

Development of Involute Profiled Spur Gear Model with Excel Spreadsheet, Solid works and CAD Technique

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Abstract — *Involute curve is the most widely used curve for gears, splines, and serrations due to the ease in its manufacture. This paper attempts to calculate the X, Y, Z coordinates of an involute curve through an algorithm; using a user-friendly Microsoft Office tool, the Excel spreadsheet. The spreadsheet stores the algebraic formulae are pertaining to the involute that will convert basic spur gear parameters into numerous points on the corresponding involute curves. The coordinates are imported as points to get graphical interpretation through the Solidworks CAD package. These points are then represented as an "XYZ Plot" of the desired gear outline, essentially plotting each point on a Cartesian axis. Various sketch tools like rotate, mirrors, circular patterns, power trim, etc., are used to achieve a perfect 2D profile, which, when extruded, produces a 3D CAD model of the involute profiled spur gear. For evaluation, a 24 Teeth, 8 modules, 20° pressure angle Pinion was modeled. The work outcome demonstrates the Excel tool's usage to develop gear in a parametric pattern with a true involute portion of the tooth profile. The Gear models on assembly could be used in kinematics simulations, structural analysis, and contact pressure between corresponding Gears, including thermal and many other analyses.*

Keywords — *Xn, Yn, Zn coordinates, Base circle, Involute, Excel spreadsheet, Solidworks.*

I. INTRODUCTION

For several years, gears are the simplest and most efficient mechanical component in transmitting motion and power. Through extensive research has been conducted on this title. Still, some basics governing the gear theory has not been satisfactorily understood. Gear designer without proper knowledge will overdesign the system, which always leads to a sacrifice in cost, material, and compactness. [1], provides the Basic gear geometry, which depicts that a clear and accurate understanding of the elements involved is indispensable to all who deal with the design, dimensioning, cutting, and measurement of gear teeth. Gears are developed with several tooth forms and applied for gearing and other applications, uniqueness. Presently used are Involute, Cycloid, Hypocycloid, Epicycloid, Trochocentric, Beveloid,

and Spiroid. Of these, the involute is the only tooth form that provides true conjugate action normal to the tangency of the tooth curves passing through the pitch point, as indicated in research [2]. The involute curve of a tooth plays an important role in gear design and analysis. For instance, friction and wear between two gears are dependent on the teeth' profile; the uniform velocity ratio is also dependent on the tooth profile. The involute tooth allows the center distance or spacing of the gears to vary over some range without affecting the velocity ratio. The Gear tooth profile, when developed accurately, leads to results with high quality. Two different published works [3,4] have described the formation of the involute tooth profile. Though it has been described, it is still challenging to construct the correct gear tooth profile in CAD and FEA code environment. The curved portion in the spur gear teeth has two portions. The involute portion and the root fillet portion. The curve generated by the end of a line unwound from the base circle is an involute, which is in action during meshing and the trochoidal curve at the root fillet portion, which helps relieve the stress concentration. Author [5] has proposed and presented an algorithm for describing the ideal spur gear profile using Visual basic macro in Excel. The parametric design process for various gears [6] has presented the method of Pro/E programs, relationships, and parameters. Conducting research [7] has explored the technique of generating the involute curve in such a fashion, so it is formed exactly symmetrical about one of the planes. A mirror image of the curve can be formed using the mirror commands. The authors [8] has presented the approximate and accurate method of generating the solid models of involute cylindrical gears using Autodesk inventor 3D CAD software. In his previous research, the author [9] has implemented a parametric technique using CATIA to develop a spur gear template. Five characteristics of the trochoidal curve have been discussed in their paper [10]. The authors have introduced a concept-virtual involute and determined the root fillet shapes generated by racks with a protuberance. Further, HPSTC and LPSTC were calculated through a specific methodology proposed using the spreadsheet application by [19]. Using the latest non-symmetric gear terminology, author [12] have proposed a new method to calculate the gear parameters and HPSTC



for non-symmetrical gear system through MATLAB GUI.

