LONG-TERM MONITORING OF TRAM TRACK CROSSINGS

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1. Introduction

On tram lines, two types of crossings (frog) are generally used in terms of groove depth. The crossings with such (sufficient) groove depth that the wheel still rolls on its road surface when passing through the bottom of flangeway between the vee rail and wing rail flangeway and there is no contact between the flange and the bottom of the groove, we call the so-called "deep crossings". The second type are crossings with a reduced depth of the groove, where the wheel passes through the crossing so that the flange runs (intentionally) for some time after the bottom of the groove, such crossings are called "shallow crossings" or crossings with a shallow groove. The difference between a "deep" and a "shallow" crossing cannot be precisely defined by the depth of the groove, as it can vary between operations depending on how high (or low) the surrounding area or the entire wheel profile is. For a closer look, for example, on the network of Prague Public Transit Company (hereinafter referred to as PPTC) has shallow crossings with a groove depth of 14 mm. [1]

The difference in the use and design possibilities of deep crossings v. shallow crossings in addition to the wheel profile used, the shallow groove also depends on other factors, such as in particular the width of the tram wheel. For a more specific idea, for example, Prague uses relatively "narrow" wheels with a width of 86 mm, Brno uses wheels with a width of 100 mm, Ostrava uses wheels with a width of 120 mm. [2] From the width of the wheels and their profile used in a given operation, the limit crossing angles then depend, when it is possible to use deep crossings. In general, it can be said that the transport company uses the wider wheel on the trams, the more (in a wider range of angles) it can use the deep groove crossings on the lines. On the contrary, the narrower the wheel, the more we are forced to approach the design and use of shallow crossings. (Note: However, the width of the tram wheel is also affected by other design and other limitations, and it is not possible to "just" change the fleet to wider wheels. However, this is far beyond the scope of this paper.). [1], [3], [4], [5]

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This paper focuses on crossings with a shallow groove and the issue and specifics of their maintenance. As follows from the above, this issue is typical for operations with smaller wheel widths - for example, the PPTC network, but even in other operations, the use of shallow grooves is usually not completely avoided. An extreme example is a vertical crossing, where even at any wheel width, when crossing a crossed groove, the wheel would fall into the groove at the crossing point, and thus such a vertical crossing must essentially always be performed with a shallow groove.

2. Tram track crossings

2.1. Definitions

For further description of phenomena and constructions, it is necessary to define some used terms, namely:

Shallow crossing (crossing with a shallow groove) - crossing with a depth of the groove such that the bottom of the groove is traversed around the flanges of vehicles.

Deep crossing (crossing with a deep groove) - crossing with such a depth of the groove that it travels exclusively along the top of the crossing (without mutual contact of the flange and the bottom of the groove).

Top of the crossing - the upper running surface of the tram crossing, respectively block of crossings.

Flangeway - is a part of the tram crossing, which in part carries and in the other part leads the wheel on its inner side (analogy to the wing rail at the railway turnout complete the downhill and starting point of the crossing).

2.2 Specificity of crossings with shallow gutter

The main specific feature of the crossings with the shallow groove is that at the intersection of the grooves and their surroundings, the crossing is driven especially not along the top of the crossing, but around the groove. This type of transit is undertaken in order to eliminate the dynamic impact (and related "falling") of the wheel into the crossed groove and onto the vee end of the crossing, which would not only significantly accelerate the degradation of the track structure (crossing) but also lead to greater wear and tear and last but not least. in turn to unwanted noise emissions, as each wheel would fall into the groove and hit the tip of the crossing.

