

MATLAB COURSEWARE FOR MECHANICAL DESIGN

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ABSTRACT

MATLAB Courseware for Machine Design is a comprehensive collection of MATLAB modules to supplement teaching and learning in machine design. The courseware is to help users visualize the computation process of important equations with interactive graphics. Each courseware module has a GUI (Graphical User Interface) with a consistent format to allow users to enter data and display results in both graphical and numerical forms. The GUI allows a different set of input before quitting for “what-if” scenarios. Additionally, each module has a help window to explain the computation process.

INTRODUCTION

Equations, tables, and figures in engineering textbooks are being supplemented by electronic versions to automate the computation process. For example, Roark's Formula for Stress and Strain [1] has an interactive version based on TK Solver [2]. The Engineering Mechanics Toolbox [3] is a MATLAB package to supplement textbooks in Mechanics of Materials, covering topics of axial loading, shafts, beams, columns, and Mohr's circle.

The MATLAB courseware reported in this paper is developed to assist teaching and learning in mechanical design. For example, it takes a long time to demonstrate one example of the shear force and bending moment diagrams of a beam because the computation and drawings are quite extensive. With the courseware, many examples can be illustrated quickly and effectively by instructors, and students can use these modules after class to

review the concept and for homework assignments.

MATLAB is chosen for the courseware because in many universities, it is the primary computational software in engineering curricula. MATLAB integrates computation, visualization and programming in an environment that is easy to learn and use. MATLAB is also easy for GUI development with GUIDE (Graphical User Interface Development Environment) [4]. GUIDE provides a set of tools to create a GUI by dragging and dropping different components, a process similar to that in Visual Basic [5]. However, as compared to Visual Basic, codes in MATLAB are much shorter and the coding is much faster.

COURSEWARE OVERVIEW

The courseware covers four topics: strength of materials, static and fatigue failures, design of machine elements, and kinematics. For the subject of strength of materials, a module calculates and plots bi-axial and tri-axial Mohr circles (as shown in Figure 1) with a GUI of biaxial stresses as input. The output contains principal stresses and the maximum shear stress. In figures 2a and 2b, the beam module calculates and plots shear force and bending moment diagrams of a simply supported beam and an overhanging beam respectively. The GUI has loads and beam dimensions as input, and the maximum moment and shear force as output. In Figure 3, the column-buckling module displays Euler equation, Johnson's equation, and secant equation.

For the subject of static and fatigue failures, the module on the static failure of ductile

materials calculates safety factors of given stresses based on the maximum shear stress theory and distortion energy theory respectively, and the module plots the contours of different theories, as shown in Figure 4. In Figures 5, the static failures of brittle materials are shown with Column-Mohr theory. In Figure 6, the fatigue failure module calculates safety factors based on Goodman, Gerber, Soderberg [8] respectively, and plots the contours of different theories.

For the subject of design of machine elements, the gear dynamic factors module is to calculate the factor based on input parameters and to plot a family of curves, as shown in Figure 7. In Figure 8, the gear geometry factors module is to calculate the factor based on input parameters and plot a family of curves. In Figure 9, the bolted joint module calculates the force on the bolt and clamped members with an external load and initial preload. Over ten different modules have been generated for stress concentration factors. Figure 10 shows the stress concentration factor of a shaft subject to torsion, and Figure 11 shows the stress concentration factor of a shaft with a hole subject to tension.

For the subject of kinematics, courseware modules in linkages, cams, and gears are developed. Figure 12 shows a fourbar linkage – the link length can be modified, and the motion can be animated. Other linkage modules developed include slider-crank, inverted slider crank, and elliptical trammel. Figure 13 shows a cam – with the function of rise and fall specified, the cam profile can be generated once the prime radius and roller radius are specified. An involute gear can be generated based on the number of teeth and pitch diameter, as shown in Figure 14. Other types of gears such as Roots blower (two-tooth or three-tooth cycloidal gear) are shown in Fig 15. Figure 16 shows a rotary engine, the Wankel engine, and the rotor and chamber can be generated with a different button selection.

