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A FATIGUE TESTING IN COMPLEX STRESS STATE IN THE CONTEXT OF PROBLEMS IN THE DIAGNOSIS AND DETECTING DEFECTS IN MATERIALS OF WHEELS IN LOCOMOTIVES

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Abstract

This paper presents preliminary results of fatigue tests of selected construction materials, which have been exposed to the simultaneous operation of the bending and torsional loads at different mix of these loads. This kind of load generally applies to much responsible construction, especially of machinery for transport. For example, rail transport is one of the most popular measures, which uses different types of locomotives. However, it is no matter what sort of the type of railway vehicle it is, because in each there we can notice a multi-axis load driving axle wheel assemblies. During the technical inspection of these items, ultrasonic flaw detectors are used to detect damage in the material that arose during the exploitation, but are not visible during the external inspection. For this reason, there are many problems, that arise during the diagnostic process using ultrasonic flaw detectors, because it is not always possible to accurately detect the resulting or arising defect in the material axes, especially in some of the built-axes, which can be studied only from the front (on both sides of the mounting of bearings). Taking into account the safety and technical problems in rail transport, it is important to carry out fatigue tests of low- and high-cycles on samples subjected to multiaxial stress state. Initially, there were taken into account the lightweight aluminum (AlMg2Mn0.47Fe0.5) that have been repeatedly multiaxial charged at different percentage of bending and twisting. The results will be referenced to the occurrence of the bending and twisting, as well as to the results obtained with the simultaneous influence of corrosive conditions due to the attempt to make the best possible mapping of the prevailing conditions in which different structural elements must actually work. The load on the low cycle fatigue and high cycle fatigue were chosen after corrosion – stress testing on the same aluminum alloy. In addition, cases of multiaxial fatigue are not as described and explained in detail as the cases of uniaxial fatigue. In spite of this fact, it is necessary to create detailed criterions for multiaxial with low- and high-cycles load.

Keywords: *multiaxial fatigue, bending, twisting, low cycle load, high cycle load, axles of locomotives*

1. Introduction

Taking into account the safety of rail transport it should be considered a possible threat from technically selected rail vehicles used for passenger transport. The most characteristic elements of the wheelset axles are both locomotives and wagons. Despite the fact that accidents happen rarely, there are many examples describing such Axis fracture after a while during the ride. These types of problems cause considerable risk to the safety of employees and users of rail transport. One of the most loaded axle locomotives are driving axles, which are subjected to simultaneous bending and twisting (while driving – especially during acceleration and braking) and the same bending (when stationary). These types of loads have an effect on fatigue strength of the material of which the axis was made. The wheel assemblies are many elements that are subject to strain and wear and tear, but undoubtedly, the most responsible is the axis on which are mounted wheels, bearings and gears possible (some gear). You also have to deal with so-called: monoblocks. Another element of the design is built, so you do not have direct access to the axis. For this reason, diagnostic control is much more difficult, because any damage to the material you can try to detect the ultrasonic flaw detector only from the front axle.

Fig. 1. The dismantled axes from diesel shunting locomotives SM42

Naturally, it is possible to temporarily remove the building that covers the axle and the accession to the specific component of the verification process. On the other hand, many companies do not have ability allowing for total removal, and the rules also permit the examination of the axis only from the forehead. This creates many problems, because the flaw in this method may not always appear on the screen, such as micro-fracture, which later will develop and lead to complete destruction of the axis during operation. In order to eliminate or minimize such errors in reading are used, so called. Reference axes for which the diagnostician applies its performance in service-axis control. Any anomalies in the readings are then recorded and carried out a review of the material in order to determine whether an axis is suitable for detailed examination in the other a proper service or perhaps that discovery on the surface of the material.

