



## Research paper

# Strengths and weaknesses of multi-point machine turnouts

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**Abstract:** In many European countries, the choice of turnout control system is determined by the traditional approach implemented for years on railway lines or systems offered by railway turnout manufacturers. The paper presents a research approach to selecting the optimal switch operation control system based on the reliability parameters of track equipment for high-speed railway lines. In particular, a general, system approach to railway turnouts is necessary. The turnout is a structure equipped with diagnostic devices for the technical condition of the most important operating parameters, intelligent heating devices for the movable elements of the switch area and the crossing area with a movable nose, and standard communication interfaces to and from the turnout. The selection of a turnout control system is extremely important for improving the parameters of railway line availability and the safety of rail traffic. Statistical modelling of the control system for the switch and crossing with a movable nose was based on empirical data for each of the devices according to their safety integrity level, i.e. a measure of the number of operations before a fault occurs. The article presents the results of field tests conducted during the operation of a railway line as well as the results of stochastic tests based on the declarations of the manufacturers of railway traffic control systems, including switch point machines.

**Keywords:** railway infrastructure, turnouts, point machine, reliability parameters, measurements

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## 1. Introduction

Requirements for newly built railway lines and a critical element of infrastructure, such as a turnout, are aimed at continuous improvement of the reliability parameters of design and material solutions. The turnout, as an element of the "Infrastructure" subsystem [1], cooperates with elements of the "control-command and signaling" subsystem [2], therefore, they should be considered together as one system, especially for turnouts with more than one locking devices. Additionally, railway turnouts are an integral part of the track, without which the implementation of transport services is not possible in practice, therefore, the selection of the optimal control of the operation of the switch and the movable blade of the crossing has a significant impact on the reliability parameter and total costs throughout the entire life cycle of the turnout [3–8].

Therefore, the analysis of strengths and weaknesses for specific types of railway turnouts requires, on the one hand, to take into account the issue of the railway road and on the other hand, issues related to the railway traffic control system, mainly devices for moving and controlling moving elements of turnouts [9–11].

The originality of the paper is review of the geometry of high speed rail turnouts considering cooperation features connected with their point machines and studying of their reliability parameters. An important research problem is the selection of the optimal turnout control system in terms of the operation of the switch and the movable blade of the crossing, not only in terms of technical parameters but also from an economic perspective, trouble-free access to spare parts, easy operation of turnouts and peripheral devices, high availability<sup>2</sup> of the railway line also in the case of negative wheel-rail cooperation and potential damage to components or failure of the entire system, especially for solutions dedicated to high-speed railways [12–14].

Good practices, results of simulation tests and field tests have been correlated with technical specifications, European standards and requirements for turnouts with a number of locking devices greater than one, which gives rise to the conclusion, that turnouts in a multi-point machine control system are characterized by increased operational reliability and, as a result, increased availability of the railway line. The aim of the paper is to relate the reliability parameters of the turnout operation to field test results and are a continuation of previous research in the switch area of the turnout [29]. High speed rail turnout is presented in Fig. 1.



Fig. 1. Turnout type 60E1-17.000/7.300-1:50 on a railway HS line in Spain

<sup>2</sup>Availability, is defined in the European standard EN-50126, in chapter 3 terms and definitions as “ability of an item to be in a state to perform a required function under given conditions at a given instant of time of over a given time interval, assuming that the required external resources are provided” [27]

## 2. Basic research problems

The geometry and design of the turnout determine the maximum speed of a railway vehicle on a section of the railway line and its capacity correlated with the technical availability of the entire railway line. Also, the geometry of the turnout and the maximum speed of the railway vehicle moving through the turnout must guarantee safety and the ability to move with dynamic forces coming from the railway vehicle moving through the turnout. Therefore, turnouts are designed and manufactured with an increasingly diverging track radius in order to ensure:

- a) Increasing the turnout reliability parameters described by functions:

$$(2.1) \quad Q(t) = P\{\tau < t\}$$

where:  $Q(t)$  is a function of the probability of failure, assuming that at time  $t = 0$  the object starts working and at time  $t = 0 + \tau$  damage occurs, where  $\tau$  is a random variable  
– reliability,

$$(2.2) \quad R(t) = 1 - Q(t) = P(\tau > t)$$

where:  $R(t)$  is the reliability function and describes the probability of an event that no damage will occur in a given time interval  $(0, t)$ , under specific operating conditions of the system

$$(2.3) \quad R(0) = 1$$

$$(2.4) \quad \lim_{t \rightarrow \infty} R(t) = 0$$

- failure rate

$$(2.5) \quad \lambda(t) = -\frac{R'(t)}{R(t)}$$

where:  $\lambda(t)$  is a failure intensity

- b) Increasing the turnout maintainability, described in a unit of time:

