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FATIGUE STRAIN SIGNAL CHARACTERISTIC AND DAMAGE OF AUTOMOBILE SUSPENSION SYSTEM

Kamarul Ariffin Zakaria, Mohamad Iqmal Faris Idris, Sivakumar Dharmalingam, SuhailaSalleh, Nortazi Sanusi and Mohd Ahadlin Mohd Daud
Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
E-Mail: kamarul@utem.edu.my

ABSTRACT

Spring suspension is one of the important parts of automobile components that supports and holds the body of an automobile from shaking and vibration. Driving becomes uncomfortable when an automobile traverses high- and low-magnitude roads, such as hills and road roughness, respectively. Therefore, this study aims to investigate the fatigue strain signal characteristic of an automobile spring suspension when driving on different road surfaces and its effect on fatigue damage. In this study, a strain gauge was mounted on the automobile spring suspension system and connected to the data acquisition set to capture the actual fatigue strain signal during normal driving condition. The fatigue strain signal characteristic was analyzed through a statistical method. Then, the fatigue damage of the automobile spring suspension system was determined using commercial finite element software. Results indicate that the characteristic of the automobile spring suspension system is influenced significantly by the type of road surfaces. Thus, this condition contributes to different damages to the automobile spring suspension system.

Keywords: automobile suspension system, fatigue damage, fatigue strain signal.

INTRODUCTION

Suspension is one of the most crucial components in a car system. The main function of the suspension system is to ensure that the wheels follow the road profile to protect passengers and cars from shaking when cars traverse roads with bumps or holes or even on smooth roads. Suspension systems are created to provide a comfortable ride and handling performance of a car (Lavanya *et al*., 2014). An automobile suspension system contains dampers and springs to absorb shocks caused by road incongruities, thereby resulting in a pleasant ride (Olumole, 2012).

Currently, car springs are classified into three types, namely, leaf, torsion bar, and coiled springs. A leaf spring is a layer of entwined metal beams and is associated with the axle. A torsion bar is a distinct, small mechanism that provides wound spring-like execution considering the contorting properties of a steel bar. One end of the steel shaft is associated with the axle, and the other end is opened into a tube and held by splines. A coiled spring is a coiled up steel bar, and its push down mechanism is similar to twisting a metal bar (Jain & Astana, 2002; Satyanarayana *et al*., 2015).

The suspension system may experience fatigue failure at a certain stage due to cyclic stress and force applied to the component. Fatigue apparently occurs when a specific task is repeatedly performed in the same metallic components subjected to variable loading, which leads to the ultimate failure of these components under specific conditions (Chetan *et al*., 2012).

Fatigue failure is caused by cyclic loading that occurs below the ultimate strength of a material. Structural or engineering components are exposed to fatigue failure when the number of cycles of applied stress resulted in the progressive degradation of material properties, which causes eventual failure (Zakaria *et al*., 2016a). Fatigue failure is a major mechanical damage that occurs in the structure and engineering components. This damage accounts for approximately 90% of the total mechanical failures (Callister, 2007; Zakaria *et al.,* 2016b).

In industrial activities, the failure assessment of a mechanical component is an important design stage. The failure of a mechanical component experiencing a variable amplitude loading (VAL) condition is a complex phenomenon and is difficult to assess, particularly because of load interactions (Carvalho *et al*., 2010). For example, the load history effect in the VAL, such as fatigue crack retardation and acceleration after tensile overload and compressive under load in the cycle, respectively, influences the number of cycles to material failures (Daneshpour *et al*., 2012; Mikheevskiy *et al*., 2009).

A signal is a series of numbers obtained from measuring through several recording methods as a function of time. In studying fatigue, signals consist of measuring cyclic loads, i.e., force, stress, and strain, against time (Abdullah *et al*., 2009). Strain can be measured and has been found to be an excellent quantity for correlating with low-cycle fatigue. Fatigue strain signals, normally measured using a strain gauge, produce strain signal patterns against a time period (Ali *et al*., 2011). Moreover, strain measurements are directly related to stress, fatigue, and failure. Strain-based measurement methods can be a potential option for structural health monitoring methods and systems. Applications, where sensor size and placement might be critical, are also potential candidates for the strain-based methods (dos Santos *et al*., 2014).

The practical challenge for fatigue life prediction in these cases is that the stress and fatigue loads in the fatigue crack area are difficult to measure. Stress information is one of the critical aspects in the analysis of fatigue life prediction. The knowledge of the stress information of a structure allows for a reliable and accurate fatigue life prediction (He *et al*., 2016). The study on fatigue damage and life prediction of the suspension system based on actual fatigue or strain should be investigated to ensure the safety and integrity of the suspension system during its operation. Currently, many researchers in the automobile industry have improved the design of the suspension system.

