ISSN 1822-2951

KAUNAS UNIVERSITY OF TECHNOLOGY
LITHUANIAN ACADEMY OF SCIENCE
IFTOMM NATIONAL COMMITTEE OF LITHUANIA
BALTIC ASSOCIATION OF MECHANICAL ENGINEERING

MECHANIKA 2017

PROCEEDINGS OF THE 22nd INTERNATIONAL SCIENTIFIC CONFERENCE

19 May 2017
Kaunas University of Technology, Lithuania

KAUNAS – 2017

Assessment of Technical Condition of 2M62 Locomotive Bogie Frames and Bolsters using Acoustic Emission Method

Sergey BRATARCHUK
Riga Technical University, Faculty of Mechanical Engineering, Transport and Aeronautic, Latvia, LV1003, Riga, Lomonosova st.1, building V, E-mail: sergey.bratarchuk@gmail.com

1. Introduction

Acoustic Emission (AE) method is one of non-destructive testing methods. It is based on the effect of mostly ultrasonic sound emission, which occurs in process of crack propagation. The method implies recording these signals and using different wave and count parameters for assessing the condition of object. To apply AE method, it is necessary to define specific criteria for control of the physical processes, which are planned to assess using AE before applying the AE method in practice. The better AE method possibilities are gained when it is possible to test a healthily object to gain the picture of acoustic emission at all stages of the lifetime of this kind of objects. The basic elements of locomotives and freight cars casted elements work in the critical conditions of influence of dynamic and static loads. This is especially true of such elements as the bogie frame, bolster, and side frame axle bogies. The destruction of these elements can lead to dangerous consequences for people, the environment and infrastructure. The problem of fracture of cast parts bogie is not new to rail transport. Sources indicate that the most common causes of defects are poor drainage resulting from the casting gases, uneven cooling of the metal, the emergence of gas pores, cracks crystallization, increased moisture content of the molding sand and other technological problems [1], [2].

Since most of the system of the railways of Baltic States is integrated CIS countries, it is indicative of Railways statistics on the number of identified breaks in the side frames. According to RZD statistics on detection of cracks and breaks in the freight car bogies cast elements for 2012 and early 2013, the situation with breaks of the side frames, the current in the train sector, quite alarming. In this regard, the technical requirements CB-32-695-2006 were adopted. This document has been tightened requirements for culling products and methods of correcting defects [3]. Side frames produced in the Russian Federation, according to the head of department of strength of "VNIKTI" E.S. Oganyan, has a safety factor of 1.1-1.3, while in the US the safety factor when designing trolleys reaches 2,1 2.3 and tends to 3, which was confirmed by the Vice-President of the industrial Relations «Amsted Rail» Amin Terrence Patrick [3]. The service life of the side frames in the United States is 50 years, and cases of failure occur 1-2 times a year. For Russia, the period of service of the frame is 32 years, but "in fact" a mismatch with declared data is confirmed.

Shown example of problem is relevant to the wide range of countries with extensive railroad networks, such as Australia, India, Germany, USA etc. Damage and defects that can lead to serious breakdowns and catastrophic risks in today's high-speed transport. One of the known cases have occurred in the recent time was a disaster in 1998 on the railway line between Munich and Hamburg. Damage to one wheel of the car led to the chain reaction and the derailment of many cars [4]. Analysis of the incident revealed that the meant wheel has not passed the quality test during several inspections, and it was not replaced. After the collapse of all the wheels of similar design were replaced with preassembled mono block.

We may summarize that railway traffic safety depends on the ability of the cast cars bearing elements to withstand the loads encountered while driving cars. Cars' wreck cases are known due to low durability of bogies cast parts. This shows the relevance of the assessment and prediction of the resource carrying parts of bogies.

RESEARCH OBJECTIVES:

1. Assess the current technical condition of the bogie frames 2M62 freight locomotives and bolsters of two-axle bogies;
2. Identify the need for other methods of non-destructive testing by assessing the state of the objects of research by AE;
3. Extend assigned service life of locomotive bogie frames;
4. In cast constructions of bogies wagons with a resource that cannot extend: to check the quality of the factory production technology and compare with the design strength calculation;
5. Check the nature of the AE occurrence of emission intensity test during fatigue tests.

