects is very important. If these discontinuities are not identified and eliminated, their amounts will exceed the critical values and will lead to irreparable damage.

The corrugations or wavy irregularity of the rail surface are successive waves with shiny heads and opaque dimples that form on the rail surface. This phenomenon is observed not only in high-speed freight and combined lines but also in very light lines such as urban railways and subways [4]. Increasing the contact/additional dynamic forces between the wheels/rails, rapid wear of the wheels, reducing the life of the rail vehicle suspension system, increasing the noise caused by the train movement, and reducing the durability of the line geometry are the most important damages that are caused by corrugation [7].

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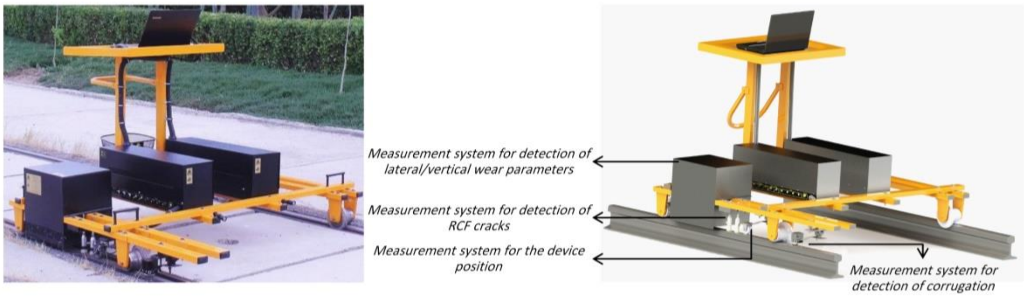
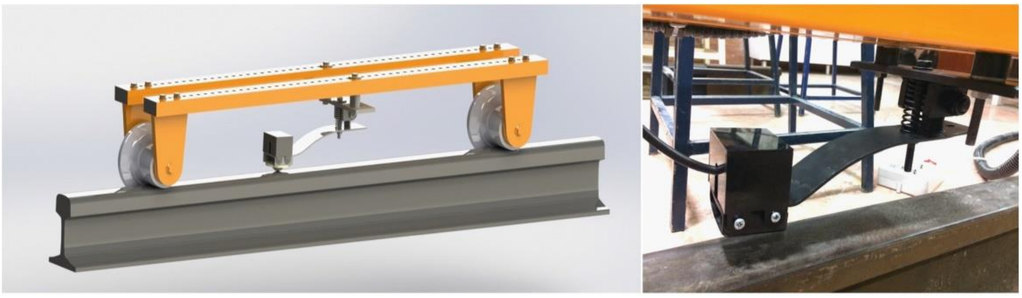


(a) (b)

Figure 1. RDD-S11 rail defect detector, (a) actual image and (b) computer model.



(a) (b)

Figure 2. System designed to detect and measure corrugation, (a) computer model and (b) actual image.

When a train passes over a corrugated rail, a roaring noise is caused, which is unpleasant to the passengers. The corrugation consists of minute depression on the surface of rails. They are usually created at places where brakes are applied, or trains start. Therefore, quantitative evaluation of corrugation is of great importance concerning costs of repair and maintenance operations of the railway industry [4].

Corrugation can be measured directly and indirectly in various ways, in which, the surface roughness of the rail is scanned and measured directly and separately from the wheel roughness. However, this method is not applicable for measuring line profiles in a large railway or metro network with thousands of kilometers of railways [8, 9]. Indirect measurement of corrugation can be done by measuring the amount of noise (via a microphone under the train or inside the wagon) or by measuring the vibration by accelerometers mounted on the axle box [10-12]. Barkhausen magnetic method has also been used as a non-destructive method in indirect detection of corrugation. In this method, due to the change in the microstructure of the rail, the corrugation created on the rail surface is identified [13]. Another indirect method works by utilizing the accelerometer. An accelerometer is a sensor that converts mechanical acceleration into a corresponding electrical signal. The accelerometer measures change in acceleration according to the position of the surface heights by moving the wheel on the rail surface. Thus, after processing the resulting signals, the rail surface profile is drawn and the presence or absence of corrugation on the rail surface is detected. The wavelength and amplitude of corrugation on the surface can also be calculated according to the drawn surface profile [14].

In this study, due to the importance of quick detection of corrugation to eliminate it in a short time, a non-destructive system for detection and measurement of corrugation has been designed and fabricated. This system is put into the RDD-S11 equipment, designed and manufactured at the Sadjad Center for Nondestructive Evaluation (Sadjad CNDE) for fast, accurate, and simultaneous detection of three common rail surface defects including corrugation, wear, and RCF cracks. This device is currently in use in Mashhad Urban Railway Company.

