

# Software Interface for Calculation of Gear Parameters

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## Abstract

Designing of helical involute gears involve several parameters to be considered. It includes the calculation of the gear parameters, the use of several commercial packages such as Autodesk drafting package, solid work package, Ansys package ... etc. The commercial packages are usually work on standard gears. Their libraries store gears that can be used by inserting the standard parameters not the modified parameters. When dealing with modified gears the profile is digitized and fed as discrete points to the package. As the modifications involve profile modification, gear undercutting, tip relief, inserting of gear backlash which result in varying all gear parameters, so a need to computerize this process and present a file that is read by the majority of the commercial packages. This paper gives a software interface capable of calculating all the parameters of involute helical gears including their modifications and saves them in Formatted files that can be read directly by the other gear packages.

**Keywords:** Helical gear analysis; gear modifications; C#; software.

## 1. Introduction

Gears are essential part in mechanical engineering. It is a subject that challenge whoever comes in touch with from the design stage passing by the manufacture stage and ending with its repair. The design procedure involves cyclic calculation until the proper parameters of gear are determined. It further needs stress and deflection analysis that may force the designer to build his own model or using any of the commercial package available such as Ansys or the modules of the finite element in solid work packages and others. Tooth profile graphing is essential in all stages. This requires transferring tooth data between the packages.

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The majority of the commercial packages store macros in their libraries, only for the standard gear profiles i.e. without any modifications. The transferring of data between these commercial packages is usually done manually. The equations and relationship between the gear parameters are well known and are given in several references and handbooks. Gitin M. Maitra [1] discussed all the parameters in detail and gave the relations for calculating the various parameters for standard gears,  $S_o$  gears (mating gears with equal but opposite profile modification coefficient) and  $S_g$  gears (mating gears with different values for the profile modification coefficients). Ognyan ALIPIEV [2] tabulated the geometric equations in a neat sequence for two cases. The first case was defined as a right problem in which the working center distance is unknown and through knowing the other parameters ( $m$ ,  $z_1$ ,  $z_2$ ,  $\alpha$ ,  $\beta$  and the correction coefficients) the working center distance was calculated. Getting the working center distance, all other geometrical parameters were determined from the equations tabulated in the reference. The second case which was defined as a reverse problem in which the working center distance is known while the correction coefficients are unknown. The equations are, also, given to determine the transverse working pressure angle and then the coefficients for modifications. In the “Elements Of Metric gear technology” [3] similar approach for the two cases are presented. All the relations were tabulated with a case study included. Gonzalo González Rey and his colleagues [4] beside listing the relations, presented a way to define some parameters through measuring them using Metrological instrument and, then, were used to calculate the rest of the geometrical parameters. All the work listed were carried out manually. Hence, the aim of this paper is to automate this process and build a software interface that is capable of performing the calculations of gear parameters taking into consideration all the modifications and, also, capable to communicate between the various commercial packages by giving outputs that can be read directly by the commercial packages enabling to proceed further in designing the gears through the use of stress analysis models.

## 2. Plan of work

Gear design proceeds from the phase of determining the geometrical parameters of the gear set to the second phase of checking their capability to stand the subjected loads, stresses and deflection. The first phase depends on the data available to start defining the tooth profile. The plan of work for the case of newly designed gear where the initial parameters (module, pressure angle, helix angle, number of teeth of the pinion and gear, the addendum modification factors circumferential backlash factors and the working center distance) are known. The plan which is summarized in figure 1, proceeds as follows as indicated below.

The equations of the gear geometry given below are taken from several literatures [2,3,4] and not deduced in this paper.

