Service Loads Prediction in the Reliability Characterisation of Automotive Rear Axle System

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INTRODUCTION

Reliability is an important factor for the evaluation of quality in the automotive industry. Mechanical reliability is dependent on many variables such as the materials, production methods, general dimensions and product architecture, environment of use, as well as human factors. In the past, reliability was determined through prototype testing as well as actual field testing. Results from the testing would then be used by the design department for future improvement.

This post-design approach in determining reliability is inappropriate for an integrated product development process that aims to incorporate engineering lifecycle requirements from the early stage [1]. In today's product development process, reliability characterisation by prediction seems to be the most promising approach, as it will enable reliability to be designed into products from the concept design stage, hence reducing design rework and development cost.

Service loads are the most important factor to be considered in the reliability characterisation of automotive components. Components such as the rear axle system are subjected to stochastic physical failures due to uncertainties in the service loads arising from driving conditions and the operating environment. Uncertainties in the service loads are known to be a factor in the fatigue failure of automotive components [2]. In this case, an accurate method in predicting the service load is important since it permits design reliability estimates to be made for operation under conditions of variable load amplitude using cumulative damage theories as proposed by the Palmgren-Miner rule [2]. Design reliability estimates employing the Palmgren-Miner rule is illustrated in Figure 1.

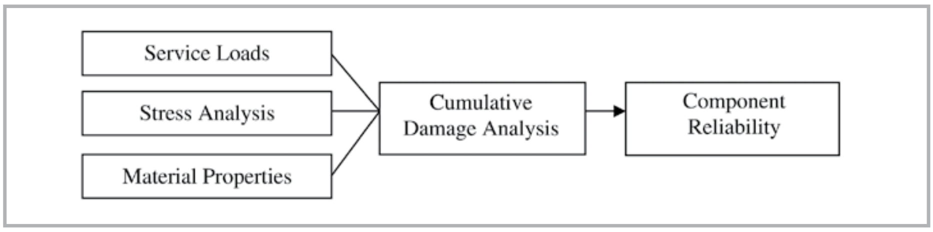

Figure 1: The cumulative damage analysis process

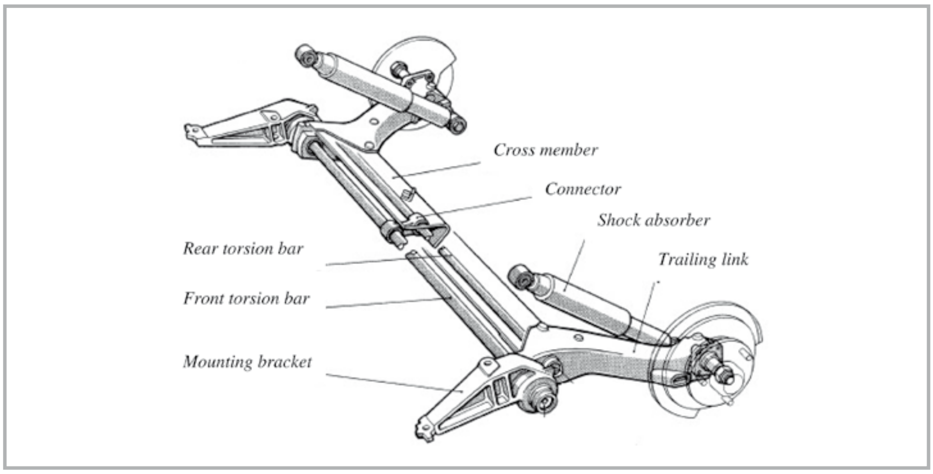

Figure 2: The torsion bar rear axle [4]

