Mechanics Transport Communications

ISSN 1312-3823 (print)
ISSN 2367-6620 (online)
volume 16, issue 3/3, 2018

Academic journal http://www.mtc-aj.com article № 1692

RESEARCH OF THE POSSIBILITY OF REPAIRING BROKEN LAMINATED SPRINGS OF FREIGHT WAGONS BY WELDING

Dragan Petrović, Milan Bižić
petrovic.d@mfkv.kg.ac.rs, bizic.m@mfkv.kg.ac.rs

University of Kragujevac, Faculty of Mechanical and Civil Engineering in Kraljevo, Dositejeva 19, 36000 Kraljevo, SERBIA

Key words: *Repairing, Broken, Laminated springs, Freight wagons, Welding.*

Abstract: *The task of this paper is to explore the possibility of repairing broken laminated springs (LS) of railway wagons by welding. The fractures of LS are very common, especially for freight wagons used in extreme operating conditions. One of the 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 LS rises. The approach in this paper is based on comparative experimental testing of repaired LS and new LS. The aim is to determine the effect of welded leafs on the behaviours and characteristics of repaired LS. The obtained results have shown that welding does not significantly affect behaviour and characteristics of repaired LS. During the fatigue tests, the fracture in the heat affected zone of welded connection is not registered. The results have shown that life-cycle of repaired LS is slightly lower with regard to new LS. The final conclusion is that welding can be possible solution for reparation of broken LS.*

1. INTRODUCTION

The design and reliability of wheelsets and suspension systems of railway vehicles has previously been the subject of many scientific papers, including those concerning the detection of faults [1–8] and analysis of failures [9-13]. 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 and railway accidents, such as derailment [14-26]. The suspension system of such wagons is usually based on LS. In most cases there is a failure of main leaf, and the problem is usually solved by replacing the entire LS with completely new, or by changing the broken leaf with completely new leaf. This requires a huge funds for the maintenance and purchase of new leafs and LS. This problem is very actual and it is one of the most important research topics in this field. As one of the best solutions, the welding of the fractured leafs is considered. This issue is very frequent in engineering and scientific circles. 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 LS. This is the motivation for the research presented in this paper. The study was conducted on LS of Fbd wagons used in railway transportation of coal from mining basin “Kolubara” to the thermal power plant “Nikola Tesla” in Obrenovac, Serbia. This line has the characteristics of the railway line of first order, and consists of about 100 kilometers of track. It is the busiest railway line in Serbia and among the busiest railway lines in Europe with a maximum daily transportation of over 100 thousand tons of coal, while it is transported annually more than 25 million tons of cargo. The transport of coal for many years is performed with about 400 Fbd wagons, made in Wagon factory Kraljevo (Serbia), specially designed for this purpose.

2. PROBLEM DEFINITION

The 4-axled wagon Fbd consists of two 2-axle units that are interconnected by joint connection (Fig. 1). The gross wagon tonnage is 80 tons and it is primarily designed 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. The floor of wagon is equipped with special door with the hydro-pneumatic drive, which provides automatic unloading and closing after that. 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 LS departs from the standard design solutions. Reducing the length of LS in relation to 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 LS (Fig. 2). 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.

Figure 1. The Fbd wagon for coal transportation

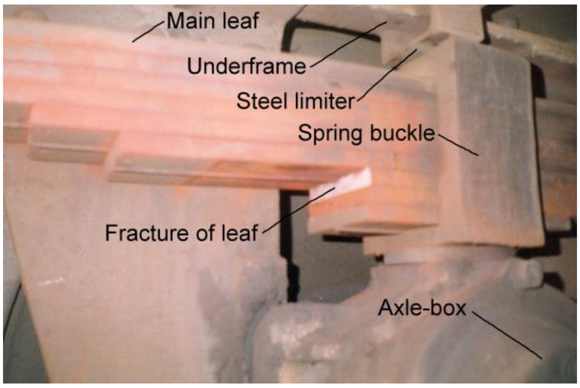

Figure 2. The example of fracture of leaf of LS

Statistical analysis shows that among the most dominant failures of the suspension system are fractures of elements of LS [9]. Among them, the most common are fractures of leafs (Fig. 2), and especially of main leafs. The frequent fractures of leafs caused derailments in many cases [10]. The consequences were huge material damage and significant decreasing the efficiency of railway transportation. All this has disturbed the stable operation of the entire system of thermal power plant. The problem of fractures of LS is usually solved by replacing the entire LS 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 LS, which caused decreasing the efficiency and profitability of rail transport. 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 LS buckle and underframe. This research is detailed in the paper [9], and its most important result is the reduction of very frequent fractures of LS and cracks on the underframes. The second direction was implied exploring the possibility for repairing LS by welding of fractured leafs. That is the topic of this paper, and its main task is to determine the effect of welded leafs on the behaviours and characteristics of repaired LS.

