



AGMA Technical Paper

Finite Element Analysis of a Floating Planetary Ring Gear with External Splines

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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

This study investigates the stresses and deflections of a floating ring gear with external splines working in a large planetary wheel motor of a mining truck. Such calculations carried out with conventional engineering approaches described in popular standards and textbooks are not comprehensive because of the complexity of the problem. These approaches can give us good stress numbers for non-floating gears and some guidance about the rim thickness factor but they lack the capabilities to effectively calculate the deflections and their influences on the stresses, especially for floating gears. Moreover they cannot calculate an entire gearing system and the interdependent influences of the different components.

The model studied consists of a floating ring gear driving a torque tube. The ring gear is driven through internal gear meshing by three planets and it transmits the torque to the torque tube through its external splines. The torque tube transmits the motion to the hub and the truck tires.

A nonlinear static analysis of the ring gear and torque tube was conducted in ABAQUS. Linear 8-node hex elements and linear tetra elements were used to model the ring gear and torque tube. External torque was resolved into corresponding tangential force, which was then applied directly onto three of the ring gear's internal teeth. Contact pairs were used to capture the load transfer between the ring gear and torque tube through the splines.

The results show that the deflections in the ring gear were so excessive that about one-tenth of the spline teeth were actually transmitting torque against the common engineering understanding that only half of the spline teeth are typically engaged. The crowning of the spline teeth had also effect on the stresses though quite small compared to the deflections. Conclusions and recommendations were made about the effectiveness of the design.

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Introduction

The design of a planetary ring gear is always a challenge due to the contradictive requirements which it must comply with. On one hand the ring gear should be strong and stiff enough to successfully carry the applied load. On the other hand, it should have as small volume as possible to account for the radial restraints of a planetary gearbox imposed by the truck tires. Additionally, the ring gears are floating in many cases. Altogether, the designer job becomes very complicated.

One of the design issues of the strength calculations of the ring gear is that none of the American Gear Manufacturers Association (AGMA) standards, including ANSI/AGMA 2001-D04 [1], rate internal gears. No acceptable methodology is defined to calculate geometry factor for internal gears, following the method for external gears in ANSI/AGMA 908-B89 [2]. ANSI/AGMA 2001-D04 provides guidelines for the calculations of the ring gear rim thickness by introducing the rim thickness factor.

Very often the ring gears have external spline teeth which transmit the torque to the final driven member of the gearbox. ANSI/AGMA 6123-B06 [3] gives a methodology for calculating splines which include shear capacity, fretting and wear as well as ring bursting. The standard assumes that 50% of the splines are carrying the torque. Other approaches suggest different ways to calculate splines [7].

The stresses in the gear and the spline teeth are influenced by the deflections of the gear itself and also by the deflections of the entire gearbox. AGMA does not have published codes for calculating these deflections. It stresses in different standards like ANSI/AGMA 2001-D04 the importance of determining the deflections, and provides examples of using Finite Element Analysis (FEA) methods.

Because of these difficulties in the engineering design of ring gears more and more researchers are using modern calculation methods like FEA. One researcher showed that when properly used, FEA and AGMA methods give closer results [6]. In this study a ring gear assembly is evaluated using FEA software in order to determine the stresses and deflections in the system.

Design model

The assembly consists of a carburized ring gear and a through hardened torque tube (Figure 1) used in the wheel motor of large electrically driven mining truck. The torque path comes from three planet gears (not shown and used in the study), whose teeth are meshed with the internal teeth of the ring gear. The ring gear transmits the torque to the torque tube through its external splines. The torque tube transmits the torque from its internal splines to the hub through a bolted joint and from there to the truck tires.

The meshing areas between each planet and internal gear teeth are marked as zones 1, 2 and 3 (Figure 2). Each one is modeled with different root radii and crowning of the external splines. The gear and spline teeth are ground to quality 6 per ANSI/AGMA 2015-1-A01 [4] and ANSI/AGMA 20015- 2- A06 [5].

Loading and constraints

The applied torque is assumed to be equally divided among the three planets per ANSI/AGMA 6123-B06 (Figure 3) which recommends a mesh load factor of “unity” for high speed and high quality gears for the presented case. For the purpose of this study the force acting on each tooth is applied at the highest point of single tooth contact for each location (Figure 4) and assumed to be equally distributed along the line of contact which means using load distribution factor of “unity”.

The application of the force transmitted through the splines is determined by the FEA software. The ring gear is floating in all directions. The radial and circular movement of the gear is limited by the backlash in the assembly and the axial movement is restricted by axial stoppers, which are not shown.

