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Fatigue analysis of a suspension for an in-wheel electric vehicle

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ABSTRACT

Electrical vehicles (EVs) have a significant role in reducing transportation emissions and dependence on fossil fuels. This research has developed a high energy density in-wheel switch reluctance motor (SRM) drivetrain for a small car. The SRM drivetrains overcome the cost and availability issues associated with the permanent magnet motor (PMM), mostly used in EVs. However, the in-wheel SRM developed has an increased mass on suspensions when compared with an equivalent power output PMM drivetrain. Hence, the main aim of this paper is to assess the durability and life cycles for a small car suspension due to an increased mass. This fatigue study used a rain flow counting cycle method to generate damage and life matrix for the suspension. Using Plamgren-miner rule, the fatigue life cycles are predicted based on identified cumulative damages to the suspension.

1. Introduction

Global demands for sustainability and compelling requirements to reduce environmental impact have encouraged the transportation industry to look into ways to reduce carbon emissions. In recent years, electric vehicle (EV) development has entered a new paradigm due to environmental pollution, global warming and depletion of fossil fuels. Unlike automobiles with internal combustion engines (ICEs), EVs have the intrinsic advantage of zero emission during operation, when a renewable energy source is used for charging batteries. Amongst various green transportation solutions, the EV has been one of the most valuable technologies and it is a commercially viable solution as well.

In an EV the in-wheel motor was ideal due to its benefits, with low transmission losses and simple design (redundancy of gear box components). Amongst several motors, permanent magnet motors (PMMs) are predominantly used in EVs as they are more efficient, compact and they provide high power density. The key disadvantage of the PMM is the need of permanent magnets (PMs) which use rare earth elements for the motor and this increases motor costs. About 90% of the rare earth elements from China are mined in Baotou, inner Mongolia and in Sichuan province [1,2]. China is currently restricting exports and implementing a strategy to conserve its natural rare earth resources. As a consequence rear earth element prices are increasing. To overcome the cost and availability issues associated with the PMM, the switch reluctance motor (SRM), is used as an alternative. However, the in-wheel SRM added an extra mass on the suspension system; hence, it was essential to investigate the fatigue failure and life of the suspension system.

Passenger safety is the primary concern of automotive design evaluation, amongst several techniques fatigue analysis is conducted. Fatigue typically leads to cracks in the vehicle components, whereby crack propagation results in the failure of the entire vehicle system. Fatigue is permanent damage that occurs when a material is subjected to cyclic loads during driving. In reality, the fatigue testing of the actual vehicle is expensive and time consuming. As a result small test cycles were used in a

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laboratory environment to virtually simulate the performance of EV suspensions. With virtual fatigue study the numbers of physical tests are minimised. Hence, in this study, it was essential to validate the durability and life cycle of suspension components with an increased mass at wheels.

In this study, as the suspension was subjected to large load cycles, it was important to analyse the effects of increased mass due to the in-wheel SRM on suspension design. The initiation of cracks within a part is typically the reason for structural failures within the components. In other words failure of parts subjected to fatigue loads is mainly result of rupture or cleavage. The Society of Automotive Engineers (SAE, 1997) lists seven fundamental causes of cracking, namely manufacturing defects, poor choice of material or heat treatment, poor choice of production technique, poor design, unanticipated service environment, poor material property data and material defects.

In the past, significant improvements in safety were achieved by analysing the fatigue life during design stages [3]. Fatigue study of suspensions and related components provides a good estimate of the life cycles [4]. Also from the literature it is evident that FE methods (Ansys® test bench 13.1) were used to identify the stress concentrations area for the suspension components. The findings suggest that plastic deformation caused by a combination of bending and torsion stresses caused fatigue failures in the components [5]. Most of the suspension parts in a passenger car (e.g., ball joints, lugs, torsions bars, springs) were previously analysed using a combination of multi-body system simulation, fatigue analysis and shape optimisation [6–8]. In this paper, FE methods were used on the life cycle performance of high stress concentration area of a suspension lug, with the aim to evaluate the long-term durability of an in-wheel SRM. An empirical method Ansys® test bench 13.1 was used in this research to perform the fatigue life analysis of the suspension components.

The main objectives of fatigue analyses were:

- Developing high stress area component within suspension using FE methods by modelling an appropriate service loads to mimic the physical conditions;
- Development of variable amplitude loading event curve by conducting experiments on the suspension from an EV (ICE converted);
- Using the load curve data, Gerber method and S-N curve data of the material for the fatigue life cycle analysis; and
- Using a rain flow counting cycle method to generate damage matrix and life matrix for the suspension lug. Using Plamgren-miner rule, predicting the fatigue life cycles based on identified cumulative damages to suspension lug.

2. Materials and method

2.1. Finite element modelling

The FE models were developed for the suspension in the Ansys® test bench 13.1, commercial FE software. The models were simplified to mesh the assembly for in-wheel SRM suspensions. A suspension of an in-wheel SRM is shown in Fig. 1(a–b), with complete model and experimental setup. The experimental setup and theoretical calculations have been described in the next

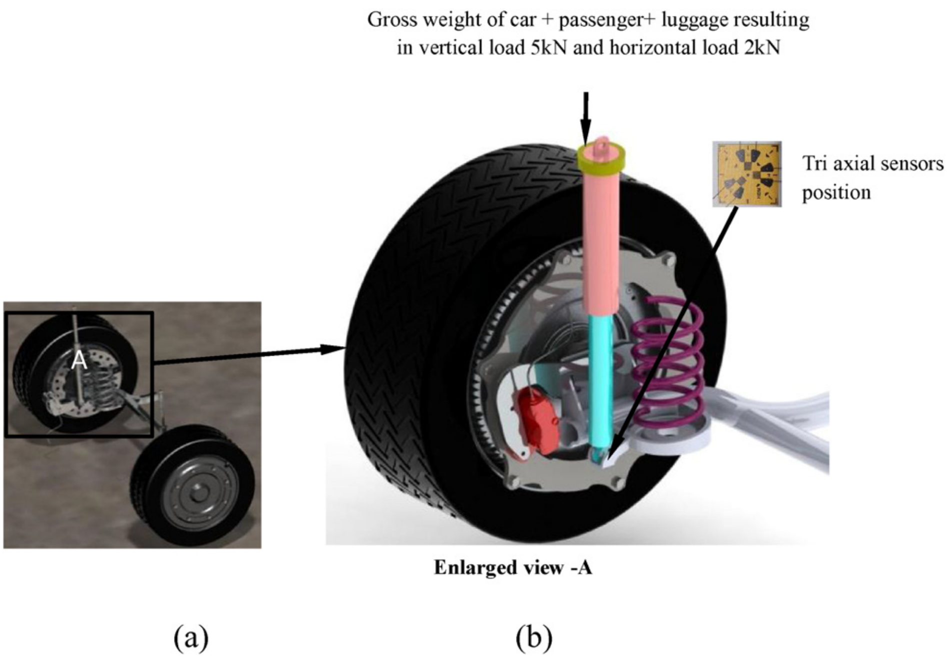

Fig. 1. Suspension model of an in-wheel SRM a) complete model, b) experimental setup.