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ROOT CAUSE ANALYSIS OF FAILURE OF SUSPENSION SPRING USED IN FIAT BOGIE OF INDIAN RAILWAYS

Dr. Rupendra Nehete

Dr. Pradip P. Patil

Tushar Jangam

Abstract

Spring is a general mechanical component used for absorption of shocks and vibration. The suspension system used in FIAT Bogie is double suspension system in which nested springs are used. The most common problem of the failure of suspension system is the failure of springs during service. Failure causes of any component should be rectified for smooth functioning. Root causes analysis is used for the same purpose; it is an integrated method to find the root causes of the failure problem and finding out the sustainable solution on the same. As the failure of spring does not causes any halt or serious breakdown of the working of railway bogie it is difficult to find out the time of failure under available resources. This paper discuss the root cause analysis of the failure of primary inner spring of Fiat Bogie along with the Pareto analysis of the same to find out the causes responsible maximum failure. The major reasons of the failure of spring are the failure due to reduction in the permissible free height, corrosion and rubbing marks. In defect analysis carried out till March 2019 total 144 defects occurred and root cause analysis and Pareto diagram is presented in this report.
Keywords-Failure, ISHIKAWA diagram, Pareto, Root Cause Analysis, and spring.

INTRODUCTION

The Fiat Bogie has been commissioned in INDIA since 2001 and for Central Railway its Periodic overhaul (POH) is done at Central Railway Loco Workshop, Parel, Mumbai. From the POH data, it is observed that the trains running between Solapur to Kolhapur and Siddheshwar Express experiences the frequent failure of springs where the actual life of spring is approximately 1 year only. The rest other failed springs are of the Express trains running for a longer route still have their life approximately 3 years from date of fitment. So according to the economy point of view the actual problem arises in the springs failed from the trains having less life. From the statistics collected from the maintenance workshop around 30 springs of non AC coaches failed in the year 2018 out of which 8 springs were from the trains running between Solapur to Kolhapur and Siddheshwar Express. Therefore, the need arises to find out the root causes contributing to the failure of the spring, finding the possible solutions for the same problem and selecting the optimal solution.

Considering the issue of spring failure in Fiat Bogies, the study is carried out in the year 2019 at Central Railway Loco Workshop Parel. There is a wide variety of tools and methods used for root cause analysis; however, this article presents those tools already accepted in the industry, which exhibit characteristics such as adaptability to cases of high or low complexity, systematic sequence and logic for its analysis and implementation, ability to integrate different specialties, among others. This article focuses on the root cause analysis of the primary outer spring of Fiat Bogie using the techniques of cause effect or ISHIKAWA diagram and Pareto chart analysis. The ISHIKAWA diagram focuses on the all-possible reason for the failure of the spring. The main limitation of ISHIKAWA diagram is that is cannot find out the main causes contributing for the failure of spring. The limitation of ISHIKAWA diagram is overcome by Pareto chart analysis, which highlights the main reasons for 80% failure. The paper describes the research work of various authors and their findings. The research works of other authors were used to study their way towards the problem solving and the method they used to obtain the objective. In this paper a case study conducted in the March 2019 is presented for the root cause analysis and Pareto analysis of spring failure of Fiat Bogie.

LITERATURE REVIEW

Many authors have attempted to investigate failure of springs made up of different materials. In Failure Investigation Report, CMT Laboratories, Parel (2018): The failure investigation reports states that the fracture plane is inclined at 45 degree to the axis of the rod. They further specifies that failure of spring has rubbing marks and corrosion marks near the fracture surface. In Raut, S. P, et.al.,(2014) research paper work the author present the comparison of various methodologies used by various authors and their application and limitations. Author discretizes the failure analysis in three different objectives of finding mode of failure, failure causes, root causes in which we specifically focus our scope of research on the failure causes and root causes. Dalvi, S. D,et.al.,(2017) carried out failure analysis of a fractured roller shaft of a pad steam machine that led to catastrophic consequences in terms of damage to other equipment, loss of production etc. Using standard procedure for failure analysis the author founds that due to stress concentration a micro-crack initiation took place at the weakest section and fracture of shaft took place. Barella,et. al.,(2011) in their paper on failure analysis of turbine blade, the author presents his views by discretizing the fracture zone as crack initiation , crack growth and final fracture. The author observes the fretting fatigue damage which caused the cracking of the component and the improper shot peening was the result of growth of crack. Hence author concludes that the failure of blade was primary due to improper service condition which caused the fretting fatigue and due to improper manufacturing conditions which lead to growth of crack. Manoj A. Kumbhalkar,et.al.,(2011) have conducted analysis the spring of WAG-9 is an electric locomotive engine and specifies that the facture takes place between 1st and 3rd coil and the fracture plane is at 45 degree w.r.t rod . Author notes that due to over loading might be due to vibrations, scratches on damper exceeds 25mm more than stationary deformation in height. Author recommends increasing the free length of the axle spring keeping the C.G of the system undisturbed