- Determining the transverse working pressure angle which is the first key parameter by finding:
  - Standard center distance ( $A_s$ ) =  $\frac{M*(Z_1+Z_2)}{2 * \cos(\beta)}$
  - Center distance correction factor ( $Y$ ) =  $(X_1 + X_2) - \frac{(A_w - A_s)}{M}$
  - Transverse pressure angle ( $\alpha_t$ ) =  $\tan^{-1}(\tan \alpha / \cos \beta)$
  - Transverse working pressure angle ( $\alpha_{wt}$ ) =  $\cos^{-1}((Z * \cos \alpha_t) / ((2 * Y * \cos \beta) + Z))$

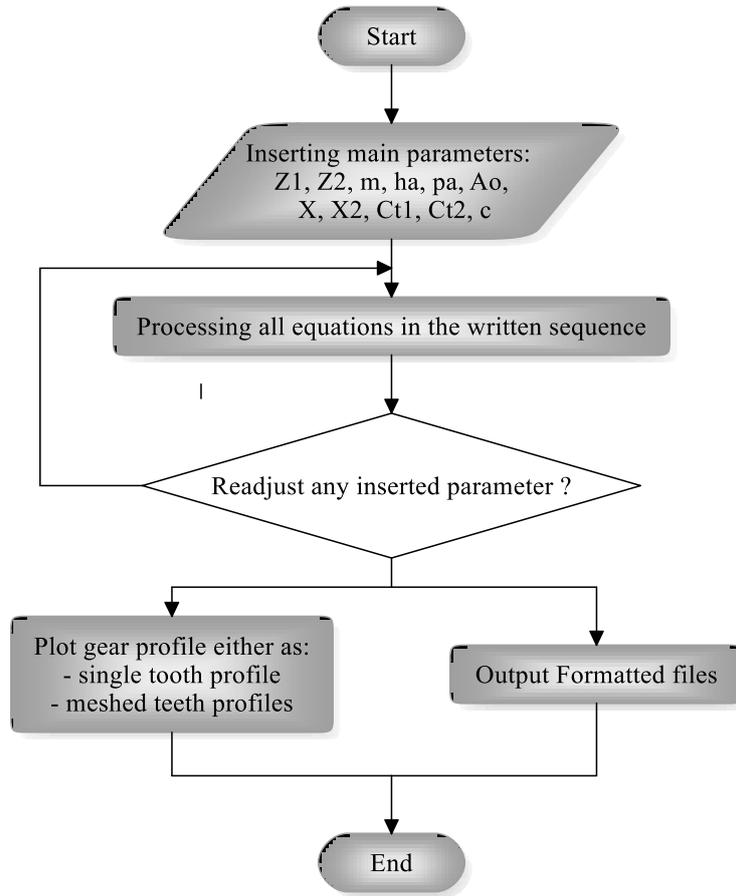


Figure 1: Research plan

- Determining the transverse working circle diameters which is the second key parameter. Through the two keys values of the pinion parameters can be linked with the corresponding values of the mating gear parameters and vice versa. (i is 1 for pinion and 2 for gear)

o Working circle diameter  $(D_{wi}) = (M * Z_i * \cos(\alpha_t)) / (\cos \beta * \cos(\alpha_{wt}))$  (1)

- Determining the tooth dimensions

o Addendum height  $(h_i) = M * (1 - Y + X_i)$  (2)

o Tooth height  $(H) = M * (2 + c - 2 * Y + (X_1 + X_2))$  (3)

- Determining the rest of the circle diameters

o Reference circle diameter  $(D_{refi}) = (M * Z_i) / \cos \beta$  (4)

o Tip circle diameter  $(D_{tipi}) = D_{refi} + 2 * h_i$  (5)

o Base circle diameter  $(D_{bi}) = (M * Z_i * \cos \alpha_t) / \cos \beta$  (6)

o Root circle diameter  $(D_{ri}) = D_{tipi} - 2 * H$  (7)

- Determining the general parameters

o The contact ratio  $(CR) = ((B * \sin \beta * \cos \alpha_t) + \cos \beta * ((D_{o1}^2 - D_{b1}^2)^{0.5} + (D_{o2}^2 - D_{b2}^2)^{0.5} - A_s * \sin \alpha_{wt})) / (\pi * M * \cos \alpha_{wt})$  (8)

o The radial clearance  $(RC) = A_s - ((D_{o2} - D_{r1}) / 2)$  (9)

