Development of a WormCAD using Parametric Design Approach

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Gears as power transmission devices are capable of changing the speed, torque, and direction of a power source and are considered to be one of the most important devices used in many types of machinery owing to their durability and higher power transmission efficiency. Worm gears as a type of gear are widely used for transmitting power at high velocity ratios between non-intersecting shafts. Worm gears are very useful in machine design but its design requires a lot of design assumptions and calculations. To achieve a rapid design devoid of errors, there is need to have a customized computer program capable of designing worm gears using standardized design equations; and that is what WormCAD stands for. The software was designed using JavaScript programming language and the Node.js platform. The WormCAD was tested to be accurate, faster and convenient hence it will be a viable software to be used by worm gear designers.

Keywords: *Worm gear, CAD, Design, Power transmission, Software*

1. Introduction

After generation of power from one part of a machine or the other, there is always a need to transfer such a power (torque) to the other element(s) of a machine. Different power transmitting devices such as belt drives, chain drives, gear drives could be used for this purpose, but gears are more preferable to others because of their ability to achieve definite velocity ratio (Akinnuli *et al.,* 2015). According to Khurmi and Gupta (2005), a gear is defined as a rotating machine element having cut teeth (or cogs) which mesh with another toothed part in order to transmit torque. Gear devices are capable of changing the speed, torque, and direction of a power source and are considered to be one of the most important devices used in many types of machinery owing to their durability as a power transmission devices and higher power transmission efficiency of up to 98% Hamrock *et al.,* 2006).

According to the position of the axes of the shaft, gears can be classified as: Intersecting shafts- bevel gears; Non-intersecting and skew shafts- worm gears, hypoid gears; and Parallel shafts- spur gears, helical gears. As reported by Khurmi and Gupta (2005) gears have been in existence for a very long time. The first worm gear was produced in 1912 and its introduction in controlling the rudder of a ship was seen as a major development in the field of marine engineering.

Worm gears are widely used for transmitting power at high velocity ratios between non-intersecting shafts that are generally, but not necessarily at right angles. The worm gear is mostly used as a speed reducer, which consists of a worm and a worm wheel or gear. The worm (the driver) is usually of a cylindrical form having threads of same shape as that of an involute rack. The worm wheel or gear (the driven member) is similar to a helical gear with a face shaped to suit the shaped of the worm. The worm is generally made of steel while the worm gear is made of bronze or cast iron. Worm gears are very use in engineering and machine design, some of its applications are found in: Elevator/Lifts; Gates and conveyor belts; Torsen differentials; and the differential gearing which protects a vehicle against rollback
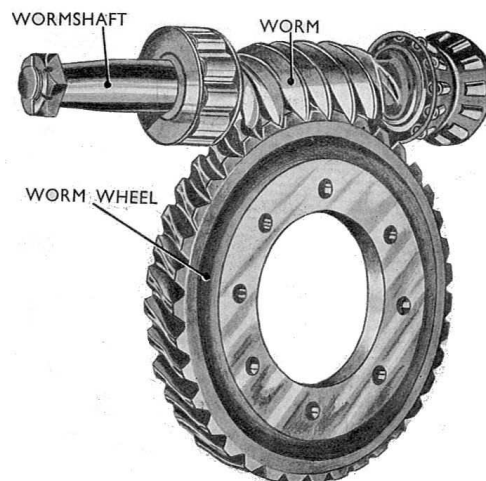

Figure 1. Typical worm gear

Computer Aided Design (CAD) involves the use of computer in modification, analysis or optimization of design (Antoniadis, 2012). Computer technology advancement also gains application in engineering designs. Gear design using computer aided approach is not left out in this development. Quite numbers of works have been done in gear design using computer aided approach for simulation or software development.

Babu and Tsegaw (2009) developed an Involute spur gear template by parametric technique using Computer Aided Design. Their research work is applicable

