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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Speed reducers incorporating cycloidal technology as their primary reduction mechanism have always been active topics of research given their unique trochoidal tooth profile. A cycloidal reducer is recognized for its strength and mainly studied for rotational performance improvement. Nowadays, this study can be performed by digital prototyping, which has become a valuable tool for simulating exact scenarios without experimenting on actual model.

This paper discusses the stress distribution, modeled in a dynamic simulation environment, on the rotating parts of Cycloidal reducer. A three dimensional finite element model is developed using Algor FEA commercial code to simulate the combined effect of external loading and dynamic as well as inertial forces on one-cycloid disc system. This model utilizes surface-to-surface contact to define interaction between rotating parts of the reducer assembly. The results are analyzed for the variation in stress and deformation with respect to time for a certain simulation period. This study gives an insight of internal load sharing of rotating parts and their capability of carrying shock loads.

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Introduction

The cycloidal style of speed reducer is commonly used in many industrial power transmission applications. This type of mechanism, known for its high torque density and extreme shock load capacity, incorporates a unique reduction mechanism which is different from that of the more commonly understood involute gearing. To recognize the technical benefits of the Cycloidal reduction mechanism, one needs to understand the forces, load distribution and contact stresses associated with the reduction components within the mechanism. This type of study is also essential in design optimization processes to improve the overall performance of the reducer [1-6].

This study can be facilitated through an example of one tooth difference type cycloidal reducer with low reduction ratio. For simplicity, let us consider one disc reducer. The main rotating components of such reducer mechanism are shown in an exploded view in Figure 1. Here, a cycloidal disc with eight holes rotates on an eccentric bearing (cam). A rotation of the input shaft mounted eccentric cam generates swaying and rotational components of motion in the system. The swaying motion is a function of the amount of eccentricity in the eccentric cam. The larger the eccentricity, the lower the reduction ratio. The large amount of eccentricity results in making bigger hole design on the cycloidal disc to accommodate low speed shaft rollers as shown by equation (1).

$$D = d + 2e \quad (1)$$

where

- D is the diameter of the disc holes,
- d is low speed shaft's roller diameter, and
- e is the eccentricity.

Consequently, this bigger hole design reduces more material from the cycloidal disc and as a result, the disc undergoes greater stresses. The analysis of load distribution in dynamic conditions gives access to examine such stresses and their effects on the rotating parts.

There are several studies performed on static and dynamic problems of the gears. Numerical, analytical, and experimental approaches are used to investigate different gear profiles for load distribution, contact stress and dynamic effects. Such work helps to gather vital information to define design guidelines and find ways to optimize the torque transmission. However, very few publications are available addressing the same analyses on the cycloidal tooth profiled gears.

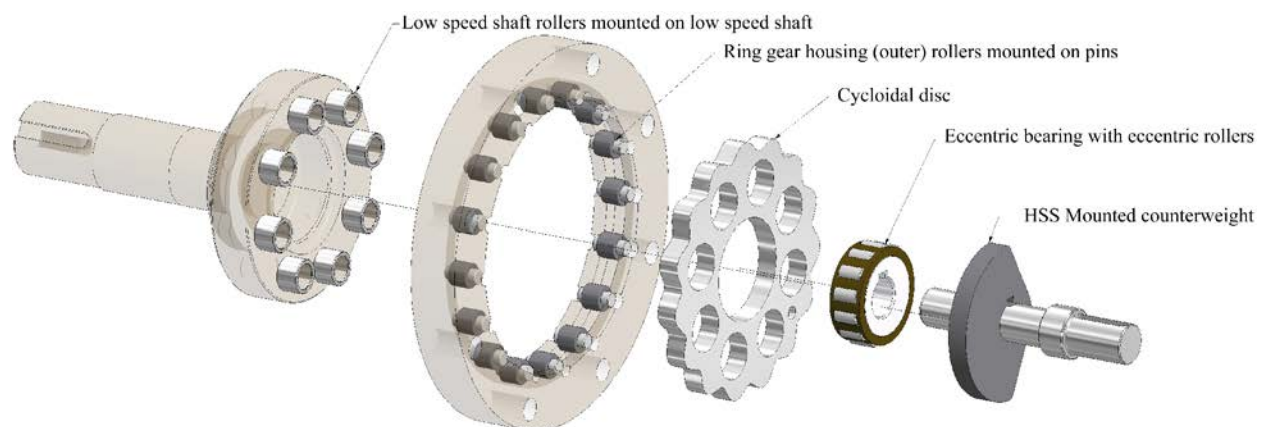


Figure 1. An exploded view of one tooth difference, one disc type of cycloidal reducer

