Computer Aided Spur Gear Design and Analysis

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I. Introduction

This paper describes a spur gear analysis program written in visual basic. The program is used to assist students to learn the procedures to size and select spur gears. The class that this is used in is called machine elements (MET-214). It is a second level mechanical engineering technology course. The student's background coming in to this course includes statics, dynamics, and strength of materials. The course covers topics related to mechanical design. Students learn the concepts and procedures to size and select components such as gears, bearings, belt drives, shafts, clutches, and brakes. The program provides the data necessary to analyze and make the decisions to properly select these components.

The focus of this paper is on the procedure used to size and select a spur gear using a software program. Spur gears are used in many machine design applications. The selection process of a spur gear system involves many calculations and decisions. This software program simplifies and streamlines the design and selection process. The program is written in visual basic, which is an event driven program. The user can go through the program inputting values into text boxes and initiating events by clicking on command buttons. Visual basic was used because of its windows environment in which most users would feel comfortable using. Also, the most important feature of this program is the ability to insert pictures, tables, graphs, drawings, and figures to enhance the program functionality. The program is visual and interactive which helps guide the user through the design process. While the user should have some basic knowledge of gears, the program assists the user through the design process. Most inputs are taken from graphs, charts, or tables so the user knows where and how the information is obtained and used. Outputs are shown with their appropriated figures or drawings to assist the user in understanding how the output was determined and how it is used. What this means is the user does not have to have a gear design book at his side in order to interpret results or to get input data.

II. Spur Gear Background

The selection of spur gear material is based on two factors, bending stress and contact stress. Bending stress in a gear is based on the concept that gear teeth act similar to a cantilever beam with a bending force applied to them. The bending stress, s_t, is calculated based on the shape,

size, width of the tooth, the force on the tooth, and several safety factors. The equation recommended by AGMA in Standard 2001-C95 for the bending stress[1] in a gear tooth is:

$$s_t = \frac{W_t \cdot P_d}{F \cdot J} \cdot K_o \cdot K_s \cdot K_m \cdot K_B \cdot K_v \quad (1)$$

where
- s_t = bending stress (psi)
- W_t = tangential force (lb)
- P_d = diametral pitch (1/in.)
- F = face width of tooth (in.)
- J = geometry factor
- K_o = overload factor for bending strength
- K_s = size factor for bending strength
- K_m = load distribution factor for bending strength
- K_B = rim thickness factor
- K_v = dynamic factor for bending strength

The bending stress should not exceed the design stress value based on the material selected.

$$s_t \leq \frac{s_{at} \cdot Y_N}{SF \cdot K_R} \quad (2)$$

where
- s_{at} = allowable bending stress (psi)
- Y_N = stress cycle factor for bending strength
- SF = safety factor for bending strength
- K_R = reliability factor

Rearranging the equation and solving for the allowable bending stress gives the following equation:

$$s_{at} = \frac{W_t \cdot P_d \cdot SF}{F \cdot J \cdot Y_N} \cdot K_o \cdot K_s \cdot K_m \cdot K_B \cdot K_v \cdot K_R \quad (3)$$

Solving for the allowable bending stress, the gear designer can select a material based on this number. As can be seen from the equation, there are many variables that need to be determined. This program assists the user in determining and selecting these variables.

The second type of failure is pitting due to contact stress. The calculated contact stress[1] is given by the equation:

$$s_c = C_p \cdot \sqrt{\frac{W_t \cdot K_o \cdot K_s \cdot K_m \cdot K_v}{F \cdot D_p \cdot I}} \quad (4)$$

where s_c = contact stress (psi)

C_p = elastic coefficient
W_t = tangential force (lb)
K_o = overload factor for bending strength
K_s = size factor for bending strength
K_m = load distribution factor for bending strength
K_v = dynamic factor for bending strength
F = face width of tooth (in.)
D_p = pitch diameter of gear (in.)
I = geometry factor based on pitting resistance

The contact stress should not exceed the design stress based value based on the material selected.