2. Design and fabrication

Figure (1) shows an image of the RDD-S11 equipment and its computer model. Here in this paper, the corrugation measurement subsystem of this device will be discussed.

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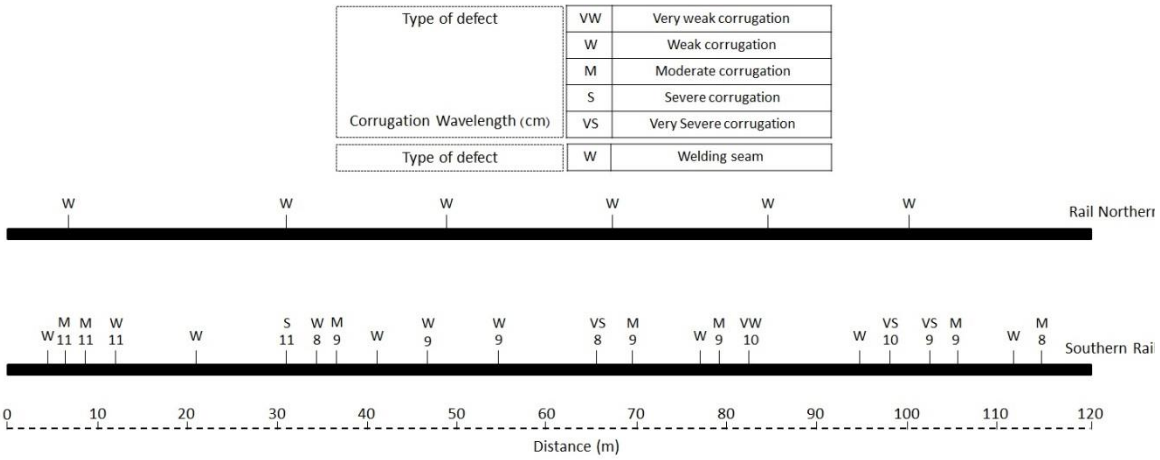

Figure 3. Results of visual inspection of corrugation detection in a 120-meter path of the railway lines of Mashhad Urban Railway Company.

2.1. Measurement system hardware

After investigating several methods for the detection and characterization of corrugation (including optical sensors, millimeter displacement, accelerometer, etc.), the accelerometer approach was applied. A three-axis MPU 9250 accelerometer sensor with a 16-bit internal analog-to-digital converter was used to gauge the corrugation. This sensor was mounted on a movable trolley on rail lines with a mechanical arm. Figure (2) shows the computer model and the real image of the used system. By using the mechanical arm, the oscillations on the rail surface are transferred to the accelerometer sensor when the trolley is moving. This mechanical arm is designed in such a way that its ball-shaped steel end is always in full contact with the rail surface. A polymeric material with suitable abrasion resistance covers the floor of the steel ball. It prevents direct contact between the metals (which can lead to acoustic instability and surface wear) when the trolley is moving. Indeed, vibrations caused by the steel ball being pulled on the surface of the rail, which can lead to invalidation of the system output, are damped by this polymeric material.

2.2. Measurement system software

After scanning the rail surface by the accelerometer sensor, the resulting data (acceleration values measured by the accelerometer sensor in the vertical direction as a function of time) received by the microcontroller board via an I2C link is transmitted to the computer through a USB port. To determine the exact position, x, of the vibrations caused by the corrugation on the rail, a distance measurement system was designed and mounted on the trolley. To draw the corrugation plot with respect to x, the time variable is eliminated between the corrugation-time and location-time functions. Finally, the vertical component of acceleration is plotted on a special page of the software after applying several frequency filters and performing various post-processes and the wavelength and the general shape of the corrugation are obtained.

3. Results

After a complete search, a region with a length of 120 meters on line one of Mashhad Urban Railway Company was inspected based on the proposed system. At that time, some locations in that region suffered from a significant corrugation. To evaluate the repeatability of the proposed method, the inspection was repeated five times. Figure (3) shows the exact positions of the corrugation resulting from the visual inspection along this region. As the figure shows, in addition to the position and intensity of the existing corrugations, the position of the welding seam of the rails is also recorded in the southern and northern rails of the path. This figure also indicates that the intensity of corrugation has increased at the end of the path.

