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# The need to generate realistic strain signals at an automotive coil spring for durability simulation leading to fatigue life assessment

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ABSTRACT

This study aims to accelerate fatigue tests using simulated strain signals. Strain signals were acquired from a coil spring involving car movements. Using a mathematical expression, the measured strain signals yielded acceleration signals, and were considered as disturbances on generating strain signals. The simulated strain signals gave the testing time deviation by only 1.5%. The wavelet-based data editing was applied to shorten the strain signals time up to 36.7% and reduced the testing time up to 33.9%. In conclusion, the simulated strain signals were able to maintain the majority of fatigue damage and decreased the testing time.

## 1. Introduction

A better way to access durability on a component, such as coil springs, is through service loads [1,2]. Durability analysis requires knowledge of service loads since these loads are used for the laboratory testing of a component in engineering practices. Thus, early in the product development process, engineers need to predict stress and strain histories for the purpose of modelling and designing for mechanical fatigue [3]. Strain signal acquisition processes, however, are very expensive, intrusive, time consuming, not error-free and require high levels of skill and training [2,4].

Automotive product development has risks such as high costs and low success rates [5]. Measuring errors arise from variations that are uncontrolled and generally unavoidable [6]. They change both the amplitude and mean stress, and thus, greatly influences fatigue damage. The errors, caused by interference of physical processes and imperfection in measuring apparatuses, not only occupy a large amount of amplitude cycles and make durability tests difficult, but also hinder an accurate fatigue life prediction due to additional amplitude cycles. In the strain signal published by Oh [7], for example, various levels of noise were imposed on the pure signal damage. Thus, fatigue monitoring of a structure has been limited by the available practical technique of current strain sensors [8]. An accurate measurement of strains, from which the stresses can be determined, is one of the most significant predictors of fatigue life [9].

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From an economic perspective, automotive companies are looking for a solution to reduce costs in order to remain competitive [10,11]. Because the strain signal at a coil spring cannot be measured directly with a high degree of accuracy, especially during normal driving, it was desirable to develop a simulation for generating strain signals. Thus, the main objective of the current study is to propose techniques to develop fatigue-based strain signals by utilising computer-based simulation with consideration of road surface profiles that may lead to fatigue failure. To the best of the author's knowledge, no such simulation was previously proposed. Therefore, the simulation is expected to bring greater meaning in automotive industries involving strain signal acquisitions. There are requirements that should be considered when generating a new fatigue random load history, such as [12]: (1) load cycles should correspond to the rainflow counting method as a standard procedure for determining damage events, (2) sequence of load cycles should be maintained, (3) damage resulting from the new load history should be the same as the original load history, and (4) the new load history should be shorter in length than the original load history to decrease the testing time, by deleting small load cycles and merging smaller ones. The rest of this paper is organised as follows: Section 2 describes the materials and methods used, the detailed experimental results and discussion are set out in Section 3, and then, Section 4 is the conclusion followed by a comprehensive list of references.

## 2. Materials and methods

### 2.1. Strain signal acquisition

The frontal coil spring of an automobile with 1300 cc capacity was used as a case study. It uses a passive McPherson strut suspension system with the spring stiffness and the damping coefficient of 18,639 N/m and 15,564 N s/m, respectively. The selected material for the simulation was the SAE5160 carbon steel since it is commonly employed in automotive industries for fabricating a coil spring [13]. Its material properties are tabulated in Table 1.

A strain signal acquisition was performed, by placing a strain gauge at the critical area of the component. Thus, a dynamic analysis was performed for determining the stress distributions at the coil spring. A force of 3600 N was applied on the bottom of the component model and the upper was fixed, considering the car weight of 10,600 N as well as the passengers and the load carried of 3800 N. The total force was divided by four because the car weight and the passengers were assumed to uniformly distribute to four springs [14]. The analysis was performed with load amplitude varying from 0 to 3600 N. The boundary condition of the component is shown in Fig. 1. The stress distributions were measured to find the critical area of the coil spring. Thus, a strain gauge could be installed in the correct position.

The position of the strain gauge installation was selected based on the possibility of higher stress area based on the finite element analysis. The strain gauge was connected to the data logging instrument through a connector. A fatigue data logger was used to record the strain signals measured by the strain gauge. Measuring parameters were set up to align the strain gauge reader, set the type of collected strain signals, set the strain signal storage area and upload the strain signals from the fatigue data logger into the computer.

According to Ilic [16], the sampling frequency for a strain signal acquisition should be greater than 400 Hz, so that the essential components of the signal are not lost. Using a collection rate higher than 500 Hz can increase the upper limit of the frequency range as small amplitude and high frequency load cycles will be captured. Collecting load histories at a frequency of 500 Hz is sufficient to detect and capture all damaging load cycles [17], and the selection of 500 Hz was seemingly suitable for the on-site strain signal collection. After installing the equipments, the car was then driven on urban and rural road surfaces at velocities of 30 km/h to 40 km/h and 20 km/h to 40 km/h, respectively. The velocities above were matched with an average car speed when driven on specified road conditions [16,18,19]. Furthermore, the measured strain signals were the input into a mathematical expression for generating acceleration signals.

### 2.2. Acceleration signal generation

A method that has been used to classify a vibration is based on its degree of freedom. A mass-spring-damper system with single degree of freedom can be characterised by Fig. 2. A single degree of freedom system was considered in the study

**Table 1**
Mechanical properties of the SAE5160 carbon steel Source: nCode [15]

| Properties | Values |
|---|---|
| Ultimate tensile strength, $S_u$ (MPa) | 1584 |
| Material modulus of elasticity, $E$ (GPa) | 207 |
| Yield strength (MPa) | 1487 |
| Fatigue strength coefficient, $\sigma'_f$ (MPa) | 2063 |
| Fatigue strength exponent, $b$ | −0.08 |
| Fatigue ductility exponent, $c$ | −1.05 |
| Fatigue ductility coefficient, $\varepsilon'_f$ | 9.56 |
| Cyclic strain-hardening exponent | 0.05 |
| Cyclic strength coefficient (MPa) | 1940 |
| Poisson ratio | 0.27 |