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The case studies of varied switches for the varied wheel profiles of the railway vehicle in terms of the derailment phenomena

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A B S T R A C T

The flange climb derailment is one of the cause of derailment for a typical switch. The derailment for the switch is a complex phenomenon since the contact area is changing dynamically. The contact angle between the wheel flange and the switch point is investegated in terms of the risk on the derailment. The contribution of this study is proving that UIC716R standard recommendation about the switch flange geometry is valid in terms preventing the derailment.

Keywords: Switch; derailment; contact angle

1. Introduction

Wheel climb derailments have many types of criteria which are developed and used by the railway engineers [1]. The types of wheel climb derailments are; Nadal single-wheel Y/Q limit criterion, Weinstock axle-sum Y/Q limit criterion, high speed passenger distance limit-US, CHXI 50-millisecond time limit-US, Y/Q time duration criterion-JNR, Y/Q time duration criterion-EMD, wheel climb distance criterion-TTCI [2].

Some of the reasons for the wheel climb derailments are stated as entering or leaving the switches at a speed which is more than the speed limit for accessing the switches [2]. The switch related derailment risks defined as; improper flange contact between the wheel flange and the switch point, excessive or unusual wear of the switch point, excessive switch rail damage and improper switch rail profile [1].

The stiffness on the track of the switch changes due to the varied lenght and spacing of the sleepers [3]. Also, both the loss of symmetry of the stiffness between left and right rail and the rail bending stiffness change at the frog can cause the transient and high-frequency vibrations in the railway vehicles as seen in Figure 1 [3]. Variation in stiffness of the tracks is causing the deterioration of the tracks as seen in Figure 2 [3].

There is not sufficient reserach in the area of the switch derailments caused by the railway vehicle dynamics. Low speed flange climb simulations suggests that limits defined by the EN 14363 and GM/RT 2141 are disagreeing [4]. Therefore, since the flange climb is major phenomena for investigating the derailment for the switch it is evident that the reserach in the area of the derailment is not sufficient.

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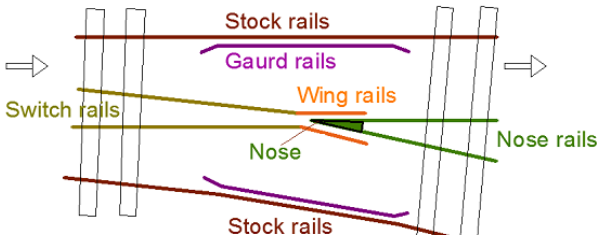

Figure 1. Stiffness change on the railway switch structure due to the varied lengths of the switch structures of the stock rail, switch rails, guard rails, nose, wing rails, nose rails [3].

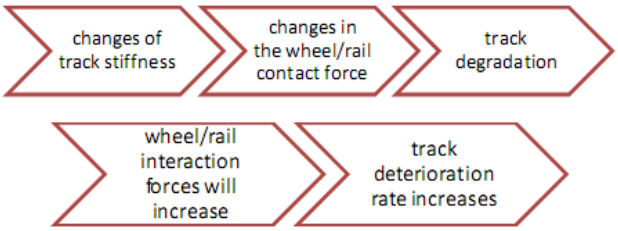

Figure 2. Variation in stiffness causing the track deterioration [3].

Wear in switches is one of the main problems stated as due to the track substructure [3]. Cast manganese frog of Figure 3 is causing the wheel-rail impact severe due to the mass change in a short distance [3]. Overall, sudden changes of stiffness and mass on the switches are causing many unwanted impacts, wear and deteriotions which can be considered in maintanence of switches,

Figure 3. Variation in mass causing the wheel-rail impact [3].

Historically, guard/restraining rails were used due to the high risk of the derailments of the long wheelbase locomotives on the track of the small horizontal curve diameters [5]. The design change of the short wheelbase of the vehicle made these guard/rastraining rails redundant [5]. However, these guard/restraining rails are s till being used on the switches, frogs and curves of the urban railway structure [5]. Also, Independent rotating wheel (IRW) of the vehicle is increasing the risk of the derailment which is one of the reason to use guard/restraining rails for the urban railway track [5].