2. Experimental details

Bolster freight car bogies 118-100, made of 20FL steel by casting has variable thickness with a plurality of ribs and technological holes of irregular shape, ranging from part to part. They are characterized by defects in the casting of origin, whose influence on the durability of the parts can vary considerably depending on a number of additional production and operational factors. As is known, cast parts have a very low controllability for most NDT methods due to the high level of interference, resulting in the diagnosis of these objects.

Studies have shown that the use of the AE method can significantly improve the accuracy of control of parts of this class, since it is possible to detect defects of different nature. In M62 locomotives and part of 2M62 locomotives trucks are jaw type (previously installed in locomotives or 2TE10L TEM2). Design is welded-cast with CT3 material. The sides and the middle transverse beams are welded, box-section. Vertical load on the body is transferred directly to the sidewall of a bogie frame by four supports. Horizontal force (traction, brake, inertia) are transmitted through the pin at the center of the truck. Pivot pin assembly design allows the angular rotation of the trolley. Support (support-return device) body - combined (sliding and rolling). Single stage spring suspension through six sets of coil springs with rubber shock absorbers on the three (3) on each side and two (2) spring, the static deflection of which - 77 mm

OBJECTS OF ASSESSMENT:

1. Carriage number 166 (1982 year of manufacturing) total mileage from the time of manufacture - 1,516,761 km. Renovated TR-3 (current repair), the term of bogie service was extended until April 2021.
2. Carriage number 184 (1970 year of manufacturing) total mileage from the time of manufacture - 1,149,520 km. Renovated TR-3 (current repair), bogie service life has been extended until April 2015 (before write-off).

Note: The deadline for service as locomotive 2M62, and its trucks, defined in 45 years.

AE EQUIPMENT USED FOR TESTING:

The unit of acoustic emission registration is multichannel modular system of AE data acquisition and processing with high-speed digital serial data link Lel / A-Line 32 DDM.

All processing of the received information and the calculation of AE parameters is carried out directly on the module, located on the control site; the transfer of the processed data is in digital form, provided by the galvanic isolation of each module. Used software is implemented in a Windows environment. The tests used data acquisition module (with built-in magnetic holder). Acoustic Emission Transducers: acoustic emission GT200 resonance type converters with operating frequency of 165 kHz and bandwidth of 130 kHz ÷ 200 were used.

STATIC BOGIE FRAME TEST PROGRAM ON THE STAND AND ON THE LOCOMOTIVE

Test programs on the stand and on-the locomotive selected identically. The difference - in the extreme force: on the stand, it exceeds the maximum operating weight of the body of the locomotive is 10%. The locomotive is fitted to the depot to four power jacks, which are designed for lifting locomotive body. Measured compression springs with the full weight of 100% workload (Fig. 1).

Fig. 1 Measurement of spring preload to calculate the loads

For data collection GT-200 AE piezoelectric transducers of A-Line system 32 DDM were arranged in such way: three sensors on a trolley, along the outer edge of the top sheet of the lateral beam of bogie frames as it shown in Fig. 2 and Fig. 3.

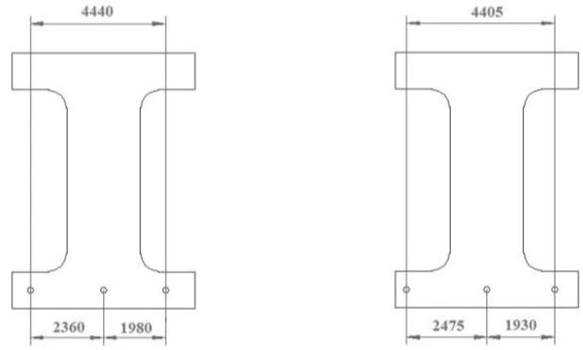

Fig. 2 The alignment of Lel / A-Line 32 DDM control system sensors on the locomotive bogies frames (dots)

Fig. 3 Control sensors attachment on the bogie frame of the locomotive

The whole system of six modules connected in a line. Initial discrimination thresholds are set to 35dB. Further, the calibration performed by the method of Su-Nielsen (breaking of a graphite pencil lead diameter 0.5 mm hardness HB) to select the gain [5] As a result of the calibration, coefficients of gain modules are set to 40 dB.

