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Dynamic Effect of Different Types of Trains on Crossing Main Line Using Field Measurement

Kaveh Mehrzad[1], Shervan Ataei[1*]

[1,2]School of Railway Engineering, Iran University of Science and Technology, Tehran, Iran

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A B S T R A C T

Switches are the vital elements of the rail network, and due to the discontinuity of the rail in these sections, the cost of repair and maintenance as well as the risk of an outbound event is greater than the other sections of the railroads. In this study by analyzing the data extracted from the instrumented crossing under combined traffic, after the initial processing of the signals, the characteristics of different trains were identified from the recorded data. The acceleration parameter of the switch crossing nose under train wheel passages was recorded as a measure of the intensity of the trains' impact on the crossing panel with an accelerometer mounted on the rail at the crossing nose. The results of field measurements for different trains with different speeds were compared and the feasibility of increasing speed of trains from the straight line of the switch was done assuming safe passage in the present situation of track. Based on the results of field tests, train sets up to speed 160 and passenger trains up to 115 km/h can be accelerated. Freight trains are not allowed to increase speed to maintain current situation of crossing response.

1. Introduction

Switches are vital elements of the rail network due to the traffic guidance on the railways .There are more than 7,000 switches in Iran's rail network. Maintenance cost of each 8 switches is approximately equal to the cost of maintenance of one kilometer of rail lines. So switches have a high share of total maintenance costs.

One of the bottlenecks in rail network capacity is the reduction of train speed in the direct part of the switch due to safety issues. One of the bottlenecks in the rail network's capacity is reduction of allowable speed of the trains in the direct part of the switches (main line) due to safety issues, because crossings are relatively high-impact areas of the train line.

When the train passes through a crossing, the inner wheel first passes through the wing rails, and then reaches the crossing nose. In this transition, Due to the geometric discontinuity in the crossing nose, there is a sudden vertical displacement and sever contact forces occur on crossing nose rail [1, 2].

In order to measure and investigate the interaction Forces between switches and trains, field tests, or numerical modeling, or a combination of both, have been carried out with the purpose of validating the models. Such measurements are effective in assessing the current situation, identifying failures, and predicting switch deterioration. The results of these tests are applicable at maintenance levels and even in operation. The field test enables the switch to be monitored over a period of time and subject to the passage of various devices. Examples of the infrastructure-based test (switch instrumentation) are presented using rail strain

*Corresponding author, Associate professor
Email: ataei@iust.ac.ir

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measurements in references [3, 4]. Also, Ossberger, U., et al., 2016 [5] have made the instrumentation, measurement and processing of switch monitoring data by installing strain gauge in a crossing nose.

Several numerical simulations have been performed to simulate the dynamics of the passage of the train over the switch, and in particular the crossing, which mainly involves the passage of a wheel or axle [6, 7, and 8]. Anderson and Dahlberg, 1998 [6] modeled the switch with a finite element model and beam elements for traverses and rails. Kassa and Nilsson, 2009 [7] obtained the time domain response for three-dimensional switch-train interaction by modeling switch finite element. V.L. Markine, 2011 [8] have investigated the relationship between the elastic properties of switch elements and the occurrence of wear and creep fracture on a crossing nose rail.

Y. Ma et al. 2018 [9] upgraded modeling details such as modified mesh in the wheel contact with the nose, improved the previous finite element model, But due to the high computational complexity, one wheel and half of crossing are used for modeling. The acceleration of the crossing nose as a measure of the impact of the wheel on the crossing is used to validate developed models and compare the field results with modeling. Accelerations are recorded by the accelerometer connected to the crossing nose.

Sources and researches in this field deal only with numerical modeling of the interaction between trains and switch and merely analyze the contact forces and the amount of forces in theory. Due to the increasing need for speeding up, one of the important issues in the field of rail network is the increase in the train passage speed on switch crossing safely. Therefore, assessing the switch condition at higher speeds and, if possible, increasing the speed with safety considerations can reduce travel time and thus increase the rail network capacity.

In the study, the switch condition monitoring information and data obtained from the switch instrumentation have been processed and the various outputs of the monitoring system have been extracted from these data. The data have been analyzed and statistical analysis has been done and the results of these studies have been presented in relation to the effect of different types of trains and appropriate train speed for their safe passage.

