International Journal of Advanced Computer Research (ISSN (print): 2249-7277 ISSN (online): 2277-7970)
Volume-2 Number-4 Issue-6 December-2012

A Review of the Fatigue Analysis of an Automobile Frames

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Abstract

In this paper an effort is made to review the investigations that have been made on the different fatigue analysis techniques of automobile frames. A number of analytical and experimental techniques are available for the fatigue analysis of the automobile frames. Determination of the different analysis around different condition in an automobile frames has been reported in literature.

Keywords

Fatigue life prediction, Automotive Vehicles.

1. Introduction

Fatigue as a technical problem became evident around the middle of the 19th century. About 100 years later, in the middle of the 20th century, the development of fatigue problems were reviewed in two historical papers by Peterson in 1950 and Timoshenko in 1954. Both authors were already well-known for important publications. Peterson reviewed the discussion on fatigue problems during meetings of the Institution of Mechanical Engineers at Birmingham held just before 1850. He also mentioned historical ideas about fatigue as a material phenomenon and the microscopic studies carried out by Gough and co-workers and others around 1930. Peterson also refers to the concept of the 'endurance limit', as already defined by Wohler. The endurance limit is generally referred to as the fatigue limit which is an important material property for various engineering predictions on fatigue.

Fatigue failures occur due to the application of fluctuating stresses that are much lower than the stress required to cause failure during a single application of stress. It has been estimated that fatigue contributes to approximately 90% of all mechanical service failures. Fatigue is a problem that can affect any part or component that moves. Automobiles on roads, aircraft wings and fuselages, ships at sea, nuclear reactors, jet engines, and land-based turbines are all subject to fatigue failures. Fatigue was initially recognized as a problem in the early 1800s when investigators in Europe observed that bridge and railroad components were cracking when subjected to repeated loading.

The age of many truck chassis are of more than 20 years and there is always a question arising whether the chassis is still safe to use. Thus, fatigue study and life prediction on the chassis is necessary in order to verify the safety of this chassis during its operation. Truck chassis used in off-road vehicles have almost the same appearance since the models were developed more than 30 years ago. This indicates that the evolution of these structures is still slow and stable along the years [1]. Many researchers in the automotive industry have taken this opportunity to be involved in the chassis manufacturing technology and development [2].

Even recently, April 1st 2011, Southwest Flight 812 suffered from a catastrophic fatigue fracture which happened 18 minutes into its flight. The fuselage skin ripped open causing a massive loss in cabin pressure and was forced to land on a remote military base in Yuma, Arizona. The cause of the damage isn't always apparent due to the nature of fatigue fracture often occurring at low stresses and elevated temperatures in most materials. It is accidents like this one that have been a leading motivation in fatigue research.

Fatigue design is one of the observed modes of mechanical failure in practice. For this reason, fatigue becomes an obvious design consideration for many structures, such as aircraft, bridges, railroad cars, automotive suspensions and vehicle frames. For these structures, cyclic loads are identified that could cause fatigue failure if the design is not adequate. The basic elements of the fatigue design process for any kind of engineering structures are illustrated in Figure 1.

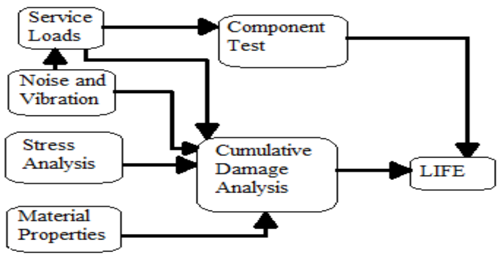

Figure 1: The basic elements of the fatigue design process [3]

Service loads, noise and vibration:
Firstly, a description of the service environment is obtained. 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.
Stress analysis:
The shape of a component or structure and boundary conditions dictates how it will respond to service loads in terms of stresses, strains and deflections. Analytical and experimental methods are available to quantify this behaviour.
Material properties:
A fundamental requirement for any durability assessment is knowledge of the relationship between stress and strain and fatigue life for a material under consideration. Fatigue is a highly localized phenomenon that depends very heavily on the stresses and strains experienced in critical regions of a component or structure.
Cumulative damage analysis:
The fatigue life prediction process or cumulative damage analysis for a critical region in a component or structure consists of several closely interrelated steps as can be seen in Figure 1, separately. A combination of the load history (Service Loads), stress concentration factors (Stress Analysis) and cyclic stress-strain properties of the materials (Material Properties) can be used to simulate the local uniaxial stress-strain response in critical areas.

2. Factors affecting the fatigue life of an automobile frames

There are number of parameters which affect the fatigue life of the structure as listed: Cyclic stress state, Geometry, Surface quality, Material Type, Residual stresses, Size and distribution of internal defects, Direction of loading & Grain size.

