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REPAIRING OF BROKEN LAMINATED SPRINGS OF FREIGHT WAGONS BY WELDING

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Abstract *– The task of this paper is to explore the possibility of repairing broken laminated springs of freight wagons by welding. Previous studies have shown that fractures of laminated springs are very common, especially for freight wagons used in extreme operating conditions. One of the most economical ways to solve this problem is reparation by welding of the fractured leafs. In that case the question about the behaviours and characteristics of repaired laminated springs rises. The approach in this paper is based comparative experimental testing of repaired laminated springs and new laminated springs. The main aim is to determine the influence of welded leafs on the behaviours and characteristics of repaired laminated springs. The applied methodology is based on static and dynamic tests. The obtained results have shown that welding of leafs does not significantly affect behaviour and characteristics of repaired laminated springs. During the fatigue tests, the fracture in the heat affected zone of welded connection is not registered. As expected, the results also have shown that life-cycle of repaired laminated springs is slightly lower with regard to the new laminated springs. The final conclusion is that welding can be possible solution for reparation of broken laminated springs.*

Keywords – Repairing, broken, laminated springs, freight wagons, welding.

1. INTRODUCTION

The one of the main ways to increase the competitiveness of railway compared to other modes of transport is reducing of the maintenance costs. The failures on railway do not happen often, but when it happens, the consequence is usually derailment accompanied with enormous material damage and losses of human life. In addition, there is huge material loss caused by the interruption of the traffic and reparation of the infrastructure. In the process of resolving of failure consequences on the railway vehicles, two approaches can be applied. The first approach involves replacing the damaged element (subassembly or assembly) with the completely new element. The second approach involves repairing the damaged element and its restoring into the appropriate function in the vehicle. It should be noted that repair is not possible for some damaged elements of railway vehicles (e.g. broken axles or wheels), but for many parts it is an extraordinary way for an enormous reduction in maintenance costs. Of course, the quality of repaired elements must be satisfactory, and their reliability should be at least approximate to the reliability of completely new elements, in order to make this approach techno-economically justifiable.

One of the most important subassembly of each railway vehicle is suspension system. The problems of the suspension system have always been among the central problems in the field of railway engineering. They have been widely analyzed in the large number of literature, scientific publications and professional papers. The main objective of all these research is to identify the behavior and design of the suspension system with the aim of improving the existing performance [1]. The quality of suspension system is one of the most important parameters which determine the reliability, quiet running and running safety of railway vehicles. The fault of suspension system is very important topic that is the subject of many scientific papers [2, 3]. The aim of all these research was to indicate the potential problems and to give the motivation for improvements in existing or newly-designed solutions of suspension systems.

The fractures in the suspension system are very often, especially at freight wagons operating in extreme operating conditions. The suspension system

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of such wagons is usually based on the laminated springs. In most cases there is a failure of main leaf, and the problem is usually solved by replacing the entire laminated spring with completely new, or by changing the broken leaf with completely new leaf. As one of the best solutions to reduce the costs of maintenance, the welding of the fractured leafs is considered. This is a very complex issue as it is well known that spring steels are not suitable for welding. Also, the additional problem is experimental testing and proving the behaviours and characteristics of such repaired laminated springs. This is the motivation for the research presented in this paper. The study was conducted on the laminated springs of Fbd wagons used in railway transportation of coal from mining basin ''Kolubara'' to the thermal power plant ''Nikola Tesla'' in Obrenovac, Serbia. The transport of coal for many years is performed with about 400 Fbd wagons, made in Wagon factory Kraljevo (Serbia).

2. PROBLEM DEFINITION

The four-axled wagon Fbd consists of two two-axle units that are interconnected by joint connection. The gross wagon tonnage is 80 tons, and its purpose is to transport of coal. The wagon is primarily designed and adapted for efficient loading in the mining basin and unloading in the thermal power plant. For this reason, the design of wagon has specific solutions of body, underframe, and mechanisms for unloading. Numerous mechanisms for opening and closing the door in the floor have reduced the space for placing of elements of suspension system. Because of these specifics, the design of suspension system which is based on the laminated spring departs from the standard design solutions. Reducing the length of the laminated spring in relation to the standard solutions and very intense loadings in exploitation caused the increasing of stresses of elements of the suspension system. The steel limiter is fixed for the underframe of wagon and has the task to limit the stroke of laminated spring (Fig. 1).

