Failure Mode Analysis of Railway Engine Spring

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Abstract—Failure analysis is pivotal when units or systems perform inadequately. This study establishes a correlation between reliability and field-failure data, providing a foundation for a comprehensive failure model. Focusing on coil springs, the research assesses various failures, conducting in-depth analyses. Techniques such as graphical analysis, root cause analysis, and Pareto analysis are employed, revealing causes and potential solutions. Comparisons between current and improved system reliability offer insights into optimal spring arrangements. This study contributes vital insights for enhancing railway system performance

I. INTRODUCTION

The WAG-9 locomotive, vital for Indian Railways' goods transportation, features 24 primary suspension springs distributed across its six axles. The pursuit of lighter components in the railway industry, including coil springs, intensifies stress levels on materials. This paper investigates these challenges, addressing issues like material quality, manufacturing precision, and the impact of stress-related failures. Through in-depth case studies, it examines failures due to load limitations, raw material defects, manufacturing flaws, and complex stress conditions. The study also explores the fundamental concept of the "unwound spring," treating helical springs as straight bars under pure torsion. By scrutinizing these aspects, this research aims to enhance understanding of coil spring failures in the WAG-9 system, offering valuable insights for improved railway design and maintenance practices.

Methodology for Spring Failure Analysis:

1. **Failure Analysis of All Springs:** Comprehensive evaluation of all springs in the system.
2. **Failure Analysis of End Axle Spring (E/A):** In-depth analysis of failure patterns specific to end axle springs.
3. **Failure Analysis of Middle Axle Outer Spring (M/A/O):** Detailed examination of failures concerning middle axle outer springs.
4. **Failure Analysis of Middle Axle Inner Spring (M/A/I):** Thorough investigation into failures related to middle axle inner springs.
5. **System Reliability of springs:** Assessment of the overall reliability of the spring system.
6. **Reliability Improvement of springs:** Strategies and techniques implemented to enhance spring reliability.
7. **Validation of Results:** Verification and validation of the obtained findings.
8. **Discussion and Future Scope:** Analysis of results, discussion of implications, and exploration of future research directions.

Understanding Failure: Failure occurs when a unit or system does not perform satisfactorily. Patterns of failure are derived from life test results, obtained by testing a large number of models until failure transpires and observing failure-rate characteristics over time. Failure data form the basis for mathematically formulating a failure model for general analysis.

Key Failure Metrics:

Failure Density (fd): This methodology provides a structured ratio of the number of failures during a specific time interval to the total initial population.

Fd = Total No. of Survivors / No. of Failures

Failure Rate (Z): Ratio of the number of failures during a unit interval to the average population during that interval

Z=Mean No. of Survivors / No. of Failures

Reliability (R): Ratio of survivors at any given time to the total initial population.

R=Total No. of Survivors / No. of Survivors

Probability of Failure: Ratio of the number of units failed within a certain time to the total population.

Probability of Failure = 1−Reliability

Mean Failure Rate (h): The sum of individual failure rates for a unit interval of time divided by the total time for failure.

$h = z_1+z_2+\text{--------}+z_t / T$

Mean Time to Failure (MTTF): The mean time to failure for *N* specimens, considering failures during specific intervals.

$MTTF = n_1\Delta t+2n_2\Delta t +\text{-----}+k\, n_t\Delta t /N$

This methodology provides a structured approach for understanding and analyzing spring failures, aiding in the development of reliable and durable spring systems for various applications.

Standard Specification Data Collected for WAG-9 Springs:

End Axle (E/A) spring:

- Outer Diameter (Do): 221mm
- Mean Diameter (Dm): 185mm
- Wire Diameter (d): 36mm
- Number of Turns (n): 4
- Free Length (Lf): 238.8mm
- Spring Rate (K): 868N/mm
- Load Height (LHT): 194 to 190mm
- Working Load: 4138 kg (or 4138 N)

Middle Axle Outer (M/A/O) Spring:

- Outer Diameter (Do): 212mm
- Mean Diameter (Dm): 180.5mm
- Wire Diameter (d): 31.5mm
- Number of Turns (n): 4
- Free Length (Lf): 258.6mm
- Spring Rate (K): 470N/mm
- Load Height (LHT): 194 to 190mm
- Working Load: 3190 kg (or 3190 N)

I **Middle Axle Inner (M/A/I) Spring:**

- Outer Diameter (Do): 104mm
- Mean Diameter (Dm): 87.5mm
- Wire Diameter (d): 18mm
- Number of Turns (n): 8
- Free Length (Lf): 252.4mm
- Spring Rate (K): 144N/mm
- Load Height (LHT): 190 to 186mm
- Working Load: 948 kg (or 948 N)

Where:

- **Do:** Outer Diameter of the spring.
- **Dm:** Mean Diameter of the spring.
- **d:** Wire Diameter of the spring.
- **n:** Number of Turns in the spring.
- **Lf:** Free Length of the spring.
- **K:** Spring Stiffness (spring rate).
- **LHT:** Loaded Height of the spring.

