METABK 55(1) 87-90 (2016)
UDC – UDK 629.11.012.3.004.64:625.2.01.004.05:621.72=111

FUZZY MODEL FOR PREDICTING THE NUMBER OF DEFORMED WHEELS

Received – Primljeno: 2015-02-12
Accepted – Prihvaćeno: 2015-07-10
Preliminary Note – Prethodno priopćenje

Deformation of the wheels damage cars and rails and affect on vehicle stability and safety. Repair and replacement cause high costs and lack of wagons. Planning of maintenance of wagons can not be done without estimates of the number of wheels that will be replaced due to wear and deformation in a given period of time. There are many influencing factors, the most important are: weather conditions, quality of materials, operating conditions, and distance between the two replacements. The fuzzy logic model uses the collected data as input variables to predict the output variable - number of deformed wheels for a certain type of vehicle in the defined period at a particular section of the railway.

Key words: wheel defects, vehicle maintenance, vehicle state parameters, fuzzy logic

INTRODUCTION

The most common reasons for the exclusion of rail wagons are damage to the wheel's rolling surface, wheel overheating due to braking on long slopes and faulty brakes, overheating of brake discs and axle bearings. Introducing systems of early detection of defects during the ride is profitable to both infrastructure managers and operators [1].

There is a common trend of applying a system for static and dynamic monitoring of the rolling stock [2]. Thus, the contribution of local stress models is significant, which is applicable for bearing capacity analysis of vital wagon elements, such as the underframe and the bogie of the wagon [3].

Wear and deformation as a result of high thermal loads cause wheel rims to crack and even break. Deformation result in damaging both the railway tracks and wagon which affect the stability and safety of vehicles. Repairs imply high costs and lack of wagons. The costs of new wheels, rim reparation, and replacement are very high. Reducing the costs requires good planning in the maintenance process. Analytical models provide good predictions, but require a detailed database [4]. Fuzzy logic is a mathematical tool for modelling processes characterized by uncertainty and inaccuracy.

With adequate availability of data this tool is suitable for predicting wheels defects. For specific cases, it can also be used for planning the maintenance of railway vehicles.

Ž. Đorđević, V. Vukadinović, ŽS ad, Beograd, Serbia
M. Vasiljević, Traffic faculty Doboj, B i H
S. Vesković, Traffic faculty, Beograd, Serbia
S. Rajilić, Municipal Novi Grad, B i H

WHEEL DEFECTS

Over the period between 2009 and 2014, 1459 wagons were excluded from the Serbian railway network due to damaged wheel rolling surfaces. Contributions of possible defects are: flat spots – 49 %, stickers – 18 %, holes and flat spots – 12 %, flat spots and stickers – 9 %, material extraction – 8 %, material accumulation – 3 %, and crease and scaling – 1 %.

The wheel and rail wear is a result of a complex dynamic interaction during the movement of the vehicle on the railway tracks while the wheels are slipping. Major factors influencing the wear rate are [5]: the wheel and rail material, the wheel-rail contact geometry, deviations in the manufacture and assembly, structural vehicle-features that affect the motion dynamics, operating conditions, and railway track geometry.

The wear rate is determined by mechanical properties of the rail and wheel. Wear rates are lower if the wheel material is somewhat harder than the rail material. The wear is also affected by the heat treating process. It has been proven that different wear rates occur for the same hardness. Tempering leads to higher wear rates, while isothermal hardening during the pearlite phase gives the best results [6].

In the European Standard EN 13262 for wheels, four steel grades are defined: ER6, ER7, ER8 and ER9. Hardness values on the Brinell scale to a depth of 35 mm below the rolling surface are given in Table 1.

UIC standards on monoblock wheel (MBW) and bandage quality indicate that the wheel is made of forged iron of types presented in Table 2. The R7 wheel is the most commonly used; its properties are as follows: R_m = 820 – 940 MPa, elasticity A % > 14, toughness (δs) at 20 °C = 15 J. It has relatively high hardness, 10 % higher than the rail hardness. The chemical composition and mechanical properties by types of MBW wheels are shown in Tables 2, respectively. Current wheels are made of R6, R7, R8 and R9 steels.