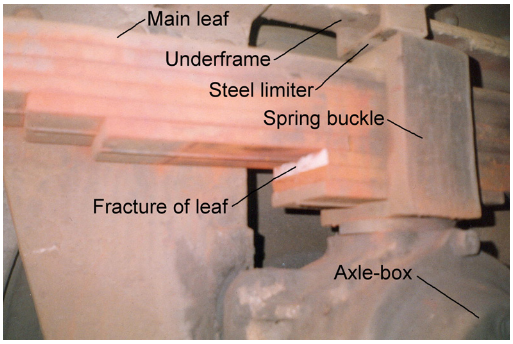

Fig.1. The example of laminated spring fracture

In extreme operating conditions at maximum loads there are intense dynamic rigid impacts of spring buckle in the steel limiter which is very unfavorable for the suspension system and the underframe of wagon. As a result there were very frequent fractures of elements of suspension system and cracks on the underframe. Statistical analysis shows that among the most dominant failures of the suspension system are fractures of elements of laminated springs [4]. Among them, the most common are fractures of leafs (as shown in Fig. 2), and especially of main leafs. The frequent fractures of leafs caused derailments in many cases [5]. The consequences were huge material damage and significant decreasing the efficiency of railway transportation of coal from mining basin to the thermal power plant.

The problem of fractures of laminated springs is usually solved by replacing the entire laminated spring with completely new, or by changing the broken leaf with completely new leaf. Because of frequent fractures, this required a huge funds for the maintenance and purchase of new leafs and laminated springs, which caused decreasing the efficiency and profitability of rail transport of coal. Research of these problems leads to the aim to reduce the enormous costs of maintenance of wagons and it is realized in two directions. The first direction was implied improving the suspension system through subsequently installation of rubber elastic element. This element is very easy to install in all existing wagons, between the laminated spring buckle and underframe [4]. The second direction was implied exploring the possibility for repairing the laminated springs by welding of fractured leafs. That is the topic of this paper, and its main task is to explore the influence of welded leafs on the behaviours and characteristics of repaired laminated springs.

3. EXPERIMENTAL RESEARCH

The basic idea of repairing of damaged laminated spring implies that its broken leaf is welded in the place of fracture, with the aim of preservation of overall designed geometry and function (Fig. 1).

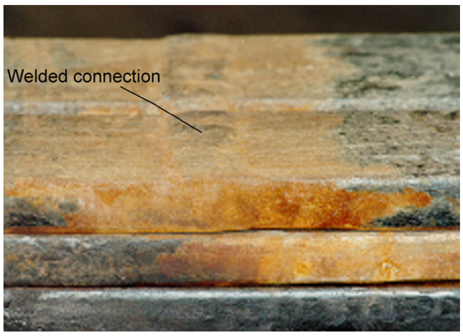

Fig.1. The welded connection of the main leaf

Research related to welding technology is realized by the company "Termoelektro" in Belgrade, Serbia. The technology is intellectual property of mentioned company, and it is not the focus of this paper. The main segments of welding technology are related to the physical, chemical, metallurgical and technological aspects of welding of broken leaf. The technology prescribes the election of welding electrodes, procedure for disassembling of laminated spring, preparation of surfaces for welding, procedure of welding, etc. Based on the projected welding technology, two characteristic laminated springs with fractured leafs in factories "Gibnjara" in Kraljevo and "Želvoz" in Smederevo, Serbia, are repaired. In the aim to explore their behaviors and characteristics, these laminated springs are subjected to the experimental tests.

The experimental tests were performed on pulsator, to the fracture of laminated springs, with prescribed amplitudes and frequency. For this purpose, the test stand for dynamic testing of production "MTS" was used (Fig. 3).