3. EXPERIMENTAL TESTS

The basic idea of repairing of LS implies that its broken leaf is welded in the place of fracture, with aim of preservation of overall designed geometry and function (Fig. 3). One of the most important segments necessary for the successful realization of this idea was troubleshooting welding technology. This research is realized by the company “Termoelektro”, Belgrade, Serbia. The technology is intellectual property of the 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 LS, preparation of surfaces for welding, procedure of welding, etc. Based on this technology, two characteristic damaged LS in factories “Gibnjara” (Kraljevo) and “Želvoz” (Smederevo), Serbia, are repaired. In the aim to explore their behaviors and characteristics, these LS are subjected to the experimental tests.

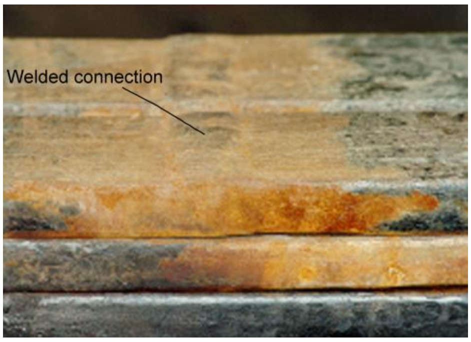

Figure 3. The welded connection of the main leaf

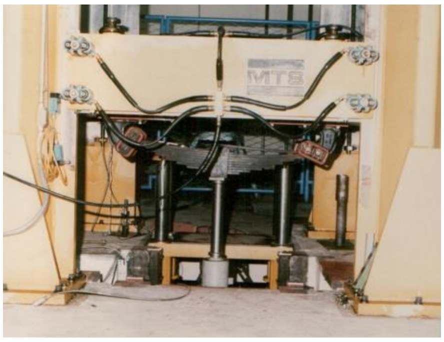

Figure 4. The dynamic testing of LS on the test stand of MTS production

The experimental tests were performed on pulsator, to the fracture of LS, with prescribed amplitudes and frequency. For this purpose, the test stand for dynamic testing of production “MTS” was used (Fig. 4). It is placed in the laboratory of the company “Prva Petoletka” in Trstenik, Serbia, and its main purpose is testing of landing gears of the aircrafts. In order to install LS and simulation of their real exploitation conditions, test stand was modified by the additional elements for introduction and acceptance of the load. The comparative tests were performed on the following LS: damaged LS with welded main leaf repaired in factory “Želvoz”, Smederevo (LS 1); damaged LS with welded main leaf repaired in factory “Gibnjara”, Kraljevo (LS 2); and completely new LS (LS 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; and dinamic fatigue testing to the fracture. The number of cycles and amplitudes of deflection of LS are defined in the regulations, and are presented in Table 1. The frequency of change of deflection amplitudes is defined in the regulations, and is equal 2 Hz.

Table 1. The prescribed number of cycles and amplitude of deflection in laboratory testing of LS

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

In dynamic tests, it was necessary to define the static load of LS around which the amplitude of the deflection oscillates. 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 LS should be about 9.25 t. However, the static load per one LS was determined from the data of exploitation [16] 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 LS with a fully laden wagon. Overloading of LS 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 LS, 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 LS 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, the geometric accuracy of all three LS was tested. It is concluded that it is within the prescribed limits. In the second step, the static characteristics of LS 1, 2, and 3 were tested and recorded. It is concluded that deviation of static characteristics of LS with welded leafs (LS 1 and 2) from the static characteristic of not welded LS 3, is less than 1%. Of course, a similar deviation should be obtained in the case of all three LS whose leafs are not welded. Based on that, it can be concluded that all three tested LS have almost identically static characteristic. The diagram of static characteristic of LS is shown in Fig. 6. The example of changes of deflection and force in time, obtained during the fatigue tests of LS are shown in Fig. 7. The results obtained by experimental fatigue tests of LS 1, 2 and 3 are shown in Table 2.

