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Gear train optimization based on minimum volume/weight design

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ABSTRACT

In this study, the general form of objective function and design constraints for the volume/weight of a gearbox has been written. The objective function and constraints can be used for any number of stages for gearbox ratio but in this paper one, two and three-stage gear trains have been considered and by using a Matlab program, the volume/weight of the gearbox is minimized. Finally, by choosing different values for the input power, gear ratio and hardness of gears the practical graphs from the results of the optimization are presented. From the graphs, all the necessary parameters of the gearbox such as number of stages, modules, face width of gears, and shaft diameter can be derived. The results are compared with those reported in the previous works and an example is presented to show how the practical graphs can be used.

1. Introduction

Gear trains are the most common of machine components and the problem of their minimum weight or minimum volume design has been a subject of many researches. By integrating the configuration design process and dimensional, Chong et al. [1] suggested a new generalized method and algorithm to design multi stage drives. Their suggested algorithm consists of four stages. At the first, the user considered the number of reduction stages provisionally. Next, by using the random search method the gear ratio of each stage is specified. Third by using generate and test methods, the basic gear parameters are chosen. At the end, by using the simulated annealing algorithm, the values of other design parameters are defined. The objective function that they considered is minimizing the geometrical volume. Prayoonrat and Walton [2] depicted an algorithm to optimize and design multi spindle gear trains. In their algorithm the designer could choose many options to optimize the gear trains such as minimum volume or minimum overall size.

Wang et al. worked on the optimal engineering design of spur gear sets and tooth profile [3,4]. By using genetic algorithm, Yokota et al. formulated an optimization problem for the weight design of a gear [5]. They considered the bending strength of gear and shafts gear dimensions as constrains of the optimization problem. Using interactive physical programming Huang et al. investigate the multi objective optimization reduction units with three-stage spur gear [6]. Pomrehn and Papalambros worked on discrete optimal design formulations with application to gear train design [7]. Gologlu and Zeyveli depicted a genetic approach to automate a preliminary design of gear drives [8]. Thompson et al. [9] worked on minimizing the volume of single and multi stage spur gear reduction units. Based on design criteria their method is applied to the units with two-stage and three-stage spur gear

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Nomenclature

b	Net face width
D_i	Diameter of gear
d	Shaft diameter
d_{w1}	Operating pitch diameter of pinion (mm)
e_l	Gap for gear and shell in length direction
e_h	Gap for gear and shell in height direction
e_w	Gap for gear and shell in width direction
F_t	Transmitted tangential load (N)
h	Height of gearbox
K_B	Rim thickness factor
K_H	Load distribution factor
K_O	Over load factor
K_S	Size factor
K_V	Dynamic factor
L_{in}	Length of input shaft
L_{out}	Length of output shaft
l	Length of gearbox
n	Number of shafts
M_a	Alternating bending moment-shaft design
m_g	Metric module of gear
m_p	Metric module of pinion
m_t	Transverse metric module (mm)
N_g	Number of teeth on gear
N_p	Number of teeth on pinion
R	Overall reduction ratio of gearbox
r	Radius of gear
S_e	Endurance limit-shaft design
S_f	Safety factor-bending
s	Number of stages
S_{fs}	Safety factor-shaft design
S_H	Safety factor-pitting
S_y	Yield strength-shaft design
T_m	Midrange torque of shaft
t	Thickness of shell of gearbox
u_i	Partial reduction ratio of each gearbox stages ($i = 1, 2, 3$)
w	Width of gearbox
Y_J	Geometry factor for bending strength
Y_N	Stress cycle life factor for bending strength
Y_Z	Reliability factor
Y_Θ	Temperature factor
Z_I	Geometry factor for pitting resistance
Z_E	Elastic coefficient $(N/mm^2)^{0.5}$
Z_N	Stress cycle life factor for pitting resistance
Z_R	Surface condition factor for pitting resistance
Z_W	Hardness ratio factor for pitting resistance
β	Helix angle at standard pitch diameter
φ_t	Transverse pressure angle
σ_{FP}	Allowable bending stress number (N/mm^2)
σ_{HP}	Allowable contact stress number (N/mm^2)

reduction. Petre et al. worked on the design and simulation of a steering gearbox with variable transmission ratio [10]. By using the genetic algorithm optimization of the modulus of spur gears, the diameter of shafts and rolling bearing is investigated by Mendi et al. [11]. Their procedure is based on minimizing the volume of the gearbox. Pi worked on minimizing the gearbox length of a four step helical gearbox [12]. By using Steady State Finite Element Analysis Joule et al. [13,14] investigated the Thermal