

Design of high-speed turnouts and crossings

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Abstract. Recently, the new ways to improve the railway switches and crossings have been sought, as the railway transport increases its operating speed. The expectation of these adjustments is to decrease the dynamic load, which usually increases together with velocity, and this influences the comfort of the vehicle passage, the wear of the structural parts and the cost of maintenance. These adjustments are primarily the turnout elements such as the optimized geometry of the turnout branch line by means of transition curves application, which minimizes the lateral acceleration during the vehicle passage through the track curve. The rail inclination is solved either by means of inclination in fastening system, or by machining of the rail head shape, because this ways of adjustment retain the wheel-rail interaction characteristics along the whole length of the turnout. Secondly, it is the crossing with movable part, which excludes the interruption of the running surface and optimization of the railway stiffness throughout the whole turnout length as well. We can see that the different stiffness along the turnout influences the dynamic load and it is necessary to optimize the discontinuities in the stiffness along the whole length of the turnout. For this purpose, the numeric modeling is carried out to seek the areas with the highest stiffness and subsequently, the system of stiffness optimization will be designed.

1. Introduction

Recently, there is an important increase of the operating speed on railways, which leads not only to higher requirements towards the railway track design, but also to higher demands towards the switches and crossings as well. The increase in operating speed brings increased dynamic load and the existence of even a small discontinuity may cause a big force effect. It may affect the railway track quality, i.e. the passengers' comfort during the vehicle passage and the maintenance cost for the infrastructure owner as well. That is why it is necessary to deal with a new design of turnout parts, which can reduce the extent of the dynamic load and this way the passage quality may be increased and the maintenance cost demands decreased at the same time. The high-speed turnouts are equipped with several specific elements. [6] These are the crossings with movable parts or the special turnout geometry used in the branch line using the transition curve. Moreover, the application of the up-to-date setting system is necessary to secure the quick throw-over of the switch rails and the points of the crossings with movable parts into required position. The setting system is equipped with positioning sensors which help to inform the operator quickly, that the operation is properly carried out and the switch rails in the switch and the point in the crossing with movable part are now switched into required position. To allow the easier movement of the switch rails and of the point of the movable part of the crossing, the



installation of the roller slide chairs is advisable, to decrease the throw-over resistance as much as possible. The application of the electric heating into the set of switches and into crossing with movable parts under our territorial climatic conditions is essential. It enables the point setting even under the most unfavourable weather conditions without any problem. The frequent application of materials with higher resistance is often carried out in the high-speed turnouts manufacture to decrease the requirements towards the wear of the critically loaded turnout parts and this way of course diminish the claims towards the volume of the maintenance activity as well. [4,5]

2. High-speed turnouts construction elements

Some of the mentioned special elements used in the high-speed turnouts were applied so far and verified under operation when installed into commonly used geometry of the turnout. For the infrastructure manufacturer and for the operator it is useful when the new elements are properly tested and verified within the standard geometry turnout and only then installed into brand-new high-speed turnout. The developed turnouts are in conformance with all Czech and European technical standards and with related specifications, such as TSI (Technical Specifications for Interoperability Relating to the Infrastructure Subsystem). [1]

2.1. Branch line geometry

The geometry parameters of rails situated within the turnout have to follow the requirements of the standard for the proposed velocity in the branch line of the turnout. In particular, it is the standard EN 13 803-2 and the Czech national standard CSN 73 6360-1. [2,3] The turnouts designed for high speed are proposed usually with respect to the following parameters: superelevation deficiency I [mm], abrupt change of superelevation deficiency ΔI [mm] and the rate of change of superelevation deficiency at an abrupt change in curvature as function of time dI/dt . Principally under higher required speed in the turnout branch line it is very useful to design the curved track as a transition curve by clothoid. Thanks to this solution it is possible to design the optimal geometry of the turnout under observing of all parameters required by the given standard. The application of track transition curve by clothoid also diminishes the side impacts from stress values higher then $1,0 \text{ m}\cdot\text{s}^{-3}$ at values up to $0,8 \text{ m}\cdot\text{s}^{-3}$ and the dynamic stress within the turnout passage as well, which means lower wear and lower cost of maintenance. The very first turnout in the Czech republic where the clothoidal curved transition branch line will be used is the turnout type J60-1:33,5-8000/4000/14000-PHS-E2.

