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Parameters Determination for the Design of Bevel Gears Using Computer Aided Design (Bevel CAD)

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Abstract

This paper prescribes a Computer Aided approach to the design of bevel gears. The approach utilizes standard design equations and standard data on bevel gears; linking them together using a Programming language(C#) to develop this special software (Bevel CAD) that designs and determines the strengths and dimensions of bevel gears. This study reviews the Procedural steps (algorithms) involved in the design of bevel gears and the development of the software package (Bevel CAD) which is to be used in designing bevel gears. When material required are selected based on the area of application, the software will make use of the data provided using the C# to determine the required; speed and velocity of the bevel gear, number of teeth, speed ratio, dynamic load, endurance strength and maximum wear load for the design bevel gear. The Bevel CAD's performance was verified by comparing the results of Algorithm calculation and the software's results. The Bevel CAD was confirmed effective as the minor differences obtained between the results were due to approximation errors. The Bevel CAD increases productivity but reduces drudgery of enormous calculations; hence, making it a recommended tool for industries and tertiary institutions for the designing of bevel gears.

Keywords: Bevel gear; design parameters; software development; CAD.

1 Introduction

A machine is the combination of various elements to perform a task. In doing so, power (torque) is needed to be transferred from one element or part to another; and this can be achieved with the use of power transmitting devices such as belt drives, chain drives, gear drives. Gears lead other power transmitting devices (chain drives, belts drives, etc) because of its ability to achieve definite velocity ratio. In precision

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machines (clock), in which a definite velocity ratio is of importance, gears and other toothed wheels could be used.

A gear is a rotating machine element having cut teeth (or cogs) which mesh with another toothed part in order to transmit torque. Geared devices can change the speed, torque, and direction of a power source. According to [1], gear is one of the most important devices used in many types of machinery. Gears allow the user to translate power, motion and torque. Gears have a power transmission efficiency of up to 98% and are some of the most durable torque transmitting machine elements.

A bevel gear system is used for transmitting power at a constant velocity ratio between two shafts whose axes intersect at a certain angle. Gear can be used to transmit large power (small car can run on belt drives but large vehicles can't, instead gears are being used). Gears are mostly applicable to small centre distances of shafts; they possess high efficiencies; they have reliable services; gears have compact layout. These among other characteristics of gears give it edge over other power transmitting devices. Bevel gears among other gears are used for transferring torque with intersecting shafts in the same plane.

While bevel-gear CAD software is a computer software that aids engineers, bevel-gear designers, manufacturers in the design of bevel gears. Since the World is turning towards computer technology and the use of computer to alleviate human efforts; the application of computer to the engineering world is not left behind. Hence, numerous works has been done on Computer Aided Design. Gear as an important machine component has also benefitted from this technological development. Works had also been done on gear design software and improvements are being achieved on daily basis. Therefore, [2] stated that model design of the bevel and hypoid gear is an area of great research interest nowadays. Recently, modeling of spiral bevel and hypoid gear made a lot of achievement, summarized as: 1) Point-to- surface modeling by fitting discrete points on the tooth surface, during which the vital steps are the solution of the discrete points on the tooth surface and their obtainment based on derivation of the tooth surface equations. 2) line-to-surface modeling by fitting tooth profile curves, whose core areas are the equation derivations of the tooth profile curves and the output in the three-dimensional graphics software [3].

Computer Aided Design CAD was defined by [4] as any design activity that involves the use of computer to create, modify and document engineering design using interactive computer graphics systems referred to as a CAD system. Since its inception, CAD has undergone continuous development. [5] reported that by the 1970's, CAD systems were being used in many drafting application and by the mid-1970s, there was an established market for CAD. CAD has grown from a narrow activity and concept to a methodology of design activities that include computer or group of computers used to assist in the analysis, development and drawing of product components. One of the areas where CAD was employed in manufacturing technology as related to gear design is the Gear skiving where CAD simulation approach was used [6].

Also, CAD surface design can be used for rapid prototyping by sweeping or rotating, and creating the curves surface from the point cloud, a variety of new modeling and their respective optimization methods were explored. This can then compensate for some deficiencies in the previous modelings, and create new conditions for fast and accurate parametric modeling of the spiral bevel and hypoid gear [7].

2 Bevel Gear Review

As reported by [8], the first primitive gears can be traced back to over 3000 years ago where early gears were made from wood. They were made of wood and had teeth of engaged pins. Early Greeks used metal gears with wedge shaped teeth; Romans used gears in their mills; stone gears were used in Sweden in the Middle Ages (Gears Manufacturers). All of these cultures found reasons to use basic gearing to convert energy or motion in one form to a form they could use in devices for the technological advancement of their societies.
Gears have existed since the invention of rotating machinery. However due to their force multiplying proportions, early engineers used them for hoisting heavy loads such as building materials. The mechanical

advantage of gears was also used for ship anchor hoist and catapults. Bevel gears are indispensable parts of drive systems found in power transmission for various machinery and equipment [9]. Due to a relatively complex geometry, continuous efforts are made to streamline the design and manufacturing process of bevel gears [10]. As a result of this, there is need for accurate modeling of spiral bevel which gives room for digitized manufacturing such as the tooth contact analysis (TCA) technology, the error correction of tooth surface technology and other key technologies [11].

According to [12], mating gear teeth acting against each other to produce rotary motion may be likened to a cam and follower. As two gears mesh, there is tendency for unwanted noise to be generated. [13] claimed that accurate tooth surface and good surface quality are critical to achieve the low-noise bevel gear drives.

Bevel gear has the numerous applications in engineering and machine design. It has several importance and applications. Among these applications are:

2.1 The Differential Drives

This can transmit power to two axles spinning at different speeds, such as those on a cornering automobile. The Fig. 1 below shows a typical example of a differential bevel gear.

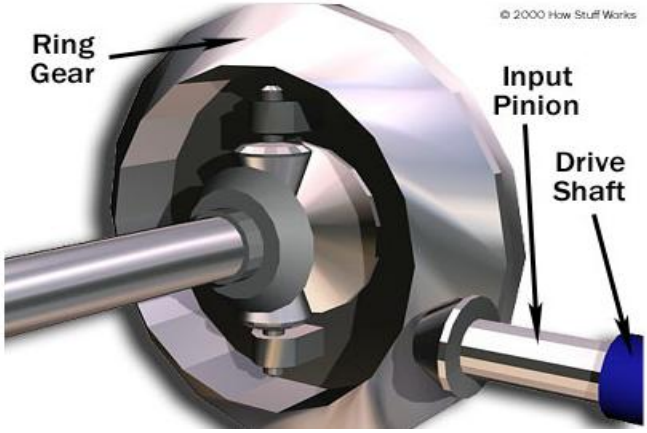


Fig. 1. Hypoid bevel gears in a car differential
Source: [14]

2.2 Dividing Head

Dividing head used machining operations like milling gears, sprockets on milling machine.

2.3 Hand Drill Mechanism

Hand drill mechanism as the handle of the drill is turned in a vertical direction, the bevel gears change the rotation of the chuck to a horizontal rotation.

2.4 Rotorcraft Drive Systems

Spiral bevel gear are important components on this system and are used to operate at high load and high speed. In this application, spiral bevel gears are used to redirect the shaft from the horizontal gas turbine engine to the vertical rotor.

Over the years, engineers have been coming out with various designs of bevel gears; trying to improve on their performances under various loads. This has assisted in the invention and production of machines with higher performances and efficiencies.

The bevel CAD software in discussion is a specialized software not meant for the designing of other gears or machine part unlike other multi-purpose software such AUTOCAD, INVENTOR, CATIA, PRO E. The software is mainly for the design of bevel gears. Its specialization has made this software easier and more flexible for bevel gear manufacturers and designers.

This paper aims at identifying the designed parameters required in designing bevel gear, collect relevant data for bevel gear design, develop algorithm for the steps required for the computation for each parameter, develop a software for implementing the algorithm developed and test the performance and effectiveness of the software model developed.