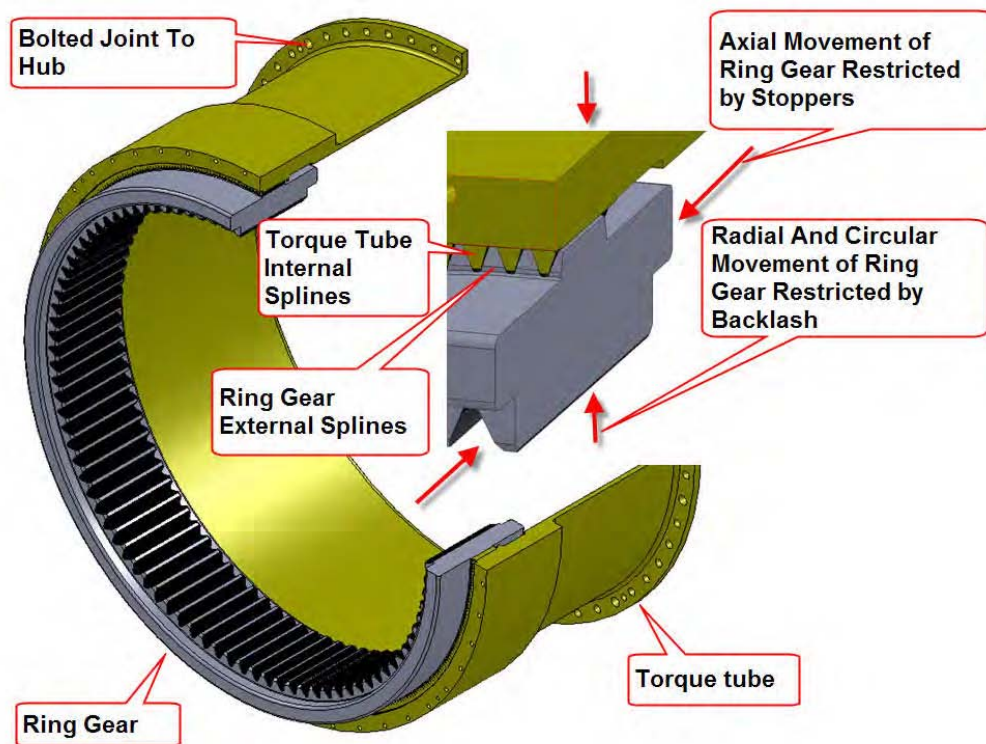


Figure 1. Ring gear and torque tube assembly view

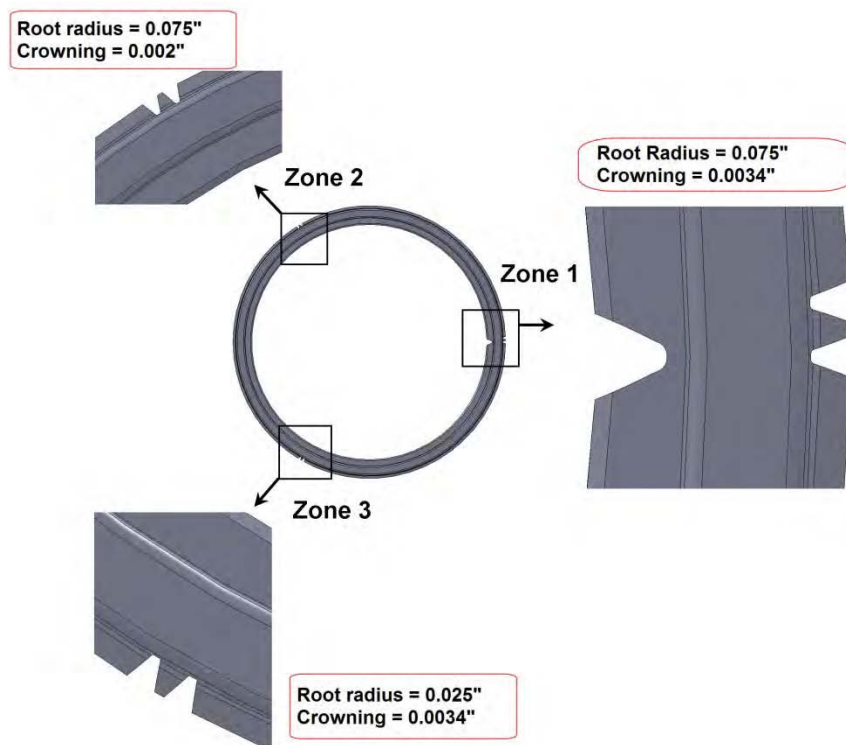


Figure 2. Ring gear splines root radii and crowning