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Research Article

Involute Tooth Spacing, Gear Profile and 3D Gear development with MATLAB® Graphical User Interface and Solidworks

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Abstract

The present work has proposed an algorithm for the development of geometry of gear tooth space and complete gear profile using MATLAB® coding. It is executed through the MATLAB®Graphical User Interface (GUI) and developing 3D Gear solid model in Solidworks® environment. The work described here, has three phase approach for the construction of GUI. The initial analysis phase has considered the user requirement and critical specifications. Next in the design phase the layout was initiated, which has targeted in meeting out the calculations and plot of the technical aspects of gear. Finally the prototyping phase that involves the development and testing of GUI. The output of calculated values of the gear parameters are displayed in their corresponding text blocks. The single tooth plot provision provides the plot of the tooth space of the pinion or gear. The complete gear profile is provided in the pushbutton of pinion or gear plot. The visual display of the tooth spacing for Pinion and gear are comprehensible. The output coordinates of the points, XYZ, of involute and trochoidal root fillet are stored in the Excel/Text files. These were imported and curve was introduced and completed for 3D modeling of gear in Solidworks® part environment with suitable editing of the gear sketch. The outcome of the work supports a lot in investigating the critical geometric parameters of standard and non-standard spur gear system, and further stress and kinematic analysis.

Keywords: Tooth spacing; MATLAB® Graphical User Interface; Prototyping; Gear Main GUI.

Introduction

Ever since the advancement of Gear technology there is an increasing demand for developing the complete gear profile and 3D CAD model of the gear. The 3D gear model supports the virtual visualization and useful in strength, optimization and kinematic study or analysis at a later stage. The advancement in the computing, visualization of CAD model avoids the cumbersome manual iteration process and large time involved in gear design. It provides Wide variety of gear solution to a single problem with drastic reduction in time to market. A host of literature references like AGMA (1997), DIN (877), ISO (1996) etc., are available for designing a standard gear with symmetric profile and conventional approach. The tooth profile of gear is obtained by involute generated from the base circle and limited by the outer circle and connected to fillet at the bottom. The root fillet region was constructed with the trochoidal curve. In this work authors have presented an algorithm for development of spur gear tooth spacing and profile and implemented it through the widely used problem solving tool the MATLAB® GUI.

Many traditionally developed MATLAB® programs are often used only by the developers. The GUI developed in this work is useful in determining the basic pinion or gear parameters like pitch circle, outer circle, base circle, root circle, and others like contact length, contact ratio, center distance. It provides XYZ coordinates of the forward and inverted side of the involute and the trochoidal root fillet portion in *.*xls* format. The output plots a typical spacing of the involute and root fillet portion mirrored and connected to the top and bottom with the outer and root circle. On rotation of the co-ordinates of the spacing plotted, the entire

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gear tooth profile of either pinion or gear could be attained. The plots are supportive in the visualization of the gear profile, and are useful in finding out the requirement for improvement of the involute, root fillet portion of the gear. Gears are known to be simplest and most efficient mechanical component in transmitting motion and power. Though 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. AGMA 933-B03 [1], provides the Basic gear geometry, which depicts that a clear and accurate understanding of the elements involved is indispensable to all who deals with the design, dimensioning, cutting and measurement of gear teeth. Gears are developed with several tooth forms and applied for gearing and other applications, which has its own uniqueness. Presently used are Involute, Cycloid, Hypocycloid, Epicycloid, Trocho centric, Beveloid, and Spiroid [2]. 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. [3] and [4] have described about the formation of 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 [5].

Authors [6] have proposed an algorithm for describing the ideal spur gear profile using Visual basic macro in Excel. Researcher [7] has presented the method of Pro/E programs, relationship and parameters to conduct the parametric design for various types of gears. The technique of generating the involute curve has been explored by [8]. In the research work done by authors [9], they have implemented parametric technique using CATIA to develop template of spur gear. Authors [10] have discussed five characteristics of trochoids in their paper. The authors have introduced a concept-virtual involute and clearly determined the root fillet shapes generated by racks with a protuberance.

