Dynamic testing of high-speed railway turnouts for safety and reliability assessment and diagnostic development

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ABSTRACT

Studies of dynamic wheel-rail interactions are most often analyzed for straight or curved track, and less frequently for a railway vehicle passing through a turnout. Turnouts represent a discontinuous area of track stiffness. In railway infrastructure, the turnout, along with its control and monitoring system, is one of the key elements that must ensure the highest level of safety. A significant number of railway incidents and train derailments occur at turnouts. Properly assessing the benefits of the design solutions that impact geometric stiffness (comparing different types of structures) can be crucial for both accessibility and safety. The described studies attempted to evaluate different types of structures by defining the appropriate measurements in the area of a railway turnout – in particular, assessment of the stiffness of switch blades during train passage. For consistent, high availability, it is also crucial to be able to determine the current condition of the turnout. This study asked the question whether the currently operating high-speed turnouts of identical radius and type meet the same requirements for geometric stiffness of moving components? The second question concerns the vehicle diagnostic capabilities within the scope of the applied test methods.

Keywords: railway turnout diagnostics, turnout-train interaction, train condition assessment.

INTRODUCTION

The constant development of railway infrastructure and rail vehicles in recent years has brought increasingly advanced diagnostic solutions aimed at continuously assessing the correct operation of the most important track and train components for safety. Observing the behavior of devices through diagnostics of individual components and monitoring the correct performance of required functions allows for the implementation of predictive maintenance and repair activities aimed at extending the time of failure-free operation. Sensors serve as data carriers for diagnostics, the most common being acceleration and displacement sensors. On the basis of the available literature, using the above-mentioned measurement methods, conclusions

can be drawn, particularly regarding the possibility of assessment of track geometry accuracy [1], the stability of this geometry [2], vibrations analyzed from the ground [3], possible measurement and monitoring techniques, and the collection of results presented in the article by Goodall [4], as well as the definition of measurements aimed at finding damaged infrastructure parts based on the study by Hassankiadeh [5]. The literature contains a number of studies using vehicle vibration measurements for example, in the assessment of vibrations transmitted by the structure [6], in the assessment of the variability of train suspension parameters [7] or in the monitoring of the railway condition [8]. The analyses include the technical condition of vehicles and the technical condition as well as detection of faults in railway infrastructure, in particular in the analysis

of wheel-rail interaction [9], description of the lateral stiffness of the track [10] or its actual condition [11], also trackside diagnostics [12], or those placed in sleepers [13] and assessment of the condition of the wheels [14]. Less common are the studies that analyze the behavior of moving elements of railway turnouts by measuring displacements and accelerations during interaction with rolling stock during dynamic tests. The studies were conducted to identify the areas that should be assessed during type approval, as well as those most important for diagnostics and maintenance. However, it should be remembered that proper evaluation of tests must also focus on observing the proper functioning of the rolling stock, as the results must eliminate any anomalies resulting from possible rolling stock defects (flat spots on wheels or suspension damage), so the article takes into account the analysis of the wheel-rail contact [15], the optimal turnout model resulting from the assessment of vibrations of sensors [16] and defined damages [17], specific phenomena that may occur on turnouts (stiffness discontinuity) [18] and theoretical aspects of dynamic analyses [19].

The conducted research aimed to: analyze the diagnostic systems currently installed on Polish railway lines operated by PKP PLK, assessing the correct operation of track infrastructure, particularly railway turnouts, and verifying various types of turnout designs as well as trains under dynamic interactions on high-speed lines. Literature frequently reports assessments of the interactions between turnouts and rolling stock using sensors installed on the rail vehicle; such observations clearly demonstrate the variable stiffness of the turnout as a structure. The acceleration measurements conducted by the certification body during the turnout approval process are presented below (Figure 1). The data refer to the accelerations recorded by the sensors installed in the wagon bogies. The diagram shows the three key elements of a railway turnout (red for the switch panel, green for the connecting rails, and blue for the crossing area). The graph illustrates the varying vertical and lateral accelerations recorded by the sensors, which is similarly described in the article [20]. When analyzing the dynamic interactions at the wheel-rail interface, it is necessary to describe the cause and theory of uneven horizontal interactions in train motion. The parameter characterizing this movement is "equivalent conicity". The described theory of equivalent conicity is the basis for determining the most realistic description of wheel-rail motion.

The described theory of equivalent conicity provides the basis for determining the most realistic description of wheel-rail motion. Equivalent conicity is defined as the actual wheel-rail contact point and is expressed numerically as the tangent
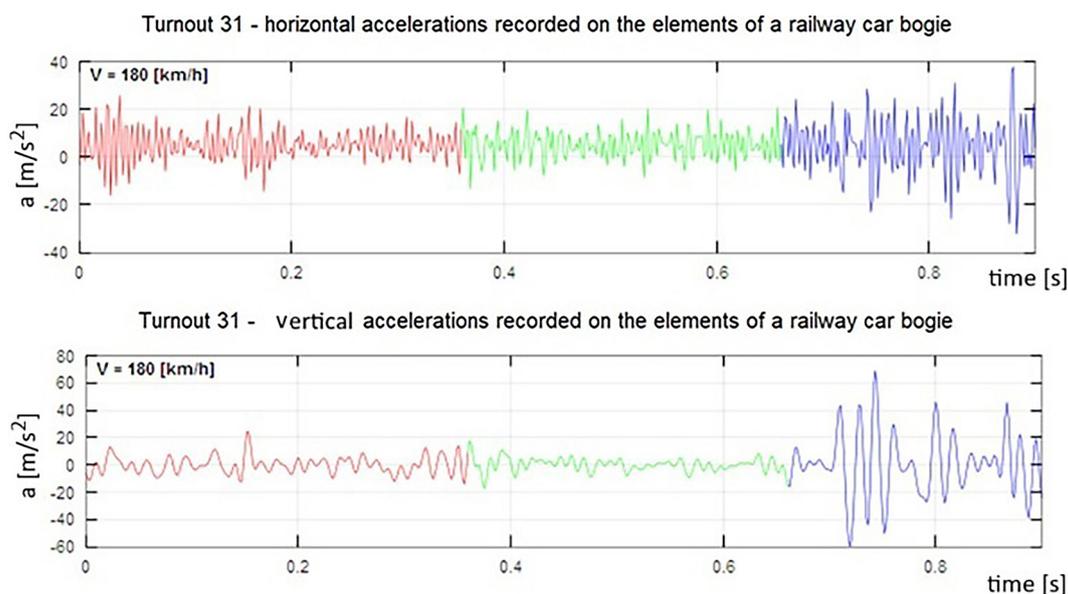