- MTTR – mean time to restore,
- MTTPM – mean time to preventive maintenance,
- MTTCM – mean time to corrective maintenance,
- MRT – mean repair time,
- MTTM – mean time to maintain,

- c) Increasing safety and comfort as:

- coefficient of derailment – the quotient of the lateral force  $Y$  to the wheel load force  $Q$ :

$$(2.6) \quad \frac{Y}{Q} = \frac{tg\gamma - \mu}{1 + \mu \cdot tg\gamma}$$

where:  $\gamma$  – means the angle of inclination of the wheel flange to the theoretical horizontal axis and  $\mu$  – the friction coefficient between wheel and rail.

The factor affecting the derailment coefficient from the wheel load force ( $Q$ ) that is the twist of the track, means the difference of track cants, measured in two track sections spaced from each other with a constant value to the distance between these sections. From the lateral force ( $Y$ ) it's mainly track irregularity and radius of the horizontal arc [15].

## 2.1. Field test

Increasing the speed of trains generates higher values of vertical accelerations and lateral accelerations in the rolling stock and value of the lateral force „ $Y$ ” and wheel load force „ $Q$ ” at the wheel-rail interface, and in particular the sum of lateral forces in the switch area. As presented by the results of research on dynamic interactions from rolling stock to the railway track<sup>3</sup>, increase in the sum of lateral forces, depending on the vehicle speed increase from a speed of  $V = 160$  km/h to a speed of  $V = 220$  km/h in the switch area while moving to the blade is 57% and in case moving from the blade the value is 96%, as presented in Fig. 2.

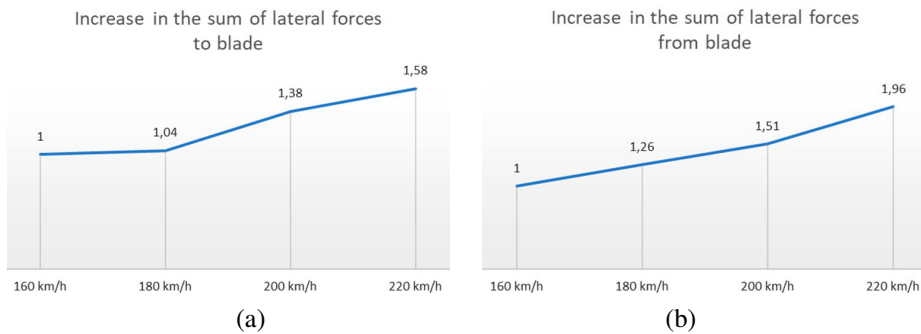


Fig. 2. Sum of lateral forces in switch area: (a) moving to the blade, (b) moving from the blade

During the dynamic impact tests carried out using the ED-250 Pendolino EMU vehicle, the following changes were recorded:

- lateral accelerations of the axle box [ $\text{m/s}^2$ ] in the switch area increased by 29% and in the area of the movable nose of the crossing by 8%,
- lateral accelerations of the bogie frame [ $\text{m/s}^2$ ] in the switch area increased by 20% and in the area of the movable nose of the crossing by 32%,
- lateral accelerations of the wagon body [ $\text{m/s}^2$ ] in the switch area increased by 38% and in the area of the movable nose of the crossing by 15%,
- vertical accelerations of the wagon body [ $\text{m/s}^2$ ] in the switch area increased by 43% and in the area of the movable nose of the crossing by 41%.

In the field tests carried out in accordance with UIC Card No. 518 [16], the maximum acceleration values were much lower than the required safety criterion.

## 2.2. Design assumptions for turnouts on high-speed lines

Turnouts intended for high-speed railway lines are designed taking into account the maximum acceleration derivative parameters as a basis [1, 17–20] considered in terms of vehicle-track cooperation [14]. For railway lines intended for train traffic at speeds above

<sup>3</sup>Report no. IK.DP-11/004/T/2019, Instytut Kolejnictwa, Warszawa 07/2019 r.