in spur gear design but the developed template has limitations that it can only be used in places where the gears are incorrect. When the gear design has modifications such as addendum, dedundum or proturberance and so on, it would further complicate the template modeling. Venkatesh *et al.* (2010) worked on the design, modeling and manufacturing of helical gear. However, manual long hand calculations were employed and the design was solely meant for helical gear. This design approach was later improved upon in 2014 by Venkatesh, and Murthy through the introduction of structural analysis using ANSYS. Tanvirkhan and Amit (2015) gave the review of design, modeling and stress analysis of high speed helical gear according to bending strength and contact strength using AGMA and ANSYS. To show that CAD is applicable to other types of gear, [9] gave a method of spiral bevel gear tooth contact analysis performed in CAD. They focused mainly on the analysis of teeth contact but Akinnuli *et al.,* (2008) gave a comprehensive design of bevel gears using a BevelCAD (Software for designing Bevel gears). They claimed that the software developed was tested and performed satisfactorily. Also, the software is meant for the design of Bevel gears alone. Extensive literature reveals that there are multi-purpose gear design softwares like KIMOS but there is no specific, customized software for the design of Worm gears. The design of worm gears involves a lot of assumptions and calculations which can make the designer/engineer to commit some errors. To avert such error(s) and to make the interface to be more user-friendly, a WormCAD software that is meant for the design of only worm gears was developed. This will reduce effort employed in routine manual calculation hence saving time in designing worm gears. Standard gear design equations and assumptions were used in developing the software.

2. Software Design Process

Software design is sub-divided into four segments (Adejuyigbe, 2002) which include: Analysis; Algorithm design; Coding; Testing.

2.1. Analysis

The key to well-designed software is analysis, as it reduces coding difficulties. Proper and accurate Analysis helps in selection of the most appropriate data structure. The software application was able to accept the input parameters and transformed into the required output by utilizing sets of mathematical relations.

2.2 Algorithm Design of Worm Gear

I Declare constants for different materials
σ_o - Allowable static strength
σ_e - Flexural endurance strength
Select materials and tooth forms
II Select materials
Select tooth form (14.5^0 full depth involute, 20^0 full depth involute, 20^0 stub)
Velocity ratio

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Select number of start or thread

III Dimension of worm

Enter the reduction or velocity ratio

Determine the lead angle(λ)

Enter the distance between the shaft

Determine the normal lead l_n from

$$\frac{x}{l_n} = \frac{1}{2\pi}\left(\frac{1}{\sin\lambda} + \frac{1}{\cos\lambda}\right) \tag{1}$$

Select the number of starts or threads from the velocity ratio

Determine the axial pitch on the worm (P_a)

Calculate module m for m = $\dfrac{P_a}{\pi}$ $\tag{2}$

Select the standard module from the calculated module

Calculate the following;

Axial pitch P_a of the threads on the worm

$P_a = \pi m$ $\tag{3}$

Axial lead of the threads on the worm L

$L = P_a \times n$ $\tag{4}$

Normal lead of the threads

$L_N = l.\cos\lambda$ $\tag{5}$

Centre distance x

$$x = \frac{L_N}{2\pi}\left(\frac{1}{\sin\lambda} + \frac{V.R}{\cos\lambda}\right) \tag{6}$$

