

Design Technologies of High Speed Gear Transmission

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American Gear Manufacturers Association



TECHNICAL PAPER

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Abstract

Competition drives productivity. Productivity drives gear speed. Gear transmissions for steel wire mill drives, turbine drives and for many other applications are operating at pitch line velocities of 25,000 feet per minute or higher. Many factors are not issues for low speed gears are serious issues for high speed gears. The presented article discusses a few critical factors and their effects on high speed gear transmissions. The first factor is centrifugal force, and its effects on tooth root strength, tooth expansion and backlash, and the interference fit between gear and shaft. The second is system dynamics, including critical speed, dynamic balancing, and the torsional effects of flexible couplings. The third is the windage loss with different combinations of helix and rotation direction, lubricant flow rate, flow distribution and their effects on tooth bulk temperature field and tooth thermal expansion.

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Competition drives productivity and gear speed. Gear transmissions for many applications are operating at pitch line velocities in excess of 25,000 feet per minute. Many factors that are not issues for low speed gears could be serious issues for high-speed gears. The presented article discusses centrifugal force, system dynamics, windage loss and their effects on high speed gear transmissions.

Introduction:

Numerous studies have been done on high speed gearing. Each study focused on different aspects of high speed gear transmission. Rotor dynamics, vibration and noise have been major subjects [1][2][3][4][5][6]. Temperature distribution and its thermal effects are another focus area [7][8][9][10]. However, the application of the research results has not been very productive.

There are two major reasons for that. One reason is that most research was conducted in universities and laboratories, where either models were created a bit different from that in reality or too many factors were included. The other reason is that most research produces massive and complicated results that are not truly feasible to be directly applied to the real design. This paper discusses a few critical factors in designing of high speed gears and provides some simple yet effective solutions to corresponding problems.

The following table gives basic parameters and working conditions of the studied gear system as our design example throughout this paper. The pinion and gear are carburized and ground to AGMA class 13. Fine pitch is selected for a higher contact ratio. Oil film bearings are used for this system.

Parameters	Pinion	Gear
Number of teeth	32	120
Speed (RPM)	45000	12000
Center Distance (inch)	6	
NDP	14	
Net Face width (inch)	3	
Pressure Angle (degree)	20	
Helical Angle (degree)	35.208	
Power Input (HP)	1800	
Service Factor	2.0	

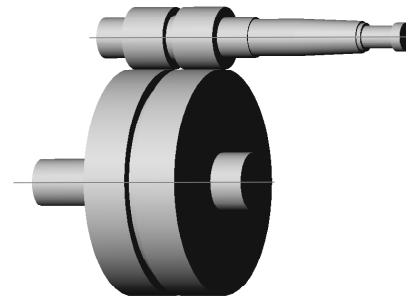


Figure 1 – Prototype of a Double Helical High Speed Gear Pair

Centrifugal force

Centrifugal force has not received significant attention in designing of high speed gearing. Though a few companies may have considered radial expansion in specification of backlash and center distance, most gear design engineers do not even consider this factor. In this article, distributions of stresses resulting from the centrifugal force are investigated.

Simplify the gear as a disk, with $h < R/2$, the following equations apply:

$$\frac{d}{dr}(rh\sigma_r) - h\sigma_t + \rho\omega^2 r^2 h = 0$$
$$\frac{d}{dr}\left(\frac{\sigma_t}{E}\right) - \frac{d}{dr}\left(\frac{\mu\sigma_r}{E}\right) - \frac{(1+\mu)(\sigma_r - \sigma_t)}{rE} = 0$$

Where, r – radius at any location
 E – elasticity of the material
 h – thickness of the disk
 μ – Poison's ratio
 σ_t – Tangential stress
 σ_r – radial stress
 ω – Angular speed
 R – Outside diameter of the disk

With given geometry, material and appropriate boundary conditions, the following results at corresponding loading conditions were obtained.