250 km/h, turnout with variable curvature of the diverging track should be used. An example solution of the turnout geometry with variable curvature of the diverging track with a diagram of distribution of inverse curvatures for type 60E-17000/7300-1:50, as presented in Fig. 3.

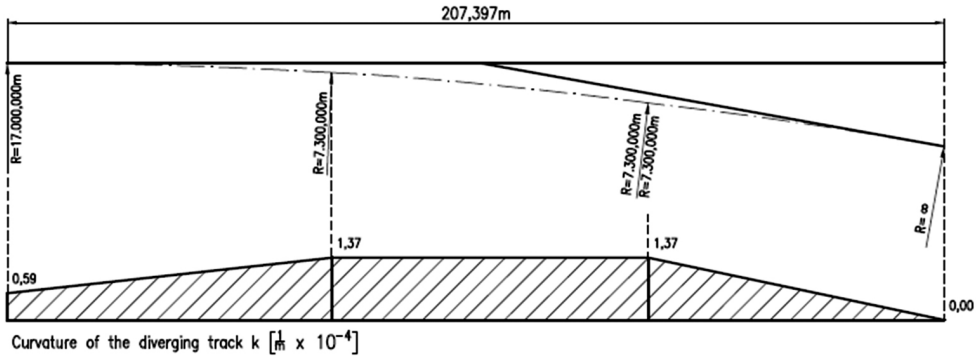


Fig. 3. The distribution of curvatures and radii for turnout type 60E-17000/7300-1:50

Switching the direction of travel through the turnout using a switch rail in the switch area and movable nose of crossing has a significant impact on the reliability, availability and maintainability of the construction. In turnouts with multiple locking devices and multi-point machines, the number of which is the same (Fig. 4), the switch rail must be moved evenly to avoid deformation of the shape and loss of contact between the switch rail and the stock rail. Therefore, the safety of railway traffic at the turnout is related not only to the steel elements itself but also from point machines, design of locking devices, effective detection of the switch rail position, the heating system used for the moving elements of the turnout in the switch area and the crossing with a movable nose, concrete sleepers and effective implementation of monitoring the technical condition of the turnout as a whole complex system [5, 21–25, 28].



Fig. 4. Turnout type 60E1-17.000/7.300-1:50 on a railway HS line in Spain

In Poland, general requirements for point machines intended for high-speed railway lines have been defined [9] as follows:

- the point machine must have a modular structure and the weight should not exceed 100 kg,
- the design of the point machine must ensure its manual emergency control with lever or crank,
- the point machine allows its locking and its detection in end position of moving turnout elements,
- for applied the multi-point machine systems, the first one to use is a non-trailable drive and it is required to monitor the resistance of the moving elements of the turnout for each point machine
- for applied the single point machine systems with coupling of locking devices, the ability to adjust the switch equipped with mechanical or hydraulic coupling of the adjustment locks is required [5].

Solutions with a single point machine included coupling of locking devices of turnout are characterized by shorter emergency manual switching time compared to a turnout with a multi-point machine configuration, as presented in Table 1. Depending on the type and geometry of the assessed turnout, the estimated extension of the switch adjustment time is as follows:

- a) Turnout 60E1-500-1:12 2 point machines in switch area. Time extended 4 times,
- b) Turnout 60E1-760-1:14 3 point machines in switch area. Time extended 6 times,
- c) Turnout 60E1-1200-1:18.5 3 point machines in switch area. Time extended 6 times,
- d) Turnout 60E1-2500-1:26.5 4 point machines in switch area. Time extended 8 times.

Table 1. Time of switch rail moving for multi-point machine control system

Type of turnouts	1 point machine + coupling	2 point machines	3 point machines	4 point machines
60E1-500-1:12	×	4×	–	–
60E1-760-1:14	×	–	6×	–
60E1-1200-1:18,5	×	–	6×	–
60E1-2500-1:26,5	×	–	–	8×

### 2.3. Design solutions for high-speed railway turnouts in Poland

In Poland, the only railway line with the parameters of a high-speed railway line [26] is the Central Railway Trunk (in Polish Centralna Magistrala Kolejowa – CMK), line no 4 Zawiercie–Grodzisk Mazowiecki. The line is 224 kilometers long and has 11 railway stations. CMK is designed and can be operated with a maximum speed  $V_{\max} \leq 250$  km/h [7]. There are 139 turnouts on the main tracks no. 1 and no. 2 on the entire line, as presented in Table 2.