In the case of LS 1, 161820 cycles were achieved to the occurrence of fracture of main leaf, as shown in Fig. 8. In the case of LS 2, 92820 cycles were achieved to the occurrence of fracture of third and fourth leafs viewed from below, as shown in Fig. 9. At the end, in the case of LS 3, 216240 cycles were achieved to the occurrence of fracture of main leaf, as shown in Fig. 10.

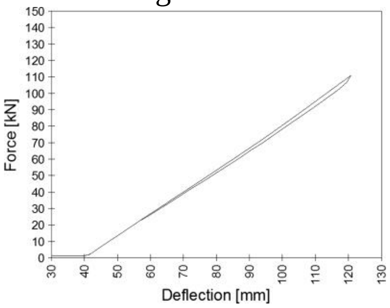

Figure 6. The static characteristic of LS

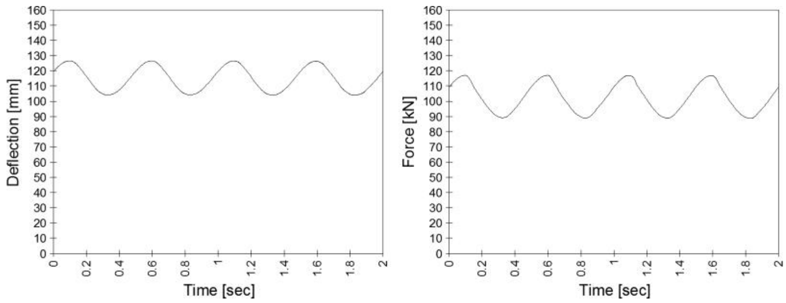

Figure 7. The change of deflection (left) and force (right) in time, obtained during the fatigue test of LS 2

Table 2. The number of cycles until the fracture of LS

LS	Number of cycles	Remark
1	161820	Fracture of main leaf (Fig. 8)
2	92820	Fracture of third and fourth spring leafs viewed from below (Fig. 9)
3	216240	Fracture of main leaf (Fig. 10)

Figure 8. The fracture of main leaf of LS 1

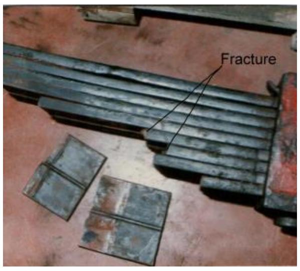

Figure 9. The fracture of third and fourth leafs (from below) of LS 2

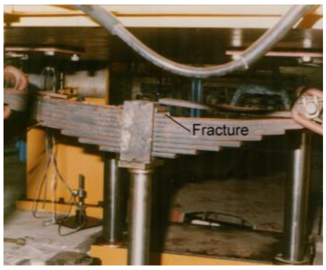

Figure 10. The fracture of main leaf of LS 3

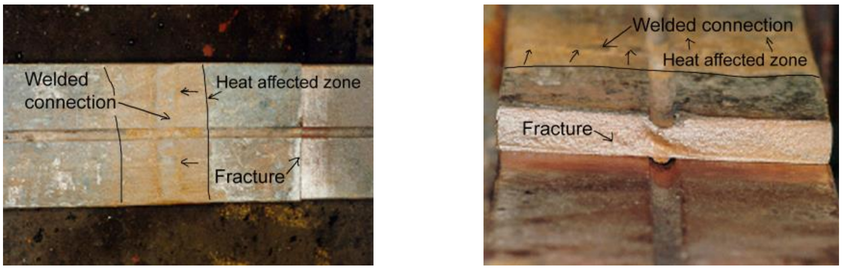

Figure 11. The fracture of LS 1 (left) and LS 2 (right) outside the zone of welded connection

In experimental tests of both LS 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 Fig. 11.

As expected, it was concluded that in these fatigue tests have not reached the expected lifetime of LS. 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 [16].

