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Experimental Study of Key Parameters in Turnout Crossing Degradation Process

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ABSTRACT

The continuous increasing demand of public transportation capacity requires the railway network operating in tight schedule. The high transporting volumes not only aggravate the degradation of railway infrastructure but also shorten the time for maintenance. Well-arranged infrastructure maintenance contributes to the budget reduction and reliability improvement.

With the purpose of key parameters investigation in the turnout crossing degradation process, a series of subsequent measurements using instrumented crossing system (ESAH-M) on a 1:15 railway turnout at various stages were performed.

The results indicate that wheel/rail impact area narrowed with deepened rail wear. This narrowing is a signal of rail damage. Frequency band pass filtered results describe the condition development of different structures in the turnout crossing section in the test period. Series of more systematic crossing measurements are in progress in a test section in the Netherlands. The ultimate purpose of this study is to form the crossing degradation function to be implemented in the structural health monitoring system(SHMS) for railway turnouts developed at the TU Delft.

KEY WORDS: Railway turnout crossing; degradation process; field measurements; dynamic frequency response function; condition assessment

1. INTRODUCTION

Maintenance arrangement is a big task for railway infrastructure manager. Correlate structural condition monitoring responses with stages in the degradation process has important guidance significance in track maintenance operation.

A number of related studies performed and published recently. In [1] introduced structure asset degradation process and applied in railway maintenance. In [2-4] the mobile device ESAH-M is introduced and the dynamic turnout crossing behavior based on experiments performed in the Netherlands is studied. In [5-6] the authors simulated the influence of profile change on the crossing dynamic behaviors, including vertical distance between wing rail and crossing nose, the shape of the crossing nose, etc.

This study is the continuation of [2-4], aiming at finding out sensitive parameters that reflect crossing conditions in its degradation process.

A 1:15 turnout crossing in different operation conditions was subsequently measured 3 times with ESAH-M in the Netherlands. Combined with visual inspections, the crossing conditions were successively defined as "worn" (operation condition), "damaged" (visual plastic deformations and cracks) and "maintained" (after welding the defects and grinding).

Figure 1 gives the visual inspections of this crossing and in Table 1 shows the schedule of measurement and maintenance arrangement.

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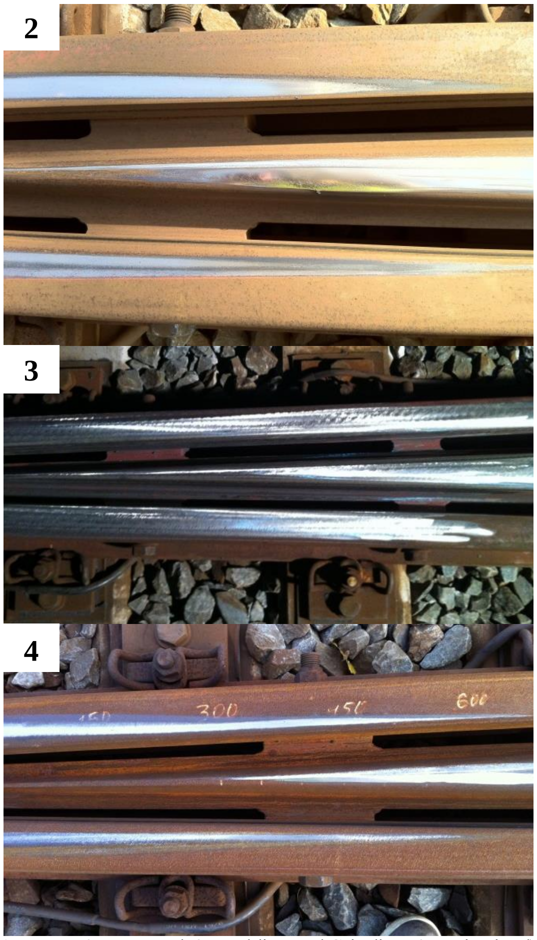

(1: Worn; 2: Damaged; 3: Welding and Grinding; 4: Maintained)
Figure 1 Overview of the measured turnout crossing

Time	Crossing Condition	Total trains	Total axles
13.01.2012	Worn	6	144
29.08.2012	Damaged	12	288
10.10.2012	Welding and grinding		
03.11.2012	Maintained	11	264

Table 1 Measurement and Maintenance arrangement

In the "Worn" stage, the crossing nose had certain degree of wear, but no significant visible damage. Plastic deformation and cracks were clearly seen in the "Damaged" crossing. Through grinding and welding the damaged part was removed and the crossing was reshaped. After short operation period in "Maintained" stage, sharp angles were mostly polished by wheel/rail interaction, from the rail point of view, the crossing condition was good.