Figure 1. Accelerations recorded in acceleration sensors on car bogie while passing through a turnout -the diagram is part of research conducted by the railway institute "Instytut Kolejnictwa" (IK), which assesses railway turnouts. The research was conducted to certify a turnout with a radius of R500 for operation at speeds up to 250 km/h (for the Polish market). The document lent with the consent of IK (study from 2020)

(or γe) of the cone angle of a conical wheel. Measurements should demonstrate the nature of the interactions described in the theory in practice. The nature of horizontal motion is one of the interactions; the other main component is vertical interactions related to the train mass, speed, and track quality [21]. In authors' opinion, assessing turnouts and rolling stock solely based on the level of sensors installed on the train is incomplete and does not provide a complete picture. Therefore, in the conducted research, their interaction was assessed based on sensors installed on the turnout. The research focused on assessing individual moving elements and their connections to the overall structure in terms of evaluating their interaction with rail vehicles, and comparing the performance of different turnout structures to identify weak and strong designs.

HORIZONTAL INTERACTIONS AND RELATED PHYSICAL THEORIES

The analysis conducted in this study is related to the horizontal, sinuous motion of a train set, as theoretically presented by Johannes Klingel. Klingel's theory describes the motion of a conical wheel set when this motion deviates from the track axis (Figure 2). This sinuous motion is counteracted by the different rolling radii of the wheels (at the moment of contact due to the conical shape of the wheels). This results in a cyclic, sinusoidal motion of the train set, captured by Klingel's theory. This motion can be visualized as the motion of two connected cones on a straight track (Figure 2).

The following parameters were used in the mathematical equations and analysis: γ = conicity of the wheel running surface (inclination), r = radius of the wheel at the central position of the wheelset (if the radii in the wheelset differ, we distinguish r_1 and r_2), R = radius of the Klingel path arc y(x), d= track gauge, y = lateral

displacement of the Klingel path, v = velocity, x = distance coordinate. In ideal rolling motion, the wheelset moves laterally a distance y from the central position. There will be a rolling radius difference of $2\gamma y$, and the lateral displacement path will have a corresponding radius R.

The wavelength is as follows:

$$L_c = 2\pi \sqrt{\frac{tan\gamma}{0.5rd}} \qquad (1)$$

where: $0.5\ d=(r_1+r_2)/2$.

Klingel motion is a kinematic motion in which forces are not analyzed. The lateral displacement y is a function of the distance coordinate x, as long as the maximum amplitude does not exceed the periphery of the path. The snaking frequency (2) according to Klingel's theory is:

$$f = \frac{v}{L_c} \qquad (2)$$

the maximum lateral acceleration (3) can be calculated as:

$$a_{max} = 4\pi^2 y_0 \frac{v^2}{L_c^2} \qquad (3)$$

When analyzing possible acceleration, the unfavorable effect of speed and/or a short wavelength can be observed. For example, a conicity of 1:40 compared to 1:20 results in a longer wavelength and lower lateral acceleration at the same speed. The gradually increasing conicity in worn profiles, caused by increased lateral axle movement, therefore has a negative effect in this respect. In general, Klingel's theory approximates the motion of the wheelset, but it does not take into account the axle-bogie connection, mass forces, and the forces associated with the specific contact described in Hertz's theory. However, for the purposes of understanding the phenomenon under study, it is sufficient. The equivalent conicity (4) is a relationship related to the actual shape of the railhead and the wheel profile (in
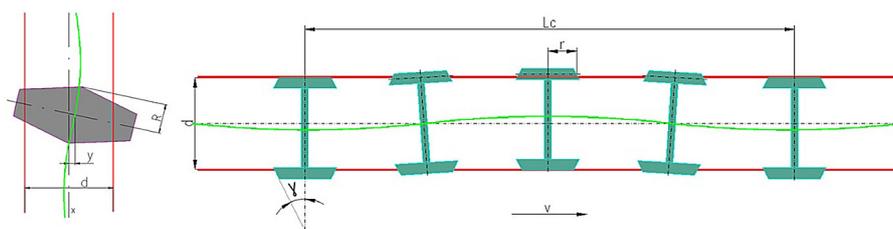
Figure 2. Movement of a wheel set on a track according to Klingel's theory - own work based on the book "Modern Railway Track" Digital Edition 2016, version 3.8 written by Coenraad Esveld

advanced analyses, it will, of course, depend on the rail camber and track clearance). The equivalent conicity, widely described in the literature in terms of estimation method [22] and by analysis of wheel and rail profile correlation [23], can be written as follows:

$$\gamma = 0.5\frac{\Delta r}{y} = 0.5\frac{r_1 - r_2}{y} \qquad (4)$$

Figure 3 shows the snaking in the case of an ideal wheelset and a set with worn wheels.

