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RAILWAY RUNNING-GEAR DIAGNOSTICS BASED ON VEHICLE SYSTEM DYNAMICS

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Abstract

In this paper, the basic principles of the railway running gear diagnostics as well as the measuring equipment applied in a diagnostic measuring station are summarized. Further on the utilization possibilities of the diagnostic measuring results are presented, then the prediction possibilities based on the vehicle system dynamics are discussed in detail with a special regard to the future operational period of railway vehicles.

Keywords: railway running gear, diagnostics, maintenance.

1. Running-gear Diagnostics and its Place in the Maintenance System of Vehicles

Running-gear diagnostics deals with testing and checking railway vehicle wheelsets, running-gears as well as the joints between body and bogie, which is performed by means of measurements without disassembly. In the course of diagnostic tests, the geometrical characteristics of the wheelsets and axleguides, the wheel loads, as well as the geometrical and force-transmitting characteristics of the axleguides and joints between the body and bogie are to be checked up.

The essence of diagnostics is to recognize the facts, identify and evaluate the actual technical state from the point of view of the future operational life of the vehicle. Diagnostics is connected with the maintenance system of vehicles so that it can decide on whether maintenance or repair activity, respectively, is required. Considering that the main units of vehicles have different service life in many cases, and their failure generally occurs after different service periods, consequently it is not necessarily required to specify the maintenance or repair activity strictly on the basis of service life or the total distance covered. Instead, it is proposed to check the technical state of the vehicle parts at definite intervals. To avoid the unnecessary disassembly, it is recommended to apply the methods of system diagnostics. By means of such checking methods, on the one hand, information can be gained directly after manufacture, while on the other hand, data can be collected about the processes of failures and wear, the extension, location and cause of those, etc.

2. The Measuring and Checking Tasks of the Running-gear Diagnostic Stations

The scope of the tests and checkings to be carried out in the diagnostic station was determined so that the geometrical and dynamical parameters important from the point of view of running characteristics would be checked systematically — first of all, the parameters of the vehicle ensuring the required running safety as well as the minimum wheel wear. (It should be born in mind that for the sake of unambiguous evaluation of the running safety, the diagnostic investigation into the geometrical and dynamical track parameters is also necessary, and really the complex diagnostic test of the whole track–vehicle system is required). Accordingly, when concentrating on the vehicle as a sub-system, the following parameter tests or checking activities, resp., are intended to be performed systematically at the running-gear diagnostic stations:

- measurement of the running tread diameter of wheels;
- checking of the running tread surface of wheels;
- recording of the wheel profile curves;
- measurement of the inner flange distance within a wheelset;
- measurement of wheel loads;
- measurement of geometrical characteristics of axlebox guidance;
- measurement of the stiffness and damping characteristics of axlebox guidance;
- measurement of the stiffness and damping characteristics of bogie suspension.

3. Measuring Equipment Applied at the Diagnostic Station

The main unit of the diagnostic station is the roller equipment located into a suitably sized pit which supports one of the wheelsets of the vehicle and drives it during the test. The equipment is shown schematically in *Fig. 1.*

Each wheel of the tested wheelset is supported by a pair of rollers, and the two rollers are connected laterally with a supporting beam. This beam is held in the specified height-position by hydraulic cylinders of vertical axis and a load cell is inserted between each cylinder and the beam. These cells are used to measure the vertical wheel loads. The devices to be applied to

