Overview of Durability and Reliability for Muffler Mounting Bracket in Automobiles

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Abstract

Durability and reliability of an automobile are equally important from industry as well as customer point of view. Automotive industries are still riddled with significant warranty costs that incur due to premature failure of their products in the customer hands. The key to reducing the design & development expenses and warranty expenses is to subject the product for reliability and/or durability tests for failure modes investigation. Design of the vehicle components must be adapted as accurately as possible to the operating conditions. In order to achieve these goals, durability tests are performed through a combination of physical testing, on road at a proving ground test track, and using a servo-hydraulic road test simulator in laboratory. Reliability is the measure of unanticipated interruptions or unexpected failures during customer use. During a reliability test, one important goal is to maximize the opportunities for observing unexpected failures, so that they can be fixed. Thus, durability life approval of individual components, individual assemblies and complete vehicle is main focus of automotive industries.

Keywords: *Durability, Reliability, Failure.*

1. Introduction

In automotive industry, vehicle safety and product quality are prime factors on which automotive manufacturers give significant attention. During vehicle manufacturing, defects arise during manufacturing, assembly and other processes. For continuous quality improvement and customer satisfaction, plant quality functions are planned, integrated and executed to detect these defects and make action plans, preventive measures to resolve them.

Currently, automotive industries are dedicating a lot of attention to improve product quality, durability and reliability already in a virtual simulation environment. A major issue that designers and manufacturers in this field have to face is to improve vehicle lifetime [1,2]. Durability and reliability of a vehicle are equally important from a customer point of view. Automotive industries are still riddled with significant warranty costs that incur due to premature failure of their products in the customer hands [3]. Vehicle manufacturers discover issues through their own vehicle tests, inspection procedures, or information gathering [2].

The demand for cost and weight reduction and for payload increase is priority in vehicle industry. Thus, vehicle design typically represents a trade-off between performance and safety, since durability, especially of safety components, is of great importance. For the development engineer this means that the design of the components must be adapted as accurately as possible to the operating conditions. In order to achieve these goals, durability tests are performed through a combination of physical testing, on road at a proving ground test track, and using a servo-hydraulic road test simulator in laboratory. Operating loads to which that vehicle has been subjected on a proving ground test track are simulated in laboratory wherever possible for cost and time reasons. A predetermined number of loading cycles on servo-hydraulic test machine simulate a specific number of kilometers traveled. Performing tests with several vehicles and observing any fatigue characteristics as deformations and/or cracks, the durability of the automobile can be determined. Thus, a central subject for the development department of automobile manufacturers is the durability life approval of individual components, individual assemblies and complete vehicle [4].

Modern vehicles exhibit a variety of performance, safety and comfort features in which they fundamentally differ from previous models. Whereas fuel dosage and the combustion process in former car generations were controlled by a throttle valve in interaction with a carburetor, nowadays electronic control units (ECU) calculate and provide the optimal amount of fuel and air for the effective load and engine speed. Besides innovative engine control, safety features like airbags, antilock braking systems (ABS), anti-skid systems, belt tensioners or the electronic stability program are standard fittings of present day car models and in some cases even stipulated by legislation. These safety systems have lead to an increased avoidance of accidents by actively affecting vehicle dynamics on the one hand and to a mitigation of the consequences of accidents on the driver and passengers by innovative restraint systems on the other hand. Comfort functions play an increasingly significant role in modern cars. This area comprises a large variety of features ranging from physical convenience, based on sophisticated air conditioning systems, over electrical adjustment devices for seats and rear view mirrors to innovative driver assistance systems such as distance radar or navigation systems. Durability and reliability in vehicle components are prime considerations for successful functioning of vehicles in all aspects mentioned above [5,6].

In automotive applications, engineering of components faces the concurrence of different complex profiles of requirements with partially contradictory demands which have to be met simultaneously [5]:

i. They have to fulfill their task in a harsh environment with high reliability over the entire lifetime of the vehicle;
ii. They have to ensure the necessary accuracy required by complex control functions;
iii. They have to be small and light;
iv. They must be producible in high volumes using low cost processes.