Using computers to assist teaching is getting easier as the hardware cost is getting lower. Many classrooms in the author's university are now equipped with network connections and ceiling-mount LCD projectors. For instructors, the MATLAB courseware can expedite the computation process with accurate results, and can present accurate graphs with multiple colors in production quality.

Although graphs are effective to present an overall picture of data, in the past, they can only be represented using transparencies or hand drawings on the board. To those instructors who lack drawing skills, it is challenging to draw accurately simple plots like Mohr circles, as in Figure 1, or a complex set of curves like the static failure contours, as in Figure 4. As compared with transparencies of static images, the computer courseware, with its GUI, not only accurately plots the graphs but also re-plots the graphs with a different set of input data, ideal for “what-if” scenarios. For example, Figure 17 shows the three Mohr circles with an input data set different from that in Figure 1. The largest circle shown, which determines the maximum shear stress, is the circle in the xy -plane, decided by σ_x , σ_y , and τ_{xy} , also shown in Figure 18. On the other hand, the maximum shear stress in the case of Figure 1(b) is decided by a Mohr circle that is outside of the xy -plane. The courseware, with different colors and legends, can illustrate this concept of Mohr three circles very effectively.

Another advantage of the courseware is the precision in output results. As compared to the estimation by sight from a figure in a textbook, courseware modules can better interpolate curves. This is especially helpful when there is a family of curves, like the gear geometry factors shown in Figure 8, when reading data correctly becomes challenging. Additionally, some

equations do not have closed-form solutions, like the secant formula in the column buckling, as shown in Equation (1) and in Figure 3(b), and the computer courseware is well suited for this type of computation.

$$\sigma_{\max} = \frac{P}{A} \left[1 + \frac{ec}{r^2} \sec\left(\frac{L}{2r} \sqrt{\frac{E}{2A}}\right) \right] \quad (1)$$

DISCUSSION

A comprehensive collection of MATLAB modules is developed to supplement teaching and learning in machine design. All MATLAB files are linked to one module with a menu-driven selector, as shown in figures 19 and 20, making every module easily accessible. Help menus, like the one shown in Figure 21, are included for each module.

With the GUI, users who are not interested in the source codes can treat these modules as a black box, and use them as a tool for homework and design projects. Other users can modify the source codes to meet their specific needs. Different modules of the courseware can be used in different course to introduce or review some concept. For example, modules for the *strength of materials* (like Mohr circles, shear force and bending moment diagrams of beams, and column-buckling) can be incorporated in a *design of machine elements* course for review. Different modules of the courseware have been published by McGraw-Hill to accompany different textbooks [6, 8, 10]. Website to download these courseware modules of respective textbooks are at [7, 9, 11].

The courseware is the outgrowth of the author's course supplements in the past ten years. Different classes at NC A&T State University have used different modules and made suggestions to improve them. With input and assistance of undergraduate and graduate students, the courseware has improved over time – earlier versions of the courseware have none or primitive GUI. Mr. Jie Yang, a former

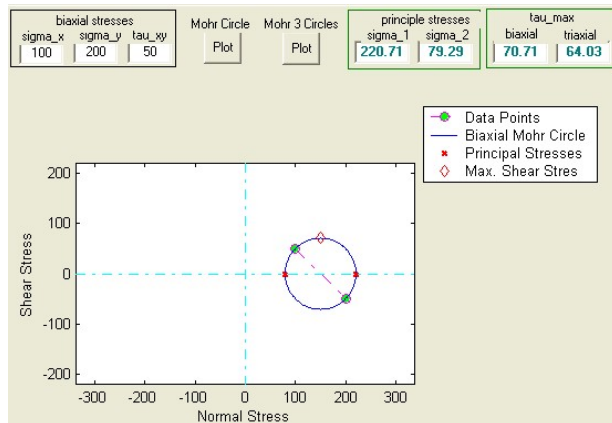
graduate student, should be singled out for his extensive contribution, and Ms. Erin Bailey, my assistant for McGraw-Hill courseware projects, has generated consistent GUI for each module.

