IRF GLOBAL R2T Conference
November 19-22, 2019 – Las Vegas, NV USA

PAPER TITLE	Rail Defect Detection Technology: A Review of the Current Methods and an Acoustic Based Method Proposed for High-Speed-Rail		
TRACK	Innovative Materials and Technology		
AUTHOR (Capitalize Family Name)	**POSITION**	**ORGANIZATION**	**COUNTRY**
Lei JIA	Ph.D. student	University of Nevada, Las Vegas	USA
CO-AUTHOR(S) (Capitalize Family Name	**POSITION**	**ORGANIZATION**	**COUNTRY**
Ming ZHU	EE Lab Director	University of Nevada, Las Vegas	USA
Ryan SHERMAN	Assistant Professor	Georgia Institute of Technology	USA
Jee Woong Park	Assistant Professor	University of Nevada, Las Vegas	USA
Yingtao Jiang	Professor	University of Nevada, Las Vegas	USA
Hualiang Teng	Professor	University of Nevada, Las Vegas	USA
E-MAIL (for correspondence)	jial5@unlv.nevada.edu		

KEYWORDS:

Acoustic emission; High-Speed-Rail; Rail defect detection

ABSTRACT:

Steel rails can generate defects, such as cracks or corrugations, due to surface fatigue from a prolonged service life. Rail deterioration presents obvious safety concerns. To promote continued safe and reliable rail operation, previous research has explored the mechanisms of rail defect origination and developed models to predict rail health status. In this paper, a critical review of relevant internal rail defect detection literature has been presented, including a summary of common defects as well as defect detection methods currently employed by the railroad industry. The pros and cons of the current technologies will be discussed in the first part of the paper. The second part of the paper will discuss a new and novel technique currently in development, acoustic emission (AE) detection. An explanation of the need of AE detection technology will be presented, as well as the advantages, potential applications, and current approaches to isolate the AE signals and reduce the effect of ambient noise. Finally, the paper will detail the prototype defect detection system and the proposed test plan for application to high-speed rail systems.

Rail Defect Detection Technology: A Review of the Current Methods and an Acoustic Based Method Proposed for High-Speed-Rail

[1]Lei Jia; [1]Ming Zhu, Ph.D.; [2]Ryan J. Sherman, Ph.D., P.E.; [1]Jee Woong Park, Ph.D.; [1]Yingtao Jiang, Ph.D.; [1]Hualiang Teng, Ph.D.

[1]University of Nevada, Las Vegas, Nevada, USA

[2]Georgia Institute of Technology, Atlanta, Georgia, USA

Email for correspondence, jial5@unlv.nevada.edu

Abstract

Steel rails can generate defects, such as cracks or corrugations, due to surface fatigue from a prolonged service life. Rail deterioration presents obvious safety concerns. To promote continued safe and reliable rail operation, previous research has explored the mechanisms of rail defect origination and developed models to predict rail health status. In this paper, a critical review of relevant internal rail defect detection literature has been presented, including a summary of common defects as well as defect detection methods currently employed by the railroad industry. The pros and cons of the current technologies will be discussed in the first part of the paper. The second part of the paper will discuss a new and novel technique currently in development, acoustic emission (AE) detection. An explanation of the need of AE detection technology will be presented, as well as the advantages, potential applications, and current approaches to isolate the AE signals and reduce the effect of ambient noise. Finally, the paper will detail the prototype defect detection system and the proposed test plan for application to high-speed rail systems.

Keywords: Acoustic emission; High-Speed-Rail; Rail defect detection

1. Introduction

Since the railway was first built centuries ago, it has become an essential component in the global transportation system. In recent years, rail has comprised more than 30% of the United States (U.S.) exports, carrying approximately 85,000 passengers and hauling five million tons of freight per day (American Society of Civil Engineers, 2017). The private freight rail industry comprises the majority of the rail infrastructure in the U.S. In 2015, more than $27 billion was invested in railway infrastructure construction. Steel rails can develop defects, such as cracks or corrugations, due to surface fatigue from a prolonged service life. Rail deterioration presents obvious safety concerns. To promote continued safe and reliable rail operation, numerous inspection and detection technologies have been proposed to monitor the condition of rail health. Currently, ultrasonic inspection is widely used by the railroad industry, while a novel acoustic emission method is under development. The advantages and disadvantages of each method will be presented as well as a discussion about the need for acoustic technology.

2. Mechanics of initiation and propagation of defects

Rail defects are one of the dominant causes of train derailments and an essential factor affecting transportation safety in the U.S. The causes behind rail defects are complicated and can be associated with various factors such as hydrogen imperfection during the cooling progress, incomplete welding of rail joints, or rolling compression on the high sides of curves (Office of Railroad Safety, 2015). Further, defects can be located anywhere along the length of a track and in a multitude of locations within a rail cross-section, such as in the head, squat, or web. Thus, a full understanding of the mechanics of defect initiation and propagation will provide a pivotal theoretical background for defect detection and railway safety.

2.1 Types of rail failures

To understand how to detect rail defects, it is important to understand the types of rail defects. Failure of modern steel rails can be divided into three groups: manufacturing defects, inappropriate installation and maintenance, wear and rolling contact fatigue. Background on each type of defect is provided in the following sections.