Pitch circle diameter of the worm D_w

$$D_w = \frac{1}{\pi\tan\lambda} \tag{7}$$

Determine the number of teeth on the worm T_G

$T_G = n \times V.R$ $\tag{8}$

Length of threaded portion or face length of the worm L_w

$L_w = P_c(4.5 + 0.02T_w)$ $\tag{9}$

Depth of tooth h

$h = 0.623 P_c$ $\tag{10}$

Addendum a

$a = 0.286 P_c$ $\tag{11}$

Outside diameter of the worm D_{ow}

$D_{ow} = D_w + 2a_w$ $\tag{12}$

IV Design of worm gear

Pitch circle diameter of the worm gear D_G

$D_{G=}$ m T_G $\tag{13}$

Outside diameter of the worm gear D_{OG}

$$D_{OG} = D_G + 0.8903\, p_c \tag{14}$$

Throat diameter D_T

$$D_T = D_G + 0.572\, p_c \tag{15}$$

Face width b

$$b = 2.15 p_c + 5 \tag{16}$$

V Design of the worm shaft

d_w = diameter of the worm shaft

Torque on the worm gear shaft

$$T = \frac{1.25P \times 60}{2\pi N_G} \tag{17}$$

Torque acting on the worm shaft

$$T_{worm} = \frac{T_{gear}}{V.R \times \eta} \tag{18}$$

VI Tangential force on the worm W_{TW}

$$W_{TW} = \frac{2T_{worm}}{D_W} \tag{19}$$

Axial force on the worm

$$W_{AW} = \frac{2T_{gear}}{D_G} \tag{20}$$

Radial force on the worm W_R

$$W_R = W_A . \tan \varnothing \tag{21}$$

Bending moment due to radial force

$$\text{Radial force} = \frac{W_R \times D_G}{4} \tag{22}$$

Bending moment due to axial force in the vertical plane

$$= \frac{W_A \times D_G}{4} \tag{23}$$

Total bending moment in the vertical plane M_I

$$M_I = \frac{W_R \times D_G}{4} + \frac{W_A \times D_W}{4} \tag{24}$$

Bending moment due to tangential force in the horizontal plane M_2

$$M_2 = \frac{W_{TW} \times D_G}{4} \tag{25}$$

Resultant bending moment on the worm shaft M_{worm}

$$M_{worm} = \sqrt{M_1{}^2 + M_2{}^2} \tag{26}$$

Twisting moment on the worm shaft

$$T_{ew} = \sqrt{T_{worm}{}^2 + M_{worm}{}^2} \tag{27}$$

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$$d_w = \sqrt[3]{\frac{16T_{sw}}{\pi\tau}} \qquad (28)$$

Compressive stress on the shaft due to axial force

$$\sigma_c = \frac{W_A}{\frac{\pi}{4}d^2_w} \qquad (29)$$

Maximum shear stress τ_{max}

$$\tau_{max} = \frac{1}{2}\sqrt{\sigma^2_0 + 4\tau^2} \qquad (30)$$

If τ_{max} is less than τ , then the design of shaft is safe.

VI Tangential Load

Determine the speed of the worm gear in rpm

N_G = speed of worm gear

$$\text{V.R.} = \frac{N_W}{N_G} \quad \text{or} \quad N_G = \frac{N_W}{V.R.} \qquad (31)$$

Therefore torque transmitted,

$$T = \frac{P \times 60}{2\pi N_G} \qquad (32)$$

∴ Tangential load acting on the gear

$$W_T = \frac{2 \times Torque}{D_G}$$

Pitch line or peripheral velocity of the worm gear,

$$v = \frac{\pi.D_G.N_G}{60} \qquad (33)$$

Where velocity factor is,

$$C_v = \frac{6}{6 + v}$$

Tooth factor y = 0.154 - $\frac{0.912}{T_G}$ (for 20^0) , 0.124 - $\frac{0.684}{T}$ (for 14.5^0) (34)

Designed tangential load

$$W_{DT} = (\sigma_0.C_V)\, b.\pi.m.y$$

If $W_{DT} \geq W_T$, the design is safe from the standpoint of tangential load.

VII Dynamic Load

W$_D$ is Dynamic load

$$W_D = \frac{W_T}{C_V} \qquad (35)$$

If $W_D > W_T$, the design is safe from the standpoint of dynamic load.

VIII Static Load / Endurance Strength

$$W_S = \sigma_e.b.\pi m.\, y \qquad (36)$$

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If $W_S > W_T$ the design is safe from the standpoint of static load / endurance strength.

IX Wear

$$W_w = D_G.b.\,k \tag{37}$$

If $W_w > W_T$, the design is safe from the standpoint of wear.

X Heat Dissipation

Determine the rubbing velocity V_r

$$V_r = \frac{\pi D_w.N_w}{\cos \lambda} \tag{38}$$

Coefficient of friction µ

$$\mu = 0.025 + \frac{V_r}{18000} \tag{39}$$

Angle of friction $\emptyset_1$

$$\emptyset_1 = \tan^{-1} \mu \tag{40}$$

Efficiency of worm gearing η

$$\eta = \frac{\tan \lambda}{\tan(\lambda + \emptyset_1)} \tag{41}$$

Percentage overload Q_g

$$Q_g = 1.25P\,(1\text{-}\,\eta) \tag{42}$$

Projected area of worm A_w

$$A_w = \frac{\pi}{4}\,(D_1W\ )^2 \tag{43}$$

Projected area of worm gear

$$A_G = \frac{\pi}{4}(D_G)^2 \tag{44}$$

Total area of projection A

$$A = A_w + A_G \tag{45}$$

Heat dissipating capacity Q_d

$$Q_d = A(t_2 - t_1) \tag{46}$$

$Q_g = Q_d$, if $t_2 - t_1$ within safe limits of 27^0 to 38^0C, then the design is safe from the standpoint of heat.