One can realize in these examples that any design deficiency on the vehicle in terms of railway vehicle dynamics can cause a design change to retrofit this change on the track. However, it would be ideal to design vehicle so that one will not need to introduce unnecessary forces and moments applied on the vehicle due to design changes made on the track for safety purpose. Therefore, these unnecessary forces and moments can cause additional wears and deteriotions on both the tracks and the vehicles.

2.Flange climb derailment

2.1 Wheel Y/Q ratio criteria

Lateral force over the vertical force between the wheel and rail is the ratio related to the flange climb which is stated by the Nadal. The equilibrium of the acting forces on the wheel rail contact is the main theory used to derive the criteria. The turnout (switch) entry can be either tangential or radial [6]. Design of experiment (DOE) analysis completed for a switch of the UIC160 190 1:9 turnout with a tangential entry in terms of the parameters defined as in the Table I [6].

Table 1. parameters of the DOE for a switch [6]

Factor	Description	Level	Value
A	Friction coefficient primary suspension	High	0.5
B	Friction coefficient sidebearers	Low	0.1
C	Friction coefficient centre pivot	Low	0.1
D	Play	High	2=1[mm]
E	Axle load	Low	5[ton]
F	Bogie C-C distance	Low	3.5[m]
G	Wheel profiles	High	Hzdiff4mm
H	Load distribution	High	0.48
I	Suspension stiffness	High	Frozen(*100)
J	Suspension tweak	Low	Skew
K	Gauge distance	Low	-0.01[mm]
L	Track	High	Twisted
M	Sleeper	High	Loose
N	Entry	High	Tangential

The track irregularity is found to be the most influencial parameter on Y/Q ratio [6]. The interaction

between the axle load and the primary suspension stiffness is found to be the most crucial combination [6]. Finally, Y/Q ratio is mostly influenced by the suspension stiffness, track, axle load and wheel profiles [6].

The lateral forces on the switch are defined for switch (turnout) design [7]. Kinematic gauge optimization (KGO) is an optimization algorithm for designing the transition region of the switch [7]. The main goal in the switch design is to reduce the variation in the lateral forces by reducing the switch entry angle [7]. The switch diverging track shall be designed with high cant deficiency to increase the capacity of the line with the high speeds [7].

2.2 Standards and related limit values

Standards used for analysis are UIC 716R and EN 14363-2005. The permissible ratios of Y/Q is defined according to the UIC 716R dependent on the values of the friction coefficient and the angle of flange contact. The angle of flange contact need to be kept more than 60 for 0.4 friction coeffcient which is recommended by the UIC716R standard. The angle of flange contact less than 60 will probably cause the risks of the derailment. It will be more than highly likely that vehicle will derail if the angle of flange contact is 40. The derailment risk will increase with the rise of the friction coefficient [8]. The derailment criterias and the related tests are defined comprehensively in the EN 14363-2005.

3. The switch used for the analysis

A switch or turnout, called as in the USA, is named for the mechanical or electro-mechanical system which enable rolling stock to access from one track to another track. Typical switch for railways is depicted as in the Figure 5 by the authors of [2]. The switch with curve is as seen in Figure 4 which will be the switch investigated by the authors here [9].

Equations

The Nadal equation is stated as in the Equation (1) by the reference [8].

$$\frac{Y}{Q} = \frac{tan\gamma - \mu}{1 + \mu \tan \gamma} \quad (1)$$

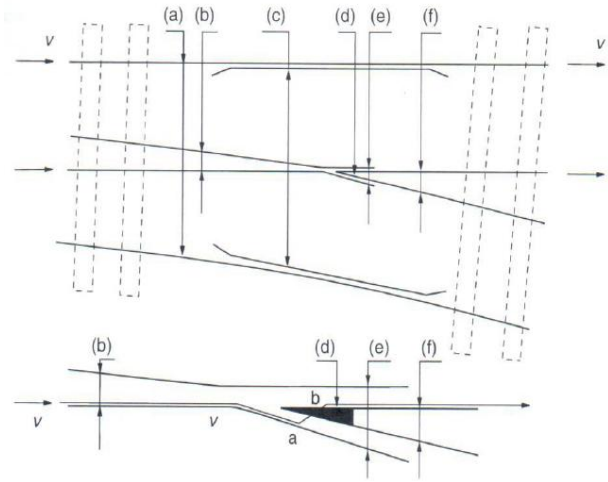

Figure 4. Railway switch. a) stock rail, b) switch rails, c) guard rails, d) nose, e) wing rails, f) nose rails [2].