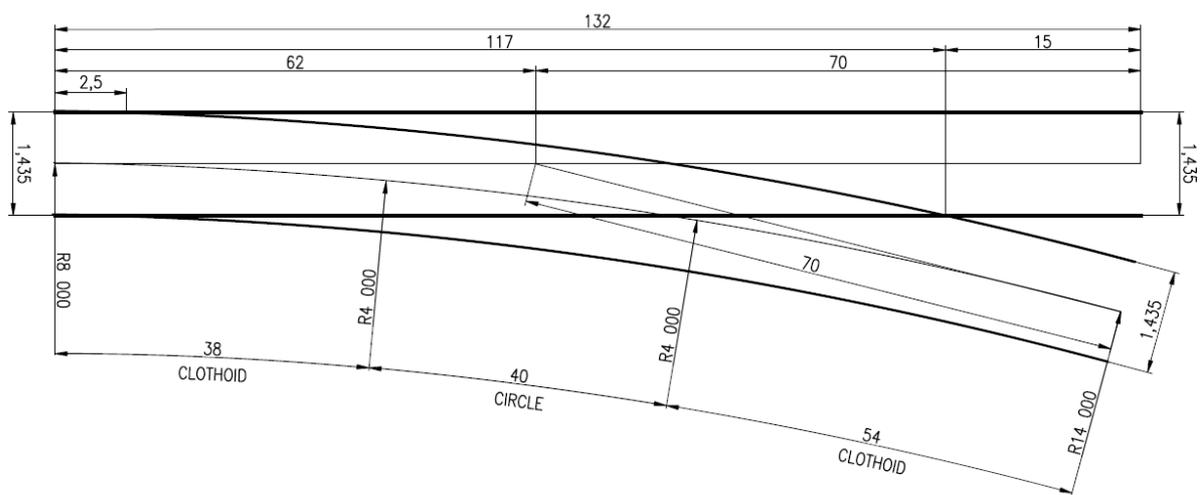


Figure 1. The very first turnout developed in the Czech Republic with unstable curvature of the branch line (type J60-1:33,5-8000/4000/14000-PHS).

In 2010 began the work on development of the turnout, which would be able to allow vehicle passage at speed 160 km.h^{-1} in the branch line, which is currently the highest possible speed within the Czech and Slovakian Railways as well. Within the proposal of the turnout geometry, the transition curves were used for the first time, which are commonly applied for the high-speed turnouts in the world. Thanks to the branch line special geometry, three different applied radii are introduced directly in the turnout name (see the Figure 1). The first number (8000) indicates the radius of the clothoid osculating circle at the beginning of the turnout. Then follows the clothoid with gradually elevating curvature (or diminishing radius as well) up to radius 4000 meters. Another element is continually joined to the transition curve, which gradually diminishes its curvature towards the osculating radius of the circle 14000 meters at the end of the turnout. If we let the transition curve of the same clothoid parameter A continue until radius ∞ (or the curvature 0 m^{-1}), this point will be exactly the point of inflection in the single crossover assembled from these turnouts with axis spacing 4,75 m. If the axial distance of 5 meters is required, it is possible to follow the turnout by the modified transition curve to reach the inflection motive again.

2.2. Rail inclination

Within the common track the rails laid under inclination 1:20 or 1:40 according to the applied section of rail and the fastening system. On the other hand, the rails in common turnouts are usually fastened vertically (the inclination 1: ∞). This change of the rail inclination influences the characteristics of the contact geometry, which may inconveniently influence the running vehicle kinematics and the increased stressing of the turnout structure may occur, mainly at high speeds. That is why in TSI (Technical Specification for Interoperability) this issue is specified and it says that for the main lines with speed higher than 250 km.h^{-1} , the rails must have the inclination. This inclination can be carried out either just by the laying on the inclined base plate, or by the shape of the active part of the rail head profile (see Figure 2). The company DT designed a special shape of the rail head marked as K (1:40), which helps to reach the properties of the contact geometry of rail profile 60 E2 laid in the inclination 1:40 for rail attached in the vertical position. DT also developed fastening system that enables placement of the rail directly in the inclination. This type of turnout has not been applied in the Czech railways network yet. [1,6]

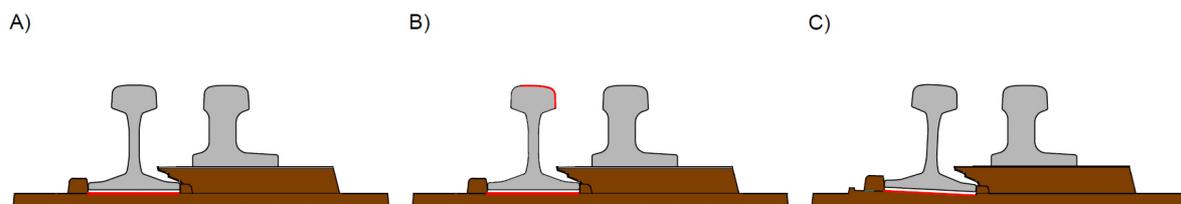


Figure 2. The possibilities how to solve the rail inclination in the slide chair. The rail can be laid either vertically (A), or inclined. The inclination can be carried out by the shape of the active part of the rail head profile (B), or by the inclined fastening system (C).

