

Accelerated Lab Test Methodology for Steering Gearbox Bracket Using Fatigue Damage and Reliability Correlation

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ABSTRACT

In the modern automotive sector, durability and reliability are the most common terms. Customers are expecting a highly reliable product but at low cost. Any product that fails within its useful life leads to customer dissatisfaction and affects the reputation of the OEM. To eradicate this, all automotive components undergo stringent validation protocol, either in proving ground or in lab. This paper details on developing an accelerated lab test methodology for steering gearbox bracket using fatigue damage and reliability correlation by simulating field failure. Initially, potential failure causes for steering gearbox bracket were analyzed. Road load data was then acquired at proving ground and customer site to evaluate the cumulative fatigue damage on the steering gearbox bracket. To simulate the field failure, lab test facility was developed, reproducing similar boundary conditions as in vehicle. Based on the damage analysis, customized lab test sequence was developed and field failure was simulated with the existing design samples. Reliability analysis was carried out and reliable life in lab test was correlated with the field. Lab cycle target for the intended vehicle life was derived by comparing the fatigue damage and reliability correlation. Improved design of steering gearbox bracket was validated in the same test conditions and compared with the life of existing design.

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INTRODUCTION

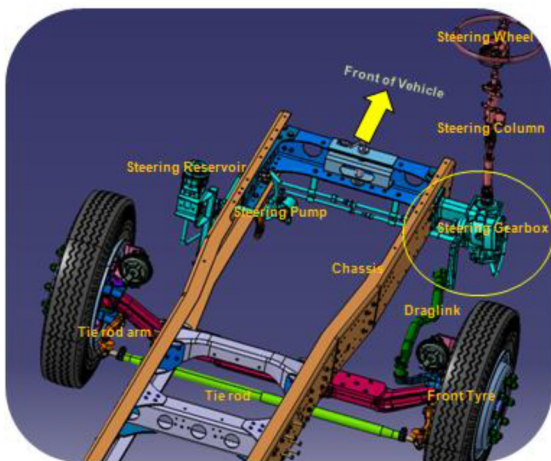


Figure 1. Steering system of an automotive vehicle

Steering system controls the direction of an automotive vehicle; thus, its components should be designed for higher durability and reliability. During product development stage, steering gearbox bracket designs were validated in our customized proving ground. Even though after design validation, few failures of steering gearbox

bracket were reported at the customer site (Refer Figure-1&2). Hence, it was decided to revalidate the steering gearbox bracket but at a shorter span of time, culling for an accelerated test [1].

The forces acting on the steering gearbox are directly transferred to the bracket which is used to integrate it with vehicle chassis.

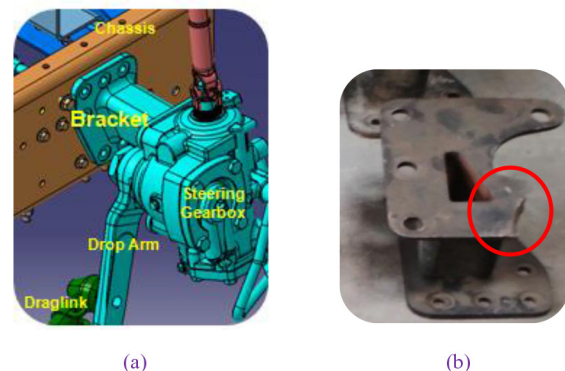


Figure 2. a) Steering gearbox bracket assembly b) a field failure sample

FIELD FAILURE ANALYSIS

Field Data Analysis

Field failure data of steering gearbox bracket was collated and reliability analysis was performed to infer the failure trend [2, 3]. Weibull plot made the best fit with a correlation coefficient of 0.988 as shown in Figure-3.

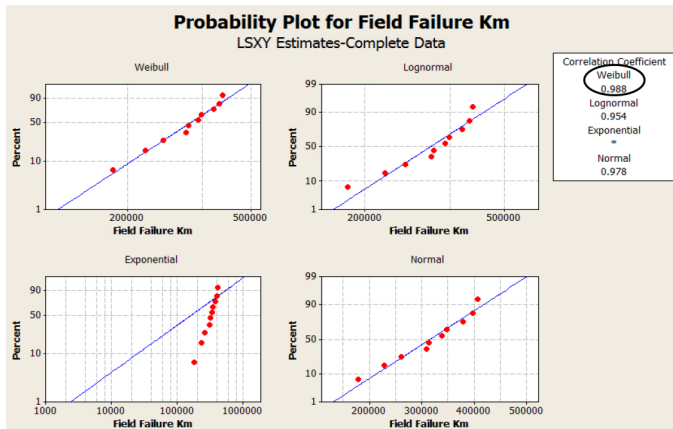


Figure 3. Distribution analysis

From the reliability analysis (Table-1&2), it was found that 10% of failures (B10 Life) occur at 205,245 km, whereas the intended vehicle life is 500,000 km. The shape factor(β) and scale factor(η) were 4.30 and 346,234 respectively.