The numerous applications of bevel gears in machines have made its design more frequent and important. As a result of its immense importance, several works are being done on improving the efficiencies of bevel gears under static and dynamic load. This among other under-listed reasons justifies this research work:

i. Time and efforts in designing Bevel gear can be far reduced by using the BEVEL CAD software in the design. This will also assist designer focus on conception of ideas.
ii. The modeled software is more flexible and user friendly; hence, making it comprehensive and easier for designer to use.
iii. The software uses standard data and formula from renowned Engineering Textbooks; thus, making its result more reliable.
iv. The computational speed of the modeled software is comparatively better than other multipurpose CAD software such as INVENTOR, AUTOCAD etc

3 Methodology

3.1 Terminologies and Design Parameters Identification

The design of a bevel gear starts from getting acquainted with various terminologies, symbols/parameters and formulae attributed to Bevel gear. A bevel gear is shaped like a section of a cone. See Fig. 2.0 for the nomenclature of a meshed bevel gear.

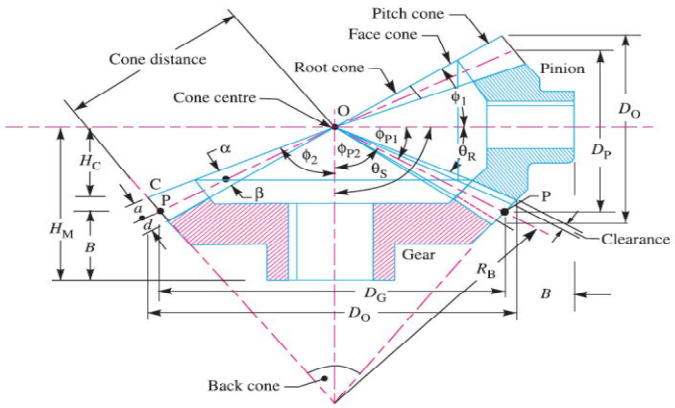


Fig. 2.0. Nomenclature of a meshed bevel gear
Source: [15]

The parameter/symbol used, description as well as the formula (as applicable) are tabulated as shown in Table 1.

Table 1.0. Parameters/symbols, description and formula used

Symbol/Parameter	Description/Meaning (unit)	Formula
σ_{o1}	Allowable static stress of pinion wheel (N/mm^2)	To be determined from the material used
σ_{o2}	Allowable static stress of gear wheel (N/mm^2)	To be determined from the material used
T_1 or T_2	Number of Teeth in pinion and wheel respectively	One of the two would be given
N_1 or N_2	Speed of pinion and gear respectively (rpm)	One of the two would be given
G	Velocity ratio or input gear ratio (unitless)	To be given
Θ_s	Shaft angle (^{o})	To be given
θ_{p1}	Pitch angle for pinion wheel (^{o})	$tan^{-1}\left(\frac{sin\theta_s}{G+cos\theta_s}\right)$
θ_{p2}	Pitch angle for gear wheel (^{o})	$\theta_{p2} = 90^o - \theta_{p1}$
m	Module (unitless)	To be determined from the AGMA standard table for tooth form
D_1 or D_2	Diameter of pinion and wheel respectively (mm)	mT_1 and mT_2 where m is the module
d_e	Dedendum (mm)	To be determined from the AGMA standard table for tooth form
a	Addendum (mm)	To be determined from the AGMA standard table for tooth form
T_d	Tooth depth (mm)	To be determined from the AGMA standard table for tooth form
r_f	Fillet radius (mm)	To be determined from the AGMA standard table for tooth form
T_{th}	Tooth thickness (mm)	To be determined from the AGMA standard table for tooth form
D_{R1} or D_{R2}	Root diameter of pinion and gear respectively (mm)	$D_1 - 2d_e$ and $D_2 - 2d_e$
L	Slant height of Pitch cone(mm)	$\sqrt{\left(\frac{D_1}{2}\right)^2 + \left(\frac{D_2}{2}\right)^2}$
$V_{1 \text{ or } 2}$	Velocity of pinion or gear (m/s)	$\frac{N_1 \pi D_1}{60000}$

3.2 Gear Teeth System

A tooth system is a standard given by the American Gear Manufacturers Association (AGMA) and the American National Institute (ANSI). It specifies relationship between addendum, dedendum, working depth, tooth thickness and pressure angle to attain interchangeability of gears of a tooth number but of the same pressure angle and pitch. Gear designers should be informed of advantages and disadvantages of the various

systems so that optimum tooth for a given design can be chosen. Basically there are four systems of gear teeth.

i 14.5º Composite system
ii 14.5º full involute system
iii 20º full depth involute system
iv 20º stub involute system

Table 2.0. Standard proportion of gear system by AGMA

S/N		14.5º Composite or full depth involute system	20º full depth involute system	20º stub involute system
1.	Addedum	1 m	1 m	0.8 m
2.	Dedendum	2.25 m	1.25 m	1 m
3.	Working depth	2 m	2 m	1.6 m
4.	Minimum total depth	2.25 m	2.25 m	1.80 m
5.	Tooth thickness	1.5708 m	1.5708 m	1.5708 m
6.	Minimum clearance	0.25 m	0.25 m	0.20 m
7.	Fillet radius at root	0.4 m	0.4 m	0.4 m

Source: Khurmi and Gupta (2005), note: m in the Table 2.0 stands for module

3.3 Lewis, Buckingham and Tregold Formula

These equations are applied to determine the tooth form, Bevelling factor, Tooth form factor and static strength. Static strength of bevel gear is obtained by determining the following parameters.

(a) Velocity factor C_v

Velocity factor C_v is determined first base on the level of cut of the gear.

$$C_v = \frac{4}{4+v} \quad \text{(For a carefully cut gear)} \tag{1}$$

$$C_v = \frac{3}{3+v} \quad \text{(For teeth cut by form cutter)} \tag{2}$$

$$C_v = \frac{6}{6+v} \quad \text{(For teeth generated with precision machines)} \tag{3}$$

where v is the velocity in m/s)

(b) Equivalent Number of Teeth T_E

Equivalent number of teeth for both Pinion and Gear wheel are obtained from the relations shown below respectively.

$$T_{E1} = T_1 \sec\theta_{p1} \tag{4a}$$

$$T_{E2} = T_2 \sec\theta_{p2} \tag{4b}$$

(c) Tooth form factor Y'

$$\text{Tooth form factor for pinion } Y'_1 = 0.154 - \frac{0.912}{T_{E1}} \tag{5a}$$

Tooth form factor for pinion $Y'_2 = 0.154 - \frac{0.912}{T_{E2}}$ (5b)

(d) Bevel Factor B.F

$B.F = \frac{L-b}{L}$ …6; where b is the face width given as $\frac{L}{3}$

(e) Tangential Tooth Load W_T

Tangential Load for pinion $W_{T1} = \sigma_{o1} \times C_V \times b \square mY'_1 \times B.F$ (7a)

Tangential Load for gear $W_{T2} = \sigma_{o2} \times C_V \times b \square mY'_2 \times B.F$ (7b)

where σ_{o1} and σ_{o2} are allowable static stress of pinion wheel and allowable static stress of gear wheel respectively.

Design condition: if $W_{T1} > W_{T2}$, it means that pinion teeth are weaker than gear teeth.

3.4 Dynamic Load

Dynamic load is mathematically expressed as the summation of incremental load due to dynamics and tangential tooth load i.e

$W_D = W_I + W_T$ (8)

where $W_I = \frac{21v(bc + W_T)}{21v + \sqrt{bc + W_T}}$ (9)

but c is a deformation factor expressed as $c = \frac{0.00535}{1/E_1 + 1/E_2}$ (10)

where E_1 and E_2 are the modulus of elasticity for pinion and gear respectively

Dynamic load of pinion wheel $W_{D1} = W_{I1} + W_{T1}$ (11a)

Dynamic load of gear wheel $W_{D2} = W_{I2} + W_{T2}$ (11b)

(f) Endurance Strength

Endurance strength for pinion wheel $W_{s1} = \sigma_{E1} b \exists m Y_1' \times B.F$ (12a)

Endurance strength for gear wheel $W_{s2} = \sigma_{E2} b \exists m Y_2' \times B.F$ (12b)

where σ_{E1} and σ_{E2} are the endurance strength of the material used for pinion wear and gear wheel respectively.