○ The top land width (TL<sub>i</sub>) = d<sub>oi</sub> \* ((S<sub>t\_refi</sub> / D<sub>refi</sub>) + inv α<sub>t\_refi</sub> - inv α<sub>i</sub>) (10)

Considering figures 2 & 3, the profile of two successive teeth are shown and is digitized to “n1” segment each ( here, 430 segments, 100 segments “n2” on the profile and 10 segments on the land). The hundred segment is chosen as the maximum module considered is 20 mm, i.e. the tooth height for the standard tooth with 0.25 clearance factor is 45 mm. The radius at which the calculation is carried out is incremented every 0.45 mm and less than 15 min of arc for the pressure angle. It is highly reasonable accuracy particularly for lesser modules. The 10 segments for each of the top and bottom lands are sufficient as those portions are arcs of circles.

The aim is to determine the angle “φ<sub>j</sub>” at each digitized point on the profile starting from point “0” at the base circle to the end point at the tip circle.

Digitized radii (D<sub>i</sub>) = D<sub>b</sub> + k1 \* [(D<sub>o</sub> - D<sub>b</sub>) / n1] where k1 = 0, 1, 2, 3, .....n1 (11)

The transverse pressure angle at any radius (α<sub>tj</sub>) = cos<sup>-1</sup>((cos α<sub>wt</sub> \* D<sub>wi</sub>) / D<sub>j</sub>) (12)

The tooth thickness at any radius (S<sub>ij</sub>) = D<sub>i</sub> \* (((π / (2 \* Z<sub>i</sub>)) + ((2 \* X<sub>i</sub> \* tan α + CT<sub>i</sub>) / Z<sub>i</sub>) + inv α<sub>i</sub> - inv α<sub>ij</sub>) (13)

The angle “φ<sub>j</sub>” at any radius is given by S<sub>ij</sub> / D<sub>j</sub> (14)

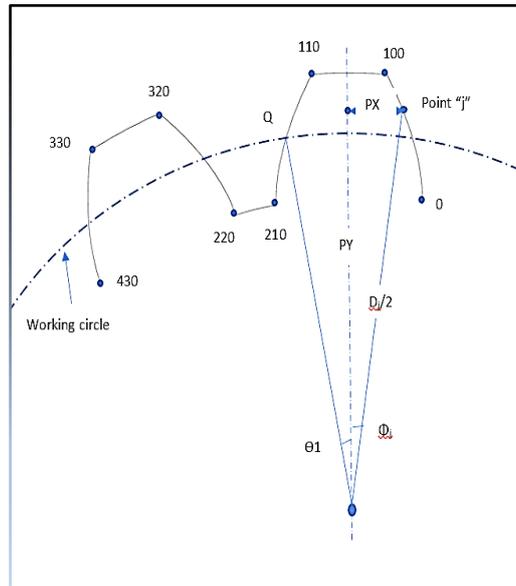
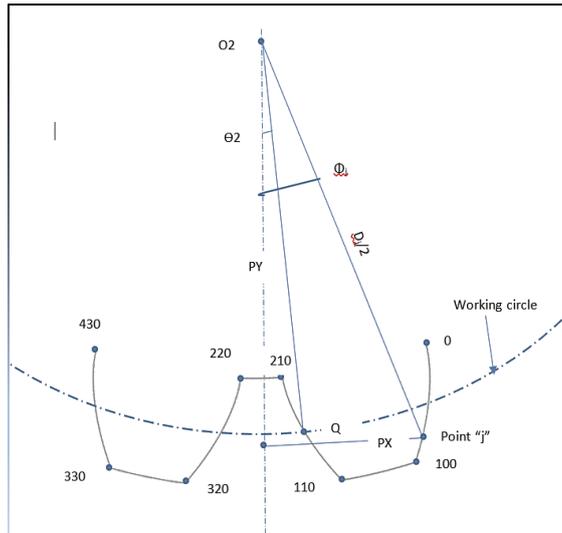