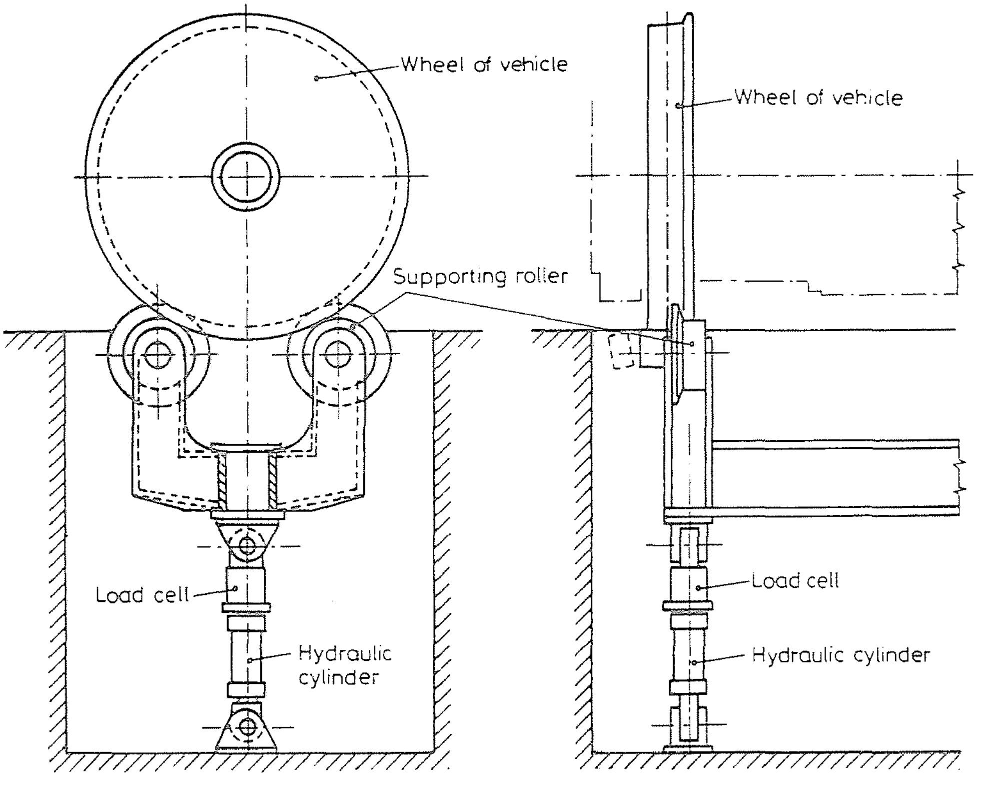

Fig. 1. Running-gear diagnostic station. Wheelset-supporting equipment

measure the geometric and other characteristics of the running gear can be placed generally on the supporting beam under the wheels.

When the tested vehicle is rolling onto the measuring equipment, the hydraulic cylinders hold the supporting beam and the roller pairs are in their lower position, so that the wheels of the vehicle roll on the laterally removable rail sections. When the vehicle is stopped in the testing position, the hydraulic cylinders raise the beam and the roller pairs, then after the rollers came into contact with the vehicle wheels, the wheelset will be lifted up a little higher in order to remove the rail sections laterally. Afterwards, the cylinders sink the wheelset back on the track level of the station. After starting up the driving motor of the rollers, the wheelset begins to rotate. During the rotation of the wheelset, each measuring device can be brought into operation one after the other.

In order to carry out the individual measuring tasks, mostly two kinds of solutions are available: on the one hand, the devices applied traditionally in measuring practice can be chosen (e. g. the well-known inductive displacement transducers), and, on the other hand, the up-to-date contact-free measuring devices (e. g. laser-diode optical displacement transducers), which are rarely used in Eastern Europe yet in the railway practice, but in some particular fields they are already wide-spread. The measuring methods and equipment applied to carry out the measuring tasks of the diagnostic stations are presented below only schematically, further information on them can be found in Reference [2].

The diameter of the tread circle of wheels can be defined by means of the method of chord measuring performed between the rollers supporting the wheel. The chord height can be measured by means of the laser displacement transducer or the inductive one with appropriate accuracy. The operational principle of the laser transducer is presented schematically in *Fig. 2* (part *a*) of the Figure). Another possibility to measure the running circle diameter is to apply a measuring wheel of specified diameter contacting the vehicle wheel (*Fig. 2,* part *b*) of the Figure); the unknown wheel diameter can be defined by counting the rotation number of the measuring wheel by means of a digital angular rotation transducer, while the vehicle wheel performs one revolution.

The wheel treads are checked to reveal the surface defects (wheel flattenings, deposits, pitting, etc.). This checking can be performed by means of the above mentioned laser displacement transducer measuring the change in the wheel tread radii. But this measurement can be performed by means of a follower roller, too, which is built together with an acceleration transducer. The roller is pressed onto the tread of the rotating vehicle wheel. By rolling the following roller through the irregularity of the wheel tread, on the basis of the measured acceleration amplitude conclusions can be drawn on the size of the damage (*Fig. 2,* part *c*) of the Figure).

The above mentioned laser displacement transducer can be used to record the wheel profile, too: scanning throughout the wheel profile by means of a suitable servo mechanism, a sufficient amount of discrete measured points can be recorded from which the continuous curve of the whole wheel profile can be produced. At the same time, this measurement task can be carried out by means of a traditional inductive displacement transducer, as well.