Passenger trains selected from each day measurement are with the same type, length (24 axles) and velocity around 130km/h, effect of vehicle variation is negligible.

The data analysis contains of two main steps. Step 1 is global analysis, focusing on data processing of whole day measurement. General information from each train including velocity, 3-D accelerations and wheel/crossing impact position are collected and analyzed. Step 2 is local analysis, which concentrated on the 3-D acceleration responses on one passing axle in both time domain and frequency domain. Combined with the crossing vibration characteristics, conditions of different components can be achieved.

2. GLOBAL ANALYSIS

When a train passing through, ESAH-M automatically collects and calculates train velocity, maximum 3-D acceleration values introduced by each passing axle and wheel/rail impact position from crossing nose of each axle. Mean values (3-D accelerations and wheel/rail contact position) of all the passing axles in one day measurement describe the general response of the crossing, and standard deviations represent the variance among different passing wheels. The global analysis is mainly based on these two indexes.

2.1 Acceleration analysis

Mean values (a) and standard deviations (σ) of 3-D accelerations as well as wheel/rail contact angles Longitudinal and Lateral directions are respectively given below.

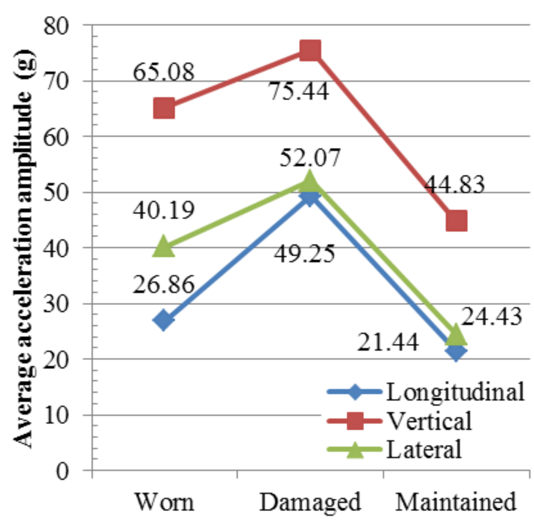

Figure 1 Average accelerations (a) in different crossing conditions

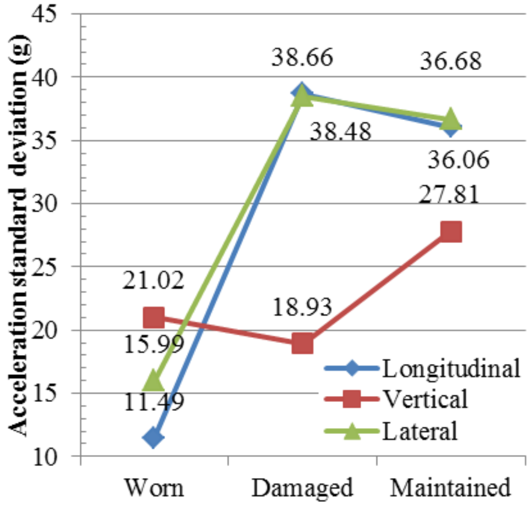

Figure 2 Standard deviations of measured accelerations

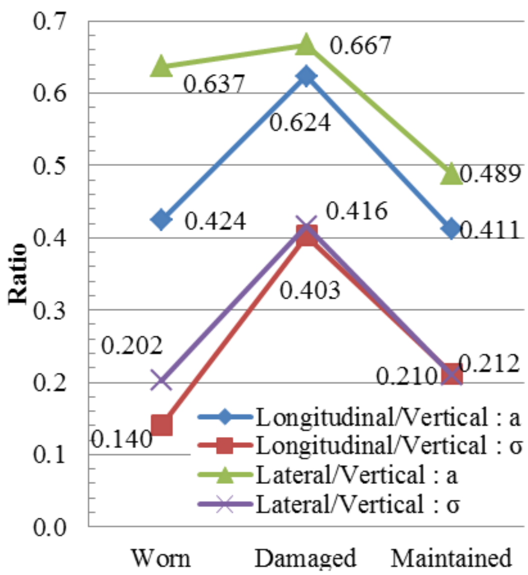

Figure 3 Mean values (a) and Standard deviations (σ) of contact angles

Figure 2 indicates the increased responses with deteriorated crossing condition (from "Worn" to "Damaged") and the positive maintenance effect (from "Damaged" to "Maintained"). Faster growth of longitudinal and lateral accelerations (from "Worn" to "Damaged") leads to larger contact angles in these two directions (Figure 4). After maintenance, crossing accelerations dropped lower than in the "Worn" stage.

Dramatically increased standard deviations in longitudinal and lateral accelerations reflect the contact uncertainty in these two directions in "Damaged" crossing, which in Figure 4 are the increase of both mean values and standard deviations in wheel/rail contact angles.

In maintained crossing, the standard deviations of 3-D accelerations are all relatively high, but not the contact angle responses (a and σ), which means that 3-D accelerations change in synchronization. Excitations (probably sharp angles) still exist in the crossing in "Maintained" stage.

