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Computer Aided Design of a Spur Gear

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Abstract: In recent times, the design of gears using computer has become a highly complicated and comprehensive subject.This study therefore present a new method of how the spur gear can be designed and detailed with computer aided design, previously, emphasis was laid on primitive and probabilistic design processes which resulted in high operation cost and prolong time. A reliability model of the spur gear when designed using computer aided performed repetitive and routine tasks involved in design drawings, review and evaluation, produces accurate and efficient design drawings as a result of interactive computer graphics and provides substantial saving in time and cost of production.

Key words: Probabilistic design, reliability model, efficient, design analysis, interactive

INTRODUCTION

Computer-aided design is the use of computer systems to assist in the creation, modification, analysis, optimization, storing and communication of design information (Farag, 1987). The CAD system allows design modifications to be performed easily and sufficiently. The analysis and optimization phases of the design are easily and accurately performed by the computer while the designer will find these tasks time consuming and tedious without the used of computer. The CAD system in this case will enable the designer to make decisions based on the analytical calculations performed.

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 CAD system in the same time. Indeed, CAD systems can increase productivity in the drafting function by roughly five times over manual drafting.

Computer aided design is becoming increasingly important today, the analysis and design procedure for quite a number of machine parts are standardized which make it possible to use standard computer programs, hence it helps the user to master the internal logic of design and realize the physical meaning of each variables involved in the design process.

The majority of design problems in the gear field at least, are such that analytical solutions in closed form are seldom possible and numerical iterative methods of calculation must be used instead, it is for this later that the digital computer finds its greatest application.

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. According to the American Gear Manufacturers Association (AGMA), gears are machine elements that transmit motion by means of successively engaging teeth. It is a toothed wheel or cylinder used to transmit rotary or reciprocating motion from one part of a machine to another. Gears are used in cutting machine tools, automobiles, tractors, hoisting and Modern power transmission requirements for greater loads and higher speeds have demanded improvements in tooth form, cutting methods, materials, It is obvious that the strength of gear teeth has had to improve to meet increased loads, this is a design problem, which will be dealt with as Computer-Aided Design (CAD) software is introduced to the design process of gear system. In gear system, theories relating to failure, wear, strength of materials, form the basis of the design procedure. These theories usually give rise to a set of equations which has to be solved to arrive at a satisfactory result.

The study is aimed at designing interactive computer graphic system software, which will enhance the

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analytical and logical power of the designer in the design of gear system. It is expected that the gear CAD will function in the following aspect, so as to:

- Generate data for use in the design process.
- Perform repetitive and routine tasks involved in design drawings review and evaluation.
- Produce accurate and efficient design drawings as a result of interactive computer graphics, ICG.
- Provide substantial saving in time and cost of production.

MATERIALS AND METHODS

The approach to this study entails the development of user-friendly computer software which will design the spur gear based on minimum specification of input parameters.

Visits to some gear manufacturing companies and computer programmers in Nigeria as well as on-line research on international companies were embarked upon. Intensive study and analysis of the manufacturing techniques adopted by different companies in gear production in order to establish design procedure were also carried out.

Basic design curve for gear teeth: There are two basic families of curves used in the design of the spur gear teeth. The cycloidal and the involute curve.

The cycloidal curve family is produced by rolling a circle called generating or rolling circle while the involute curve family is defined as the curve which is kept taut while being unwound from a circle, of these two curves, the involute curve is generally in use in the design of the spur gear so as to meet requirement stated for it.

Gear design equations: The determination of the proper gears to use in a particular application is a complex problem because of the many factors involved Singh (1997) highlighted some of the factors involved in the design of gears as:

- The gears must operate together without tooth interference with a poor length of contact and without undue noise.
- The gear teeth must have the ability to transmit the applied loads without failure and with a certain margin of safety. This load is commonly referred to as the dynamic load.
- The wearing qualities of the teeth must be considered. This is known as wear load.

Designs for adequate strength of gear teeth: The static strength of the gear tooth of a gear is determined by Wilfred Lewis in 1892, to be a cantilever beam acted upon by the moment resulting from the load obtained from the power transmitted. The design stress based upon the ultimate strength of the material with a considerable factor of safety being a steady load on a single pair was analyzed. This led to the design equation known as Lewis equation

$$Ft = \delta b y \pi m \quad (1)$$

Where,
m = Module, mm.
y = Lewis form factor.
b = Face width, mm.
δ = Maximum bending stress, N mm^{-2}.
Ft = Tangential force, N.