P.V.V. Kishore,et.al.,(2017)research work describes the method train rolling stock examination in which visual examination was done by an individual of railway to keep visual observation of the parts of the train during motion. However, it is not possible to have visual observation with effectiveness because it is not possible to observe each part. Author uses a Single shape prior to power the level set function for object segmentation using a wide-angle high-speed camera to observe the parts and uses algorithms for segmenting defective parts with Non-defective shape priors by weigh vector adjustment. Das,et.al.,(2007) in their research work in the failure analysis of coil spring the author describes through his work that although most chances of failure of spring is due to fatigue failure but the spring which is failed after 100km working distance is not due fatigue. After standard failure procedure from spectroscopy author reveals that amount of Si and Mn were beyond prescribed limit as increasing the amount of Si increases the fatigue resistance to fatigue failure. Also non-etchant surface optical microscopic observation reveals the presence of inclusion in the microstructure which is the problem of improper material and heat treatment. Apart from that author uses XRD method for measurement of residual stress and found that there is large variation in the stress value that is because of uneven shot peening and this is a surface discontinuity type of fault. Kumar,et.al.,(2013) have done static analysis of primary suspension spring, the author uses two materials for comparing the stress value and deflection values. 60Si2MnA steel & Chrome Vanadium were used for research work and then using ansys 14 and analytical calculations author concludes that both the material have nearly same stress values but the deformation value is less for 60Si2MnA steel compared with Chrome Vanadium. Prawoto,et.al.,(2008) in their research work the authors compared the parameters affecting the performance of spring. The failures presented range from the very basic including insufficient load carrying capacity, raw material defects such as excessive inclusion levels, and manufacturing defects such as delayed quench cracking, to failures due to complex stress usage and chemically induced failure. Author describes all the possible defects that causes failure of the spring including inclusion and corrosion by modeling both as a FEM Model. Author also includes decarburization in his research work and considers as least weighted compared to all other defects. Also the author found that the values of residual stress induced on the surface due to shot peening are less for decarburized material hence he characterizes the shot peening as surface imperfection defect. Pyttel,et.al.,(2014) presented research paper which deals with the comparison of various spring material and their fatigue life. The author also studies about the shot peening conditions and experimented about the effect of double shot peening on the end coil failures ad found no change in the percentage of failure due to double shot peening in case of SiCr- and SiCrV. Bloch,et.al.,(1997), the author of the book has compiled many problem regarding to failure of machineries and equipment and uses statistical quality tools for the solving various problems regarding the maintenance and quality control. The problems were mainly regarding to failure of pump impeller, mechanical failure and metallurgical failure etc. Author uses the cause effect diagram from finding The number of causes and sub causes for the failure of the machineries and uses Pareto diagram to find out the 20% causes that contribute for 80% of failure. Joshi,et.al.,(2014), studied the casting and the casting defects in various stages of the process. Using quality control techniques for finding out the remedies for the problem. The author uses cause effect diagram for listing the causes of specific failure reasons in the systematic way. The author also conducted Pareto analysis for identification of major defects those are contributing in major rejection percentage.

RESEARCH METHODOLOGY

We have carried out failure analysis of suspension spring used in fiat bogie and described various cause of failure. The characteristics of various defects specifically raw material defect, manufacturing defect, improper service condition, environmental defects, surface imperfection etc. are considered in the study. So considering their way towards finding the cause of failure of spring as a primary step of research on the root cause finding on failure of spring is to have an actual visual inspection of the failure surface for effective observation the visual observation must be done immediately after the occurrence of failure. Visual inspection include all the possible observations seen during the inspection of the springs and noting the observation along with the comments about their appearance, nature, colour, any surface irregularity etc. seen near the surface of failure. We used the cause effect diagram and Pareto analysis for finding all the possible causes for failure and the finding which failure is contributing the maximum times. The collected data about the failure surface and areas nearby is directly presented as ISHIKAWA (Cause & Effect) diagram for better understanding of the actual causes. ISHIKAWA diagram is well prepared by all the observations done in the maintenance workshop, observation at the testing lab and the human error included in the failure of spring.

The collection of data for the Pareto analysis includes frequencies of number of springs that fail due to several reason.