II. GEAR TERMINOLOGY

Important nomenclature related to this work is recapitulated hereunder: a) Pitch circle (d): This is an imaginary circle that contacts any other mating gear's pitch circle. b) Pitch Diameter (D): The diameter of the pitch circle. c) Number of teeth (Z): The Number of projections on the periphery of the cylindrical surface. d) Module (m): The ratio of pitch circle diameter to the Number of teeth specified in millimeters. It is also the reciprocal of the diametral pitch

A. Involutometry & Important angles

In general, spur gears are divided into two families, the involute and non-involute. The involute gears are popularly used today with distinguished advantages. On all occasions when two curved surfaces act against each other, the line of action between them will be along the common normal to the two curves at that point of tangency. Some of the important angles that define the involute curve should be well understood and it is referred to as in AGMA 933-B03. The involute curve, extensively used as a gear tooth profile, is generated by the end of a line, which is unwound from a circle, as illustrated in Fig 1. The circle from which the line is unwound is commonly known as the base circle. AB represents the string, while A represents the involute curve, which is the locus generated by the free endpoint 'a' of the string. Spur gear equations are found in many handbooks and manufacturing books [13, 14]. To find the coordinates of standard spur gear involute, the authors have implemented MATLAB GUI. Later these points were imported in Solidworks to create gear tooth spacing, gear profile, and 3D Gear [15].

e) Pressure angle (α): Passes through the pitch point and is normal to the tooth profile. It is the line along which the tooth pressure acts. With involute tooth profiles, the line of action is also the path of the point of contact.

f) Roll angle (β): The roll angle at the radius is defined as the angle between the radius through Y and the involute tangent at B.

g) Involute angle (θ): is the involute function and defined as $\text{inv } \alpha$. The equation and mathematical description of the involute curve are developed below. [16].

The position, r, where this involute occurs is proportional to the angle α , and it is defined as:

$$r = \frac{R_b}{\cos(\alpha)} \quad [1]$$

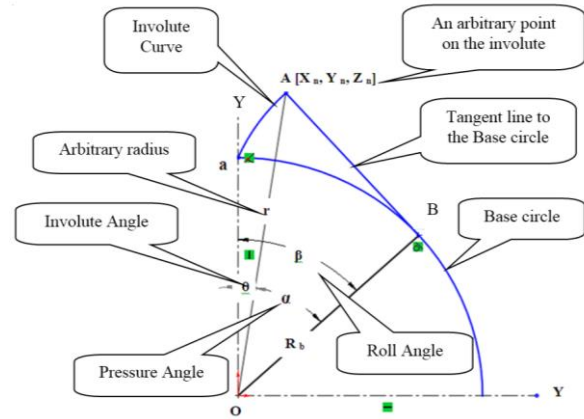


Fig 1 Basic relation and angles of involute profile

And the X and Y coordinate where this involute occurs is equal to:

$$X_n = r \sin(\theta) \quad [2]$$

$$Y_n = r \cos(\theta) \quad [3]$$

$$\theta = \left[\frac{t_p}{2r} + \text{inv}(\alpha) - \text{inv}(\alpha_i) \right] \quad [4]$$

Where:

α = Pressure angle at the pitch circle and t_p = Tooth thickness at the pitch circle.

III. METHODOLOGY

A. Excel Spreadsheet & Solidworks

Research mostly involves the organization and manipulation of data and information. There are many ways to do this, including programming, spreadsheets, and custom applications. Microsoft Excel is used to do the intent of this paper. Excel spreadsheet is selected for the calculation of the coordinates due to its usage by scientists and engineers and its improved analytical capability. In many cases, it is reported to be better than FORTRAN to solve problems. Moreover, Excel is installed on millions of computers, which features rich built-in analysis tools, and includes an integrated Visual Basic for Applications (VBA) programming language. Excel performs routine calculations and even to the extent of performing more complex calculations, too, calculations that once fell in the domain of specialized tools. The trigonometric functions and the function PI() are utilized to calculate the pressure angle, roll angle, etc. The author successfully uses an Excel spreadsheet [17] to promote the conceptual change in mechanical system

design and analysis. In an Excel Spreadsheet, students can perform alternative design and analysis.