2.1.1 Manufacturing defects.

Modern steel rails contain some defects from the manufacturing process, such as hydrogen imperfection, split head, piped rail.

Hydrogen imperfections during the cooling process can cause transverse defects in high-chrome rails, known as transverse fissures. Unfortunately, transverse fissure defects are not easy to detect. Cyclic loading from passing trains may cause a hydrogen imperfection to grow into a fatigue crack. The crack will grow faster the longer it becomes, thereby accelerating the failure progress. Upon reaching a critical size, a rail can suffer a complete fracture (Office of Railroad Safety, 2015).

During the manufacturing process, rails may also generate internal seams and segregations. The seams may cause a split head to form. Split heads can be either horizontal (longitudinal to the rail) or vertical (transverse to the rail). Generally, a horizontal split head will originate approximately 1/4 inches under the rail surface, while a vertical split head will usually generate through or near the center of the head and progress to the surface. The split will grow quickly once the seam or separation begins to spread, ultimately leading to failure of the rails (Office of Railroad Safety, 2015).

Inappropriate cooling can also cause a longitudinal seam or shrinkage cavity in the middle of the web, which may lead to a defect known as piped rail (Figure 1). Once development begins, the defect will grow vertically towards the two sides of the rail. Axle loading will then cause the defect to develop in a horizontal direction, resulting in a huge cavity inside the web (Office of Railroad Safety, 2015).

Figure 1. Piped rail originated from web split (Office of Railroad Safety, 2015)

2.1.2 Inappropriate installation and maintenance defects

During the installation process, improper handling methods such as wheelburn. A lead to rail damage. Seams and segregations can be formed due to poor installation. Such as web defect, broken base, defective weld, flaws can cause severe defects in joints and bases during service, ultimately leading to failure.

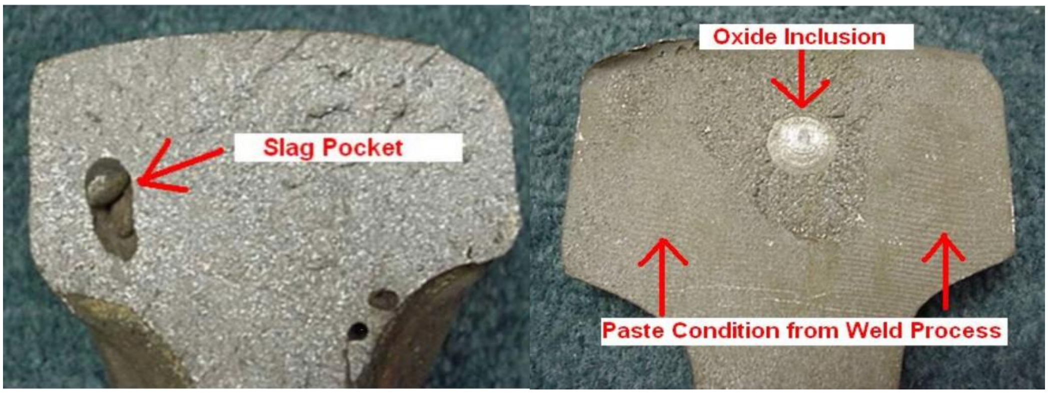
Rail bases at grade crossings are vulnerable to corrosion from asphalt-based acidic filled materials. Most of the corrosion fatigue originates at the web-to-head connection which causes rail separating at the head-to-web joint (Figure 2). Further, improper canting of the rail, gravel in crossings, or excessive speeds on curves can cause accelerated defect development. Similar cracking can also be found in the head fillet area at the jointed rail end, which is usually caused by an extreme stress condition (Office of Railroad Safety, 2015).

Figure 2. Head and web separation moving into the web (Office of Railroad Safety, 2015)

A base break can be generated during rail installation. Base breaks can be divided into two failure types: broken base and base fracture. A broken base commonly generates in the lower flange area, and has a curved shaped, such as “half-moon” break (Figure 3). A base fracture is usually developed from a breach or gap, and cause a perceptible dent. The failure is typically due to a seam, segregation, or improper bearing on the tie plate. Defect development in the transverse direction can be relatively slow before the defect extends into the rail surface. However, sudden rapid failure may still occur with little transverse defect development (Office of Railroad Safety, 2015).

Figure 3. Half-moon-shaped broken base (Office of Railroad Safety, 2015)

Defective welds are discontinuities or cavities in welded connections due to insufficient penetration, slag entrapment (Figure 4a.), shrinkage, or lack of fusion (Figure 4b.), such welding issues are possible in both field and plant welds. Defective welds may generate in joints at the head-to-web or base-to-web joints, and extend into either or both rail ends. Also, defects may develop longitudinally through welded joints, which may result in a split web (Office of Railroad Safety, 2015). Plant welds generally remove excessive weld material during the shearing process to flush the web surface while field welds will present excessive weld material at the surface of the web-to-base joint. However, both types of welds can lead to failure in an inclined direction.