REFERENCES

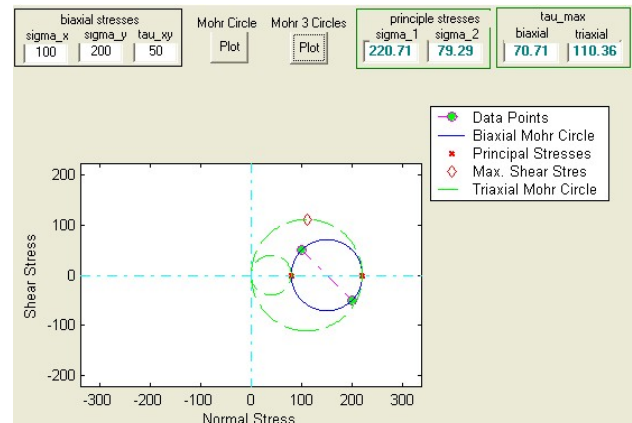
1. Roark, R.J., Budynas, R.G., and Young, W. C., *Roark's Formula for Stress and Strain*, 7th edition, McGraw-Hill June 2001.
2. Universal Technical Systems, Inc., *Interactive Roark's Formulas* URL: <http://www.roarksformulas.com/>
3. Mechworks Software, Inc. *Solving Mechanics of Materials Problems with MATLAB*, Prentice Hall, 1999.
4. The MathWorks, Inc, URL: <http://www.mathworks.com>.
5. Microsoft Visual Basic.net URL: <http://msdn.microsoft.com/vbasic/>
6. Norton, R., *Design of Machinery*, 3rd ed., McGraw-Hill, 2004.
7. McGraw Hill Online Learning Center for Norton 3e http://highered.mcgraw-hill.com/sites/0072470461/information_center_view0/
8. Shigley and Mischke, *Mechanical Engineering Design*, 7th ed., McGraw-Hill, 2004.
9. McGraw Hill Online Learning Center for Shigley 7e http://highered.mcgraw-hill.com/sites/0072520361/information_center_view0/
10. Ugural, A., *Mechanical Design: An Integrated Approach*, McGraw-Hill, 2004.
11. McGraw Hill Online Learning Center for Ugural http://highered.mcgraw-hill.com/sites/007242155x/information_center_view0/

BIOGRAPHICAL INFORMATION

Shih-Liang (Sid) Wang is Professor and Director of Mechanical Engineering in the Department of Mechanical and Chemical Engineering at North Carolina A&T State University. Dr. Wang received his B.S. in Mechanical Engineering at National Tsing Hua University in 1977, and his M.S. and Ph.D. in Mechanical Engineering at Ohio State University in 1983 and 1986 respectively. His research interests include computer-aided design, machine and mechanism design, motion simulation of mechanical systems, design theory and methodology, and robotics.

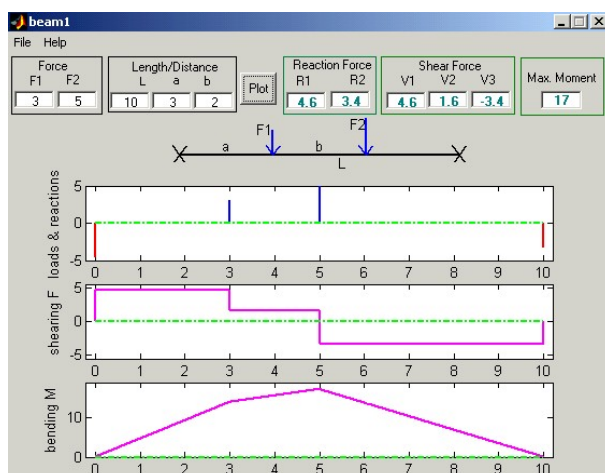


(a)

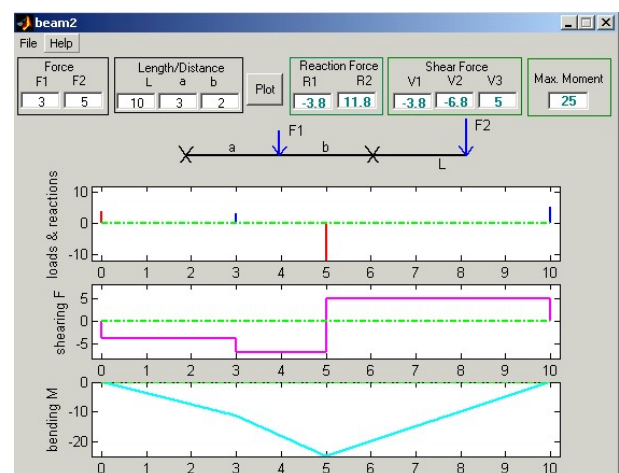


(b)

