



American
Gear Manufacturers
Association

Technical Resources

10FTM06

AGMA Technical Paper

Finite Element Analysis of High Contact Ratio Gear

By M. Rameshkumar, G.
Venkatesan and P. Sivakumar,
DRDO, Ministry of Defence

Finite Element Analysis of High Contact Ratio Gear

M. Rameshkumar, G. Venkatesan and P. Sivakumar, DRDO, Ministry of Defence

[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

Modern day vehicles demand higher load carrying capacity with less installed volume and weight. The gears used in the vehicles should also have lesser noise and vibration. Even though helical gears will meet the requirement, they are prone for additional axial thrust problem. High contact ratio (HCR) is one such gearing concept used for achieving high load carrying capacity with less volume and weight. Contact ratio greater than 2.0 in HCR gearing results in lower bending and contact stresses. Previously published literature deal with studies on various parameters affecting performance of HCR gears but a comparison of HCR and normal contact ratio (NCR) gears with same module and center distance has not been carried out so far. This paper deals with finite element analysis of HCR, NCR gears with same module, center distance and the comparison of bending, contact stress for both HCR, NCR gears. A two dimensional deformable body contact model of HCR and NCR gears is analyzed in ANSYS software. ANSYS Parametric Design language (APDL) is used for studying the bending and contact stress variation on complete mesh cycle of the gear pair for identical load conditions. The study involves design, modeling, meshing and post processing of HCR and NCR gears using single window modeling concept to avoid contact convergence and related numerical problems.

Copyright © 2010

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

October 2010

ISBN: 978-1-55589-981-3

Finite Element Analysis of High Contact Ratio Gear

M. Rameshkumar, G. Venkatesan and P. Sivakumar, DRDO, Ministry of Defence

Introduction

A majority of the heavily loaded transmissions used in military applications use gears with a contact ratio less than 2.0. The contact ratios of these transmissions are in the range of 1.3 to 1.8. So, the number of teeth in engagement at any instant is either one or two. Many gear designs use increased pressure angle for increasing the load carrying capacity of gears with fixed module and center distance, but the contact ratio decreases. Tooth dynamic loads and noise increase due to decreased pressure angle. Hence increasing the load carrying capacity of gears for the above conditions can be done by the design of gears with a contact ratio greater than 2.0. High contact ratio gears having a contact ratio greater than 2.0 have load sharing between two or three teeth during engagement and less load per tooth [1]. The high contact ratio (HCR) gears guarantees that a minimum of two teeth always share the load. The variation of gear mesh stiffness for HCR gears is less than the normal contact ratio (NCR) gears; the transmission error for HCR gears is minimum compared to NCR gears.

The literature survey indicated that HCR gearing was designed [2] and successfully used in helicopter transmissions [3], to improve power to weight ratio of the gear trains. This study deals with estimation and comparison of tooth root bending stress and contact stress over the path of contact for high contact ratio gears [1, 4] and normal contact ratio gears designed with identical module, center distance, gear ratio and face width using Finite Element Analysis. In order to overcome the numerical and convergence difficulties [5] involved a new single window modeling approach [6] using ANSYS Parametric Design Language (APDL). The contact stress and bending stress are compared and plotted for identical load conditions.

Design for HCR gear pair

Contact ratio of a gear pair is defined as the average number of teeth in contact during the course of engagement. The contact ratio of the gear pair plays an important role in increasing the load carrying capacity of gears.

The contact ratio (CR) for any gear pair is given by equation 1.

$$CR = \frac{\sqrt{(r_1 + a)^2 - r_1^2 \cos^2 \alpha}}{\pi m \cos \alpha} + \frac{\sqrt{(r_2 + a)^2 - r_2^2 \cos^2 \alpha} - (r_1 + r_2) \sin \alpha}{\pi m \cos \alpha} \quad (1)$$

where

- r_1, r_2 are the operating pitch radius of the pinion and gear,
- α is the operating pressure angle;
- m is the module and a is the addendum (based on the operating pitch radius) which is equal to one module for standard gears.

High contact ratio can be achieved by different ways namely:

- Increasing the number of teeth;
- Lowering the pressure angle;
- Increasing the addendum factor.

Figure 1, Figure 2 and Figure 3 show the variations of contact ratio with respect to above parameters. In order to achieve a contact ratio more than 2.0 for a gear pair with identical module, center distance, gear ratio and pressure angle the addendum factor of the gears pair is increased from a standard 1.0 m to 1.25 m . The entire tooth parameters of a HCR gear pair are calculated using a Matlab code and tabulated in Table 1.