2. Theories and Practices

Senthilnathan Subbiah et al. [3] have made failure analysis of muffler mounting brackets of three-wheeler vehicles observed during the durability test. Many possible causes of the failures were identified using fishbone diagram. Analysis of the design suggested that bracket was acting as a cantilever beam with one-plane welding mounted on the engine cradle. D. G. Yang et al. [6] have investigated the effect of high temperature aging on the thermo-mechanical properties, microstructure of the moulding compounds for packaging in automotive electronics. With the strong increase of electronics in the car, the potential chance for failures is likely to increase, if no measures to ensure the reliability would be taken. Furthermore, the demand for high temperature application electronics in automotive has increased tremendously during last few years. Aging-induced shrinkage was found for all the samples of packaging polymers. Oxidation is believed to be the major mechanism for the changes of microstructure and degradation of material properties. Cracks were generated in some samples due to these reasons.

J. M. Gallardo et al. [7] have investigated service failures in automobile shock absorbers and made failure analysis. In this case, several service failures had occurred at the head of shock absorbers manufactured by the same company. Main reasons for failure were found as undesirable porosity, cracks, inclusions and low strength microstructures developed during welding. Failure, nevertheless, was mainly attributed to a poor alignment of the junction parts during the welding operation. J. J. Fuentes et al. [8] have studied premature fracture in automobile leaf springs. Common failure diagnosis methods involving examination of manufacturing and failure histories, macroscopic inspection, chemical analysis, metallographic analysis, hardness measurements, static loading tests and fatigue tests, were employed. Various potentially effective remedial actions are proposed such as minimizing stress concentrators resulting from design, metallurgical or manufacturing factors, the use of a bolt threaded only at its ends.

3. Reliability Technology for Assessing Lifetime

Quality is defined as a characteristic ensuring that a product meets the requirements and expectations of the customer when shipped to and put into operation by the user and reliability is the sum of all characteristics of a device concerning its ability to achieve specified requirements under well-defined conditions over a given period of time [5]. In this sense reliability is a constituent of quality and describes the changing of quality over time. The basic parameter to quantify the reliability of a device and to give a numerical definition is the lifetime, defined as the mean time to failure (MTTF). Definitions of quality and reliability comprise specific customer expectations, well-defined conditions of use and an intended cycle life. Quantifying reliability means to make predictions about the lifetime and the failure probability. The most widely used probability functions are [5]:

1. The reliability function $R(t)$: Fraction of units still in operation after time t.

2. The cumulative distribution function *F(t)*: Fraction of units that failed after time t.
3. The probability density function (PDF) *f(t)*: Fraction of original population that fails between time *t* and *t*+d*t*.
4. The failure rate h(*t*): Fraction of the remaining population at time *t* that fails between time *t* and *t*+d*t*.

If the lifetime distribution is known, the statistical average lifetime itself can be calculated on the basis of the mean time to failure MTTF as,

$$\text{MTTF} = \frac{\int_0^{\infty} t\,.\,f(t)\,dt}{\int_0^{\infty} f(t)\,dt}$$

4. Durability Test on Muffler Mounting Bracket

Senthilnathan Subbiah et al. [3] have performed durability tests on muffler mounting bracket of three wheeler vehicle and made failure analysis for it. Accordingly changes were made in the design of mounting brackets. Figure 1 shows muffler mounting brackets on engine cradle.