(a) (b)

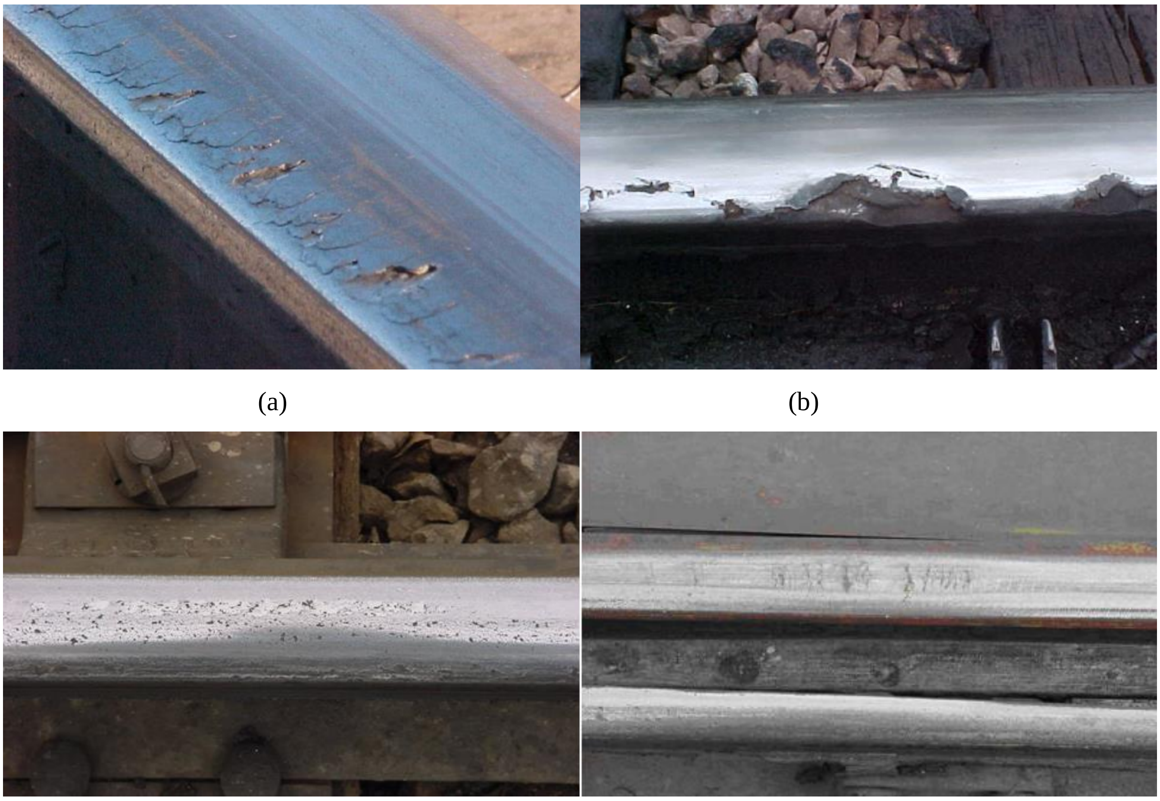
Figure 4. Defective weld: a) slag entrapment; b) lack of fusion (Office of Railroad Safety, 2015)

2.1.3 Wear and rolling contact fatigue defects

Rolling contact fatigue (RCF) is a crack-like defect which is caused at the wheel-rail contact area by recurring loads. Typically, if a rolling component is properly installed, aligned, lubricated, and loaded, then the primary failure mode of material will be RCF (TA Harris, 2007). Rolling contact fatigue is the primary reason for maintenance and replacement on heavy-haul railways (Cannon et al., 2003; Office of Railroad Policy and Development, 2011). Such an issue may generate through the formation of crack-like flaws, due to very high contact pressures, which are typically over 1000 MPa. The dominant mechanism is rather complicated, influenced by elements such as surface condition, lubricant, and maintenance. RCF is different from classical fatigue in the following conditions (Sadeghi et al., 2009):

1. The state of stress in irregular contacts is complicated and multiaxial, governed by the Hertzian contact theory.
2. The loading diagram shows the changes at a specified location below the surface is not proportional, such that the stresses of the point varies in a non-proportional way.
3. Non-conformal contacts can generate high hydrostatic stress component.
4. Occurs in a very small area of stressed material; 200–1000 um are the common contact sizes.
5. Can result in a fatigue spall through the following stages: 1) shakedown, 2) steady-state elastic deformation, 3) instability.
6. Generally initiated from local plastic deformation, as well as growing residual stresses.

Head checking, shells, flaking, burned rails are the common types of RCF, which are classified by crack initiation region and cause of initiation. Head checking (Figure 5a) is a small separation of rail steel occurring on the switch areas and gauge side, especially the high side of curves. Head checking is caused by the lateral force effect from wheel displacement on the railhead; the separation can eventually result in a transverse separation. Shells (Figure 5b) are defined as developing horizontal separations, which commonly occur on the gauge side of the rail head. Shelling can digress into a transverse separation and is considered a detail fracture. Such separations can result in parent metal displacing from the railway. Flaking (Figure 5c) can be defined as a horizontal separation with small segments scaling from the parent steel. It usually initiates on the rail surface and can be found near the rail switch joints, where concentrated force affects the rail steel. Burned rail (Figure 5d) is a head issue, which generally caused by rail-wheel friction from slipping. The impacted region can gradually scale and abrade with repetition. Possible defects generate from thermal cracks in the burned area.