2. Multiaxial fatigue of construction materials

Addition to the regular screening and reception it should be carried out also scientific research aimed at better understanding the phenomena occurring in materials for responsible industrial structures. One of the most important studies is fatigue tests. Fatigue tests are carried out strength of the structure, which are durability tests. These tests lead to the destruction of objects or subjects to achieve a fixed number of load cycles, for example, 10 million cycles. Fatigue tests allow you to specify the breaking of the whole structure and stability of its individual components, depending on the load. On the basis of the results it is assessed or insufficient supply of strength or node. This research is subjected to particular wagon bogie frame and the individual nodes axle's boxes, wagons and wheel sets. Evaluation of fatigue strength design typically relies on a comparison of the characteristics of fatigue strength, resistance to determine the structure subjected to varying loads, with the characteristics of the load, under which the action takes place in the evaluated structure fatigue damage accumulation. While the fatigue tests carried out on test rigs, which are equipped with hydraulic cylinders pulsators and to put the burden and the corresponding control systems.

Long-term operation with variable load pulsator is made possible by the hydraulic system, the device-containing stabilizers. Frequency changes in loads of 200–800 per minute. Studied the structure deflection caused by the pressure of hydraulic cylinders are generally not exceed a value of 10 mm. The modern position for fatigue tests have load control program stored according to the appropriate medium, which depict the spectrum of the actual loads or deflections occurring in the field [5, 6].

Given the nature of the load, i.e. the simultaneous bending and torsion axle low cycle fatigue tests were carried out construction of isotropic materials with different percentage of bending and twisting samples. Preliminary results were analyzed and presented in Tab. 1. Initially there was selected isotropic material made of aluminum alloy AlMg2Mn0, 47Fe0, 5 (5251). This material is not applied by the responsible structures or highly loaded axle, but on this basis, you can create an analogy to the materials used in industry for production, such as the axis of selected types of locomotives or wagons. In addition, over time you can go to study materials with increasing strength properties for various purposes in different conditions. The studies will be supplemented by the influence of corrosive environment on fatigue strength of test samples by using 3.5% NaCl. For comparison, as well as a full set of results will be carried out also high cycles fatigue test, especially since most of the materials, such as the purpose of construction of rail transport must survive at least several million cycles. This principle is achieved by artificial means many years of operating conditions selected materials. Laboratory test stand is presented in Fig. 2.

Tab. 1. Preliminary results of fatigue tests

The angle of the head	Type of loading	The value of the load [MPa]	Corrosive agent	Frequency [Hz]	Time [s]	Number of cycles
0°	Bending	40	—	—	—	—
0°	Bending	50	—	10.4	6698	70329
0°	Bending	60	—	11.2	2215	24808
~~30°~~/ 45° /~~60°~~	Bending + Torsion	40	—	—	—	—
~~30°~~/ 45° /~~60°~~	Bending + Torsion	50	—	11.1	3747	45135
~~30°~~/ 45° /~~60°~~	Bending + Torsion	60	—	12.2	1610	19642
90°	Torsion	40	—	—	—	—
90°	Torsion	50	—	—	—	—
90°	Torsion	60	—	—	—	—

Fig. 2. The laboratory fatigue testing of materials

The position of Fig. 1 allows you to perform fatigue tests in bending, torsion and bending and twisting at the same time with different share of the burden. The transition between bending and twisting is achieved by rotating the head stable, in which is attached to the test sample. When the head is set to 0 degrees, then it is only applied bending load, and at 90 degrees – turning. Intermediate settings, i.e. for example 30, 45, 60 degrees allows for simultaneous bending and twisting of the domination of one of these charges or the same level for samples. Quantities obtained cycles are recorded on a computer using special software and an electronic module that is connected to a movable arm with electrical strain gauges. Flywheel with mounted weights takes proper speed, which results are in the required load. To the flywheel is retrofitted arm, in which is set in vibration – the other side of the arm is inserted into the sample, on which directly affects the load.

In Fig. 3 there is shown a plot of the signal chosen from the time of test performed. The signal is expressed in mV unit and selected from the specifications and instructions for technical devices, which are stored depending on the size of the signal on the type and size of the load. The course of the received signal can keep track and control on the screen, so that with each successive attempt to check the reproducibility of the behaviour of the material. After successful attempt is made to calculate the number of cycles based on the selected frequency and the resulting time. This kind of research is very important for the industry, because in practice usually we meet complex states of stress, not only bending or twisting, especially when it comes to the various means of transport, where fatigue strength of the important mechanical elements has a big impact on safety during operation.