Thus, this study aims to examine and predict the fatigue damage of the suspension system by analyzing the fatigue strain signal characteristic of the spring suspension system during travel on different road profiles through a statistical method. This investigation is conducted by attaching a strain gauge to the suspension system connected to a data acquisition device to obtain the signals. The fatigue life of the suspension system will be predicted at the end of this study.

METHODOLOGY

Fatigue life can be predicted using three major approaches, namely, stress life, strain life, and fracture mechanics. The strain life fatigue model is related to the plastic deformation that occurs at a localized region, where fatigue cracks weaken the durability of the structure. This model is used for ductile materials with relatively brief fatigue lives. This approach can also be used on materials with minimal plasticity at extensive fatigue lives. Therefore, this comprehensive approach can be used as a substitute to the stress-based approach (Abdullah et al., 2009).

The application of strain life analysis requires describing the material response to cyclic elastic– plastic strains and the relationship between these strains and fatigue life to crack initiation. The fatigue life prediction for strain life analysis is normally applied with the model of strain life fatigue damage. In the present study, Morrow's fatigue damage model was used. The life curve modified by Morrow to represent the effect of mean stress was used for conducting the fatigue analysis through finite element analysis. Morrow alters the value of fatigue strength coefficient in the elastic component of the stress-strain relationship for accurate estimation (Wagare & Hundekari, 2015). Morrow's fatigue model is expressed by the following equation:

$$\frac{\Delta\varepsilon}{2} = \frac{(\sigma_f - \sigma_m)}{E}(2N_f)^b + \varepsilon_f (2N_f)^c \tag{1}$$

where $\Delta\varepsilon$ is the equivalent strain range; ε_f is the fatigue ductility coefficient; b is the fatigue strength exponent; c is the fatigue ductility exponent; σ_f is the fatigue strength coefficient; σ_m is the local mean stress; and N_f is number of cycles to failure. Fatigue damage D for each cycle can be calculated using the following equation:

$$D = \frac{1}{N_f} \tag{2}$$

Fatigue strain signals typically consist of a set of observed strain values obtained at equally spaced intervals of time. In normal practice, global signal statistics are frequently used to classify random signals (Nuawi*et al*., 2009). For a signal with a number n of data points in a sampled sequence, the mean value is expressed by

$$\bar{x} = \frac{1}{n}\sum_{j-1}^{n} x_j \tag{3}$$

Standard deviation (SD) measures the spread of data around the mean value. SD is mathematically defined as

$$SD = \left\{\frac{1}{n}\sum_{j-1}^{n}(x_j - \bar{x})^2\right\}^{1/2} \tag{4}$$

Root mean square (rms) value, which is the second statistical moment, is used to quantify the overall energy content of the signal. For discrete datasets, the rms value is defined as

$$rms = \left\{\frac{1}{n}\sum_{j=1}^{n} x_{j^2}\right\}^{1/2} \tag{5}$$

Kurtosis, which is the fourth statistical moment, is a global signal statistic that is sensitive to fluctuation of the data. Mathematically, kurtosis value is defined as

$$K = \frac{1}{n(rms)^4}\sum_{j=1}^{n}(x_j - \bar{x})^4 \tag{6}$$

In this study, fatigue strain signal data were collected from the spring suspension system of a 1300 cc national car. The critical area was obtained by conducting the finite element analysis using a commercial software. Then, the spring suspension was installed with a 2 mm strain gauge 120 Ω, as illustrated in Figure-1, to capture the fatigue strain signal history.

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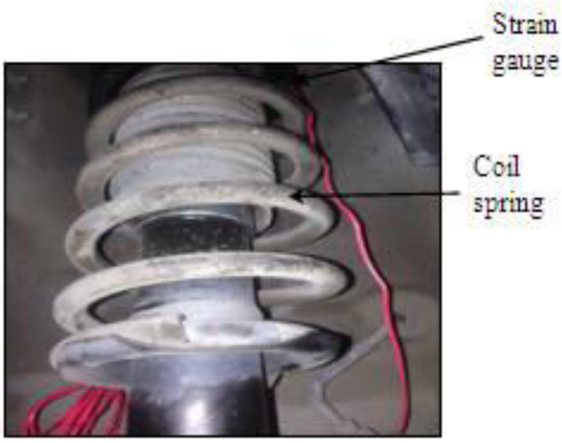
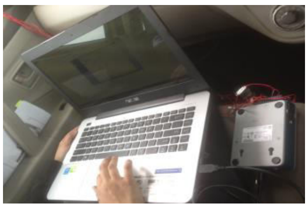


Figure-1. Strain gauge attached to the automobile spring suspension system to collect fatigue strain signals.