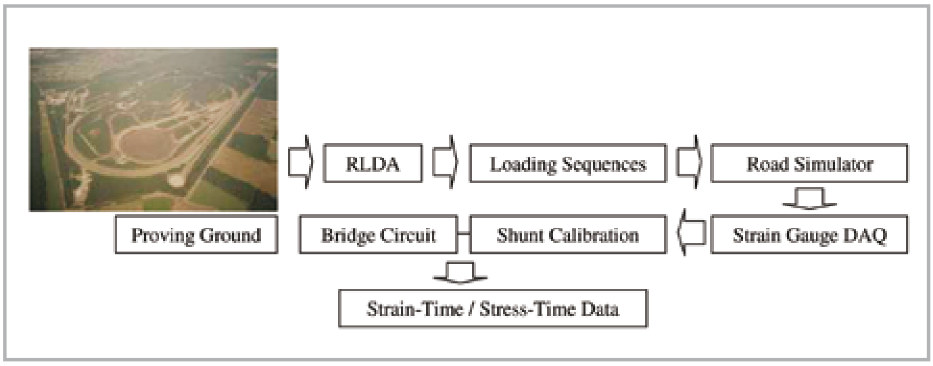

Figure 3: Strain-time data acquisition based on proving ground load sequences

AUTOMOTIVE REAR AXLE

The rear axle is a module in the automotive suspension system which is responsible for directing the forces and moments that operates in the wheel contact area into the body. Apart from this, the rear axle also helps in reducing the rolling stiffness of the tyres and short-stroke movements in a longitudinal direction resulting from the road surface [3]. This paper will focus on the torsion beam axles which are mainly used as a form of rear wheel suspension in frontwheel drive vehicles. The torsion beam axles is an extremely compact four-bar twist beam axle with two torsion bar springs both for the left and right axle sides as shown in Figure 2.

Besides the torsion bars, each left and right side of the axle is also supported by five other components which are the mounting bracket, trailing links, shock absorber, connector and the cross member.

There are several forces and moments which operate in the rear axle due to various environmental and operating

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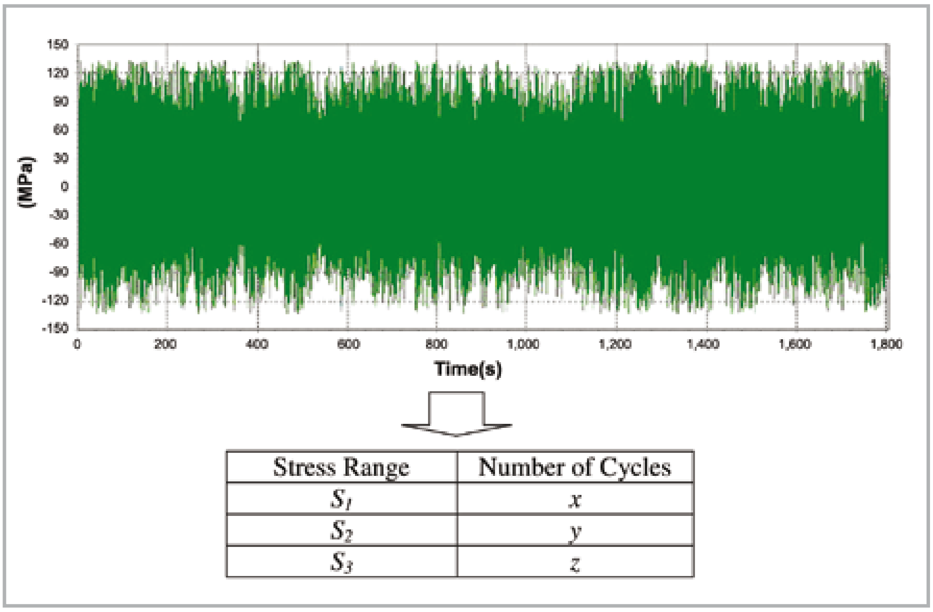

Stress Range	Number of Cycles
S_1	x
S_2	y
S_3	z

Figure 4: Decomposition of irregular stress-time history by rainflow cycle counting

conditions. Lateral wheel forces resulting from driving and braking operations while cornering results in twist and spindle bending forces.

DATA ACQUISITION

Description of the operating environment is a vital component in the service load prediction process [5]. The goal is to develop an accurate representation of the loads, deflections, strains, noise, vibration, *etc.*, that would likely be experienced during the total operating life of the component. Loading sequences are constructed from load histories measured and recorded during specific operations. In the case of automotive components, loading sequences are acquired using the Road Load Data Acquisition (RLDA) activity where the load-time histories of accredited proving ground are obtained.