2.3. Crossing with movable parts

The first important constructional part, which is necessary for high-speed turnouts is the crossing with movable part (Czech abbreviation “PHS”). According to the TSI (mentioned above), the fixed crossing can be applied just up to the velocity 250 km.h^{-1} . Since the high-speed turnouts are designed for operation under higher speeds within the main lines, application of the crossing with movable parts seems to be a necessity. At high speeds, the dynamic stresses coming from vehicles towards the track become more prominent. That is why the elimination of any irregularities on the rail running surface is necessary. Such irregularity is the fixed crossing itself, where the wheel guiding is interrupted and is substituted by the check rail situated into opposite rail. The railway vehicle running on the straight line rail performs the natural sinusoidal movement, coming from the wheel profile shape and from the rail

head profile, i.e. from equivalent conicity. At the crossing with movable parts the wheel set is not forced to interrupt this sinusoidal movement, which has advantageous influence towards the passage dynamics and towards the comfort ride for passengers as well.

Two basic types of the common crossings with movable parts are employed. They differ with parts, which are moving. The former, widely used in Europe, it is the movable point rail situated into frame between the wing rails. The latter, not so frequently used, are the movable wing rails and the point is tightly attached. The DT selected the first one from mentioned options, when the crossings with movable parts are applied. The very first single turnout equipped with crossing with movable parts was the turnout type J60-1:12-500-PHS installed in Vranovice railway station to be verified under operation. Another turnout with crossing with movable parts was manufactured in 2007. It was the type J60-1:26,5-2600-PHS installed in Poricany railway station. Using of crossings with movable parts was gradually extended on the whole production of the turnouts designated by tangens of turnout angle and designed for application of the rail profile 60 E2. The original construction of the frame for crossing with movable parts was made of flat bottom rails (see Figure 3 B). The production was subsequently extended to the design of welded and even cast frame with optimized shape, which is successfully used for lowest-angle turnouts. The successful development can be found in the applied material as well, because our effort is to deliver materials with increased wear resistance. As to brand-new manufactured frames for crossings with movable parts, we are prepared to apply the bainitic steel, which meets all requirements.

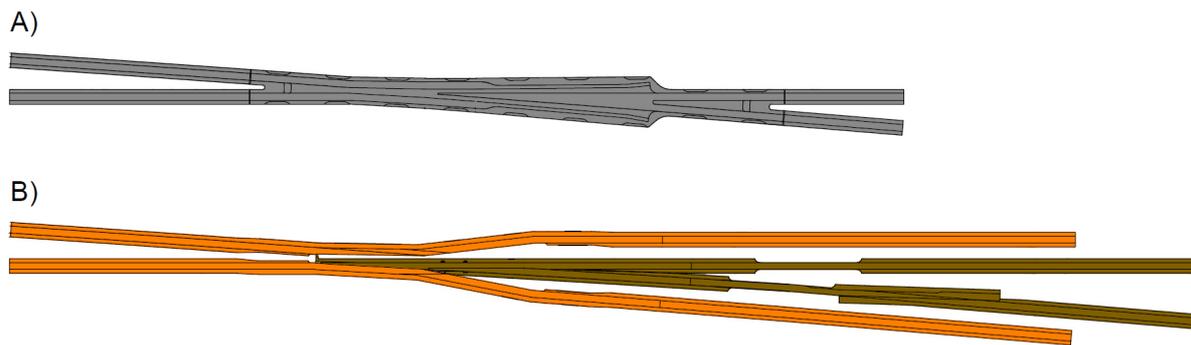


Figure 3. Comparison of the fixed crossing with interrupted running edge (A) and the crossing with movable parts (B).