Buckingham in 1932, modified the Lewis equation by a velocity factor in order take into account the effects of tooth fabrication and additional loads to impact giving rise to Eq. 2. Again Singh (1997) reported that Eq. 2 can best be used to determine the strength of gear design having considered the dynamic load, the endurance limit of the material and the wear load. Therefore, these equation is used in the design of gear and strongly considered in developing the Computer -Aided Design for Gears Software under study.

$$F_t = \delta_o \, b y \pi m C_v \quad (2)$$

Where,
m = Module, mm.
Y = Lewis form factor.
b = Face width, mm.
C_v = Velocity factor.
δ_o = Permissible stress/ factor of safety Nmm^{-2}.
F_t = Tangential force, N.

The value of the lewis form factor, y, may be obtained from the following relations

$$y = 0.124 - 0.684z^{-1} \text{ for } 14\tfrac{1}{2}^{o} \text{ involute full depth} \quad (3a)$$

$$y = 0.154 - 0.912z^{-1} \text{ for } 20^{o} \text{ involute full depth} \quad (3b)$$

Where z = Number of teeth of the driver or driven gear

Table 1: Recommended speed of gear and their quality

Minimum quality	Peripheral speed of gears, v, ms^{-1}
5- 6	15-30
6-7	7.5-15
7-8	5-7.5
8-9	2.5-5
10-12	below 2.5

Source: (Singh, 1997)

From Eq. 3a and b, it is required that the values of $\delta_1 y_1$ and $\delta_2 y_2$ for both the driver and driven gear, respectively are computed. The weaker gear will then be used in the design for strength, toughness and wear. If $\delta_1 y_1$ is less than $\delta_2 y_2$, it implies that the values of δ_1 and y_1 are used in the design, otherwise δ_2 and y_2. It should be noted that the amount of force that can be transmitted to a function of the δy product. For two mating gears, the weaker will have the smaller value Table 1.

RESULTS AND DISCUSSION

Tangential force, f_t: The tangential load, Ft at the pitch line may be obtained from the power being transmitted. This equation is modified to account for service conditions. Thereby

$$Ft = \frac{1000}{Vm \times Ks} \times P \qquad (4)$$

Where,

P = Power transmitted, Kw.
Ks = Service factors.
V_m = Pitch line velocity, ms^{-1}.
F_t = Tangential load, N.

Velocity factor, Cv: Slight inaccuracies in the tooth profile and tooth spacing, teeth being not absolutely rigid. Variations in the applied load and repetition of the loading cause impact and fatigue stresses that become more severe as the pitch line velocity increases. So the velocity factor, Cv which is introduced into the Lewis equation is to allow for these additional stresses. This factor is given by:

$$Cv = 3/3 + V_m \qquad (5)$$

$$Cv = 6.1/6.1 + V_m \qquad (5a)$$

For ordinary industrial gear operating at velocity up to $10ms^{-1}$

$$Cv = 5.56/5.56 + V_m \qquad (5b)$$

For accurately cut gear operating at velocity up to $20ms^{-1}$

For precision gears cut with a high degree of accuracy and operating at velocities of 20 ms^{-1} and over.

Where, V_m = Pitch line velocity, ms^{-1}

Designs for tooth dynamic loads: The inaccuracies of the tooth profiles and the deflection of the teeth under load, causes periods of acceleration, inertia forces and impact loads on the teeth with an effect similar to that of a variable load superimposed on a steady load. According to Earle Buckingham, the maximum instantaneous load (dynamic load) on the tooth, is given by,

$$\frac{Fd = Ft + 10\ Vm\ (bC + Ft),}{10\ Vm + 0.474\ (bC + Ft)^{1/2}} \qquad (6)$$

Where,

F_d = Dynamic load, N.
F_t = Tangential force (load), N.
b = Face width, mm.
V_m = Pitch line velocity, ms^{-1}.
C = A constant in N/mm, which depends on the tooth form and material.