The RLDA activity is normally established using a vehicle equipped with an electronic data acquisition system (EDAQ). The system, which consists of accelerometers and force transducers, is capable of sensing inclination, vibration and shock experiences by the vehicle's components as it progress along the path of proving ground. The acquired loading sequences data from the RLDA is utilised as input in the system and component level fatigue durability test using spindle coupled road simulator. In this process, a complete build vehicle unit in floating body condition or complete system mounted on a four-stokes rig is tested using a multiaxial road simulator machine. This servo hydraulic actuators equipped machine is capable of generating RLDA recorded loading patterns in vertical, lateral and longitudinal as well as moments in lateral direction.

Mechanical and structural behaviours of components subjected to the RLDA acquired load patterns are observed using strain gauges. Torsion, bending and axial strain gauges are strategically positioned to directly reflect the input loads experienced by the component or structure. The quarter bridge circuit as well as shunt calibration is applied in order to convert electrical units measured by the strain gauge into random strain-time and stress-time data. The complete process of data acquisition is illustrated in Figure 3.

DATA ANALYSIS

Cycle Counting

The response of structure or components towards load patterns is usually expressed as a strain or stress time history. In cases where the response time history is made up of constant amplitude stress or strain cycles, then the cycle-to-failure can be determined using the typical S-N diagram [6]. However, in the case of the torsion bar rear axle, this condition does not apply where the load-time histories obtained from the road simulator are generally in the form of variable amplitude stress signals. This condition requires an empirical approach to be applied in order to evaluate the damage caused by the stress signals. In this case, rainflow cycle counting is used to decompose the irregular stress-time history obtained from the road simulator into the number of cycles and stress range as shown in Figure 4.

Employing the Palmgren-Miner rule along with the rainflow cycle counting procedure, life estimates in terms of the cycle-to-failure of components can be made as shown in Figure 5.

EXTRAPOLATION OF SERVICE LOADS

Service loads is an important factor to be considered in the determination of the service life of automotive components. However, due to the constraints of development time, stress-time histories obtained from the road simulator are limited to a certain period of time [7]. In this case, it is important to precisely estimate the load history for a full design life. The extrapolation of service loads obtained from limited load history data permits a simulation of full life service loads to be made in a compressed time frame.

Rainflow cycle counting registers irregular load-time histories to a fixed number of load levels, as shown in Figure 4, which enables efficient storage of the cycles in the form of a matrix. The rainflow matrix represents each of the closed amplitude loops in the irregular load-time histories by its minimum amplitude (Y-axis) and maximum amplitude (X-axis) as well as the number of cycle of a certain amplitude range (coloured histomap) as shown in Figure 6.

Rainflow matrix extrapolation can be achieved using range-pair filtering and peak-valley definition as the repeating factor, N. In this case, rainflow matrix F can be extrapolated until the desired design life as illustrated in Equation 1.

$$F_{life} = N \times F \qquad (1)$$

ESTABLISHMENT OF SERVICE LOAD PROFILE

The next phase of data analysis is calculating the optimal mix of test track sequences and events that match actual kilometres target. In this case, a number

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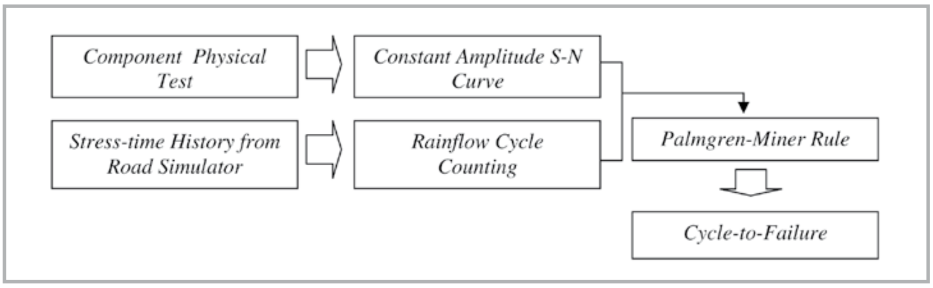