Body rose to complete unloading of trucks and the spring compression at zero load was measured. Compression measured at 25% of workload. Next, it was switched on the A-Line 32 DDM AE system and produced cyclic loading body of carts by the weight of the locomotive on the program shown in Fig. 4.

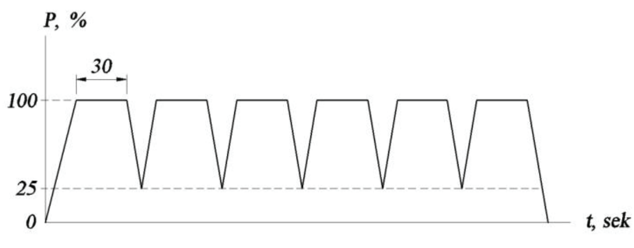

Fig. 4 The program of statically repeated loading

Loading program included the registration of "non-repeatable AE" effect or "Kaiser Effect" described in the 1st chapter, the characteristic behavior of acoustic emission in the absence of defects (cracks) in the material under repeated loading.

Fig. 5 shows a picture of the actual combination of the load during the test trucks with the registration of AE signals from all sensors digital AE control system. Clearly shows no significant AE during hold under 100% load, which allows to conclude that there are no defects in the design of 2M62 locomotive bogie frames.

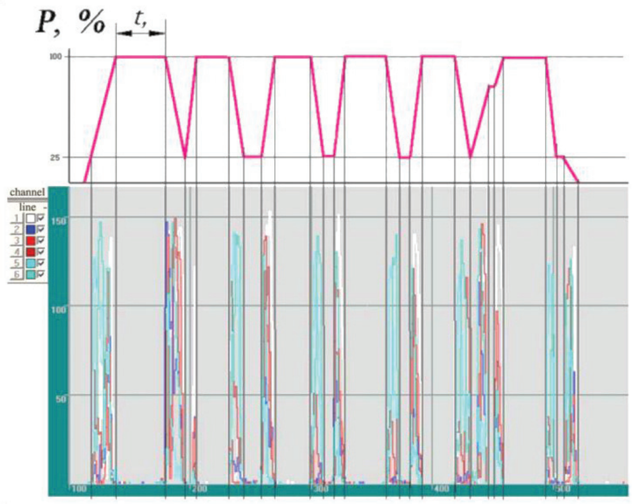

Fig. 5 The intensity of 6-channel AE registration at cart loading

FATIGUE FRAMES AND BOLSTERS TEST PROGRAM ON THE STAND

For the fatigue loading it was made a special stand to simulate the performance of variable loads acting on the bogie frame

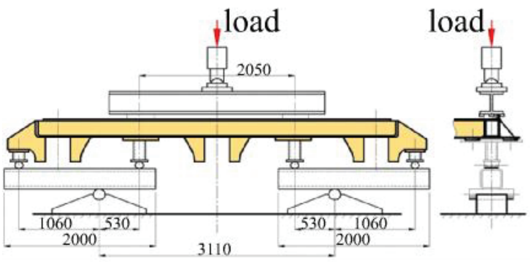

Fig. 6 Stand for fatigue testing of the bogie frame

The program included a sinusoidal variable loading of constant sign as shown in Fig. 7. At 8 Hz, amplitude sweep ΔP=25 t and static load component P_{static} = 30 t.