The theory presented above provides a simple framework for understanding equivalent conicity and the lateral movement that has a fundamental impact on lateral interactions in track-train interactions. Assuming an S1002 wheel profile according to EN 13715 and a 60E1 rail profile according to EN 13674 (with a camber of 1:40) and a ground clearance of 1435 mm are considered, this gives an equivalent conicity of 0.2. Additionally, the lateral movement amplitude of the wheelset can be determine as 10 mm at a speed of 160 km/h (the maximum speed at which the trains were tested), thus providing insight into the interactions between rolling stock and the rail.

CURRENT RAILWAY DIAGNOSTIC SYSTEMS

The rapid development of diagnostics and the ability to analyze large sets of digital data has led to the implementation of diagnostic systems to assess the behavior of vehicles and railway infrastructure as well as verify their correct operation, e.g. as in the literature used, where the qualitative approach of diagnostics was analyzed to assess the correct operation of vehicles [24] or railway routes [25]. Currently, devices mounted on straight tracks are used, most often to assess vehicle condition. The most commonly used system is the dSaT system. The following are the basic functions and a brief description (dSAT – a rolling stock failure detection system):

- dynamic overload (PD) – measurement of the loads acting on the track;
- wheel load (OK) – detection of exceeding the permissible axle load and linear load;
- hot axleboxes (GM) – detection of excessive axle bearing (axlebox) temperatures;
- hot brakes (GH) – detection of excessive brake rim (brake pad) and brake disc temperatures;
- flat spots (PM) – detection of train wheel deformation.

The second type of device, in this case for assessing the correctness of track geometry, are diagnostic systems installed on measuring vehicles used by PKP PLK. The installed camera and laser system allows for the assessment of parameters such as the correctness of track geometry (comparing it to the theoretical requirements of the horizontal plans) [26] and checking the correctness of cant. In 2020, the condition of over 50,000 km of track was inspected. This allows the diagnostic center of PKP to plan repairs in advance.
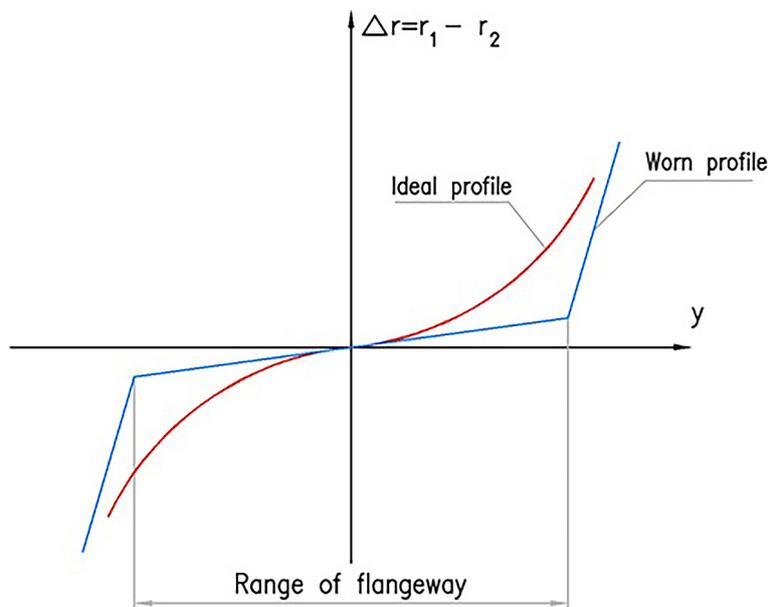

Figure 3. The movement of a wheelset on a track shown for an ideal wheelset and an ideal

However, none of the above-mentioned systems can comprehensively assess the condition of a complex device, such as a turnout. Currently, several companies in western Europe are working to design comprehensive turnout diagnostic systems as for example presented in the article on monitoring of turnouts [27]. In Poland, on PKP PLK lines, the diagnostic system tested at Psary station, installed on a 60E1 R1200 turnout, is particularly noteworthy. The implemented system has the following functions:

- diagnostics of drive and control devices,
- measurement of drive motor voltages,
- measurement of drive motor currents,
- measurement of detection accuracy,
- environmental factors.