Figure 5: Life estimates of components using the Palmgren-Miner rule

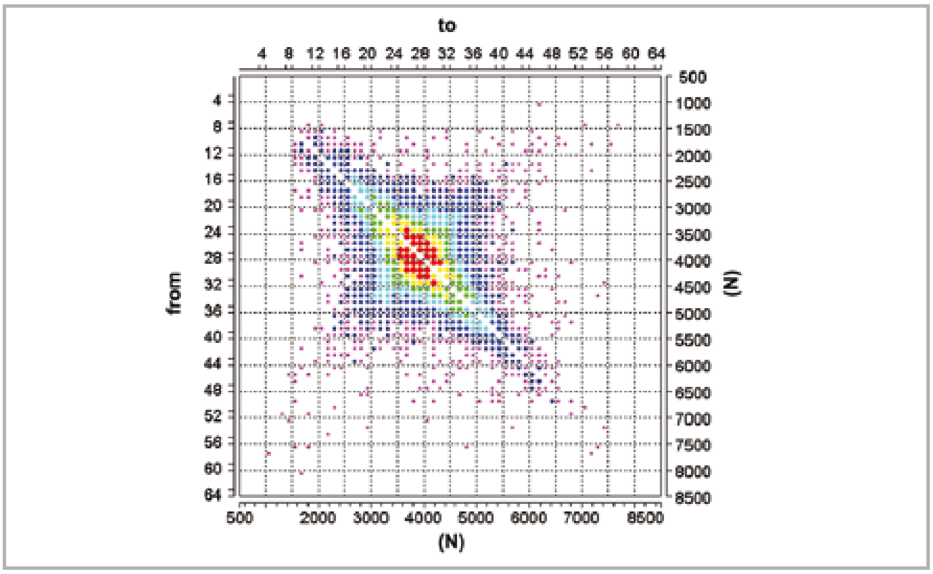

Figure 6: Rainflow matrix representing stress range and the number of occurrences of cycle for each stress range

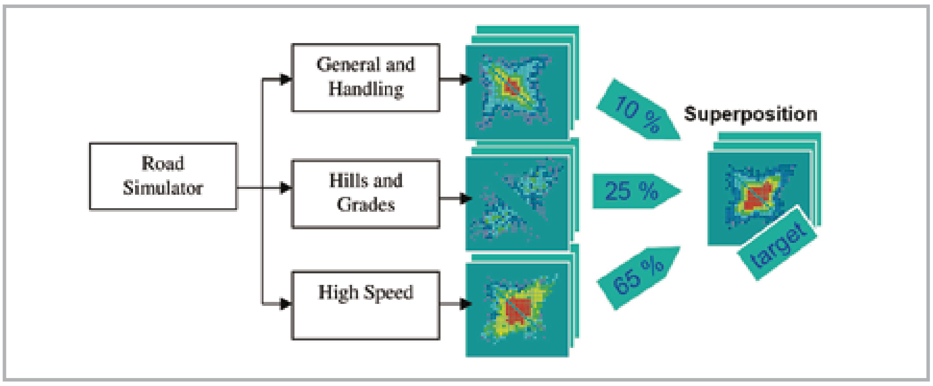

Figure 7: Rainflow matrix superposition [8]

of track sequences such as general and handling, gravel, comfort, high speed, as well as hills and grades, are optimally combined in order to replicate real service load profile. Figure 7 shows the rainflow matrix superposition method applied to merge all the extrapolated rainflow matrices obtained from the road simulator.

CONCLUSION

The prediction of service loads is demonstrated for automotive torsion bar rear axle system. RLDA activity replicate proving ground load pattern for the accelerated durability test using road load simulator. The response of structure and components towards load patterns are expressed in terms of irregular stress-time data, and the rainflow cycle counting is used in order to decompose the data into number of cycles and stress range. Fixed numbers of load levels attained from the rainflow cycle counting are expressed in the form of a matrix, where it is extrapolated to simulate full life service loads in a compressed time frame. The establishment of the service load profile is carried out using rainflow matrix superposition where a number of track sequences are optimally combined.

Utilising damage accumulation method such as the Palmgren-Miner rule, accurate service loads prediction offers precision in determining the life of components and system. Furthermore, the accuracy of cycle-to-failure resolved from this damage accumulation technique is significant in reliability characterisation of components and system. ■

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