Figure 1 Mohr Circle Showing Principal Stresses and Maximum Shear Stress

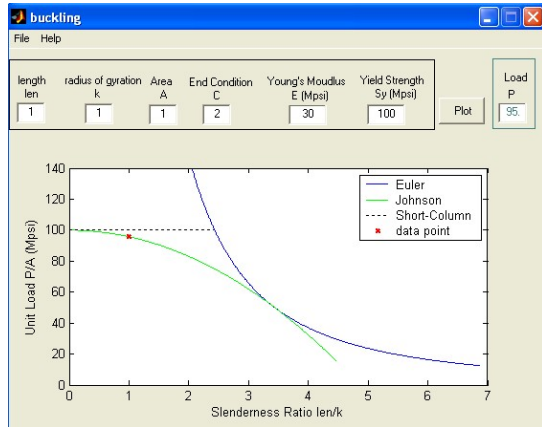


(a)

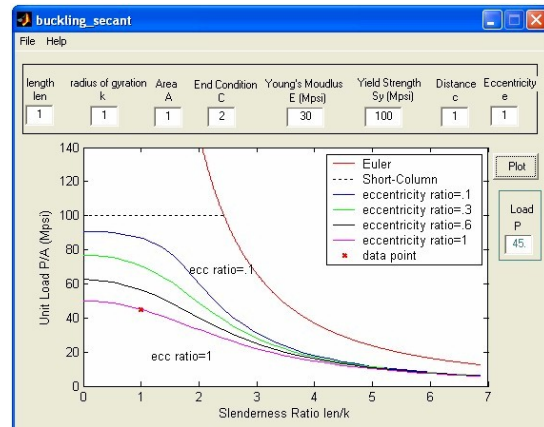


(b)

Figure 2 Shear Force and Bending Moment Diagrams of Beams



(a)



(b)