The most suitable method to measure the distance between the flanges of wheelsets is the application of two laser displacement transducers at the same time, because the two transducers can reach the two flanges separately in a much easier way.

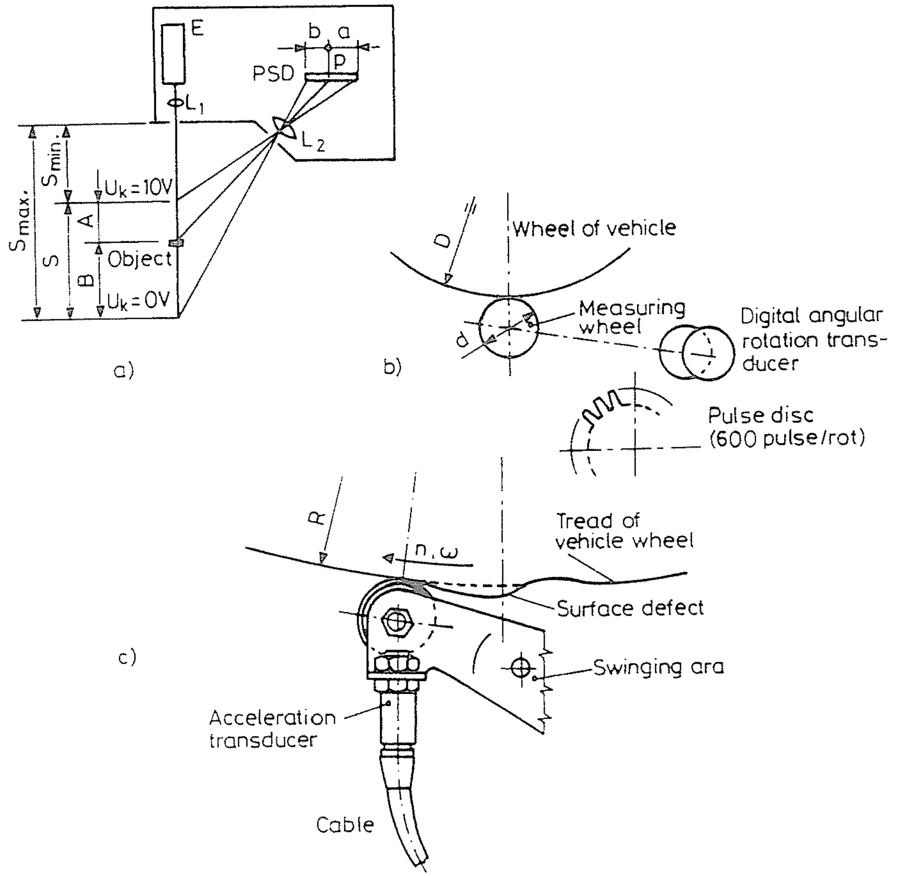

Fig. 2.

The measurement of the wheel loads is performed by means of the above mentioned load cells. The wheelset is supported by means of hydraulic cylinders at the height of the precisely levelled track connected to this measuring equipment, then each load cell senses the vertical load of its own tested wheel. If the hydraulic cylinders are controlled by servo valves, it is possible to define the actual characteristic interval of vertical springing and damping.

Among the geometric characteristics of axle guidances, the following ones are taken into consideration: the skewness of the wheelset axle (i. e. the angle between the wheelset axle and the ideal lateral direction), the 'diagonal size' of the axle guidances, as well as the running centre of the wheelset (this means the halving point of the distance between the contact points of wheel flange and rail). These characteristics are measured by an equipment (*Fig. 3*), which fixes both wheels of the wheelset to a beam supported by air cushions. Considering that the beam supported by the practically friction-free air cushions can be moved along horizontal plane by a negligibly small force, consequently the beam will also take the original standstill position of the wheelset, which can differ from the ideal lateral position. By measuring the difference between the real and ideal beam positions at both wheels, the skewness of the wheelset axle, as well as the position of the centre can be defined. The 'diagonal size' can also be defined from these results.