Design for wear tooth loads: The load limit for wear is determined by the surface endurance limit of the material, the curvature of the surface and the relative hardness of the surface. The driver should always be harder to allow for work-hardening of the driven, to preserve the involutes profile and to allow for greater abrasive wear on the driver.

To ensure the durability of a gear pair, the tooth profile must not have excessive contact stress as determined by the wear load Fw.

Design for durability of gear teeth: To ensure the durability of a gear pair, the tooth profiles must not have excessive contact stress determined by the wear of load Fw.

$$Fw = Dp\ bkQ \quad \text{Buckling equation} \qquad (7)$$

Where,

Dp = Pitch diameter for smaller gear.
b = Face width of gear.
K = Fatigue stress factor.

$$\text{But } Q = 2Ng\ /\ (Np+Ng) \qquad (8)$$

Where,

Ng = Number of gear teeth.
Np = Number of pinion teeth.

Table 2: Proportions of standard gear teeth

	14½ composite	14 ½ full depth involute	20° full depth involute	20°stub involute
Addendum	M	M	M	0.8 m
Minimum dedendum	1.157 m	1.157 m	1.157 m	m
Whole depth	2.157 m	2.157 m	2.157 m	1.8 m
Clearance	0.157 m	0.157 m	0.157 m	0.2 m

Source: (Spots, 1990)

$$\text{and } K= S^2e_s(\sin ø)(1/Ep + 1/Eg) \quad (9)$$

Where,

Se_s = Surface endurance limit of gear pair.
Ep = Modulus of elasticity of the pinion material (Nm^{-2}).
Eg = Modulus of elasticity of the gear material (Nm^{-2}).
Q = Pressure angle.

$$Se_s = (2.75(BHN) -70(19Nm^{-2}) \quad (10)$$

Where the BHN (average Brinell Hardness Number) of the gear and pinion up to 350 for steel. Several values of k for various materials and tooth form are tabulated in Table 2 as recommended by Buckingham.

Design to avoid interference: Under certain conditions, involute profiles overlap or cut into the mating teeth. This interference can be avoided if the maximum addendum radius (ra) for each gear is equal or less than

$$[r_b{}^1 + \alpha^2(\sin\alpha)^2]^{1/2} \quad (11)$$

Where,

a = Center distance, mm.
r_b = Radius of base circle, mm.
α = Pressure angle, deg.

Interference will occur when the actual addendum circle radius exceeds the value as calculated by Eq. 11.

Software system design and implementation

Software system design: There are different ways of writing a software program. However, a number of clearly defined and identifiable steps that are always involved in software programming process and provide a convenient framework for studying this process are considered in developing the Computer-Aided Design for Gears software.

These steps are to:

- Define the problem.
- Plan a solution.
- Implement the solution.
- Maintain the program.

Results of Cadgear (2007): Cadgear (2007) is an ellipsis for computer-Aided Designed Gear developed by the presenter in the year 2007. The design of Cadgear (2007) was prepared in two phases.

Phase 1: This involved the development of a flowchart taking into consideration all theories, tasks and activities related to gear design and drifting.

Phase 2: This concerned the coding of the flowchart into a programming language which will enable the user to perform repetitive gear design task. The coded program is used to determine the planned gear parameters and drawings. This was achieved by creating a user interface, setting object properties and writings codes.

The set of instructions written, allow the software to accept variety of inputs. These inputs consists of parameters like module, driver/driven teeth number, gear material, pressure angle, power, driver speed, etc. The software accepts the inputs, process it and display the output on the screen. The result can be stored in a file or database depending on the gear designer (end-user).

The results from design of Cadgear (2007) shows that it can precisely determine the gear geometry parameter and it automatically draws with dimension, the required driver and driven gear to precision.

CONCLUSION

During the course of this study an interactive computer graphics that enhance the analytical and logical power of the designer (end-user) of gear system known as Cadgear (2007) was developed. This system permits proper communication/interface with users (user-friendliness) having a common input/output language familiar to them.

It generates accurate data used in design process; perform repetitive and routine tasks involved in gear design. Cadgear (2003) was able to produce precise and efficient 2D (two dimensional) design drawings of the gears. It also store information for used in manufactured and future design activities.

Conclusively, it was observed that the system developed will successfully increase productivity by roughly twenty times over manual gear design and drafting at reduced cost.

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