Table II is the abbreviations used in this paper.

Table 2. Abbreviations

Abbreviations	Table Column Head
	Table column subhead
Y/Q	Ratio of the lateral and vertical forces for the wheel-rail contact
UIC 716R	Maximum permissible waer profiles for switches
EN 14363-2005	Railway Applications – Testing for the acceptance of running charecteristics of railway vehicles – Testing of running behaviour and stationary tests

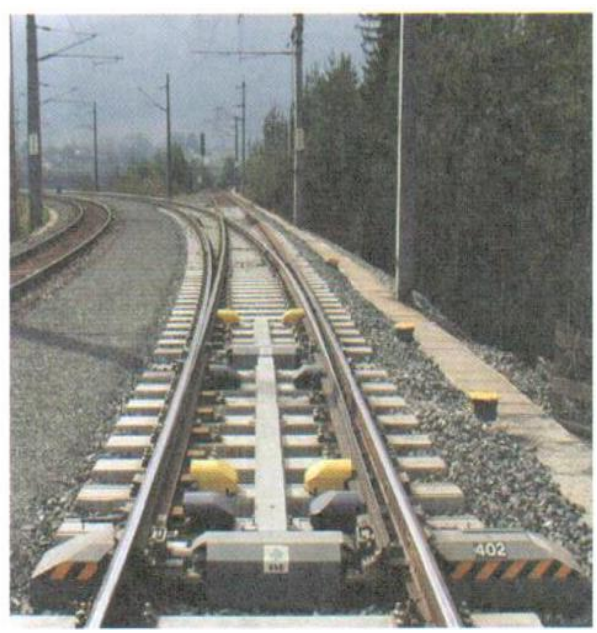

Figure 5. Switch on a curve [9].

4. Analysis of the contact angle between the wheel flange and switch rail

4.1 Methodology

It is not quite easy to obtain the switch profile by measuring via normal measurement methods in intricate geometries like switches. Therefore, 3D scanner preferred frequently in reverse engineering applications was used. In these study 3D scanner was preferred to measure 2 different types of worn wheel profiles and 3 different types of worn switch profiles in time. In this way, measuremental discrepancies caused by surface defects was determined. Thereafter, surface models of the switches and the wheels was generated using the dimensions obtained via 3D scanning method. The 3D solid models was obtained using these surface models transferred to the CAD environment. The contact angle between the switches and the wheels was investigated and evaluated using these 3D solid models created . During the process of 3D scanning, the special camera and scanner was used (Fig. 6).

Figure 6. 3D Scanner

Before taking the photos with 3D scanner, the position adjustment of the scanner was performed by someone. At the same time data acquisition was achieved by the expert for the related software (Fig. 7).

Figure 7. Preparation of the 3D Scanner system on the switches and the wheels.

During the scanning, the stickers used as reference points for the software was pasted random on the switches and the wheels to be scanned (Fig. 8). This because, in case the

Afterwards, all around of the switches and the wheels to be scanned was coloured by special spray to avoid flash, to satisfy opacity and to prevent the shape defects originating from reflection (Fig. 9).

Figure 8. Spraying on the switches and the wheels.

After these operations, ambience was satisfied with a certain extent of darkness. Thereby clear and sensitive scanning was satisfied.

3D scanning on the switches and the wheels were depicted respectively as seen below (Fig. 10, Fig. 11, Fig. 12).

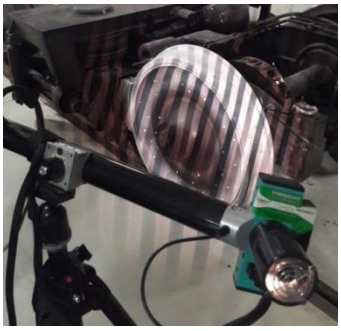

Figure 9. 3D scanning on the wheel.