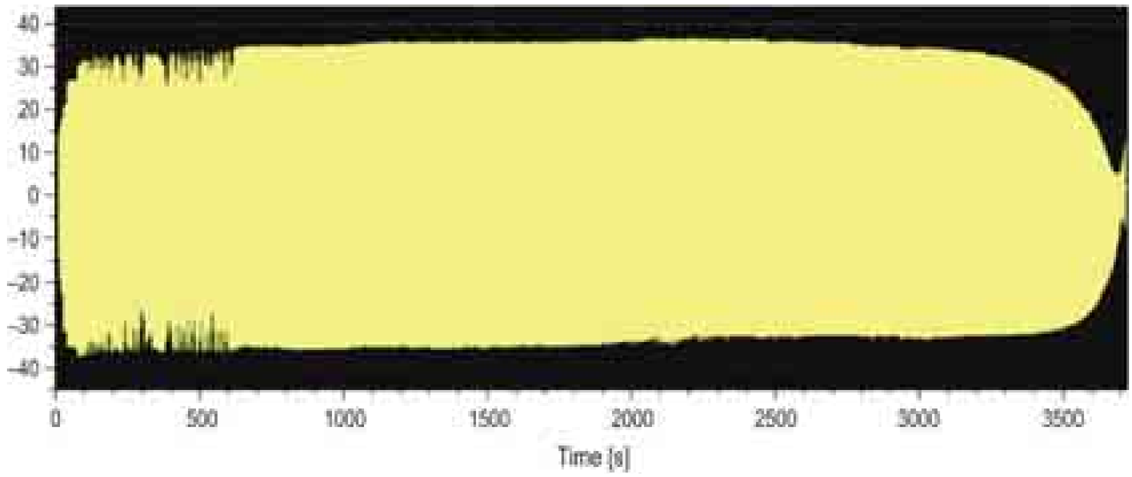

Fig. 3. A fragment of the computer record for a sample, subject to simultaneous bending and twisting

Tab. 2. Bending moments, torques, and replacement moments

Type of loading	The angle of the head	The value of the load [MPa]	Moment of bending M_g [Nm]	Moment of torsion M_s [Nm]	Replacement moment M_z [Nm]
Bending	0°	50	1.0517	—	—
		60	1.2941	—	—
Bending + Torsion	45°	50	—	—	1.0809
		60	—	—	1.2752
Torsion	90°	50	—	2.1249	—
		60	—	2.5403	—

On the basis of preliminary results of fatigue tests, we can see a large discrepancy in numbers between the values of load cycles 50 and 60 MPa for the bending and bending with torsion. But more important is the analysis used for specific loads and comparing them, which will predict the behaviour of the material for the next load in the form of, for example, the twisting or increase/ decrease in the share of bending while twisting effects (with the same values). Number of cycles, after which the sample is damaged significantly decreased with the equal participation of bending and twisting to the bending, i.e. 36% for 50 MPa and 21% for 60 MPa. To make a full analysis, as well as get answers on how to get the optimal way to charge the material to be able to move as many cycles to obtain results for the same test with the same twisting, because we cannot at this stage accurately predict the behaviour of the sample at the next types of loads. Of course you can in some way estimate probable results, taking into account various hypotheses or complex algorithms, but the results obtained experimentally best represent the true picture of material behaviour at different operating conditions, especially as the attempt will be repeated in a corrosive environment and at the same time be able to judge its real effect on the fatigue life of selected isotropic materials. It should also be noted that in every case there are bending and torsional moments, depending on the chosen load. In case of simultaneous bending and torsion there was used Huber's hypothesis, so we can find the so-called: replacement moment.

3. Analysis of defects in materials and present principal diagnostic methods for detecting damage to the diesel powered SM42 example

The axes are loaded vehicle weight. Railway wheelset consists of the axle and two wheels embedded. Wheelset axle loaded with vertical forces on the weight of the wagon and horizontal forces from the track through the rim and wheel discs, while driving turns and it is one of the most loaded parts of the wagon. The axis carries the whole weight on the weight of the wagon, wagon-guiding forces on the track, while doing the rotation. Axis dimensions are based on fatigue strength. That is why the axes are made from high quality material. Axis surface must be very smooth, without cracks and sharp edges, which reduce the fatigue strength and can cause cracking of the axis. Sometimes in order to improve the fatigue strength of axles are used in special technological procedures, such as surface hardening certain parts of the rolling axis, which causes tension in the area of the opposite sign than the stress levels while driving [3, 7].