Note: Percentile represents the estimated field failure kilometer. This result will be referred in the later sections to compare with lab testing.

Table 1. Characteristics of Distribution

	Estimate	Standard Error	50.0% Normal CI Lower	Upper
Mean (MTTF)	315147	25843.2	298190	333069
Standard Deviation	82745.3	27343.7	66213.1	103405
Median	317967	27312.7	300069	336933

Table 2. Probability table of field failure data

Percent	Percentile	Standard Error	50.0% Normal CI Lower	Upper
1	118889	49957.6	89547.5	157845
2	139831	50251.0	109732	178185
3	153828	49812.8	123646	191378
4	164660	49168.8	134622	201399
5	173632	48452.8	143843	209591
6	181367	47713.4	151878	216581
7	188212	46971.7	159053	222717
8	194385	46237.2	165571	228212
9	200028	45514.8	171569	233209
10	205245	44806.8	177143	237805
20	244344	38546.9	219680	271777
30	272478	33568.9	250752	296088
40	296198	29759.0	276790	316965
50	317967	27312.7	300069	336933
60	339271	26681.2	321744	357753
70	361495	28484.6	342784	381227
80	386717	33552.5	364736	410023
90	420277	44061.7	391585	451073

Failure Cause Analysis

There are many probable reasons for failure of a component. Knowing the potential causes of failures is the fundamental to prevent them [2]. Figure-4 illustrates fishbone diagram to categorize the potential causes for failure of steering gearbox bracket [4,5].

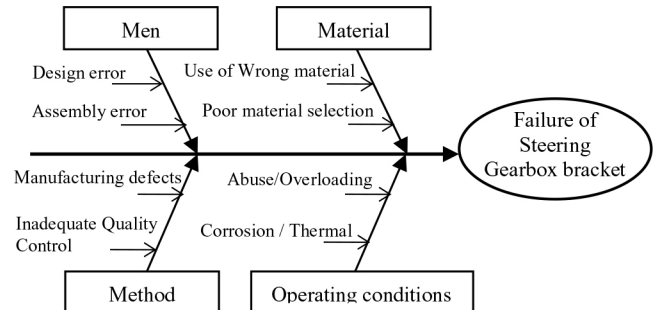


Figure 4. Fishbone diagram for steering gearbox bracket failure

Some variables that could be the causes of the failure were eliminated after detailed analysis of each case, and were not considered to be origin of failures. They are: Inadequate quality control, assembly error, corrosion/thermal environment. Thus, we focused on analyzing the major causes i.e. use of wrong material, manufacturing defects, design error and overloading.

Material Analysis

Chemical composition, microstructure and brinell hardness tests were conducted on three of the field samples to evaluate the failure causes.

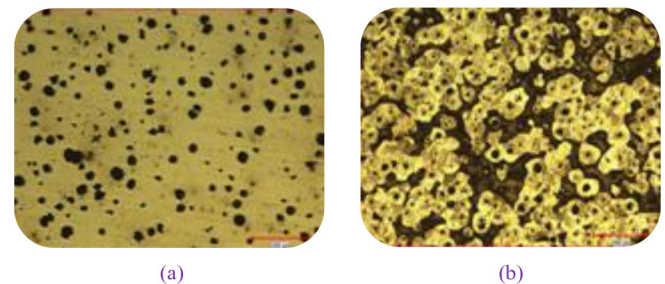


Figure 5. Material analysis a) Nodularity 80-90% b) Ferrite-Pearlite matrix

Additionally, tension testing was conducted on three sample specimens to evaluate mechanical strength of the material. Tested samples met the material specifications.

Table 3. Result of Material analysis

Details	Specification	Observation		
		Sample-1	Sample-2	Sample-3
Material Grade	SG 500/7	SG 500/7		
Hardness	160-240 BHN	212	207	223
Microstructure	Nodular graphite Nodularity: Graphite Form - V & VI Matrix - Ferrite Pearlite	Nodular graphite Nodularity: Graphite Form - VI Ferrite (50%) Pearlite (50%)		

From the results of metallurgical, hardness and tension testing (Refer Figure-5 and Table-3), it was found that the material meets the specification [6,7]. Also, there were no manufacturing defects present in the component [8]. Hence the quality and mechanical strength of the component were removed from the probable causes of failure.