Figure 2: Pinion Profile



**Figure 3: Gear Profile**

The angle “ $\phi_j$ ” for the points from the end point on the profile to the mid-point on the arc of the top land (point 100 to 105) =  $\phi_{100} - k_2 * [S_{t\_tip} / (n_2 * D_o)]$  where  $k_2 = 0, 1, 2, \dots, n_2/2$  (15)

The angles “ $\phi_j$ ” for the points from 106 till 210 is the mirror image about Y-axis.

The angles for the points on the base land (points 210 to 220) =  $\phi_{210} - 2 * k_2 * [((\pi * D_b / Z_1) - S_{tb}) / n_2] / D_b$

$$\text{Where, } k_2 = 0, 1, 2, 3, \dots, n_2 \quad (16)$$

The angles of any other profile for the successive teeth are considered by rotating the Y-axis through a successive angle of  $(2 * \pi / Z_1)$  (17).

$$\text{The Cartesian coordinates of any of the points; } PX_j = (D_j * \sin(\phi_j)) / 2 \text{ and } PY_j = (D_j * \cos(\phi_j)) / 2 \quad (18)$$

For the mating gear same procedure is carried out considering that point “Q” is the contact point on the two circumferences of the working circles. The transverse pressure angle at this point is the same for both gears. From literature [2,3], the transverse pressure angle and the tooth thickness at the reference circle are:

$$\alpha_{t\_refi} = \cos^{-1}((\cos \alpha_{wt} * D_{wi}) / D_{refi}) \quad (19)$$

$$\text{The tooth thickness at the reference circle } (S_{t\_refi}) = M * (\pi/2 + CT_i + 2 * X_i * \tan \alpha) / \cos \beta \quad (20)$$

$$\Theta_1 = 2 * \text{arc}(PQ_1) / D_{w1} = 2 * \text{half the tooth thickness at working circle} / D_{w1} = S_{w1} / D_{w1} \quad (21)$$

$$\text{Similarly, } \Theta_2 = S_{w2} / D_{w2} \quad (22)$$

$$\text{Angles on the profile 210 to 220 on the mating gear equal to } [(\pi * D_{j2} - S_{ij2} * Z_2) / (* D_{j2} * Z_2)] \quad (23)$$