The system installed at the turnout allows, among other things, for cyclical and long-term monitoring of the voltage and current waveforms supplying the hydraulic pump motor. This pump, through the pressure generated in the hydraulic lines, causes the movement of the actuators and mechanical locks that adjust and lock the railway turnout switch blades. Continuous monitoring and comparison of voltage as well as current waveforms over time allows for the assessment of the condition of the entire mechanical-hydraulic system and the detection of excessive resistance in the switch (or even obstacles between the switch blade and the stock rail). Furthermore, entering and comparing data from several months into tables can allow for the assessment of degradation of the entire turnout system, including the drive and switching system, and possible rail wear. The adjacent figure shows the voltage and current waveforms during the switch operation (Figure 4), as well as the correctness of the detection status after the cycle is completed. In the case of the system and turnout described here, measurements are taken at the switch and the crossing with a movable nose. Additionally, a weather station was installed in the turnout diagnostic system. Detailed environmental conditions, such as humidity, temperature, atmospheric pressure, and the level of potential rain or snowfall, can be assigned to the appropriate switching cycles. By combining the data on voltages and currents with specific weather conditions, specific measurements and problems can be assigned to the causes related to these conditions. The diagnostic system has a permanent internet connection, owing to which all data from the system is transmitted in real time to the turnout manufacturer's database and analyzed in order to analyze the results for predictive actions [28] or the data regarding the planned maintenance model [29]. When assessing the installed system, it should be noted that it does not address the issue of assessing the correct
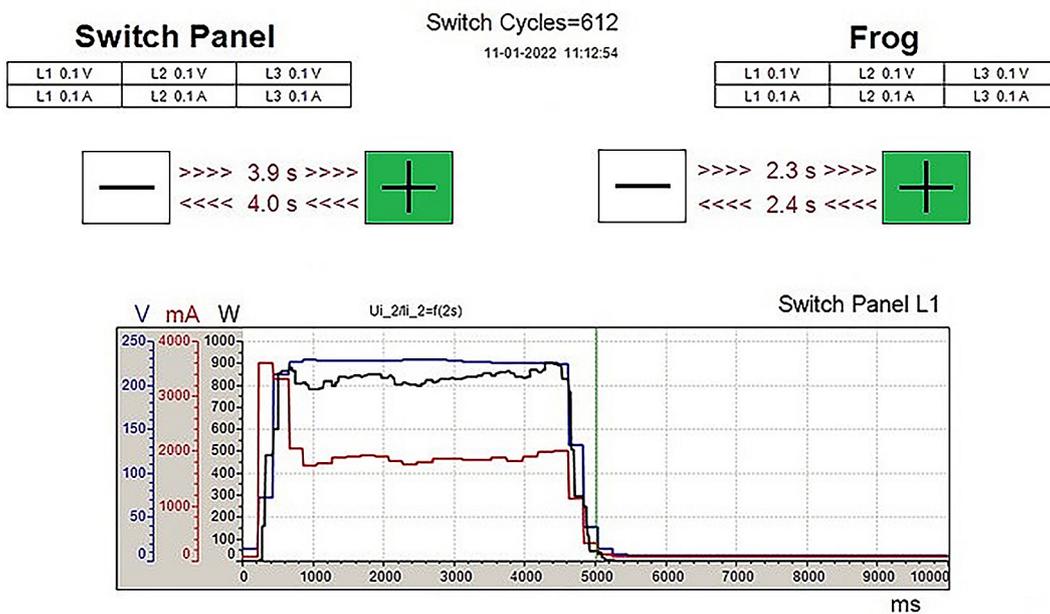

Figure 4. Reading current and voltage waveforms from the switch drive system

operation of the turnout in the context of dynamic interactions between the train and the turnout described in the article [30]. As part of the ongoing research, an attempt was made to determine the significance of this issue for diagnostics.

DESCRIPTION OF RESEARCH

On the basis of the experience gained, in this stage of research it was decided to examine the switch area which could potentially pose problems in maintaining the continuity of stiffness and geometric stability during the train passage, i.e. the blades. Turnout blades are held by locker devices in the front part, while at the brackets distance they are supported by stop inserts by pressing (based on the shape set at the factory). The research compared two turnout designs with the same radius R500 and identical approval allowing trains to operate at speeds of up to 250 km/h. To summarize, the research attempted to investigate the following issues:

- the ability to maintain the correct geometry and stability of moving elements,
- gaining knowledge regarding dynamic interactions with a rail vehicle.

The research also analyzed standard methods for verifying the correct operation of a railway turnout. Periodic tests carried out throughout the life cycle of a railway turnout, which are undertaken by the manufacturer's service or persons responsible for infrastructure maintenance employed by the user, are limited to static tests of geometry. The examples of measurements used to verify a railway turnout include: tests of track gauges and flangeway, tests of distance to touch of blades and opening, length measurements. However, none of the static measurement methods take into account dynamic changes in geometry during the passage of a rail vehicle. For many years, it has been assumed incorrectly that such influence does not relevant effects on clearances and other measured elements. The main assumptions of the dynamic tests carried out (stage 1) were: examination of selected spaces and turnout elements in terms of displacements and accelerations. Figure 5 shows the area examined. As mentioned earlier, this is a place where the blades do not have locker devices (the blade is supported only by brackets). Through the research, the authors wanted to find out how unfavorable the impacts are and whether all turnout structures are equally safe.

METHODS ANALYSIS

This part briefly describes the research methods and the sensors and devices used in the research. Due to the lack of space and the complicated shapes of the rails, it was necessary to design and manufacture devices that would stably mount the sensors, in particular a digital clock sensor that was responsible for the measurement of the blade's displacements. The displacement sensor was attached to the blade rail so that the measuring needle was pre-tensioned to the stock rail foot (Figure 6). The designed system made
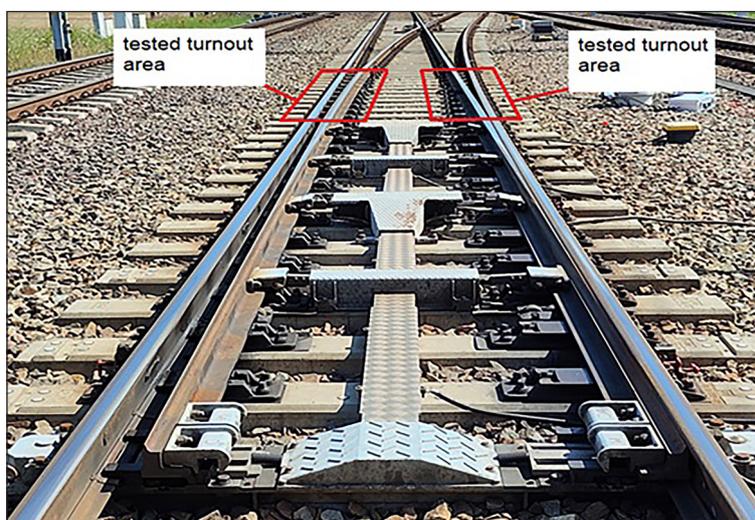