Table 1 **Min HB values**

Type of steel	Min values by categories	
	K1 (>200 km/hr)	K2 (<200 km/hr)
ER6	-	225
ER7	245	235
ER8	245	245
ER9	-	255

Table 2 **Chemical composition, max content /wt %**

MBW type	Chemical composition – max content / %										
	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	V	Cr+ Mo+ Ni
R1	0,48	0,90	0,50	0,035	0,035	0,30	0,30	0,08	0,30	0,05	0,50
R2	0,58	0,90	0,50	0,035	0,035	0,30	0,30	0,05	0,30	0,05	0,50
R3	0,70	0,90	0,50	0,035	0,035	0,30	0,30	0,08	0,30	0,05	0,50
R6	0,48	0,75	0,40	0,035	0,035	0,30	0,30	0,08	0,30	0,05	0,50
R7	0,52	0,80									
R8	0,56										
R9	0,60										

R6 and R7 wheels are of optimum technical and service quality for public transportation and high speeds. Due to the increased C (0,52 %) and Mn (0,8 %) content, R_m and HB values of type R7 wheels are about 5 % higher; they show the same toughness and slightly lower elasticity than the R6 wheels. R8 and R9 wheels are stronger, and their R_m values are 10 % higher, but they are also more brittle and less elastic.

Improper seating of brake shoes on the wheel rolling surface induces high and uneven thermal loads. Studies have shown that wheels are usually reprofiled as a result of poor brake performances [6].

Defects are caused by wheel warming when braking as plastic deformation and increased wear occurs in layers. Wheel fracture (Figure 1) can be affected also by the vehicle's poor structure and poor quality of wheel materials. Wheel defect results in exclusion from the traffic, and the number of excluded wagons is significant (more than 6 000 freight and 2 500 passenger wagons over the last 5 years,).

FACTORS AFFECTING WHEEL WEAR

There are a number of factors affecting wheel wear, and the main are the following: poor maintenance, condition of the superstructure, operating conditions (mountain railway tracks with sharp curves), wheel design – shape, material and manufacturing technology.

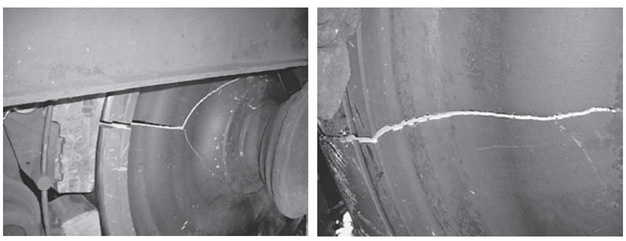

Figure 1 Typical wheel breaks

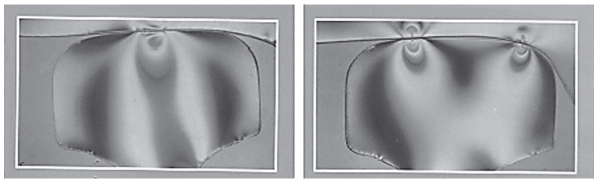

Figure 2 Stress distribution in the rail head

a) Effects of rail and wheel materials

According to the UIC, the optimum hardness ratio of wheel/rail steels is $R_{m,w} = 1,1\ R_{m,r}$. The UIC standard prescribes R7 wheels of R_m = 820 – 880 MPa. Studies have shown that in this case the ratio of investment in rails and vehicle service life is 2:1 [7].

b) Operational conditions

- Influence of the wheel-rail contact interface elements

Pressure stresses along the contact interface (max. 1 000 MPa) are over the limits of the rail steel elasticity. Parameters that define the wheel-rail contact include adhesion, slip and wear.

The contact surface is flat and elliptical, and depends on the degree of wheel and rail wear, while the wheel rests only on one or two points. The stress distribution in the rail head for the two types of contacts obtained by photo-elastic measurements is shown in Figure 2 [6].

- Effects of railway track parameters

Research (DB, CR and SR) have shown that wheel wear is directly affected by errors in railway track geometry, i.e. distortion, narrowing, and cant.

