

GRAŻYNA BARNA\*

CONTROL SYSTEM OF WHEEL SLIDE PROTECTION  
DEVICES FOR RAIL VEHICLES MEETING THE  
REQUIREMENTS OF EUROPEAN NORMATIVE  
DOCUMENTS

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SYSTEM STEROWANIA UKŁADÓW  
PRZECIWPOŚLIZGOWYCH DLA POJAZDÓW  
SZYNOWYCH SPEŁNIAJĄCY WYMAGANIA  
EUROPEJSKICH DOKUMENTÓW NORMATYWNYCH

Abstract

This paper presents requirements of European normative documents concerning control system of Wheel Slide Protection Devices for rail vehicles.

*Keywords: rail vehicle, braking, slide, control, requirements*

Streszczenie

W artykule przedstawiono wymagania europejskich dokumentów normatywnych dotyczące systemu sterowania urządzeń wykrywania i likwidacji poślizgu dla pojazdów szynowych.

*Słowa kluczowe: pojazd szynowy, hamowanie, poślizg, sterowanie, wymagania*

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\* DSc. Eng. Grażyna Barna, Rail Vehicles Institute „Tabor”.

## Designations

$C_r$	– relative air consumption [–]
$v_{1..6}$	– circumferential velocities of axle wheels [km/h]
$v_{ref}$	– WSP controller reference velocity [km/h]
$v_r$	– vehicle translation velocity [km/h]
$V_{Tmax}$	– maximum vehicle translation velocity [km/h]
$\sigma$	– absolute slide [km/h]
$p_{ra1}$	– initial pressure in the auxiliary reservoir [kPa]
$p_{ra2}$	– residual pressure in the auxiliary reservoir with reduced adhesion [kPa]
$p_{ra3}$	– residual pressure in the auxiliary reservoir with good adhesion [kPa]

## 1. Introduction

### 1.1. Principle of operation of WSP devices

During braking of a rail vehicle, a braking system produces braking torque, which is transferred to the vehicle axle sets. If a value of this torque exceeds a maximum value, which depends on the adhesion between rail and wheels, the circumferential speed of the vehicle wheels starts to decrease. This phenomenon is called a wheel slide. If neither braking torque is reduced, nor adhesion coefficient increases, the wheels in a short time can be locked. To prevent such situations, rail vehicles are equipped with Wheel Slide Protection (WSP) devices, which detect slide of the vehicle wheels and adequately control the braking torque.

Recovery of adhesion is performed by controlling pressure in braking cylinders by means of dump valves, which results in adjusting the braking torque. Therefore a WSP system consists of the following elements: wheel speed sensors, a controller and dump valves. A WSP controller performs measurements of angular velocities of all of the vehicle wheel-sets, performs calculation of estimated vehicle velocity (called the reference velocity), circumferential wheel velocities and determines circumferential wheel accelerations and wheel slide, and then, on the basis of two latter values appropriately controls the dump valves, in order to adjust the braking torque to the instantaneous adhesion values. The principle of WSP systems operation is described in details e.g. in [2], [4] and [6].

### 1.2. Wheel Slide Protection device as a safety critical system

Failure of a WSP device during braking at low adhesion can result in several negative consequences, out of which two are critical. First and foremost, the adhesion force remains relatively low, making impossible effective braking of a vehicle, and thus increasing the braking distance, which impairs the safety of passengers, train staff and people in proximity. Secondly, when locked wheels slide along the rails, flat spots (called "flats") can be produced on wheel treads. Wheel flats are sources of vibration and noise, they lower riding quality of a vehicle as well as passenger comfort, but first of all they lower safety, as they can cause a train to be derailed.

Because a safety critical system is a system which failure can result in severe consequences, e.g. death of injury of people, significant damages to property or environment,

thus it is evident that a WSP device is a safety critical system [1, 5]. For this reason, providing adequate specification of requirements for both structure and functions of the device is indispensable. Standard [7] and leaflet [8] contain such a specification. These two mentioned above normative documents are results of research works, which had been carried out by rail specialists from different countries, and therefore reflects an advanced expert knowledge concerning the slide phenomenon and WSP systems.

