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Problems of computer-aided technical state evaluation of rail-vehicle wheel sets

Key words

Technical diagnosis, technical state evaluation, wheel sets, rail-vehicles.

Słowa kluczowe

Diagnostyka techniczna, ocena stanu technicznego, zestawy kołowe, pojazdy szynowe.

Summary

This article presents issues related to the construction of a computer-aided system evaluation of the technical condition of rail-vehicle wheel sets. Physical features which make a diagnostic feature vector are discussed and classified in the paper. This vector may be used for the identification of a vehicle condition state. Examples of formulas for distinguishing the classes of the technical states of rail-vehicles based on the evaluation of the thickness of a rim and the thickness and height of a wheel flange have been specified. The article also presents the guidelines for building a database for the computer-aided evaluation system of wheel sets.

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Introduction

Wheel sets constitute a set of rail vehicles. Their technical state change during operation due to the wear processes and damage (examples shown in [4]), and it determines whether the vehicle is certified fit for use. It requires carrying out measurements of certain features in the units of the technical support and comparing their values with the boundary values in order to identify the current technical state of the wheel sets. It enables one to make a decision on certifying the vehicle fit for use or directing it to the servicing system.

Measurements and evaluation results are recorded in a traditional “paper” form. The introduction of the computer-aided evaluation of the wheel set technical state is a much better solution. This system enables the registration of the research results, and it automatically generates the decision. It also actively controls the registration process through the analysis of the archive data conducted in a real time. The issues concerning the development of such a system is the subject of this paper.

Diagnostic features of rail vehicle wheel sets and their classification

Wheel sets can be described by a set of a whole range of physical features, i.e. the features of the internal structure [2]. The technical state of the wheel set can be defined as a characteristic determined by the vector of these features in the following form [5]:

$$\mathbf{X}(t,a)=\left[\, x_1\left[f_{1,a}(t)\right],\, x_2\left[f_{2,a}(t)\right],\ldots,\, x_n\left[f_{n,a}(t)\right]\,\right] \tag{1}$$

where:

$\mathbf{X}(t,a)$ – the vector of the technical state after the period of operation t in the conditions a,

$x_1,\ldots,x_n$ – the values of the internal structure features,

$f_{1,a},\ldots,f_{n,a}$ – the functions describing the changes in the values of these features in operation,

n – the number of the components of the technical state vector.

These characteristics are the operation safety features and their set contains 29 items [5]. They can be divided into groups of measurable features and non-measurable features. The measurable features are divided into the primary ones (individual and collective) and the secondary ones (internal and external).

The majority of measurable features are the primary features which can be measured in a direct way (for instance: wheel flange thickness, wheel diameter) or an indirect way (tyre thickness) with the use of proper physical value converters. The measurable features of an individual type are evaluated on the basis of one measurement result (an unbalance moment or the resistance of a wheel set). For the collective features, the checked value is an average of some results (e.g. the thickness of a tyre measured in three planes every 120°). The secondary features apply to the additional bonds among the primary features, and they have the appropriate boundary values of these bonds. The internal secondary features apply to one wheel set under evaluation, and the external secondary features apply to the bonds among the primary features of the wheel set of a given bogie or rail vehicle.

The non-measurable features also undergo evaluation, and this evaluation is essential while deciding whether the whole rail vehicle can be certified fit for operation. The examples of such features are, e.g., the purity of a wheel sound or the aligning of control signs on a tyre and a wheel centre. In order to take the non-measurable features into account in a computer-aided process of decision-making, a certain binary-type value, for instance [1,0] or [true, false], should be assigned to the result of the control of these features.

Having the measured or assigned values of individual diagnostic features and neglecting their origin, one can identify the current technical condition of a wheel set, in a certain operation point t, on the basis of the diagnostic feature vector $\mathbf{Y}(t,a)$, in the following form [5]:

$$\mathbf{Y}(t,a)=\left[\ y_1\left[\varphi_{1,a}(t)\right],\ y_2\left[\varphi_{2,a}(t)\right],\ldots,\ y_{29}\left[\varphi_{29,a}(t)\right]\ \right] \tag{2}$$

where:

$y_1,\ldots,y_{29}$ – a wheel set diagnostic features,

$\varphi_{1,a},\ldots,\varphi_{n,a}$ – the forms of the functions describing the changes in the values of these diagnostic features during operation.

The evaluation procedure of the individual features which are the vector $\mathbf{Y}(t,a)$ components is not uniform and requires the use of appropriate relation operators for the comparison of the measured and boundary values of a given feature or for the identification of non-measurable unfitness of a wheel set.

Additionally, for certain features, a uniform trend of value changes in the course of operation cannot be defined. Such trends may apply to individual operational periods determined by the machining of wheels. It is illustrated in Figure 1, which shows the example of the changes in the thickness of a tyre and the changes of the thickness and height of the wheel flange.