3D mechanical computer-aided design (CAD) is very popular in SolidWorks 2012. Alex R. Ruiz and Gabi Jack (2010) indicates that it is a favorite design tool for many of today's engineers, mechanical designers, and industrial designers. The Gear model available in the toolbox library can produce standard gears, but the gear's involute portion is often not true and approximate. The disadvantage of the toolbox is that it does not support custom-built or tailor-made Gears. Owing to the advantage of an easy-to-learn graphical user interface and powerful set of tools, SolidWorks is selected for developing gear in this work. SolidWorks's core ability is to create 3D solid geometry and create drawings, manufacturing instructions, instruction manuals, animations, full-color renderings, and other document types. These advantages are also claimed for the Gear models developed using the procedure developed in this work. The sequence of steps carried out to create a 3D model of the gear is provided in the fig1. A clear understanding of the involutometry was attempted, and the formula related to it were listed out. The excel spreadsheet was used to create the X_n, Y_n, Z_n coordinates for the involute geometry. The coordinate file was by default stored with the extensions *.xls, later was saved as*.txt file, for the convenience of importing it in the Solidworks environment. The part file is opened and kept available in the Solidworks, the option "create curve through XYZ" was invoked, which displays a browser titled curve file as in fig 6 for locating the text file. On locating the file, the OK button is clicked to accept the points. The sketcher plane was selected to be the front view, and the curve was converted to an entity using the convert entities option. Later, the curve was rotated, mirrored, and arranged to develop the gear's 2D sketch and 3D model.

B. The proposed scheme of the involute point spread

The work's main target is in determining the X, Y, Z coordinates for curve fitting an involute profile at any instantaneous position. A widely preferred Metric system is considered in the entire calculation process. The key and important input parameters viz., Module (m), Pressure angle (α), and the Number of teeth (Z), which define the gear, are fed to an excel spreadsheet. As seen in Table 1. These three parameters makes a remarkable influence on determining the involute coordinates. The various derived parameters essential in the coordinates' calculation are Pitch circle, base circle, root circle, chordal tooth thickness, i.e., tooth thickness at PCD, etc. As noticed from equations 1 to 4 and from figure 1, finding the coordinates of the point lying on the involute curve is essential to find out the pressure angle, roll angle, and involute angle. A scheme is proposed to get different points spread over certain intervals, as seen in Fig 3. Three points are fixed on the circle diameters whose dimensions can be commonly calculated from the standard formulae knowing the basic input parameters module, pressure angle, and teeth. The three points lie on diameters 1. Outer circle diameter - DZ1, 2. Pitch circle diameter - DZ5, and 3. The root circle diameter - DZ10. Four points on circles, including the outer circle diameter (DZ1), is constructed above the pitch circle diameter referred with DZ2, DZ3, DZ4, and four further four points circles constructed below the PCD, namely DZ6, DZ7, DZ8, DZ9, including the root circle. Finally, the base circle is constructed with DZ0. The proposed 10 points *A1 to A10*, lying on the diameters above and whose coordinates are to be identified.