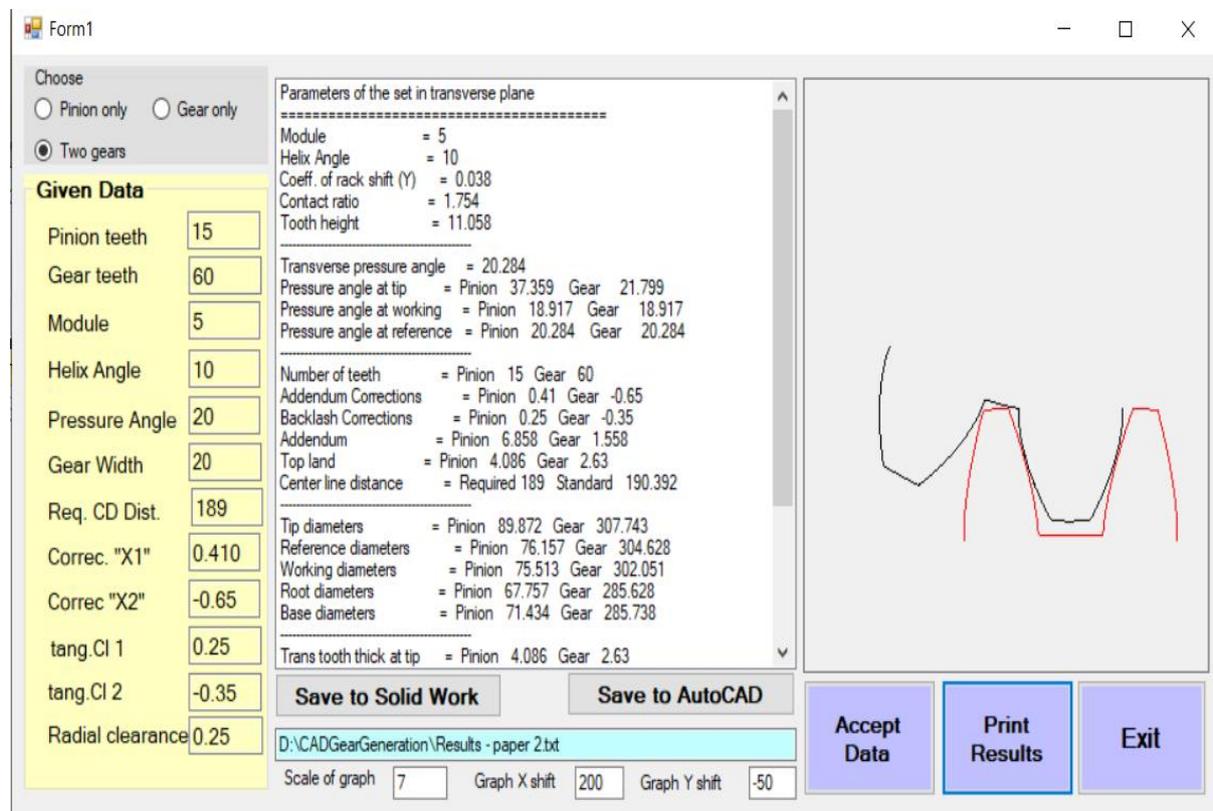
The angles are corrected by the difference (if any) between  $\Theta_2$  and the angle at the working circle. The rest of the angles “ $\phi_j$ ” are determined by similar way as the pinion. The tooth profile shape is plotted either for one of the gears or with the pinion and gear in mesh. Changing any of the values of the coefficients is allowed to study the corresponding changes in the gear profile or in their way of meshing. To facilitate the transfer of the output data for further studies the teeth profile are achieved as formatted files ready to be read directly by Autodesk “AutoCAD”, through ‘SCRIPT’ command or in plain text for the use either of solid work or Ansys packages. The software coding is written using Visual studio C# 2019 language.

### 3. Case Studies

The program was tested for several cases. One case is given in table 1. The computed parameters are given in table 2. A snap shot of the on line screen is shown in figure 4. The figure shows the input values, the listing of the calculated parameters and the plot for the profile which can be obtained for a single gear (pinion or gear) or for the meshed pair. Any change in the input values is allowed with the immediate response is obtained.

**Table 1:** Parameters as inserted to the interface

Case	M	Z1	Z2	B	A	B	Ao	X1	X2	CT1	CT2	C
#1	5	15	60	10	20	20	189	0.41	- 0.65	0.25	- 0.35	0.25