Data Collected from Loco shed of WAG-9 Spring.

Sr. No.	Month	Types of Spring	No. of Failure	Total
1	April	E/A	14	
		M/A/O	20	53
		M/A/I	19	
2	May	E/A	11	
		M/A/O	13	39
		M/A/I	15	
3	June	E/A	12	
		M/A/O	25	63
		M/A/I	26	
4	July	E/A	15	
		M/A/O	19	59
		M/A/I	25	
5	August	E/A	14	
		M/A/O	22	60
		M/A/I	24	
6	Sept.	E/A	15	
		M/A/O	20	54
		M/A/I	19	
7	October	E/A	11	
		M/A/O	21	57
		M/A/I	25	
8	Nov.	E/A	13	
		M/A/O	15	47
		M/A/I	19	
9	Dec.	E/A	19	
		M/A/O	24	69
		M/A/I	26	

10	January	E/A	17	
		M/A/O	19	58
		M/A/I	22	
11	February	E/A	13	
		M/A/O	17	50
		M/A/I	20	
12	March	E/A	13	
		M/A/O	18	53
		M/A/I	22	

Formulae

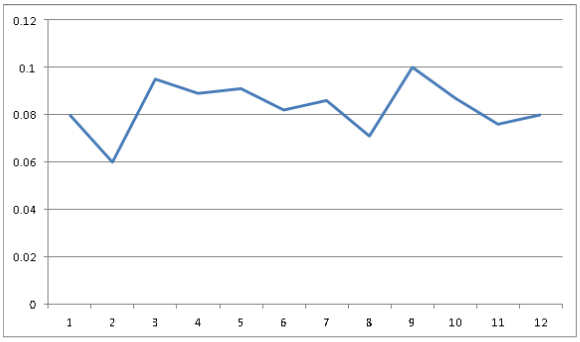
1. Cumulative failure (f) = sum of no. of failure
2. No. of survivors (s) = total no. failure – no. of failure during the unit time interval
3. Failure density (fd) = no. of failure / total no. of survivors
4. Failure rate (z) = no. of failure / mean of no. of survivors
5. Reliability (r) = no. of survivors / total no. of survivors

Calculation

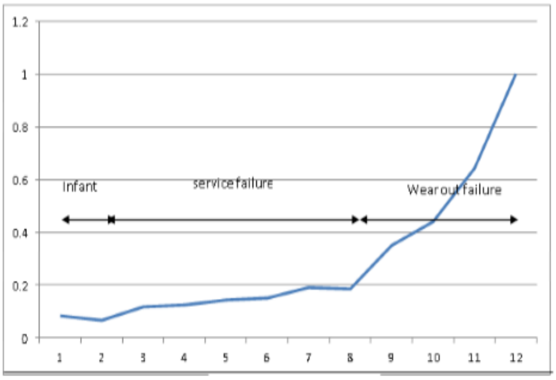
1. Mean failure rate (h) = (z1+z2+z3+...+zn)/T h = (0.083+0.066+0.117+0.124+0.143+0.15+ 0.19+0.185+0.35+0.44+0.641+1)/12 h = 0.291.
2. Mean time to failure (MTTF) = n1+2n2+...+knk/N MTTF = (53+2x39+3x63+4x59+5x60+6x54+7x57 +8x47+9x69+10x58+11x50+12x53)/662 MTTF = 4342/662 MTTF = 6.56 months.
3. Failure analysis of WAG-9 spring

Time in month (T)	No. of failure (f)	Cumulative failure (F)	No. of survivor (S)	Failure density (fd)	Failure Rate (Z)	Reliability
0		00	662			1.00
	53			0.08	0.083	
1		53	609			0.92
	39			0.06	0.066	
2		92	570			0.86
	63			0.095	0.117	
3		155	448			0.77
	59			0.089	.0.124	
4		214	388			0.68
	60			0.091	0.143	
5		274	334			0.59
	54			0.082	0.15	
6		328	277			0.504
	57			0.086	0.19	
7		385	230			0.42
	47			0.071	0.185	
8		432	161			0.35
	69			0.10	0.35	
9		501	103			0.24
	58			0.087	0.44	
10		559	53			0.16
	50			0.076	0.641	
11		609	00			0.08
	53			0.08	1.00	
12		662				0.00