2.4. Rail track stiffness

The feature, which is given by its construction, is higher stiffness of the turnout, than that of the plain track. This is given by the fact that the turnout structure consists of much more stiff elements fundamentally influencing the stiffness along the turnout. The elements getting the turnout stiff, are usually for instance the switch rails laid onto tough slide chairs (without rail pad), the crossing, check rail, and also the concrete sleepers, because the sleepers installed within the turnout are longer and more robust than those installed within the plain track. The same facts apply for the high-speed turnout J60 1:33,5-8000/4000/14000-PHS and this is our effort to optimize the railway track stiffness across the turnout length by means of the fastening system stiffness adjustment. There is an assumption, that the certain parts of this turnout shall have much higher stiffness than the standard turnout. The basic element principally influencing the high-speed turnout stiffness is the crossing cast frame for movable point rail, which has the robust steel structure. [7]

The stiffness variations across the turnout length fundamentally influence the railway vehicle dynamic behaviour when running across the turnout. The influence of the dynamic effects increases together with higher speed, which means that the way of the high-speed turnouts designing, as long as the running vehicles are supposed to reach speed exceeding 300 km.h^{-1} , the turnout variable stiffness across the whole turnout length has to be taken into consideration. At the speeds mentioned above,

even lesser variations of the stiffness can cause much bigger loading of some parts, resulting in the quicker degradation of the some parts, consequently sooner intervention of the maintenance staff, including possible worn part exchange. Moreover the occurrence of the quicker destruction of the rail geometry parameters within the turnout can be found. All this can bring the necessity to carry out the adjustment of the rail position within the turnout area more often. The stiffness optimizing, pertinently the surfacing of declined base along the turnout length should bring, besides the other, the diminished cost of maintenance, which is one of bigger requirements in connection with the high-speed turnouts. The knowledge acquired within the dynamic behaviour research of the turnout J60 1:33,5-8000/4000/14000-PHS, which is designed for speed 160 km.h^{-1} , will for sure be used within the future development of the further low-angle turnout for high-speed tracks, e.g. for turnout allowing the passage through the branch line with speed 230 km.h^{-1} . [6]

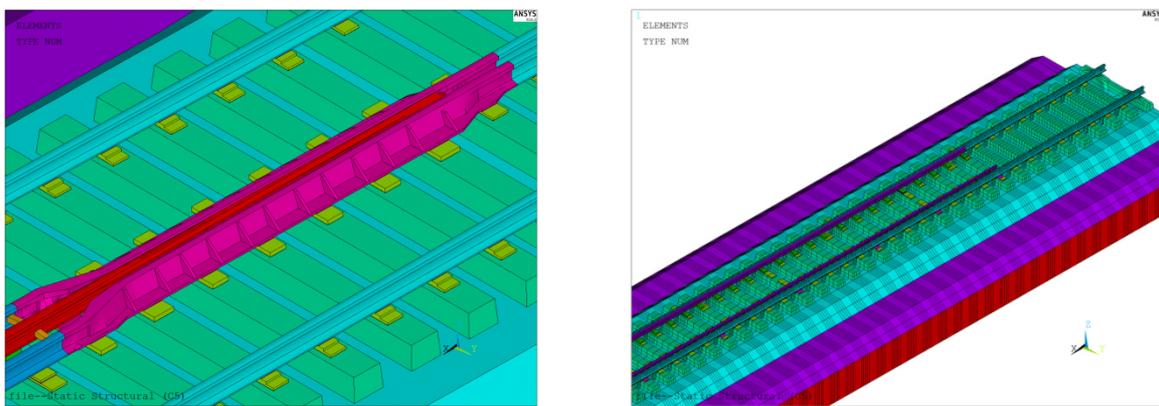


Figure 4 and 5. The high-speed turnout model processed by ANSYS software. The left picture shows the area of crossing, the right picture shows the set of switches with switch rails.

The first step was to establish the 3D geometric model, which takes account of all important elements of the turnout. All substantial parts were designed under considerations that they can influence the stiffness across the turnout length and then the dynamic behaviour of the whole turnout structure as well. It applies for example to the rails, stock rails, switch rails, frame of crossing including the movable part of the crossing, fastening systems and the sleepers. In some cases the certain simplifications had been adopted, based on the idea to exclude some designing details, which should uselessly increase the needs to disgrace the issue with final elements and could prolong the computing period as well. The further fundamental step was the 3D geometric model import into FEM software ANSYS, in which all important computations were carried out (Figures 4 and 5). After a model file import into ANSYS program, the adding of material characteristics was carried out and the model was equipped with another data, representing the weight features of used parts, which influence the dynamic characterization of the system. Consecutively, the discretionary action towards the final elements was performed and this way the turnout computing model was prepared for the individual static and dynamic computation. The first output is the development of the stiffness expressed by the rail top deflection along the turnout length (Figure 6). From this scene we can assess that the highly stiff part is predominantly the crossing part of the turnout, where after the wheel transition from the curved stock rail onto straight switch rail the prominent increase of stiffness is manifested, thanks to the stiff and flexible pad-free slide chairs. Moreover, we can see the apparent influence of sleepers with changing increased length, which influences the stiffness of the turnout internal rail. According to our assumption, the crossing area also shows high stiffness.