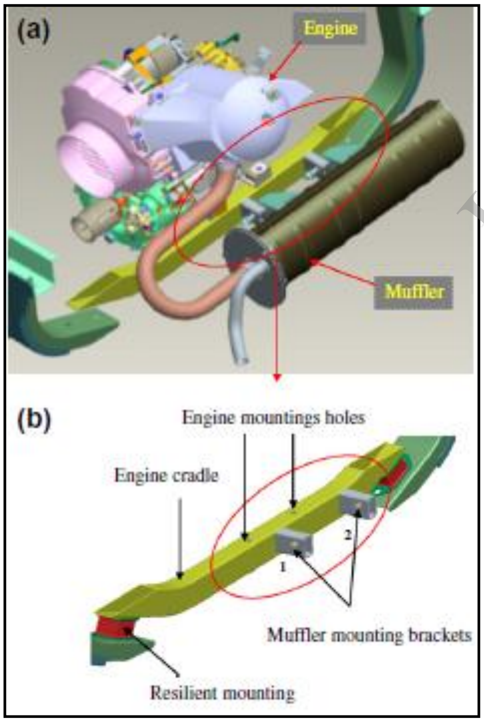

Figure 1. (a) Muffler and engine mounting system on the engine cradle and (b) Engine cradle showing the design of the two muffler mounting brackets [3].

Both engine and mufflers are mounted on an engine cradle. The muffler is mounted on two brackets (1 & 2). The muffler adjoins the each bracket from one side and they are fastened together with plain bushes. These plain bushes are welded to the mounting brackets and these brackets are in turn welded to the engine cradle.

4.1 Durability Test Background

The durability testing consists of city, rural, torture and highway tracks. Each track has a specific range of road profile. The rural and torture track durability are accelerated road testing and the city and highway durability are very similar to the end user road load pattern. The durability driving patterns were arrived based on the customer usage patterns in the field. Each vehicle run consists of the different loading patterns for particular kilometres and in cumulative it is taken as one cycle. These cycles varies based on the type of durability testing. Though this type of testing is really time and energy consuming it simulates the very practical conditions. This type of accelerated testing is done to find the actual durability life of the vehicles. Failure was observed at average distance of 10,000 km. The weld cracks were identified, as shown in figure 2, through a non-destructive method called dye penetrant inspection (DPI).

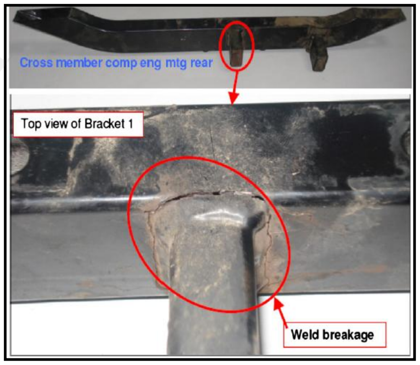

Figure 2. Failed bracket at 14,402 km [3].

4.2 Root Cause Failure Analysis

The four main causes of the failures are identified as man, method, material and design in fishbone diagram. The first three causes viz. man, method and material would result in weld related defects like incomplete penetration, incomplete fusion, undercutting, bad weld design, metallurgical failures etc. Analysis of the relationships suggests that one-plane welding (design problem), bracket acting as a cantilever beam (design problem), concentricity between the two bushes (design problem), high thermal stresses due to radiation effect (design problem) and less CO_2 weld penetration (man skill problem) has a strong influence on the weld failure. Detailed quality checks were conducted on weld materials and welding processes. Weld quality was as per standards. One-plane welding of bracket to cradle, which resulted in bracket acting as a cantilever beam would result in high stresses at the weld location. Further, since the muffler is placed in the proximity to the brackets, thermal stresses in the weld can develop due to high temperature. However, since the measured temperature of the weld and brackets were less than 80^0C, failure investigation due thermal stresses was not considered. Concentricity between the two bushes is also important to avoid additional stresses induced during operation. However, the two bush axes were in same plane. Fishbone diagram analysis indicates that the design of the bracket could be the reason for the weld failure.

The data collected from the field failures was examined using Weibull statistical distribution to draw insights into the failures and to determine the cause-effect patterns. Also FEM analysis was carried out for existing design. Both resulted in root cause as behaviour of bracket as cantilever beam causing higher stresses in weld area of engine cradle and brackets.

4.3 Design Modifications in Bracket to avoid Failure

To facilitates two-plane welding at bracket-engine cradle interface, instead of a single-plane welding as seen in the previous design, the rectangular bracket design is changed to the 'L' section as shown in the figure 3.