27 nos. of spring were observed which failed due to reductions in free height. 10 nos. of springs that were observed and was found that there is the removal of paint at some spots and these springs were observed immediately when bought from manufacturer to workshop. This means that there is mishandling during the shipment of springs from manufacturer.30 nos. of fractured springs were observed and out of the 30 nos of fractured springs all springs were found to have corrosion mark and rubbing marks. 25 nos. of spring had paint removal on the bearing coil where facture took place.18 springs were found to have scratch marks on the outer surface of active coil. 3 nos of spring had welding spatter marks and 1nos. (approx.) of spring were failed and not even replaced due to urgent requirement and this means that there is improper scheduling of maintenance.

RESULT AND DISCUSSION

The study of various defects occurring in springs is carried out with reasons and remedies for it is recommended as shown in table below,

Table1: Analysis of defects

Sr.	Defect	Reason	Remedy
1	Yielding	Yielding occurs when the imposed load exceeds the load bearing capacity of the structural elements.	Appropriate designing and selection of materials and heat treatment
2	Buckling	Buckling is caused by high compressive stresses "sandwiching" the vertical column between its 2 ends, thereby giving it no other alternative than to buckle outward at its weakest point.	Appropriate designing and selection of materials and heat treatment
3	Corrosion	Corrosion is the often unwanted and detrimental chemical reaction engineered materials have with their surroundings, leading to a reduction in material cross section and eventually its load bearing capacity.	Proper selection of material, protective surface coating on springs
4	Creep	It can occur due to high stress levels that are lower than the yield strength of the material but are high enough to cause slow deformation.	Appropriate designing and selection of materials
5	Fatigue	Fatigue failure is the formation and propagation of cracks due to a repetitive or cyclic load. Most fatigue failures are caused by cyclic loads significantly below the loads that would result in yielding of the material.	Appropriate designing, proper selection of materials and material processing and post processing treatments
6	Fracture	Brittle fracture is a sudden and complete breakage of a brittle material, whereas ductile fracture – also called as rupture – displays considerable plastic deformation before fracture.	Proper selection of materials and working conditions
7	Wear	Components that are in direct contact with moving parts are subject to wear. This is the gradual removal or erosion of surface material and consequently, cross sectional area, leading to eventual failure.	Appropriate designing and selection of materials

• ISHIKAWA DIAGRAM

The defect of spring failure is shown at the extreme right side with various causes extending to the left. The defect forms as the head of the fish and the major cause's branch off the backbone and the root causes form sub branches.

The key relationships among various variables, and the possible causes provide additional insight into process behavior is revealed by the root cause analysis.

As shown in the figure, there are 6 major causes of defects which are the main branches, each having various root causes which form sub branches.

1) Material: Failure due to surface discontinuities results due to corrosion marks, surface cracks and dent marks, welding spatter and rubbing marks. Surface protection failure results due to improper thickness of paint and removal of paint during handing. Failure results due to non-uniformity in all springs and non-uniform grain size. Failure due to internal cracks results due to heat treatment defects and dislocation due to high fatigue stress cycle.

2) Measure: Failure due to dimension crossing limits results due to free length of spring below minimum value. Failure due to improper measurement of dimensions results due to improper use of standards and using uncalibrated equipment

3) Management: Failure due to Management policies results due to incomplete and defective research and investigation on the problem, lack of implementation of new policies and lack of proper maintenance scheduling

4) Man force: Failure due to workforce results due to unnecessary hammering and welding electrode striking, improper handling and human error in measurement.

5) Machine: Failure due to improper sample preparation results due to burning the sample microstructure and not following proper preparation procedure. Failure in maintenance results due to preventing buckling during compression.

6) Environment: Failure due to corrosion us a result of, stress corrosion cracking and oxidation of the parent material.

• PARETO ANALYSIS DIAGRAM

Several authors used PARETO analysis to know more specific reasons associated with the defects. Raluca NICOLAE et.al. (2015) have used Pareto analysis for improvement the quality of industrial products. Pareto chart is one of the basic and efficient cause analysis tools. It helps us understand the cause of a problem. The causes are arranged from left to right in descending order. The most frequently occurring cause of the left and least frequent on the right.

The y-axis (left) represents the number of occurrences or the frequency of a case and the y-axis (right) represents the percentage of occurrence. The red curve in the chart is the plotted cumulative percentages. In the above Pareto chart we can easily conclude that the most frequent type of cause of failure of spring is corrosion, the next frequent cause is rubbing marks (fretting marks) and so on from left to right of which improper scheduling being the least probable cause of failure.