(a) (b)

(c) (d)

Figure 5. Common RCF defects: a) head checks; b) shells; c) flaking; and d) thermal cracks (Office of Railroad Safety, 2015)

Rolling contact fatigue is an inevitable failure type of the rolling contact elements. RCF defects are extremely dangerous since cracks are typically formed at the rail surface. Fracture due to a single crack can increase the stress in neighboring rails, which will increase the potential for of additional breaks and rail disintegration. Therefore, regular track inspection and railway maintenance, are essentially to the rail lifetime health, and AE technology is an excellent method to locate such defect in developing.

3. Past and present inspection technologies

Many inspection and detection technologies have been proposed to monitor rail health. The technologies generally use imaging or sound for detection. Additionally, some unique methods have been proposed to solve the defect detection problems, such as field hammer test measurements and electromagnetic tomography. The following sections will briefly describe selected inspection technologies previously and currently employed, including optical imaging technology, ultrasonic technology, and alternating current field measurement (ACFM).

3.1 Optical imaging technologies

The optical imaging method is based on a recognition technology using graphics scanning and processing. The core rig of the testing system is a camera equipped with high processing speed and resolution. An optical encoder performs graphics recognition and classification. Experimental research has been presented demonstrating real-time detection at speeds over 216 km/h (Li & Ren, 2012).

An automatic optical detecting system, which used color line-scan cameras and a spectral image differencing procedure to detect flaws had been developed (Deutschl et al., 2004). The most significant advantage is the ability to detect small defects, including invisible cracks. It was estimated that approximately 95% of the inspection work could be replaced by this automatic method, thereby greatly increasing the efficiency of inspection compared to previous techniques. However, the system is limited to only inline checking of new rails.

Advances had also been made on the software side of optical detection. A new method based on two-dimensional discrete wavelet transform was employed to extract the rail surface region (Bojarczak, 2013). The technology employs a support vector machine (SVM) and a Gabor filter bank. Test results show the classification rate was over 93%. However, the scanning speed is below 61 km/h, restraining the technology. Similar research has been performed in the area of image enhancement, which is aimed at creating an inverse Perona-Malik (P-M) diffusion model for image enhancement (He et al., 2016). The advantage, compared with the previous system, is the rate of inspection. The Perona-Malik diffusion model is capable of inspection at speeds over 240 km/h; unfortunately, the precision is much lower, at 85.9%.

Advanced optical technologies include a 3D laser profiling system (3D-LPS) (Xiong et al., 2017). The system contains an inertial measurement unit (IMU), a GPS (Global Positioning System), a laser scanner, and an odometer to collect information from the surface of the rail. Results showed the algorithm could recognize a surface defect and can locate the defect area with recognition rate at 93.78%. However, the experiment was performed at approximately 5.5 km/h; thus, further research on the application at higher speeds is still required.

While research has improved the optical detection systems, problems still exist, limiting system-wide implementation. The main problems come from complex disturbance factors, limited recognition features, and the requirement for real-time notification (Office of Railroad Policy and Development, 2011). For example, distribution factors are complicated by inconsistent illumination and surface reflection variations caused by corrosion or stains. Recognition could be extremely difficult if the rail is heavily covered with impurities such as drops of oil, dirt, soil, or sand (Deutschl et al., 2004). Optical methods have shown potential; however, until the shortcomings are addressed, implementation will be limited.

3.2 Non-contact ultrasonic detection method

Non-contact ultrasonic (NCU) method is a non-destructive testing technology, which utilizes ultrasonic inspection without the sensor making direct contact with the material. NCU technology is widely used in structural health inspections. The following discusses experimental studies of NCU for rail defect detection.

A rail inspection method using ultrasonic guided waves, developed by the University of California at San Diego (UCSD), employs pulse-echo for rail scanning (F. L. di Scalea et al., 2005). An excitation frequency of approximately 200 kHz was used for testing. The frequency provided acceptable surface wave mode and penetration depth. Concurrently, a spatial averaging technique was employed to minimize the signal complexity and remove unusable wave modes. Results demonstrated the technology worked well for both artificial and real defects. The research was limited to low speeds.

Guided-wave defect detection in rails has also been proposed for non-contact testing (Rizzo, P., Coccia, 2009). Defects could be detected where the energy of the propagating wave varied. The research used discrete wavelet transform to help increasing signal reliability and improving the signal-to-noise ratio (McNamara, John, 2004; F. L. di Scalea et al., 2005; F. di Scalea et al., 2007; Rizzo P, 2007). Testing results showed good overall detection frequency, and high-frequency waves, approximately 200 kHz, were dominant.

A novel non-contact ultrasonic rail inspection system was developed by UCSD (Mariani et al., 2017). To maximize the recognition of defects and minimize false positive results, the system employs a focused air-coupled transmitter, real-time statistical algorithm, and symmetrically placed air-coupled receivers. Results demonstrated excellent performance at low speeds, 1 to 8 km/h, and showed promise at speeds of 16 to 24 km/h.