(g) Wear

Maximum wear load of pinion wheel $W_{w1} = \frac{D_1 b Q k_1}{cos\theta_{p1}}$ (13a)

Maximum wear load of gear wheel $W_{w2} = \frac{D_2 b Q k_2}{cos\theta_{p2}}$ (13b)

but Ratio factor Q is given as Q = $\frac{2T_{E2}}{T_{E2}+T_{E1}}$ (14)

Load stress factor $K_1 = \frac{\sigma_{SE1}^2 \times 0.3}{1.4}(\frac{1}{E_1}+\frac{1}{E_2})$ (15a)

where σ_{ES1} is the surface endurance limit of pinion wheel

Load stress factor $K_2 = \frac{\sigma_{SE2}^2 \times 0.3}{1.4}(\frac{1}{E_1}+\frac{1}{E_2})$ (15b)

where σ_{ES2} is the surface endurance limit of gear wheel

Design condition: If $W_{w1}>W_{T1}$ & $W_{W2}>W_{T2}$ (design is satisfactory from the standpoint of wear).

3.5 Algorithm for the Design of Bevel Gear

1. Declare constants for different materials (using Table 1.0)

   σ_o- Allowable static strength
   σ_e- Allowable endurance strength
   σ_{es}- Allowable surface endurance strength
   E- Young modulus

2. Select Materials and Gear Forms

   I. Select materials
   II. Select tooth form(14.5° full depth involute, 20° full depth involute, 20° stub)
   III. Select level of cut- (first class cut, carefully cut, precision cut
   IV. Select forms of gear loading (steady load, pulsating load, shock load)

3. Dimension of Bevel Gear

   i. Select module from list of standard module module
   ii. Enter the gear ratio
   iii. Enter the number of teeth of the pinion gear
   iv. Enter the ratio of slant height (l) of face width (b)
   v. Determine the face width (b)
   vi. Determine the pitch angle (θp_1) of the pinion $\theta_{p1} = \tan^{-1}\frac{1}{G}$ where G= velocity ratio/ gear ratio.
   vii. Determine the pitch angle(θp_2) of gear $\theta_{p2} = \theta_s - \theta_{p1}$
   viii. Determine the number of teeth of the second wheel $T_2 = G \times T_1$
   ix. Determine the pitch diameter of gear (D_G=m X T_G)
   x. Determine the pinion pitch diameter (D_P=m X T_P)
   xi. Determine the tooth depth (a+d)
   xii. Determine root diameter (D_p-2d)
   xiii. Determine the outside diameter (D_P+2a)

4. Speed and Velocity

   i. Enter velocity of pinion wheel in rpm
   ii. Determine the velocity of the gear wheel (N_P/G)
   iii. Determine the pitch line velocity 'v' in m/s
   iv. Determine the velocity factor C_V

5. Gear Design using Tregolds, Buckingham & Lewis Formulas

   i. Select the Allowable static stress
   ii. Determine the equivalent tooth form $T_E = T \sec\theta$
   iii. Determine the bevel factor. $B.F = \frac{L-b}{L}$
   iv. Determine the tooth form factor(y^l)
   v. Determine the static strength using lewis formula($W_T=(\sigma_O C_V)\, b\pi m y^l\ B.F$)

6. Dynamic Load

   i. Determine service factor C_S
   Determine increased load due to dynamic force $W_I = {21V(bC + Wt)}\Big/{21v + \sqrt{bc + W_T}}$

   ii. Determine the dynamic load ($W_D=W_T + W_I$)

7. Endurance Strength W_s

   i. Select the endurance strength of the material selected (σ_e, table)
   ii. Determine the endurance strength ($W_S = \sigma_O b\pi m y^l\left(\frac{l-b}{l}\right)$) Conditions for endurance strength if

   $W_S \geq 1.25\ W_D$ (Steady load)
   $W_S \geq 1.35\ W_D$ (Pulsating load)
   $W_S \geq 1.5\ W_D$ (Shock load)

   then design is satisfactory from the standpoint of dynamics
   ELSE
   design is not satisfactory from the standpoint of dynamics

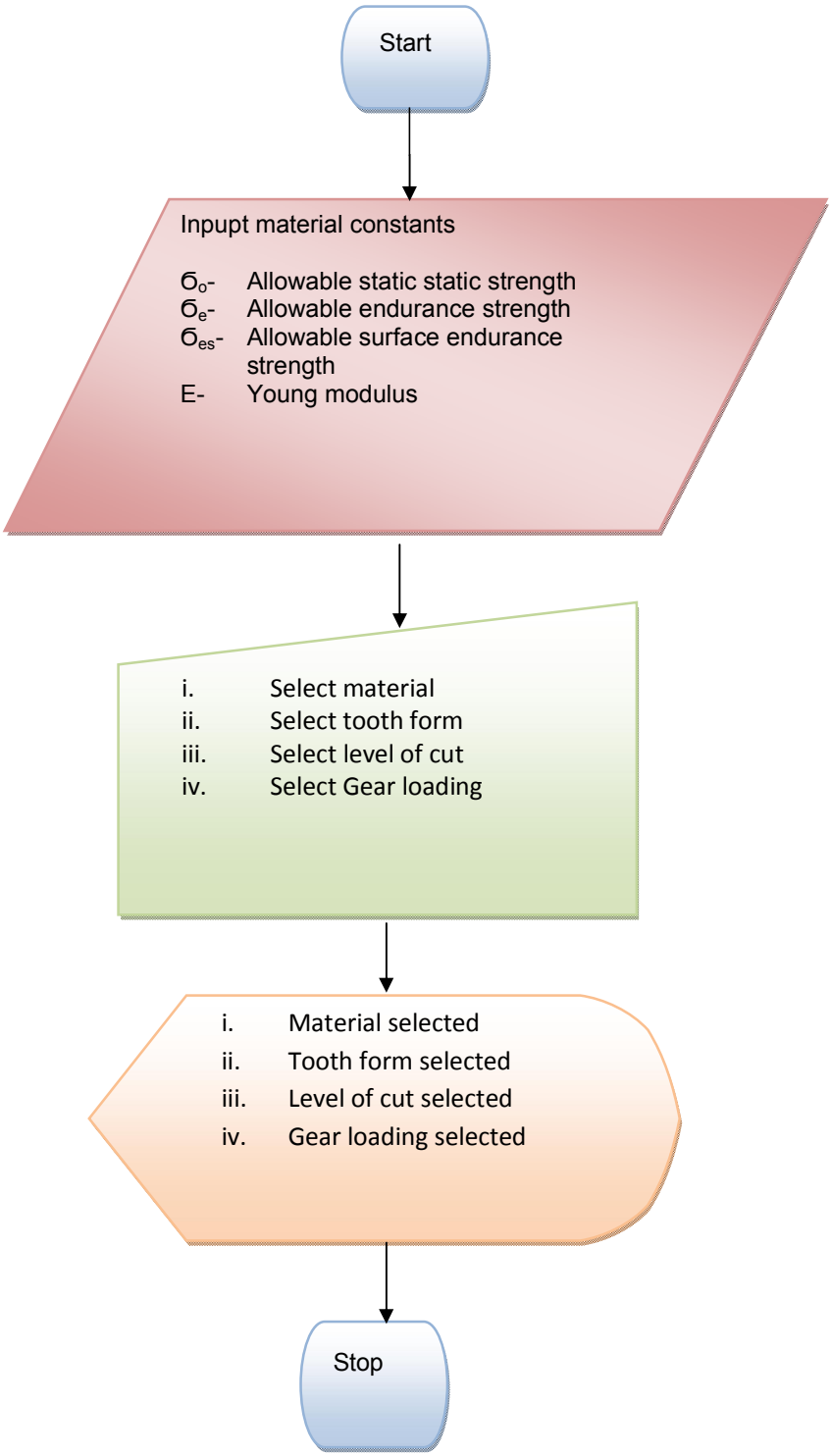
8. Wear Resistance/ Surface Endurance Strength