Figure 3 Column Buckling

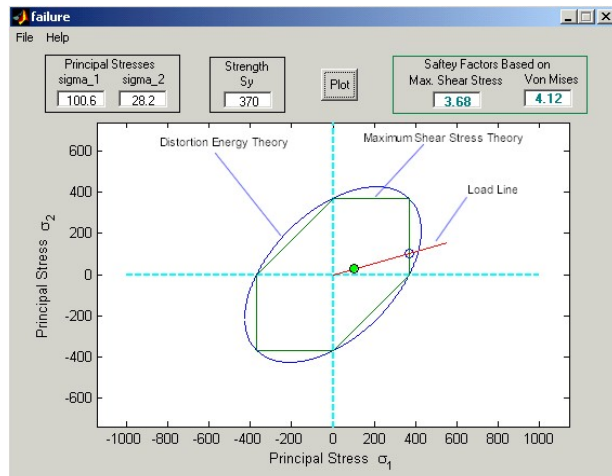


Figure 4 Static Failures

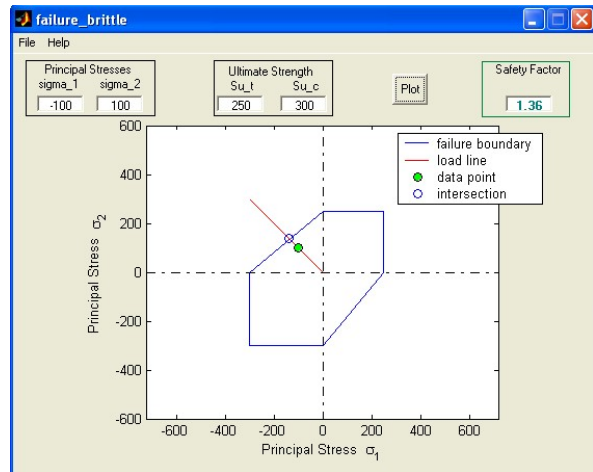


Figure 5 Column-Mohr Theory

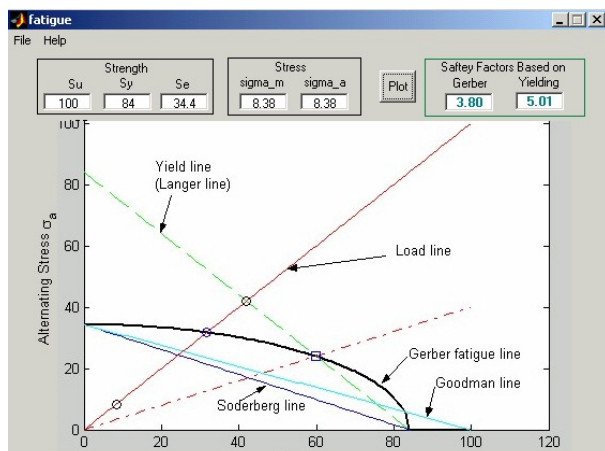


Figure 6 Fatigue Failures

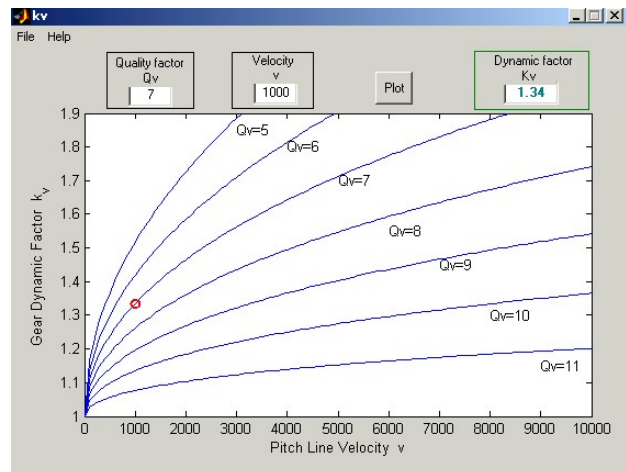


Figure 7 Gear Dynamic Factors

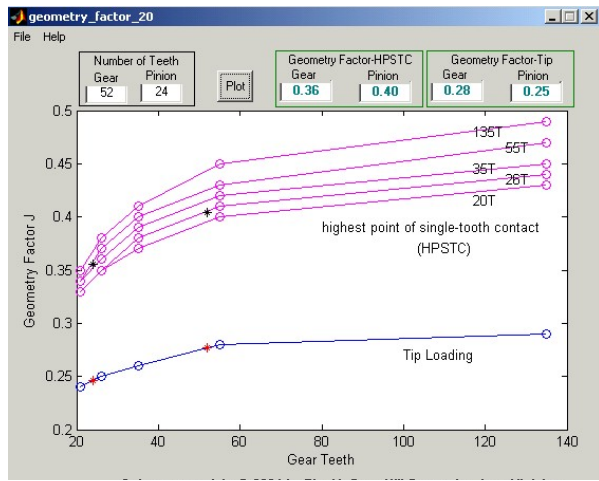


Figure 8 Gear Geometry Factors

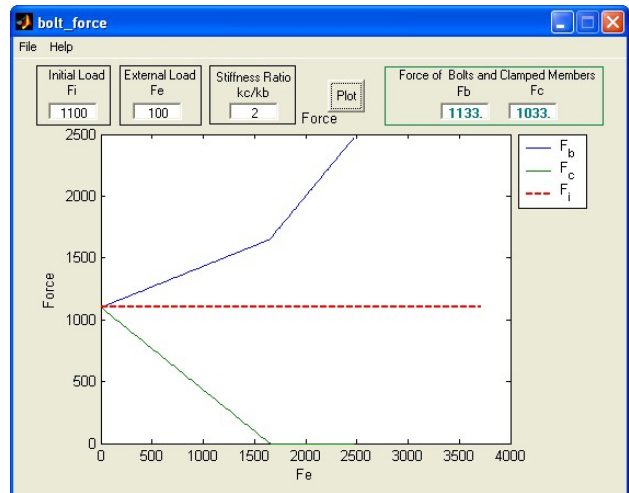


Figure 9 Forces on a Bolted Joint

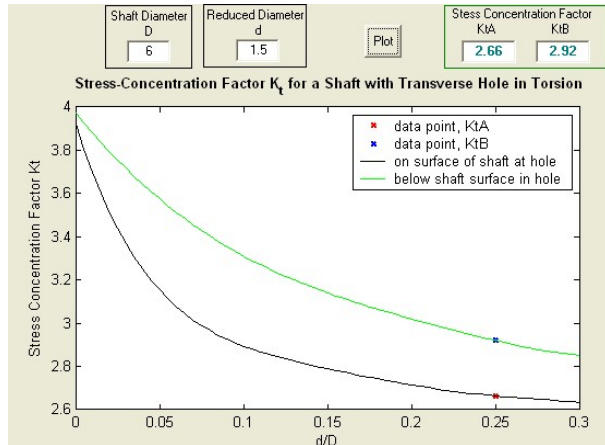


Figure 10 Stress Concentration – Shaft in Torsion