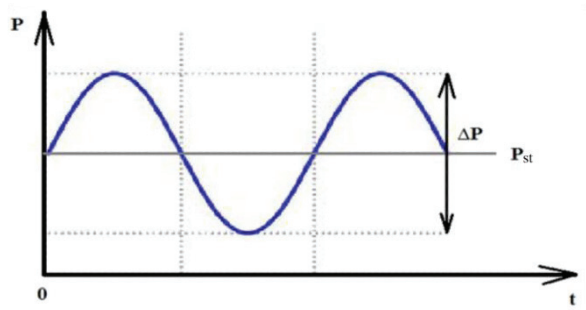

Fig. 7 Bogie frame loading program

Fatigue bogie frame tests were carried out under this program. With an operating time of approximately 5 x 106 cycles when the fatigue crack has not yet been noticed visually, the bogie frame test structure was modified through a step-by-step introduction of the cut concentrator in one of the power units of the frame supports as shown in Fig. 8. It has been made for the early appearance of a fatigue crack.

Fig. 8 Cuts concentrators corresponding to the first stage of loading

From this moment on the test carried out in four stages. The first stage was carried out in a number of concentrators cuts in gussets and at the base of the power unit support frame. In the second phase concentrator cuts in power unit support gussets added. In the third stage of the power unit support gussets were cut off. In the fourth stage, it was performed cut in the corner area of the power unit support.

Fig. 9 shows the sequence of operations for making the cuts concentrators in the power bearing hub

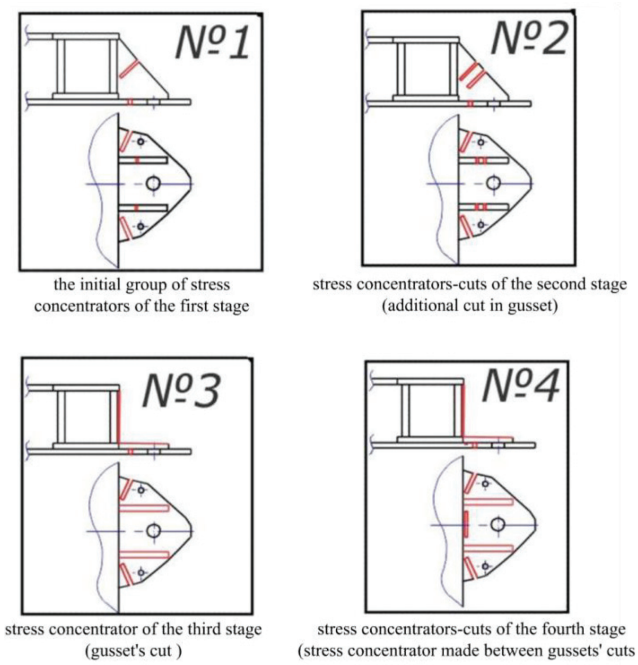

Fig. 9 The stepwise introduction of cuts-concentrators in bogie frame support assembly

In the fourth step of loading at the bottom of the power unit support has been destroyed. At this point, the node has worked only 6 seconds, which corresponds to 48 cycles. Analysis of fracture showed that the fatigue crack really began at the base of concentrator section, which was confirmed by the method of the AE.

THE BOLSTERS TEST PROGRAM:

The test program was the same as for the bogies frame. Bolster tested under the three-point variable cyclic-bending constant-sign scheme with the frequency of the load 8 Hz, amplitude ΔP=12.5 t (Fig 10).

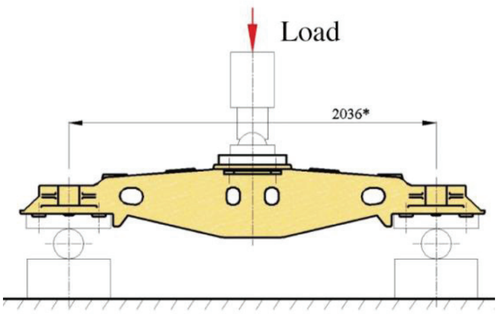

Fig. 10 Scheme of bolster cyclic loading

THE RESULTS OF THE AE CONTROL OF DYNAMICS OF FATIGUE CRACK GROWTH IN THE FRAME OF THE BOGIE:

As mentioned, fatigue tests of the bogie frame began without artificial stress concentrators and led until the operating time of approximately 5 x 10^6 cycles. After that, the test scenario was changed as neither by visual method nor by AE method, the beginning of destruction was not observed. Beyond that, the cuts were made in one of the power unit's support and the test was conducted until the loss of carrying capacity.