Figure 5. The turnout with a highlighted research area (in the photo we can see the switch area and elements such as point machine, actuators and detection devices)
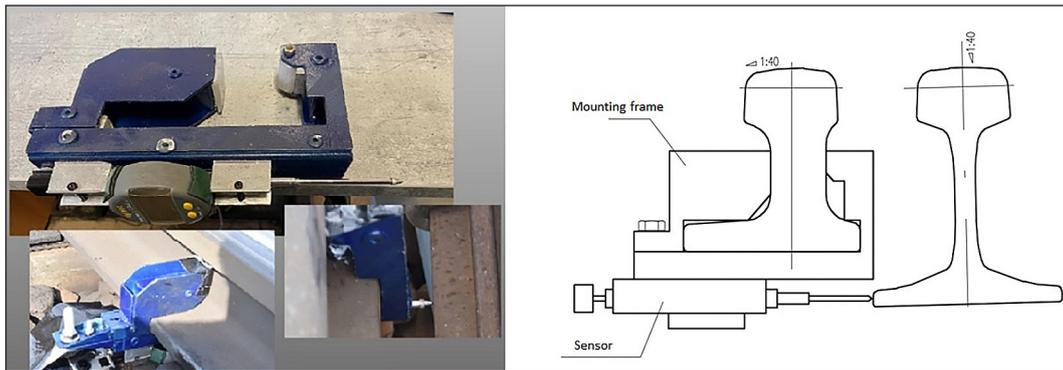
Figure 6. Measurement of blades displacements during the passage of rolling stock by using a digital dial sensor

it possible to assess mutual displacements of the distance between the rigidly built-in stock rail and the blade.

Additionally, during the initial period of research, the movements were observed by a camera. A measure was placed in the observed place to observe movements during the passage of a train. From the bottom, the whole thing was recorded by a camera with an appropriate frame rate. The purpose of the observation was to correctly select the range of the dial sensor (Figure 7).

The accelerations were measured on the blades foot in the discussed area of the railway switch. When analyzing accelerations and vibrations, waveforms of natural and forced vibrations of mechanical systems occur (infrastructure and rail vehicle). For simple systems, these waveforms can be determined analytically. For such complex systems as the interaction of a vehicle with infrastructure (wheel-rail), these waveforms are the result of the superposition of natural vibrations and the most effective method is the actual measurement of mutual interactions. Accelerations are evaluated by the instantaneous acceleration vector a. This vector is determined by measuring its coordinates: ax, ay, az. The acceleration is proportional to the force acting. The measurements used three-axis piezoelectric sensors considered to be basic for diagnostic applications. Acceleration sensors were attached to the blade foot using magnets. The Dewesoft software was used to process the signals. Dewesoft is a leading provider of data acquisition (DAQ) systems and signal processing solutions. Data acquisition and analysis software Dewesoft is used among research and development leaders in automotive, aerospace, defense, transportation, power, and other industries (Figure 8).

TESTED RAILWAY TURNOUT STRUCTURES

The tests were carried out at two railway turnouts at the Psary Station on the CMK railway line. Both turnouts are located on the main tracks of the mentioned line. The CMK line is one of
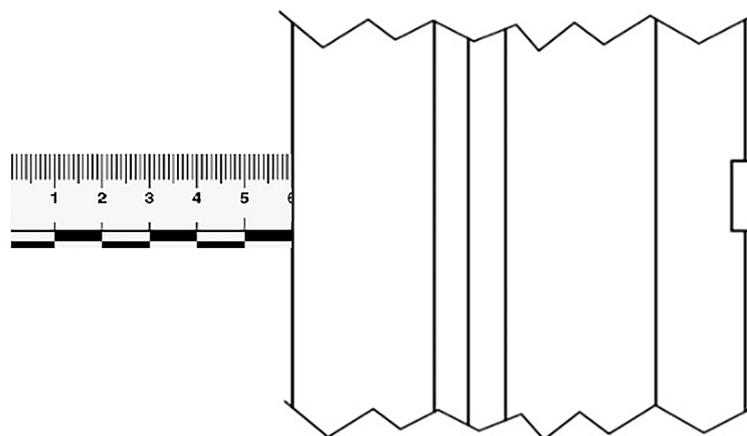

Figure 7. The measuring tape for observing displacements through a camera - own work
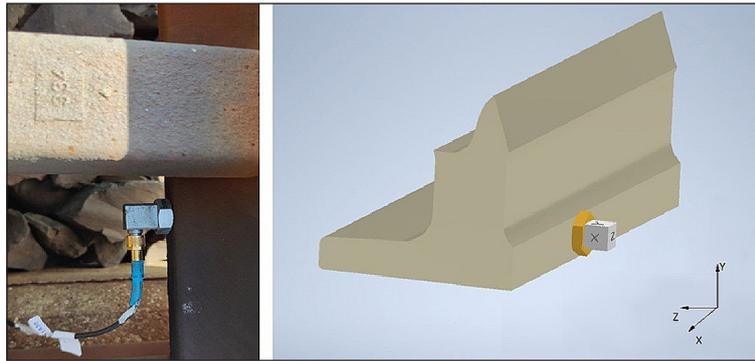
Figure 8. Sensor installation method and reference to the actual projection of the coordinate system - own work

the high-speed lines in Poland. The railway line is managed by the national user - PKP PLK. The tables (Tables 1 and 2) present the technical specifications of both turnouts along with a description of the installed devices responsible for switching and detection. Type of tested turnouts and technical details (Tables 1, 2).

RESULTS OF THE RESEARCH ON MUTUAL INTERACTIONS BETWEEN TURNOUT AND RAIL VEHICLE

The measurements analyzed the interactions between the rail vehicle and the turnout (wheel-rail contact). About a dozen measurements at each turnout were captured. Various types of trains and wagons took part in the journey. For the article below, journeys of the same type of train at similar speeds were taken into account. It is worth mentioning that the travel speeds were not very high, due to the restrictions related to renovation works at nearby stations. Measurements in the next stages will be updated to include trips at higher speeds.