To further understand the issues discussed, it is also necessary to comment on (among other things) the profile of the tram wheels. As mentioned above, the profile of wheel (as well as their width) varies between transport companies. For example, the profile of the PR-K wheel used in PPTC trams is shown here in *Fig. 1.* [1]

It can also be noticed in *Fig. 1* that the flange height of the new tram wheel with PR-K profile is about 22 mm. As a result, each crossing on the PPTC tram network with a groove depth of less than 22 mm can be considered a shallow crossing, as a tram with a given profile passes it (at least partially) around it. However, the value of 14 mm is used as a basis for crossings with a shallow groove in Prague, which is further based on the fact that the profile of wheels (flanges) is gradually moving through traffic, and reflects other requirements given by Decree No. 173/1995 Coll. issuing the Rail Traffic Regulations [6], which sets the minimum height of the tram wheel flange depending on the rails used. As can be seen, the whole issue is somewhat more complex and exceeds the considered scope and focus of the paper, for further study you can further refer to other literature and publications. [1], [3], [5], [7], [8]

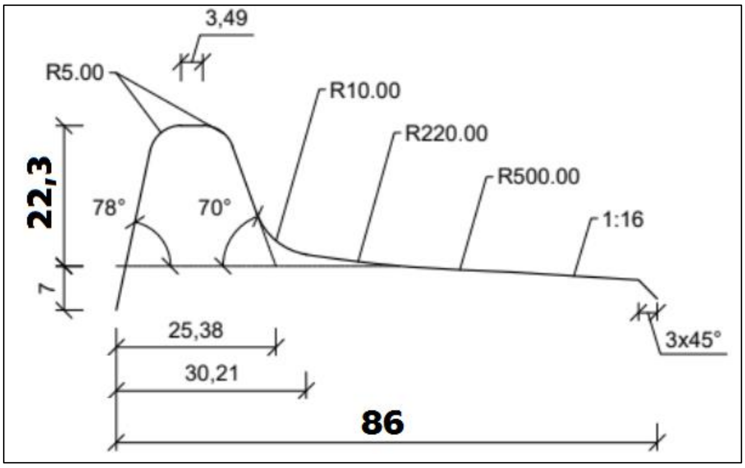

Fig. 1 – PR-K wheel profile 86 mm wide used for a tram wheel in PPTC [1]

For illustration, *Fig. 2* and *Fig. 3* show specific examples of contact surfaces (respectively "contact tracks" of tram wheels when passing through the crossing along the top of the crossing (typical for a deep groove) and for driving around (typical for a shallow groove). Detection of contact areas, the monitored crossings were covered with a fine layer of white chalk spray, which the tram wheels wiped off on the individual contact surfaces during the passage, thus creating a contact trail.

Fig. 2 – Riding on the top of the crossing
(without contact with the groove, typical for *a deep groove)*

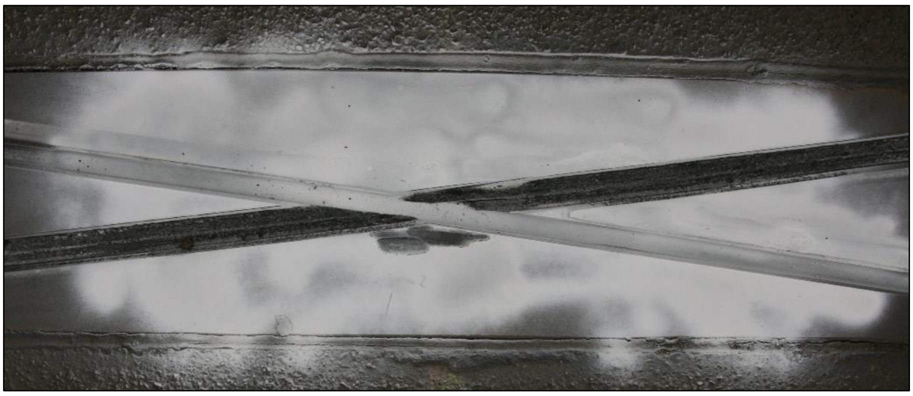

Fig. 3 - Riding through the crossing around the groove (typical of a shallow groove)

From the photographs shown in *Fig. 2* and *Fig. 3*, the principle of the passage of the wheel and the difference between the passage through the deep and shallow crossing is very clear and understandable. Chalk spray can be wiped off on the contact surfaces. The picture of the crossing running along the top of the crossing (*Fig. 2*, deep groove) also shows an understandable and clearly visible effect of the width of the wheel, which comes into contact with the wing of the crossing gradually. The contact area between the wheel and the wing is visible in different widths and distances from the groove until the subsequent transition of the wheel to the vee end of the crossing and continues along the top in the direction of travel.