Defects and damage to material axis is divided into two basic groups: metallurgical and created during the operation. The disadvantages of steel include:

a) shrinkage residue in the middle of the cross section,
b) internal crack in front of and under hub in the middle of cross-axis,
c) discontinuity,

The disadvantages include the following:

a) transverse surface cracks in the pivot,
b) cracks in the hub axle,
c) crack axis starting from the point located at the edge of the keyway,
d) crack axis at the cross-section changes,
e) other places (from scratches, pitting and other surface defects).

Non-destructive flaw detection testing for many years used in the railway as a method to detect in a timely hazardous material defects and defects that arise during the operation, and further their development has a significant impact on safety [1]. An example of a flaw with the control shown in Fig. 4.

You cannot always quickly identify harmful defects found, because it should focus on a number of comparative endurance tests. On the other hand, they are laborious and expensive, and therefore they have been developed with the relevant requirements and recommendations to deal with a faulty element (when using non-destructive testing). Usually the defective part is removed from further service for reasons of safety – even if the defect has not been fully tested and has not been established precisely its harmfulness. Currently in the early stages of the important and responsible part of the fleet are examined by ultrasonic methods, so you can minimize the risk of release to service the defective component and its removal, but also greatly save in this way on the costs of treatment. Another important aspect is emerging fatigue cracks over time that are developing in the variables of stress concentrations around defects caused not only by material defects but also occurring during operation, i.e. overloads, cuts, residual stress, etc. For this reason, periodic inspections of both conclude defectoscopic allow the occurrence of cracks and their

Fig. 4. Material flaw inspection of the front axle shunting locomotives SM42

propagation speed. Experiments and results of ultrasonic testing and the causes of these injuries are the basis for the development of requirements and acceptance criteria based on which we recommend replacing the damaged components [1].

4. Summary

Considering the seriousness of the problem, which relates to fatigue cracking multi-axially loaded elements by simultaneous bending and torsion, laboratory fatigue tests will evaluate the impact of loads on the strength of the analyzed materials, and the dependence of fatigue life test specimens from the corrosive environment and the extent to corrosive environment has an effect on fatigue life. Experimental studies have been adapted as possible to the actual conditions external to the responsibility of selected mechanical components, which are subject to complex stress states, such as during operation of locomotive axle. Despite the development of diagnostic methods, still there are problems associated with fatigue cracks, which have a major impact on the safety of people using different modes of transport.

References

[1] Bawolski, R., Chmiel, E., Skibka, C., Świderski, Z., *Defektoskopowe badanie elementów pojazdów szynowych*, Wydawnictwa Komunikacji i Łączności, Warszawa 1979.

[2] Gąsowski, W., *Wagony kolejowe – Konstrukcje i badania*, Wydawnictwa Komunikacji i Łączności, Warszawa 1988.

[3] Janiak, M., Kalinkowski, A., *Konstrukcja i eksploatacja wagonów kolejowych*, Wydawnictwa Komunikacji i Łączności, Warszawa 1979.

[4] Praca zbiorowa Autorów Czechosłowackich, Niemieckich, Polskich, Węgierskich, *Aluminium Poradnik*, Warszawa, PWN 1967.

[5] Sokołow, S. I. (red.) i in., *Badanie dynamiki i wytrzymałości wagonów pasażerskich*, Wydawnictwa Komunikacji i Łączności, Warszawa 1983.

[6] Gąsowski, W., Nowak, R., *Badania wagonów kolejowych*, Wydawnictwo Politechniki Poznańskiej, Poznań 1989.

[7] Kalinkowski, A., Orlik, A., *Wagony kolejowe i hamulce*, Wydawnictwa Komunikacji i Łączności, Warszawa 1981.