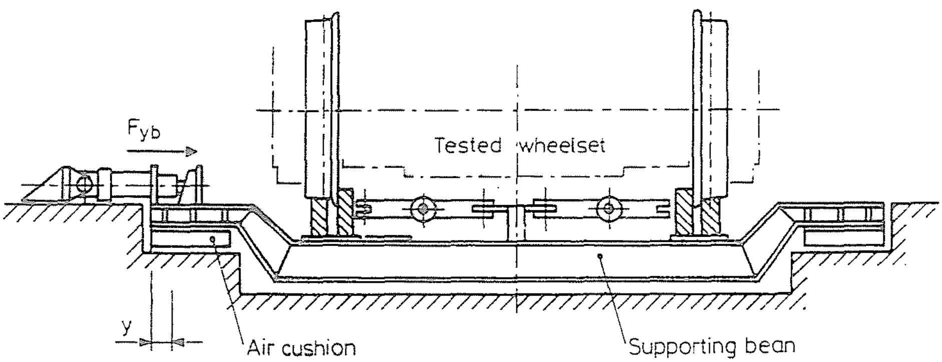

Fig. 3.

Finally, the stiffness characteristics of axle guidances can also be defined by means of the above mentioned beam supported by air-cushions and fixed to the wheels. This measurement is performed so that longitudinal or lateral force, resp., is exerted by means of hydraulic cylinders on the supporting beam resting on air-cushions. At the same time, the position of the other wheelset is fixed by a similar beam. The exerted force can be measured by means of load cells, the displacement of the beam can be measured by means e. g. of a laser displacement transducer. So the occasional hysteresis of the axle guidance joints can also be recorded, further on — by applying hydraulic cylinders furnished with servo valves — the damping characteristics can also be tested.

4. Control of the Measuring System and Data Acquisition

Among the devices of the running-gear diagnostic station, the computer has an important role because, on the one hand, it controls the execution of the individual measurement activities, and acquires the measured results, and processes them, on the other. This is performed so that each measuring device is set into its own measuring position by the hydraulic cylinders controlled by a computer, then the computer starts up the measurement, the values (sets of values) of the measured results are acquired, the necessary data-processing steps are performed, finally the computer sets the applied measuring equipment back into its basic position by means of the hydraulic cylinders. Each measuring cycle consists of those steps, and contains similar operations.

As an example, the measuring cycle of the spring characteristics $F = f(d)$ is presented in *Fig. 4* relating to the lateral axle guidance. The computer starts the measuring cycle by raising the starting voltage U_1 to the value U_{10} (at instant t_1). Consequently, each hydraulic cylinder coupled to the beam supported by air cushions gets a 'zero feed' (a feed of small quantity), because so each piston in the cylinders will hold its position until a new feeding. This is performed in time interval $t_2 - t_3$. Then the active cylinder exerting the lateral force gets more and more feeding beginning at instant t_4 and extending in time in order to move the axle box relatively slowly. The exerted force F is measured by load cell, and the transduced voltage U_F will be proportional to the measured force. Displacement d of the axle box is measured by a laser displacement transducer (or other suitable device) transducing voltage U_d proportional to the measured displacement. The computer increases the feeding of cylinder up to a specified limit, meanwhile through the A/D converter, voltages U_d and U_F are measured automatically at given intervals, from which the real measured discrete displacement and force values can be defined by using the given scales of force and displacement. The computer acquires these calculated force and displacement values continuously and stores them. When the increase in voltage U_d stops (at instant t_5), the computer stops performing the measurement and the acquisition of the measured data, subsequently all the hydraulic cylinders are discharged at instant t_6. Finally, the starting voltage U_1 is also decreased to zero, by giving a signal that the measurement is finished, and the next measuring cycle can be initiated.