FAILURE DENSITY GRAPH



FAILURE RATE GRAPH



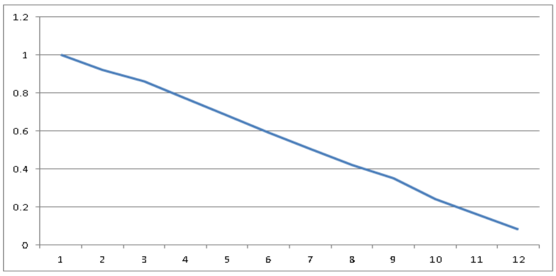
INFANT FAILURE:- The first is the short initial period during which the failure iscalled infant or early failures. This period is the break in period when components fail due to defect in manufacture, being inherently weak because of weak part, bad assembly, poor insulation and so on…

SERVICE FAILURE:- The failure in the second zone are termed as service failure. During this period, the failure or hazard rate is constant. These failures are random and are fairly distributed.

WEAR OUT FAILURE:- The failure in the third zone are the wear out failure. The incidence of failure in this zone is high since most of the components will have

TOTAL FAILURE OF SPRING
INFANT FAILURE = 92SPRINGS.
SERVICE FAILURE = 340 SPRINGS.
WEAR OUT FAILURE= 230 SPRING

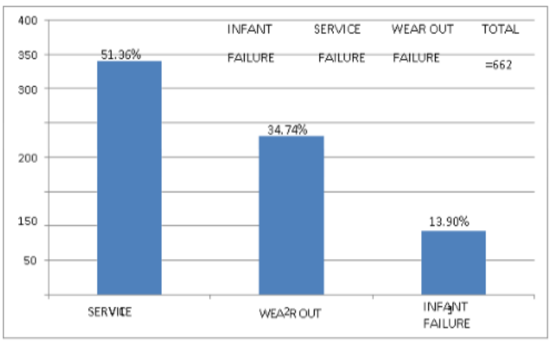
RELIABILITY GRAPH



PARETO ANALYSIS

A Pareto Chart is generally shown as a vertical bar chart. A Pareto Chart is a special form of a histogram where the categories have been sorted from most frequent to least frequent. One would not want to sort the categories from most frequent to least frequent if there is a natural order to the categories, such as a distribution by age or cycle time.

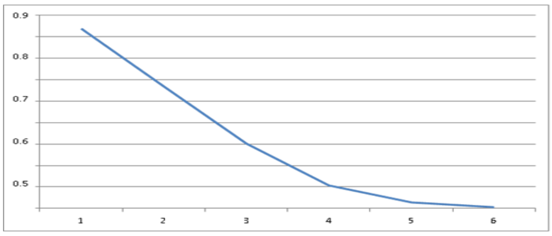
PARETO CHART FOR WAG-9 SPRING



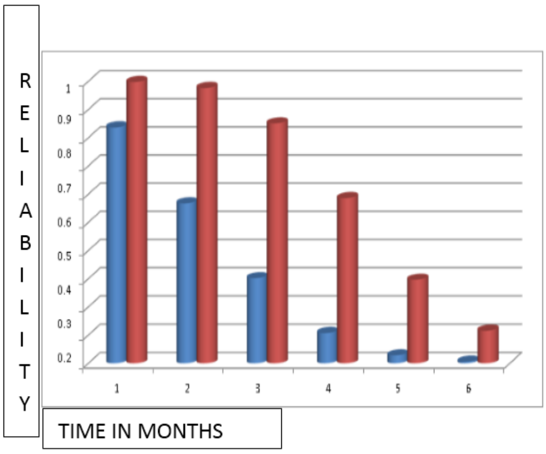
FAILURE ANALYSIS OF WAG-9 SPRING

The failure data collected from loco shed of WAG-9 Engine where the total 32 nos. of spring are used to attach in end, middle outer and inner axle. The failure of spring of 12 month was collected and failure density, failure rate, number of failure and reliability of all spring are calculated and observed that how much are failed in service, wear out and infant failure.

SYSTEM RELIABILITY GRAPH



RELIABILITY IMPROVEMENT OF SPRING



From the above analysis it is observed that the reliability of spring can be increased by using parallel, series and mixed operation of reliability data and following graph clearly show that the reliability of system is increased.

RESULT AND CONCLUSION

The reliability of the springs is increased by adding End Axle spring into the WAG-9engine. This result will prove a milestone for future research work by the railway department.

Time in Month	System Reliability	Improved System Reliability	Increase in Reliability
1.	0.8361	0.9976	0.1615 = 16.15%
2.	0.5673	0.9764	0.4091 = 40.91%
3.	0.3019	0.8510	0.5491 = 54.91%
4.	0.1073	0.5859	0.4786 = 47.86%
5.	0.0282	0.2964	0.2682= 26.82%
6.	0.005587	0.1157	0.110= 11.01%

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