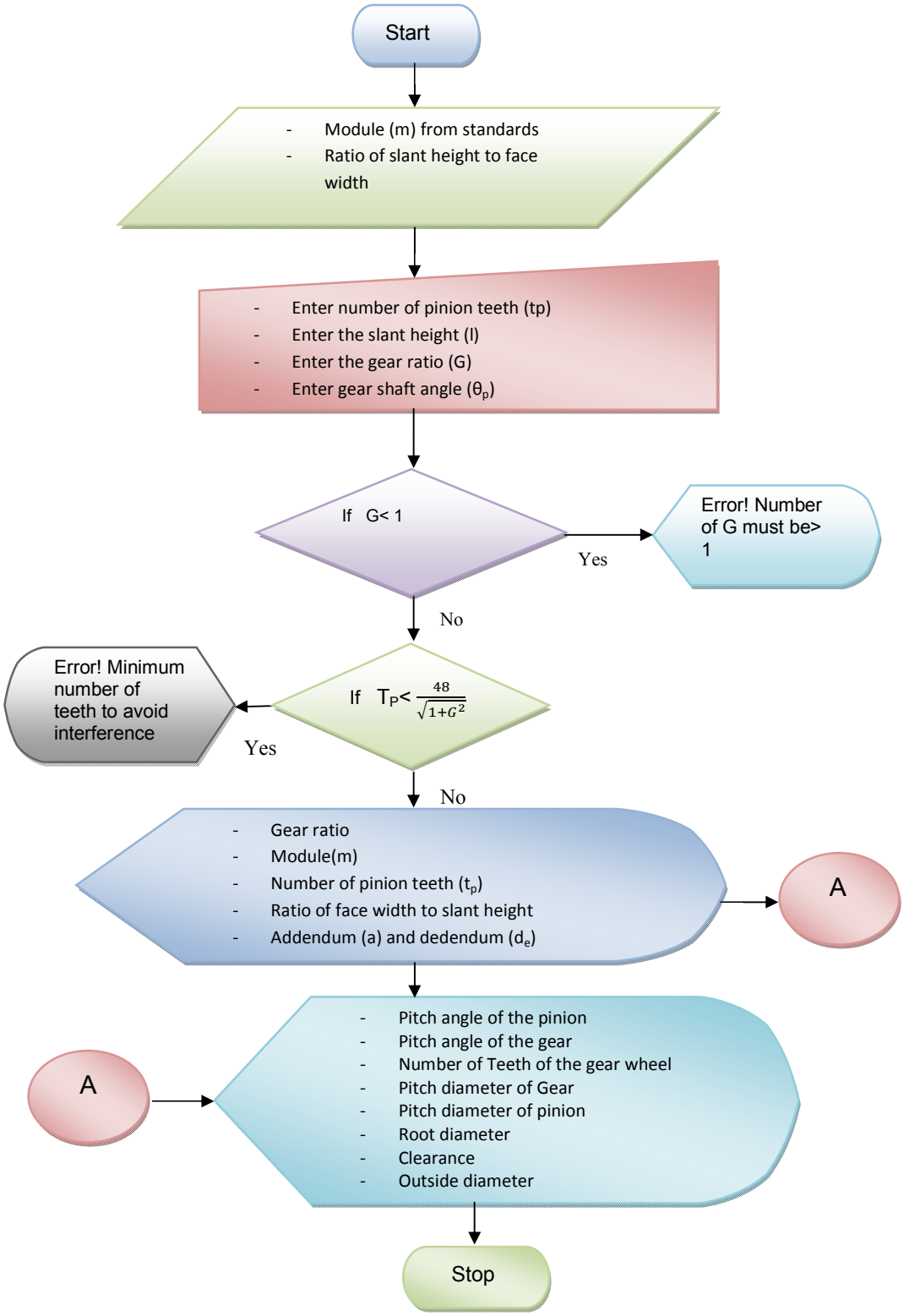
   I. Determine young modulus of the pinion material (table)
   II. Determine the surface endurance (σ_{es}) from (table)
   III. Determine the young modulus of gear ratio (table)
   IV. Determine the stress factor $k = \frac{\sigma_{es}{}^2 sin\phi}{1.4}\left(\frac{1}{E_P} + \frac{1}{E_P}\right)$
   V. Determine the limiting load for wear $W_W = \frac{D_P bQk}{\cos\theta_p}$

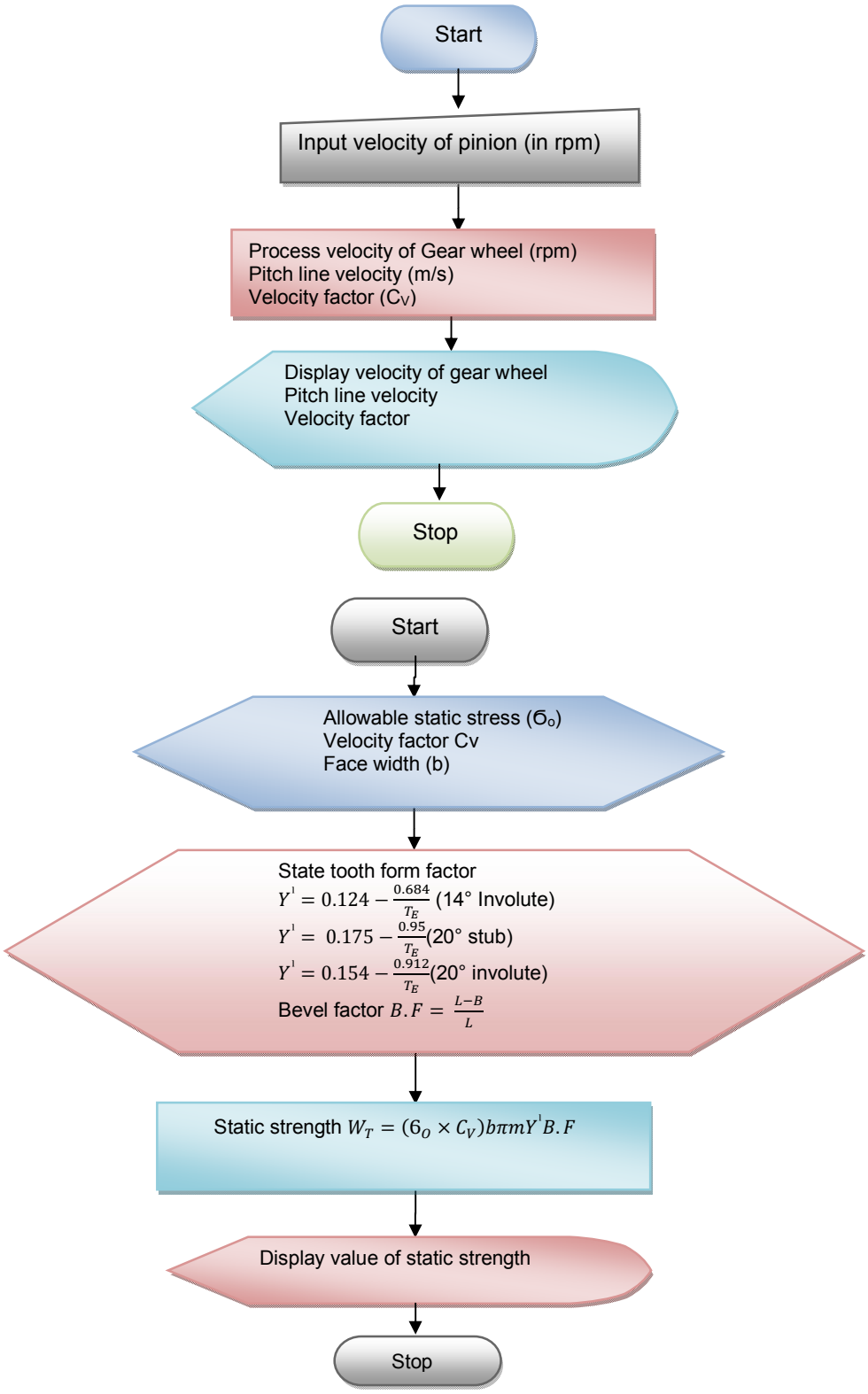
If $W_w > W_t$ then, design is satisfactory from the standpoint of wear Else design is not satisfactory from the standpoint of wear.