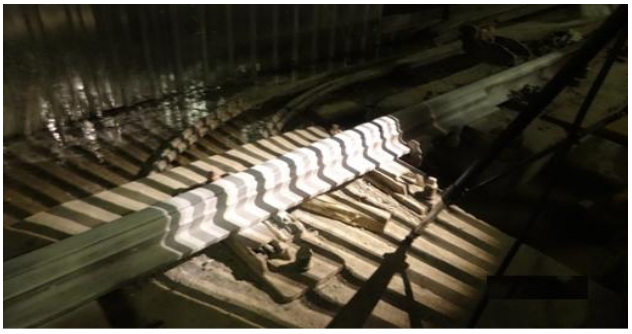

Figure 10. 3D Scanning on the switch.

Figure 11. 3D Scanning on another switch.

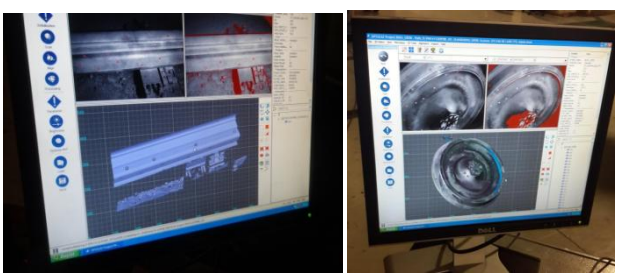

Figure 12. The created surface geometries after the scanning of the switches and the wheels.

After the scanning, data gathered from the each different photos were coupled with the regarding software and the geometry created. Thus, it was made ready to transfer to the CAD environment as a single model (Fig. 13).

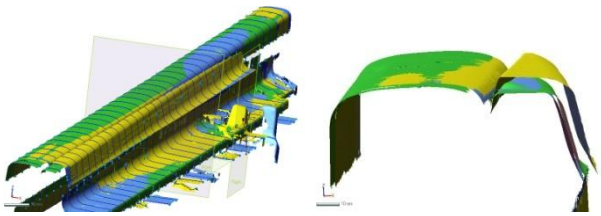

Figure 13. The created surface geometries after the scanning of the switches.

Superposed of the surface geometries of 3 different switch profiles specified previously were taken place in Fig. 14.

4.2 Analysis of the results

Figure 14 and 15 are scanned CAD data and Y/Q ratios.

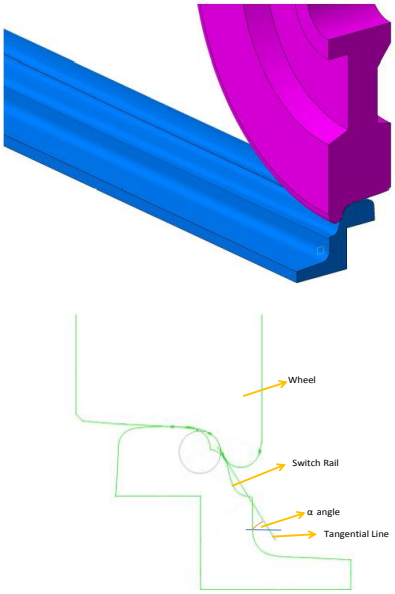

Figure 14. Scanned data transferred into the CAD environment.

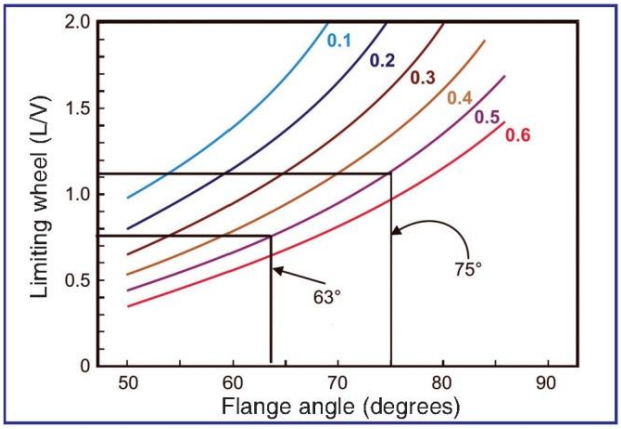

Figure 15. L/V is used abbreviations in USA for the representation of the Y/Q which is used commonly in Europe. The relations amongs the Y/Q, friction coefficient and flange angle [10].