2. Switch Instrumentation and Measurement

Generally, a switch is formed from a switch panel, an intermediate panel and a crossing panel (Figure 1). Given the experience with the switch field, various failures occur for multiple rail networks. One of these important failures is related to the crossing panel. Crossing nose can suffer from deterioration, fracture, or deviation in case of inappropriate load or due to impacts. In this case, the wheels collisions with crossing nose produce a high noise and vibrations. Therefore the ability to quantify the forces or vibrations of the crossing panel by passing the train is of great importance.

Continuous monitoring of crossing vibrations induced from trains and permanent measurement of the switch blades during the train pass creates margins to improve safety and prevents the sudden failure due to gradual deterioration or dangers of impermissible speed or axle load. In recent years, the instrumentation of critical switch components and continuous switch condition monitoring under the rail traffic in the national rail network, at the entrance to the Yarty station at the Tehran-Mashhad axis have been operated by the executive team of Intelligent Monitoring of Infrastructure experts (Iran University of Science and Technology)[10]. In this system, parameters such as axle load and velocity, blade vibrations and crossing acceleration are measured continuously [10, 11].

The main line of the Yarty Station is of particular importance due to its position and the importance of increasing trains speed of operation. The switch examined is a 1:9 left hand turnout that in the branch line it has a radius of 300 meters and the switch full section rail section type is 60E1.

Figure 1 shows the location of train detection sensors, including the axle counter and axle load sensors, and crossing nose accelerometer sensor in switch plan view. In Fig. 2-a, accelerometer sensor and in fig. 2-b train detection sensors (axle counter, load index, and speed) are shown. Data were measured in the main line and facing direction of the switch.

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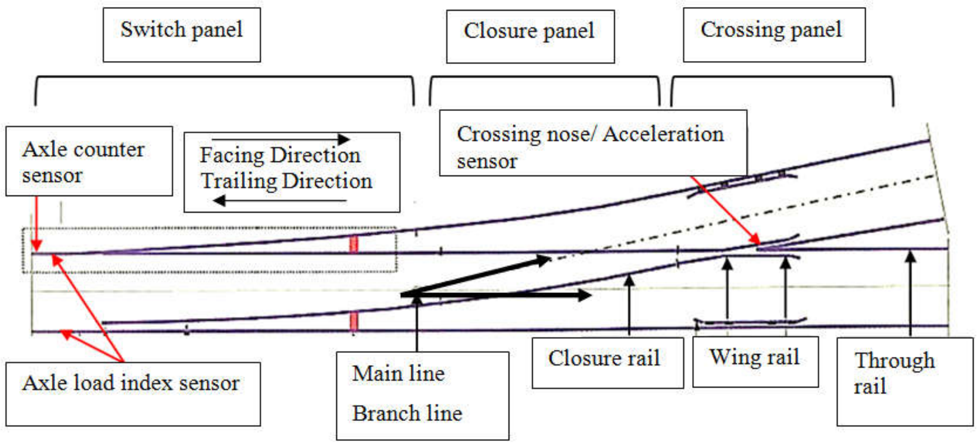

Figure 1. Schematic of railway switches and location of sensors in Yatri switch instrumentation

Figure 2. Switch instrumentation a) Accelerometer sensor b) Train detection sensors

Table 1. Statistical property of the measured data

Train type	Number of trains	Parameters	Min.	Average	Max.
Trainset	30	Speed (km/h)	65	112	130
		Averaged wagon axle load	10	12	14
		Number of wagons	4 or 5 traction unit		
Passenger	172	Speed (km/h)	32	85	109
		Averaged wagon axle load	13	17	20
		Averaged Loco. axle load	7	10	13
		Number of wagons	8	11	14
Freight	14	Speed (km/h)	35	44	58
		Averaged wagon axle load	13	16	18
		Averaged Loco. axle load	8	13	18
		Number of wagons	18	26	36

