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A Literature Survey on Condition Monitoring Techniques for Wheel Flat Detection

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Abstract—*The skidding of the wheel tread leads to severe localized wear in the wheels i.e. wheel flat. Presence of wheel flats generate impact load and vibration. The wheel flat is one of the many issues causing severe rail stress and sometimes derailment due to rail fracture. Therefore, it is necessary to monitor impact load due to wheel flat. This paper aims to give an overview of the existing condition monitoring techniques, such as on-board and way-side techniques, for detection of wheel flat at an early stage.*

Keywords— *Wheel flat, On-board, way-side, condition monitoring, vibration, signals detection.*

I. INTRODUCTION

Railways form the largest manmade transportation in the world and play a vital role in driving the economic growth of any country. The railway's safety is still a major matter of concern. 46.6% of the accidents in the railways are because of wheel or bearing failures, which cause derailment of certain part of the train. [1] Severe braking causes defects either on the wheels of the train or on the rail. The defects caused on the wheels take different patterns such as flats, eccentricities, polygons, corrugations on block-braked wheel treads, and other irregularities. These defects have the potential to impose damage to both track and train components.

Although other defects are important, the wheel flat occurrence is unpredictable and cause rapid degradation of the ride safety. They are a major factor of increasing maintenance costs in the railway system. By temporary lock of the wheel axis because of incorrect breaking process, or decreased traction in the wheel-rail area causes flat spots. [2]. This causes high wear on the rolling surface of the wheel, with lengths ranging from 20 to over 100mm which is typically referred as a wheel flat. If this defect is not detected at an early stage, it may lead to wheel failure and hence, contribute to accidents due to derailment. In-order to prevent this, timely detection of a wheel flat becomes mandatory.

Wheel flats generate high magnitude load impacts at the wheel-rail contact and abnormal vibrations, acoustics which are transferred to the track and thereby contribute to abnormal increase in stress levels on railway system. Various wheel flat detection and condition monitoring systems based on these signals have been developed. Therefore, there is great interest in studying and exploring early detection and estimation technologies of wheel flat. This paper carries out a detailed survey on several such methods proposed.

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II. LITERATURE SURVEY

To ensure the successful working of the railway system, a good condition monitoring system which can predict faults in real time is required. Presence of a fault causes certain parametric deviations within the system and acquisition of these deviated parameters helps in the identification of the defect. On this accepted theory, several condition monitoring techniques have been proposed. These techniques continue to evolve and provide new possibilities for utilizing condition monitoring in railways. Firstly, this paper describes wheel flat defect through references and further provides an overview of existing systems developed for the detection of wheel flat defect.

A wheel flat is a flat part on the circumference of the wheel which develops due to locking of brake, brakes in bad condition, frozen brakes and bad adhesion between the wheels. It is classed as an Out of Roundness (OOR) type A defect. A typical parametric description of a wheel flat includes the height and the length of the defect as illustrated in the fig.1. 60mm is the approximate length of the flat for an alarm to be triggered. [3] There are two sensing categories based on sensors' placement used in condition monitoring, namely, wayside monitoring technology and on-board monitoring technology.

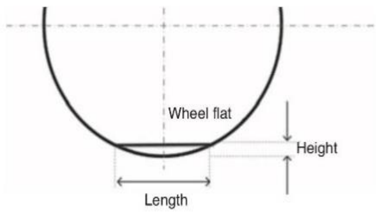

Fig.1 Wheel flat

In wayside monitoring techniques, the sensors are installed along the track. Its advantage is that once installed, it can monitor the condition of all the trains passing through that rail. But it also records noise and other interferences along with the data. In the on-board sensing technology, the sensors are mounted on the bogie. Their location on the bogie depends on their specific application. Its advantage is that it is able to acquire signal directly from the mechanical part of the train which might have the defects and also eliminates other interferences. Its major drawback is that sensors have to be installed on each wheel. Thus, increasing the cost of the system. [4] A survey of several wheel flat detection and estimation techniques based on these approaches is explained below.