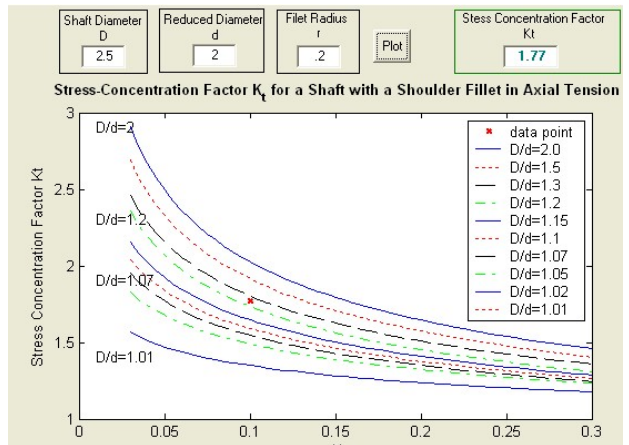


Figure 11 Stress Concentration – Step Shaft in Tension

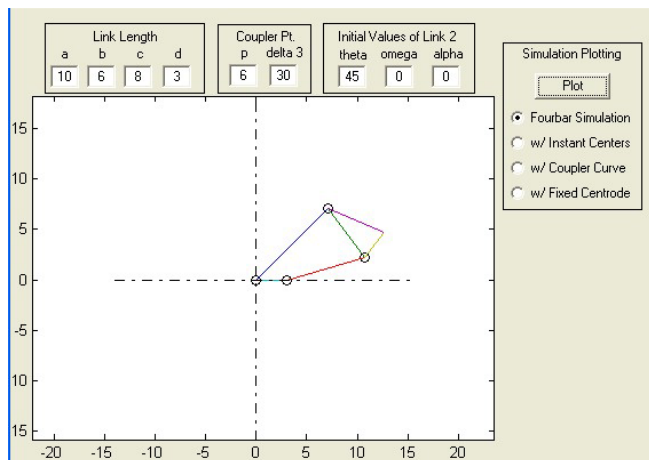


Figure 12 Fourbar Linkage

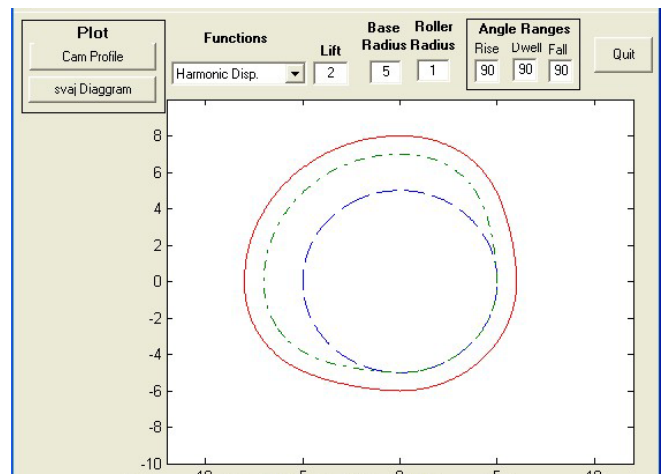


Figure 13 Cams

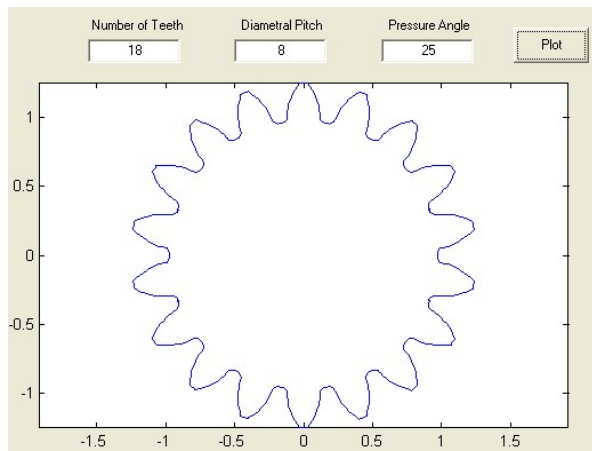


Figure 14 Involute Gears

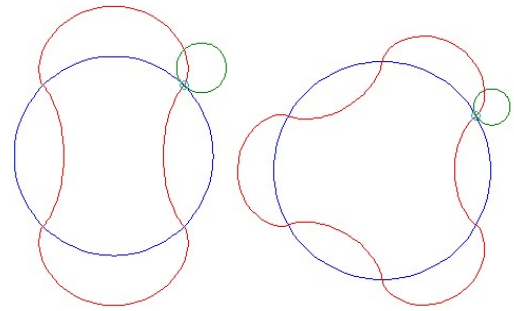


Figure 15 Root Blower

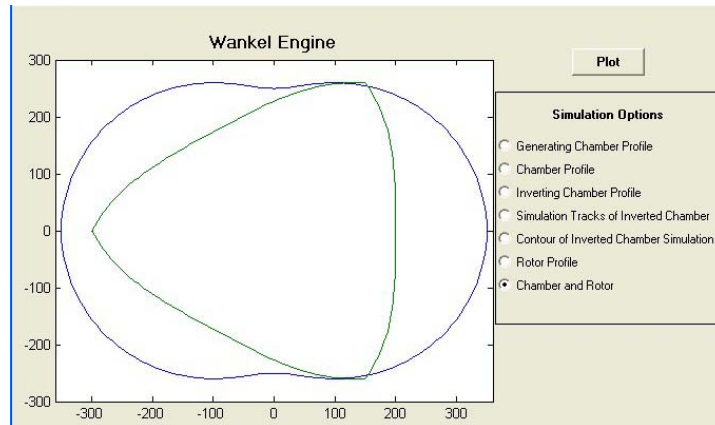


Figure 16 Rotary Engine

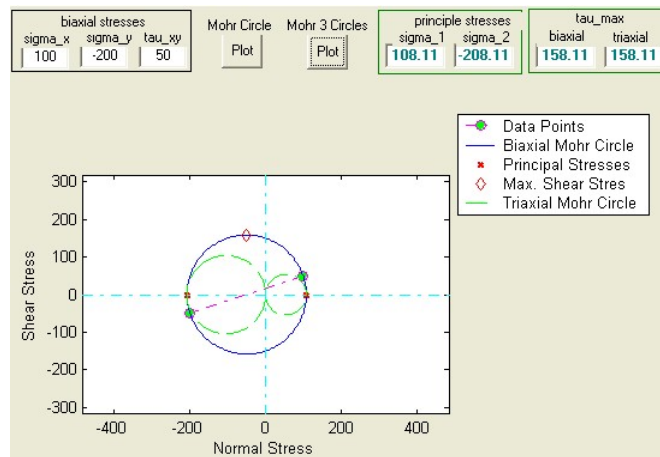


Figure 17 Mohr 3 Circles

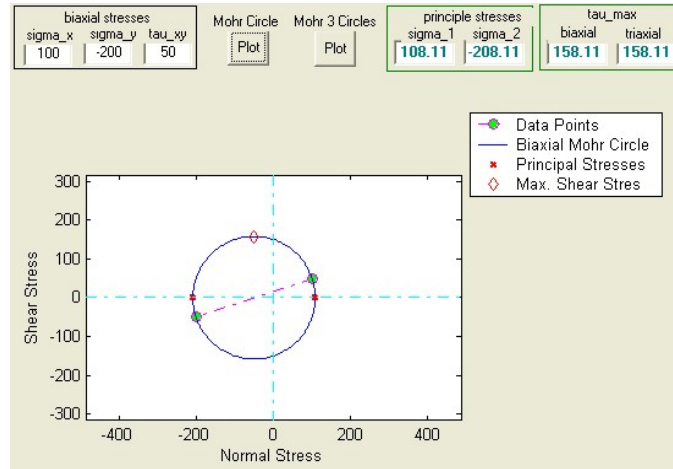


Figure 18 Mohr Circle