In the further step, the calculation of the dynamic example is carried out by means of application of the wheel forces magnified by the dynamic effect coming from the railway track inequalities and from

non-homogeneity in stiffness calculated by the static way. The result shall be the proposal to make the fastening system more flexible to remove the biggest discontinuities.

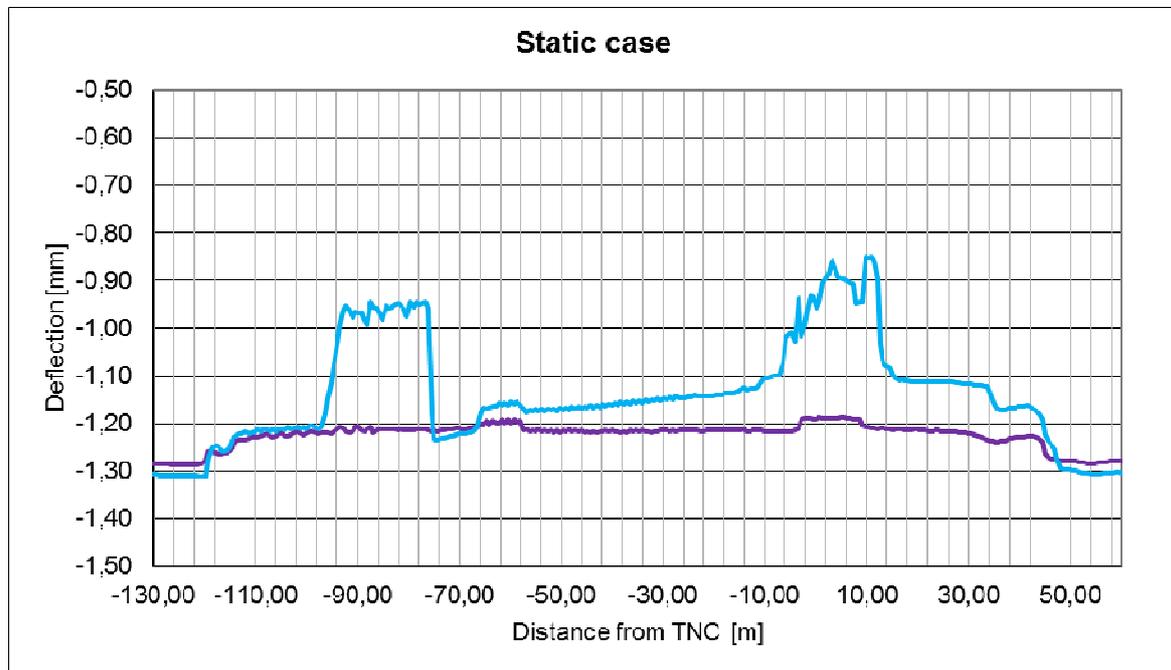


Figure 6. Stiffness diagram shows the vertical deflection within the high-speed turnout. The rail coming across the crossing is of blue colour and the opposite rail is of violet colour. The horizontal axis displays the distance from the theoretical nose of crossing.

3. Conclusion

The development of the high-speed turnouts is a continuous activity which have been carried out for many years. During this activity the innovative elements are developed and usually verified at first within the framework of the standard geometry turnouts. In the process of verification many parameters are usually checked, measured and consecutively assessed. After acquired experience the new elements may be still improved. A new constructional solution can be consecutively enforced into high-speed turnouts. Considering the demanding character of the manufacture and the constructional solution of the high-speed turnout, a functioning sample of the turnout type J60-1:33,5-8000/4000/14000-PHS was manufactured in DT in 2012, at which a number of structural elements, setting mechanisms and the retention systems testing is carried out.

Shortly, the first high-speed turnouts type J60-1:33,5-8000/4000/14000-PHS-E2 shall be installed into Czech railways network in Prosenice railway station. This event will become another milestone within the Czech Republic railway infrastructure development, which leads to increasing the running speed across the turnouts, possibly within the whole adjacent segments of the track. The turnout installations open the door for testing turnouts in the real operation, which will become the source of important knowledge with respect to the correctness of the proposed solution and to its functionality, which should consecutively become an impulsion for further improvement of the design with the aim to install fully verified turnouts into Czech first high speed rails. The high-speed turnout development is naturally still going on and our next goal is to extend our portfolio with turnout which will allow the passage in the branch line by speed $230 \text{ km}\cdot\text{h}^{-1}$.

Acknowledgements

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