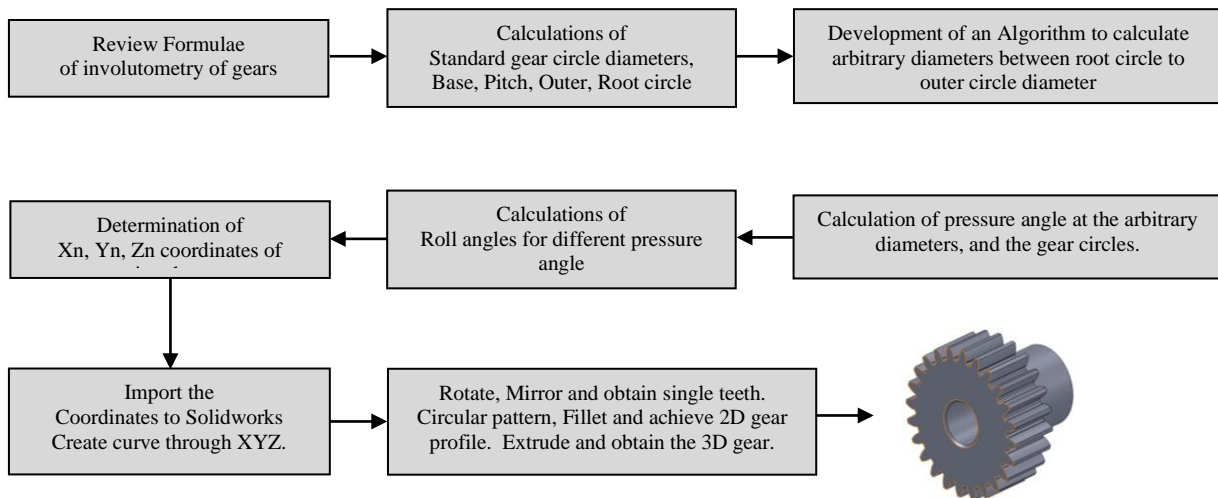


Fig 2 Algorithm for Gear development

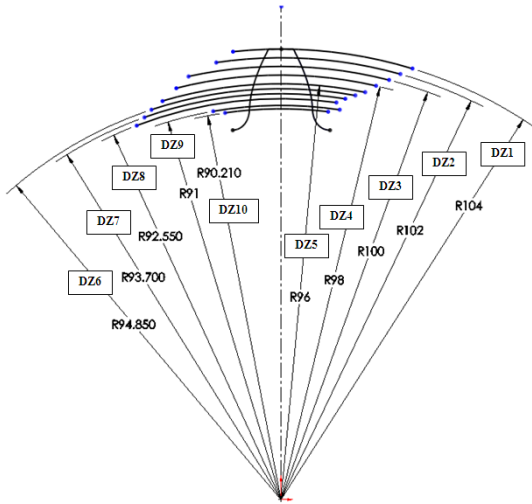


Fig 3 Proposed scheme for involute point spread

In the range of column A1:A55, the comments are declared as Input / calculated or any such details which provide an understanding of the parameters. This also ensures whether the parameters participate in the numerical calculations. In these cells, no calculations are planned. The cells B and C are merged to describe the parameters, like Module, Number of teeth, etc. These are incorporated in the range of the column B1:B55 & C1:C55, the corresponding formula is keyed in, which provides the output values. The inputs and calculations are carried out in the column ranging from D5:D55. The Excel syntax for the standard formulae and the corresponding cell in which it is processed is indicated in Table 1 and Fig 4.

The arbitrary diameter calculation is executed through the equation 5 to 11 listed in section 3. It has been considered to have 10 points,

Description	Parameters	Values	Units
Input	Module	3	mm
Input	Pressure Angle (α)	20	Degrees
Input	Pressure Angle(in radians)	0.34906585	radians
Input	Number of teeth	17	
Input	Addendum	3	mm
Input	Dedendum	3.75	mm
Calculated	Standard Pitch circle radius (Rs)	25.5	mm
Calculated	Base circle radius (Rb)	23.9621618	mm
Calculated	Standard circular pitch (Ps)	9.42477796	mm
Calculated	Base circular pitch	8.8563943	mm
Calculated	Involute of pressure angle Inv(α')	0.01490438	radians
Calculated	Pressure Angle (α'T)	0.57207836	radians
Calculated	Involute of pressure angle Inv(α'T)	0.07182634	radians
Calculated	Outside circle radius	28.5	mm
Calculated	Root circle radius	21.75	mm
Calculated	Tooth thickness at the pitch circle (ts)	4.71238898	mm
Calculated	Tooth thickness at the outer circle(tT)	2.02223606	mm
Calculated	Determination of "r"	25.5	

Fig 4 Excel sheet for calculation

whose coordinates will be determined through these equations. The vertical centerline (X-axis) and the horizontal centerline (Y-axis) are considered having origin 0, 0, 0, which is the gear wheel center. The XYZ is calculated by knowing the dimensions of

different diameters. In continuation of the point spread discussed in article 2.1, the arbitrary diameter is determined through simple logic and calculation. The corresponding Excel syntax is referred to in Tab 4.

Table 1 Input and calculated parameters using excel

E-C	Parameters[B1:B55 & C1:C55]	Excel Syntax[D1:D55]
D5	Module [mm] [m]	Input
D6	PAngle [Degrees] [α]	Input
D7	PAngle(in radians) [α]	=(D6*PI())/180
D8	Number of teeth [Z]	Input
D9	Addendum [mm] [a]	=D5
D10	Dedendum [mm] [f]	=1.25*D5
D13	Standard PCR [Rs]	=(D5*D8)/2
D14	Base circle radius [Rb]	=D13*COS(D7)
D15	Circular pitch [Ps]	=PI()*D5
D16	Base circular pitch [mm]	=(2*PI()*D14)/D8
D17	Involute PAngle Inv(α')	=TAN(D7)-D7
D18	PAngle (α'T) [radians]	=ACOS(D14/D24)
D19	Involute of PAngle Inv(α'T) [radians]	=TAN(D18)-D18
D24	Outside circle radius [mm]	=D13+D5
D25	Root circle radius [mm]	=D13-D10
D26	Tooth thick@PCD [mm] [ts]	=D15/2
D27	Tooth thick@OD [mm] [tT]	=D24*((D26/D13)+(2*(D17-D19)))
D28	Radius "r" [mm]	=D14/COS(D7)