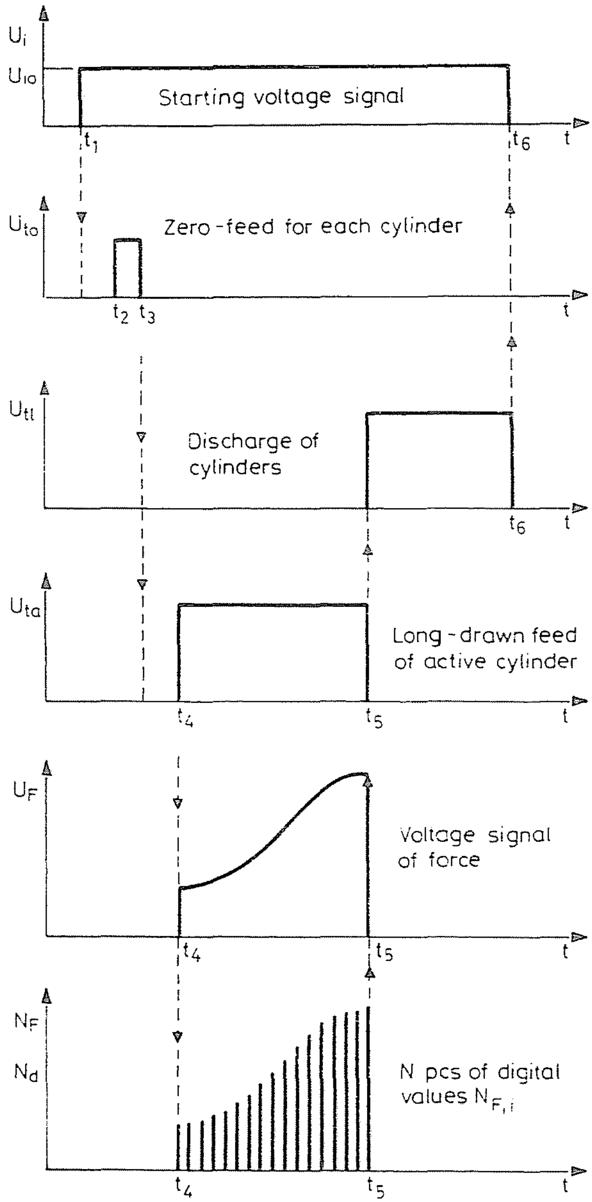
U_i
U_io
Starting voltage signal
t_1
t_6
t
U_to
Zero-feed for each cylinder
t_2 t_3
t
U_tl
Discharge of
cylinders
t_6
t
U_ta
Long-drawn feed
of active cylinder
t_4
t_5
t
U_F
Voltage signal
of force
t_4
t_5
t
N_F
N_d
N pcs of digital
values N_F,i
t_4
t_5
t

Fig. 4.

5. Processing of the Measured Data and the Utilization Possibilities

The processing of the measured data consists of certain checkings to be performed with respect to the measured values. These checkings decide, on the one hand, whether certain measured values exceed a specified limit or not, and, on the other hand, whether the difference between certain measured data exceeds a specified limit or not; but in many cases, the computer simply records the measured results. The computer begins with the processing of the measured data directly after the individual measurements, however, in case of certain measurements a part of the processing can be performed only after another similar measurement. For example, checking whether the difference between the diameters of both wheels exceeds the limit specified in the standards or not can be performed only after the measurement of *both* wheel diameters. In case of wheelsets coupled by cardan shaft, all the four wheel diameters should be measured for checking the diameters, etc. In the course of checking the wheel-tread damages, both treads of the wheelset should be checked, too, before deciding whether the wheelset should be turned on a lathe or not. The recording of the wheel profile can also have a similar important role when deciding on whether the flange wear exceeds the permitted tolerance or not.

After the required checking operations on the measured values, the computer stores all the measured and calculated results in a data bank together with the data necessary to identify the vehicle. The purpose of establishing and maintaining a data bank is to ensure the storage of a systematically measured assembly of characteristic values related to the running-gear of the tested vehicle during the whole service life for further checking of processing the measured results. In the course of this period, the change of certain measured results can be traced throughout the service life of vehicles (e. g. on the basis of vehicle identification number, it is possible to look up the diagnostic test results of any vehicle measured in the given time). Further conclusions can be drawn about the trend hidden in the measured data by means of special statistical evaluations, finally predictions can be made related to the future operation of vehicles as well as to the maintenance and repair activities. This requires, on the one hand, the measurement results of the diagnostic tests, and, on the other hand, the computer-calculated results related to the vehicle operational and vehicle system-dynamical simulations.

There are two kinds of predictions. One of them is based on the diagnostic measurement results related to the actual technical state of vehicles. By means of this prediction, it is possible to follow the change of certain measured characteristics (wear of flange, wear of the wheel tread, change in axle guidance stiffness) due to regular operation. Fitting a curve on the obtained numerical values predictions can be made for the expected change in the checked characteristics.