Ultrasonic detection methods have excellent performance in detecting both surface and internal defects. Laboratory and field tests have demonstrated a high recognition rate in field detection. However, most ultrasonic technologies can only be employed at speeds below 40 km/h. The rate of inspection is one of the biggest obstacles common to ultrasonic detection experimental studies.

3.3 Other methods proposed

A variety of other, less common, defect detection methodologies have been proposed. One such technology is the ACFM, which based on the theory of generating a uniform electromagnetic field and sensing turbulence caused by the defects in structures. Another less common method is based on electromagnetic tomography (EMT) technology which utilizes tomography to inspect the track health.

ACFM is a non-destructive testing technology, capable of sizing surface breaking cracks through the disturbance of measurements in the magnetic field (Papaelias et al., 2010). The technology does not require direct electrical surface contact, allowing it to work in many different environments. Research results from various simulated defect conditions suggest that ACFM can be employed to reliably and accurately detect surface-breaking defects at speeds of over 240 km/h. Results have confirmed the ACFM sensor has the capability of detecting visible crack lengths as small as 1.2 mm long.

EMT method measures the alternating magnetic signal modulated by rail cracks by using the tomographic approach (Liu et al., 2015). From the signal, a reconstruction of the crack distribution is produced. The disadvantages of EMT include the expense and experience required. Compared to the conventional inspection method, EMT requires professional knowledge to manipulate the equipment.

4. Acoustic emission technology in the detection of railway defects

4.1 Theory and advantages of acoustic emission technology

Acoustic emission (AE) is defined as an elastic wave generated by changes in the internal structure of the material, which is caused by a sudden change of internal stress or external impact (Bruzelius & Mba, 2004; Nivesrangsan, Steel, & Reuben, 2007). Microstructure changes are responsible for such phenomena. Changes can include crack growths in the body and sectional displacements in material, as well as phase change, fiber breakage, and decomposition. Typically, an AE testing system contains a sensor, preamplifier, and filter, as well as processing, display, and storage. When AE signals are generated due to elastic deformation, sensors respond to the dynamic motion and collect the signals. However, signals combine with ambient noises; therefore, preamplifiers are designed to filter interference. The frequency of the AE signals collected is generally between 1KHz and 1MHz. After filtering, the signals are transferred to the AE processing equipment for analysis and storage. During the signal processing, the signal goes through a measurement circuit which compares the conditioned signals with a previously programmed threshold voltage value. Finally, the signal is recorded into the storage device.

AE technology is different from other non-destructive testing technologies for a variety of reasons (Huang et al., 1998; Bruzelius & Mba, 2004). First, the origin of the signal is different. Instead of providing energy to the object during the examination, AE technology receives the energy released by the material passively. Second, AE technology only responds to dynamic processes, or changes, in a material. The dynamic response is particularly important because it can be used to trace continuous changes in the material. Through the initial research on AE technology, advantages have been presented, such as easy installation and manipulation as well as the ability to monitor internal structural changes (Al-Ghamdi & Mba, 2006; Thakkar, Steel, & Reuben, 2010).

4.2 Experimental study on AE technology

Research has been conducted aimed at applying AE to rail inspection for rail-track defect diagnosis (Bruzelius & Mba, 2004; Thakkar, Steel, & Reuben, 2010). Although the research only presents simple experimental tests, the results have demonstrated promising potential for further applications. In one study, AE technology was used to collect raw data on train and tram wheels, preliminarily proving its feasibility in rail detection (Bollas & Papasalouros, 2010). In similar research, AE was used to detect rail defects at high speeds using a rail–wheel test rig (X. Zhang et al., 2015). The results demonstrated the proposed method could detect rail defects effectively at over 123 km/h. The studies represent a basic foundation for further research in rail defect detection at high speeds. However, it is necessary to combine the analysis with specialized software to determine the full function of the employed method. Additionally, further work is required to locate defects accurately.

Defect location is a key objective of health monitoring of in-service railway switches. A novel technology has been proposed in identifying and locating railroad switch joint defects (J. Zhang et al., 2016). Continuous wavelet transforms (CWT) were used to analyze the Lamb wave propagation of an AE signal range of concentrated high-frequency AE signals is distributed in 100–150 kHz, indicating new or existing defects can be found by comparing the AE signal characteristics in the frequency domain. The CWT is also used to analyze the Lamb wave dispersion features of the AE signals for locating the defects. However, the study only proved the feasibility in the lab with a known defect, while field testing with the more complicated testing environment was not presented. Further, such theories must be developed and proven through field tests.

Other research for rail defect detection were performed on simulated AE sources having various propagation distances, types, and depths (X. Zhang et al., 2014). In the study, three different simulated frequency AE sources were used on the rail, and the depths of the AE sources were changed in the vertical direction. However, the method only worked well for short distances with insignificant mode mixing and reflection, due to the limitations in propagation distance.

4.4 Development in AE signal isolation

The key objective of AE inspection is extracting the defect signal from ambient noises. Therefore, reducing the effect of ambient noises and extracting defect signals have been an important objective to increase detection accuracy.