### 1.3. Specification of the WSP requirements and its application

The two mentioned above standards provide specification of the requirements for both structure and function of the WSP devices. The aim of this paper is to provide the specification of those requirements, which concern the WSP control system. This specification becomes a starting for designing WSP control system algorithms. The specification of the requirements is presented in the next section.

## 2. Requirements for the control system of a WSP controller [7] and [8]

### 2.1. General

The principle of operation of a WSP device for rail vehicles is defined as follows: *A WSP system is designed to make the best use of available adhesion for all intended-operating conditions by a controlled reduction and restoration of the brake force to prevent wheel sets from locking and uncontrolled sliding due to low adhesion. Thus the stopping distance is optimized and the extension of stopping distance minimized [7].*

### 2.2. Minimizing the braking distance

During braking at low adhesion conditions the increase of the braking distance cannot exceed a specified value, which depends on braking conditions, initial vehicle velocity and adhesion between rail and wheels. Both normative documents contain test program designed to test the WSP performance in this respect.

### 2.3. Vehicle velocity range

The WSP device should function properly up to the following velocity:

- $V_{T_{\max}} + 20\%$  for  $V_{T_{\max}} \leq 200$  km/h
- $V_{T_{\max}} + 10\%$  for  $V_{T_{\max}} > 200$  km/h.

During acceleration the WSP should function properly from the velocity of 6 km/h, and during deceleration the WSP should function properly down to velocity of 5 km/h. The WSP should not modify braking torque below the velocity of 3 km/h.

### 2.4. Wheel lock limit

Due to the necessity of protecting the wheel rims, the WSP shall not allow wheel locks if the vehicle velocity is greater than 30 km/h. If the vehicle velocity is below 30 km/h, the WSP shall not allow wheel locks of duration greater than 0.4 s.

## 2.5. Wheel slide limit

Due to the necessity of protecting the wheel rims, the WSP shall not allow excessive slide as well. The specific requirements concerning the absolute wheel slide (difference between vehicle velocity and wheel circumferential velocity) are as follows;

- the instantaneous value of the absolute wheel slide shall not exceed the following values for time period greater than 3 s:
  - 40 km/h for vehicle velocity between 200 km/h and 160 km/h,
  - 25% of instantaneous vehicle velocity value for vehicle velocity between 160 km/h and 120 km/h,
  - 30 km/h for vehicle velocity lower or equal to 120 km/h;
- for vehicle velocity greater than 200 km/h the instantaneous value of the absolute wheel slide shall not exceed 40 km/h for time period greater than 5 s.

The specified above requirements are presented graphically in Fig. 1.

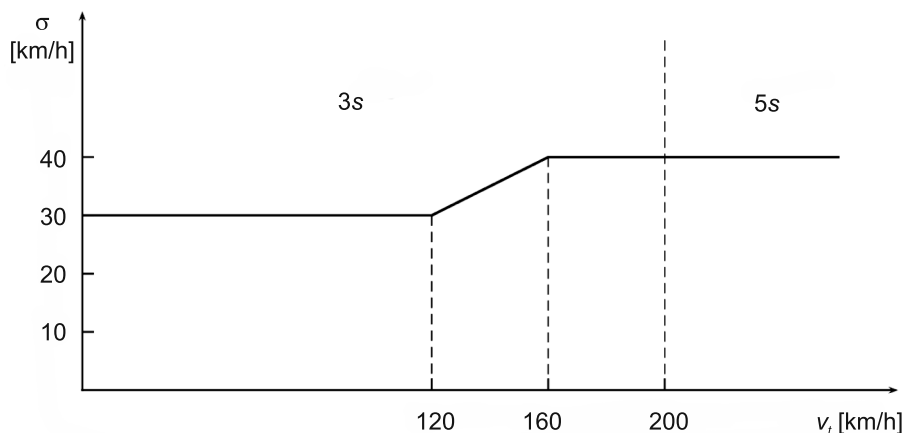


Fig. 1. Admissible absolute  $\sigma$  slide versus vehicle velocity  $v_t$  [2]

Rys. 1. Dopuszczalny poślizg absolutny  $\sigma$  w funkcji prędkości pojazdu  $v_t$  [2]

## 2.6. Behaviour at extremely low adhesion

During braking at extremely low adhesion, i.e. when the adhesion coefficient  $\tau < 0.03$ , the WSP shall not allow locking of the wheels. Both normative documents contain test program designed to test the WSP performance in this respect.