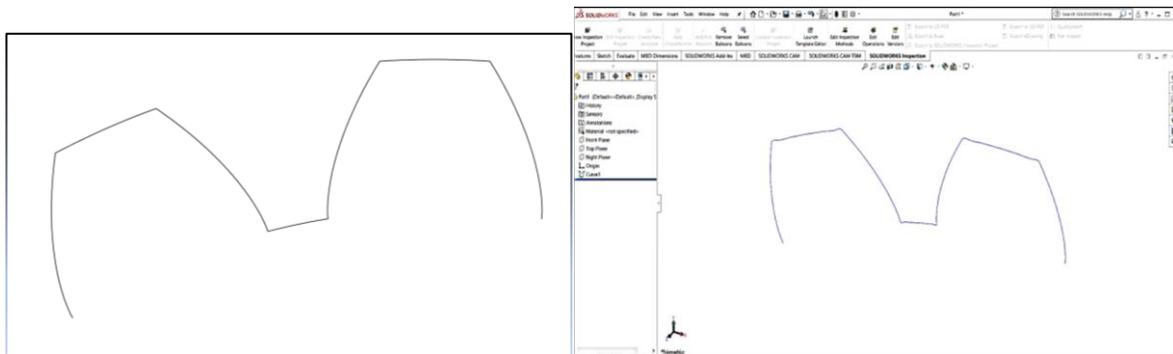


**Figure 4:** Screen shot for case #1

**Table 2:** Results obtained from the interface

Parameters of the gears in transverse plane			
Module	5		
Helix Angle	10		
Center distance coefficient (Y)	0.038		
Contact ratio	1.754		
Tooth height	11.058		
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Transverse pressure angle	20.284		
Pressure angle at tip	Pinion 37.359	Gear	21.799
Pressure angle at working	Pinion 18.917	Gear	18.917
Pressure angle at reference	Pinion 20.284	Gear	20.284
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Number of teeth	Pinion 15	Gear	60
Addendum Corrections	Pinion 0.41	Gear	-0.65
Backlash Corrections	Pinion 0.25	Gear	-0.35
Addendum	Pinion 6.858	Gear	1.558
Top land	Pinion 4.086	Gear	2.63
Center line distance	Required 189	Standard	190.392
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Tip diameters	Pinion 89.872	Gear	307.743
Reference diameters	Pinion 76.157	Gear	304.628
Working diameters	Pinion 75.513	Gear	302.051
Root diameters	Pinion 67.757	Gear	285.628
Base diameters	Pinion 71.434	Gear	285.738
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Trans tooth thick at tip	Pinion 4.086	Gear	2.63
Trans tooth thick at ref	Pinion 10.76	Gear	3.796
Trans tooth thick at working	Pinion 10.897	Gear	4.678
Trans tooth thick at base	Pinion 11.205	Gear	8.009
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Parameters of the gears in normal plane			
Pressure angle	20		
Normal Tooth thick at tip	Pinion 4	Gear	2.589
Normal tooth thick at ref	Pinion 10.596	Gear	3.738

Figure 5, shows the output from the AutoCAD 2018 Mechanical and from the Solid work 2020, respectively.



**Figure 5:** AutoCAD Output X50 & Solid work output

#### 4. Conclusion

The interface proved its capability to calculate all the parameters for the helical involute gears and to plot the modified tooth profile. It worked successfully in transferring directly the information of the gear modified profiles to Autodesk "AutoCAD" version 2019, SolidWorks version 2019 and Ansys version 2019 packages. This later step is essential for future work when studying the design criteria (stresses and deflections) in helical modified gears. The software has the capability to accept any changes in any of the input parameters thus serving in the study of the inter-effects between the gear parameters. So, it is not only a tool to communicate between various commercial design packages, but also is a tool for research and education in gears.

#### 5. Nomenclature

$Z_1, Z_2$  number of teeth for pinion and gear

$A_s$  Standard center distance

$A_w$  Working center distance

$Y$  Coefficient for center distance modification

$\alpha_t$  Pressure angle in transverse plane

$\alpha_{wt}$  Working Pressure angle in transverse plane

$h_i$  Addendum

$H$  Tooth height

$D_{refi}$  Reference circle diameter

$D_{bi}$  Base circle diameter

$D_{wi}$  Working circle diameter

$D_{ii}$  Inner circle diameter

$D_{ri}$  Root circle diameter

CR Contact ratio

$\alpha_{t\_refi}$  Pressure angle at reference circle in the transverse plane

$\alpha_{t\_tipi}$  Pressure angle at tip circle in the transverse plane

$\beta_{tipi}$  Helix angle at reference circle in the transverse plane

$S_{t\_refi}$  Tooth thickness at reference circle in the transverse plane

$S_{n\_refi}$  Tooth thickness at reference circle in the normal plane

$S_{t\_tipi}$  Tooth thickness at tip circle in the transverse plane

$S_{n\_tipi}$  Tooth thickness at tip circle in the normal plane

RC Radial clearance

$TL_i$  Top land thickness

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