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COMPUTER AIDED DESIGN OF HELICAL GEAR

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Abstract: In recent times, the gear design has become a highly complicated and comprehensive subject. A designer of a modern gear drive system must remember that the main objectives of a gear drive is to transmit higher power with comparatively smaller overall dimensions of the driving system which can be constructed with minimum possible manufacturing cost, runs reasonably free of noise and vibrations and which requires little maintenance. As a result, an interactive user friendly low cost software "HelOSpur2011" was developed to relieve designer of analytical way of calculating needed parameters for design of helical and spur gears, generating reliable data for use in manufacturing process. The software is able to produce accurate and efficient 2D (two dimensional) and 3D (three dimensional) detail working drawings as a result of interactive computer graphics and provide substantial saving in time and cost of production. Results generated by the software shows that the computed face width (for strength check) and wear check for helical gears design as against manual methods were in relative error of 0.64% and 0.35% respectively. Relative accuracy of the software stand at 99.6%.The work has demonstrated the effectiveness of using the software to cater for helical gear design problems as well as spur gears when helix angle is zero. The introduction of this software to the society will in no small way increase productivity and reliability of helical and spur gears design.
Keywords: Helical gear, interactive, efficient, reliability

1. INTRODUCTION

Computer Aided Design (CAD) was defined by Farag (1987) to be the use of computer system in the creation, modification, analysis, optimization, storing and communication of design information. The CAD system allows design modifications to be performed easily and efficiently. The analysis and optimization phases of the design are easily and accurately performed by the computer while the designer will find these task times consuming and tedious without the use of computer. The use of computers and the development of computer aided design techniques have resulted in significant reductions in design project costs, working hours, inconsistencies and mistakes (Ray, 1987).The introduction of CAD to engineering design has yielded economic benefits. Farag (1987) reported that the work of 32 draftsmen working without a CAD system may be done by 8 draftsmen with the use of computer aided.

Jain (2001) defined the term 'gear system' as a power transmission element commonly used to transmit power or rotary motion from one shaft to another. Maitra (2005) stated that the designed gear must be able to transmit high power with little or less noise and vibration .The determination of the proper gears to use in a particular application is a complex problem because of many factors involved. Singh, (1997) highlighted some of the factors in the design of gears such as: the gear must operate together without tooth interference with a poor length of contact, the gear teeth must have the ability to transmit applied load without failure and wearing qualities of the teeth must be considered. These theories usually give rise to a set of equations which has to be solved to arrive at a satisfactory result. Venkatesh, kamala and Prasad (2010) work on Design, Modeling and Manufacturing of helical gear for marine engine. The CATIA software was developed to study the structural analysis on a high speed helical gear used in marine engine. This work was carried out to establish stresses generated and deflection of the tooth for the different materials. This work came out with the findings of materials best suited for the marine engine.

Nordiana et. al.,(2007) study computer aided design for a spur gear called Cadgear(2007),an interactive computer graphics able to generate accurate data and produce precise and efficient 2D design drawings based on strength and wear calculations. In this present work, proprietary software that will cater for helical gear design as well as spur gear (when helix angle is zero) was developed. The software is also expected to relieve designer of analytical ways of calculating needed parameters for design of gears, generate reliable data for use in manufacturing process, produce gear description; accurate 2D (two dimensional) and 3D (three dimensional) design drawings as a result of interactive computer graphics and provide substantial saving in time and cost of production

2. RESEARCH METHODOLOGY

This section describes the methodology used for conducting this study. This includes the general design consideration for a gear drive, design for adequate strength of helical gear tooth, gear parameters for strength consideration, helical gear tooth dynamic loads, helical gear tooth wear loads and software development and its application.

— Background of Study

Approach to this study entail the development of software which will design helical and spur gears based on minimum specification of input parameter. Visits to some manufacturing company such as Alara Tech machine Tools in Oshogbo Osun State, DonBosco College Training Centre in Ondo State, Nigeria were conducted to assess how helical gears are designed and produced. Consultations with standard Machine Design text book, as well as oral interview were also conducted by experienced gear designer in order to establish design procedures

— General Design Considerations for A Gear Drive

The proper design of gears for power transmission in a particular application is a function of the availability of the following data as highlighted by Khurmi and Gupta (2009).Expected transmitted power, driver gear speed, driven gear speed or speed ratio and centre distance. The essential conditions that must be met in the design of a gear drive according to Khurmi and Gupta (2009) includes the gear teeth will not fail under static loading or dynamics loading during normal conditions, the gear teeth should posses good wear resistance so that they will not fail under static loading or dynamics loading during normal conditions. The gear teeth should posses good wear resistance so that gear life is satisfactory, the use of space (in terms of module selection) and material should be economical hence, smaller modules are preferable and the gears must operate together without tooth interference with proper length of contact and without noise. Generally, the design of gear tooth involves essentially the determination of proper pitch and face width for adequate strength, durability and economy of manufacture. Thus spur and helical gears are designed from the standpoint of strength and wear