## 2.7. Vehicles with brakes independent on adhesion

When a vehicle is equipped with brakes independent of adhesion, when the brakes are applied, thus increasing a vehicle deceleration, the WSP shall function properly both at normal and low adhesion.

## 2.8. Traction units

For traction units equipped with a dynamic brake, the WSP should function properly when both dynamic and pneumatic brakes are applied at the same time (brake blending) and in case of failure of the dynamic brake.

## 2.9. Unjustified operation

The WSP shall not lower the braking force if the adhesion coefficient is not lowered, and the vehicle is not braked more intensively than designed.

## 2.10. Vehicle reference velocity calculation accuracy

If the reference velocity is greater than the vehicle velocity, it shall not exceed the vehicle velocity by more than 5 km/h.

If the reference velocity is smaller than the vehicle velocity, it shall not fall below:

- 10 km/h, if the vehicle velocity is smaller than 200 km/h,
- 15 km/h, if the vehicle velocity is greater than 200 km/h.

## 2.11. Air consumption

Compressed air consumption caused by the WSP operation should be as small as possible. Calculation of the relative air consumption can be performed with one of two methods. The first method is based on the measurements of the pressure before and after brake test, both with good and poor adhesion. The relative air consumption  $C_r$  is given with:

$$C_r = \frac{P_{ra1} - P_{ra2}}{P_{ra1} - P_{ra3}} \quad (1)$$

The principle of the direct method is shown in Fig. 2. The relative air consumption  $C_r$  is given with:

$$C_r = \frac{\sum \Delta P_i}{P_n} \quad (2)$$

During the brake tests the values of the relative air consumption shall not exceed the limits given in Table 1.

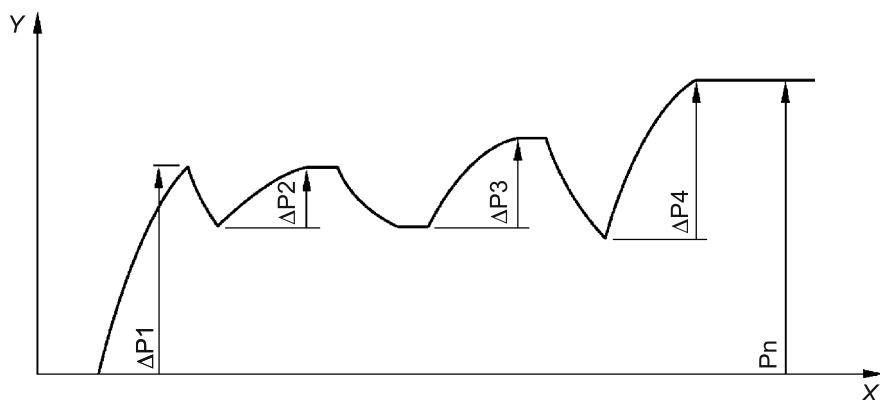


Fig. 2. Direct method of relative air consumption [7]:  $Y$  – pressure in a brake cylinder,  $X$  – time

Rys. 2. Bezpośrednia metoda obliczania względnego zużycia powietrza [7]:  $Y$  – ciśnienie w cylindrze hamulcowym,  $X$  – czas

Table 1

**Relative air consumption  $C_r$  [7], [8]**

Initial vehicle velocity $V_{70}$ [km/h]	Relative air consumption $C_r$ [-]
120	3,5
160	7

### 3. Test program and test evaluation criteria

The normative documents provide specification of tests, which verify meeting by a WSP device the normative requirements concerning functionality of the WSP control system [2, 3, 7, 8].