XI Worm Gear Shaft

d_G = diameter of worm gear shaft

Bending moment due to axial force on the worm gear Y

$$Y = \frac{Axial\ force \times D_G}{4} \tag{47}$$

Bending moment due to radial force on the worm gear

$$Z = \frac{Radial\ force \times x_2}{4} \tag{48}$$

Total bending moment in the vertical plan
$$M_3 = Y + Z \tag{49}$$
Bending moment due to tangential force in the horizontal plane M_4
$$M_4 = \frac{Tangential\ force \times x_2}{4} \tag{50}$$
Resultant bending moment on the worm gear shaft M_{gear}

$$M_{gear} = \sqrt{M_3{}^2 + M_4{}^2} \tag{51}$$
Equivalent twisting moment T_{eg}

$$T_{eg} = \sqrt{T_{gear}{}^2 + M_{gear}{}^2} \tag{52}$$

$$d_G = \sqrt[3]{\frac{16T_{eg}}{\pi\tau}} \tag{53}$$

$$\sigma_c = \frac{Axial\ force}{\frac{\pi}{4}\,d_G^2} \tag{54}$$
Maximum Shear stress τ_{max}

$$\tau_{max} = \sqrt{\sigma_c^2 + 4\tau^2} \tag{55}$$

Coding

The algorithm above was used to develop the software (Worm CAD).This was made possible by transforming the required formulas and data of worm into a set of instruction codes. The codes written could validate the user inputs by giving the user the necessary information as output. The software was designed using JavaScript programming language and the Node.js platform. The Node.js platform is an open-source, cross-platform runtime environment for developing Web applications. Node.js applications can run on Mac OS X, Microsoft Windows, Nonstop and UNIX servers

2.4 Testing

WormCAD was tested and validated with an example from a Machine Design textbook by Khurmi and Gupta [2]

A worm and a worm gear with both made of steel (BHN 250) and phosphor bronze respectively were designed using the developed WormCAD software. The gear to be used has the following input parameters.

Tooth form – 20° involute
Number of start or thread – 4
Speed reduction/V.R – 12:1
Distance between the shafts (x) – 225mm
Power transmitted - 10000W

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All the above input parameters were fed into the Design interface of the software as shown in figure 2
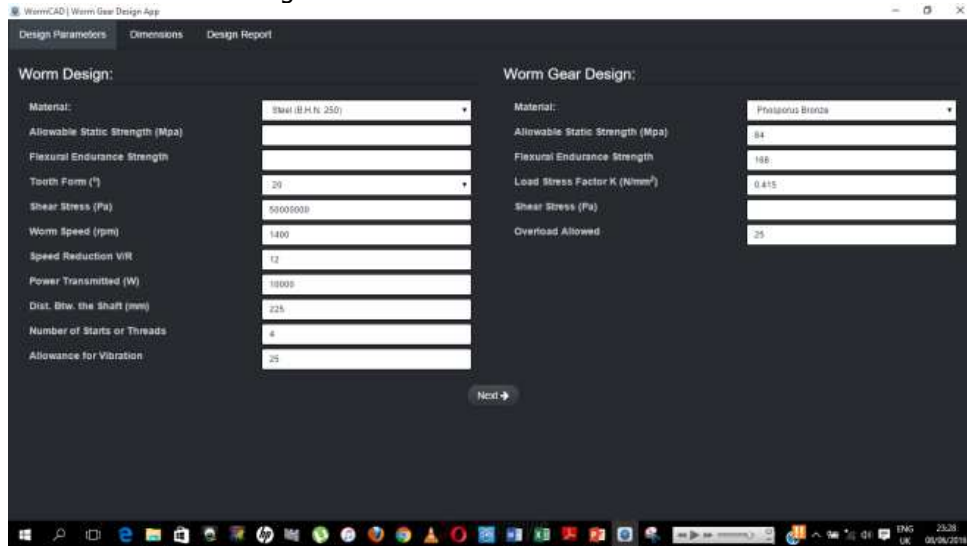