Strength of Materials

Mohr Circle

Mohr Circle

Mohr Circle for Triaxial Stress

Mohr Circle for Brittle Materials

Beams - Shear Force and Bending Moment

Simply Supported Beams

Simply Supported Beams with Thrust Loads

Overhang Beams

Overhang Beams with Thrust Loads

Column Buckling

Euler - Johnson Equation

Secant Formula

Figure 19 Menu- Strength of Materials

Static Failure

Ductile Materials

Distorsion Energy Theory

Brittle Materials

Mohr Theory

Fatigue Failure

Failure Theory

Design of Machine Elements

Gear Geometry Factor

20 degree Pressure Angle

Gear Geometry Factor

25 degree Pressure Angle

Gear Dynamic Factor

Bolt Force

Figure 20 Menu- Failures and Elements

This program requires two inputs — gear tooth numbers of two engaged gears, gear and pinion respectively. Gear geometry factors are plotted based on two types of loading - HPSTC (highest point of single-tooth contact) and tip loading. The values of Gear Geometry Factors are displayed in the output box. The input values can be modified to re-plot.

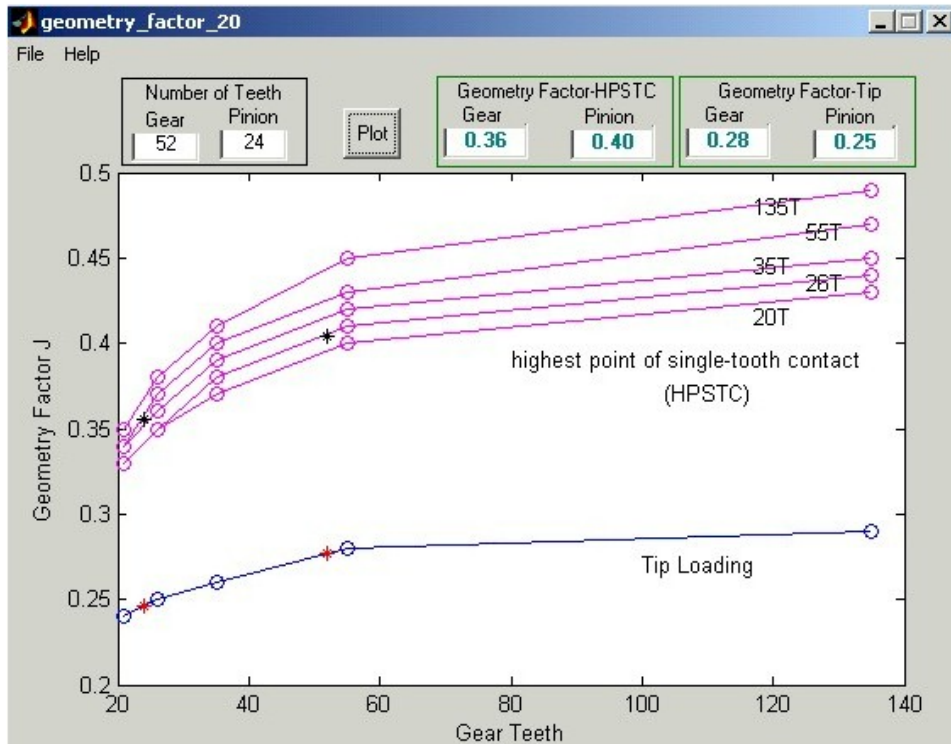


Figure 21 Help Screen for Gear Geometry Factors