Spur gears are categorized under two families, the involute and non-involute. The involute gears have distinguished advantages. 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 like Pressure angle (α), Roll angle (β), and the Involute angle (θ), as in AGMA 933-B03 [1], is represented in the Figure 1, which defines the involute curve. The involute curve is generated by the end of a line which is unwound from a circle, as illustrated in Figure 1. The circle from which the line is unwound is the base circle. AB represents the string, while a represents the involute curve, which is the locus generated by the free end point 'a' of the string. The equations and relations are found in many handbooks and manufacturing books by [11] and [12]. The equation and mathematical description of the involute curve are developed below and referred from [13]. The position, r, indicated through equation 1, where this involute occurs is proportional to the angle α and it is defined as:

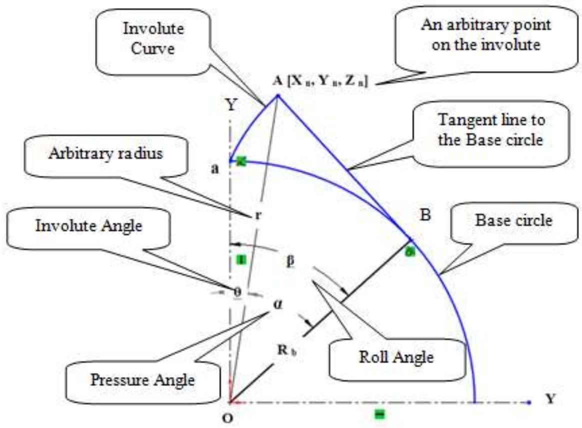

Figure 1. Involute profile

$$r = \frac{R_b}{\cos(\alpha)} \qquad (1)$$

And the X and Y coordinate, equations 2 and 3, where this involute occurs are equal to:

$$X_n = r\sin(\theta) \qquad (2)$$

$$Y_n = r\cos(\theta) \qquad (3)$$

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

Where, α is the pressure angle at the pitch circle and t_p is the tooth thickness at the pitch circle, in equation 4.

The Solidworks Toolbox [14] provides gear components, with approximated teeth. If geometrically accurate teeth are required then the model should be customized. [15] Indicates that true 3-D solid models of gear pairs are desirable to simulate real conditions and reduce expensive test phases. [16] Mentions that Solidworks is a favourite design tool for many of today's designers. Solidworks was selected for developing Gear in this work, owing to the advantage of easy to learn and use the powerful set of tools, easy to create 3D solid geometry, drawings and manufacturing instructions. Suresh et al., in their research work has proposed development of Non-Symmetric Gear System using MATLAB® GUI, and proved the tool can be extensively used by gear designers, educators, who are desirous of designing high performing gears. This tool also has created gear profiles with lowest possible time, that much reduces the design cost and time to market [17]. Approximate and accurate method of generating the solid models of involute cylindrical gears using Autodesk inventor by have been presented by [18].

Materials and methods

Developed algorithm shown in figure 2 and figure 3, is executed and the gear main GUI was created. The methodology for creating GUI is carried out in three distinct phases, namely analysis, design and prototyping. The outcome is as noted in figure 4.

Layout for gear main GUI

The three phases of Gear Main GUI are 1. Analysis, 2. Design and 3. Prototyping. The activities under each phase is explained under the appropriate headings below. The Gear Main GUI layout has been initially sketched manually and later created as GUI. Similar such work has been successfully implemented by the authors in their earlier works [17]

Analysis phase

In the analysis phase the intended goal and the likely user of the GUI are identified. The synthesis of extensive usability specifications, user case scenarios, expertise of the user, computer system limitations and plans for further up gradation based on user feedback are considered. The GUI designed finally addresses the requirements of the target recipient.

Design phase

In the Design phase the layout of the GUI was designed. Primary concerns that were addressed are components, tasks, and sequence that are required to make the GUI design effective. The Gear main GUI designed has the attributes like flexibility, quickly go back and forth and it does not overwhelm user. The user can quickly apply different methods or plot techniques, and undo if the selection turned out to be undesirable, this is provided through 'clear all' button or entering a new value in place of the old one. The user is also not overwhelmed with too many choices. The choices and options are arranged in a logical fashion and limited to a logical extent which makes the user comfortable. Help and tips are provided with each parameters offered in GUI. The GUI is so designed that it allows user to fully exploit his/her cognitive capabilities, meaning that the user can facilitate the use of his eyes, hands and possibly ears. It permits the use of keyboard, mouse and monitor for effectively interacting with the computer.

Prototyping phase

Prototyping phase is the pre-design planning required to formulate the layout and the functionalities associated with GUI. Before starting the actual GUI design work a prototyping exercise regarding all aspects of the likely outcome is a healthy practice and reduces a lot of intricacies. The planning related to the design of the work should consider aspects like appearance, tools to be incorporated, support provided, interactive modes, etc., the prototyping exercise in the simplest way could be carried out using a paper and a pencil. The layout sketch of the design can be the primary basis of the work.