On the contrary, in the case of a shallow groove (*Fig. 3*) it is evident that except for the minimum area directly on the wing, which is caused by the unequal depth of the straight and curved grooves due to driving, the wheel tread does not come into contact with the crossing. The nature of the gradual recovery of the crossing evident in the other parts of the article fully corresponds to the above.

2.3 Used, deformations and typical defects on shallow crossings

As can be seen from the photo documentation, the tram traffic is reason of lateral wear of the rail. This use is characterized by a loss of material and thus both the groove widens and deepens. [9] Furthermore, this use is characterized by deformations of the bottom of the groove, which creates a different profile of the groove in the crossing. These changes in shape lead to the need to maintain the crossing or to the need to reprofile its groove. Deformations of the grooves in the crossing (in terms of their character and shape) depend mainly on the geometry of the crossing - the groove in the junction has different characteristic deformations than the groove in the straight direction. *Fig. 4* shows an example of emerging defects and used (following the context of the wheels passing through the crossing in the pictures).

The trough in the junction direction, ie the trough in the arc (1), is characterized by its deepening and the formation of the so-called double trough - at the bottom of the groove there is a longitudinal edge due to the surrounding flange, which divides the trough into two parts.

The groove in the straight direction (2) is characterized in particular by its deepening and rounding of the groove edges and wing edges (3).

A specific and, unfortunately in a way, characteristic defect is the breaking off of the vee end of the crossing (4) of the crossing at a certain operating moment.

It can be seen that all the wear on the top of crossing, grooves and other parts of the crossing seen in *Fig. 4* fully corresponds to the tactile traces described above.

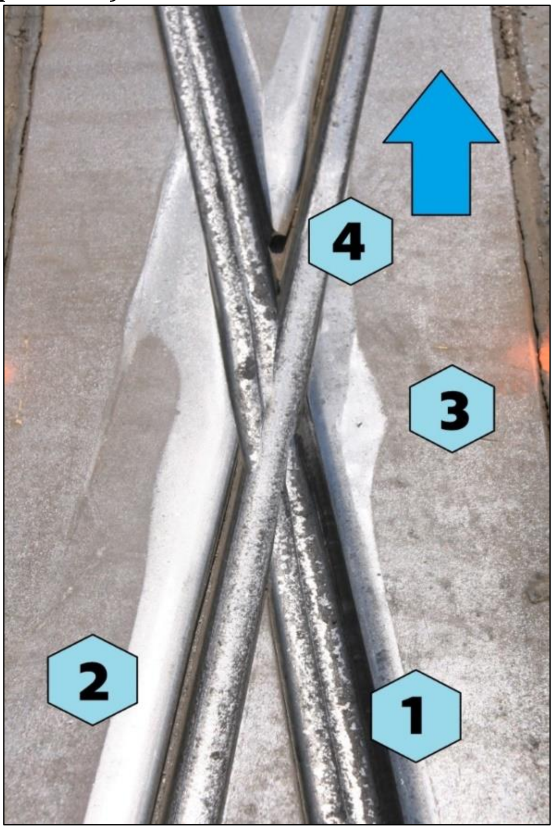

Fig. 4 – Typical defects and deformations of crossing with a shallow groove

3. Measurement of cross profiles of grooves in crossing

As part of the work on the project Long-term monitoring of track structures at tram junctions, in which the Faculty of Civil Engineering of the Czech Technical University in Prague, Pražská strojírna a.s. and PPTC. The monitored crossings are regularly measured by the Contour II measuring device. The Contour II device is generally used mainly for checking the lateral movement of rails in curves in the PPTC tram network, but it can also be used for checking the condition or correct design of welds, etc. The device scans the surface of rail structures using a swept laser beam and transmits digital form. This measurement takes place either continuously or pointwise. Continuous measurement scans the rail surface in a regular step - usually 3.84 mm or 5.75 mm in the longitudinal profile, 0.13 mm in the transverse profile. [1] Measurement takes place during operation, without the need of possesion. An example of the measurement and the Contour II device is shown in *Fig.5*

