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Fatigue Damage Assessment of the Engine Mount Bracket Using a Statistical Based Approach

K.A.Zakaria[1, a], S. Abdullah[2, b], M.J. Ghazali[2, c], M.Z.Nuawi[2], M.M.Padzi[2]

[1]Department of Structure and Materials, Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, MALAYSIA

[2]Department of Mechanical and Materials Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, MALAYSIA

[a]kamarul@utem.edu.my, [b]shahrum@eng.ukm.my, [c]mariyam@eng.ukm.my

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Abstract. Fatigue damage assessment is very important in design process of the component to determine their durability under service loading conditions. In service, the great majority of structures and components are subjected to stress of variable amplitude loading. The purpose of this research is to analyse statistically of two types of strain signals from road loading and compare their effect on fatigue damage of the engine mount bracket. Strain gauges were attached to the engine mount bracket and were connected to the data acquisition set in order to capture the actual strain signals when an automobile was driven on two different road surfaces. The strain signals were then analysed using global signal statistic and integrated kurtosis based algorithm for Z-filter (I-kaz) method. Meanwhile, damage of the engine mount bracket was evaluated using finite element commercial software. From the analysis, it was found that the fatigue damage showed an increment with the respective statistical values of the strain signals.

Introduction

Fatigue failure in mechanical component is caused by cyclic loading which occurred below the ultimate strength of a material. This cyclic loading causes a progressive degradation of the material properties and eventual failure. Traditionally, most of the fatigue characterisation of a material is performed under constant sinusoidal loading [1], but in service, the great majority of structures and components are subjected to stress of variable amplitude. There is extensive evidence to suggest that variable amplitude stress cycle could be more damaging than the same stress cycle under constant amplitude loading [2]. Thus, it is of great important to understand the failure mechanism associated with variable amplitude loading and fatigue and to have a capability of quantifying fatigue under variable amplitude loading [3]. In design features, it is essential to have a thorough understanding the behaviour of the material in the vicinity of the feature itself in order to preserve the safety and integrity of the components [4].

In a fatigue study, the signal consists of a measurement of a cyclic load, i.e. force, stress and strain against time [5]. The strain based approach in fatigue problems is widely used at present. Strain can be measured and has been found to be an excellent quantity for correlating with low cycle fatigue. The value of the strain amplitudes are varies with the time depends on the load applied to the structures. Statistical methods have been found extensively used in processing real world signals [6]. However, current global signal statistical analysis is only sensitive to either signals amplitude or frequency.

This paper present the fatigue damage assessment of the engine mount bracket using different fatigue strain signals. The characteristic of strain signals of the road vehicle while driving on the highway and residential area road surfaces were analysed using I-kaz technique, which is a new statistical analysis method developed by Nuawi [7]. These signals behaviour were then used to predict the total damage of the engine mount bracket. It is expected that changes in I-kaz coefficient will be parallel with the changes of the signals behaviour and total fatigue damage.

Theoretical Background

Fatigue strain signal typically consist of a set of observations of strain value taken at equally spaced intervals of time. In a normal practice, global signal statistics are frequently used to classify random signals [8]. The I-kaz technique is an alternative and an effective tool to summarize the data and to assist in interpretation. I-kaz coefficient is capable to detect both signal amplitude and frequency changes. Three dimensional representatives in I-kaz method give an additional advantage to interpret the changes of signal frequency. The time domain signal is decomposes into three frequency ranges, which are low, high and very high frequency ranges. It provide three dimensional graphical representation of the frequency distribution and the I-kaz coefficient, which is defined as

$$\cancel{Z}^{\infty} = \frac{1}{n}\sqrt{K_L S_L^4 + K_H S_H^4 + K_V S_V^4} \quad (1)$$

where n is the number of data, S_L, S_H, S_V are the standard deviation values and K_L, K_H, K_V are the kurtosis values of a signal in L_H, H_F and V_F range, respectively. The standard deviation for n data point is mathematically defined as

$$SD = \left\{\frac{1}{n-1}\sum_{j=1}^{n}(x_j - \bar{x})^2\right\}^{\frac{1}{2}} \quad (2)$$

Kurtosis, which is the signal 4th statistical moment, is a global signal statistics which is highly sensitive to spikiness of the data. In mathematically, kurtosis value is defined as

$$K = \frac{1}{n(r.m.s.)^4}\sum_{j=1}^{n}(x_j - \bar{x})^4 \quad (3)$$

The application of strain life analysis requires a description of the material response to cyclic elastic-plastic strains and relationship between these strains and fatigue life to crack initiation. Fatigue life prediction for strain life analysis is normally applied with strain life fatigue damage model. Three different fatigue damage models [9], namely Coffin-Manson, Smith-Watson-Topper (SWT) and Morrow, were used in this analysis.