The car traveled on two road surfaces, i.e., on the highway and residential area roads, with nearly constant velocities of 80-90 and 15-25 km/hr, respectively. A strain gauge was mounted at the top of the engine mount bracket and was connected to the strain-based data acquisition system. Figure-2 depicts the National Instrument data acquisition system used for capturing fatigue strain signals and test track condition.



(a)

(b) (c)

Figure-2. (a) Data acquisition system connected to a computer, (b) Highway road and (c) Residential area road.

The coil spring suspension system was modeled using the commercial finite element software, ANSYS, to determine the critical area. A statistical analysis calculated the effects of steady loading conditions on a structure but ignored the effects of inertia and damping, such as the outcomes caused by time-varying loads. Tetrahedral meshing was applied to produce high-quality meshing for the boundary representation solid model as demonstrated in Figure 3. The coil spring was constrained as a fixed support at the bottom of the coil spring, and a 2000 N load was applied at the top of the coil spring based on the approximate weight of the car applied to each coil spring.

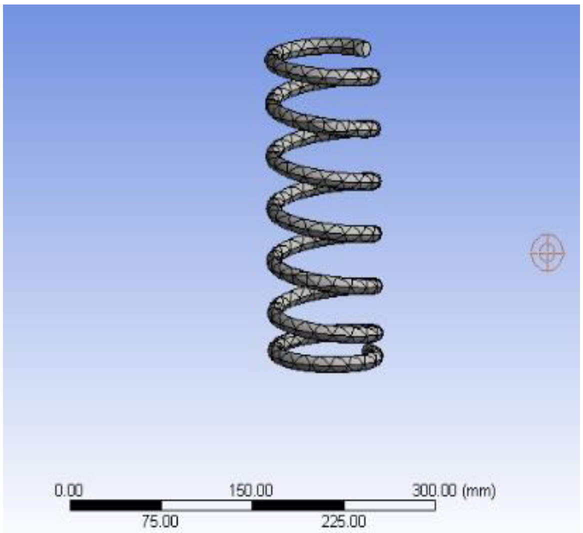


Figure-3. Finite element model of the coil spring.

RESULTS AND DISCUSSIONS

There Two plots of fatigue strain signal history were obtained from the automobile spring suspension system when traveling on the highway and the residential area roads, as illustrated in Figure-4. The fatigue strain signal characteristic based on the statistical analysis is displayed in Table-2. The data showed that the maximum and minimum strain values for the residential road surface are 532 and -433με, respectively, while the maximum and minimum values for the highway road surface are 57 and -221 με, correspondingly.

The result indicated that the fatigue strain signal history from the residential area road has a mean value of 4.72 με, SD of 72.56 με, and rms value of 39.04 με. Furthermore, the fatigue strain signal history from the highway road had a mean value of −134.945 με, SD of 69.23 με, and rms of 19.86 με. The higher values of mean, SD, and rms at the residential road was due to the spring suspension experienced a rapid compression and tension displacement when the automobile was driven at the residential area road than the highway road surface. The presence of holes and road bumps at the residential area produced a high-peak in the amplitude of strain signals and caused the frequent movements of the automobile.

The fatigue strain signal history of the residential area road (4.941 με) also showed a higher kurtosis than the highway road (1.640 με). Kurtosis is used to measure the peak of the probability distribution of a r-valued random variable. The high value of kurtosis for the residential area road indicate the presence of many extreme values in a Gaussian distribution (Zakaria *et al*., 2014). Kurtosis is used in engineering for detecting fault symptoms because of the sensitivity of kurtosis to high amplitude (Li *et al*., 2017).