MEASUREMENT RESULTS FROM THE BLADE DISPLACEMENT SENSOR

The analysis of the displacement sensor results gives clear results and allows describing different characteristics of the behavior of the blades in both turnouts. In all measurements turnout direction was set in straight ahead. Table 3 shows the highlighted results. The selection of results resulted solely from an attempt to collect measurements of similar speed and the same type of train (Pendolino train type). The stiffer structure of the switch frame in turnout 31 and the use of special rollers with the function of holding the blades make the blades significantly less susceptible to deflection. The maximum deviation from the base position was 0.382 mm. Then, measurements were taken at turnout No. 5. The displacements recorded in the older type structure (however, this system is still the most frequently used construction configuration in turnouts with a radius of R500 in Europe) were clearly larger.

The maximum deviation from the base position was 2.513 mm. Comparing the results of both turnouts gives almost 7 times greater impact at the

Table 1. Type of tested turnouts: 60E1-500-1:12 Turnout no. 31 in Psary Station, description of the structure

Point machine specification		
Type of point machine	Hy-Drive (Alstom) with hydraulik backdrive	
Quantity of switching points	Three switching points	
Rods	Two extra rods	
Switch rolls system	Switch rolls system with holding function (blades holding)	

Table 2. Type of tested turnouts: 60E1-500-1:12 Turnout no. 5 in Psary Station, description of the structure

Point machine specification	
Type of point machine	Bombardier EEA5 (two point machine)
Quantity of switching points	Two switching points
Rods	Without extra rods
Switch rolls system	Switch rolls system without holding function (blades holding)

Table 3. Comparison of measurement and calculation results for turnouts No. 5 and 31

Turnout No	Measurement No	Speed [km/h]	The value for the static position was assumed to be the initial value [mm]	Verage value [mm]	Standard deviation [mm]	Maximum deviation from the static value (line/ -)	Maximum deviation from the static value (line/ +)
31	1	100	13.607	13.685	0.13	-0.358	0.202
	2	98	13.845	13.793	0.147	-0.382	0.239
5	16	103	14.71	13.676	0.811	-2.513	0.285
	17	105	14.362	14.078	0.735	-2.123	1.865

older type of structure. Taking into account the mechanism occurring during the train passage, this means continuous elastic deflection of the rails and their attack by the approaching wheels. Of course, the level of increased wear is difficult to analyze in such short studies, but the conclusions regarding the increased wear of rails and wheels in older structures turnout are obvious. The differences in the results of the observed displacements in two different types of turnouts are very clearly shown in the chart (Figure 9). By analyzing the measurements, and particularly the graphs, from the displacement sensor installed on the turnout

switch, the attacks of subsequent wagon bogies can be clearly distinguished. Below are the results of measurements taken on a train characterized by its semi-permanently attached, articulated design (Figure 10). This is measurement No. 1 taken at turnout No. 31. The subsequent rectangles (dashed green line) describe subsequent wagons defined based on the shape of the graph.

Another question was whether it was possible to distinguish the type of train or locomotive based on a comparison of graphs resulting from the impact on the turnout rails and the displacements measured on that basis. For the purposes of
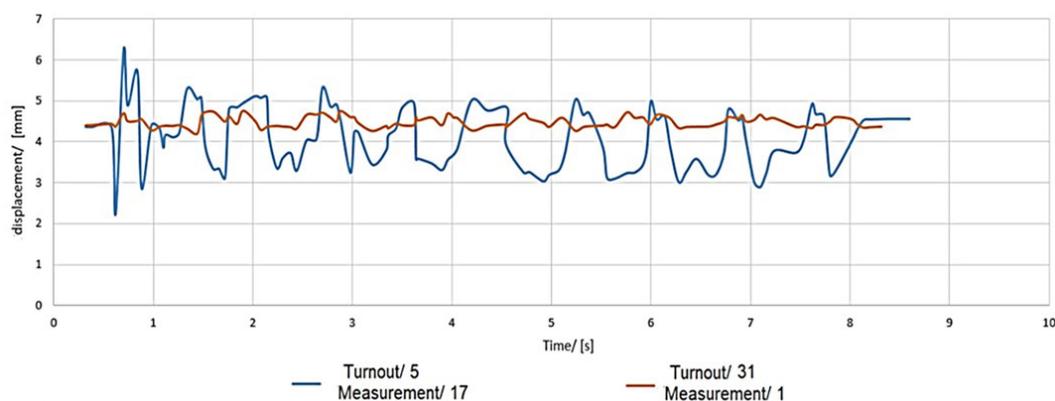

Figure 9. Comparison of blades displacements at turnouts No. 5 and 31 when trains run at the same speed
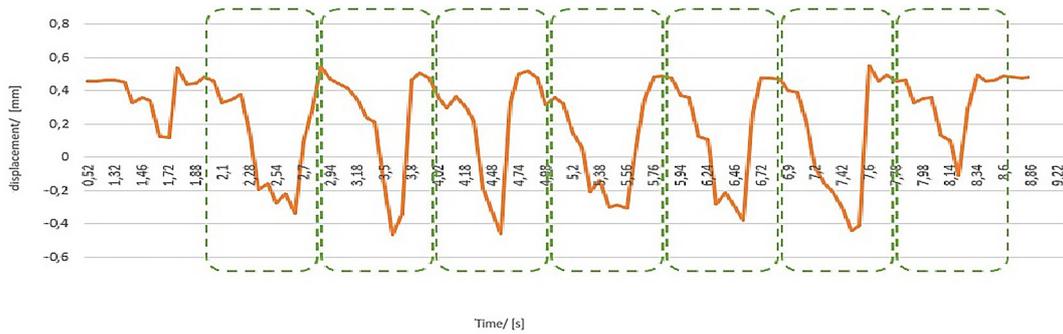
Figure 10. Blades displacements at turnouts No. 31 measurement No. 1 - own work

this comparison, the graphs are plotted from the average value of the displacement results, which is assumed to be 0 in the graph. When comparing the graphs of trains with a semi-permanently attached, articulated design, similarities in the nature of the curves can be observed (Figure 11). In this case, the wagons of the train set can also be clearly distinguished, and in both graphs, the entire train sets overlap (the speed of both trains was also approximately similar, around 100 km/h).