Material and methods

Aluminum alloy has been widely used for automotive and air plane parts because of its light weight, excellent weldability and corrosion resistance [10]. The aluminum alloy, AA 6061 has been selected for simulation purpose due to its acceptable mechanical properties coupled with its relative ease with which it can be cast, extruded, rolled, machined, etc., market acceptance and relative ease of development [11]. Their typical chemical composition [12] is shown in Table 1. The modulus elastic of the material is 69 GPa, the tensile strength is 125 MPa, the yield strength is 55 MPa and the poisson ratio is 0.33.

Table1: Chemical composition of AA 6061

Element	Mg	Si	Cu	Mn	Fe	Cr	Al
Weight [%]	0.8-1.2	0.4-0.8	0.15-0.40	0.15	0.7	0.04-0.35	bal.

In this study, strain data were collected from engine mount bracket of a 1300 cc national car. A strain gauge was mounted on the top of the engine mount bracket and was connected to the strain data acquisition system. The strain gauge location was determined based on the most critical area simulated by finite element analysis, which was done prior to the testing. The car was travelled on two different road surfaces, i.e. on the highway road and residential area road with almost constant velocity of 80-90 km/hr and 15-25 km/hr, respectively. These velocities are the approximate speed for most automobile on the respective road and said to be stable for capturing the strain data signals.

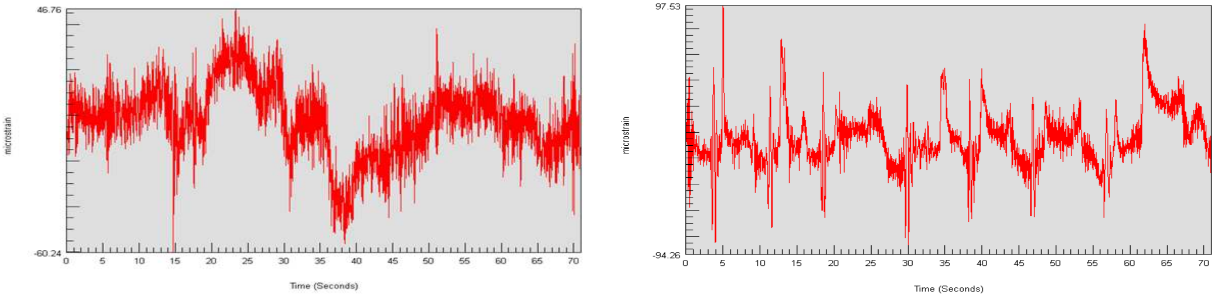
Three dimensional engine mount bracket model was drawn using the CATIA software. The model was then exported to MSC Nastran/Patran as a finite element model and defined all the input properties. The geometry model, material and loading histories were mapped together and analysed using the DesignLife® software to predict the fatigue damage of the engine mount bracket. Fig. 1 shows the condition of test track and data acquisition system.


(a) (b) (c)

Fig. 1: (a) Highway road (b) Residential area road (c) Data acquisition system

Results and Discussion

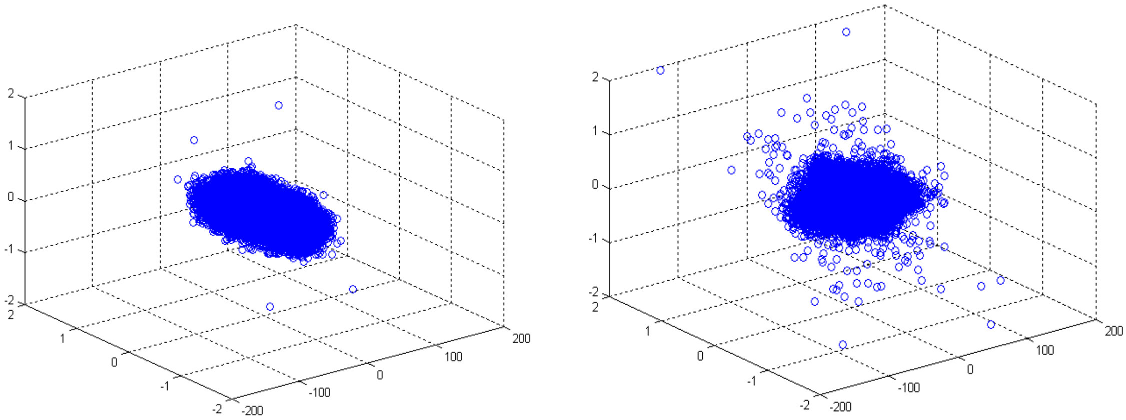
There are two graph plots (see Fig. 2) of fatigue strain signals obtained from the engine mount bracket of an automobile when travelled on the highway road and residential area. Referring to the plot, the strain signal from the highway road gave the maximum value of 46.76 με, the minimum of -60.24 με and the total strain range of 107 με. Meanwhile, residential area road gave the maximum value of 97.53 με, the minimum of -94.26 με and the total strain range of 191.79 με. Higher strain range in residential area road indicated that the engine mount bracket experienced a larger displacement compared to highway road surfaces.