Every reconditioning of the wheel profile significantly reduces the thickness of a tyre, whereas the reduction of this thickness in the rail vehicle operational period is systematic but relatively insignificant. It is different in the case of the wheel flange thickness, which decreases significantly, and the reconditioning of the wheel profile causes this dimension to be restored close to the nominal value. The individual reconditioning of the profile must be recorded in the register of the research results. The wheel flange height is practically unchanging in the presented case. It may result from the errors in the recording. In order to avoid this problem, one has to properly design the database structure as well as the structure of the evaluation of measurement results correctness, which should be used by a computer system for the evaluation of the technical condition during the data handling.

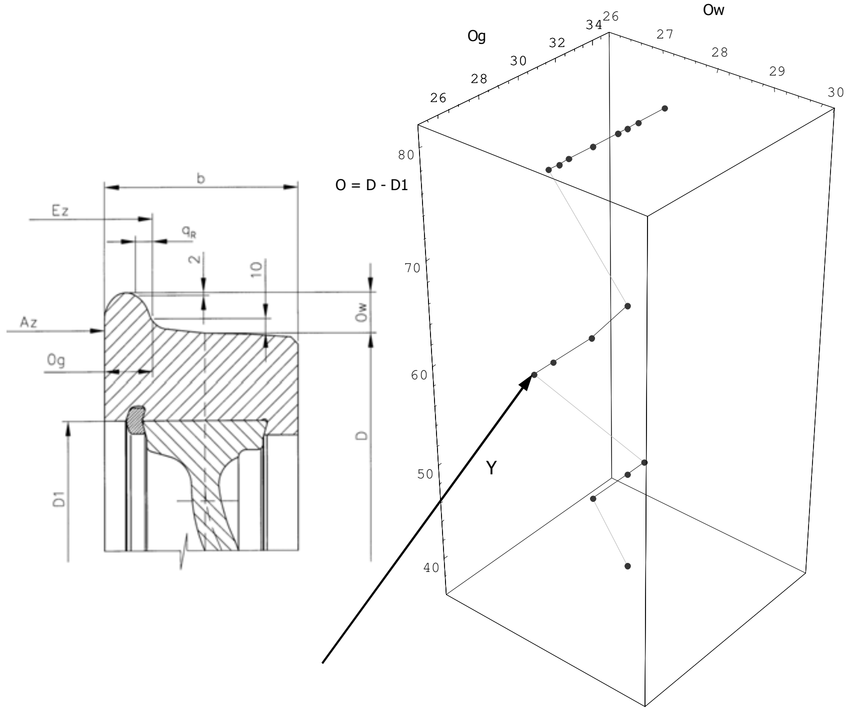

Fig. 1. An example of the technical condition state vector of the wheel set (Y) for the chosen diagnostic features $\{y_1, y_2, y_3\}$, i.e. the thickness of a rim and the thickness and height of the wheel flange

Rys. 1. Przykładowy wektor stanu technicznego zestawu kołowego (**Y**) dla wybranych cech diagnostycznych $\{y_1, y_2, y_3\}$, tj. grubości obręczy oraz grubości i wysokości obrzeża koła

Formal classification of the technical condition of rail vehicles taking into account the wheel set

Defining the classification forms of technical condition states for a simple case of the evaluation of one feature of a given element requires taking into account at least one boundary value of this feature's changes. A completely different situation refers to the features of a wheel set that is evaluated. These features constitute a certain set. With more than two boundary values of some features, each measured feature value should be compared with a few boundary values. With the existing number of features, there is the possibility to initiate incorrect actions, because the final operational decision referring to a rail vehicle also depends on the differences of feature values between the individual wheel sets of the given rail vehicle.

The variety of occurring limitations also requires using more than three classes of technical condition which are usually mentioned in professional literature, e.g. in [1, 2, 3].

The formulae which allow for the automatic generation of the evaluation of the technical condition of the wheel set and consequently enable one to make an operational decision with the reference to a given tested rail vehicle may be formed on the basis of the boundary values of the features included in [5]. For the features whose changes are illustrated in Fig. 1, the ranges of boundary values are shown in Table 1. On the basis of Table 1, one can build examples of formulae that determine classes of the technical condition states of the tested vehicle and the appropriate decisions from a set of four operational decisions and two maintenance decisions. These formulae are as follows:

– for the usability state S_z and decision U_0,

$$U_0 \Leftrightarrow S_z \Leftrightarrow \underset{i \in \{1,2,3,4\}}{\wedge} \left\{ y_i : \begin{bmatrix} (y_1 \geq 40) \wedge (25 \leq y_2 \leq 32) \wedge \\ (25 \leq y_3 \leq 33) \wedge (y_4 \geq 53) \end{bmatrix} \right\} \tag{3}$$

– for the conditional usability state S_{zw1} and decision U_1,

$$U_1 \Leftrightarrow S_{zw1} \Leftrightarrow \underset{i \in \{2,3,4\}}{\wedge} \left\{ y_i : \begin{bmatrix} (32 \leq y_2 \leq 36) \wedge (22 \leq y_3 < 25) \\ \wedge (48 \leq y_4 < 53) \end{bmatrix} \right\} \tag{4}$$

– for the conditional usability state S_{zw2} and decision U_2,

$$U_2 \Leftrightarrow S_{zw2} \Leftrightarrow \underset{i \in \{1\}}{\wedge} \left\{ y_i : [30 \leq y_1 < 40] \right\} \tag{5}$$