For comparison purposes, the graphs of the semi-permanently attached, articulated design and the train with a separate locomotive and passenger cars were plotted. The graph recording the train with the locomotive is measurement no. 17. Comparing all the measurements, we know that the displacement amplitudes in turnouts no. 5 and 31 differed by about six times (exactly 6.2). Therefore, we decided to scale the graph by this amount and compare it with the combined train. The result is very interesting, as the different locomotive signature is clearly visible (Figure 12). It can also be clearly seen that the train with the locomotive has three more wagons.

On the basis of the presented graphs, it can be seen that the diagnostic potential for the assessment of scales is quite large and offers opportunities for significant development.

MEASUREMENTS OF ACCELERATIONS RECORDED ON THE BLADES

The assumption of the first stage of accelerations research was to observe the interactions between the rail vehicle and the turnout and to correlate the values of the measured displacements and accelerations. Acceleration charts allowed for the observation of the interactions caused by subsequent wheel sets and wagon bogies. Each subsequent run of the wheelset was shown on the graph as a reading of subsequent acceleration peaks. In the Table 4, the maximum recorded accelerations for the four highlighted measurements can be observed (already discussed earlier). The large discrepancy in the results is noteworthy. It was decided to thoroughly analyze measurement numbers 1 and 2 in order to explain the large differences in the recorded accelerations (both recorded measurements took place at the same turnout, at a similar speed and the same type of train).

A detailed analysis of accelerations showed that most of the recorded accelerations during the
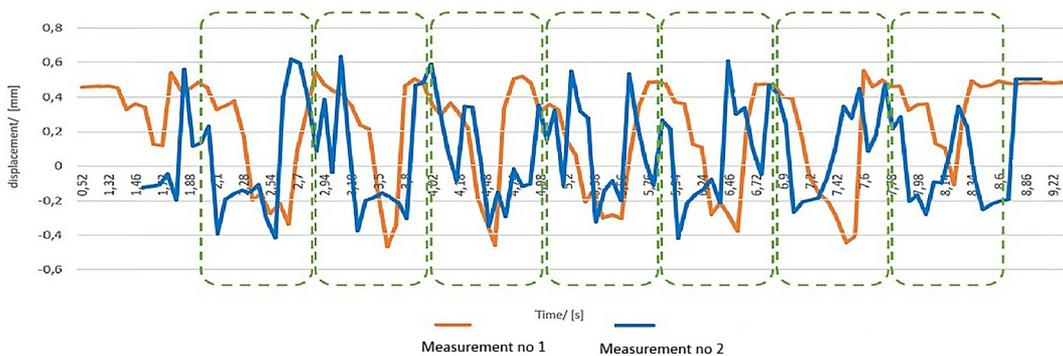

Figure 11. Comparison of blades displacements at measurement No. 1 and No. 2 - own work
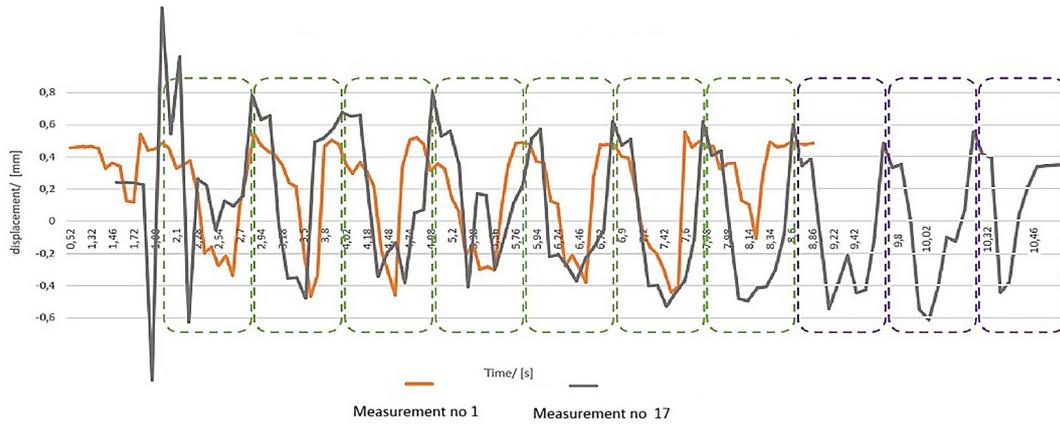
Figure 12. Comparison of blades displacements at measurement No. 1 and No. 17 - own work