The purpose of this paper is to investigate the load and stress distribution on the cycloid disc under dynamic as well as inertial effect using 3-dimensional finite element analysis. In dynamic conditions, the loads are applied as a function of time. Authors of this paper previously worked on the rigid body dynamic simulation of the cycloidal reducer to calculate motion related dynamic forces of the reducer [7]. Those forces were then applied to the rotating parts in a static FEA environment. The results, however, are limited by the rigid-body assumption which cannot deduce material-based contact stiffness and consequently accurate contact stresses. This limitation is overcome in the current study by performing analysis in a dynamic FEA environment.

To the authors' knowledge, the following studies have been done on this topic.

Malhotra and Parameswaran proposed a theoretical method to calculate contact force distribution on the cycloidal disc [8]. The analysis is based on one disc cycloidal reducer with one tooth difference. It was assumed that only half number of the low speed shaft and housing (outer) rollers participate in torque transmission at any instance. They also discuss the effect of various design parameters on forces and contact stresses using Hertzian formula. The work further addresses theoretical efficiency of the reducer considering friction. Blanche and Yang investigated backlash and torque ripple of the cycloidal drive using a mathematical model which considers machining tolerances [9]. The above mentioned analytical (conventional) methods, however, cannot predict precise contact loading because of their inherent assumptions and simplifications.

In the last two decades, there has been ongoing research performed using finite element based numerical methods. Gamez et al. mentioned contact stress analysis in trochoidal gear pump application [10]. His work gives a comparison between analytical model and FEM analysis of contact stress. Photoelasticity technique is also elaborated to evaluate the stress. For finite element analysis, his work mainly focuses on two dimensional quasi-static model of trochoidal tooth profiled gear pump. Li et al. used various tools, including Abaqus finite element software, to observe contact stresses in pinion-gear system by varying pressure angle [11]. The work also addresses stresses in planetary gear boxes by varying gap tolerance. The finite element model was developed using two dimensional, four node bilinear element for nonlinear sliding contact solution.

Barone et al. investigated load sharing and stresses of face gears building a three dimensional FEA model in Ansys software to simulate the effects of shaft misalignment and tooth profile modification. The results are shown by plotting graphs of load sharing, contact pressure, contact stress, and contact path against rotational angle [12]. This model implements penalty and augmented Lagrangian methods for surface to surface contact.

Geometry of cycloidal reducer

One tooth difference Cycloidal reducer can reduce the input speed up to 87:1 in a single stage. The gearbox Cyclo® CNH609-15, which is a horizontal, foot mounted, concentric shaft speed reducer of ratio 15:1, is selected for the simulation modeling and analysis [13]. The gearbox is chosen from the low reduction ratio category offered by the manufacturer. As discussed in Introduction section, the low reduction ratio results in greater induced stresses in the cycloidal disc on account of reduced material content of the disc. This model would be observed for such stresses in the cycloidal disc. The reducer design is comprised of one disc mechanism along with a counterweight (as shown in Figure 1), acting as a substitute to the second disc which is apparent in high torque transmitting reducers for dynamic balance and load sharing. This mechanism gives an advantage to focus on the contact loading behavior of only one cycloidal disc.

The epi-trochoidal tooth profile of the cycloidal disc is a vital feature in the reducer mechanism. Theoretically, for the one tooth difference reducer, all disc teeth or lobes on the profile remain in contact with subsequent ring gear housing rollers (outer rollers) and half of the rollers are considered participating in torque transmission at any instance [8]. However, the manufacturing errors and clearances for lubrication etc. impede the application of all tooth-roller contacts. The trochoidal profile in this model is developed from the manufacturing drawing which takes tooth modifications and tolerances into account.