An innovative ultrasound technique designed to detect and quantify wheel-flats is introduced by Jose Brizuela [5]. In the proposed idea, the surface waves are sent over a measuring rail instead of rolling surface for interaction between contact points. Two alternatives have been considered in this methodology. The first one is based on doppler technique which are suitable to detect velocity changes of a moving reflector and the second consists of measuring the round trip time of flight (RTOF) of the echo produced at the rail wheel contact point. The results show that in the Doppler method, wheel flats can be easily distinguished but the measurement of their lengths is not possible due to uncertainty in time- frequency analysis. However, RTOF offers sizing of the wheel flats. One of its drawback is that the system resolution decreases as the speed increases and the maximum

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possible speed for estimated flat lengths with relative errors below 5% is 3m/s.

The parallelogram mechanism to detect wheel flat based on an eddy current sensor and a measuring ruler is suggested in ‘Railway Wheel Flat Detection System Based on a Parallelogram Mechanism’ [6]. It detects the wheel flat depth dynamically and quantitatively using the vertical displacement change of the flat wheel. As the train passes, it presses down the upper plate causing vertical displacement between the sensor and the measuring ruler. It is measured by the eddy current sensor. For a normal wheel, vertical displacement does not change but for a wheel with flat, it changes. Preliminary experimentation of this mechanism was conducted in the laboratory, where the wheel flat was measured at low speed (5 km/h). However, during the field experimentation, there was no prior theoretical basis available for installation, which resulted in the poor performance.

John Ball and Martin F. Karchnak have put forth the idea of Robust Laser interferometer (RLI) concept to monitor both the advanced rail health and advanced wheel health by analyzing the acoustic emission signals. It compares the reflected signal from the target with the transmitted signal to obtain a measure of target motion. This technology has the ability and has proven to provide quality, highly linear measurement of Acoustic Emissions (AE) in a complex noisy environment. In the laboratory experiment, it was proven that RLI has more desirable sensing capability for measuring AE than current commercial piezoelectric technology. However, investment cost of RLI is high. [7]

Another approach towards wheel flat detection system is introduced by Jihyun Cho [8] based on accelerometer for measuring vibration signals. It uses discrete wavelet transform and cepstrum analysis to identify the existence of wheel flat from the signal acquired from an array of accelerometers. It also uses an additional optical sensor for train speed measurement. The detailed measurement layout is shown in fig.2. One benefit of the discrete wavelet analysis is the ability to calculate the train speed without an additional magnetic or optical sensor. The paper finds a table of train speed by two methods. One through optical sensor and another through invert sensor(accelerometer) and concludes that optical sensor provides slightly better results than invert sensor. Cepstrum analysis gives the potential presence of wheel flat depending on the repetitive impacts generated by the wheel due to a wheel flat. Its disadvantage is that the overlap of wheel diameters and the separation distance between axles on the same bogie creates a potential error between identifying which wheel on a bogie has a defect. Therefore, the results for the cepstrum analysis need to be presented per bogie and also it requires more processing power than any other types of systems.

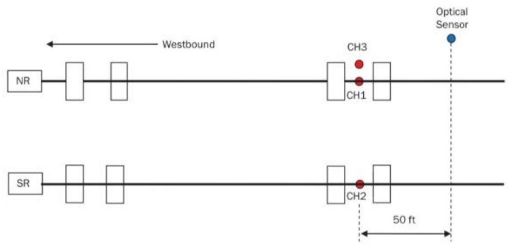

Fig.2 Measurement Layout using accelerometers and optical sensor

As suggested above, the acquisition and analysis of vibration signals enable to detect the presence of a wheel flat. In Tomasz Nowakowski’s paper on wheel flat detection, vibration signal data acquired from several vibration transducers is processed in time and frequency domain through an algorithm. Envelope analysis allows the extraction of a signal envelope containing a low frequency modulation, which corresponds to cyclical impulses, indicating a flat spot on the wheel. This algorithm performs

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envelope analysis of the signal by using Hilbert transform for detection of wheel flat.