5. CONCLUSION

The methodology applied in this research is based on comparative experimental research of LS with welded and non-welded leafs. Based on experimentally obtained results, the following conclusions are derived: geometric accuracy of LS with welded leafs satisfy all demands of exploitation and technical practise and does not deviate from the geometric accuracy of non-welded LS; static characteristic of LS with welded leafs satisfy all demands of exploitation and technical practise and is almost identical to static characteristic of non-welded LS, while deviations are less than 1%; dynamic characteristics of LS with welded leafs satisfy the design and exploitation requirements. Conducted fatigue experimental tests have shown that fractures do not occur in the zone of welded connection or heat affected zone. It is important to note that life-cycle of repaired LS is slightly lower with regard to the new LS. The reasons lie in the fact that repaired LS already undergone a certain number of cycles before fracture.

Thus, it can be concluded that welding can be possible solution for reparation of broken LS. Repairing of broken leafs of damaged LS according to the prescribed welding technology allows to restore these LS into exploitation. The welding of broken leafs does not affect the behaviors and characteristics of LS. More precisely, behaviors and characteristics of repaired LS almost completely satisfy the demands of the design and exploitation. Of course, in this statement should be taken into account that these LS are already used and that their life-cycle is slightly lower compared to the completely new LS. Therefore, in the 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. This research conducted on the Fbd wagons can be very good motivation for applying similar solutions on other wagons whose suspension is based on LS. In addition, applied methodology and obtained results can be of great significance for generation of ideas for further deeper investigations in this area.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Serbian Ministry of Science and Technology for supporting this paper through project TR35038.

REFERENCES

[1] Huichuan Fan, Xiukun Wei, Limin Jia, Yong Qin, Fault detection of railway vehicle suspension systems, Computer Science and Education (ICCSE), 5th International Conference on Computer Science and Education, (2010) 1264-1269, doi: 10.1109/ICCSE.2010.5593724.
[2] X. J. Ding, T. X. Mei, Fault Detection for Vehicle Suspensions Based on System Dynamic Interactions, https://ukacc.group.shef.ac.uk/proceedings/control2008/papers/p92.pdf
[3] Xiukun Wei, Hai Lui, Yong Qin, Fault isolation of rail vehicle suspension systems by using similarity measure, 2011 IEEE International Conference on Service Operations and Logistics and Informatics (SOLI), (2011) 391-396, doi: 10.1109/SOLI.2011.5986591.
[4] 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 Volume 1, Issue 1, (2008) 88-99, doi: 10.1299/jmtl.1.88.
[5] A. Chamseddine, H. Noura, T. Raharijaona, Full vehicle active suspension: Sensor fault diagnosis and fault tolerance, IFAC Proceedings Volumes (IFAC-PapersOnline), Volume 6, Issue PART 1, (2006) 468-473.
[6] Atmadzhova D. Modeling of rolling stock spring suspension with an automated control system, XIX International scientific conference T. Kableshkov, "TRANSPORT" 2009, pp VI-44
[7] Atmadzhova D., Mihaylov E., Elastic rubber elements as component parts of resilient wheels for light-rail transportation XV Conference RAILCON‘12 Niš, Serbia, at the Faculty of Mechanical Engineering Oct., 2012
[8] Atmadzhova D., Method for determining safety against derailing at railway accident, Electronic journal "Mechanics Transportation Communications", vol. 16, issue 3/1, 2018, pp II 1- II 8
[9] Atmadzhova D., Nikolov V., Modeling and comparative structure analysis of different structures of leaf springs for two axle freight wagons, Academic journal Mechanics Transport Communications, vol. 17, issue 3, 2018