One can see as in the Figure 16 that the relation between the Y/Q ratio, flange angle and friction coefficient exist according to the standard and the reference [10]. The increase in the flange angle is

increasing the Y/Q ratio which means safer vehicle according to the standard. However, the flange angle increase can cause the increase of the wear on the wheels when compared with the wheels of the same running conditions [10]. Therefore, the rail profiles are reshaped to reduce the wear caused by the increase of the flange angle [10]. Also, the guard/girder/restraining rails are improved to reduce the wheel and rail wear [5]. The requirements of the vehicle dynamics is effecting the profiles of the both wheel and the rail. The profile of the rail and the profile of the wheel are in evolution phase for the varying needs of the varying railway vehicles. As an example, the Independent Railway Wheels (IRW) are introduced for the low-floor LRVs recently. The flange angle is increased since the IRWs are increasing the risk of the derailment [10].

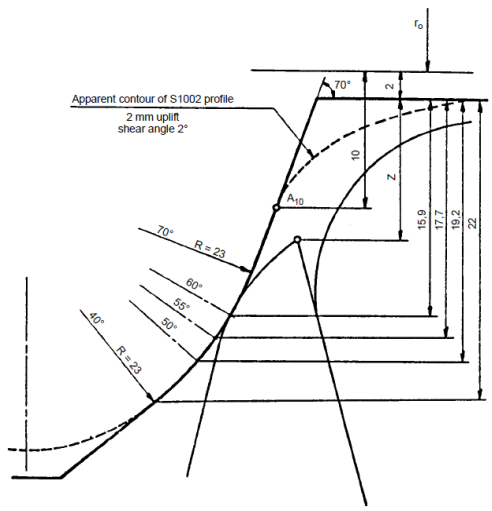

Figure 16. Example of a figure which is from the standard UIC716R.

Results of the measurements on a typical switches with assembly of the wheels on a CAD software to compare with the standard of the UIC716R is shown in Table III [12]. The angles measured are the results of the tangent between contact region of the switch of the rail and the wheel. These two types of the switches have lower than 60 degrees of the tangent angle between the wheel and the rail's touching region. 60 degrees is the minimum advised safe angles according to UIC716R for 0.4 friction coefficient [12]. The measured parameter is shown in Figure 16 which is from the standard of UIC716. Therefore, these switch types are not safe for these types of wheels according to the standard.

Table 3. Contact angle of the three varied switches versus two varied wheel

The distance from the origin	Tangent between the Y1 wheel and the X1 rail contact angle	Tangent between the Y1 wheel and the X2 rail contact angle	Tangent between the Y2 wheel and the X2 rail contact angle	Tangent between the Y2 wheel and the X3 rail contact angle
mm	Degrees			
300	-	-	-	70
400	-	-	-	70
450	-	-	54,68	-
500	-	-	55,64	-
600	48,60	50,83		-
650	53,27	51,47		-
700	-	-	58,59	-
750	58,75	55,24	-	-
800	-	-	-	70
850	61,27	56,49	-	-
1000	64,32	58,36	61,98	-
1250	67,95	62,5	-	-

5. Conclusion

The contribution of this study is proving that UIC716R standard recommendation about the switch flange geometry is valid in terms of preventing the derailment. There is not sufficient research in analyses of the switch wheel profile contact dynamics which is aiming to aid closing this gap.

Figure 17. Mark of the flange climbing can be seen by e report [5].

Flange climbing mark can be seen in Figure 9 which is the rail accident report of the RAIB [13]. The White collor notch can be seen in Figure 10 to measure the 60 degrees limit according to the UIC716R for the switch [1].

Figure 18. The white color notch is showing the 60 degrees which is the limit for the minimum advised safe angles according to UIC716R for 0.4 friction coefficient [1].

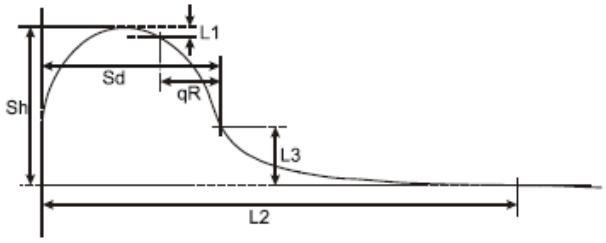

Figure 19. Wheel flange profile parameters according to the UIC 510-2 [10].

The wheel flange parameters are critical to analyze the wheel climb risk as seen in Figure 11. 3D scanning can be used for complex geometries of the swichtes to specify the derailment on the switches.

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