Figure 2. Input parameters for Worm CAD

Running the software, it displayed the calculated module which was rounded off to the nearest standard module. After supplying the value of standard module, and on clicking on next, it displayed the various dimensions as shown in figure 3
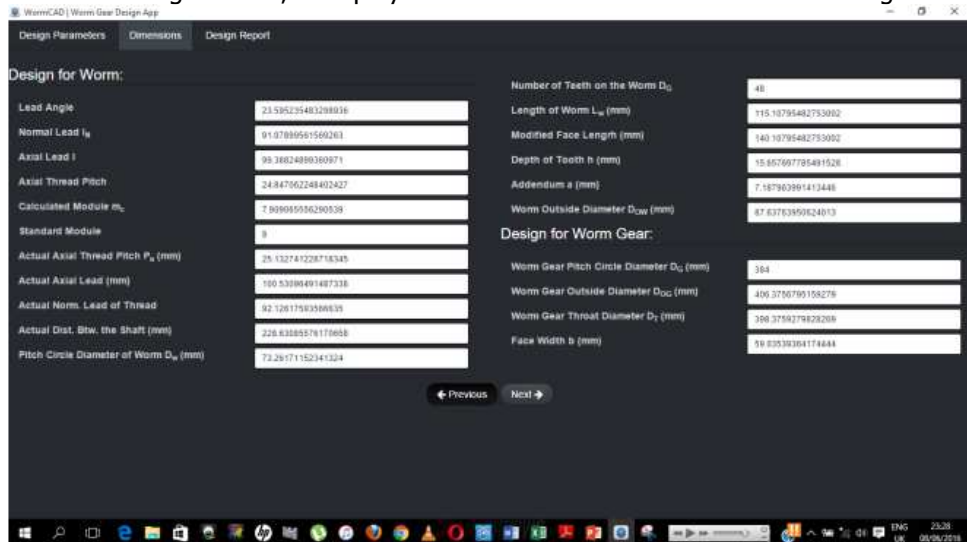

Figure 3. Worm CAD Dimensions Window

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Clicking on the next button again, another window as shown in Figure 4 was displayed which gave report about the status of the design (either safe or unsafe)
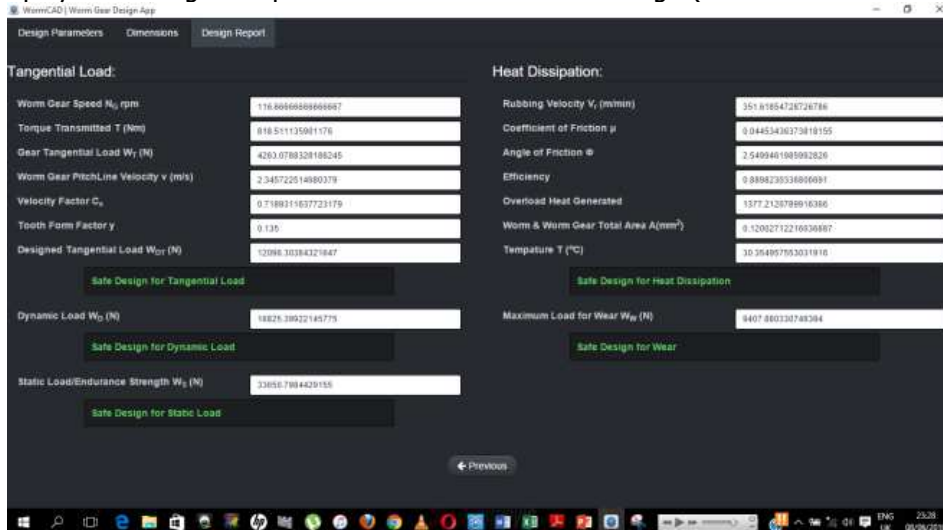

Figure 4. Worm CAD Report Window

3. Results and Discussions
3.1 Results

The software was able to generate the following key parameters: Module, Pitch circle diameter of worm, Number of teeth on the worm, Length of tooth of the worm, Worm outside diameter, Pitch circle diameter of the worm gear, Worm gear outside diameter, Face width, Torque transmitted, Gear tangential load; and gave the following reports about the status of the design (either Safe or Unsafe): Tangential load, Dynamic load, Static load, Heat dissipation, and Wear

3.2 Discussions

Comparing the manually calculated results with the WORM CAD results, the following observations were made:

Accuracy in calculations

The software calculations are believed to be more accurate because it uses uniform approximation in all its results. Hence, negligible differences in the results were obtained between WormCAD software and manual calculation..

Reduction in errors

In addition to the precision of the software, errors and mistakes were greatly minimized. Errors due to drudgery of manual computation are also reduced in designs.

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Time management

The software minimizes the time used for computation. The WORM CAD calculations only take seconds to generate the results with precision. This ensures time management which is an advantage over manual computation.

Suggesting design conditions to designers

The software suggests the physical condition of the designed worm gear using the computed result. These remarks help designers to achieve better designs.

4. Conclusion

Gears are used in the transmission of motion and power from a machine element to the other. Standard design equations were used in developing the codes for the WormCAD which is an easy-to-use worm gear design software. The benefits of the WormCAD over the routine manual method have been highlighted and discussed. It is of no doubt that this WormCAD will help designers achieve better designs when designing worm gears.

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