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Modification of spider gear back to uniform the stress and improve the anti-wear performance of a real thrust washer

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ABSTRACT

The maintenance cost of a heavy truck increases due to the severe damage of thrust washer in the differential. The wear was usually related to the contact stress concentration. In the study, the finite element analysis (FEA) was performed for identifying the source of the abnormal wear of thrust washer. An improved approach of modifying the surface profile of spider gear back was proposed. FEA simulations were further conducted to investigate the effect of different spider gear back parameters on the tribological behavior of thrust washer. The FEA simulation results were verified by tribological experiments. Results showed that: (i) the abnormal wear of thrust washer pairing the original gear was caused by the local stress concentration; (ii) the local stress concentration could be eliminated by modifying the surface profile of spider gear back; (iii) using the modified spider gear back, the wear mass loss of the thrust washer was reduced significantly; (iv) the promising surface radius of spider gear back was 73.15 mm.

1. Introduction

A differential is the main part which transmits the movement from engine to wheels in a heavy truck. The vehicle power is equally distributed to the left and right wheels on the plain road. While it moves on a corner, the differential facilitates in turning without lateral slipping and being flung [1]. As shown in Fig. 1(a), the differential consisted of a pinion shaft, side gears, spider gears, thrust washers and differential case.

A thrust washer is used to separate the spider gear and differential case, which can improve the lubrication performance and enhance the transmission efficiency. The damage of thrust washer plays negative effect on the vehicular steering and shortens the lifetime of the differential. When a truck experiences overload and speeding frequently, the thrust washer that is made of tin bronze will tend to produce the abnormal failures, such as the fracture and severe wear, as shown in Fig. 2(b). The gap between the spider gear and differential is increased due to the severe wear of thrust washer. It may cause the vehicle vibration, structure noise and secondary airborne noise [2]. In addition, the wear of thrust washer leads to lubricating oil deterioration, the excess amounts of copper debris and large amount of sludge in the oil. It further aggravates the wear and damage of the gear [3], as well as increases cost for repair and unexpected downtime [4]. Therefore, it is necessary to reduce the wear of thrust washer for the whole life cycle design of a heavy truck [5].

Finite element analysis (FEA) has been widely used to guarantee the vehicle quality and design in automotive industry in last several decades [2]. Bayrakceken et al. [6] studied the stress distribution of the failed section in a vehicle power transmission system using FEA method. The results showed that the beginning of the crack in the joint yoke was corresponded to the highest stress point. Some modifications on the joint design were considered to prevent the failures. Lee et al. [7] proposed an aluminum

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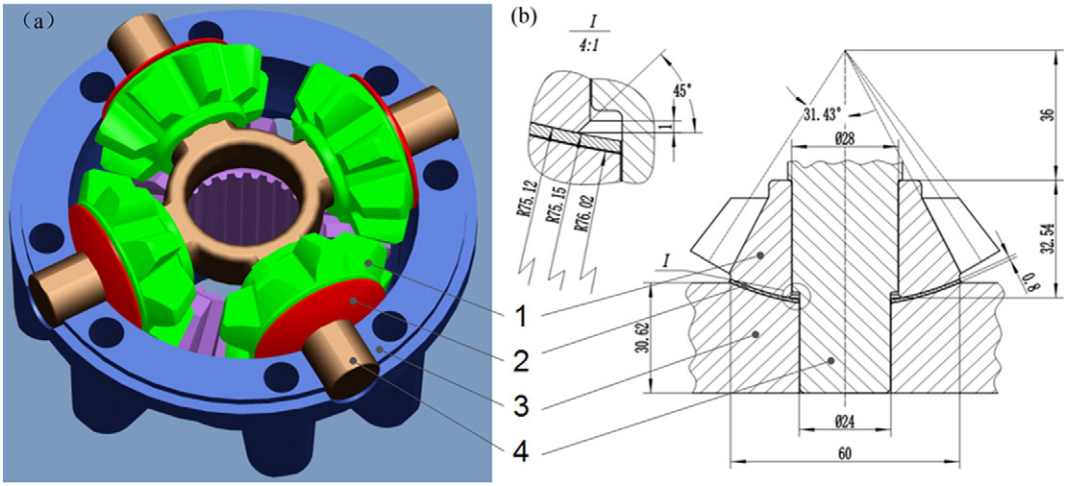