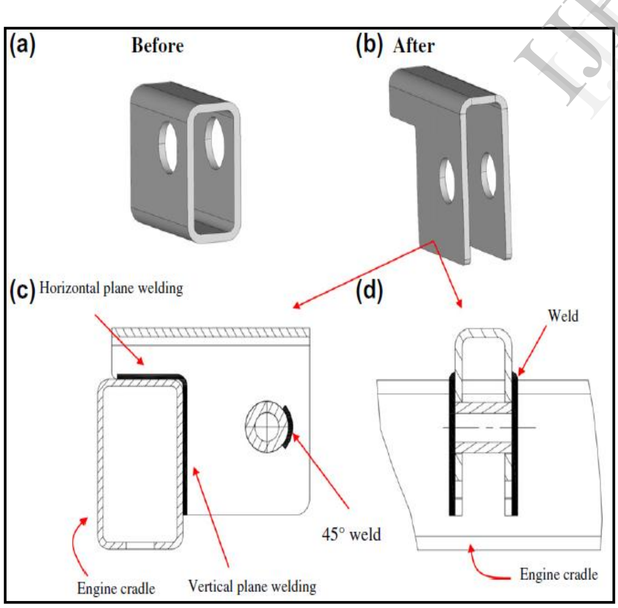

Figure 3. (a) Old design of the bracket (b) 'L' type new design of the bracket (c) Side view: line diagram for the new 'L' type bracket design (d) rear view [3].

In this design the failure mode of mounting bracket getting crack at the weld location between the cradle and bracket got totally eliminated. However, a new failure mode of bush weld crack on both sides of bracket was noticed. The bush-bracket coupling becomes weaker not only because the loss of constrain generated by the incompleteness of the welded seam, but, moreover, due to the notch effect of the slot which produces stress concentration in this zone. To increase the weld ability of the bush the bracket was modified. An 'L' type relief (cut) was provided on the bottom of the bracket to increase the accessibility of the bush welding (Figure 4). The weld area has now increased from 45^0 to 180^0.

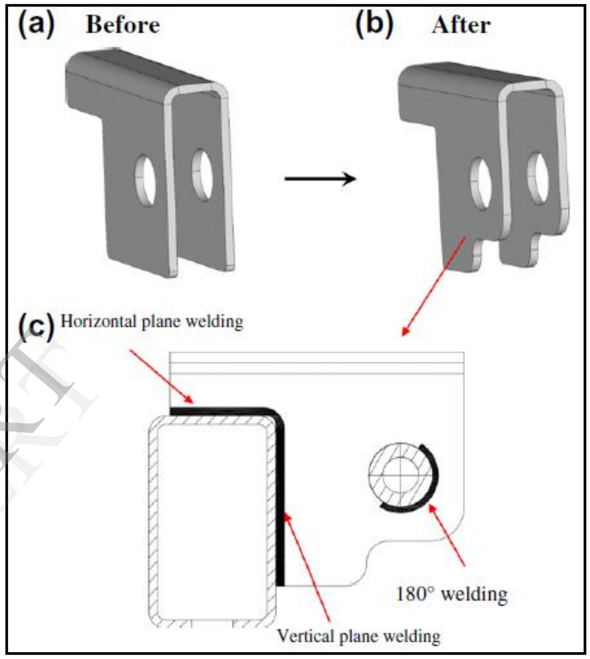

Figure 4. (a) Old 'L' type design of the bracket (b) New 'L' type design with 'L' relief at the bottom (c) Weld area is increased by 180^0 in the new design [3].

5. Conclusion

i. Durability and reliability of vehicle are prime factors in automotive sector for successful performance of vehicle over longer time.
ii. Reliability in automobiles is very essential for performance, safety as well as comfort aspects.
iii. Durability tests and failure analysis for muffler mounting bracket was carried out by Senthilnathan Subbiah et al. [3].
a) Root cause of failure was 'Cantilever beam type behaviour of bracket'.
b) Old design of bracket was changed to 'L' type new design.
c) The new design of the system passed the durability target of 1,00,000 km.

6. References

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