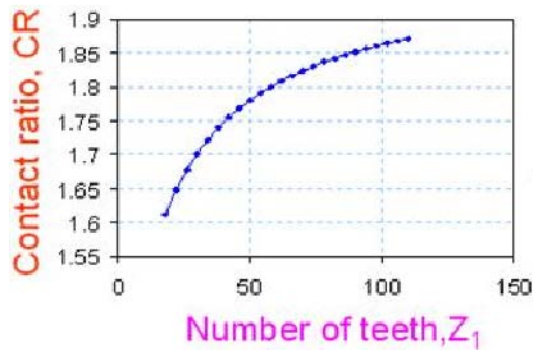


Figure 1. Contact ratio versus number of teeth

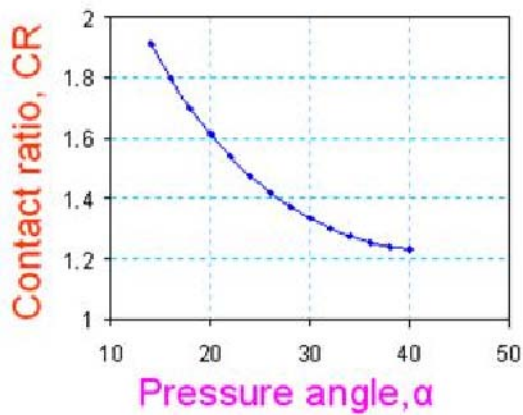


Figure 2. Contact ratio versus pressure angle

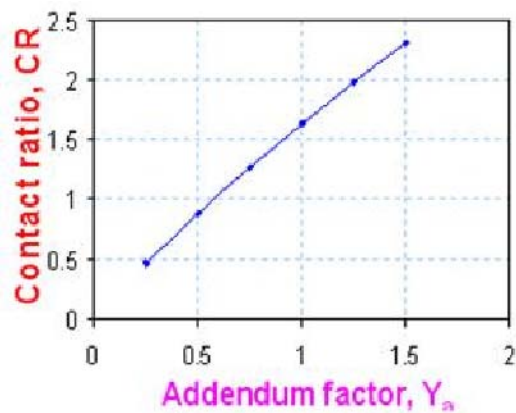


Figure 3. Contact ratio versus addendum factor

Generation of gear pair model

Spur gear geometry

The profile of an involute spur gear tooth is comprised of two curves. The working portion is the involute and the fillet portion is the trochoid. The trochoid tooth fillet as generated by a rack cutter is

modeled exactly using the procedure suggested by Buckingham [7]. An “APDL” computer language code in ANSYS was developed for generating an exact tooth profile with a trochoidal fillet. The trochoidal fillet form is generated from the dedendum circle up to the limiting circle, where it meets the involute profile at the common point of tangency and the involute profile extends up to the addendum circle.

Table 1. Gear parameters

SI No.	Parameters	NCR	HCR
1.	Profile	Involute	Involute
2.	DIN accuracy class	7	7
3.	Module, m	2.5 mm	2.5 mm
4.	Number of teeth in gear, Z_1	50	50
5.	Number of teeth in pinion, Z_2	47	47
7.	Profile correction in gear, X_1	0.1552	0.1552
8.	Profile correction in pinion, X_2	0.152	0.152
10.	Center distance, C_d	122 mm	122 mm
11.	Reduction ratio, G_r	1.06383	1.06383
12.	Addendum factor, Y_a	1.0	1.25
13.	Contact ratio, CR	1.6860	2.06266
14.	Face width, F	18 mm	18 mm

Figure 4 shows generation of a trochoidal fillet by the tip of the basic rack with $a = 0$ (sharp cutter). Coordinates of the trochoid are calculated using the APDL program using equation 2 through 8 as noted in [7]. The type of Trochoidal fillet changes with parameters of the cutter like type of cutter (pinion or rack), edge radius (a), addendum (b), pressure angle and profile correction required in the gear.

$$\theta_t = \tan^{-1} \left[\frac{\sqrt{R_t^2 - (R - b)^2}}{(R - b)} \right] - \left[\frac{\sqrt{R_t^2 - (R - b)^2}}{R} \right] \quad (2)$$

$$\tan \psi_t = \frac{R(R - b_2) - R_t^2}{R \sqrt{R_t^2 - (R - b_2)^2}} \quad (3)$$