3. Database

In this study, data from the monitoring system exposed to 216 trains in about 12 consecutive days was used to evaluate the effect of different trains on the switch vibration. In Figures 3-a to 3-c demonstrated the measured raw signals related to axle counter, the axle load index and crossing nose vertical acceleration respectively for a passenger train with one locomotive and 8 wagons at a speed of 95 km/h. Data sampling was performed at a frequency of

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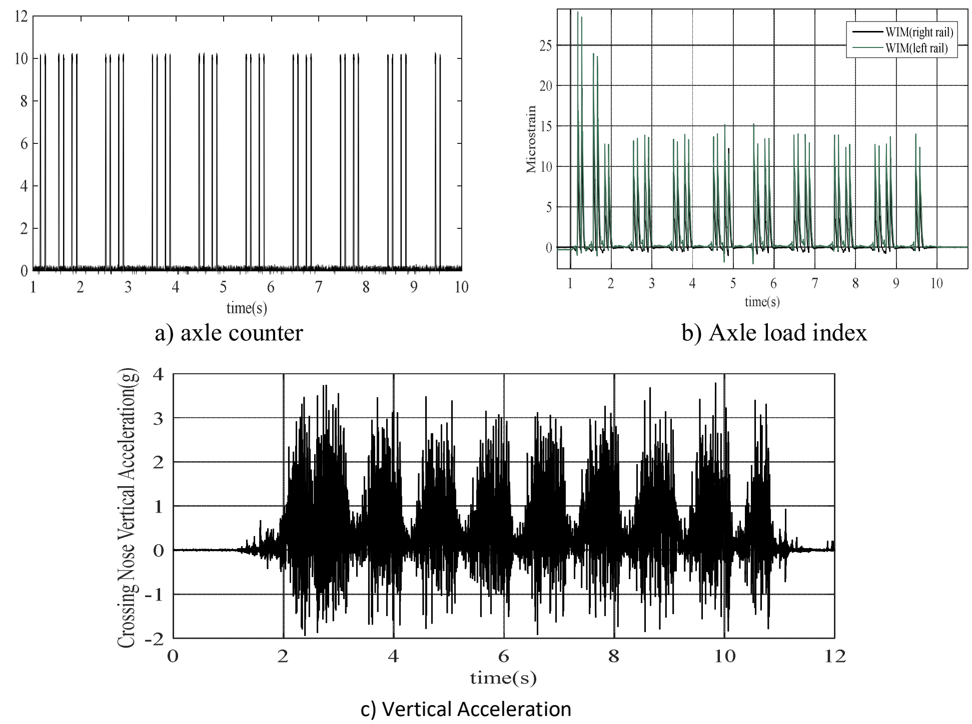


Figure 3. An example of signals recorded while passing the train

10 kHz. Table 1 presents the statistical properties of the data used. The trains are divided into three general self-traction, passenger and freight groups. Freight trains are distinguished from two characteristics of the numerous axles and the number of axles of the locomotive (3 axles). Self-traction trains or trainsets have 4 or 5 self-traction units, and therefore 16 or 20 axles with identical axle pivots in the bogies and a relatively uniform axle load are characteristics of these trains. Passenger trains are trains that are not in the freight and trains group.

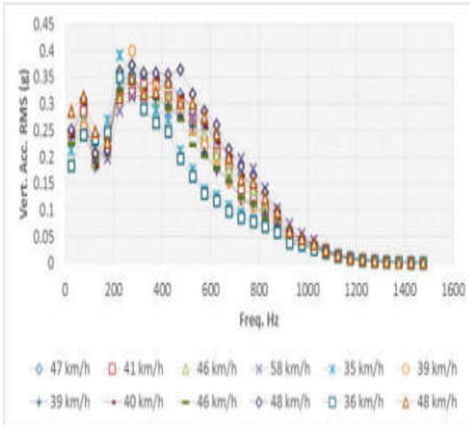
3.1. Preprocessing and processing of data