Development of MATLAB® GUI

The work by [19] refer the MATLAB® UIs, which otherwise is known as graphical user interfaces or UIs. The main purpose of these UIs are to deliver point-and-click control of software applications. This eliminates the need to learn the MATLAB® language or type commands in the command window to run the application. These apps contains programs with GUI at the front end and that automate a task. The GUI typically contains controls such as menus, toolbars, buttons, and sliders. Researchers [20] in their attempt to developed customized apps that include their corresponding UIs. The study describes a number of software and language options that are available to build GUIs and undertake a comprehensive comparative assessment of possible alternatives in the light of a benchmark educational program used in a course on computational fluid dynamics (CFD) at the University of Michigan.

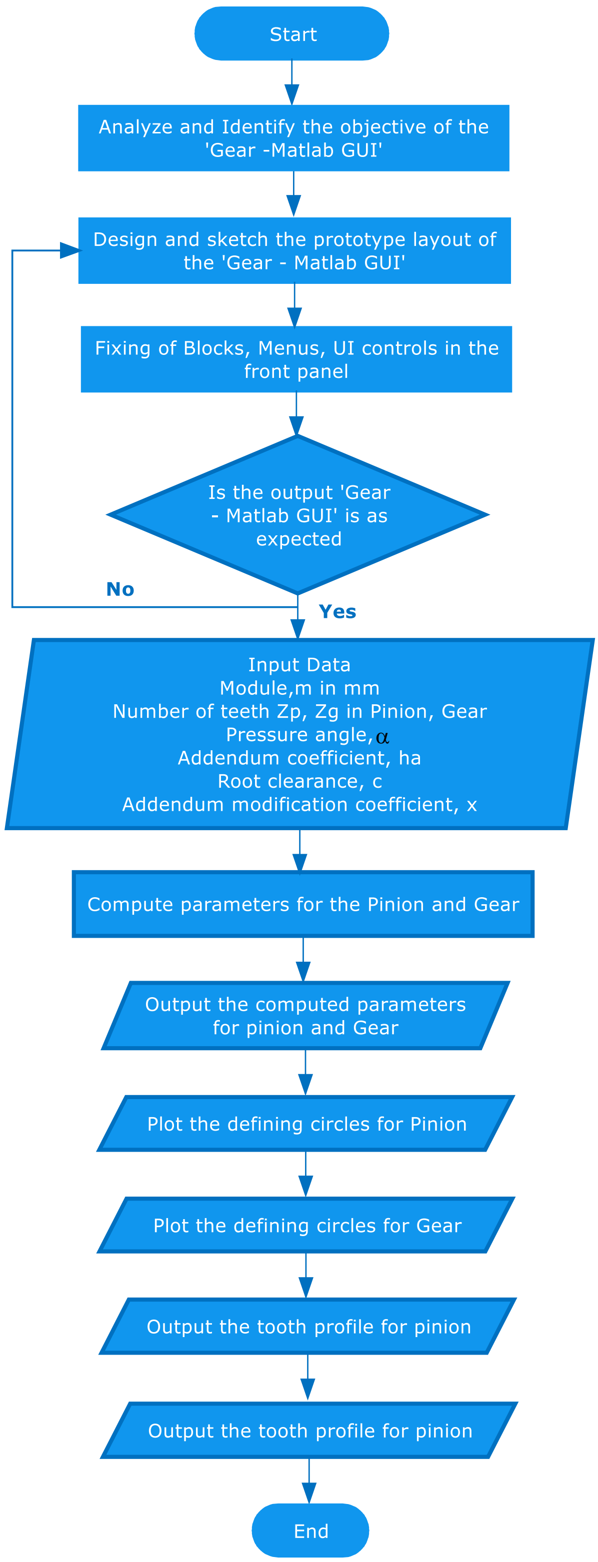

Figure 2. Algorithm for Gear GUI

Gear main form

For the purpose of illustration, the Gear main form of GUI is tagged as in the Figure 4. In the MATLAB® command, GUIDE command is typed and form design is completed referring to [21]. The GUI file is saved as **.fig* and *.m file in the MATLAB® environment. It contains the basic GUI components like panels, frames, push buttons, and User Interface editable text, pull down menus, and custom figure window menus that are available in MATLAB®.