Fig. 1. The model of the differential (a) The 3D model of the differential (b) The schematic technical drawing of the spider gear-thrust washer-case assembly and 1 — spider gear, 2 — thrust washer, 3 — differential case, 4 — pinion shaft.

matrix composite shaft and carried out some stress analysis of the shaft by FEA technique. A single part shaft instead of the conventional two part shaft reduced the weight by 75% and increased the torque transmission capacity by 160%. In the present study, FEA simulation was carried out to investigate the contact stress concentration of thrust washer and give a stress equal-distribution solution. The lubricating state of thrust washer pairing the modified spider gear was verified with a wear test rig of full scale spacer.

The objective of this research work is to investigate the contribution of the surface profile modification of spider gear back in the contact pressure distribution and the wear performance of thrust washer. Firstly, FEA simulation was performed to investigate the stress distribution between the original spider gear and thrust washer. The tribological testing was conducted in a custom test rig for the real spider gear, thrust washer and case, which simulates the lubricating state of the thrust washer. Secondly, an improved approach was proposed to modify the surface profile of the spider gear back. It can change the contact area between the gear back and thrust washer, and avoid the local stress concentration. Finally, FEA simulations and tribological testing were performed to verify this feasible approach. In addition, the preferable modified parameters were selected to prolong the service life of the vehicle axle.

2. Simulations and experimental procedures

2.1. FE analysis of the stress in spider gear-thrust washer-case

The three dimension (3D) model of the spider gear-thrust washer-differential case is shown in Fig. 1(a). The four spider gears and thrust washers were distributed uniformly and symmetrically in the differential, and each spider gear contacts with two half axle gears. The resultant axle force was applied on the spider gear along the central axis. Herein, one spider gear-thrust washer-case contact pair was selected to study the stress distribution, as shown in Fig. 1(b). Although the real structure stress analysis is a 3D procedure, it is often considered to represent stress with an axisymmetric FE model for the spider gear-thrust washer-case [8].

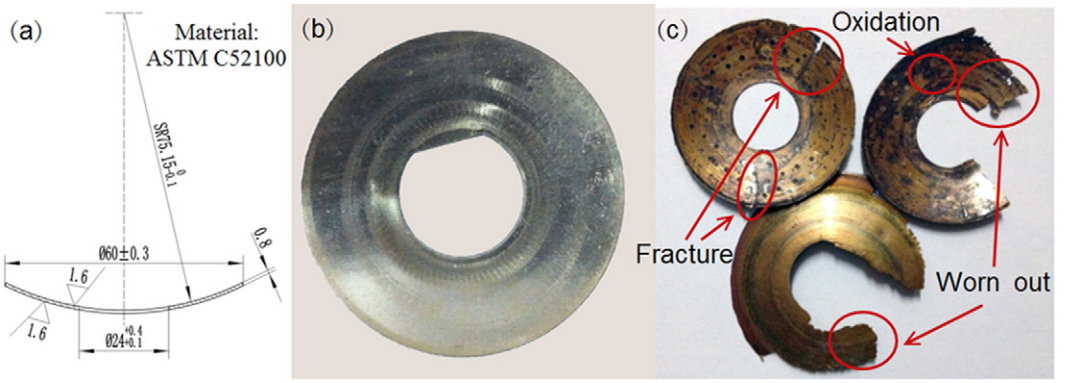

Fig. 2. The thrust washers in the differential. (a) A schematic technical drawing. (b) A photograph. (c) Failure of thrust washer.