- Effects of cant of a railway track

The cant depends on the curve radius and technical velocity. Based on the research conducted in several countries (Germany, India), R. Wenty of Plasser & Theurers suggests that railway companies will be better off by high-level track maintaining, keeping thus the ride comfort, saving the tracks and vehicles, and the cost-effective business [6].

c) Effects of the weather

Rates of lateral friction and wheel wear are lower in wet weather. This cannot be affected, but should be kept in mind. According to UIC ORE [7] trains in UIC member states run 36 days in wet and 144 days in dry weather, when rims and wheels wear the most along the rolling circle. Along with the similar dynamical conditions, this is the case when trains easily derail and the noise is increased.

d) Other influential factors

Wheel wear is affected by many factors. In addition to the above, they are: deviation in the manufacture and assembly of axle assembly, bearings and bogies, operating conditions, quality of trucks, cargo distribution and type, towing conditions, level of use of wagon bearing capacities, the impact of structural properties of the wheel set, and quality of maintenance of elements of suspension.

MONITORING THE WEAR RATE OF PASSENGER WAGON WHEELS

According to the UIC standard, the service life of MBW passenger wagons on lines with little curves is about 1 100 000 km, and on lines with many curves, especially with small radius, it is about 600 000 km, taking into account the two reprofiles of the wheel during its service life. In 1982, ŽTP Zagreb has published a study on wheel wear. All passenger wagons were equipped with R2 type wheels. In addition to the difficulties in conducting the analysis due to the lack of statistical data, the study revealed that the wheels of passenger wagons are reprofiled after 100 000 – 150 000 km. The analysis of studies researching the wheel-wear problem has shown that about 90 % of data is related to the wear of locomotive and train wheels in, about 9 % to passenger wagons, and only 1 % to freight wagons.

FUZZY MODEL FOR PREDICTING THE NUMBER OF BROKEN WHEELS

When wheels are rapidly wearing, the eternal question is whether it is mainly due to the state of tracks or vehicles. However, there are a number of authoritative exact parameters for assessing the number of wheel deformation, for example, operating conditions on the track, weather conditions, state of the wheel, material of which the wheel is made, etc. The required number of replacement wheels has been usually assessed by using heuristic methods and the estimates of experts of competent bodies based on simple statistics, personal opinion and intuition without the inclusion of mathematical methods.

The fuzzy model for assessing the number of deformed wheels that need to be reprofiled or replaced is defined with four input variables: weather conditions (Figure 3a – **L**ow, **M**iddle and **H**igh **C**oefficient of the **F**riction), the quality of the wheel and rail materials (Figure 3b – **F**ine and **H**igh **S**atisfactory **Q**uality), operating conditions (Figure 3c - **G**ood and **P**oor **C**ondition of **E**xploitation) and the status of the wheel – distance travelled, i.e. the time between two reparations the state of the railway (Figure 3d – **L**ittle **I**mpact, **M**edium and **A** **M**ajor **I**mpact). The membership function for the output variable number of broken wheels is defined with three fuzzy sets: LOW, MID, HIGH (Figure 4). Fuzzy logic enables making decisions based on incomplete information, and it is defined through algorithms for approximate reasoning. Values and boundaries of input and output variables of fuzzy sets are defined by normalized data for each data category and for each specific case. Fuzzy logic system comprises of 36 rules. These fuzzy rules translate 4 input fuzzy variables into one output fuzzy variable. Input variables in fuzzy systems are linguistical and have different values: "wet weather", "good operating conditions", "operating conditions between two wheel revisions".