IV. ARBITRARY DIAMETER CALCULATION

The arbitrary diameters are calculated using the formulae indicated in equations 5 to 7 for getting the point spread above the pitch circle diameter and 8 to 10. DZ1 will be the outer circle diameter, DZ5 will be the pitch circle diameter, and DZ9 will be the root circle diameter, and DZ10 will be the base circle diameter.

$$DZ2 = \left[\frac{[m \times z] + [2 \times m] - [m \times z]}{4} \right] \times 3 + [m \times z]$$

[5]

$$DZ3 = \left[\frac{[m \times z] + [2 \times m] - [m \times z]}{4} \right] \times 2 + [m \times z]$$

[6]

$$DZ4 = \left[\frac{[m \times z] + [2 \times m] - [m \times z]}{4} \right] \times 1 + [m \times z]$$

[7]

$$DZ6 = \left[\frac{[m \times z] - [2 \times 1.25 \times m]}{4} \right] \times 3 + [[m \times z] - [2 \times 1.25 \times m]]$$

[8]

$$DZ7 = \left[\frac{[m \times z] - [2 \times 1.25 \times m]}{4} \right] \times 2 + [[m \times z] - [2 \times 1.25 \times m]]$$

[9]

$$DZ8 = \left[\frac{[m \times z] - [2 \times 1.25 \times m]}{4} \right] \times 1 + [[m \times z] - [2 \times 1.25 \times m]]$$

[10]

The pressure angle and the roll angle at DZ1 to DZ10 are calculated based on the formula and syntax indicated in Table 5 and Table 6.

Table 4 Calculation of arbitrary diameter

D33	PCD [mm][DZ9]	=D13*2
D34	OD [mm] [DZ1]	=(D5*D8)+(2*D5)
D35	RCD[mm] [DZ10]	=(D13*2)-(1.25*D5)
D38	Any diameter[mm] [DZ2]	=((D34-D33)/4)*3+D33
D39	Any diameter[mm] [DZ3]	=((D34-D33)/4)*2+D33
D40	Any Diameter[mm] [DZ4]	=((D34-D33)/4)*1+D33
D41	Any Diameter [mm][DZ5]	(((D33-D36)/4)*3)+D36
D42	Any Diameter [mm][DZ6]	(((D33-D36)/4)*2)+D36
D43	Any Diameter [mm][DZ7]	(((D33-D36)/4)*1)+D36
D44	BCD [mm] [DZ8]	=D33*COS(D7)

Table 5 Pressure Angles PA at any arbitrary diameter

E-C	PA @ Dia	Excel Syntax For PA (For Degrees)	Excel Syntax (For radians)
D46	DZ1	=ACOS((D44/D34))*180/PI()	=D46*PI()/180
D47	DZ2	=ACOS((D44/D38))*180/PI()	=D47*PI()/180
D48	DZ3	=ACOS((D44/D39))*180/PI()	=D48*PI()/180
D49	DZ4	=ACOS((D44/D40))*180/PI()	=D49*PI()/180
D50	DZ5	=ACOS((D44/D41))*180/PI()	=D50*PI()/180
D51	DZ6	=ACOS((D44/D42))*180/PI()	=D51*PI()/180
D52	DZ7	=ACOS((D44/D43))*180/PI()	=D52*PI()/180
D53	DZ8	=ACOS((D44/D44))*180/PI()	=D53*PI()/180
D54	DZ9	=ACOS((D44/D33))*180/PI()	=D54*PI()/180
D55	DZ10	=ACOS((D44/D35))*180/PI()	=D55*PI()/180