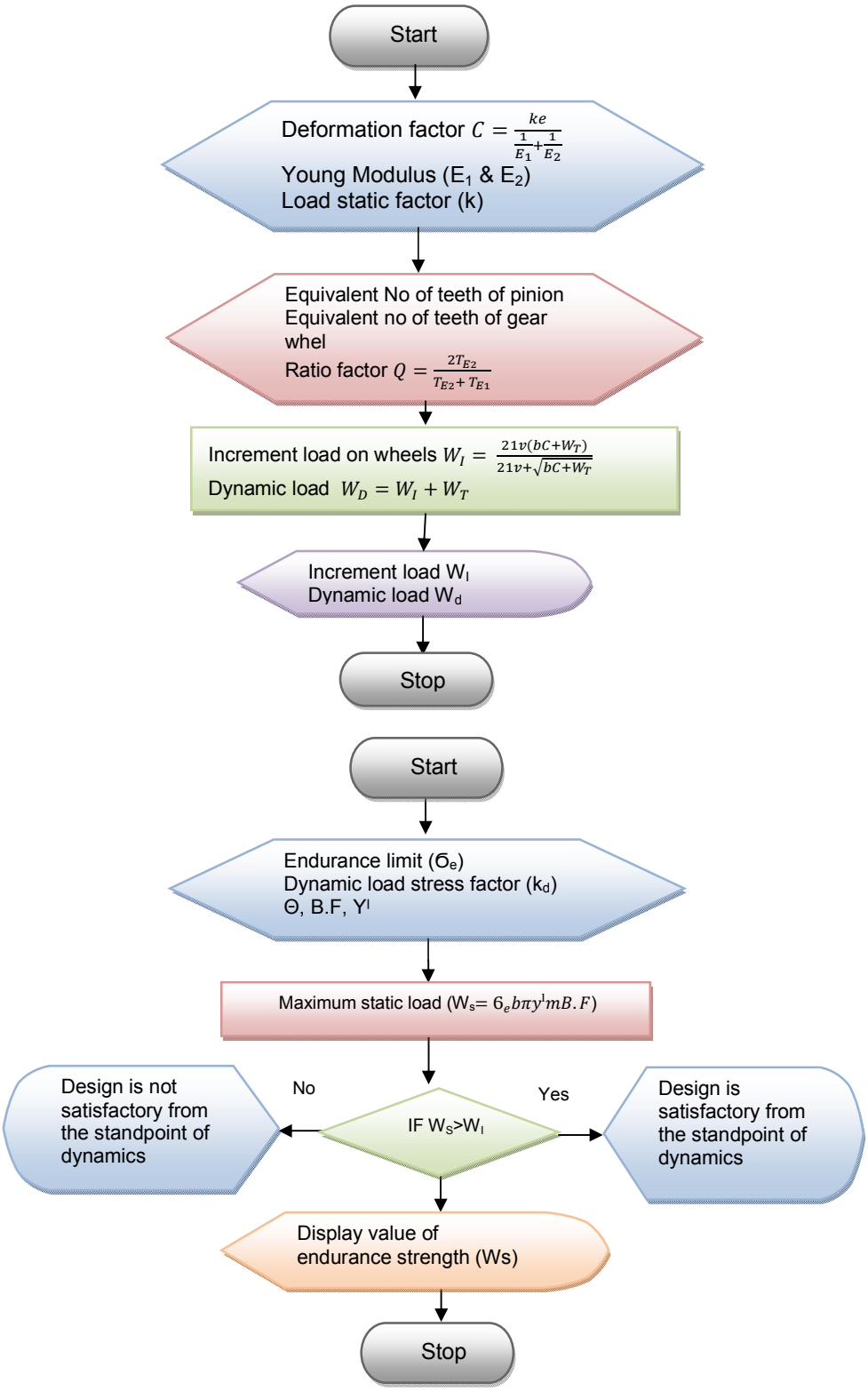
3.6 Algorithm Flowchart

The Algorithm flow chart in Fig. 3.0 shows the stepwise procedures for the design of bevel gear using the Bevel CAD.


Start
Inpupt material constants
σ_o- Allowable static static strength
σ_e- Allowable endurance strength
σ_{es}- Allowable surface endurance strength
E- Young modulus
i. Select material
ii. Select tooth form
iii. Select level of cut
iv. Select Gear loading
i. Material selected
ii. Tooth form selected
iii. Level of cut selected
iv. Gear loading selected
Stop


Start
- Module (m) from standards
- Ratio of slant height to face width
- Enter number of pinion teeth (tp)
- Enter the slant height (l)
- Enter the gear ratio (G)
- Enter gear shaft angle (θ_p)
If G< 1
Yes
Error! Number of G must be> 1
No
If $T_P < \frac{48}{\sqrt{1+G^2}}$
Yes
Error! Minimum number of teeth to avoid interference
No
- Gear ratio
- Module(m)
- Number of pinion teeth (t_p)
- Ratio of face width to slant height
- Addendum (a) and dedendum (d_e)
A
A
- Pitch angle of the pinion
- Pitch angle of the gear
- Number of Teeth of the gear wheel
- Pitch diameter of Gear
- Pitch diameter of pinion
- Root diameter
- Clearance
- Outside diameter
Stop


Start
Input velocity of pinion (in rpm)
Process velocity of Gear wheel (rpm)
Pitch line velocity (m/s)
Velocity factor (C_V)
Display velocity of gear wheel
Pitch line velocity
Velocity factor
Stop
Start
Allowable static stress ($б_o$)
Velocity factor Cv
Face width (b)
State tooth form factor
$Y^{'} = 0.124 - \frac{0.684}{T_E}$ (14° Involute)
$Y^{'} = 0.175 - \frac{0.95}{T_E}$(20° stub)
$Y^{'} = 0.154 - \frac{0.912}{T_E}$(20° involute)
Bevel factor $B.F = \frac{L-B}{L}$
Static strength $W_T = (6_O \times C_V) b\pi m Y^{'} B.F$
Display value of static strength
Stop


Start
Deformation factor $C = \frac{ke}{\frac{1}{E_1}+\frac{1}{E_2}}$
Young Modulus (E_1 & E_2)
Load static factor (k)
Equivalent No of teeth of pinion
Equivalent no of teeth of gear whel
Ratio factor $Q = \frac{2T_{E2}}{T_{E2}+T_{E1}}$
Increment load on wheels $W_I = \frac{21v(bC+W_T)}{21v+\sqrt{bC+W_T}}$
Dynamic load $W_D = W_I + W_T$
Increment load W_I
Dynamic load W_d
Stop
Start
Endurance limit (σ_e)
Dynamic load stress factor (k_d)
Θ, B.F, Y'
Maximum static load ($W_s = \sigma_e b\pi y' mB.F$)
No
IF $W_S > W_I$
Yes
Design is not satisfactory from the standpoint of dynamics
Design is satisfactory from the standpoint of dynamics
Display value of endurance strength (Ws)
Stop