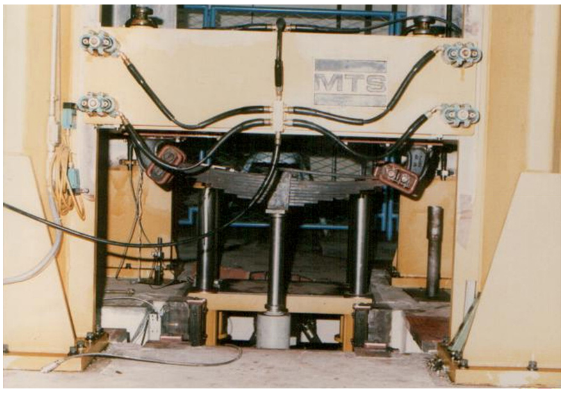

Fig.3. The dynamic testing of laminated springs on the test stand of MTS production

The comparative tests were performed on the following laminated springs:

- previously damaged laminated spring with welded main leaf repaired in a factory "Želvoz" in Smederevo (laminated spring 1),
- previously damaged laminated spring with welded main leaf repaired in a factory "Gibnjara" in Kraljevo (laminated spring 2),
- completely new laminated spring that is not welded (laminated spring 3).

Laminated springs with welded leafs (laminated spring 1 and laminated spring 2) were repaired in according to the prescribed welding technology from Chapter 3. The testing program is designed in accordance with applicable international UIC standards for testing the static and dynamic strength of springs. It included the following tests:

- testing the geometric accuracy,
- identification of static characteristics,
- dinamic fatigue testing to the fracture.

The number of cycles and the amplitudes of deflection of laminated springs are defined in the regulations, and are presented in Tab. 1. The frequency of change of deflection amplitudes is defined in the regulations, and is equal 2 Hz. In dynamic tests, it was necessary to define the static load of laminated spring around which the amplitude of the deflection oscillates.

Tab. 1. The prescribed number of cycles and the amplitude of deflection

Test	Num. of cycles	Amplitude of defl. [mm]
1	260000	12
2	1500	30
3	93000	15
4	2200	27
5	37000	18
6	6300	24
7	18500	21

Taking into account the gross wagon tonnage of 80 t, and subtracting the non-suspended mass of four wheelsets of approximately 6 t, the static load per one laminated spring should be about 9.25 t. However, the static load per one laminated spring was determined from the data of exploitation [5] and is Q_{st}=103 kN, which is about 10.3 t. This value is significantly higher (about 10 %) than the designed static load of one laminated spring with a fully laden wagon. Overloading of laminated springs during the exploitation is caused by uneven distribution of load on the wheels during the filling of wagons with coal. Given in mind the increased static load of 103 kN, it can be expected to obtain a lower life-cycle for all three tested laminated springs, compared to the values given in Table 1. In addition, the amplitude is also increased in relation to the prescribed. The aim of research in this phase was primarily to lead laminated springs to the fracture, and to determine if the fracture occurs in the heat affected zone of welded connection. Thus, the dynamic tests were performed with the static load of 103 kN and the amplitude 15 mm, with the frequency of 2 Hz.

4. RESULTS

In the first step, according to the prescribed testing program, the geometric accuracy of all three laminated springs was tested. It is concluded that it is within the prescribed limits. In the second step, the static characteristics of laminated springs 1, 2, and 3 were tested. It is concluded that deviation of static characteristics of laminated springs with welded leafs (laminated springs 1 and 2) from the static characteristic of not welded laminated spring 3, is less than 1%. Of course, a similar deviation should be obtained in the case of all three laminated springs whose leafs are not welded. Based on that, it can be concluded that all three tested laminated springs have almost identically static characteristic. The diagram of static characteristic of laminated springs is shown in Fig. 4. The results obtained by the experimental fatigue tests of laminated springs are shown in Tab. 2.

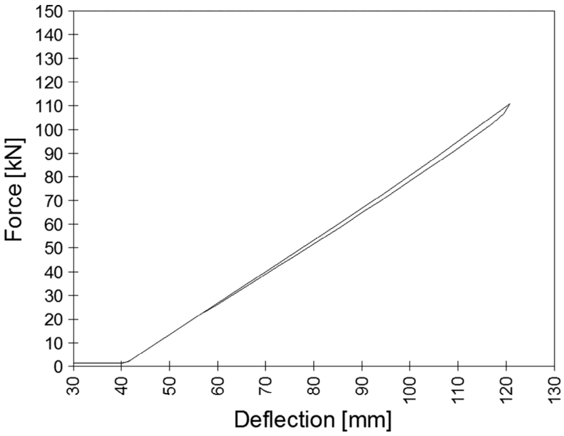

Fig. 4. The static characteristic of laminated springs

Tab. 2. The number of cycles until the fractures

Lam. spring	Num. of cycles	Remark
1	161820	Fracture of main leaf
2	92820	Fracture of third and fourth spring leafs viewed from below
3	216240	Fracture of main leaf