Since its introduction of the first series of cuts the character of the plots of sum of AE and its intensity changed. Figs. 13, 14 show dependency of sum and the intensity of the AE over time since the start of the test in the presence of concentrators until fracture of the frame near cuts (Figs. 11, 12).

Fig. 11 The final break in the concentrator cutting zone at the base of the corner bearing bogie frame

At the Fig.15 it is seen that when the stand being operational during the 1100-1200 seconds with initially introduced cuts, the AE intensity began to grow sharply, pointing out that there began to form fatigue cracks in the area of the 2nd sensor near concentrators. In this mode, the test lasted for 80,000 second more. Periodic visual inspection did not find anything similar to the appearance of fatigue cracks. However, when the cumulative AE graph was identified with the fracture failure morphology, it was found that the moment α_1 of cumulative AE steep rise corresponds to the appearance of fatigue cracks, and the moment α_2 - to the early macrocracks emergence and growth.

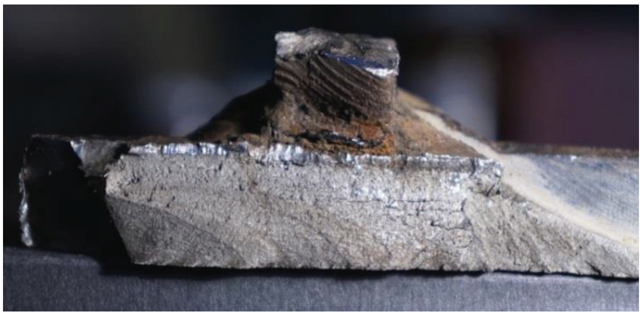

Fig. 12 Fracture relief, where the growth of a fatigue crack began

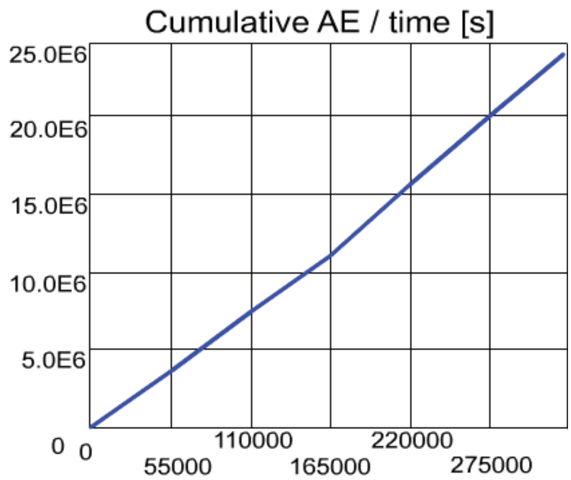

Fig. 13 Graph of change of cumulative AE during bogie frame cyclic loading until failure

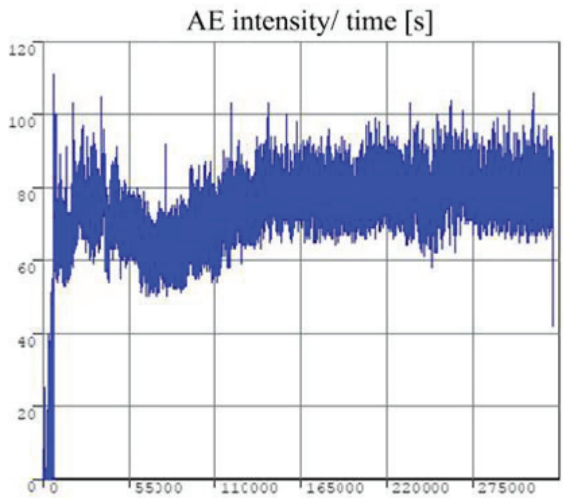

Fig. 14 Graph of change of AE intensity during bogie frame cyclic loading until failure

It is evident from the fracture morphology corresponding to the 1st stage of destruction with one group of cuts. Fig. 16 shows cumulative AE change at all stages of loading with series of cuts insertion. Same figure also shows the stepwise identification of fracture morphology with a total AE, as well as the scheme of step-by-step introduction of concentrators.