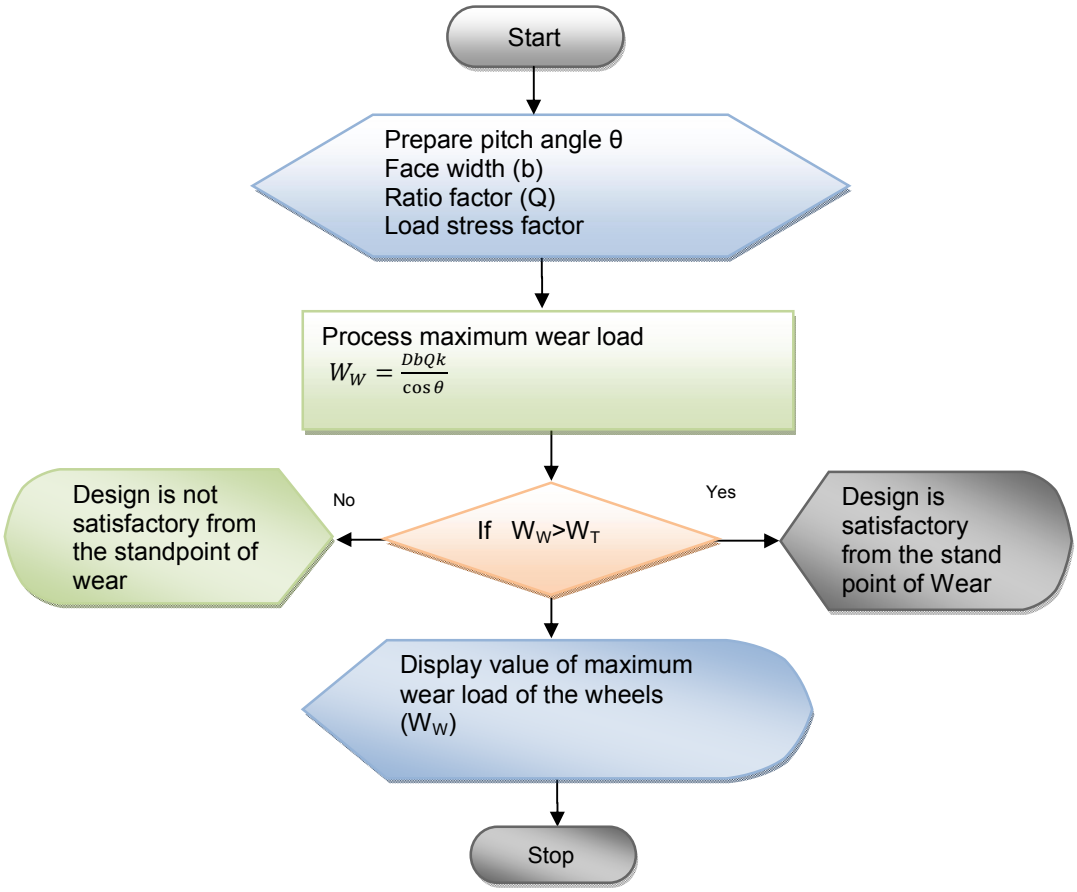


Fig. 3.0. Algorithm flow chats

3.7 Software Development

The algorithm above was used to develop the software (Bevel CAD) used in the design of bevel gear. This was made possible by transforming the required formulas and data of bevel into a set of instruction codes. The codes written could validate the user inputs and respond by giving the user the necessary information. The software was designed using C# programming language and the Net Platform. The .Net Platform is a new and efficient platform from Microsoft cooperation that is invented to fill in the deficiency gap created by its predecessor platform like Win 32, MFC, Visual Basic, to name but few.

3.7.1 Reasons for using net platform

The .Net is preferred over other platforms due to the following reasons:

1. It is neutral language. Numerous languages can be employed to write programs on this platform. There are over 250 programming languages presently available. Microsoft created four out of this. They are C#, VB. Net, J#, C++ /CLI).
2. The platform is fully object oriented and this accounts for its unmatched ability in managing the automation of the most complex problems.
3. It is very secure. Security is planted at the core (most inner section) of the platform.

Concerning its features, C# inherited 70% of java, 5% of VB, 10% of C/C++, and it adds 15% new. The programs emulated good aspects of the suspect and became better software. This among other reasons lends credence for the selection C# for designing Bevel CAD Designer.

3.8 Main Window

The Bevel CAD main window as shown in Fig. 4.0 consists of four tabs as listed and described below:

i. Material /Gear type
ii. Dimensions
iii. Speed and velocity
iv. Gear design

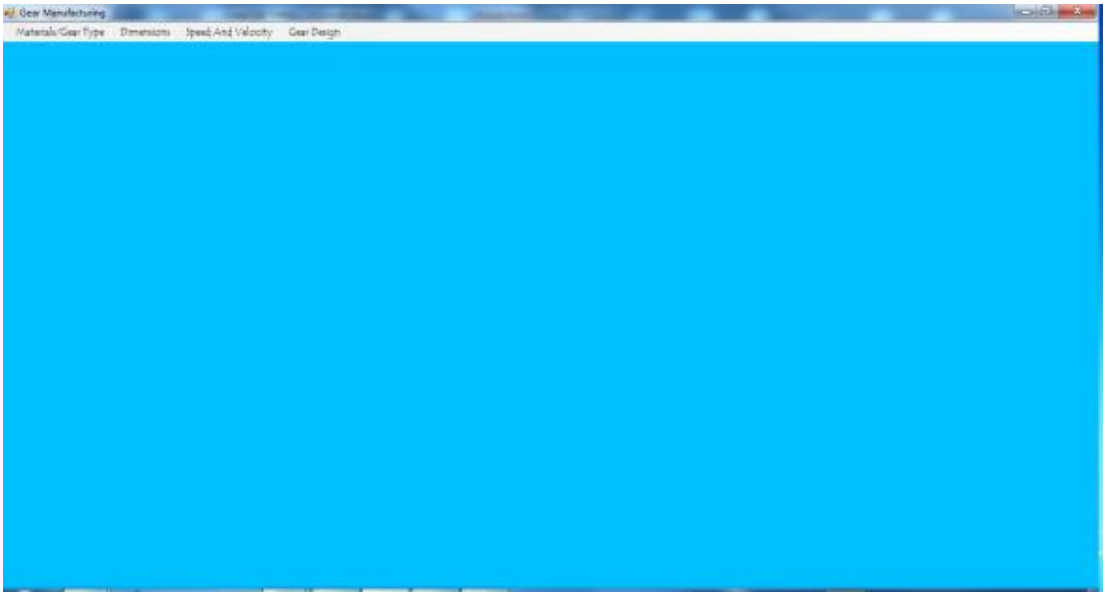


Fig. 4.0. Bevel CAD main window

3.9 Material/Gear Type Interface

The environment shown in Fig. 5.0 pops-up and request for the gear and the pinion and input information (parameter).

The parameter requested for include the following:

i **Material**- the material required include: cast iron of different grades, carbon steel, cast steel, aluminium steel, phosphor, bronze, alloy steel etc.
ii **Select tooth form**- the various types of tooth forms which include : 20° stub, 20° involute, 14.5° involute
iii **Level of cut**- the accuracy of cut can be selected which include the following : precision cut, ordinary cut, carefully cut
iv **Gear loading**- this software makes available margins for the type of loading that the gear will be subjected. The gear loading types include pulsating load, steady load and shock load.

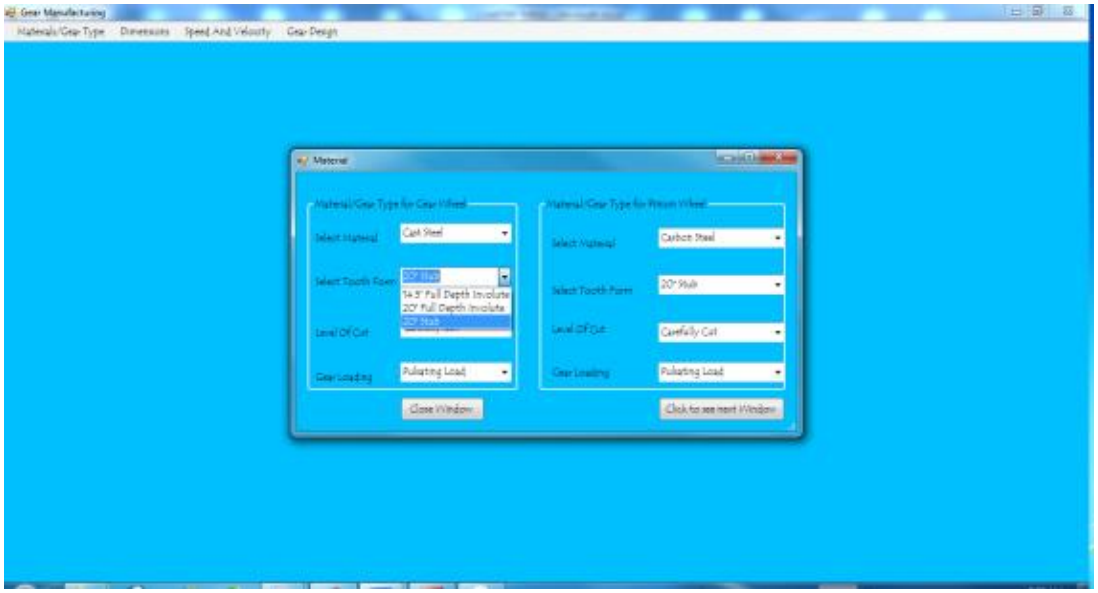


Fig. 5.0. Material/gear type environment

3.9 Dimension Window

The dimension window shows the interface of the inputs in the dimensions. The window is as shown in Fig. 6.0.