Fig. 5 – Measurement of the cross-section profile of crossing grooves

The measured data are evaluated using Contour III - Eval software. For the evaluation, 3 characteristic profiles of each monitored crossing were selected – both crossing tips and the center of the crossing. The data evaluated in this way are then compared over time, which shows the development of deformations of individual profiles over time. In the "Prague - Výtoň" locality, the construction has been monitored for 2.5 years (since August 2019). [9] The long-term development of the shape and use of the groove, showing the downhill tip of the monitored Výtoň crossing, is shown in the following *Fig. 6*.

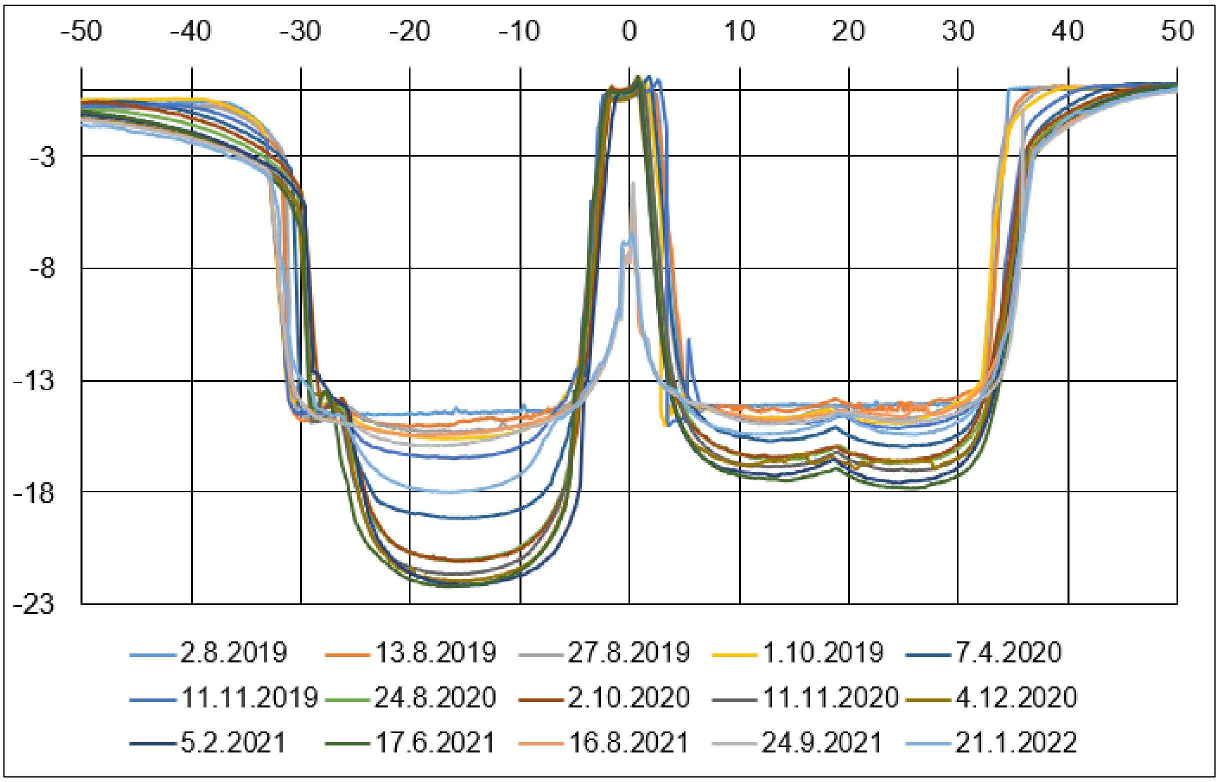

Fig. 6 – Comparison of the condition and development of the grooves behind the vee end of the Výtoň crossing over a period of 2.5 years.

