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Finite-element modeling of the failure of interference-fit planet carrier and shaft assembly

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ABSTRACT

A planet carrier and shafts assembly with interference-fit was modeled based on 3-D finite element method by applying thermal loads to the shafts with orthotropic coefficients of thermal expansion. A 3-D finite element contact model verified that the contact pressure is identical compared with the calculated pressure by Lamé's equations for the thick-wall cylinder interference-fit. A displacement history analysis by the 3-D finite element multi-contact simulation under alternate loads reveals the root cause for the interference-fit shafts coming out of the planet carrier after 65 h of planetary gear reducer working test.

1. Introduction

A planet carrier is one of the core components of a planetary gear reducer. The integral-double-arm planet carrier is widely used for a heavy load transmission due to its advantages such as higher stiffness and larger loading capacity compared with a single arm planet carrier. The interference-fit is widely put into use to connect a planet carrier with shafts for its higher assembly accuracy and compact and lightweight design. In order to support the planet gears reliably, it is necessary to assure that there is no slip at the interface, no plastic deformation and fracture [1,2] for each part during operation.

In general, Lamé's equations can be used to compute stresses and deformations of two cylindrical parts under an interference-fit [3]. However, Lamé's equation is mainly based on two-dimensional (2-D) stress analysis in the linear elastic stage for the thick-wall cylinder interference-fit. It assumes the radial stress is non-zero. Therefore, it is not suited for the design of the thin-wall cylinder interference-fit and other interference-fits with more complex structure [4]. Nowadays, numerical methods such as finite element method (FEM) have become widespread in order to evaluate the stresses and deformations at the interface by considering the actual geometry and working conditions [5]. However, most research focuses on the hub and shaft assembly with interference-fit subjected to torque [6–11] and tensile [12,13] loading. The planet carrier and shaft assembly mainly accommodate forces perpendicular to the planet shafts. Nishimura et al. [14] conducted an axle extrusion test of an interference-fit on a conventional cantilever type rotating bending fatigue test machine, and then 2-D FEM analyses regarding the tested axle assemblies were carried out with computer program MARC to research on the phenomenon of ratchet extrusion. Croccolo et al. [15] provides a useful methodology to calculate the actual mean coupling pressure of a non-axisymmetric shaft–hub coupling used in front motorbike suspensions taking the asymmetric shape of the hub into account. A 2-D finite element interference-fit model was analyzed with the effect of thermal strains included [4]. In order to predict contact pressure and holding force, a closed form equation was proposed and verified with the experimental results measured and by 3-D thermal–structural coupled field analysis [7]. To avoid the time-consuming procedure of iteration and

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increment, the super element technique was used in an interference-fit analysis [16,17]. 3-D finite element simulations have been performed to obtain stress histories and distributions around the hole due to interference-fit using FEM package [18].

In our study, two types of 3-D finite element interference-fit models were analyzed using ANSYS software, and the results for the contact pressure are identical in comparison with that calculated using Lamé's equations for the thick-wall cylinder interference-fit. Contact problems are difficult to solve, being highly non-linear and often extremely sensitive to the elements in the contact zone [16], and it is especially difficult to analyze an interference-fit contact model with large initial geometrical interference. An effective method was employed to overcome the difficulty by applying temperature to the shaft with orthotropic coefficients of thermal expansion to achieve a radial expansion only. Applying cyclic symmetry constraint equations effectively decreases the computational scale of a finite element model of an interference-fit planet carrier and shaft assembly. Finally, a simulation of a planet shaft pushed out from a planet carrier under alternate loads reveals the root cause for the interference-fit shafts coming out of the planet carrier during the planetary gear reducer working test.

2. Description of the problem

The planetary gear reducer is a yaw drive that is used to orient a wind turbine properly with respect to the wind. A working test was carried out to confirm the design parameters of a new type of gear reducer. However, the result verifies that the parameters of the fifth planet carrier cannot meet the operating requirements for the planet shafts were pushed out from the planet carrier after 65 h working. The tested planetary gear reducer is composed of five stages of spur gears in series without bearings between each stage (Fig. 1). After 30 h working under alternate loads, the planet shafts of the fifth stage assembly came out a distance of 2 mm from the planet carrier (Fig. 2), and after another 35 h working, a planet shaft broke down (Fig. 3), and the fourth stage planet carrier was badly worn by the shafts (Fig. 4).

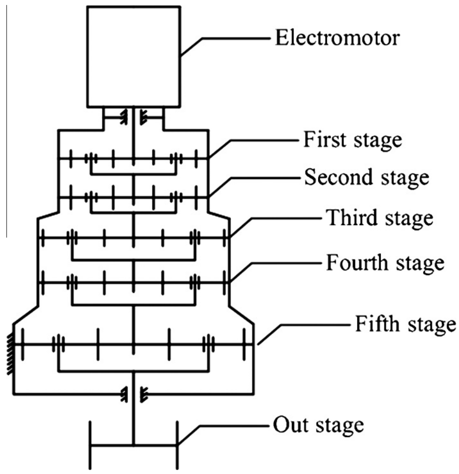

Fig. 1. Scheme of the five-stage planetary spur gear reducer.

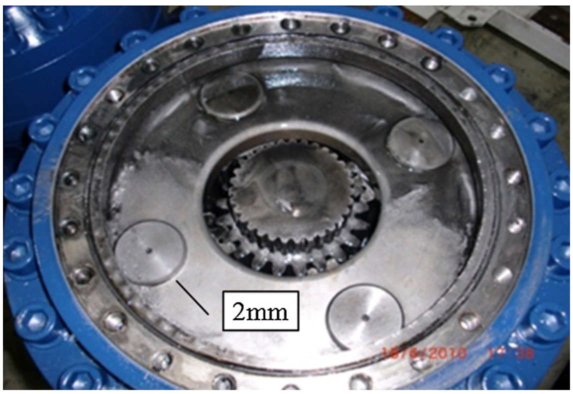

Fig. 2. Planet shafts came out a distance of 2 mm from the fifth stage planet carrier.