— Design for Adequate Strength of Helical Gear Tooth

In helical gears the contact between mating gear starts at one end move along the line of contacts. Thus in order to find the strength of helical gears, a modified Lewis equation reported by Singh,(1997) for determined strength of gear tooth is given in Equation 1;

$$b = \frac{F_t}{(\sigma_b \times C_v) m y^1 \pi} \tag{1}$$

where b =face width (mm); F_t = Tangential force (N); m = module, y^1 = Lewis form factor corresponding to formative number of teeth, σ_b = allowable static stress (N/mm^2), C_v = velocity factor.

$$\sigma_b = \frac{\text{Permissible stress}}{\text{Factor of Safety (as given in Table 1)}} \, N/mm^2$$

Face width are commonly used for strength check and it lies between ranges $\frac{1.15\pi m}{\tan\varphi}$ to $20m$ for helical gears and between 9 m to 13 m for spur gears

Table 1: Factor of Safety for Gears

Types of drive and load	Factor of safety
Steady load on a single pair	3
Suddenly applied on a single pair	4
Steady load of gears of train beyond first mesh	5
Sudden load on gears of train beyond first mesh	6

Source: Khurmi and Gupta (2009)

3. GEAR PARAMETERS FOR STRENGTH CONSIDERATION

— Velocity Factor

When gears are running at high speed, the gear may be subjected to dynamic effect. To account for this a velocity factor C_v is considered Thus Barth equations for velocity factors for helical gears according to Khurmi and Gupta (2009) are given in Equations 2 – 5:

$$C_v = \frac{6}{6+v} \text{ for peripheral velocities from 5m/s to 10m/s} \tag{2}$$

$$= \frac{15}{15+v} \text{ for peripheral velocities from 10m/s to 20m/s} \tag{3}$$

$$= \frac{0.75}{0.75+\sqrt{v}} \text{ for peripheral velocities greater than 20m/s} \tag{4}$$

$$= \frac{0.75}{1+v} + 0.25, \text{ for non-metallic gears} \qquad 5)$$

Velocity factor C_v for spur gears are given in Equations 6 – 9:

$$C_v = \frac{3}{3+v}, \text{ for ordinary cut gear operating at velocities up to 12.5m/s} \tag{6}$$

$$= \frac{4.5}{4.5+v} \text{ For carefully cut gear operating at velocities up to 12.5m/s} \tag{7}$$

$$= \frac{6}{6+v} \text{ for ground metallic gear operating at velocities up to 20m/s} \tag{8}$$

$$= \frac{0.75}{0.75+\sqrt{v}} \text{ for precision gears cut with accuracy operating at 20m/s} \tag{9}$$

where v, is the pitch line velocity v is given as shown in Equation 10.

$$v = \frac{\pi D n}{60} \tag{10}$$

where D = pitch diameter (mm), n = number of $\frac{revolutions}{min}$ (rpm), Source: Khurmi and Gupta (2009)

— Tangential force F_t

The tangential force F_t can be related to power transmitted. To account for gear service conditions, a modified equation is given in Equation 11:

$$F_t = \frac{1000 \times P \times Cs}{v} \tag{11}$$

where: P = power transmitted; V = pitch line velocity; Cs = Service factors. (as given in Table 2)

The service factor can be a multiplier applied to the known load which redefines the load in accordance with the conditions at which the drive will be used or it can be a divisor which defines the rating in accordance with the drive conditions.

Table 2: Service Factor for Gears

Type of load	Intermittent on 3hrs /day	8-hrs/day	Continuous 24/hrs/day
Light shock	1.00	1.54	1.80
Medium shock	1.25	1.54	1.80
heavy shocks	1.54	1.80	2.00

Source: Khurmi and Gupta (2009)

— Lewis form factor

The form factor based on the formative number of teeth y^1 can be obtained from Equations 12 – 14.