The other type of predictions requires results of a large-scale computer simulation related to the vehicle operation and vehicle system dynamics. It means that by using suitable dynamic models, the operation of vehicles having different parameters reflecting the actual technical-diagnostic state should be simulated in advance. By means of such a computer simulation, it is possible to define the motion of certain structural elements of the vehicles having different parameters, the forces acting on certain vehicle elements, the safety against derailment, etc.; in the course of simulations, the tracks can be considered with the given irregularities and running-dynamical characteristics (different track profiles and curvatures, maximum speed, etc.). In the dynamical model of the vehicles, the geometrical deviations (e. g. the skewness of wheelsets, etc.), the different wheel loads, the different characteristics of springs and dampers, further on the actual characteristics of the wheel wear can also be considered. With the knowledge of the process of forces and motion characteristics as a function of time, the rate of wear of certain vehicle components (e. g. the flanges) can be defined as a function of the given vehicle parameters. For example, it is possible to follow how a given vehicle runs along a given track having specified running-dynamical characteristics, meanwhile skewness φ_m of a wheelset has a given value (*Fig. 5*). By changing the given skewness value for each computer running ($\varphi = 0$, then φ_1, φ_2, φ_3, ..., φ_n), a data-row W_0, W_1, W_2, ..., W_n will be obtained related to the flange wear as a function of the wheelset skewness resulting in an empirical wear-skewness function $W = W(\varphi)$ belonging to a given vehicle and track. If in the course of the diagnostic test of a given vehicle, skewness φ_m of a wheelset is measured, then, on the one hand, by interpolating the empirical function $W(\varphi)$ obtained on the basis of the motion simulation results, the expected flange wear W_p can be defined belonging to the measured skewness φ_m, on the other hand, by comparing this wear value W_p with the wear W_0 obtained for an ideally-positioned wheelset ($\varphi_m = 0$), the expected wear surplus ratio q_p of the tested flange can also be defined. Such a previous computer simulation can be performed for many kinds of parameters, for geometrical deviations of the running-gear, etc., then by storing the computed results in a suitable data bank, various predictions can be made for the characteristics of the expected operation, safety service life, etc.

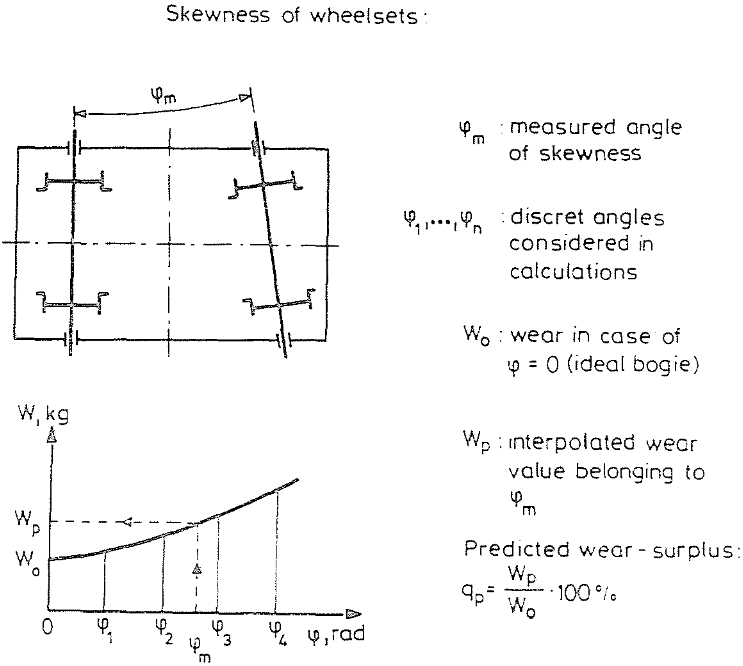

Fig. 5. Showness of wheelsets:
φ_m: measured angle of skewness
$\varphi_1, \ldots, \varphi_n$: discrete angles considered in calculations
W_0: wear in case of $\varphi = 0$ (ideal bogie)
W_p: interpolated wear value belonging to φ_m
predicted wear-surplus: $q_p = \frac{W_p}{W_0} \cdot 100\%$

6. Conclusions

In addition to the short introduction of the running-gear diagnostic principles, as well as the system of the developed diagnostic station, in conclusion the importance of the approach based on vehicle system dynamics should be emphasized. It means that the well-identified dynamical model of the vehicle to be tested is necessary for the diagnostic test of the vehicle in question, then the effects of failures revealed in the course of the diagnostic test should be evaluated from point of view of the consequences related to vehicle operation, by applying the parameter sensitivity of this model. Consequently, by using the actual parameter deviations revealed in the course of the diagnostic test, it can be predicted whether an unallowable change within a given period of the vehicle operation can be expected or not, in consequence of which the running-safety would decrease below a specified limit. So the further demands for the required maintenance activities can be analysed-planned (work costs, storage of components, etc.).

By performing the presented running-gear diagnostic procedures, on the one hand, the safety of vehicle operation will increase significantly, while on the other hand, the maintenance costs will decrease, because the operation based on the technical state of the vehice results in a significant reduction in operational costs.

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