Figure 1: Cause and effect diagram

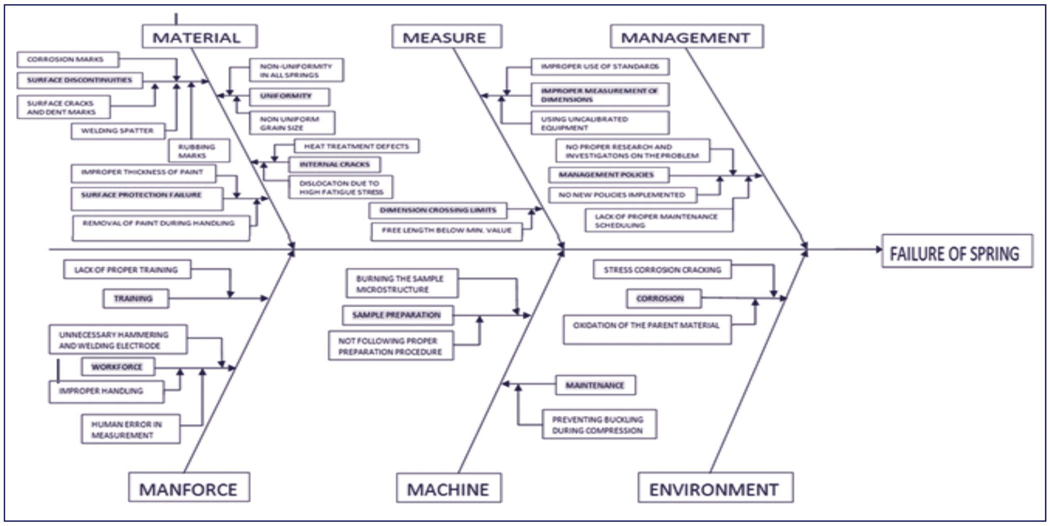
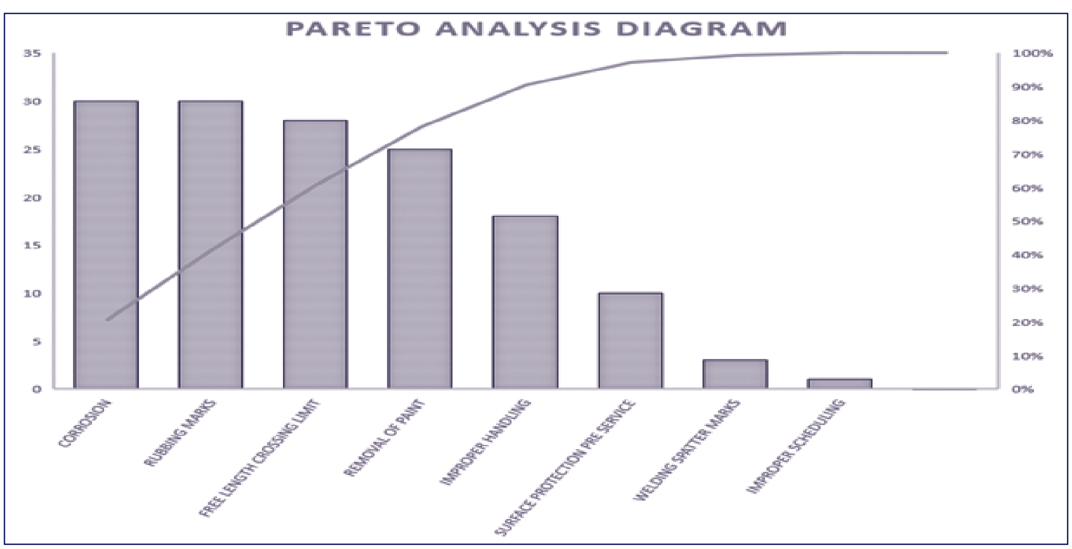


Table 2: Defect analysis (March 2019)

No.	Type of defects	Total number of defects	Defects percent
1	Corrosion	30	20.83
2	Rubbing Marks	30	20.83
3	Free length crossing limit	28	19.44
4	Removal of paint	25	17.36
5	Improper handling	18	12.5
6	Surface coating pre service	9	6.25
7	Welding spatter marks	3	2.08
8	Improper scheduling	1	0.60
	Total	144	

Figure 2: Pareto Analysis for March 2019



RECOMMENDATIONS

Manufacturing Recommendations:

1. The broken springs were found with rubbing mark due to fretting. Taking fretting into consideration, the spring base material must not come in contact with the water (moisture) or water particles or oxidizing environment.
2. The broken spring sample was found with rough and wavy surface. These peaks and troughs can be the region for stress concentration and the crack initiation starts from the weakest portion, to avoid the fracture of spring due to improper surface finish, it is recommended to have proper surface finish which can increase the life of the spring.
3. The shot peening process must be done uniformly throughout the length on both inner and outer surface. Poor shot peening action on the inner surface due to less space issues can be the reason of less compressive stresses, because of which crack initiated starts propagating with speed and fractures the coil mostly from the inner surface of the spring coil.
4. The new spring arrived from manufacturer was found with paint removal marks and the corrosion marks. Hence removal of paint can be the reason for corrosion which causes Stress Corrosion Cracking. It is recommended to properly paint the springs and handle the spring properly during shipment so that the spring doesn't get damaged during the transportation. It is also recommended to use material handling devices to handling the spring during maintenance.
5. For avoiding the corrosion of springs, it is suggested to apply red oxide paint on the metal portion and then allow the red oxide paint to dry, after that the paint must be applied on new spring so that when paint is removed the base metal doesn't comes in direct contact with environment.
6. The paint on the springs was irregular and it is suggested to use spray pumps to paint the spring so as to maintain the uniform thickness of the paint throughout.

Design Recommendations:

1. The design of the spring should be done taking the maximum no. of passenger travelling during peak hours and must be optimized by taking limiting space into consideration.
2. The design of spring must be updated taking new emerging material which deforms less on same loading condition must be commissioned so that the number of springs which failed due to reduction in free height will be reduced. Kumar,et.al.,(2013) uses two materials for comparing the stress value and deflection values. 60Si2MnA steel & Chrome Vanadium & concludes that both the material have nearly same stress values but the deformation value is less for 60Si2MnA steel compared with PAINT REMOVAL MARKS. Paint removal sample Chrome Vanadium. Hence using 60Si2MnA can reduce the rejection frequency of spring failed due to reduction in free height.
3. The free length of the coil must be increased so that the clearance between the coil is maintained after installation and fretting (rubbing) will be reduced which maintains the fatigue life of the component.

Maintenance Recommendations:

1. The maintenance of the bogie must be done by trained officials so as to make them aware of proper maintenance procedure which must be followed strictly.
2. The maintenance of any bogie part must be done free from water so as to avoid corrosion of the spring.
3. During every maintenance the spring must be checked for surface cracks and also fretting marks, if found with such must be maintained and not to be installed without fool proofing.
4. The spring must be handle safely above the ground surface and must not be rolled on the workspace as rolling of the spring causes surface scratches which can be the initiation of the crack.
5. The maintenance record from date of fitment to date of failure for each and every part of the bogie must be properly maintained so as to have clear calculation of the life of the part.
6. From the statistics collected from the maintenance workshop around 33 springs of non AC coaches failed in the year 2018 out of which 8 springs were from the trains running between Solapur to Kolhapur and Siddheshwar Exp. Therefore, the need arises to find out the root causes contributing to the failure of the spring, so it suggested to maintain the track terrain and also to clean the spring surface using dry air jet so as to avoid the pitting corrosion of the surface.
7. Before applying the paint on spring or any other part, the previous paint must be removed and after that cleaned using high pressure air jet instead of manual cleaning and be made dust free. After that red oxide paint must be applied and paint properly adheres to the metal surface avoiding metal to environment contact. red oxide is applied so as to avoid the contact of base metal and environment if paint is removed during service condition.

CONCLUSION

In this paper the attempt have been made to do the root cause analysis of fiat bogie spring. From the research work on the spring failure the ISHIKAWA DIAGRAM gives the possible root causes and the Pareto diagram concludes that the 80% of failure is due to the 20% of causes that includes corrosion marks on the surface of the springs. In addition of the removal of the protective film of paint causes the direct metal to metal contact of the bearing coil and active coil of the spring and rubbing marks causing the wear of the surface due which crack initiation starts & the reduction in the free length after use is also causing rejection frequency of spring.

The further study of the work can extended using the general failure analysis procedure and evaluating the microstructural properties of the material and verifying for the surface compressive stresses by using the XRD techniques, evaluating the material composition using spectroscopy.

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AUTHORS

Dr. Rupendra Nehete, Faculty, SIES Graduate School of Technology, Sri Chandrasekarendra Saraswati Vidyapuram Sector-V, Nerul, Navi Mumbai – 400 706, (MS)
Email: rsnehete@gmail.com

Dr. Pradip P Patil, Faculty, SIES Graduate School of Technology, Sri Chandrasekarendra Saraswati Vidyapuram Sector-V, Nerul, Navi Mumbai – 400 706, (MS)

Shri Tushar Jangam, Student, SIES Graduate School of Technology, Sri Chandrasekarendra Saraswati Vidyapuram Sector-V, Nerul, Navi Mumbai – 400 706, (MS)