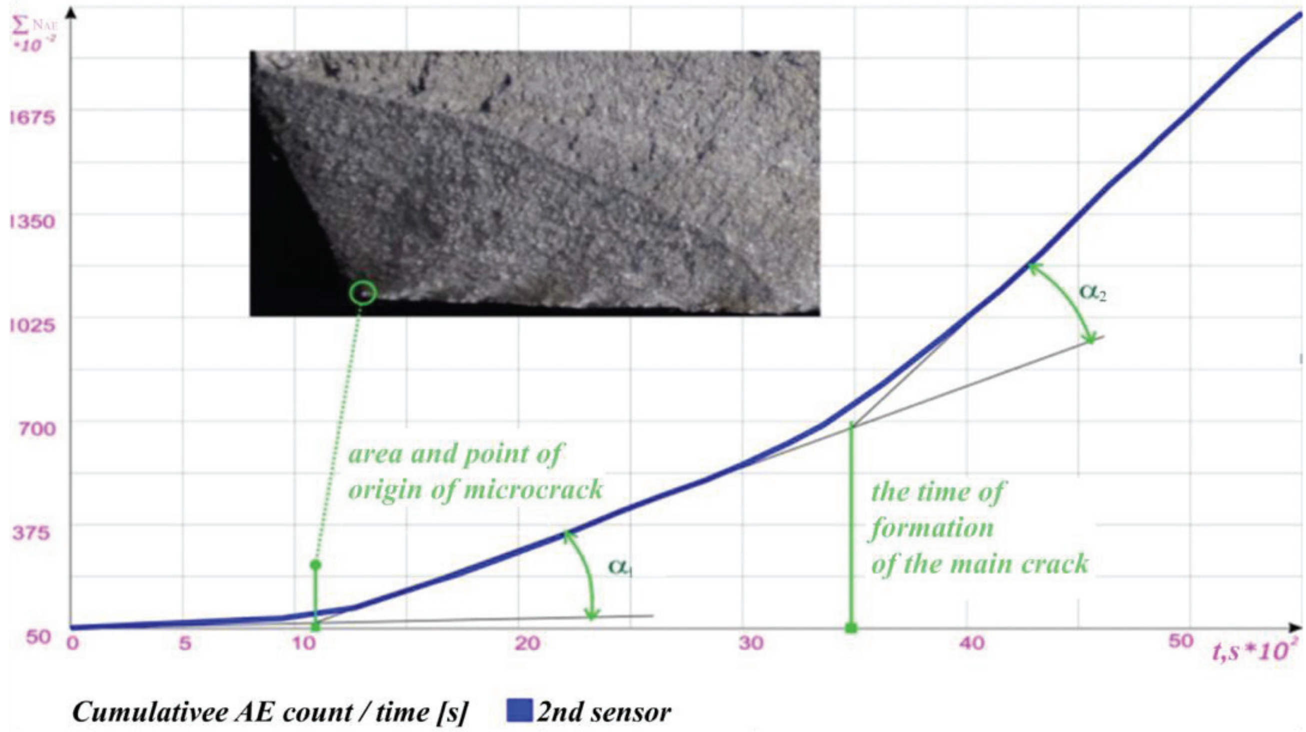

Fig. 15 The dependence of the amount of AE on loading from the moment of the first group of hubs and the morphology of the fracture at this point