As can be seen from *Fig. 6*, due to the tram traffic, the crossing was gradually used and characteristic deformations occurred. The defects and deformations of grooves described above (and visible in the photo in *Fig. 4*) are very clearly visible on the evaluated profile. From this depiction of the development of deformation and drawback, it is evident that both grooves deepen, as well as in the junction and the formation of a "double trough " in the bottom. With regard to the method of evaluation, the junction in the evaluation is mirror - in the view on the right - compared to the reality behind the vee end on the crossing, where the arc is located to the left of the point. From the original depth of the new groove of 14 mm, it deepened within 15 months to a total value of almost 22 mm. Here we can notice the continuity and interconnection with the height of the flange of the tram wheel of the PR-K profile shown in *Fig. 1* above, and the maximum value of just 22 mm is definitely not accidental.

Furthermore, it can be seen from the illustration in *Fig. 6* this rounding also had an effect on the loss of material at the points of transition from the wing rail. There was a total height loss of about 4 mm. This use is created mainly due to the deepening of the bottom of the groove, while the trajectory for the surroundings is reduced, which puts a strain on the wing by the wheel surface.

In *Fig. 6* it is also possible to notice the shape of the groove after the performed maintenance (see next text), where the values from the measurements on 16.8.2021, 24.9.2021 and 21.1.2022 show the state and development of drawbacks and deformations after welding on 12.7.2021.

4. Crossing welding and reprofiling

After reaching the limit state, when the depth of the groove reached the height of the new flanges (22 mm), a preventive intervention was performed - welding of new material and restoration of the groove shape, both transverse - reprofiling of grooves and spatial - remodeling of the tip (s). If such an intervention does not occur in operation, the use of the crossingworm will subsequently begin to increase over a larger area of the crossingworm, or a larger width of the wingworms. [9]

The crossing is welded so that the resulting depth of the groove is again (ideally) 14 mm.

Fig. 7 – Welding and reprofiling of the crossing Výtoň 12.7.2020

The material can be added to the crossing in two ways: longitudinal weld beads or transverse weld beads. Longitudinal welding beads are made parallel to the edges of the groove, resp. parallel to the direction of travel. Therefore, longitudinal welding is more suitable due to the dynamic shocks when guiding the flange through the crossing. The disadvantage of longitudinal welding is that it is more time consuming to perform (weld beads are long). In contrast, transverse weld beads are shorter and therefore less time-consuming to perform. However, due to the fact that they are transverse to the direction of the flange through the crossing, they cause greater dynamic shocks, which again leads (until the time of capture) to a temporarily greater stress on the crossing and higher noise emissions. Due to the fact that the welding of crossings takes place without exclusion during normal (night) operation, in practice transverse welding is preferred, because it does not limit tram traffic. The welding of the crossing is shown in *Fig. 7*, the reprofiled groove (crossing) in *Fig. 8.*

Fig.8 – Crossing Výtoň after welding and reproflation.
The transverse application of the caterpillars is noticeable

5. Conclusions

Based on the current knowledge of the issue, the implementation and evaluation of all measurements, it can be stated that with regard to maintenance, it is more appropriate to use and design deep crossings. This can be achieved by the design of rail structures optimization during the crossing of rail strips, which can affect the conditions with sufficient suitable spatial, network placement, etc. Furthermore, it is possible to use deep crossings to influence the transition to wider wheels in individual transport networks, but this already entails additional initial financial costs.

When using shallow crossings, it is advisable to continuously monitor the crossings and their parts and to plan maintenance by welding and reprofiling the crossings in the crossings before reaching the limit depth of the groove, which depends on the height of the flange. As can be seen from the presented results, the limit state of crossing occurs at loaded junctions after only about 2 years of operation.

Other conclusions, such as the difference between the development of new and reprofiled crossings, noise emissions depending on the coils used and suggestions for optimizing maintenance processes, will be presented in other articles, based on further monitoring of monitored crossings.

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