Table 2. Types of turnouts including the control system and frog used [4]

Station	Multi point machine turnouts	Single point machine turnouts with coupling	Type of frog
Grodzisk Mazowiecki	8	0	Fix
Korytów	10	0	Fix
Szeligi	0	13	Movable
Biała Rawska	0	4	Movable
Strzałki	1	11	Movable
Idzikowice	0	20	Movable
Opoczno Południe	0	12	Movable
Pilichowice	0	4	Movable
Olszamowice	0	12	Movable
Włoszczowa Północ	0	14	Movable
Knapówka	5	0	Movable
Psary	5	8	Movable
Góra Włodowska	12	0	Movable
Zawiercie		x	Fix

Currently, the basic solution for switching of turnouts on the Central Railway Trunk is a single-point machine system, constituting approximately 70% of all turnouts, more than half of them are equipped with hydraulic coupling of locking devices (Table 3).

Table 3. Turnout control systems

Turnout control systems		
Multi point machine Turnouts	Single point machine Turnouts with coupling	
–	mechanical	hydraulic
30%	20%	50%

Indicated multi-point machine systems for switching of the turnout in (Table 2) at the stations: Psary, Góra Włodowska and Knapówka result from the fact that no modernizations have yet been carried out. PKP PLK SA – Investment Implementation Center introduced in the description of the subject of the order which is an annex to the Specification of the terms of the order<sup>4</sup>, demand for turnouts in a single-point machine system with coupling of locking devices. Therefore, after the modernization, almost 100% of the turnouts used on the Central Railway Trunk will be equipped with a single-point machine system.

Simple turnouts on the Central Railway Trunk are operated in three geometries: Rz-60E1-2500-1:26,5; Rz-60E1-1200-1:18,5; Rz-60E1-500-1:12 in the rail inclination 1:40.

<sup>4</sup>Annex No. 1 to the SWZ – OPZ, Description of the Subject of the Contract for the procurement of railway turnouts necessary to adapt railway line No. 4 (CMK) to a speed of 250 km/h at the Knapówka junction post, Psary station, and Góra Włodowska station, as part of the project entitled “Adaptation of the CMK to a speed of 250 km/h”, PKP PLK S.A., Warsaw, October 2021 (in Polish).

## 2.4. Evaluation of control systems in the reliability model

The key parameters for assessing the condition of the switch control system will be determined according to the costs of the product throughout its life cycle. From the point of view of the Infrastructure Managers, each decision-making process related to maintaining the technical condition of the turnout is a continuous process, which involves permanent optimization of operating processes, including:

- a) Monitoring and analysis of reliability and maintainability having a direct impact on decision-making processes regarding technical maintenance,
- b) Monitoring of availability and safety parameters resulting directly from the analysis of reliability and maintainability [27].

Reliability is measured as the probability that the system, in our case a railway turnout, will operate without failure within an assumed time interval under specific environmental and operational conditions. Most often, the reliability parameter is given as the mean time between failures – MTBF.

For irreparable elements, reliability is defined by the product of the number of failures per unit of time. Where  $R$  is the number of damages / operation time, which can be described by a random function of an exponential distribution:

$$(2.7) \quad R(t) = \exp(-\lambda t) = \exp(-t/\text{MTBF})$$

$R(t)$  is within the scope  $0 \leq R(t) \leq 1$ , therefore in time  $t = 0$ ,  $R(0) = 1$ .

This means that the probability of failure increases over time, while reliability decreases over time. The basic characteristic of the reliability of a technical object is its failure rate function  $\lambda(t)$ . Parameter  $\lambda$  failure rate  $\lambda = 1/\text{MTBF}$ , describes the probability of occurrence of a system failure event  $Q(t)$  and is expressed as the relationship:

$$(2.8) \quad Q(t) = 1 - R(t)$$

If a railway turnout in a multi-point machine control system is to perform the task of moving of switch rails in the switch from running on the main track to the diverging track, the reliability should be considered jointly for the entire set. In this case, the system creates a set of objects that correspond to the operation of the turnout point machine, and the system reliability can be expressed as a function of time:

$$(2.9) \quad R(t) = \phi(R_1(t), \dots, R_n(t))$$

In simple terms, such a system corresponds to a serial connection reliability structure consisting of n-number of point machines and is in an operational state for use only when all of its elements are in an operational state for use, as presented in Fig. 5.