Table 4. Acceleration measurements carried out by installed accelerometers

| Turnout No	Measurement No	Acceleration value on the X axis [m/s2]			Acceleration value on the Y axis [m/s2]			Acceleration value on the Z axis [m/s2]		
		w (+)	w (-)	Amp-litude	w (+)	w (-)	Amp-litude	w (+)	w (-)	Amp-litude
31	1	1334.8	-1434.8	2769.6	528.1	-570.6	1098.7	783.8	-635.6	1419.4
	2	175.6	-255.8	431.4	288.2	-132.5	420.7	615.7	-293.8	909.5
5	16	282.0	-258.0	540	228.7	-299.5	528.2	540.5	-557.5	1098
	17	742.1	-447.6	1168.7	1794.4	-1857.4	3651.8	1106.2	-1875.5	2981.7
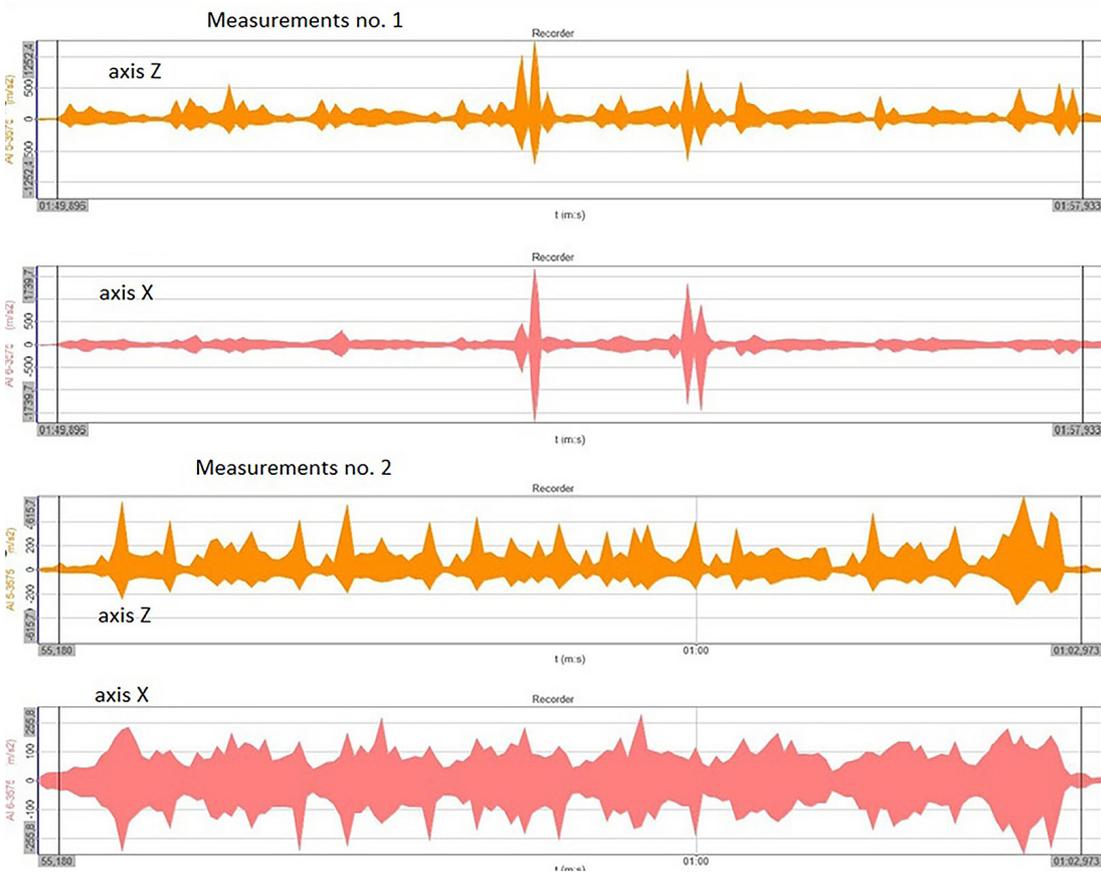
Figure 13. Comparison of measurements no. 1 and 2 on the Z and X axes for the same speed and type of Pendolino train

trip were similar, and the result was influenced by two distinct acceleration peaks which were the result of the passage of two trolleys with a clearly different operating condition. At this stage, periods of increased displacements and acceleration peaks were clearly visible - based on the observations, the passage of the wheel could be detected very precisely.

In the chart below (Figure 13) the result of the passage of the two trains discussed above can be seen. It is clearly visible that in run no. 2 all passing wheels give similar results, while in run no. 1 two sets of wheels gave clearly different results (that is why the graph was scaled).

CONCLUSIONS

The conducted research allowed observing the behavior of critical points of the turnout in interaction with rail vehicles. The studies revealed defects and problems related to maintaining the stability of the turnout geometry during train passage. Analyses of currently used diagnostic systems revealed a significant deficit in railway turnout performance assessment systems. The summary included in the following points will also be an attempt to answer the theses and questions posed at the beginning of the article regarding the possibility of assessing the quality of turnouts and problems resulting from wheel-rail interaction based on the measurements carried out and the assessment of the need to use diagnostics:

1. The observations conducted using a blade displacement sensor and their interactions indicate differences in the performance of turnouts of different designs and technological advancements. It is clearly visible that new, more refined turnout designs better maintain correct geometry at critical points on turnouts. This signals to users that it is worthwhile to invest in more modern designs for high-speed lines.
2. The measurements also enabled observation of the behavior of rail vehicles, which creates opportunities for diagnosing the condition of bogie and wheel components – in this case, the measurements taken with acceleration sensors were crucial. The acceleration results from the observed runs showed that some components of the wagon and train chassis exhibited significantly increased impact on the track, which should be interpreted as likely problems with the quality of rolling stock maintenance.
3. As part of the evaluation of currently used diagnostic systems, it was concluded that the currently rarely used diagnostic systems for railway turnouts should be further developed to better monitor their condition and improve safety. Furthermore, the authors see potential in the conducted research for train diagnostics.
4. The first phase of the research demonstrated that the research has significant potential for diagnosing both railway turnouts and the rail vehicles passing over them. The selected observation techniques yielded many interesting, though not always expected, results. Given the findings, the research will be expanded to include observations of other critical elements in order to understand the specific interactions that significantly impact rail traffic safety.

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