The results provided by the time domain analysis signal show vibrations in the form of root mean squared value of acceleration(a_{RMS}) and the presence of wheel flat increases the values of a_{RMS} by approximately 30% in both Y and Z direction at the measurement points. Analysis in frequency domain indicates a wheel flat through identifying the difference in the values of amplitudes in frequency bands for a faultless and faulty wheel. The results produced by the method used in this paper are beneficial and hence, this method can be used for further studies. [2]

In order to overcome the high cost and low reliability of other methods, an attempt to develop a simple device to effectively identify wheel flats is made in 'Effective wheel flats detection through a simple device'[9] It presents a system consisting of treadles to detect wheel passage and an piezoelectric cable based wheel flat detector(WFD) which is sensitive to vibrations in all the directions. The processing algorithm is based on the principle that a wheel flat is characterized by series of peaks. A single figure that can be easily compared with predefined threshold is acquired after carrying out filtering, Hilbert transform, autocorrelation, power spectral density estimation. The results showed that the developed procedure led to a number of false detection lower than 0.5%, making it a reliable and robust method. However, the WFD equipments need to be quite high for highly interconnected networks and all the electronics used in this device needs to be specifically developed by GETS. Moreover, it uses a very complicated procedure which cannot be easily adopted.

Measuring the surface defects by means of strain gauges is one of the methods mentioned in "Condition monitoring approaches for the detection of railway wheel defects" [10]. The working principle of the strain gauge sensor is based on variation of resistance caused by the strain transmitted to the rail during the train passage. Four special resistance strain transducers were embedded on the neutral axis of the track (refer fig.3). [11] This system measures the vertical force by means of two strain gauges and the lateral force by means of other two strain gauges at each point This distribution covers 90% of the circumference of the wheels in different sizes. Installation of strain gauges is performed by sticking them directly on the web and foot of the rail, hence strain gauge is exposed to aggressive environment, that makes it difficult for system to measure vertical force component. To overcome this, an accelerometer was mounted onto the edge of beam for measuring vertical accelerations. [11] This improved the quality of results obtained and hence, it has the potential to form a base for future research.

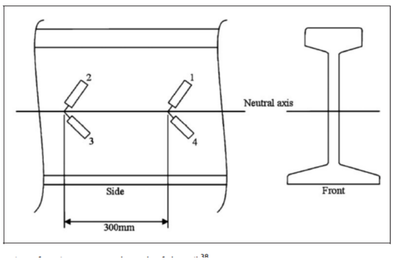

Fig.3 Strain gauges placement on the neutral axis of the railway track

The studies conducted in the above papers show the usefulness of impact load signal and vibration signal at the wheel- rail contact point to detect wheel rolling surface defects. The paper 'Analysis of Freight Wagon Wheel Failure Detection in Lithuanian Railways' examines the reliability of Wheel Impact Load Detectors (WILD) which are based on both strain gauge to measure force and accelerometer to measure change in motion. [12]. The paper deals with calculating the value of

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dynamic coefficient (DC) which is capable of providing the information regarding the status of the wheel. Upon performing calculations, it produces dynamic interaction between wheel flay and rail. It also gives the DC dependence on wheel flat depth and crack length, i.e. wheel flat and crack correlation. This paper concludes that WILD system has an operational reliability up to 99%. By further assessing the loading level on rail, exploring the methods of dynamic coefficient calculations, this method is capable of providing more promising results.

The table given below shows the summary and comparative study of various approaches discussed above.

Sr No	Name of the Paper	Author	Technology	Sensors Used	Result/ Conclusion	Drawback
1	Condition monitoring and e-maintenance solution of railway wheels.	Asplund, M., Famurewa, S., & Rantatalo	It gives an overview of out-of-roundness defects.			
2	A Review On Condition Monitoring Technologies for Railway Rolling Stock.	Kundu, Pradeep & Darpe, Ashish & Singh, Satinder & Gupta, Kshitij	It explains wayside and on-board condition monitoring techniques.		From the comparative study conducted in the paper, wayside has proven to be a cost efficient method.	
3	New Ultrasonic Techniques for Detecting and Quantifying Railway Wheel-	Brizuela, J., Fritsch, C., & Ibez, A.	Detection and quantification of wheel flat by ultrasonic approach- 1. Doppler technique 2. Round		1. **Doppler Technique-** Easily distinguishable wheel flat but measure	System resolution decreases as speed increases.