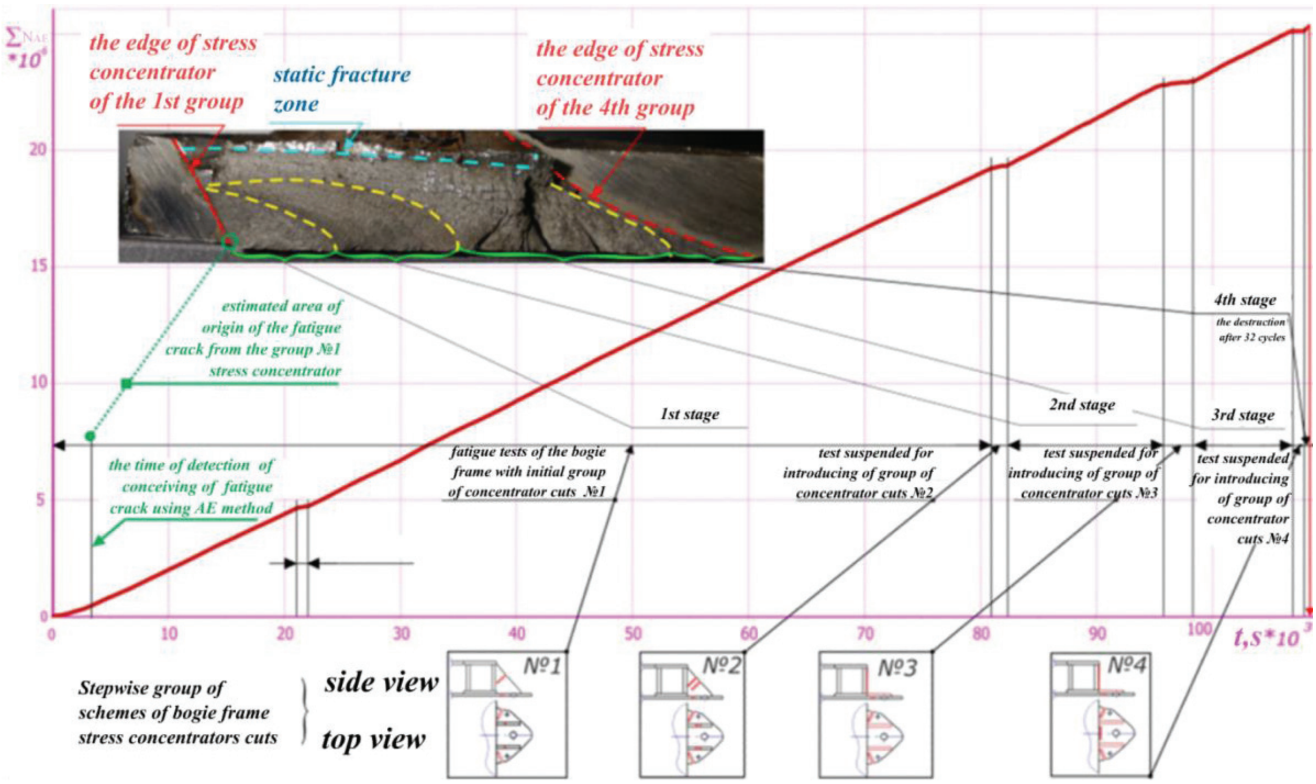

Fig. 16 Staged identification of fracture morphology on the fatigue crack and a plot of cumulative AE

As can be seen the entire frame testing lasted approximately 120,000 seconds process before the destruction, which corresponds to approximately one million load cycles. Analysis of the amount and intensity of AE shows that the lifetime of the frame assembly, where concentrators were incrementally introducing is about 970,000 cycles. This suggests a large operational reliability of the bogie frame in working conditions presence of a concentrator.

RESULTS AND ANALYSIS OF TESTS OF THE BOLSTERS:

The variation of AE parameters depending on time under bolster cyclic loading to failure under the program. It is evident that a fast grow in the cumulative AE appeared which is the point of $\alpha_{criterion}$. The intensity of AE increased sharply at the time of the relevant operating time of 48,000 cycles. This AE behavior is characterized by the fact that at the time of abrupt changes of AE parameters, a fatigue crack appeared (Fig 17).