2.2 Wheel/rail contact position analysis

ESAH-M is equipped with a pair of speed sensors to calculate train velocity and wheel/rail contact positions according to the peak responses introduced by passing wheels. Mean values and standard deviations of wheel/rail contact positions are shown below.

Condition	Average (mm)	Standard Deviation σ (mm)	σ Variation
Worn	548.05	78.30	-31%
Damaged	542.43	59.67	
Maintained	524.12	93.68	+57%

Table 2 Wheel/rail contact positions

Contact positions of all the recorded passing trains are displayed in Figure 5. Due to the space limitation, "Worn", "Damaged", "Maintained" and ±σ are respectively aliased as W, D M and ±. The 80% coverage (a±σ) area of each measurement condition is shown as a triangle.

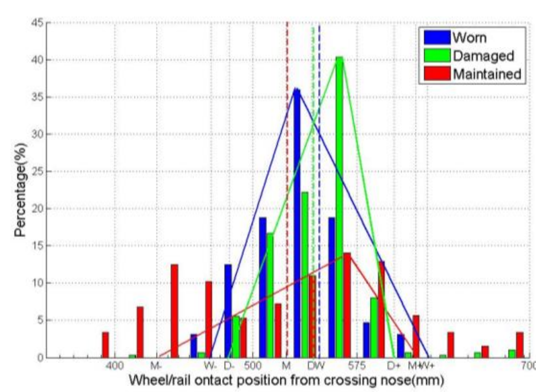

Figure 4 Histogram of wheel/rail contact positions

Table 2 and Figure 5 illustrate that the average wheel/rail contact position is relatively stable, but σ decreased with degraded crossing and increased after maintenance. The wheel/rail contact position centralized with "Damaged" crossing rail. Combine with Figure 4, wheel/rail contact angles varied in short contact section, which also reflects the irregularity of rail profile as shown in visual inspection.

2.3 Discussion

Based on the data analysis, the crossing conditions in the measurements can be defined more precisely.

In the stage of "Worn", the wheel/rail contact position shows a tendency of centralization and the average lateral contact angle is in the same high level as "Damaged" crossing. This condition is suitable for operation but already shown the potential for damage. In this stage, maintenance preparation is recommended.

In the "Maintained" stage, low mean values and high standard deviations of 3-D accelerations indicate that the crossing is in good condition, but still has some sharp angles related to the extra excitation.

3. LOCAL ANALYSIS

Based on the average 3-D accelerations and wheel/rail interaction, a representative passing axle is selected from the measurement in each crossing condition. Among all three directions, longitudinal and lateral accelerations mainly reflect vibration of the crossing rail, while vertical acceleration is the combination of vertical responses in all the components. Filter out the responses correlated with different parts is instructive in condition assessment. According to [7], each time domain vertical acceleration signal is band pass filtered into 0-40Hz (subgrade), 40-400Hz (superstructure exclude rail), 400-1500Hz (rail) and 1500-5000Hz (noise). The band pass filtered results of all the selected axles are given in Table 3.