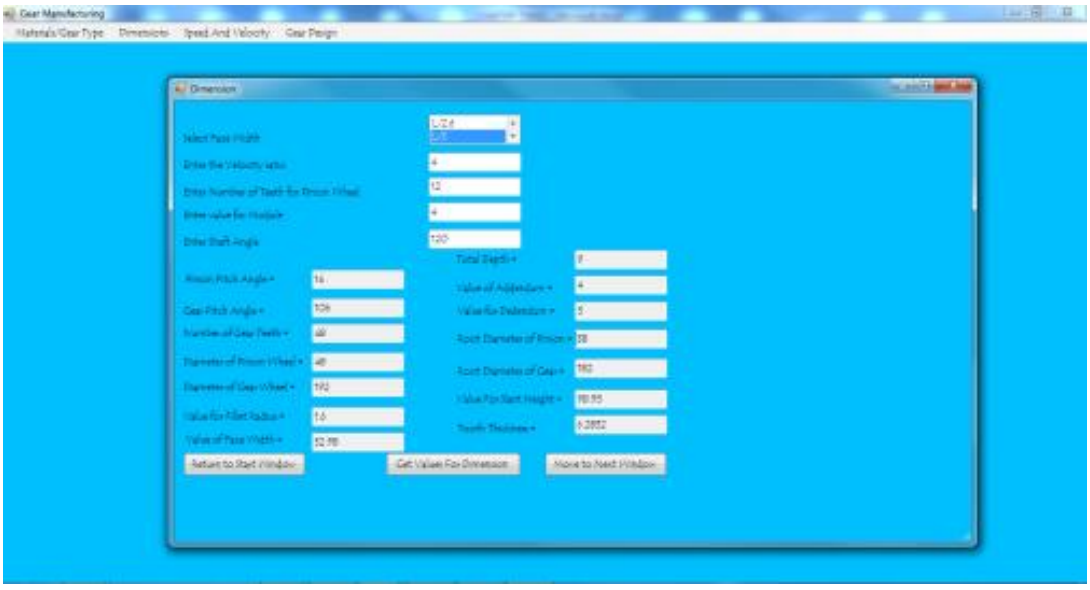


Fig. 6.0. Bevel CAD dimension interface

The software requires for the following input dimensions which include.

i **Ratio of the face-width to the slant height:** The slant height ratio to face-width value is demanded for. Examples of these values are (l/2, l/2.3,l/2.5, l/3, l/4).
ii **Velocity Ratio:** Also known as the Gear Ratio is also an input parameter in the design of the bevel gear
iii **Number of Pinion Teeth:** The software request for the number of the initiated pinion gear.
iv **Enter the value of the module:** The module value is also required for the design of bevel gear.
v **Shaft angle:** The software is capable of processing any form of bevel gear of different shaft angles of 90º, angular bevel gears (120°, 130°, 125°, 140 etc.).

Clicking on the tab 'get value for dimension' the computer does the calculations in the algorithm and displays value for the following parameter. Pitch angle of pinion, pitch angle of gear, Number of pinion Teeth, Number of Gear teeth, diameter of gear teeth, diameter of pinion teeth, value of fillet radius, tooth depth, value of addendum, value of dedendum, root diameter of pinion, root diameter of gear, etc.

There are 2 other tabs in this window, making it the 3 tabs in this window. Clicking the tab "return to the start window" takes the designer back to the start window. Clicking the tab" Move to Next Window" pops-up the "speed and velocity window".

3.10 Speed and Velocity Window

The window requires just the velocity of the pinion in rpm. The computer itself generates velocity of the gear wheel in rpm and the pitch line velocity of the pair of gears. The window also has 'move to the Next window' which takes the designer to the last phase called the 'gear design window'. Snap shot of the speed and velocity interface is shown in the Fig. 7.0.

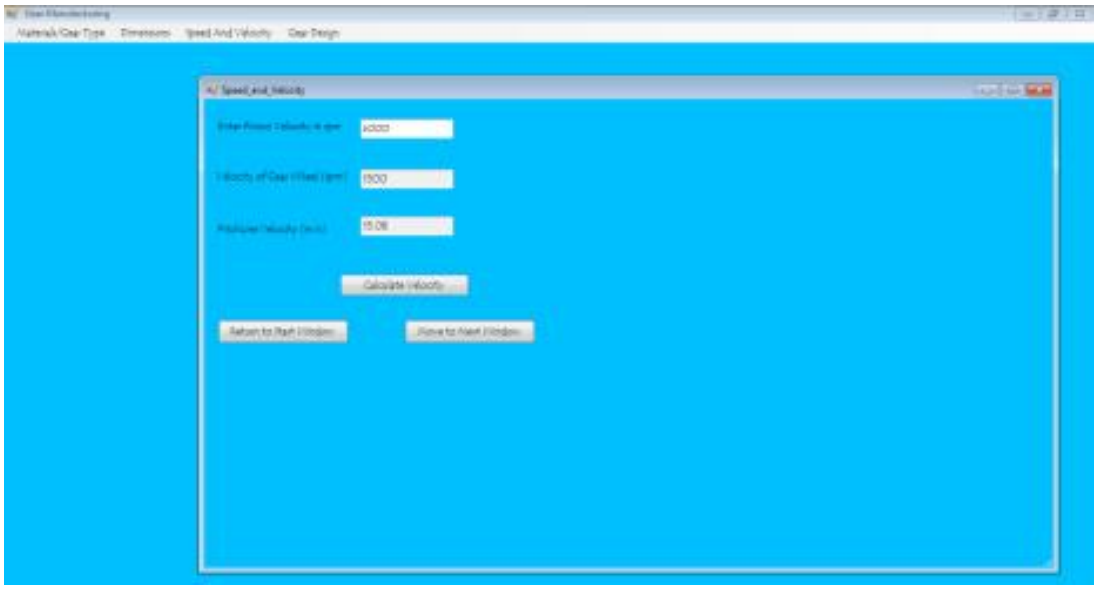


Fig. 7.0. Gear speed and velocity interface

3.11 Gear Design Window

This window is the main citadel of the software. The phase does not require for any input but uses the existing input to calculate and display the following gear characteristics.

i Beam strength of pinion Tooth
ii Beam strength of Gear tooth
iii Deformation factor
iv Increment load of pinion wheel
v Dynamic load of pinion wheel
vi Dynamic load of Gear wheel
vii Endurance Strength of pinion wheel
viii Endurance Strength of Gear wheel
ix Maximum Wear load of pinion wheel
x Maximum wear load of gear wheel
xi Load stress factor for pinion wheel
xii Load stress factor for gear wheel
xiii Ratio Factor

A snapshot of this window is shown in Fig. 8.0.