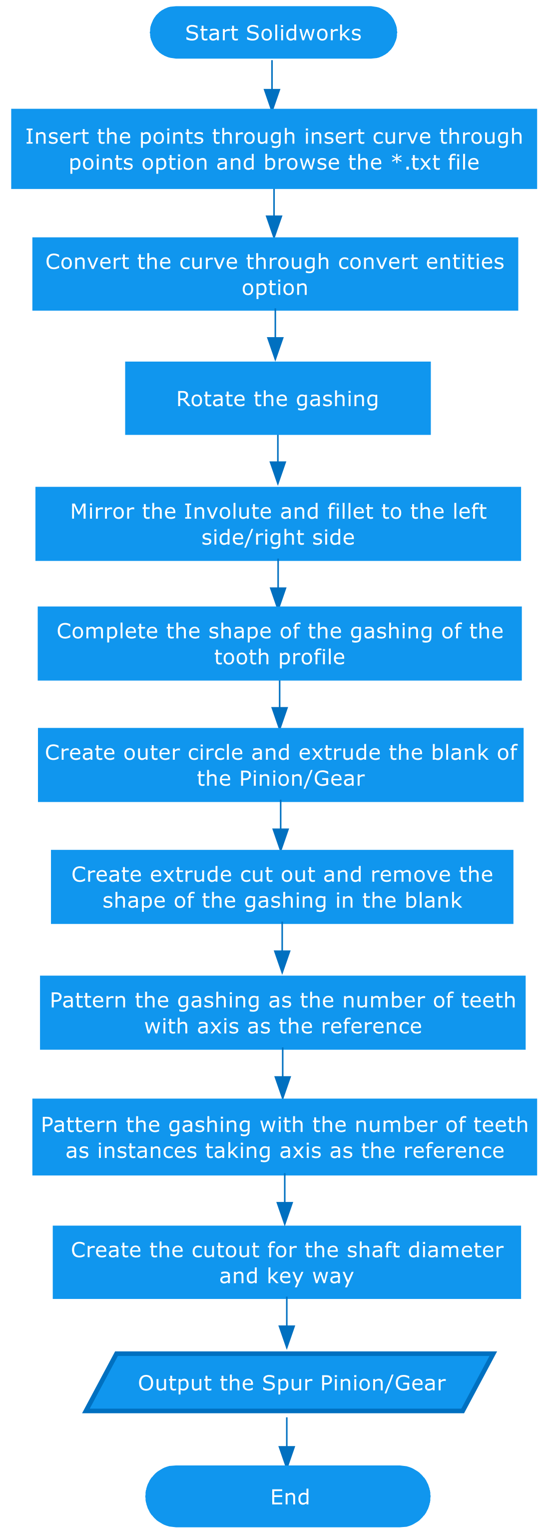

Figure 3. Algorithm for 3D Gear in Solidworks

T1 – Panel takes Pinion Input parameters. T2 – Panel takes Gear Input parameters. The pinion input panel receives the data input through the text box. Module (m), Number of teeth (z), Pressure angle (α), Addendum coefficient, root clearance and Addendum modification coefficient are keyed in through the key board.

T3 and T4 panel – Calculates, Plots and clears all details of pinion output parameters. T3a and T4a – The values calculated in T3 and T4, is displayed as pinion / Gear output parameters. The output parameters displayed are PCD, BCD, RCD, OD, Tooth thickness at PCD, length of contact, contact ratio and center distance. T5 – Layout contains Menu bars like File, Open, Exit. It is also built with the capacity of calculating, plotting the Pinion output and provision for XYZ coordinates. It further can transfer the output in the Excel format *. *xls*. Apart from these panels, pull down menu with File-open-print-exit options are coded. The XYZ options are alternate for transferring the co-ordinates to excel. The Help menu contains example calculations and tutorials. The appropriate coding is created in the Matlab-m file to execute the calculations and display the calculated value in the appropriate text box.