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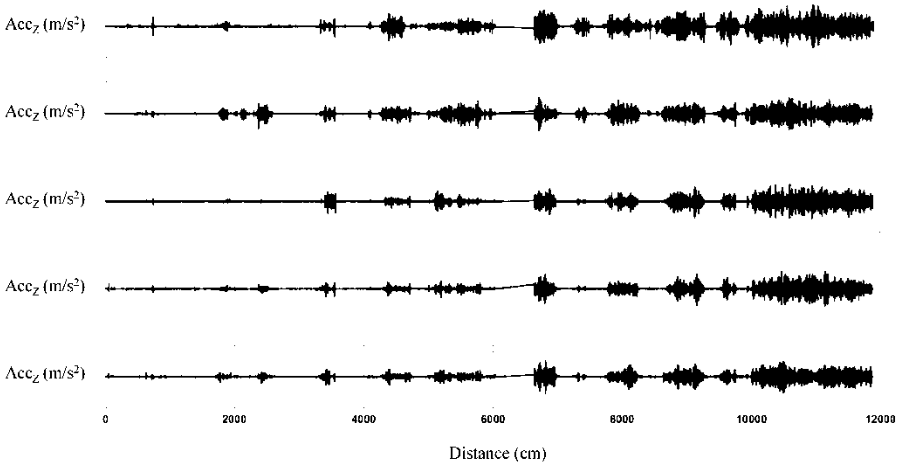

Figure 4. Results of rail surface scanning by corrugation detection and measurement system in a 120-meter path.

The results of corrugation measurement with the RDD-S11 are shown in Figure (4). In the 12,000 cm inspected region, in some positions, a change in outputs is observed in the form of noise. The pattern of the noises and their intensity are following the data obtained from visual inspection. For example, an increase in the intensity of corrugation is observed in the final parts of the region in both Figures (3) and (4). It is worth noting that the data obtained from the proposed non-destructive measurement system contain more information than visual inspection. Especially, corrugations with too low depths could not be seen by the naked eyes, but the sensitivity of the proposed method is high enough to detect minor changes and it could detect those hidden corrugations. The same trend of five inspections is another important point that could be seen in Figure (4). This indicates the high repeatability of the method, which confirms the equipment's proper performance in detecting the position and intensity of the corrugation. For a closer look, Figures (5) and (6) show the information related to rail surface sweep by the proposed system to detect and measure corrugation in low and high ranges, respectively. The information obtained from these two figures is fully consistent with the data obtained from the visual inspection and is a confirmation of the correct operation of the measurement system.

Comparing the results of Figures 4 to 6 with the results of visual inspections in the scanned path shows that an increase in corrugation intensity (increasing depth) increases the peak intensity in the acceleration change curve. This, as a criterion, can be used to diagnose corrugation and its severity. For this purpose, in the corrugation page of the RDD-S11 software (Figure 7), it is possible to define thresholds to determine the ranges where the amount of corrugation exceeds the acceptable limit. If the peak intensity of a corrugation passes the moderate or severe thresholds, a yellow or red alarm will appear respectively in the software on to the correct position of the defect. Thus, after calibration, using this simple method, it is possible to detect the corrugation defect, its position, and intensity according to the defined thresholds.

4. Conclusions

This study aims to design and fabricate a nondestructive system for detecting and measuring corrugation in railway lines. The most important results are as follows:

- The results show that the proposed system can detect different corrugations with different wavelengths and intensities with high accuracy and reproducibility. With the help of the device software and by changing the thresholds, it is easy to detect even low-intensity corrugations.

- The data obtained from the proposed method contain more information than those obtained from visual inspection. Due to the very shallow depth of the corrugation defect, it is not possible to identify some of them with the visual inspection, while this identification is possible with the proposed method. Moreover, the location of the corrugation defect in the scanned rail track is determined with the help of spatial information obtained from the distance measurement system with high accuracy.

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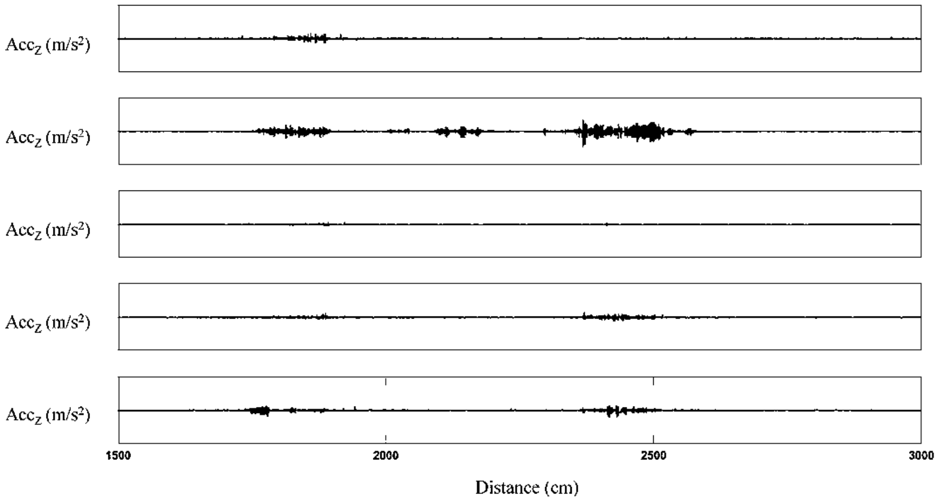