Tab 6 Roll angles (RA) at any diameter

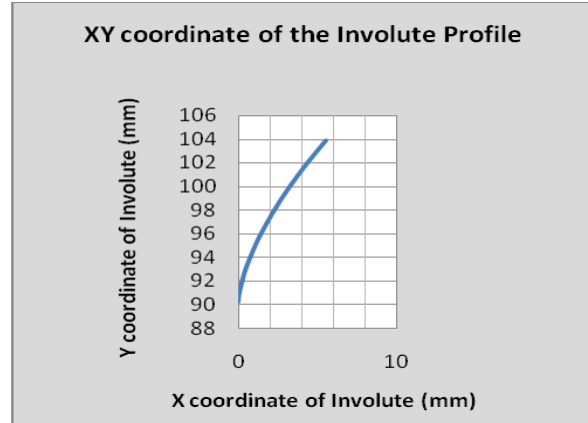
E-C	Roll Angle (RA)	Excel Syntax
G46	RA at DZ1	=TAN(RADIANS(D46))*180/PI()
G47	RA at DZ2	=TAN(RADIANS(D47))*180/PI()
G48	RA at DZ3	=TAN(RADIANS(D48))*180/PI()
G49	RA at DZ4	=TAN(RADIANS(D49))*180/PI()
G50	RA at DZ5	=TAN(RADIANS(D50))*180/PI()
G51	RA at DZ6	=TAN(RADIANS(D51))*180/PI()
G52	RA at DZ7	=TAN(RADIANS(D52))*180/PI()
G53	RA at DZ8	=TAN(RADIANS(D53))*180/PI()
G54	RA at DZ9	=TAN(RADIANS(D54))*180/PI()
G55	RA at DZ10	=TAN(RADIANS(D55))*180/PI()

Tab 7 Unwind radius

Unwind Radius	mm
Unwind Radius - UR1	99
Unwind Radius - UR2	97.5
Unwind Radius - UR3	96
Unwind Radius - UR4	94.5
Unwind Radius -UR5	92.137
Unwind Radius -UR6	91.275
Unwind Radius -UR7	90.412
Unwind Radius -UR8	87.391
Unwind Radius -UR9	93
Unwind Radius -UR10	89.25

V. CONCLUSIONS

The data for the coordinates calculated is plotted in Excel to locate any error. The data points are stored in the *.txt format. The Solidworks environment is invoked, and a new part file is opened. The tools pull-down menu is activated to click on a curve through XYZ points. The curve file dialog appears as in Fig 6, which on browsing the earlier point file created in excel and acceptance produces involute in the front plane. Different circles are verified for illustration in fig 7. The relationship of different circles with coordinates, pressure angles, and roll angles is provided in Table 9.



The involute profile is now converted to entities through convert entity icons in the sketcher menu. The circular thickness is calculated, which is the circular thickness distance along the pitch circle's circumference. This distance is converted to an angular measurement using equation 5, and the involute profile is now rotated with an angle of 7.5°. The involute point intersecting the base circle is extended, passing through the root circle to join the center. This is a straight-line portion of the tooth profile. After mirroring this line and joining, The standard fillet profile is applied, and the fillet portion is patterned. The entire 2D profile of the gear resembles as in fig 10

Tab 8 X, Y, Z Involute coordinates

X1	5.492	Y1	103.85	Z1	0
X2	4.296	Y2	101.90	Z2	0
X3	3.216	Y3	99.948	Z3	0
X4	2.258	Y4	97.973	Z4	0
X5	1.430	Y5	95.989	Z5	0
X6	1.019	Y6	94.844	Z6	0
X7	0.660	Y7	93.697	Z7	0
X8	0.360	Y7	92.549	Z8	0
X9	0.069	Y8	90.999	Z9	0
X10	0	Y9	90.21	Z10	0