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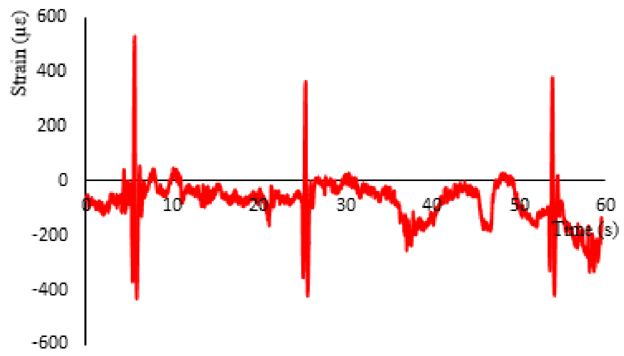
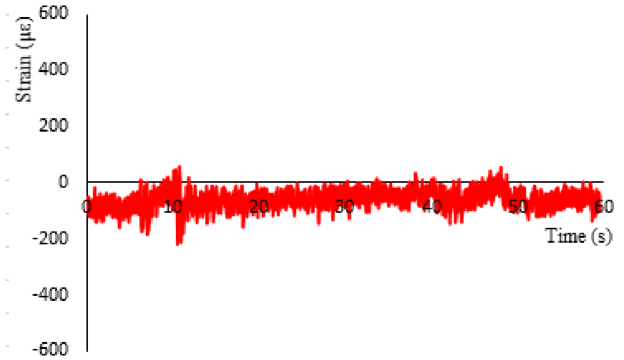


(a)



(b)

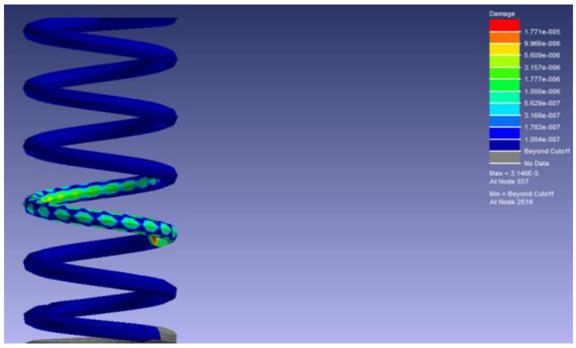
Figure-4. Fatigue strain signals obtained from the automobile spring suspension while traveling on (a) the residential area road and (b) the highway.

Table-1. Statistical values of fatigue strain signals.

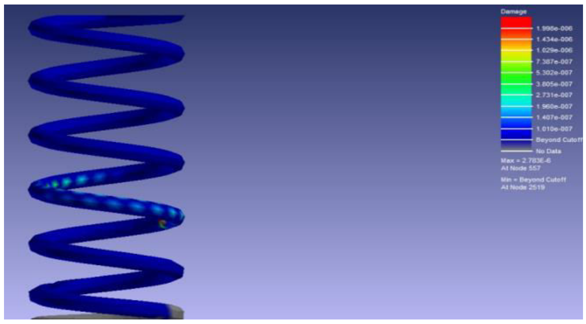
Road surface	**Mean** (με)	**SD** (με)	**RMS** (με)	**Kutosis** (με)
Residential area	-64.72	72.56	39.04	4.94
Highway	-73.94	69.23	19.86	1.64

Figures 5 and 6 display the plot of damage contour on the spring suspension after traveling on the residential area and highway roads. From the result, the most critical area is found at the middle portion on the inner side of the coil spring based on the maximum damage value. This area represents the potential location of cracks initiated under fatigue loading. The maximum damage values from the finite element simulation of the coil spring when driven on each road surface are listed in Table 2. The result showed that the fatigue damage from the residential area road is 1.78×10^{-5} compared with the highway road, which is 1.99×10^{-6}. The fatigue damage is approximately 10 times higher under the residential area road loading than under the highway road loading. Therefore, more damage occurred during the travel on the residential area than on the highway road.

The coil spring experienced significant movements due to the high magnitude of displacement or elongation during the travel on the residential area road surface. The residential road surface was slightly rough with small pit holes and bumps, thereby causing high amplitude of fatigue strain signals and additional damage to the coil spring. In addition, the condition of the highway road surface was smooth, which caused low amplitude of fatigue strain signals and further uniform distribution. For most mechanical systems subjected to fatigue loads, fatigue damage mainly depends on applied stress history under realistic condition (Wang *et al*., 2016; He *et al*., 2016). In this case, the actual load is obtained from the fatigue strain signal history of the coil spring, indicating that their amplitude depends on the condition of the residential area and highway road surfaces.



(a)



(b)

Figure-5. Fatigue damage of the coil spring subjected to strain history on the (a) residential area road and (b) the highway road.

Table-2. Statistical values of fatigue strain signals.

Road surface	**Maximum damage**
Residential area	1.78×10^{-5}
Highway	1.99×10^{-6}

CONCLUSIONS

This study aims to investigate the fatigue strain signal characteristic and damage of the spring suspension system. The fatigue strain signals were obtained from the automobile spring suspension system during normal driving condition on residential and highway roads. The results showed that the different conditions of road surfaces significantly affect the fatigue strain signal characteristic and damage of the automobile spring suspension system. The signal characteristic of the residential road loading demonstrated higher rms, kurtosis, and PSD values than the highway road loading. This condition also contributed higher damage values for the residential area road loading than the highway road loading. Future study will be performed to correlate the fatigue strain signal characteristic with the fatigue damage of the automobile component.