Figure 5. Results of rail surface scanning at a distance of 1500 to 3000 cm from the path of 12000 cm (area with a low degree of corrugation defect).

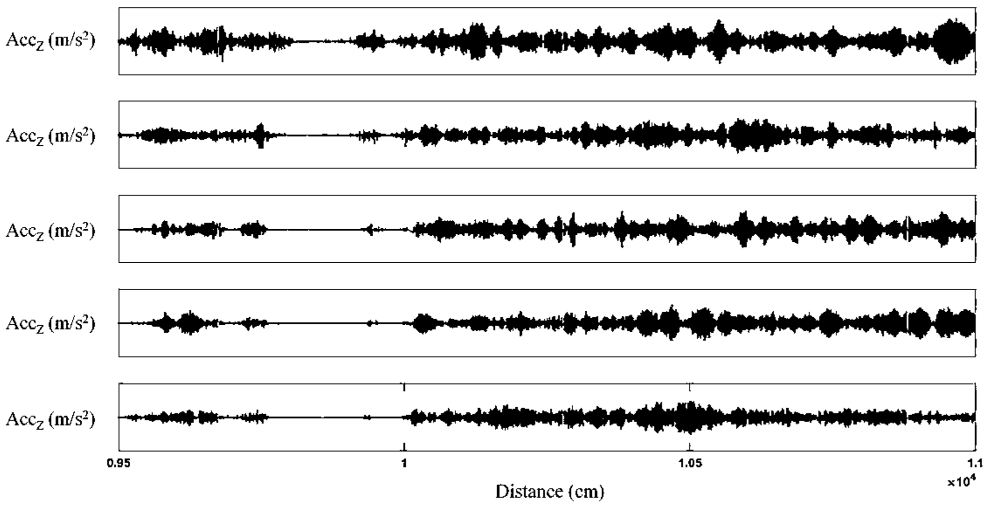

Figure 6. Results of rail surface scanning at a distance of 9500 to 11000 cm from the path of 12000 cm (area with a high degree of corrugation defect).

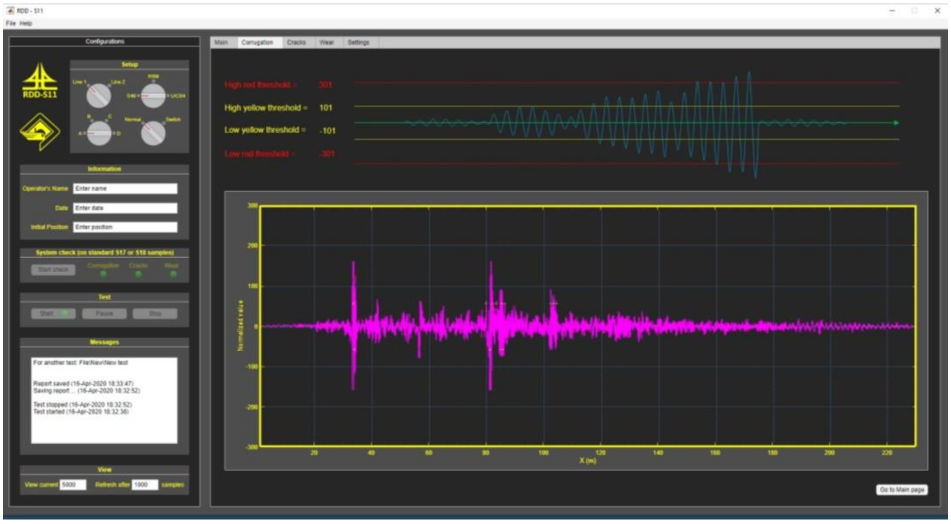

Figure 7. Corrugation page in rail defect detector (RDD-S11) software.

- By applying frequency filters and performing appropriate processing, more information, including the wavelength and the general shape of the corrugation, can be obtained. These tasks are performed by the device software.

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