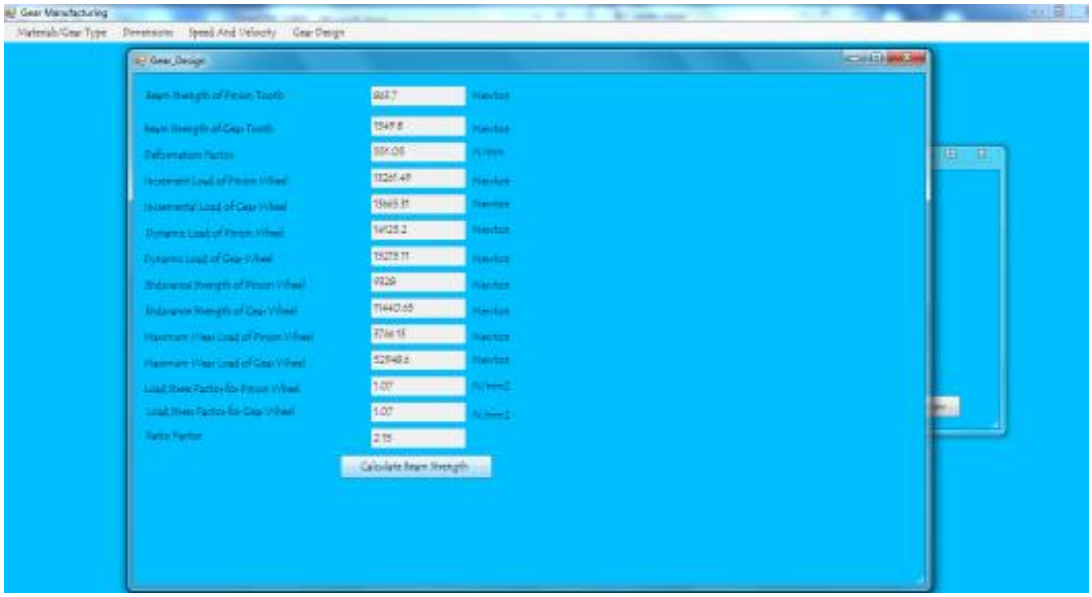


Fig. 8.0. The gear design window

The outstanding characteristics about this software is its ability to suggest to designer the conditions of the gear been designed in term of

i Stronger teeth among the pinion and the gear
ii Endurance characteristic of the teeth under dynamics.
iii Wear characteristic of the gear teeth under dynamic load.

Fig. 9.0 is a snapshot of condition suggested after a test designed using the Bevel CAD.

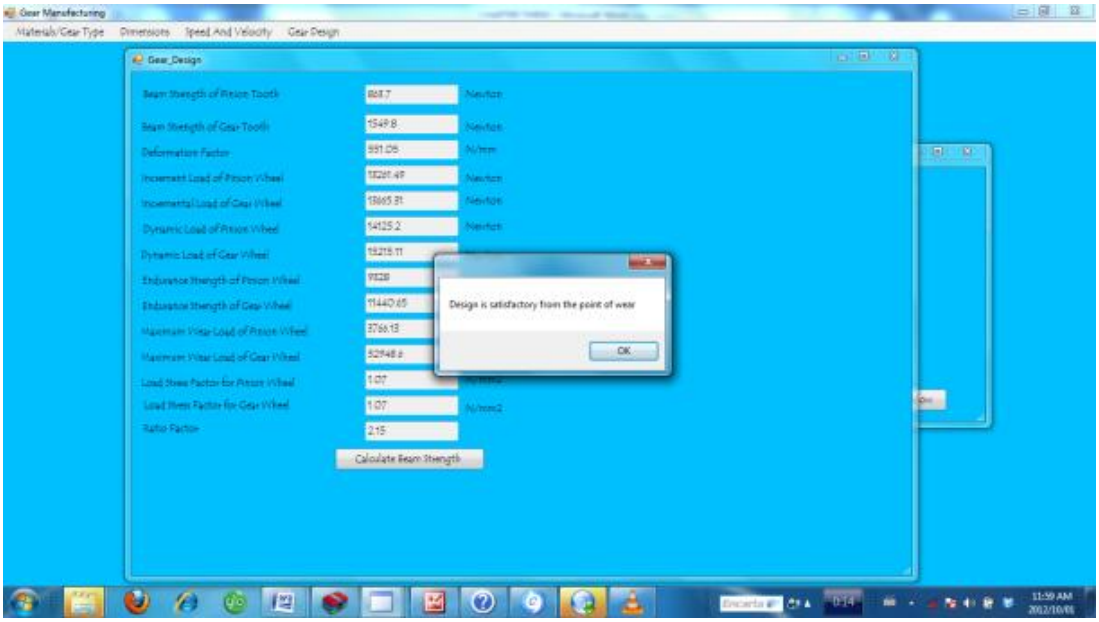


Fig. 9.0. Design condition snap-shot

4 Results and Discussion

The software was tested by comparing its result with the manually computed result using the same examples. The software found an excellently close answer with that of the result obtained from the textbook and the algorithm test above. The software was again tested with other inputs from renowned textbooks and similar/close answers were also gotten. The little differences in the answers were due to errors due to approximation. See Table 3.0 for the results of the manually computed results and Bevel CAD results.

4.1 Design of Bevel Gear

Material used for both Pinion and Gear wheel =Cast iron grey, Carefully cut with stead loading. Velocity ratio/gear ratio = 1.25, module = 5 mm, Number of teeth in the Pinion wheel = 16, Angle of shaft = 90º, Speed of pinion wheel = 1100 rpm.

Table 3.0. Comparism between the results

S/n	Parameters	Value from manual/hand computation	Values from bevel CAD software
1	Pinion pitch angle	38.66^{o}	39^{o}
2	Gear pitch angle	51.34^{o}	51^{o}
3	Number of gear teeth	20	20
4	Diameter of pinion wheel	80 mm	80 mm
5	Diameter of gear wheel	100 mm	100 mm
6	Fillet radius	2 mm	2 mm
7	Face width	21.34 mm	21.34 mm
8	Total depth	11.25 mm	11.25 mm
9	Addendum	5 mm	5 mm
10	Dedendum	6.25 mm	6.25 mm
11	Root diameter of pinion	67.5 mm	67.5 mm

Table 3.0 continued…….

12	Root diameter of gear	87.5 mm	87.5 mm
13	Slant height	64.03	64.03
14	Tooth thickness	7.854 mm	7.854 mm
15	Velocity of gear	880 rpm	880 rpm
16	Pitch line velocity	4.61m/s	4.61m/s
17	Beam strength of pinion tooth	796.9N	796.06N
18	Beam strength of gear tooth	911.03N	916.98N
19	Deformation factor	302.28	302.27
20	Incremental load of pinion wheel	3856.42N	3855.52N
21	Incremental load of gear wheel	3905.18N	3902.25N
22	Dynamic load of pinion wheel	4653.32N	4651.59N
23	Dynamic load of gear wheel	4822.16N	4813.28N
24	Endurance strength of pinion wheel	2056.52N	2056N
25	Endurance strength of pinion wheel	2366.41N	2352.56N
26	Maximum wear load of pinion wheel	4027.6N	4002.59
27	Maximum wear load of gear wheel	6293.05N	6208.09N

Comparing the manually calculated results with the CAD result, the following inferences are made:

4.2 Accuracy in Calculations

Very close results were generated by both the manual calculation and that of the CAD software. The modeled calculation is believed to be more accurate because it uses uniform approximation in all its results.

4.2.1 Reduction in errors and time savings

In addition to the accuracy of the software, errors and mistakes in computations were drastically reduced. Care must be taken in the calculations as the designers are proned to mistakes due to complex calculations. Hand calculation takes a lot of time. From Table 3.0, it is observed that manual hand calculation takes average of 52 minutes to design a typical bevel gear but the same design takes just an average of 11 minutes when using Bevel CAD Designer software.

4.2.2 Suggestion of design conditions to designers

The modeled software also suggests the physical condition of the designed bevel gear using the computed result. These suggestions help designers to achieve better designs.

5 Conclusion and Recommendations

The required parameters for the design of bevel gears were identified which led to the formation of mathematical models. Algorithm was developed from the model which was later transformed to Bevel CAD software.

The developed software was evaluated by comparing its results by the manual mathematical computation and the results were found to be similar. Apart from the fact that the software saves time for the parametric design of bevel gear, it also suggests design conditions to assist bevel gear designers in decision making. Human errors are eliminated using the software.

It is recommended that the software be introduced to the tertiary institutions as a teaching aid to student on gear design and also designers should give proper considerations to design conditions suggested by the software to aid proper designs.

Competing Interests

Authors have declared that no competing interests exist.

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