Various methods have been proposed and tested in practice. Multi-level Adaptive Noise Cancellation (ANC) with Variable Step-Size Least Mean Square (VSS-LMS) has been proposed as a rail defect detection method (X. Zhang et al., 2018). The study removed complex noises at high speeds by using multi-level noise cancellation, based on Self-Adaptive Noise Cancellation (SANC), and ANC. To improve the variable-step-size algorithm, the researchers proposed a tongue-shaped curve with an index adjustment factor. The findings demonstrated a significant improvement with respect to noise interference. However, the method can be only employed under 140 km/h; therefore, further research is required for improved adaptability to high speeds.

A correlation technique has been researched to investigate the ability of noise cancelation in AE detection (Sadoudi et al., 2016). A series of research studies have been conducted, including active response measurement, noise correlation measurement, the sensitivity of detection, and application in rail defect inspection. In noise correlation measurement, the higher correlation was observed with multiple noise-sources, which makes it possible to extract AE signals from ambient noises. Isolation experiments demonstrated the characteristics of defect signals could be extracted and located, proving the possibility of utilizing noise correlation to reconstruct AE signals. However, the paper did not discuss the application in running vehicles or the extraction of defects in random ambient noises.

Ambient noise has been used as a damage indication and localization in a wind turbine blade (Tippmann, Zhu, & Lanza Di Scalea, 2015). Reciprocity was examined in the response function. The response of the non-defective structure should be the same in any direction of energy travel. Due to material discontinuity around defects, the signal was interrupted in the causal and non-causal wave components, which denotes the existing of the defect in the materials. The passive defect defection experiments were carried out on a homogeneous aluminum plate and inhomogeneous wind turbine blade. Results indicate a promising method to passively detect defects. The paper provides a workable method to locate defect signals, which contributes to AE passive detection. However, noise propagation in inhomogeneous materials is still unclear.

According to previous research, ultrasonic energy and property will be changed due to discontinuities in the rails (S Coccia & Phillips, 2011; Stefano Coccia et al., 2011; Mariani et al., 2013, 2016; Mariani & di Scalea, 2018). Thus, the transfer function between two sensors can be reconstructed by cross-correlation operation (Weaver & Lobkis, 2002; Roux & Fink, 2003), then the transfer function which indicated the local defect could be extracted. Passive extraction method has been used in isolating defect signals for trains running at high speeds (Lanza di Scalea et al., 2017). Three possible options were listed to present the differences in isolating the defect signal, including cross-correlation operation, normalized cross-correlation operation, and deconvolution operation. Through experimentation, an AE inspection prototype was developed consisting of two arrays of air-coupled receivers designed to collect defect signals (Figure 6). The inspection performance at different speeds needs to be fully characterized to realize real high-speed monitoring and fast data analysis, such as adjusting the bandwidth of the reconstructed transfer function.

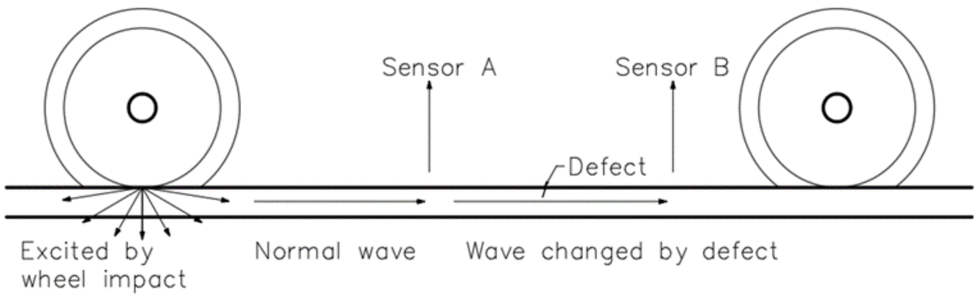


Figure 6. Theoretical consideration of passive extraction of defect information

Wavelet Transform (WT) has been employed to extract defect signals (Ni & Iwamoto, 2002; Ping et al., 2002; Liao Chuanjun, Li Xuejun, 2009). WT can obtain both signal time and frequency information, which is a significant feature compared with Fourier transform. Further, wavelet scalogram can present the amplitude level of signals in different scales and the time information. Such features will help identify the duration of the defect signal, as well as the time step for data analysis. Both duration and time step can improve the accuracy of frequency resolution. Also, ambient noises can be eliminated and the defect signal can be isolated during wavelet scalogram reconstruction progress.

5. Ongoing project of AE technology in High-Speed-Rail defect detection

A prototype of an AE testing device is being developed at the University of Nevada, Las Vegas (UNLV). The equipment is designed to detect and record AE signals for data analysis after collection. AE signals will be fused with location data from an onboard GPS to provide accurate location information. In addition, the study aims to develop a signal-processing algorithm to reconstruct a transfer function for acquiring defect signals. Ultimately, the project goal is to develop a functional product to detect rail defects at 350 km/h.