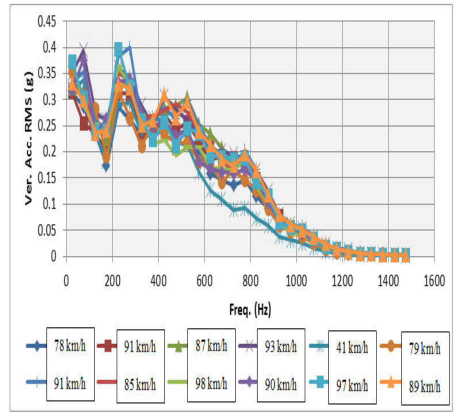
In addition to the initial pre-processing of signals, including zero padding and moving averages necessary to eliminate noise and repeatability of data, the characteristics of the trains include speed, estimated axle load index and type of detection of trains including freight trains, passenger and trainset with processing axle counter sensor data and axle load index sensors have been extracted. Regarding the frequency content of the recorded accelerations, a low-pass filter of 1500 Hz was applied to acceleration data. Also, root mean square (RMS) of crossing nose vertical acceleration is calculated in 50 Hz intervals. The results for vertical acceleration RMS due to freight trains, a number of passenger trains and trainsets, as presented in Figures 4-A, 4B and 4-C relatively. As shown in Figure 4, with increasing speed, the level of RMS values increases in different frequency ranges. In addition, in each of the figures (freight /passenger /trainset), the location of the peaks for trains follows a similar trend.

In order to detect the highest correlation frequency range with speed parameter, the correlation analysis in four frequency ranges according to the location of the peaks in Fig. 4 has been performed. The results of this analysis are presented in Table 2. According to the results, RMS of vertical acceleration has been selected in two frequency ranges of 0-50 Hz and from 200 to 1500 Hz.

4. Novelty Detection

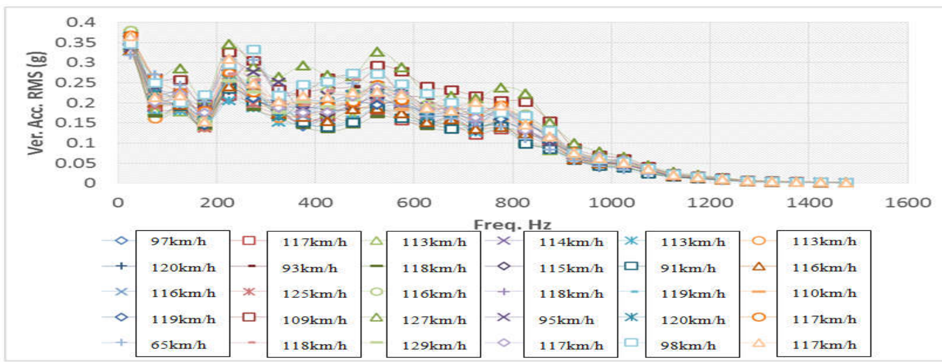
The upper limit of the acceleration RMS values is much more important, because of showing bigger impacts. To show the upper limit of the RMS values of the recorded accelerations, the boxplot statistical method has been used. According to Fig. 5, values greater than 0.39g for acceleration RMS in the frequency range of 0-50 Hz and values greater than 4.1 g for acceleration RMS in the frequency range of 200-1500 Hz





a) Results for freight trains

b) Results for some passenger trains



c) Results for trainsets

Figure 4. RMS values of crossing vertical acceleration in 50 Hz intervals

Table 2. Correlation values of vertical acceleration RMS in different frequency bands with speed parameter

Parameter	0-50 Hz	50-200 Hz	200-1500 Hz	0-1500 Hz (Tot.)	Speed
0-50	1				
50-200Hz	0.71	1			
200-1500Hz	0.79	0.82	1		
0-1500Hz- Tot.	0.82	0.86	0.99	1	
Speed	0.83	0.47	0.70	0.70	1

were considered as novelty values. These limits assumed to be margins for current safe condition of trains passage from switch crossing.