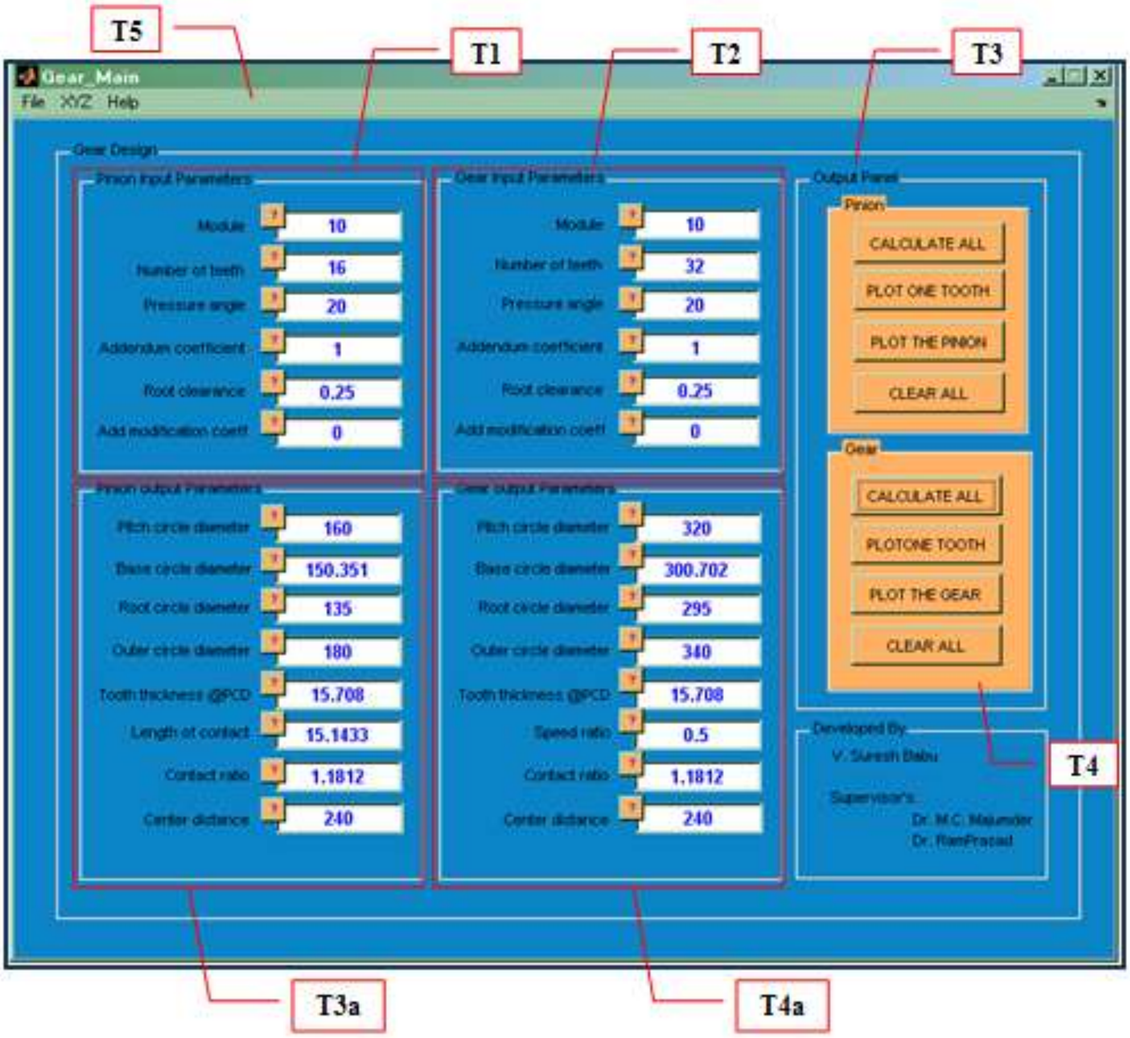

Figure 4. Gear main form

Results and discussion

The following outputs are possible in the Gear main GUI. a) The push button 'calculate all' in the pinion and gear output panel calculates all output parameters and also saves XYZ co-ordinate of the involute in an Excel/Text file in the computer drive. Table 1 shows the left and right involute co-ordinates which is saved in the excel format. Further, b) the button with "plot one tooth" while click displays the output of shape of single tooth spacing as in figure 5. c) Similarly, the button with "Plot the pinion" creates the shape of the tooth profile of pinion, and the complete profile as in figure 6.

The part file was opened and available in the Solidworks, The option "create curve through XYZ" was invoked, which displays a browser titled curve file, for locating the text file saved earlier. On locating the file, OK button is clicked for accepting the points. Sketcher plane was selected to be front view, and the curve was converted to an entity using the convert entities option noticed in figure 7. Later the curve was rotated, mirrored, and arranged to develop the 2D sketch and 3D model of the gear [22] (figure 8).