Crossing Condition		Worn	Damaged	Maintained
Impact area (mm)		400	200	1000
Original response (g)		69	79	41
Frequency band pass responses (g)	0-40Hz	0.7	0.6	1.3
	40-400Hz	8.9	25.8	20.5
	400-1500Hz	41.8	42.7	25.7
	1500-5000Hz	50.6	58.5	18.9

Table 3 Frequency band pass filtering results comparison
Note: Impact area is estimated from the peak interaction area in time domain response in combination with train velocity.

The impact area illustrates similar tendency as shown in Table 5. The wheel/rail interaction area centralized with deepened wear. From "Worn" to "Damaged" stage, the increase of acceleration is mainly contributed by ballast degradation (40-400Hz). After grinding and welding, responses from rail vibration (400-1500Hz) and noise (1500-5000Hz) were dramatically reduced. Relatively high responses in 0-40Hz and 40-400Hz reflect unstable foundation.

Figure 6-9 are the frequency band pass responses of selected passing axles in both time and frequency domain.

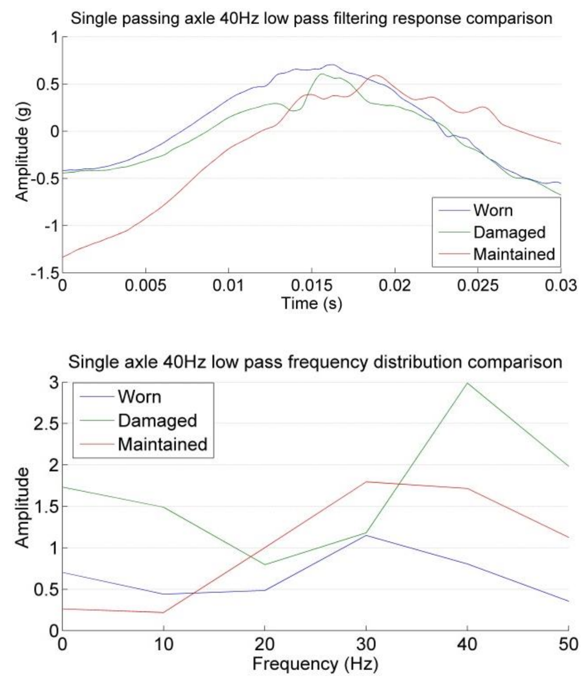

Figure 5 Vertical acceleration 40Hz low pass responses comparison (Time and frequency domain, same below)