3. Early fatigue analysis research history of an automobile frames

Many researchers carried out study on truck body components. Karaoglu and Kuralay [4] investigated stress analysis of a truck chassis with riveted joints using FEM. Numerical results showed that stresses on the side member can be reduced by increasing the side member thickness locally. Fermer et al[5] investigated the fatigue life of Volvo S80 Bi-Fuel using MSC/Fatigue. Conle and Chu [6] did research about fatigue analysis and the local stress-strain approach in complex vehicular structures. Structural optimization of automotive components applied to durability problems has been investigated by Ferreira et al [7]. Fermer and Svensson [8] studied on industrial experiences of FE-based fatigue life predictions of welded automotive structures. Filho *et. al.* [9] have investigated and optimized a chassis design for an off road vehicle with the appropriate dynamic and structural behavior.In1837, Wilhelm Albert publishes the first article on fatigue. He devised a test machine for conveyor chains used in the Clausthal mines[10] and in1842,William John Macquorn Rankine recognises the importance of stress concentrations in his investigation of railroad axle failures. The Versailles train crash was caused by axle fatigue [11].

4. Fatigue damage concepts

Stress-Life Diagram (S-N Diagram): The basis of the Stress-Life method is the Wohler S-N diagram, shown schematically for two materials in Figure 2.The S-N diagram plots nominal stress amplitude S versus cycles to failure N. There are numerous testing procedures to generate the required data for a proper S-N diagram. S-N test data are usually displayed on a log-log plot, with the actual S-N line representing the mean of the data from several tests.

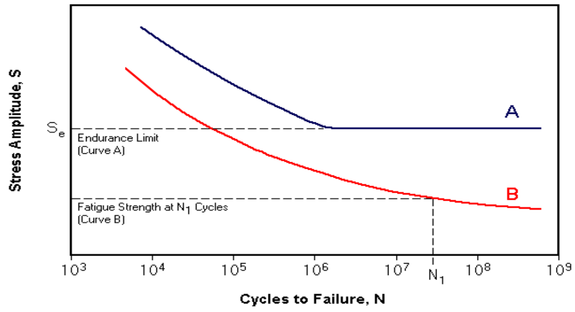

Figure 2: S-N diagram

Endurance Limit: Certain materials have a fatigue limit or endurance limit which represents a stress level below which the material does not fail and can be cycled infinitely. If the applied stress level is below the endurance limit of the material, the structure is said to have an infinite life. This is the characteristic of steel and titanium in benign environmental conditions. A typical S-N curve corresponding to this type of material is shown Curve A in Figure 2.

Miner's rule: In 1945, M. A. Miner popularized a rule that had first been proposed by A. Palmgren in 1924. The rule, variously called Miner's rule or the Palmgren-Miner linear damage hypothesis, states that where there are k different stress magnitudes in a spectrum, S_i ($1 \le i \le k$), each contributing $n_i(S_i)$ cycles, then if $N_i(S_i)$ is the number of cycles to failure of a constant stress reversal S_i, failure occurs when:

$$\sum_{i=1}^{k} \frac{ni}{Ni} = C$$

C is experimentally found to be between 0.7 and 2.2. Usually for design purposes, C is assumed to be 1.

Paris' Relationship: In Fracture mechanics, Anderson, Gomez and Paris derived relationships for the stage II crack growth with cycles N, in terms of the cyclical component ΔK of the Stress Intensity Factor K [12]

$$\frac{da}{dN} = C(\Delta k)^m$$

Where a is the crack length and m is typically in the range 3 to 5 (for metals).This relationship was later modified (by Forman, 1967) to make better allowance for the mean stress, by introducing a factor depending on (1-R) where R = min stress/max stress, in the denominator.

Crack Initiation and Propagation: Failure of a material due to fatigue may be viewed on a microscopic level in three steps:

1. **Crack Initiation:** The initial crack occurs in this stage. The crack may be caused by surface scratches caused by handling, or tooling of the material; threads (as in a screw or bolt); slip bands or dislocations intersecting the surface as a result of previous cyclic loading or work hardening.
2. **Crack Propagation:** The crack continues to grow during this stage as a result of continuously applied stresses.
3. **Failure:** Failure occurs when the material that has not been affected by the crack cannot withstand the applied stress. This stage happens very quickly.

Mean Stress Effects: Most basic S-N fatigue data collected in the laboratory is generated using a fully-reversed stress cycle. However, actual loading applications usually involve a mean stress on which the oscillatory stress is superimposed. The following relations are available in the Stress-Life module:

Goodman (England, 1899): $\frac{S_a}{S_e} + \frac{S_m}{S_u} = 1$

Gerber (Germany, 1874): $\frac{S_a}{S_e} + (\frac{S_m}{S_u})^2 = 1$

Soderberg (USA, 1930): $\frac{S_a}{S_e} + \frac{S_m}{S_y} = 1$

Morrow (USA, 1960s): $\frac{S_a}{S_e} + \frac{S_m}{\sigma_f} = 1$

A graphical comparison of these equations is shown in Figure 3. The two most widely accepted methods are those of Goodman and Gerber. Experience has shown that test data tends to fall between the Goodman and Gerber curves. Goodman is often used due to mathematical simplicity and slightly conservative values.