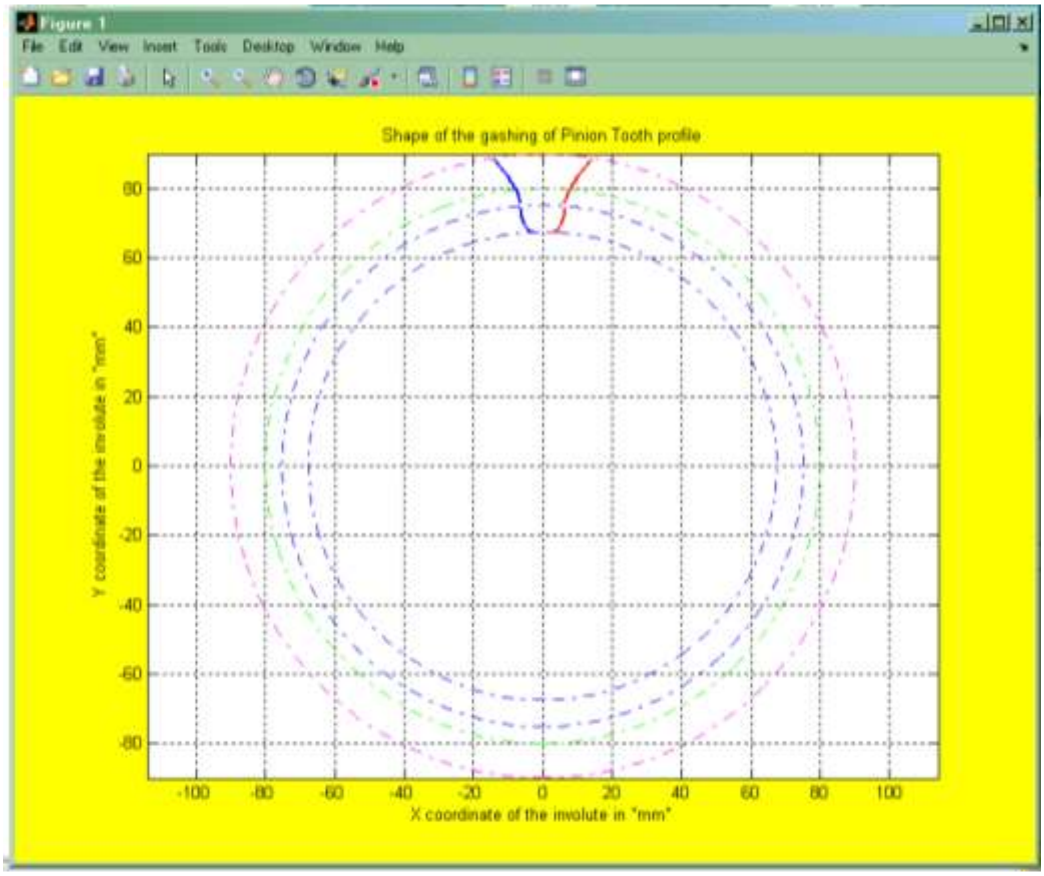

Figure 5. Single tooth spacing of pinion

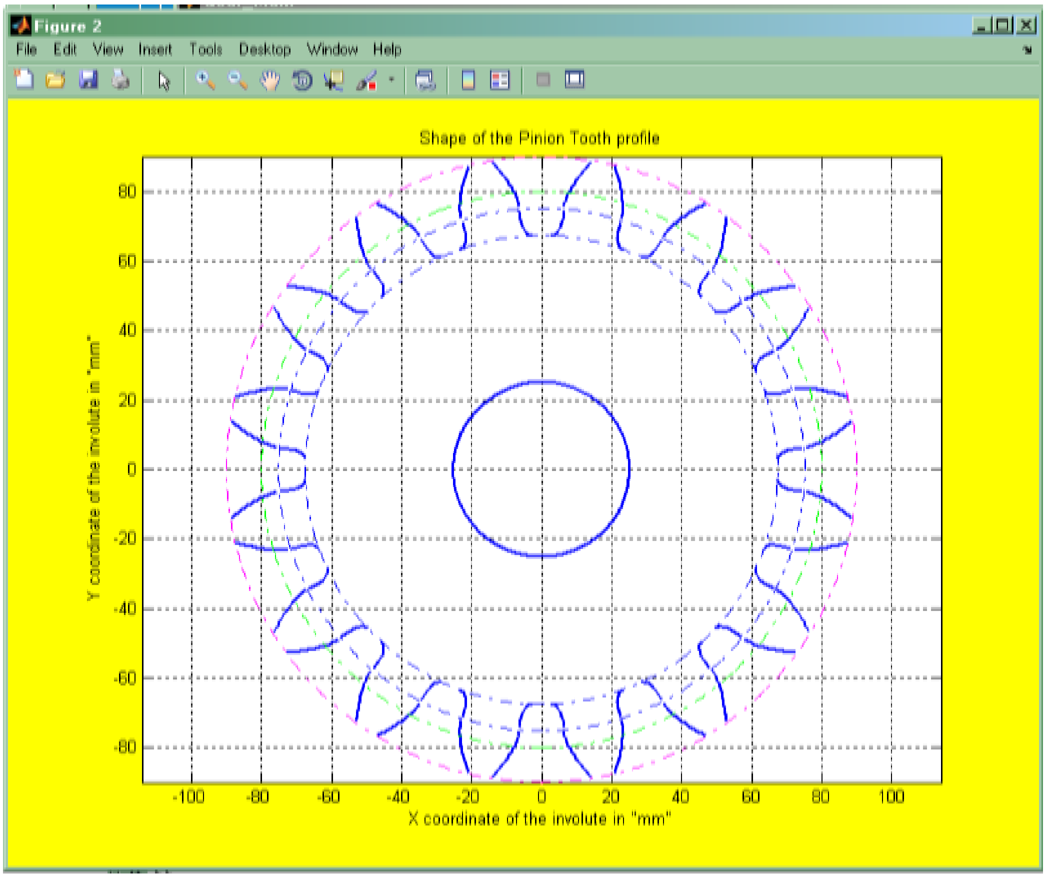

Figure 6. Complete Gear profile

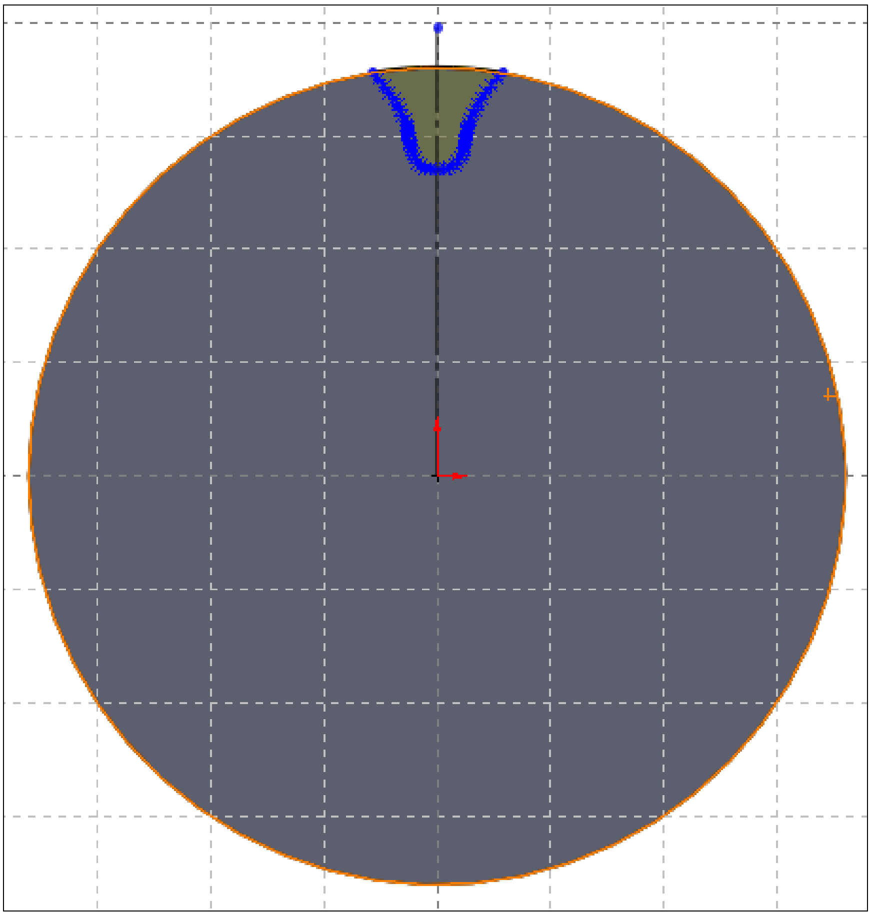

Figure 7. Single tooth of Pinion in Solidworks

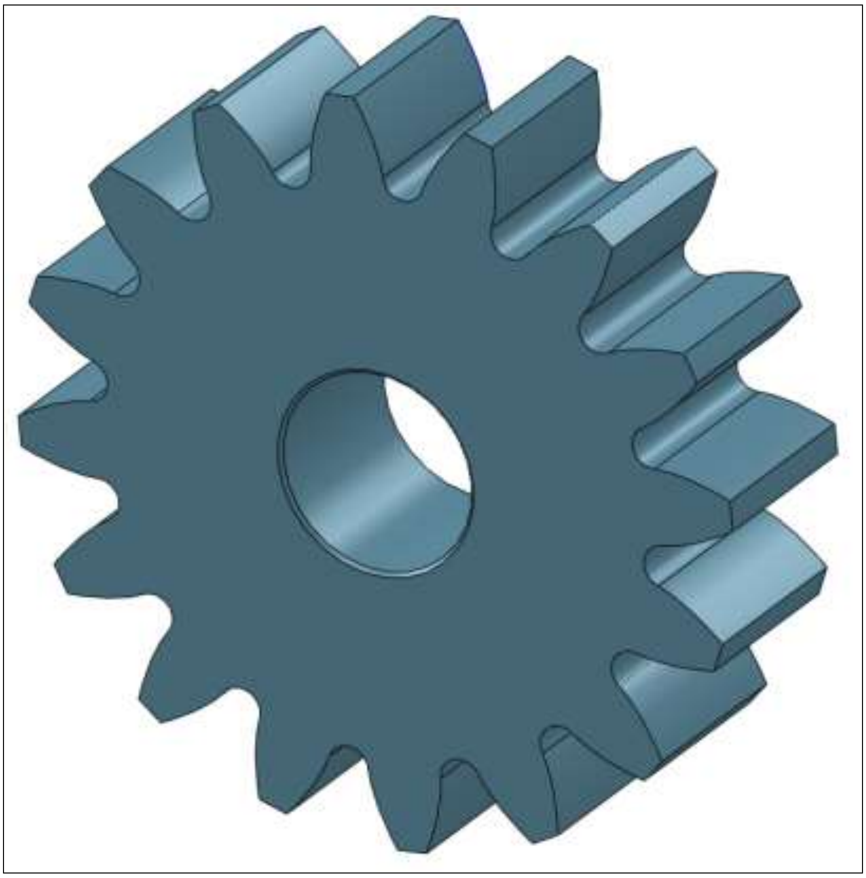

Figure 8. 16Teeth, 10 Module, standard 3D Gear

Table 1. The XYZ coordinates of the involute left and right

X	Y	Z	X	Y	Z
-14.30	88.90	0	14.30	88.90	0
-12.95	87.35	0	12.95	87.35	0
-11.72	85.82	0	11.72	85.82	0
-10.65	84.35	0	10.65	84.35	0
-9.71	82.96	0	9.71	82.96	0
-8.92	81.65	0	8.92	81.65	0
-8.25	80.44	0	8.25	80.44	0
-7.71	79.33	0	7.71	79.33	0
-7.27	78.33	0	7.27	78.33	0
-6.92	77.45	0	6.92	77.45	0
-6.67	76.69	0	6.67	76.69	0
-6.48	76.06	0	6.48	76.06	0
-6.36	75.56	0	6.36	75.56	0
-6.29	75.20	0	6.29	75.20	0
-6.19	74.13	0	6.19	74.13	0
-6.13	73.59	0	6.13	73.59	0