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	Flats.		Trip Time of Flight(RTOF)		ment of length not possible. 2. **RTOF-** Sizing of wheel flat is possible.	
4	Railway Wheel Flat Detection System Based on a Parallelogram Mechanism.	Gao, R., He, Q., & Feng, Q.	Detection of wheel flat depth measurement based on parallelogram mechanism.	Eddy Current sensor	In laboratory experimentation, wheel flat was detected at low speed(5 kmph) by measuring the vertical displacement change between the sensors and measuring ruler.	Field experiment lacks theoretical basis which resulted in poor performance.
5	Advanced Rail Health and Wheel Health Measurement Technology	Ball, J., & Karchnak, M. F.	It uses Acoustic Emission signal to detect wheel flat.	Robust Laser Interferometer(RLI) and Piezoelectric sensor	Comparative study between results produced by RLI and Piezoelectric Sensor shows that RLI has more desirable sensing capacity.	Investment cost of RLI is high.
6	Development of an Accelerometer Based Wheel-Flat Detection System for a Subway Transit System in	Cho, J., & Preager, T.	Detection of wheel flat through vibration signals and signal processing techniques(Cepstrum Analysis and Wavelet Transform	Accelerometer and Optical Sensor	1. Optical Sensor provides better results for finding the speed of train than	1. More processing power required 2. The result need to be presented for bogie.

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	Toronto.		Technique)		invert sensor. 2. Cepstrum Analysis gives the presence of wheel flat due to repetitive impact generated by a wheel.	
7	Wheel-Flat Detection on Trams Using Envelope Analysis with Hilbert Transform.	Nowakowski, T., Komorski, P. ł., Szymański, G. M., & Tomaszewski, F.	Vibration signal processing in time and frequency domain by using Hilbert Transform Algorithm	Vibration Sensor	Extraction of signal envelope gives the presence of wheel flat- 1. In time domain, due to increase in value of root mean square acceleration (a_{rms}) 2. In frequency domain, due to difference in amplitude in frequency bands of faulty and faultless wheels.	
8	Effective	Bracciali,	A system	Piezoelectric	The	1. Complica

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	Wheel Flats Detection Through A Simple Device.	A., Lionetti, G., & Pieralli, M.	capable of detecting wheel flat through vibrations and its processing algorithm.	cable based wheel flat detector.	processing algorithm characterizes wheel flat by series of peaks. The procedure produces fault detection lower than 0.5%.	ted procedure 2. Detector equipment are high for highly interconnected network.
9	Condition monitoring approaches for the detection of railway wheel defects.	Alemi, A., Corman, F., & Lodewijks, G.	Detection of vertical and lateral impact forces.	Strain Gauge Sensor	Four Strain Gauges are embedded on the neutral axis measuring vertical and lateral forces on the track, covering 90% circumference of the wheel.	Since, strain gauge is pasted directly on the foot of the rail. It is exposed to aggressive environment makes it difficult to measure vertical forces.
10	Weight In Motion Systems For Railways.	Kumar, S.	Detection of vibrations and load impact on the rail.	Strain Gauges and Accelerometer	Using series of strain gauges along with an accelerometer ensures longitudinal as well as lateral load detection.	
11	Analysis of Freight Wagon Wheel Failure Detection in Lithuanian Railways.	Lunys, O., Dailydka, S., Steišūnas, S., & Bureika, G.	Wheel impact load detector based on strain gauge and accelerometer.	Strain Gauge and Accelerometer.	1. It calculates the value of dynamic coefficient(DC) which gives information about	

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					the wheel. 2. It concludes that WILD system has 99% operational reliability.	

III. CONCLUSION

This paper was an attempt to collect and compare the techniques used for condition monitoring of railway vehicle dynamics. According to the survey conducted above, the monitoring of wheel defects for trains could be done through track mounted sensors and it is practical to use the wayside method as it is more economical and although interferences are present in the wayside method, they can be overcome by using advanced signal processing algorithms. From the survey, it is noted that wheel flat detection technologies based on strain gauge and accelerometer for detection of load and vibration signals have proven to be most reliable. The described method in one of the papers mentioned above uses four strain gauges, however, it is feasible to use a biaxial strain gauge rosette through which it is capable to obtain both the tensile and compressive strain values individually. Hence, the use of strain gauge rosette and accelerometer can prove to be an effective condition monitoring approach for wheel flat detection.

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