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Optimal Design of a Heavy Duty Helical Gear Pair using Particle Swarm Optimization Technique

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Abstract

A helical gear pair of a heavy duty gear reducer is considered for the objective of minimum volume, since the most power transmission systems require low weight energy efficient and cost effective system elements. The various factors for sizing and strength of gears are computed for gear geometry parameters using DIN standard. The formulation of the constrained non-linear multi-variable optimization problem with derived objective function and constraints is presented. The solution is attempted using Particle Swarm Optimization (PSO). The results achieved are satisfactory and helps designer to employ for minimum material and cost by fulfilling the strength and performance requirements.

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Keywords: Helical gear design; Genetic Algorithm; Particle swarm optimization;

1. Introduction

Helical gears are currently being used increasingly in cranes, power plant, sugar mills, automobiles, marine, coal plant, and rolling mills as a power transmitting gear owing to their relatively smooth and silent operation large, load carrying capacity and higher operating speed. Designing highly loaded helical gears for power transmission systems that are good in strength and low level in noise necessitates suitable analytical methods which can easily be put into

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practice and also give useful information on contact and bending stresses. Many researchers attempted finite element methods to analyse the gears.[1,2,3,4,5]. Chan et al.[6] analysed the gear tooth surface for minimum noise for multiple loads. Padmanabhan et al.[7] used Genetic Algorithm (GA) and Finite Element Analysis (FEA) for gear pair design for optimum space requirements by satisfying bending and crushing stress. The PSO has been used by other researchers [8,9,10,11,12] for optimal design of welded beam, pressure vessel, compression spring, etc. Since the helical gear pair finds ample applications, an attempt is presented here for optimizing the volume of a certain heavy duty application gears.

Nomenclature

m_n	normal module, mm
b	face width, mm
Z_1	number of teeth on pinion
Z_2	number of teeth on gear
β	helix angle, degrees
	transverse contact ratio for pinion
	transverse contact ratio for wheel

2. Design Methodology

For a certain application considered in present work based on [13], the design inputs are (a) power to be transmitted=120 kW (b) gear ratio=5.18 (c) pressure angle=20^0 (d) helix angle=12^0, (e) material is case hardened steel (20MnCr5). By Lewis equation, the module is yielded as 14.

2.1. Calculation of geometrical parameters and strength based factors

Using DIN 3990 and 3960 standards [14,15], various parameters are calculated and shown in Table 2, while in Table 3 the individual parameters for pinion and wheel are shown. Table 4 shows computed strength based factors. All tables are shown in Appendix.

3. Formulation of minimum volume problem

The design variables for the formulation are face width (b or x_2), gear teeth (Z_1 or x_3 and Z_2 or x_4), helix angle (β or x_5) as m_n (or x_1) is already computed as 14.

3.1. Formulation of objective function

For the present case of optimization, the objective function is the minimization of volume of cylindrical gear pair given by [13],

$$V = \frac{\pi}{4}\frac{m_n^2 b}{\cos^2\beta}\left(Z_1^2 + Z_2^2\right) \tag{1}$$

Representing the objective function in the form as below,

$$f(x) = V = f\left(m_n, b, Z_1, Z_2, \beta\right) = f\left(x_1, x_2, x_3, x_4, x_5\right) = \frac{\pi}{4}\frac{m_n^2 b}{\cos^2\beta}\left(Z_1^2 + Z_2^2\right) \tag{2}$$