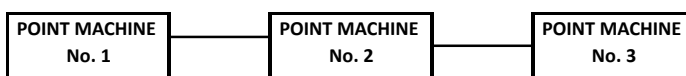


Fig. 5. Serial connection of 3 point machines in the switch area

In this case, it is correct to say that a system is only as reliable as its weakest link. Therefore, in order to increase the reliability parameter, additional devices are introduced to monitor the operation of the turnout switch control devices or possibly using redundant devices whenever technically possible.

Based on the above data, a reliability model for the multi-point machine switch control system can be defined. Assuming that we are analyzing a Rz60E1-1200-1:18.5 type turnout with a swing nose crossing, which has 3 point machines in the switch area and another 2 in the crossing area, which we will mark with the letter "N", as presented in Fig. 6 and Fig. 7,



Fig. 6. Turnout type 60E1-1200-1:18,5, controlled in a multi-point machine system

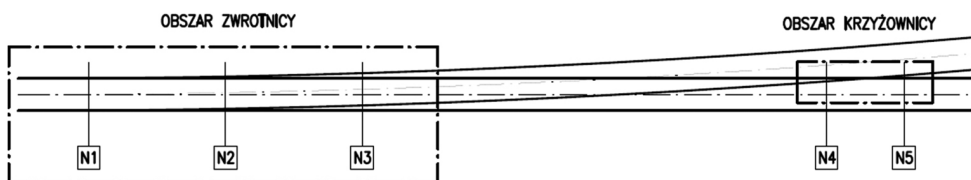


Fig. 7. Five-point machines control system for turnouts type 60E1-1200-1:18,5

In the stochastic random model, we assume that the occurrence of a fault in point machine „ $N_n$ ” is independent of the occurrence of a fault in another point machine, e.g. „ $N_1$ ”, and each point is characterized by the same reliability distribution during operation  $R_N(t)$ .

Turnout control system is in an operational state when each of the five point machines are technically operational. This means that the reliability structure for this example looks like the drawing of a system consisting of five point machines in a series structure.

The reliability of this structure is determined by the equation:

$$(2.10) \quad R(t) = [R_N(t)]^5$$

Assuming, and based on the manufacturer's data, that the initial reliability value for one point machine at the time of commissioning is, for example:  $R_{N0} = 0.999$  at the moment of turnout operating start, the reliability of the multi-point machine of the turnout consisting of five drives is  $R = 0.999^5 = 0.995$ , in percentage terms 99.5%.

However, if we use a point machine with a reliability factor of  $R_{N0} = 0.995$ , the approximate reliability for the entire control system will be  $R = 0.995^5 = 0.975$ , in percentage terms 97.5%, which are gathered in Table 4.

Table 4. Simulated reliability of turnout with multi-point machines control systems

Number of point machines in the turnouts	Reliability of the multi-point machine system	
	$R_{N0} = 0.999$	$R_{N0} = 0.995$
1	99.90%	99.50%
2	99.80%	99.00%
3	99.70%	98.51%
4	99.60%	98.01%
5	99.50%	97.52%

The indicated values are a n experiment illustrating the dependencies of railway turnout control systems in terms of operational reliability. Therefore, when selecting an appropriate point machine for multi-point machine turnouts (having the same number of point machines as the number of locking devices in the turnout), the technical availability of the point machine must be very high.

It should be remembered that the reliability of the entire structure decreases with the number of point machines working during the turnout adjustment. On the other hand, if the technical availability of the interlocking system and point machine is very high, i.e. the simulated value above 0.999, the problem of manual switching of the turnout ceases to be a critical factor in the operation and maintenance of the railway turnout.

To sum up, it is obvious that due to the use of more point machines in a turnout, the reliability of the entire system decreases but as practice shows, for example high-speed railways in Spain, where turnouts with very large radii of the diverging track are used, allowing driving on the diverging track at a maximum speed of  $V_{\max} \leq 220$  km/h, such as the simple turnout 60E1-17.000/7.300-1:50, which has 10 point machines in the switch area and 4 point machines in the swing nose crossing area, the point machine used are characterized by high reliability during operation,  $R$  close to 1. In this case, the parameter of manual switching of the turnout in order to ensure the availability of the turnout in emergency situations is also not a critical parameter.