In the case of laminated spring 1, 161820 cycles were achieved to the occurrence of fracture of main leaf. In the case of laminated spring 2, 92820 cycles were achieved to the occurrence of fracture of third and fourth leafs viewed from below. At the end, in the case of laminated spring 3, 216240 cycles were achieved to the occurrence of fracture of main leaf. In experimental tests of both laminated springs with welded leafs it was concluded that fracture did not occurred in the zone of welded connection or heat affected zone. These extremely important results are shown in Figs. 5 and 6.

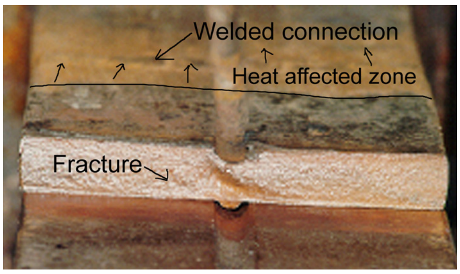

Fig. 5. The fracture of laminated spring 1

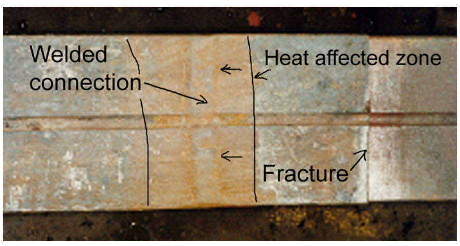

Fig. 6. The fracture of laminated spring 2

As expected, it was concluded that in these fatigue tests have not reached the expected lifetime of the laminated springs. The reasons for this lie primarily in the inadequate quality of embedded material, as well as in the increasing of static stress during the exploitation and in the aforementioned experimental tests. Poor quality of material is caused by the presence of chemical impurities, as already noted in previous researches [5], with the aim of solving the problem of frequent failure on the suspension system of Fbd wagons.

5. CONCLUSION

It can be concluded that welding can be possible solution for reparation of broken laminated springs. Repairing of broken leafs of damaged laminated springs by welding can allow to restore these laminated springs into exploitation. The welding does not affect the behaviours and characteristics of laminated springs. More precisely, behaviours and characteristics of repaired laminated springs almost completely satisfy the demands of the design and exploitation. Of course, in this statement should be taken into account that these laminated springs are already used and that their life-cycle is slightly lower compared to the completely new laminated springs. Therefore, in consideration of application of this solution in practice, it is necessary to conduct techno-economic analysis of its feasibility in specific case. However, practical application of this solution in Fbd wagons for coal transportation in thermal power plant "Nikola Tesla" in Obrenovac, Serbia, has enabled the enormous reduction of costs of maintenance of these wagons. This has enormously increased the efficiency of railway transportation of coal from mining basin to the thermal power plant.

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REFERENCES

[1] Garg V K, Dukkipati R V. *Dynamics of Railway Vehicle Systems*. New York: Academic Press, 1984.

[2] Huichuan Fan, Xiukun Wei, Limin Jia, Yong Qin. *Fault detection of railway vehicle suspension systems*. Computer Science and Education (ICCSE), 5th Int. Conference on Computer Science and Education, 2010, 1264–1269.

[3] Hayashi Yusuke, Tsunashima Hitoshi, Marumo Yoshitaka. *Fault Detection of Railway Vehicle Suspension Systems Using Multiple-Model Approach*. Journal of Mechanical Systems for Transportation and Logistics, 2008, Vol. 1, Iss. 1, 88–99.

[4] Petrović D, Bižić M. *Improvement of suspension system of Fbd wagons for coal transportation*. Engineering Failure Analysis, 2012, Volume 25: 89 – 96.

[5] *Identification of the causes of the fractures of main leafs of laminated springs on the Fbd wagon*. Study, Test Center of Wagon Factory Kraljevo; 1983. [in Serbian]