The test program consists of several tests, divided into three groups: slip tests (when a vehicle is braked from a initial velocity until standstill), drag brake test (when a braked vehicle is hauled) and a test at low adhesion. The exact specification of tests depends on a vehicle type: passenger coaches, wagons, locomotives and train-sets or high speed trains. The initial vehicle speed and brake position, as well as additional conditions, are specified for each test.

Before performing the real tests, preliminary brake tests at good adhesion conditions are performed. The purpose of the tests is determining both reference braking distance and reference compressed air consumption for slip tests.

For slip test the rail is sprayed or covered with soap in order to lower the adhesion coefficient value. Then slip tests are performed. The stopping distance is measured and the compressed air consumption is determined. The test assessment criteria are as follows:

- instantaneous slide value cannot exceed a specified value, for a specified time, depending on an instantaneous vehicle speed,
- wheel lock limits should be observed,
- reference speed should be determined with a specified accuracy,
- undesired venting does not occur.

Besides, for the tests with sprayed rails from speeds 120 and 160 km/h, the following additional requirements should be met:

- braking distances cannot exceed specified values,
- air consumptions cannot exceed specified values, depending on a initial vehicle speed.

For a drag braking test a braked vehicle is hauled at constant speed for a specified time period. All of the wheels should slide. The test assessment criteria are as follows:

- none of the wheel-sets may be locked,
- instantaneous slide value cannot exceed 30 km/h for a time period longer than 3 s,
- undesired venting does not occur,

For a test at low adhesion none of the wheels cannot be locked.

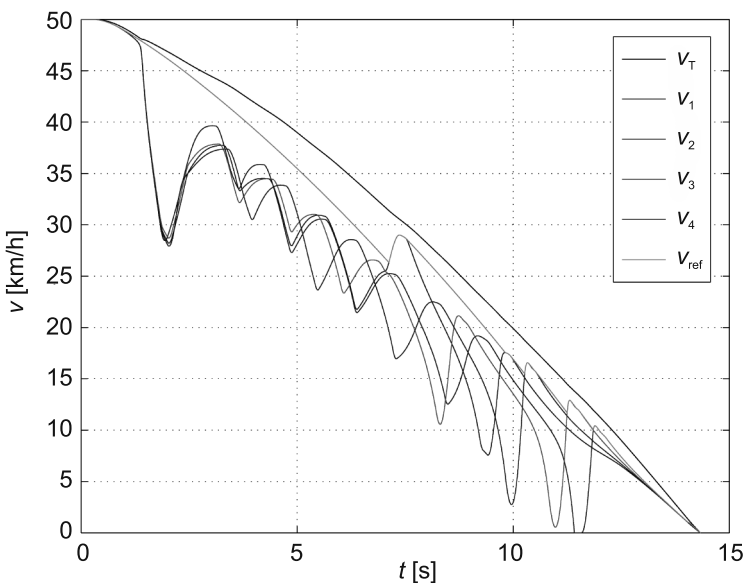


Fig. 3. Vehicle translation velocity ( $v_T$ ), circumferential velocities of axle wheels ( $v_{1..6}$ ), and controller reference velocity ( $v_{ref}$ ) for a slip test, at initial vehicle speed of 50 km/h for a 150A type passenger coach [3]

Rys. 3. Prędkość postępową pojazdu ( $v_T$ ), prędkości obwodowe kół ( $v_{1..6}$ ) i prędkość referencyjna pojazdu ( $v_{ref}$ ) dla próby hamowania z prędkości 50 km/h dla wagonu 150A [3]

#### 4. Conclusion

The specification presented in this paper is primarily a base for designing control algorithms for WSP devices. It can also be a basis for developing a comprehensive simulator test bench. A control system of WSP for rail vehicles meeting the requirements specified in this paper has been implemented in Matlab Simulink® [2, 3]. A test program has been developed, which not only allows assessment of WSP systems in terms “passed\failed” against the requirements of the respective standards, but which also makes possible comparing different types or variants of systems with each other.

Simulated tests results of a model of a passenger coach 150A for a slip test, at initial vehicle speed of 50 km/h [3] are shown in Fig. 3.

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