In the case of single-point machine turnout control systems with mechanical or hydraulic elements for transferring forces from the point machine to the subsequent locking devices, should also be treated as a series structure consisting of one point machine in the switch area

and a force transmission system (coupling of locking devices) consisting of  $n$  elements and one point machine in the crossing area with a movable nose and a force transmission system consisting of  $n$  elements, as presented in Fig. 8 and Fig. 9.



Fig. 8. Turnout 60E1-1200-1:18,5 in single-point machine system with coupling

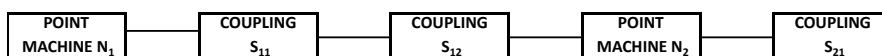


Fig. 9. Turnout 60E1-1200-1:18,5 diagram, in single-point machine system with coupling

The event of a fault in the point machine „N” is independent of the occurrence of a fault in the coupling of the locking device „S”, therefore the reliability for the entire structure can be calculated in a similar way as for the multi-drive control system as:

$$(2.11) \quad R(t) = R_{N1}(t) \cdot R_{S1}(t) \cdot R_{N2}(t) \cdot R_{S2}(t)$$

However, if a fault occurs in the elements of transmission force from the point machine „S” for the next locking devices number 2 and number 3 in the assessed type turnout 60E1-1200-1:18,5, containing 3 locking devices in the switch area and 2 locking devices in the crossing area with a movable nose, is dependent on the failure event of an element, e.g. S2 of the coupling, because the elements are mechanically or hydraulically linked to each other. Thus, the probability of failure depends on the correlation of events involving component failures. In such a case of positive event correlation, failure of one component causes failure of other components of the system.

In practice, for single-point machine turnout control systems with transmission of forces to subsequent locking devices, it is necessary to answer how often the turnout will be damaged and whether, as a result of damage, the turnout can still be switch to the indicated train direction.

The risk of damaging the coupling of the locking devices and, as a result of this event, the locking devices may become completely immobilised and it cannot be manually adjusted by one person in order to ensure the availability of the turnout in emergency situations.

In the case of a multi-point machine turnout control system, damage to one point machine does not result in the impossibility of manual, emergency switching of the turnout. Therefore, a system for which reliability and safety parameters are important from the point of view of

train traffic management, a turnout configuration consisting of elements in which the failure of one can have a direct impact on the failure of the next one, should be considered a system with a higher operational risk than the use of elements in which the failure of a particular point machine does not affect the operational status of the next one.

## 2.5. Application of multi-point machine systems

The current demand for fast and punctual rail transport from point A to point B requires the design and construction of turnouts with increasingly larger turnout radii, which is dictated by the possibility of rail vehicles moving at increasingly higher speeds both on the straight track and on the diverging track.

In the plans for the Central Communication Port in the published Technical Standards, Volume I.1 rail track – geometrical layouts in Annex 5 of the document [6], the types of turnouts in the designed track connections are given. There are turnouts with variable curvature of the diverging track with radii commonly used on high-speed railways, e.g. in Spain:

- a) R17000/7300-1:50. Maximum speed: 350/220 km/h. The switch has 10 locking devices. The crossing with a movable nose has 4 locking devices,
- b) R10000/4000-1:36.9. Maximum speed: 350/160 km/h. The switch has 8 locking devices. The crossing with a movable nose has 3 locking devices,
- c) R3000/1500-1:22.2. Maximum speed: 350/100 km/h. The switch has 6 locking devices. The crossing with a movable nose has 2 locking devices and simple turnouts with one radius of the diverging track in the switch area as:
- d) R2500-1:26.5. Maximum speed: 250/130 km/h. The switch has 4 locking devices. The crossing with a movable nose has 2 locking devices,
- e) R1200-1:18.5. Maximum speed: 250/100 km/h. The switch has 3 locking devices. The crossing with a movable nose has 2 locking devices,
- f) R760-1:14. Maximum speed: 250/80 km/h. The switch has 3 locking devices. The crossing with a movable nose has 2 locking devices,
- g) R500-1:12. Maximum speed: 250/60 km/h. The switch has 2 locking devices. The crossing with a movable nose has 1 locking device.

The number of locking devices increases with the increase of the radius of the diverging track of turnout. In this respect, the modelling of the structure of the integrated railway turnout system should be considered as a non-decomposable system with a fixed installation configuration.