The prototype developed at UNLV will employ both air-coupled and bone-conduct sensors. Sensor frequency ranges from 0~30 kHz and 30~300 kHz. The system will be outfitted with a GPS to provide geo-location information. The initial goal is to test the feasibility of the system, followed by continued advancements and improvements. Multiple methods will be used to extract the rail transfer function, and the pros and cons of each method will be evaluated. The sensor will be evaluated initially through field testing at the Nevada State Railroad Museum in Boulder City, NV. Tentatively, additional field validation testing is proposed at the Transportation Technology Center, Inc. (TTCI) in Pueblo, CO and Chinese Academy of Railway Sciences. The performance of the testing device at low speeds (below 128 km/h) will be evaluated in the NV and CO, the evaluation at high speed (up to 350 km/h) will be conducted in China. During the initial testing in Nevada, the device will be mounted to a test car and passed over rail segments with known defects. Data will be collected to test the prototype as well as the AE signal extracting program. In addition, the precision of the GPS information provided by the testing device will be compared to the geo-location of the defects.

Acknowledgments:

The Research Team would like to acknowledge the financial support of the United States Department of Transportation (USDOT) University Transportation Center (UTC) for product development and field testing support. The support by the Nevada Railroad Museum is also appreciated.

References

Al-Ghamdi, A. M., & Mba, D. (2006). A comparative experimental study on the use of a comparative experimental study on the use of acoustic emission and vibration analysis for bearing defect identification and estimation of defect size. Mechanical Systems and Signal Processing, 20, 1537–1571.

American Society of Civil Engineers. (2017). 2017 Infrastructure report card, 111.

Bojarczak, P. (2013). Visual algorithms for automatic detection of squat flaws in railway rails. Insight - Non-Destructive Testing and Condition Monitoring, 55, 353–359.

Bollas, K., & Papasalouros, D. (2010). Acoustic Emission inspection of rail wheels. Journal of Acoustic Emission, 28, 215–228.

Bruzelius, K., & Mba, D. (2004). An initial investigation on the potential applicability of acoustic emission to rail track fault detection. NDT and E International, 37, 507–516.

Cannon, D. F., Edel, K. O., Grassie, S. L., & Sawley, K. (2003). Rail defects: An overview. Fatigue and Fracture of Engineering Materials and Structures, 26, 865–886.

Carpinteri, A., Lacidogna, G., & Pugno, N. (2007). Structural damage diagnosis and life-time assessment by acoustic emission monitoring. Engineering Fracture Mechanics, 74, 273–289.

Coccia, S, & Phillips, R. (2011). UCSD/FRA non-contact ultrasonic guided-wave system for rail inspection: an update. In Proceedings of the SPIE (Vol. 7981).

Coccia, Stefano, Bartoli, I., Marzani, A., Lanza Di Scalea, F., Salamone, S., & Fateh, M. (2011). Numerical and experimental study of guided waves for detection of defects in the rail head. NDT and E International, 44, 93–100.

Deutschl, E., Gasser, C., Niel, A., & Werschonig, J. (2004). Defect detection on rail surfaces by a vision based system. In IEEE Intelligent Vehicles Symposium (pp. 507–511).

di Scalea, F., Bartoli, I., Rizzo, P., & Fateh, M. (2007). High-Speed defect detection in rails by noncontact guided ultrasonic testing. In Transportation Research Record: Journal of the Transportation Research Board (Vol. 1916, pp. 66–77).

di Scalea, F. L., Rizzo, P., Coccia, S., Bartoli, I., Fateh, M., Viola, E., & Pascale, G. (2005). Non-Contact ultrasonic inspection of rails and signal processing for automatic defect detection and classification. Insight: Non-Destructive Testing and Condition Monitoring, 47, 346–353.

Douglas, R. M., Steel, J. A., & Reuben, R. L. (2006). A study of the tribological behaviour of piston ring/cylinder liner interaction in diesel engines using acoustic emission. Tribology International, 39, 1634–1642.

Granger, S., Loukili, A., Pijaudier-Cabot, G., & Chanvillard, G. (2007). Experimental characterization of the self-healing of cracks in an ultra high performance cementitious material: Mechanical tests and acoustic emission analysis. Cement and Concrete Research, 37, 519–527.

He, Z., Wang, Y., Yin, F., & Liu, J. (2016). Surface defect detection for high-speed rails using an inverse P-M diffusion model. Sensor Review, 36, 86–97.

Huang, M., Jiang, L., Liaw, P., & Brooks, C. (1998). Using acoustic emission in fatigue and fracture materials research. JOM, 50, 1–12.

Lanza di Scalea, F., Zhu, X., Capriotti, M., Liang, A. Y., Mariani, S., & Sternini, S. (2017). Passive Extraction of Dynamic Transfer Function From Arbitrary Ambient Excitations: Application to High-Speed Rail Inspection From Wheel-Generated Waves. Journal of Nondestructive Evaluation, Diagnostics and Prognostics of Engineering Systems, 1, 1–12.

Li, Q., & Ren, S. (2012). A real-time visual inspection system for discrete surface defects of rail heads. IEEE Transactions on Instrumentation and Measurement, 61, 2189–2199.

Liao Chuanjun, Li Xuejun, L. D. (2009). Application of reassigned wavelet scalogram in feature extraction based on acoustic emission signal. Journal of mechanical engineering, 45, 273–279.