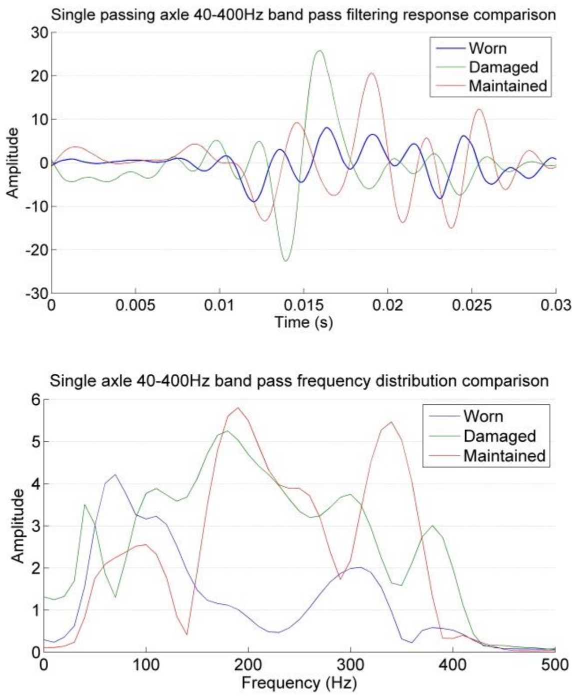

Figure 6 Vertical acceleration 40-400Hz band pass responses comparison

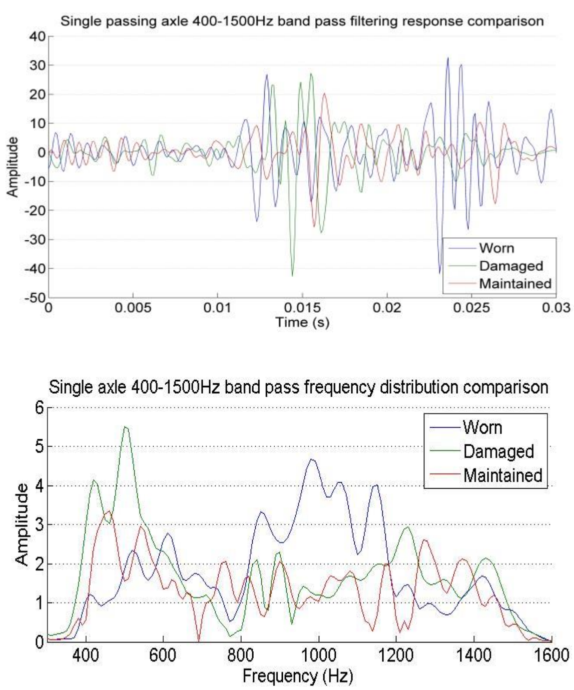

Figure 7 Vertical acceleration 400-1500Hz band pass responses comparison

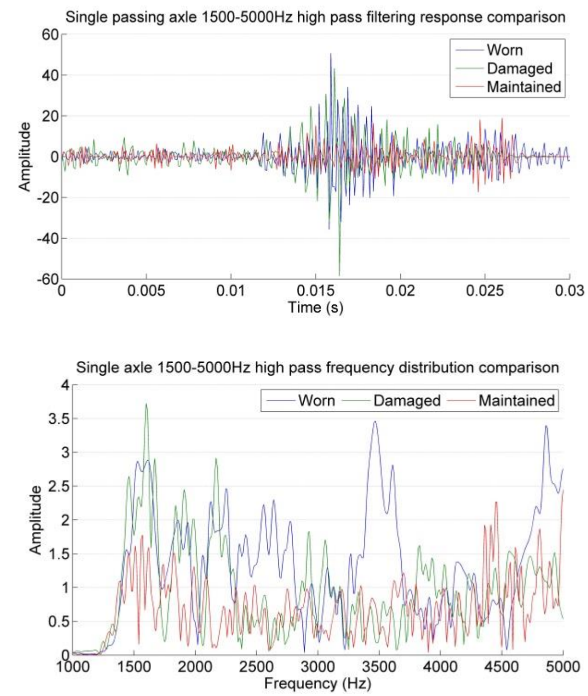

Figure 8 Vertical acceleration 1500-5000Hz high pass responses comparison

In this series of measurements, frequency domain substructure responses (40-400Hz) continuously shifted to higher frequency band (Figure 6), which is related to the ballast degradation.

Compared with the other two measurement results in 400-1500Hz, “Worn” crossing response in frequency domain is in the highest frequency band (800-1200Hz). Since this condition is a turning point when the crossing rail is going to be damaged, the shift of frequency response is also instructive.

4. CONCLUSIONS

One turnout crossing of different operation conditions is measured using ESAH-M and analyzed globally and locally.

In global analysis, the crossing conditions are more precisely investigated. High lateral contact angle and centralized wheel/rail contact position indicate potential damage in this crossing. High standard deviations of 3-D accelerations in “Maintained” crossing reflect the existence of sharp angles after maintenance.

Local analysis decomposed the degradation process of different components in the turnout crossing. From “worn” to “damaged”, crossing rail vibration is stable but substructure vibration significantly increased. This factor should also draw enough attention not only in ballast condition investigation but also in rail degradation process. Rail grinding and welding significantly reduced rail vibration and high frequency noise, but unstable substructure means the damage risk in this section is not well eliminated.

Due to track work limitation, this crossing was measured only three times. More frequent and systematic measurements are required to describe structure degradation process.

In turnout crossing, different components correlate and interact with each other. Maintenance need to be done systematically to keep every part of the structure in good operation condition.

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