-6.06	73.07	0	6.06	73.07	0
-5.96	72.56	0	5.96	72.56	0
-5.71	71.61	0	5.71	71.61	0
-5.38	70.72	0	5.38	70.72	0
-4.95	69.88	0	4.95	69.88	0
-4.39	69.12	0	4.39	69.12	0
-3.66	68.41	0	3.66	68.41	0
-2.69	67.84	0	2.69	67.84	0
-1.02	67.49	0	1.02	67.49	0

Conclusions

The work has clearly developed an algorithm and implemented it for developing the gear tooth profile using MATLAB® GUI. Different shapes of gear spacing can be visualized and controlled with the necessary input parameter combinations of the gear. The algorithm supports the development of standard and non-standard gears. A specific case of 10 modules, 16 teeth gear with trochoidal root fillet was considered and constructed with coordinates. The involute coordinates was accurately transferred to Solidworks environment and output 3D model of gear is developed. Gear Model developed could further be used in stress analysis and kinematic analysis. Further, contact ratio of gear pair with different combinations of gear parameters can be studied through the GUI. The coordinates produced can also be imported to Pro/E wildfire, Autodesk Inventor, Solidworks or similar such CAD software environment and using spline datum curve options and other tools, the 3D model could be achieved. Further, the GUI helps in understanding the profile shift when correction factor or addendum modification is applied in the gear design. It is well observed that usage of GUI minimizes the time taken for calculating the gear parameters, coordinates and overall display of single tooth space and gear plot before transferring the coordinates to the CAD software's.

Conflicts of interest

Authors declare no conflict of interest.

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