## 3. Conclusions

Based on the considerations and research conducted, the following issues should be noted:

1. The multi-point machine control system should be operated while ensuring the required technical availability parameters, provided that point machines with reliability parameters ensuring failure-free operation throughout the product life cycle are used.
2. Due to the limited time of operation and the relatively small population of turnouts with a multiple of locking devices controlled by a single point machine with mechanical or

hydraulic coupling of subsequent locks on the Central Railway Trunk Line in Poland, it is difficult to compare their technical availability with turnouts in a control system with multi-point machines corresponding to the number of locking devices in the switch area and the swing nose crossing area.

3. Field tests will be continued to address the results of simulation studies related to the reliability parameter set by the manufacturers of point machines.
4. The serial reliability structure of the multi-point machine turnout control system is more advantageous due to the limited impact of failure of one control element on the failure of another.
5. Turnouts equipped with more than 3 locking devices in the switch area must be operated by multi-point machines.
6. A turnout intended for high-speed railway lines should be an integrated system with a fixed configuration in the context of cooperation with the object controller and the product technical condition monitoring system.

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## Mocne i słabe strony rozjazdów wielonapędowych

**Słowa kluczowe:** infrastruktura kolejowa, rozjazd, napęd zwrotnicowy, parametry niezawodności, pomiary

### Streszczenie:

Dobór odpowiedniego systemu sterowania pracą obszaru zwrotnicy oraz obszaru krzyżownicy z ruchomym dziobem ma istotny wpływ na poprawę parametrów niezawodności i podatności utrzymaniowej całego zintegrowanego systemu jakim jest rozjazd kolejowy z przeznaczeniem do zabudowy w liniach kolejowych dużych prędkości. Potrzeby poprawy wskaźników dostępności i bezpieczeństwa linii kolejowej są skorelowane z dostępnością rozjazdów w tym informacji i sygnałów pochodzących z permanentnego monitorowania stanu technicznego budowli i urządzeń torowych. Podczas badań terenowych, zmierzone wartości wskazują na stałą zależność, że zwiększanie prędkości pociągów generują większe wartości przyspieszeń pionowych i przyspieszeń poprzecznych w taborze oraz zwiększające się siły pionowe „ $Q$ ” i siły poprzeczne „ $Y$ ” na stuku koło-szyna. Celem rozjazdu kolejowego w połączeniach banalizacyjnych jest zmiana toru poruszania się taboru kolejowego z zachowaniem maksymalnie dużych wartości prędkości jazdy na tor zwrotny. W tym celu projektowane są rozjazdy o zmiennej krzywiznie toru zwrotnego z wielokrotnymi zamknięciami w obszarze zwrotnicy i w obszarze krzyżownicy z ruchomym dziobem. Zatem dostępności linii kolejowej oraz bezpieczeństwo ruchu kolejowego związane jest nie tylko z samą budowlą, jaką jest rozjazd ale również z poprawnie dobranym systemem przestawiania, skuteczną kontrolą położenia iglicy, systemem ogrzewania ruchomych elementów rozjazdu w obszarze zwrotnicy i obszarze ruchomego dzioba krzyżownicy. Relacje i zależności odnośnie doboru układu starowania pracą rozjazdu z podziałem na układ złożony z tej samej ilości napędów co zamknięć nastawczych oraz jednego napędu zintegrowanego z sprzężeniem kolejnych zamknięć nastawczych zostały zaprezentowane poprzez ocenę układów sterowania w modelu niezawodnościowym. W wyniku badań terenowych jak również badań statystycznych opracowanych na bazie danych empirycznych pochodzących od producentów urządzeń, pewne założenia do projektowania linii kolejowej z uwzględnieniem rozjazdów zostały zdefiniowane. Badania wykazały, że w szeregowej strukturze niezawodności, układ z ilościami napędów odpowiadającymi ilości zastosowanych zamknięć nastawczych sterowania jest korzystniejszy ze względu na ograniczony wpływ uszkodzenia jednego elementu sterowania na uszkodzenie innego. Pozyskane wartości charakterystyczne mogą mieć wpływ na procedury i techniczne specyfikacji przetargowe. Niemniej jednak wartości projektowane mogą być nieproporcjonalne do wartości rzeczywistych w zależności od kolejnych czynników eksploatacji linii kolejowej. Dlatego w przyszłości powinno się zwiększać ilość zależności korelacyjnych parametrów toru dla bardziej precyzyjnego opisu współpracy rozjazdu z systemem sterowania pracą zwrotnicy oraz pracą krzyżownicy z ruchomym dziobem.

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