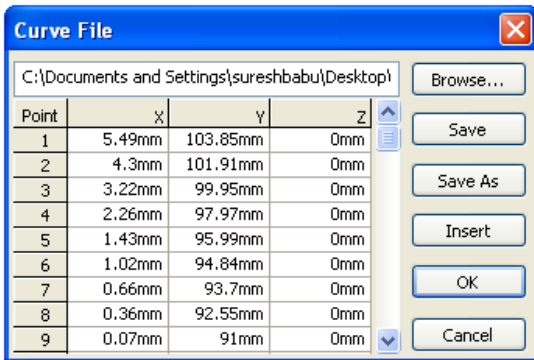


Fig 6 Points imported from excel to Solidworks

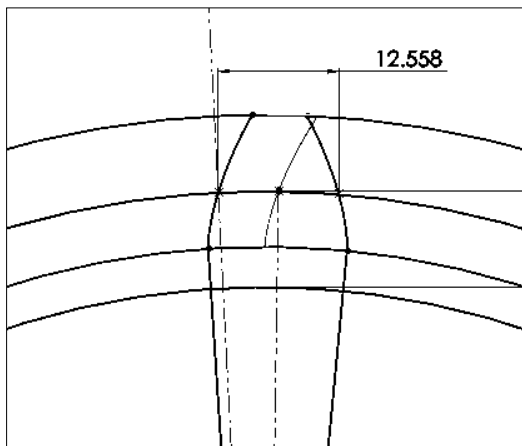


Fig 7 Rotation of involute about a canter

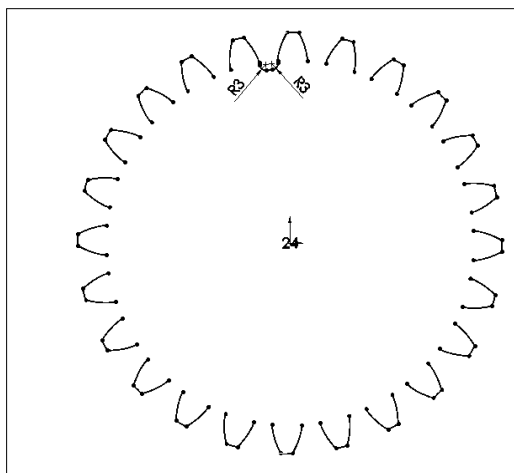


Fig 8 circular pattern of 24 Teeth

After extruding and cut out of shaft hole, the gear appears to be as in figure 11 and figure 12.

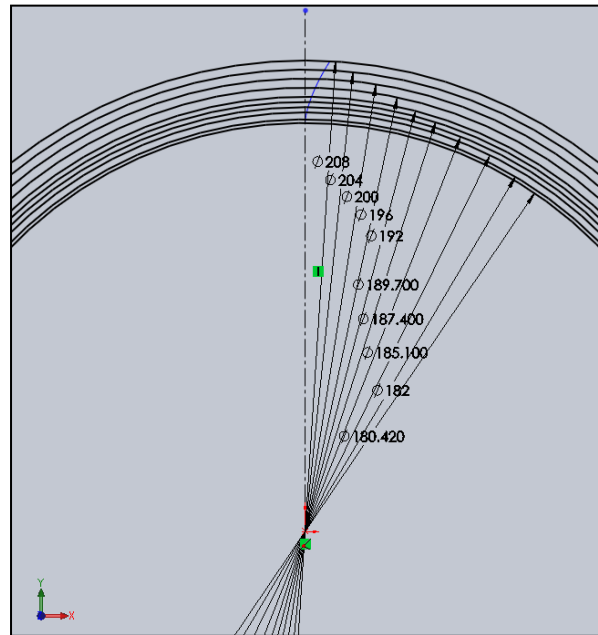


Fig 9 Dimensions for circles of the gear

Diameters	Coordinates			PA	RA
DZ	X	Y	Z	α	β
DZ1=208	5.49	103.85	0	29.84	32.86
DZ2=204	4.29	101.90	0	27.82	30.23
DZ3=200	3.21	99.94	0	25.56	27.40
DZ4=196	2.25	97.97	0	22.99	24.31
DZ9=192	1.43	95.98	0	20	20.85
DZ5=189.7	1.01	94.84	0	17.99	18.61
DZ6=187.4	0.66	93.69	0	15.68	16.08
DZ7=185.1	0.36	92.54	0	12.91	13.13
DZ10=182	0.06	90.99	0	7.55	7.59
DZ8=180.42	0	90.21	0	0	0

This paper proposes an algorithm for creating the coordinate points on the involute profile through arbitrary diameter calculation method. It is shown how a spreadsheet could be effectively utilized in calculating the coordinates for proposed points of the involute profile of gear based on the analytic kinematics. The Solidworks points were successfully imported and manipulated in the part design mode for graphics presentation of 2D or 3D modeling of cylindrical gears through effective usage of CAD modeling software. The work outcome indicates that the proposed method could be well utilized for calculating the coordinates of involutes for both standards and with little modification for non-standard Gears.

VI. RECOMMENDATIONS

The present work could further be explored in the following directions. The present Excel spreadsheet was developed for the Mmetric system of gears. The study could be extended for the diametrical pitch system by adopting a similar procedure. The points developed in the spreadsheet could be retrieved in different CAD environments like AutoCAD, Autodesk inventor, Pro/E, etc. The work could be extended to

produce helical gear and crossed helical Gear and Herringbone gears in the CAD environment. Set of Pinion with Gear of same Module and pressure angle can be developed using the Algorithm and can be assembled. The developed 3D assembly model could be imported into the FE analysis environment to analyze contact stress and the root fillet radius on the root stresses. The assembly could be used for motion study and analysis.

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