5. Results and Discussion

The results of increasing speed on the vertical acceleration in the switch crossing for three types of passenger trains, trainsets and freight trains investigated. The ability to increase the speed of trains is investigated by comparing output values with maximum observations in the switch monitoring system. In figs. 6 and 7, vertical acceleration RMS of the crossing are plotted for two frequency ranges of 0-50 Hz and 200-1500 Hz, respectively via speed changes. For each group of trains, a distinct line on the data is fitted as a linear regression estimation of the acceleration caused by various trains against

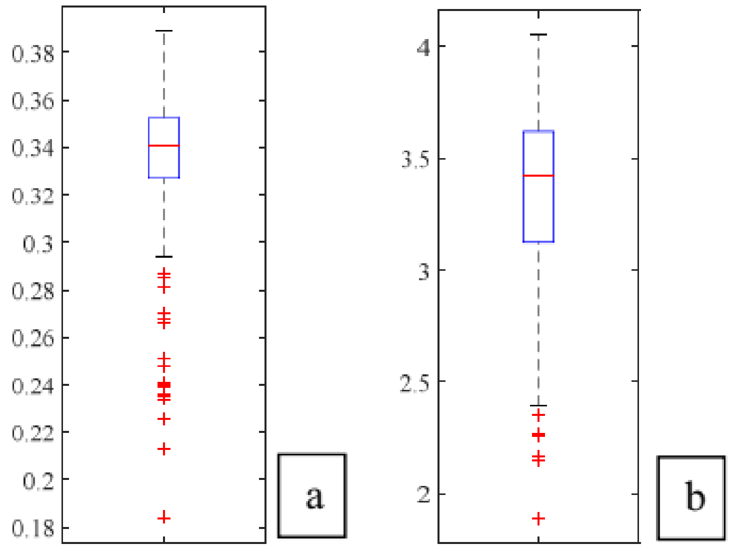


Figure 5. Boxplot of crossing nose acceleration RMS a) 0-50 Hz b) 200-1500 Hz

speed parameter. Given that the trains in current situation are in transit without problem, the maximum amount of acceleration RMS data recorded so far is assumed to be the upper limit of trains' safe traffic index and indicated with the red line in Figure 6.

According to the results of Fig. 6, the greatest effect of increasing the speed in the frequency range of 0-50 Hz is evident on the acceleration due to freight trains. Also, the accelerations caused by the passage of passenger trains and trainsets show relatively similar results with increasing speed. However, the acceleration of the vertical acceleration (in the range of 0-50 Hz) in passenger trains is slightly higher than trainset trains.

If the trend lines are drawn up to higher speeds in accordance with Fig. 6, the trend line with a standard deviation of 0.02g for freight trains will result in a speed limit of these trains of up to 100 km/h. A similar analysis for passenger trains with a standard deviation of 0.01g results in a maximum speed of 150 km/h. However, trainsets do not intersect with the line of maximum limit up to 160 km/h. Therefore, it is predictable that the passage of a trainset up to

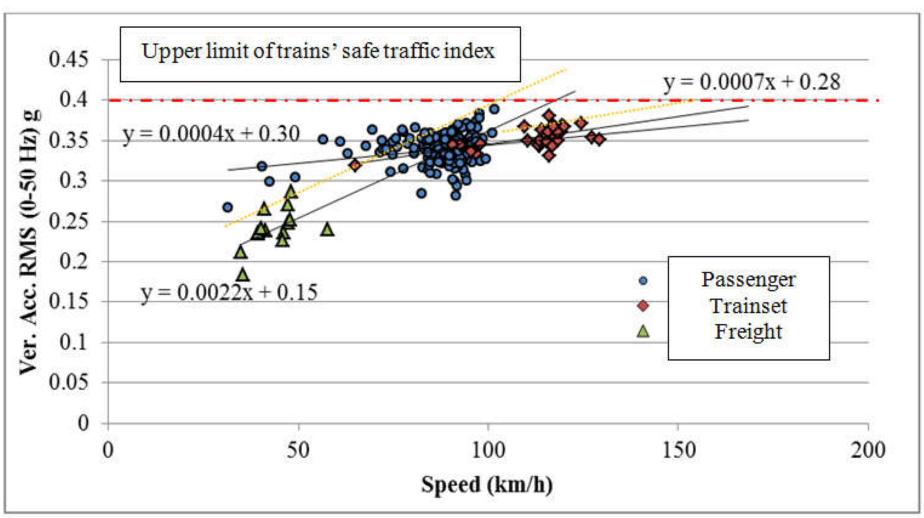


Figure 6. Results of the investigation of crossing nose vertical accelerations RMS in the range of 0-50 Hz