– for the conditional usability state S_{zw3} and decision U_3,

$$U_3 \Leftrightarrow S_{zw3} \Leftrightarrow \hat{i \in \{4\}} \{ y_i : [y_4 < 48] \} \tag{6}$$

– for the non-usability state S_{nz1} and decision O_1,

$$O_1 \Leftrightarrow S_{nz1} \Leftrightarrow \hat{i \in \{2,3\}} \left\{ y_i : \begin{bmatrix} (y_2 < 25) \vee (y_2 > 36) \vee \\ (y_3 < 22) \vee (y_3 > 33) \end{bmatrix} \right\} \tag{7}$$

– for the non-usability state S_{nz2} and decision O_2,

$$O_2 \Leftrightarrow S_{nz2} \Leftrightarrow \hat{i \in \{1\}} \{ y_i : [y_1 < 30] \} \tag{8}$$

Table 1. The boundary values of the selected safety features for the tyre wheel set for an electric locomotive
Tabela 1. Wartości graniczne wybranych cech bezpieczeństwa dla zestawu kołowego z obręczą do lokomotywy elektrycznej

Item number	Denotation and name of the feature	Relation to boundary values in [mm]	Decision type	Meaning of decision
1	y_1 – the thickness of the tyre O	$y_1 \geq 40$	U_0	operation without restrictions
2		$30 \leq y_1 < 40$	U_2	freight or passenger traffic v < 70 km/h
3		$y_1 < 30$	O_2	change of a tyre
4	y_2 – the height of the flange Ow	$25 \leq y_2 \leq 32$	U_0	operation without restrictions
5		$32 < y_2 \leq 36$	U_1	v < 140 km/h
6		$y_2 < 25 \vee y_2 > 36$	O_1	reconstruction of a profile
7	y_3 – the thickness of the flange Og	$25 \leq y_3 \leq 33$	U_0	operation without restrictions
8		$22 \leq y_3 < 25$	U_1	v < 140 km/h
9		$y_3 < 22 \vee y_3 > 33$	O_1	reconstruction of a profile
10	Y_4 – the sum of the flange thicknesses in the set $Og_l + Og_p$	$y_4 \geq 53$	U_0	operation without restrictions
11		$y_4 < 53$	U_1	v < 140 km/h
12		$y_4 < 48$	U_3	freight traffic

In the formulae (3 to 8), various operational operators and a various number of boundary values of the evaluated features are present. It requires constructing appropriate variants of the procedures of the computer evaluation that will take into account all possible situations. It is not too difficult a task because, regardless the programming language, one can easily construct appropriate simple or complex conditional instructions of the type: *if ... then ...else*.

The guidelines for constructing the database for the computer-aided evaluation of the technical condition state of wheel sets

The realisation of the system of the computer-aided evaluation of the technical condition of wheel sets also requires, apart from building the operational use application, the appropriate designing of the database [6], which enables storing a wide variety of essential information. This data refers to the following:

- the values of measured or evaluated features,
- the boundary values of measured or evaluated features,
- the trends of feature value changes and the relation operators of their evaluation,
- the repertory of operation decisions,
- the means of the wheel set identification and their location in rail vehicles, and
- the persons conducting diagnostic tests.

The properly designed structure of the database allows for the recording of the information obtained from the mentioned groups in the properly related database tables. It creates both the possibility of registering the research results with the use of the feature values describing the wear and damage of wheel sets and taking appropriate operational decisions as well as making and analysing the trends of these unfavourable changes. With the growth of the database, it makes it possible to use archive recordings for the active control of the introduction of the data of the current measurement results. Proper warning functions may be then automatically started in each attempt of recording values that are unjustified by the observed trend of changes. Moreover, introducing into the database the information about location of the wheel sets in the rail vehicle enables the current analysis of the secondary feature values. Other data also has its significance, e.g. the identification of the persons conducting research favours an increase in the reliability of the obtained results.

Conclusions

The issues connected to the computer-aided evaluation of the technical state of a wheel set presented in this article have considerable significance for the process of the control of rail vehicle operation. The appropriate application which realises the data registration functions referring to wheel sets in vehicles and the results of the tests run on these wheel sets and which generates the appropriate operational decisions is currently being constructed. It is also expected that there will be the possibility of conducting the analysis of the research results. It can be, however, effectively applied after an experimental period of using this application and after collecting enough data in the databases.

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Problemy wspomaganej komputerowo oceny stanu technicznego zestawów kołowych pojazdów szynowych

Streszczenie

W artykule przedstawiono zagadnienia związane z budową systemu wspomaganej komputerowo oceny stanu technicznego zestawów kołowych pojazdów szynowych. Cechy fizykalne tworzące wektor cech diagnostycznych. można wykorzystać do identyfikacji stanu technicznego pojazdu. Na podstawie ocen przykładowych cech określono formuły pozwalające na wyodrębnienie klas stanów technicznych pojazdów szynowych. Przedstawiono również wytyczne do budowy bazy danych dla wspomaganego komputerowo systemu oceny stanu technicznego zestawów kołowych.