Liu, Z., Li, W., Xue, F., Xiafang, J., Bu, B., & Yi, Z. (2015). Electromagnetic tomography rail defect inspection. IEEE Transactions on Magnetics, 51.

Mariani, S., & di Scalea, F. L. (2018). Predictions of defect detection performance of air-coupled ultrasonic rail inspection system. Structural Health Monitoring, 17, 684–705.

Mariani, S., Nguyen, T., Phillips, R. R., Kijanka, P., Lanza di Scalea, F., Staszewski, W. J., Fateh, M., & Carr, G. (2013). Noncontact ultrasonic guided wave inspection of rails. Structural Health Monitoring, 12, 539–548.

Mariani, S., Nguyen, T., Zhu, X., & Lanza di Scalea, F. (2016). Field Test Performance of Noncontact Ultrasonic Rail Inspection System. ASCE Journal of Transportation Engineering, 143, 040170071–0401700714.

Mariani, S., Ph, D., Nguyen, T., Ph, D., Zhu, X., Ph, D., Lanza, F., & Ph, D. (2017). Field Test Performance of Noncontact Ultrasonic Rail Inspection System, 459, 1–14.

McNamara, John, F. L. D. S. (2004). Improvements in noncontact ultrasonic testing of rails by the discrete wavelet transform. Materials evaluation, 62, 365–372.

Ni, Q. Q., & Iwamoto, M. (2002). Wavelet transform of acoustic emission signals in failure of model composites. Engineering Fracture Mechanics, 69, 717–728.

Nivesrangsan, P., Steel, J. A., & Reuben, R. L. (2007). Source location of acoustic emission in diesel engines. Mechanical Systems and Signal Processing, 21, 1103–1114.

Office of Railroad Policy and Development. (2011). Rolling contact fatigue: A comprehensive review. U.S. Department of Transportation.

Office of Railroad Safety. (2015). Track inspector rail defect reference manual. Federal Railroad Administration.

Papaelias, M. P., Roberts, C., Davis, C. L., Blakeley, B., & Lugg, M. (2010). Further developments in high-speed detection of rail rolling contact fatigue using ACFM techniques. Insight: Non-Destructive Testing and Condition Monitoring, 52, 358–360.

Ping, Z., Ke, S. H. I., Rong, G., & Gong, S. (2002). Application of wavelet transform to acoustic emission testing. Nondestructive Testing, 24, 436–440.

Rizzo, P., Coccia, S. (2009). Noncontact rail monitoring by ultrasonic guided waves. Encyclopedia of structural health monitoring, 2397.

Rizzo P, L. di S. F. (2007). Wavelet-based unsupervised and supervised learning algorithms for ultrasonic structural monitoring of waveguides. Progress in smart materials and structures research, 227–290.

Roux, P., & Fink, M. (2003). Green’s function estimation using secondary sources in a shallow water environment. The Journal of the Acoustical Society of America, 113, 1406–1416.

Sadeghi, F., Jalalahmadi, B., Slack, T. S., Raje, N., & Arakere, N. K. (2009). A review of rolling contact fatigue. Journal of Tribology, 131, 1–15.

Sadoudi, L., Moulin, E., Assaad, J., Benmeddour, F., Bocquet, M., & Hillali, Y. El. (2016). Experimental study of acoustic noise correlation technique for passive monitoring of rails. Materials Sciences and Applications, 07, 848–862.

TA Harris, M. K. (2007). Rolling bearing analysis: essential concepts of bearing technology. (B. Raton, Ed.) (5th ed.). CRC Press.

Thakkar, N. A., Steel, J. A., & Reuben, R. L. (2010). Rail-wheel interaction monitoring using Acoustic Emission: A laboratory study of normal rolling signals with natural rail defects. Mechanical Systems and Signal Processing, 24, 256–266.

Tippmann, J. D., Zhu, X., & Lanza Di Scalea, F. (2015). Application of damage detection methods using passive reconstruction of impulse response functions. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 373.

Weaver, R., & Lobkis, O. (2002). On the emergence of the Green’s function in the correlations of a diffuse field: Pulse-echo using thermal phonons. Ultrasonics, 40, 435–439.

Xiong, Z., Li, Q., Mao, Q., & Zou, Q. (2017). A 3D laser profiling system for rail surface defect detection. Sensors, 17, 1791–1810.

Zhang, J., Ma, H., Yan, W., & Li, Z. (2016). Defect detection and location in switch rails by acoustic emission and Lamb wave analysis: A feasibility study. Applied Acoustics, 105, 67–74.

Zhang, X., Cui, Y., Wang, Y., Sun, M., & Hu, H. (2018). An improved AE detection method of rail defect based on multi-level ANC with VSS-LMS. Mechanical Systems and Signal Processing, 99, 420–433.

Zhang, X., Feng, N., Wang, Y., & Shen, Y. (2014). An analysis of the simulated acoustic emission sources with different propagation distances, types and depths for rail defect detection. Applied Acoustics, 86, 80–88.

Zhang, X., Feng, N., Wang, Y., & Shen, Y. (2015). Acoustic emission detection of rail defect based on wavelet transform and Shannon entropy. Journal of Sound and Vibration, 339, 419–432.