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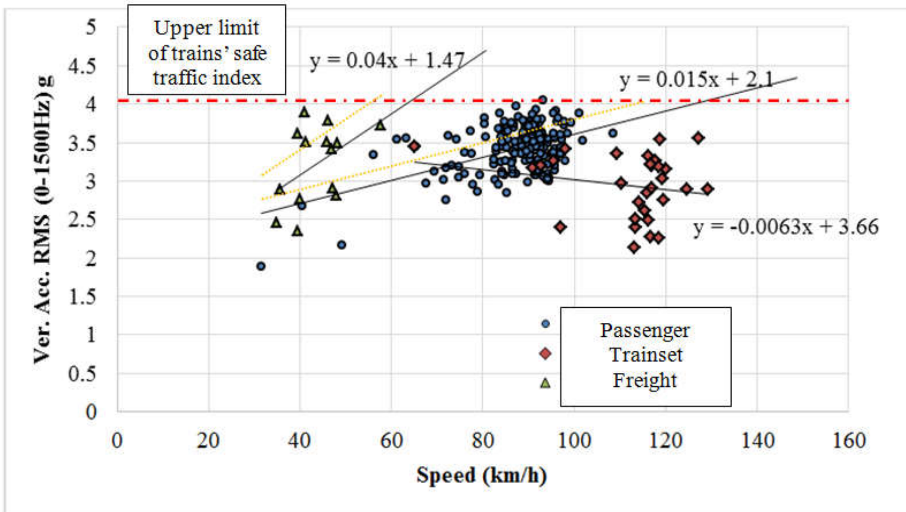

Figure 7. Results of the investigation of crossing nose vertical accelerations RMS in the range of 200-1500 Hz

160 km/h does not increase the record of vertical acceleration in the range of 0-50 Hz.

According to the results in Fig. 7, for acceleration RMS in the range of 200-1500 Hz, the greatest effect of increasing speed is evident on the acceleration due to the passing of freight trains. Based on the results, to maintain the existing condition, increasing in speed for freight trains is not possible. For trainsets, contrary to the results of Fig. 6, here, the crossing nose acceleration is completely different from that of speed and the acceleration in the frequency range of 200-1500 Hz does not limit the speed of trainsets. If the trend lines are drawn up to higher speeds in accordance with Fig. 7, the trend line with a standard deviation of 0.5g for freight trains will result in a maximum speed of around 50 to 60 km/h. The same analysis for passenger trains with a standard deviation of 0.3g result in a maximum speed of 115 km/h.

According to the results presented in Figures 6 and 7, it seems that the greatest effect with the speed increase on the impact of crossing nose is related to freight trains. By increasing the speed of freight trains compared to their current speed, it is possible to record values higher than the maximum observational values of measured acceleration, and this could potentially have negative effects on the crossing or the rolling stocks. In the case of passenger trains, after a speed of 115 km/h, it is possible to outputs exceed the maximum recorded values, and in the end, in trainsets up to the maximum permissible speed of the direct line of switches (160 km/h), there is no limitation due to vertical acceleration values.

6. Conclusions

In this study, using the parameters measured on the crossing nose rail of the railway switch in a field test and processing of recorded signals, the effect of speed on the crossing accelerations due to the traffic flow of passenger, freight and self-traction trains examined. The results of this research are based on field measurement /non-destructive test on the switch crossing. The main purpose of this study is to examine the switch behavior in case of increasing the speed of different trains, as well as comparing crossing accelerations. The ability to increase the speed of trains is investigated by comparing output values with maximum observations in the switch monitoring system. Therefore, this study can be done on other switches in the form of a case study with different conditions of construction, service life and different traffic flows, and the results will be used case by case. In light of the measured data in the crossing segment, the following results from the research are summarized:

* In the case of trainsets, the passage of a train up to 160 km/h does not make acceleration values to pass from the maximum observation.

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* The maximum speed of passenger trains was obtained at 115 km/h in order to maintain the crossing acceleration to the maximum observation.

* Freight trains are not allowed to increase speed to remain in current safe condition.

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