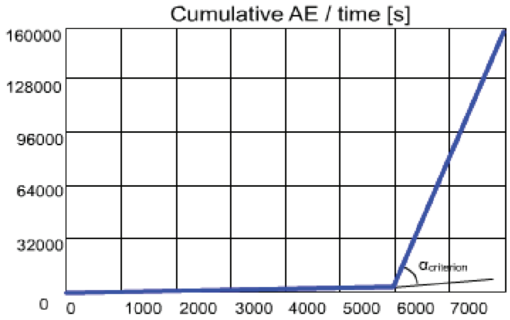

Fig. 17 Graphs of change of cumulative AE at the stage of occurrence of fatigue crack in the bolster under cyclic loading

3. Conclusions

The problem of determining the state of cast parts bogie successfully solved by AE method. Thus AE method allowed to determine the occurrence of fatigue cracks much earlier than the visually optically. Tests showed descriptiveness of AE dynamic criterion (α-angle of cumulative AE graph) in the problem of determining of the stage of damage during fatigue tests of bogie frames and bolsters.

The experiment shown the variation of AE parameters depending on time under bolster cyclic loading to failure. It is evident that a fast grow in the cumulative AE appeared which is the point of α. The intensity of AE increased sharply at the time of the relevant operating time of 48,000 cycles. This AE behavior is characterized by the fact that at the time of abrupt changes of AE parameters, a fatigue crack appeared. The problem of determining the state of cast parts bogie successfully solved by AE method. Thus AE method allowed to determine the occurrence of fatigue cracks much earlier than the visually optically. Tests showed descriptiveness of AE dynamic criterion in the problem of determining of the stage of damage during fatigue tests of bogie frames and bolsters. It was concluded that in some cases of "fingerprinting" healthily objects are also possible to speed-up occurrence of cracks by introducing concentrators into the design.

A new approach to speed-up the healthily object AE-imaging was proposed and successfully used. It is possible drastic acceleration of fatigue test AE-session recording by introducing artificial cut concentrators. This approach was agreed upon depot quality service and allowed recording the full bogie frame lifetime AE intensity development process without exceeding the available testing time limit. Despite the object of testing has been modified with introducing cuts during test to run up the time of testing, this does not bias the conclusion of *possible* lifetime of tested object in the expression of loading cycles, it cuts weren't introduced.

References

1. Identifying Casting Defects, American Foundry Society [online] AFS [accessed 28 Febr 2017] Available from Internet: http://www.afsinc.org/content.cfm?ItemNumber=6944.
2. **Rajkolhe Rajesh, Khan J.G, Defects,** Causes and Their Remedies in Casting Process: A Review, International Journal of Research in Advent Technology, Vol.2, No.3, March 2014.
3. **Savchuk V, Zobog G**, Side frames of freight cars Failure analysis, "Technology of railways" 2nd vol (22), May 2014
4. **Zoroufi M, Dr**. 5 Disasters Caused by Material Fatigue and What We Learned From Them", [online] Element.com, 10/06/2016, [accessed 28 Febr 2017] https://www.element.com/nucleus/2016/06/10/5-disasters-caused-by-material-fatigue-and-what-we-learned-from-them.
5. **Vallen, H**., 2002. AE Testing. Fundamentals, Equipment, Applications. Munich: Vallen-Systeme Gmbh

S. Bratarchuk

ASSESSMENT OF TECHNICAL CONDITION OF 2M62 LOCOMOTIVE BOGIE FRAMES AND BOLSTERS USING ACOUSTIC EMISSION METHOD

S u m m a r y

The non-destructive testing AE method is used widely in the field of transportation. This paper presents a case study of the elements of locomotives. This paper shows the possibility of using the intensity of the appearance of the AE as criterion in assessment of locomotive bogie frames and bolsters. The research has confirmed possibility of use of dynamic AE criterion for bolsters and bogie frames technical state assessment.

Keywords: Acoustic Emission, Non-destructive testing, bolsters, bogie frames, alfa-criterion.