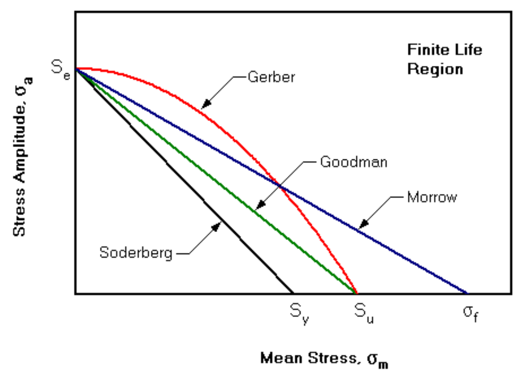

Figure 3: Comparison of Mean Stress Effects

5. Design against fatigue

Dependable design against fatigue-failure requires thorough education and supervised experience in structural engineering, mechanical engineering, or materials science. There are three principal approaches to life assurance for mechanical parts that display increasing degrees of sophistication:

- Design to keep stress below threshold of fatigue limit (infinite lifetime concept).
- Design (conservatively) for a fixed life after which the user is instructed to replace the part with a new one (a so-called lifted part,

finite lifetime concept, or "safe-life" design practice).

- Instruct the user to inspect the part periodically for cracks and to replace the part once a crack exceeds a critical length. This approach usually uses the technologies of nondestructive testing and requires an accurate prediction of the rate of crack-growth between inspections. This is often referred to as damage tolerant design or "retirement-for-cause".

6. Different types of methods and applications of fatigue analysis

Sr no	Author	Year	Method used	Area where it was used
1	Devlukia and Bargmann [13]	1997	the deterministic and probabilistic approaches	assessment of a suspension arm
2	Haiba *et al.*[14]	2002	finite element analysis (FEA)	A real automotive engineering.
3	Kim *et al.*[15]	2003	finite element program of HydroFORM-3D	an automobile lower arm
4	Fatemi and Zoroufi [16]	2004	using FEA, the durability assessment and an optimization analysis	A wide range of automotive and other components.
5	Zoroufi and Fatemi [17]	2006	constant-amplitude load-controlled fatigue tests	vehicle suspension components
6	Roslan Abd Rahman, Mohd Nasir Tamin [18]	2008	FEM(finite element method)	Stress analysis of truck chassis
7	CICEK KARAO GLU AND N. Sefa Kuralay [19]	2001	FEM(finite element method)	Stress analysis of a truck chassis with riveted joints.

Roslan Abd Rahman, Mohd Nasir Tamin [18] did the stress analysis of heavy duty truck chassis. The stress analysis is important in fatigue study and life prediction of components to determine the critical point which has the highest stress which is shown in fig 4. The analysis was done for a truck model by utilizing a commercial finite element packaged ABAQUS.

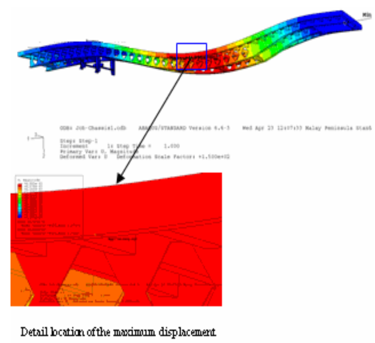

Fig 4: Displacement distribution of truck frame

Cicek Karao glu and N. Sefa Kuralay [19] did the finite element analysis of a truck chassis as shown in fig 5.The analysis showed that increasing the side member thickness can reduce stresses on the joint areas, but it is important to realize that the overall weight of the chassis frame increases. Using local plates only in the joint area can also increase side member thickness. Therefore, excessive weight of the chassis frame is prevented.

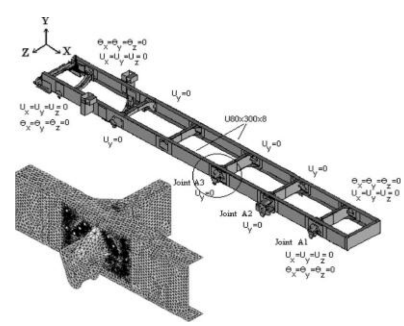

Fig 5: Truck chassis model

7. Conclusions

In this paper an effort is made to review the investigations that have been made on the fatigue analysis of various automobile frames. An attempt has been made in the article to present an overview of various techniques developed for the analysis of automobile frames. An information of assessment of a suspension arm, vehicle suspension components, fatigue analysis of truck chassis, fatigue analysis of a truck chassis with riveted joints are considered.

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