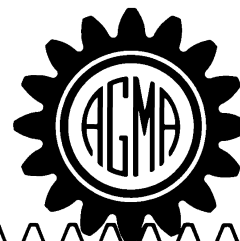


Modal Failure Analysis of a Gear and Drive Ring Assembly

by: D.D. Behlke, Twin Disc, Incorporated

American Gear Manufacturers Association



TECHNICAL PAPER

Modal Failure Analysis of a Gear and Drive Ring Assembly

Darwin D. Behlke, Twin Disc, Incorporated

[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

After years of successful reliable applications, a component failure on a new application cannot be explained with static stress analyses, modal failure analyses may be required. Finite element modal analyses was used to identify the mode and its frequency that cause a high range gear and drive ring assembly to fail prematurely. A Campbell Diagram was used to identify modes in the operating range of a six-speed transmission that could cause the drive ring to fail. Redesigning the assembly to move the critical modes out of the operating range is described.

Copyright © 2005

American Gear Manufacturers Association
500 Montgomery Street, Suite 350
Alexandria, Virginia, 22314

October, 2005

ISBN: 1-55589-860-2

Modal Failure Analysis of a Gear and Drive Ring Assembly

Darwin D. Behlke, P.E., Gear Design Specialist
Twin Disc, Incorporated, Racine, WI

BACKGROUND

With the advent of personal computers in the past two decades, modal analysis has become a major technology for determining, improving and optimizing dynamic characteristics of mechanical components. With the requirements for greater power densities, transmissions are being applied at higher horsepower and lower weight and size. When the vibration of a component is of concern, the challenge lies on better understanding its dynamic properties using analytical means, or experimental, or a combination. In this paper, only numerical analysis will be used.

To provide background about modal analysis, the following information was paraphrased from He, et al [1]. Finite element analysis (FEA) requires rigorous theoretical guidance to ascertain meaningful outcome in the relation to structural dynamics. Modal analysis (MA) alone cannot determine completely the dynamic behavior of the component, because certain properties such as damping and nonlinearity do not conform to traditional modeling treatment. Also, boundary conditions influence the dynamic analysis and must be applied with great care.

Modal analysis is the process of determining the inherent dynamic characteristics of a component—natural frequencies, damping factors and mode shapes. These characteristics are used to formulate a mathematical model for its dynamic behavior. The formulated mathematical model is referred to as the modal model of the component. The information for the characteristics is known as its modal data.

The dynamics of a component are physically decomposed by frequency and position. Modal analysis is based upon the vibration response of the linear time-invariant dynamics system. It can be expressed as the linear combination of a set of simple harmonic motions called the natural modes of vibration. This concept is parallel to the use of a Fourier combination of sine and cosine waves to represent a complicated waveform. The natural modes of vibration are determined completely by its physical properties (mass, stiffness, damping) and their spatial distributions.

Each mode is described by its mode shape. The mode shape may be real or complex. Each mode corresponds to a natural frequency. The contribution of each natural mode in the overall vibration is determined both by properties of the excitation source(s) and by the mode shapes of the component.

The theoretical modal analysis anchors on modeling the physical characteristic of a dynamic system comprising its mass, stiffness and damping properties. These properties may be given in forms of partial differential equations. For example, the wave equation of a uniform vibratory string is established from its mass distribution and elasticity properties. The solution of the equation provides the natural frequencies and mode shapes of the string and its forced vibration responses. A more realistic physical model will usually comprise the mass, stiffness and damping properties in terms of their spatial distributions, namely the mass, stiffness and damping matrices. These matrices are incorporated into a set of normal differential equations of motion. The superposition principle of linear dynamic systems enables us to transform these equations into a typical eigenvalue problem. Its solution provides the modal data of the system. Modern FEA empowers the use of almost any linear dynamic structure and has greatly enhanced the capacity and scope of theoretical modal analysis.

The resultant finite element model, which is in the form of mass and stiffness matrices, can be essential for further applications such as sensitivity analysis and prediction due to proposed component changes. Using the modal model of the component, simulation and prediction of “what if” can be conducted. A sensitivity analysis is used to determine the sensitivity of its modal parameters due to a component physical parameter change. The emphasis here is to identify which physical change is the most effective in making a proposed modal parameter change, such as shifting a natural frequency. Structural modification is guided by variations of modal parameters due to a selected physical change.