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REFERENCES

Abdullah S., Nizwan C.K.E & Nuawi M.Z. 2009. A study on fatigue data editing using the Short-Time Fourier Transform (STFT). American Journal of Applied Sciences. 6(4):565-575.

Ali M.B., Abdullah S., Nuawi M.Z., Padzi M.M. & Zakaria K.A. 2011. Experimental Analysis of an Instrumented Charpy Impact using Statistical Study Based Data Analysis. International Journal of Mechanical and Materials Engineering. 6(2): 260-268.

Callister W.D. 2007. Material Science and Engineering. New York: John Wiley & Sons.

Carvalho A.L.M., Martins J.P & and Voorlwad H.J.C. 2010. Fatigue Damage Accumulation in Aluminium 7050-T7451 Alloy Subjected to Block Program Loading under Step Down Sequence. Proceedia Engineering. 2: 2037-2043.

Daneshpour S., Dyck J., Ventzke V. & Huber N. 2012. Crack Retardation Mechanism Due To Overload in Base Material and Laser Welds of Al Alloys. International Journal of Fatigue. 42: 95-103.

Dos Santos F.L.M., Peeters B., Lau J., Desmet W. & Goes L.C.S. 2014. An Overview of Experimental Strain-Based Modal Analysis Methods. Proceedings of the International Conference on Noise and Vibration Engineering (ISMA), Leuven, Belgium.

He J., Zhou Y., Guan X., Zhang W., Wang Y., Zhang W. 2016. An Integrated Health Monitoring Method for Structural Fatigue Life Evaluation Using Limited Sensor Data. Materials. 9: 894-912.

Jain K.K. & Asthana R.B. 2002. Automobile Engineering. New Delhi: McGraw-Hill Publishing.

Lavanya N., Rao P. S. & Reddy M. P. 2014. Design and Analysis of a Suspension Coil Spring for Automotive Vehicle. International Journal of Engineering Research and Applications. 4(9): 151-157.

Li Y., Wang L. & Guan J. 2017. A Spectrum Detection Approach for Bearing Fault Signal Based on Spectral Kurtosis. Shock and Vibration. 2017: 1-9.

Magare V. & Hundekari R. 2015. Fatigue Life and Damage Prediction of Plate with Central Hole using Finite Element Method. 2015. Journal of Materials science & Surface Engineering 3(1): 202-206.

Mikheevskiy S. & Glinka G. 2009. Elastic–plastic fatigue crack growth analysis under variable amplitude loading spectra. International Journal of Fatigue. 31: 1828-1836.

Nuawi M.Z., Abdullah S., Haris S.M. & Arifin A. 2009. MATLAB: A Comprehensive Reference for Engineers. Kuala Lumpur: Mc Graw Hill (Malaysia) Sdn. Bhd.

Oluwole O. 2012. Matlab and Simulink Use in Response Analysis of Automobile Suspension System in Design. International Journal of Traffic and Transportaion Engineering 1(2):19-31.

Satyanarayana V., Ramakraisna Rajasekhar, S., Murthy K. 2015. Design and Optimisation of Leaf Spring Using Composites. International Journal of Science Engineering and Advance Technology.3 (11): 890-897.

Wang Y. & Susmel L. 2016. The Modified Manson Coffin Curve Method to Estimate Fatigue Lifetime under Complex Constant and Variable Amplitude Multiaxial Fatigue Loading. International Journal of Fatigue. 83(2):135-149.

Zakaria K.A., Jimit R.H., Ramli S.N.R., Aziz A.A.Bapokkuty O. & Ali M.B. 2016a. Study on fatigue life and fracture behaviour of fibreglass reinforced composites. Journal of Mechanical Engineering and Sciences. 10(3): 2300-2310.

Zakaria K.A., Abdullah S. & Ghazali M.J. 2016b. A Review of the Loading Sequence Effects on the Fatigue Life Behaviour of Metallic Materials. Journal of Engineering Science and Technology Review. 9: 189-200.

Zakaria K.A., Abdullah S. Ghazali M.J., Nuawi M.Z., Beden S.M. &Nopiah Z.M. 2014. Fatigue Strain Signal Behaviour and Damage Assesment of Engine Mount Bracket. Journal of Scientific and Industrial Research. 73: 112-116.