$$y^1 = 0.124 - \frac{0.684}{N_F} \quad \text{for } 14\tfrac{1}{2}^0 \text{ full depth} \tag{12}$$

$$= 0.154 \frac{0.912}{N_F} \quad \text{for } 20^0 \text{ full depth} \tag{13}$$

$$= 0.175 - \frac{0.841}{N_F} \quad \text{for } 20^o \text{ stub system} \tag{14}$$

where N_F is the formative number of teeth and it is given in Equation 15

$$N_F = \frac{N}{Cos^3 \varphi} \tag{15}$$

— Helical Gear Tooth Dynamic Loads

When a pair of gears is running at moderate or high speeds, there is generation of noise and inaccuracies in the meshing of gear teeth in action. As a result, the gear is subjected to dynamic effect. The dynamic tooth load on the helical gear is given by the sum of the transmitted load and an incremental load due to dynamic effects (Equation 16)(Shigley, 2001)

$$F_d = F_t + \frac{21\,V(C\,b\cos^2\varphi + F)\cos\varphi}{21\,V + \sqrt{C\,b\cos^2\varphi + F_t}} \tag{16}$$

where: F_d = dynamic load (N); F_t = tangential force; V = pitch line velocity (m/s); φ = helix angle (degree)

C = Values of deformation factor based on the tooth form, material and the degree of accuracy with which the tooth is cut (KN/m) .The proper values of C can be computed by using maximum error for the various classes of gear cutting as given in Table 3.

Table 3: Maximum errors in Action between Gears (mm)

Module, mm	Class, 1 industrial	Class 2, accurate	Class 3, precision
20	0.1219	0.0609	0.0305
12	0.1016	0.0508	0.0254
8	0.0813	0.0406	0.0203
6	0.0660	0.0274	0.0139
5	0.0559	0.0274	0.0127
4 and less	0.0508	0.0254	0.0127

Source: Singh (1997)

— Helical Gear Tooth Wear Loads

The maximum load that gear teeth can carry without premature wear depends upon the radii of curvature of the tooth profiles and on the elasticity and surface fatigue limits of the material. The limiting wear load F_w for helical gears may be determined by the Buckingham equation for wear (Equation 17)

$$F_w = \frac{D_p\,bQK}{\cos^2\varphi} \tag{17}$$

$$Q = \frac{2Dg}{Dp + Dg} = \frac{2Ng}{Np + Dg} \tag{18}$$

$$K = \frac{(\sigma_{es})^2 \sin\phi_N}{1.4}\left[\frac{1}{E_p} + \frac{1}{E_g}\right] \tag{19}$$

where: F_w is wear load (N), D_p is pitch diameter of pinion (mm), D_g is pitch diameter of gear (mm), b is face width of the pinion (mm), Q is ratio factor , K is load stress factor (N/m^2), σ_{es} is surface endurance limit (N/m^2), ϕ_N is normal pressure angle (in degree), E_p and E_g are Young's modulus of pinion and gear material (N/mm^2), N_p and N_g are Numbers of teeth of pinion and gear (mm)

It has been observed that for the design to be satisfactory from the consideration of wear the value of F_w must not be less than F_d .if otherwise, then the hardness of the designed gear is increased by equating $F_w = F_d$ to find desired value of Brinell hardness.

The drafting of the 3D design drawing was done using graphical methods in AutoCAD 12 and dynamically loaded into JAVA workspace of the application .The software is written to be menu driven and user friendly

4. RESULTS AND DISCUSSION

The software developed "HelOSpur2011" was used to solve problems on helical gear design as well as a case of spur gear design (when helix angle is zero).The designed gear was organized in two phases.

- Phase 1: Development of a flowchart taking into consideration theories and activities involved in design and drafting of helical gears
- Phase 2: This concerned coding of flowchart into programming language which enables the users to perform repetitive gear design task. The coded program was achieved by creating user friendly interface. This program allows the software to accept variety of inputs these input consist of number of parameters like module, number of teeth of driver, number of teeth of driven, Helix angle and gear manufacturing process. The software accepts the input, process it and display the output on the screen which can later be stored in the database. The results from the design of HeloSpur2011 shows that it can effectively check for the strength and wear of the gear, determine the gear data and automatically draws with dimension the required driver and driven gear to precision.

5. CONCLUSIONS & RECOMMENDATIONS

"HelOSpur2011" was developed to precisely determine the geometric parameter, detail design for helical and spur gear and automatically draw 2D (two dimensional) and 3D (three dimensional) driver and driven gear, the software was relatively accurate (up to 99%) when compared with the results from Standard Textbooks on Machine Design such as (Khurmi and Gupta 2009) and Singh(1997) and it was observed that the system developed will successfully increase productivity by roughly twenty-five times over manual gear design and drafting at reduced cost

The software should be revised with 3D tooth form stress analysis and 3D error analysis so as to observe the meshing line of contact of gear rotation by tooth form rendering, it is recommended for commercialization so that feedback from user can be used to improve on it and software should be introduced as teaching aid in tertiary institution, workshop and small scale industries to facilitate system of gear design

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