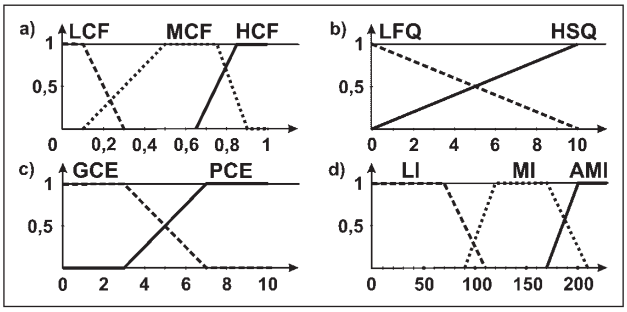

Figure 3 Membership functions of input fuzzy variables

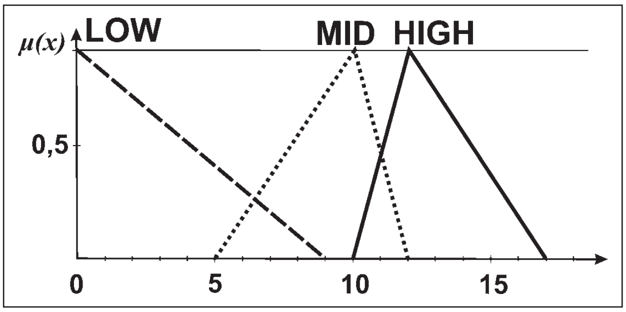

Figure 4 Membership func. of the output fuzzy variable

Analysis of model for determining the level of monthly stock wheels, or the number of deformed wheels that have to go to treatment or substitute for the various weather conditions (W-LCF low, W-MCF middle and W-HCF high coefficient of the friction) Analysis of model for determining the level of monthly stock wheels, or the number of deformed wheels that have to go to treatment or substitute for the various weather conditions as a function of the number of kilometers to the first treatment, the second treatment and replacement for certain quality materials and operating conditions shows that the new wheels are most affected by weather conditions and the quality of materials (Figure 5). In further exploitation increasingly coming evident other parameters, primarily operating conditions and status of wheels.

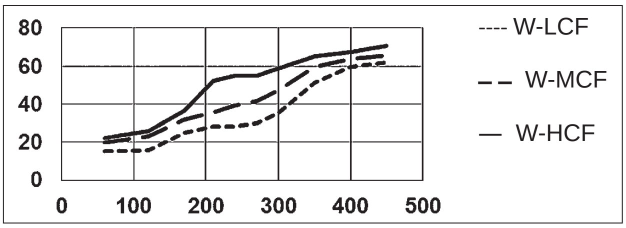

Figure 5 Number of deformed wheel for a variety of weather conditions as a function of km travelled

CONCLUSIONS

Railway companies are making efforts to reduce operating costs and explore the key costs which are induced by: inadequate and rapid wheel wear, high rates of damaging geometry and dynamic properties of the railway track by the vehicles, costs of remediation of environmental problems of noise and vibration caused by the disturbed dynamic relation between the vehicle and the railway track. This threatens passenger comfort, safety due to derailment, while the bad "wheel-rail" relation due to the increased tribological effect increases power consumption.

There are more sophisticated methods that can detect defects during the movement of trains. In addition to preventive detection of defects, the installed network of devices for dynamic monitoring of vehicles allows obtaining comprehensive value base values of key parameters for assessing the condition of vehicles. The quality of analysis of the recorded data needs to be improved and harmonized with European trends.

The model enables monitoring and determining the number of deformed wheels for different combinations of factors, as well as different variants of defining basic (unchanging) parameter. Outputs can be grouped according to the type of vehicle, type of axle stands, the quality of the material from which is wheel made, manufacturers, etc.

Acknowledgment

The authors acknowledge the support of research project TR 36012, funded by the Ministry of Science and Technological Development of Serbia.

REFERENCES

[1] G. Stojić, S. Vesković, I. Tanackov, S. Milinković, Model for Railway Infrastructure Management Organization, Promet – Traffic & Transportation 24 (2012) 2, 99-107.

[2] S. Vesković, Ž. Đorđević, G. Stojić, J. Tepić, I. Tanackov, Necessity and effects of dynamic system for railway wheel defect detection, Metalurgija 51 (2012) 3, 333-336.

[3] J. Tepić, R. Doroslovački, M. Đelošević: Unconventional Bearing Capacity Analysis and Optimization of Multicell Box Girder, The Scientific World Journal, (2014), Article ID 496398, DOI: 10.1155/2014/496398.

[4] C. T. Dick, C. P. L. Barkan, E. Chapman, M. P. Stehly, Multivariate statistical model for predicting occurrence and location of broken rails. Transportation Research Record, Vol. 1825 (2003), 48-55.

[5] A. H. Wickens: Fundamentals of rail vehicle dynamics, guidance and stability, Loungborough University, Leicestershire, UK, 2007, ISBN 90 265 1946 X

[6] Transportation Institute CIP, Causes of accelerated wear of rail vehicle wheels of Serbian Railways and the possibilities for improvement (study), Beograd, 2008.

[7] UIC 510-2, Trailing stock: wheels and wheelsets. Conditions concerning the use of wheels of various diameters, 4. Edition, 2004., ISBN:2-7461-0405-9.

Note: The responsible translator for English language is prof. Jelisaveta Šafranj, Novi Sad, Serbia