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Generating strain signals under consideration of road surface profiles

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ABSTRACT

The current study aimed to develop the mechanism for generating strain signal utilising computer-based simulation. The strain data, caused by the acceleration, were undertaken from a fatigue data acquisition involving car movements. Using a mathematical model, the measured strain signals yielded to acceleration data used to describe the bumpiness of road surfaces. The acceleration signals were considered as an external disturbance on generating strain signals. Based on this comparison, both the actual and simulated strain data have similar pattern. The results are expected to provide new knowledge to generate a strain signal via a simulation.

1. Introduction

Control and stability of a car entirely depend on the collision and the friction between the road surface and the tyre [1], which is uncertain and can change extremely and quickly [2]. This dynamic interaction gives a certain amount of vibration causing problems with respect to the car components and the ride quality. The vibration acts as a catalyst to speed up the crack initiation interfacing the function of the components and gives a great impact on the performance of the car, contributing to mechanical failure due to fatigue, as the component is exposed to cyclic loads. In such cases, the external disturbance is necessary and its isolation advantageous [3]. Thus, a system absorbing the energy of the vertically accelerated wheel is needed. The best system to resolve this problem is the suspension system.

When the tyre experiences shock, the vibration transmitted to the car is increased. At the same time, it increases the displacement of the tyre and the car body. The vibration is absorbed by the tyres, the springs in the car seats and the coil spring in the suspension systems. The tyres and the seat springs absorb a little vibration, while the coil spring does the rest. In this case, the coil spring has forced vibration. A significant amount of shock affects the coil spring, and at higher rates than other car components. Thus, the coil spring plays a vital role in the failure of car structures. According to Aykan and Çelik [4], a better way to access the fatigue life on a component is through fatigue data analysis.

Some fatigue data acquisition experiments have been performed to monitor the dynamic structural responses. For examples, Oh [5] measured the strain data on a light railway train. Furthermore, Haiba et al. [6] collected the strain data at lower suspension arm. Ilic [7] measured the service loads applied to the output shafts of automatic transmission. The strain

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data at the end beam of a freight car bogie was measured by Baek et al. [8]. The last one, Alaoui et al. [9] collected strain data at ship structure.

Experiments typically require multiple vehicles, numerous sets of tyres and expensive instrumentation to obtain indicative data on all the relevant parameters. Tyre force is measured during the prototype phase and is mostly estimated using tyre models and auxiliary sensors. However, this process is very expensive and intrusive. Measurement of tyre force involves many sensors to be placed in many locations since the tyre force does not always flow in the same way for different manoeuvres. After all this, there is still a possibility that the test results show that the desired results cannot be obtained, thus making the whole experiment a waste of resources [10].

For an economic perspective, automotive companies are looking for solution to reduce costs to remain competitive [11]. Industries nowadays rely heavily on computer simulations to study the general trends before investing in actual experimental tests. To alleviate the expenses associated, a model is first created and simulations are run on it to make sure that the trend shows improvement and that one may indeed go ahead and invest in actual experimentation [10]. Many problems arising in the automotive areas have been solved simulating the dynamic behaviour of the structural components on which the dynamic forces are acting, in order to provide convenience to passenger(s) and ensure driving safety.

Sun [12] designed road-friendly vehicles though optimising suspension system subjected to a rough pavement surface. Several mathematical models to minimise the vibration on vehicles using various methods have been proposed by [3,13–16]. Furthermore, military vehicle suspension systems has been optimised by [17–18] developing a multi-body dynamic (MBD) simulation model to withstand high load. Oke et al. [19] and Polach and Hajžman [20], respectively, simulated the bahaviour of the car suspension system and the slow-floor trolleybus when passing over virtual test track. A control system for road roughness of whole vehicle active suspension system parameters has been designed by Eski and Yildirim [21]. Ferreira et al. [1] and Roman et al. [22] proposed method to generate damper internal pressures and artificial road profile, respectively. Recently, Zhang et al. [23] discussed the stabilisation problem to enhance the vehicle safety and the handling considering time-varying velocity. Similar concept also has been applied to some simulation works for other fields, such as investigating the sliding mode control for the EHA system [24], designing the filter for nonlinear systems [25] and investigating the filtering problem of discrete-time Takagi-Sugeno fuzzy systems [26].

Because the tyre force cannot be measured directly with a high degree of accuracy, especially during normal driving, and motivated by the success of the above studies related to vehicle simulations, it is desirable to develop a mathematical model for generating strain signal. Thus, the current study proposed technique to develop fatigue-based strain signal at the coil spring subjected fatigue-based acceleration signal performing MBD simulation. To the best of the authors' knowledge, no such simulation was previously proposed. The model should be able to produce strain signal showing patterns to the actual strain signal.

2. Literature overview

2.1. Mechanism of automotive suspension system

When the tyres touches or hits a pothole, bump or curb, the reaction forces are produced which causes the tyres to move up and down, perpendicular to the road surface. In such a situation, sometimes the tyre may lose contact with the road surface completely. When the compression is almost complete, a reflection is present which cause the coil spring to stretch. The coil spring acts as a reservoir of energy used to absorb the vibration quickly delaying the vibration transfer to the car body with suitable reduction. During that time, the damper responds to ensure the coil spring does not oscillate.

Next, the vibration is released in the form of heat energy to prevent a rebound, and the elastic spring slowly returns to its original position when no vibration occurs anymore [27]. Therefore, no vibration is transmitted to the car body. Later, under gravity force, the tyre stomps back to the road surface. It allows the car body to not interfere with driving. The reduction of the vibration is not only to provide comfort to passenger(s), but also as important, to help in reducing the probability of the fatigue failure at car components, which results in less cost and the reduces possibility of a fatal accident from occurring.

2.2. Mass-spring-damper system

A mass-spring-damper system with two degrees of freedom is usually used to solve the vibration problems that can be characterised by Fig. 1. Two degrees of freedom system were considered in the current study assuming the vibration acts in each tyre, without affecting other tyres.

The governing equation of this suspension system can be derived from Newton's second law. From this free body diagram, the equation of the system motion is obtained as follows [19]:

$$F_i + F_d + F_s = F \tag{1}$$

This shows the relationship among four basic components of the dynamic system, which are mass, resistance (spring), energy dissipation (damper) and applied load. Expanding Eq. (1) and re-arranging, it is obtained:

$$m\ddot{x} + d\dot{x} + kx = F \tag{2}$$