[10] M. A. Kumbhalkar, Y. L. Yenarkar, A. K. Grover, Failure Analysis of Inner Suspension Spring of Railway Engine: A Case Study, Proc. of Int. Conf. on Advances in Robotic, Mechanical Engineering and Design 2011, (2011) 12-16, doi: 02.ARMED.2011.01.22
[11] Secondary suspension failure on a train at Connolly Station, 7th May 2010, Investigation Report 2011-R002, Railway Accident Investigation Unit – RAIU, 2011.
[12] D. Petrović, M. Bižić, Improvement of suspension system of Fbd wagons for coal transportation, Engineering Failure Analysis, Volume 25 (2012), 89–96, doi:10.1016/j.engfailanal.2012.05.001
[13] Atmadzhova D. A Method to Evaluate the Service Life of Rubber Springs in Rolling-Stock. S., Electronic journal "Mechanics Transportation Communications" issue 2, 2008 BG-2.9 BG-2.14
[14] Atmadzhova D., Nenov N., Study on fatigue of Rubber metal springs of primary spring suspension of electric locomotives XV Scientific – Expert Conference on Railways Railcon '12, October 4 – 5 2012, Nis, Serbia, pp. 41-44., University of Nis, Serbia 2012
[15] Atmadzhova D., Nenov N., Study of the Rubber Metal Springs Fatigue of Primary Spring Suspension of Electric Locomotives, Journal FACTA UNIVERSITATIS SERIES MECHANICAL ENGINEERING, Vol.10, No 1, 2012 pp. 63 – 70
[16] 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].
[17] Atmadzhova D., Some data for calculation of fatigue in probabilistic aspect of railway vehicles. XIV Conference RAILCON‘10 takes place in Niš, Serbia, 2010
[18] Atmadzhova D., Parametric analysis reliability of railway vehicle bogie frame, Electronic journal "Mechanics Transportation Communications" issue 2, 2011
[19] Atmadzhova D., Mihalev M., Fatigue strength and resources of elements from rolling stock, XX International scientific conference T. Kableshkov, "TRANSPORT", 2011
[20] Atmadzhova D., Mihalev M., Automated calculation of durability of elements from rolling stock, XX International scientific conference T. Kableshkov, "TRANSPORT", 2011
[21] Petrović D., Atmadzhova D., Bižić M., Advantages of rubber-metal elements in suspension of railway vehicles, IIIrd International Conference on Road and Rail Infrastructure CETRA 2014, 28-30 IV, Croatia, 2014
[22] Petrović D., Bižić M., Atmadzhova D., Application of rubber elastic elements in suspension of railway vehicles, Mechanics Transport Communications volume 15, issue 3, 2017, pp VI-44 VI-51
[23] Atmadzhova D., Determination criteria for the derailment of railway wheelset. Quasi-static analysis of wheelset, Electronic journal "Mechanics Transportation Communications", ID: 579, issue 3, 2011, pp VI 35- VI 41.
[24] Atmadzhova D., Analysis of mathematical expressions for determine the criteria derailment of railway wheelset, Electronic journal "Mechanics Transportation Communications", ID: 579, issue 3, 2011, pp VI 42- VI 49.
[25] Atmadzhova D., Research and scientific contributions of our country concerning security against derailment of rolling stock, Mechanics Transport Communications volume 16, issue 3/1, 2018, pp II 17- II 22.
[26] Atmadzhova D., Transforming analytical and analog dependencies of criteria against derailment of different classes. XVIII Scientific – Expert Conference on Railways Railcon '18, University of Nis, Serbia 2018.

ИЗСЛЕДВАНЕ НА ВЪЗМОЖНОСТТА ЗА РЕМОНТ НА СЧУПЕНИ ЛИСТОВИ РЕСОРИ НА ТОВАРНИ ВАГОНИ ЧРЕЗ ЗАВАРЯВАНЕ

Драган Петрович, Милан Бижич,
petrovic.d@mfkv.kg.ac.rs, bizic.m@mfkv.kg.ac.rs

Университет в Крагуевац, Факултет „Механика и строителни инженери” в Кралево, ул. Доситиева 19, 36000 Кралево, СЪРБИЯ

Ключови думи: *Ремонт, Листови ресори, Счупени листови ресори, Товарни вагони, Заваряване.*

Резюме - *Целта на тази статия е да проучи възможността за ремонт на счупени листови ресори (ЛР) на железопътни вагони чрез заваряване. Счупванията на ЛР са много чести, особено за товарни вагони, използвани при екстремни условия на работа. Един от начините за решаване на този проблем е ремонт чрез заваряване на счупените листове. В този случай се повдига въпросът за поведението и характеристиките на ремонтираните ЛР. Подходът в тази статия е базиран на сравнително експериментално изпитване на ремонтирани ЛР и нови ЛР. Целта е да се определи ефекта на заварените листа върху поведението и характеристиките на ремонтираните ЛР. Получените резултати показват, че заваряването не влияе значително върху поведението и характеристиките на ремонтираните ЛР. По време на изпитванията на умора не е регистрирана повреда в зоната на заварката. Резултатите показват, че жизнения цикъл на ремонтираните ЛР е малко по-нисък по отношение на новите ЛР. Крайното заключение е, че заваряването може да бъде възможно решение за ремонт на счупени ЛР.*