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Failure assessment of a leaf spring eye design under various load cases

Y.S. Kong [a], S. Abdullah [a,b], M.Z. Omar [a,b,*], S.M. Haris [a,b]

[a] Department of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia
[b] Centre for Automotive Research, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

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ABSTRACT

This paper analyzes the capability of various leaf spring eye designs to prevent failure under braking, cornering, and pothole striking loading conditions. A leaf spring is a vital suspension component of heavy trucks, such that the failure of leaf spring eyes could cause fatal accidents. However, the current design of leaf spring support eyes is solely estimated based on the maximum vertical loads exerted on the leaf spring. The actual torsion or shear loads exerted by the ground to the leaf spring eye extremely high, but the experimental proving ground methods are too expensive to perform load analysis. In this analysis, the forces exerted on the spring eye are simulated under extreme load cases, such as braking, cornering, and pothole striking. The magnitudes of the different loadings were extracted from a multibody dynamics model and were used as the load inputs to the finite element explicit simulation. The principal surface stresses of four different spring eye designs were obtained and compared to the material yield and the ultimate tensile strengths to evaluate the sustainability of the spring eye during extreme load cases. Results show that a minimum thickness of 17 mm is sufficient for the leaf spring eye design to prevent failure under extreme torsional loadings. This research provides insightful analysis of leaf springs to prevent the occurrence of failure during engineering design.

1. Introduction

The majority of heavy vehicles utilize leaf springs as their primary suspension system because of its low cost, easy maintenance, and high load-carrying capabilities. As a spring component, leaf springs absorb and then gradually release loads. Therefore, the strength of leaf spring materials should be considered during the design stage of vehicle components. In general, a leaf spring is designed with a pair of support eyes to connect the spring to the chassis, while the center of the spring is connected to the solid axle. Various leaf spring eye designs have been introduced for specific vehicle applications. Two types of spring eyes are commonly used: Berlin eye and upturned eye [1]. Compared with the common upturned eye, the Berlin eye has a stronger resistance to unwrap because longitudinal loads are applied centrally to the main leaf. By contrast, the advantage of the upturned eye is that the second leaf can be extended to give support to the eye. Berlin eyes are used when high torsional loads are applied because the loading profiles of the leaf spring are exerted toward the center of the eye.

Recent analyses of leaf springs have focused on leaf stress level or material strength. The popular trend in analyses conducted in previous works is that the support eyes of leaf springs are defined as rigid components [2,3]. Previous analyses by Qin et al. [4] on leaf spring roll and windup have also adopted the rigid leaf spring eye. However, in real-life scenarios, leaf springs are

* Corresponding author at: Department of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia.
E-mail address: zaidiomar@ukm.edu.my (Y.S. Kong).

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subjected to various load cases, such as windup during vehicle braking and suspension roll, which exert additional loads to spring eyes. These types of load are ignored during the leaf spring design stage. Each unpredicted load contributes to the increased chances of leaf spring eyes to fail. The severity of failure of spring eyes is much higher than expected. Clarke et al. [5] have investigated a catastrophic accident involving a sport utility vehicle caused by the failure of the leaf spring eye, and they found the importance of devising a proper leaf spring eye design. An improper design could lead to failure of the leaf spring and causes catastrophic vehicle accidents.

Composite leaf spring eyes have been evaluated for heavy loads [6] under static load consideration. The applied static load was based on the estimations of unknown actual vehicle conditions. An ideal leaf spring design must achieve optimum material usage while satisfying specific requirements. Therefore, the loads transmitted from the ground to the spring eye during various cases should be identified to validate the effectiveness of the proposed the eye design. A recent research publication by Kong et al. [7] has performed nonlinear finite element explicit simulations to investigate leaf spring stress under various load cases. However, their analysis was not concerned with the leaf spring eye, and rigid spring eyes were used. Moreover, in the finite element explicit method, load extraction is inefficient and time-consuming. For this reason, multibody dynamic modeling of leaf springs has been proposed for the simulation of vehicle suspension modules to attain higher efficiency computation [8]. For example, road load simulation of a hybrid vehicle has been performed [9] through multibody dynamic simulation. In their work, the forces extracted from simulations are perfect matches to the ground experimental data. In their analysis, multibody dynamic method has demonstrated the capability to simulate vehicle loading transmitted from the ground.

Multibody dynamic modeling of the leaf spring is widely used during the initial vehicle design and development stage. For a leaf spring type suspension, the spring was modeled by multibody dynamic method to predict vehicle handling and rolling stability for trucks [10] and ride comfort for urban buses [11]. The reason is that multibody vehicle dynamic analysis can be solved in a very short period of time by the transient solver. However, for the structural mechanics aspect, multibody analysis cannot provide the complete solution. Therefore, finite element analysis is always adopted after multibody dynamic analysis to obtain stress and strain results. The combination of multibody dynamics and finite element method has been shown in the simulation of the leaf spring axle whine phenomenon in light trucks. Authors have coupled multibody dynamics method with finite element analysis to investigate highly nonlinear dynamics axle whine phenomena [12]. Nowadays, even though a flexible body is capable for structural analysis [13], it is still limited by several drawbacks. Finite element method is still preferable for obtaining the stress of components. The combination of finite element and multibody dynamics methods has been widely applied to prevent the failure of automotive components as a result of poor design. Improper leaf spring designs lead to instant failure when a high load is induced.

This study aims to assess the leaf spring eye design for failure prevention under vehicle braking, cornering, and pothole striking load cases. The leaf spring of a truck was modeled by poly-beam method in multibody dynamic approach to simulate the tensional pulling and torsional forces exerted on the support eye. A traditional multi-leaf type spring was used for the current analysis. Most of the traditional multi-leaf springs are characterized by a spring eye design with the same thickness of the main leaf for ease of manufacturing. However, recent failures of spring eyes imply that the current practice is unsuitable for vehicle applications. This study attempts to determine the tensional and forces exerted on the spring eye during severe truck driving conditions, such as braking, cornering, and pothole striking, and proposes an appropriate spring eye design that can prevent spring failure. By increasing the size of the leaf spring eye design, the failure under the severe load cases can be prevented.

2. Methodology

The first step in performing the analysis was to obtain an accurate CAD model for the leaf spring. Fig. 1 shows the CAD model of a multi-leaf spring design. This design consists of 10 leaves and two support eyes at the main leaf. The top and bottom of each leaf of the spring are in contact with each other. The force was evenly distributed on every single leaf. The thickness of the leaf spring was set to 13 mm, whereas the width was constant at 90 mm. The thickness and width of the spring affects its vertical stiffness, which was calculated by using beam deflection to be 34.3 N/mm, as shown in Eq. (1) [1]:

$$k = \frac{Ebh^3}{6L^3} \tag{1}$$

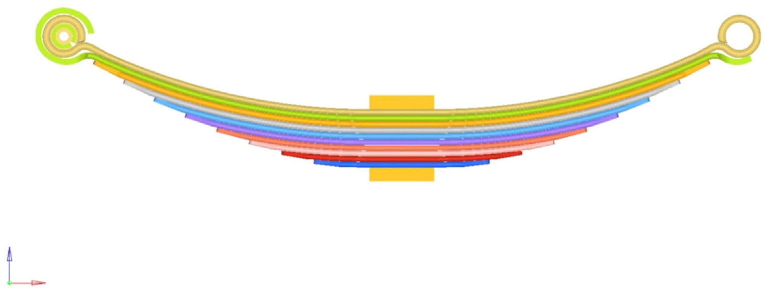

Fig. 1. Leaf spring CAD model for a truck.