(a) (b)

Fig. 2: Strain signal collected at different road surfaces: (a) highway road (b) residential area road

An I-kaz approach is a statistical-based method with a concept of data distribution to centroid point of the data. This method provides a three dimensional graphical frequency distribution of measured signals and also I-kaz coefficient. Fig. 3 illustrating the I-kaz graphical representations for both road signals. The graphical representation shows a larger data scatter of residential area road strain signal compared to highway road strain signal. The I-kaz coefficients for both types of road surfaces are summarized in Table 2, indicating that the I-kaz coefficient for the highway and the residential road surfaces are 0.0280 and 0.0125, respectively. This finding shows that a larger strain ranges amplitude produce a larger data scatters and higher I-kaz coefficient.



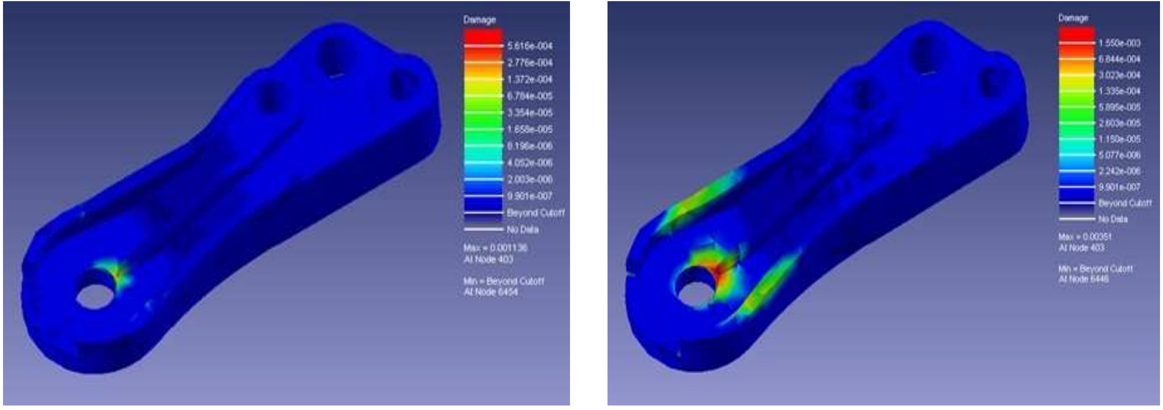
(a) (b)

Fig. 3: I-kaz representation for different road surfaces: (a) highway road (b) residential area road

Table 2: I-kaz coefficient value for each road

Types of road	I-kaz coefficient (Z^{∞})
Highway road	0.0125
Residential area road	0.0280

Fig. 4 shows plot of damaged area contour for highway and residential area road loading. From the results, the most critical area is around a pin hole of the bracket. This area represents the potential of crack initiation location under fatigue loading. The damage values for each fatigue damage model are shown in Fig. 5. From this figure, the SWT model gave the highest fatigue damage value for both road conditions. SWT model is more accurate for brittle metals such as cast iron and aluminum alloys [9]. This graph also illustrates the fatigue damage values for residential area was found to be more than twice of the highway road loading for all types of damage models. It shows that higher strain ranges amplitude will give the larger data scatter and the I-kaz coefficient which will also contributes to more damage on the component.



(a) (b)

Fig. 4: Damage contour distribution (a) highway road (b) residential area road

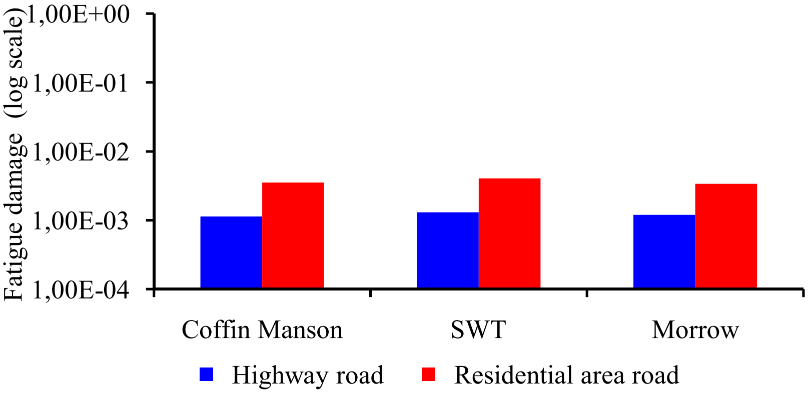


Fig. 5: Fatigue damage values for both road conditions

Conclusion

This paper discussed on fatigue damage of the engine mount bracket of an automobile when it was driven over two different road surfaces. Fatigue strain signals for residential area road has higher strain ranges amplitude compared to highway road. It can be concluded that larger strain ranges amplitude produces more data scatter, higher I-kaz coefficient and larger damage values. This finding shows that I-kaz coefficient can be used to assess the total damage of the engine mount bracket. However, it is suggested to test and analyse more data in future work in order to achieve a good correlation and more accurate results.

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