Since the failure was neither due to improper material nor manufacturing defect; the focus was mainly on analyzing the forces and moments acting on the steering gearbox bracket.

Forces on Steering Gearbox Bracket

The road reactions are transmitted to the steering gearbox through draglink. Hence it induces forces and moments on the steering gearbox bracket. Additionally, the weight of the steering gearbox and its corresponding moment plays a significant role (Refer Figure-6).

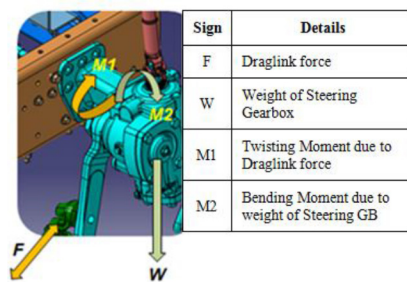


Figure 6. Forces and moments on the steering gearbox bracket

The steering gearbox design specifications are tabulated in Table-4. Calculated draglink force at 100% rated torque condition is 27.5 kN.

Table 4. Steering gearbox specification

Steering gearbox rated torque	T	6780 Nm
Drop arm length	L	0.246 m
Draglink force (at 100% rated torque)	F_R	27.5 kN

Draglink Calibration

To comprehend the forces acting on the draglink in field conditions, draglink was instrumented to acquire the strain corresponding to the forces in the field. For this, draglink was calibrated by applying a known force using hydraulic actuator (Refer Figure-7&8).

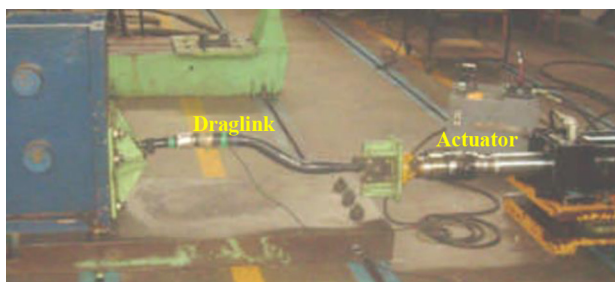


Figure 7. Draglink calibration setup

$$\text{Draglink force (kN)} = [0.0798 * \text{microstrain}] + 0.2676$$

(1)

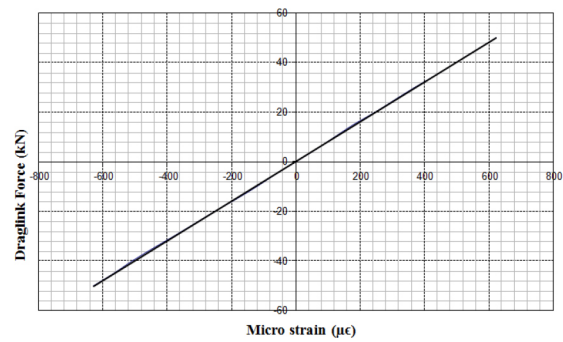


Figure 8. Draglink calibration plot

Equation-1 was used to convert the measured strain in terms of draglink force. Prior to field data acquisition, proving ground data was acquired to analyze the reason for not simulating the failure during its initial design validation process.

Proving Ground Data Acquisition and Analysis

The calibrated draglink was assembled in a 25T vehicle (field failure model) and the draglink force data was acquired at 6 of our PG tracks with laden and overload conditions (Refer Figure-9).



Figure 9. A few of our PG tracks a) Pavement b) High speed cornering

From the draglink force time history in Figure-10, the maximum tension and compression force on the draglink was 28.5 kN and -33.34 kN respectively [9].

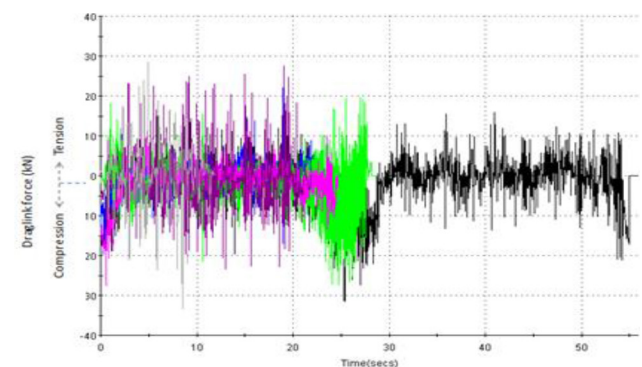


Figure 10. Draglink force time history in different PG tracks

From the analysis of draglink force distribution in Figure-11, 1% of the draglink force was greater than 27.5 kN (100% rated).