$$s_c \leq s_{ac} \cdot \frac{Z_N \cdot C_H}{K_R \cdot SF} \tag{5}$$

where s_{at} = allowable contact stress (psi)
Z_N = stress cycle factor for pitting resistance
C_H = hardness ratio for pitting resistance

Rearranging the equation and solving for the allowable contact stress gives the following equation:

$$s_{ac} = \frac{K_R \cdot SF}{Z_N \cdot C_H} \cdot C_p \cdot \sqrt{\frac{W_t \cdot K_o \cdot K_s \cdot K_m \cdot K_v}{F \cdot D_p \cdot I}} \tag{6}$$

A gear material can be selected based on both the allowable bending stress and the allowable contact stress that were just calculated.

III. Spur Gear Program

The program assists the user in determining all the factors and variables of the above equations for a specific application. These input variables are determined from the tables, graphs, and figures shown in the program. The program then calculates the allowable bending stress and contacts stress for this application. The gear designer can then select a material that satisfies both allowable stresses.

The software program takes the user step by step through the design process. Initial design criteria are usually known. Information such as, system design horsepower and speeds are input in the program. From this information, the gear ratio[2] can be calculated and therefore the number of teeth on the two mating gears can be determined in figure 1. This figure prompts the user to enter the input data. The inputs here are used through out the program. One feature of visual basic is how values can be displayed. The horsepower entered on this form of the program will also appear in figure 2 on the left side of the graph labeled horsepower[2]. The pinion angular velocity input in figure 1 will also appear in figure 2 on the bottom of the graph. The user can then determine the diametral pitch from a graph based on horsepower and speed in

figure 2. The diametral pitch is the size of the gear tooth. The larger the diametral pitch number the smaller the tooth, as shown in the figure below. The user enters the diametral pitch in the given text box. Initiating the "Continue" command button shown in figure 2 would bring up the
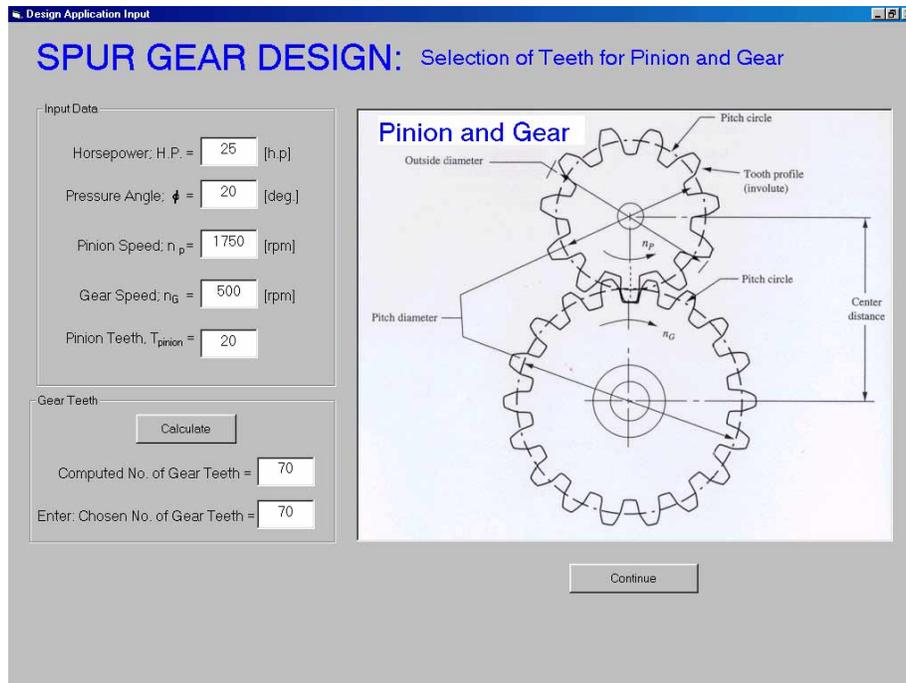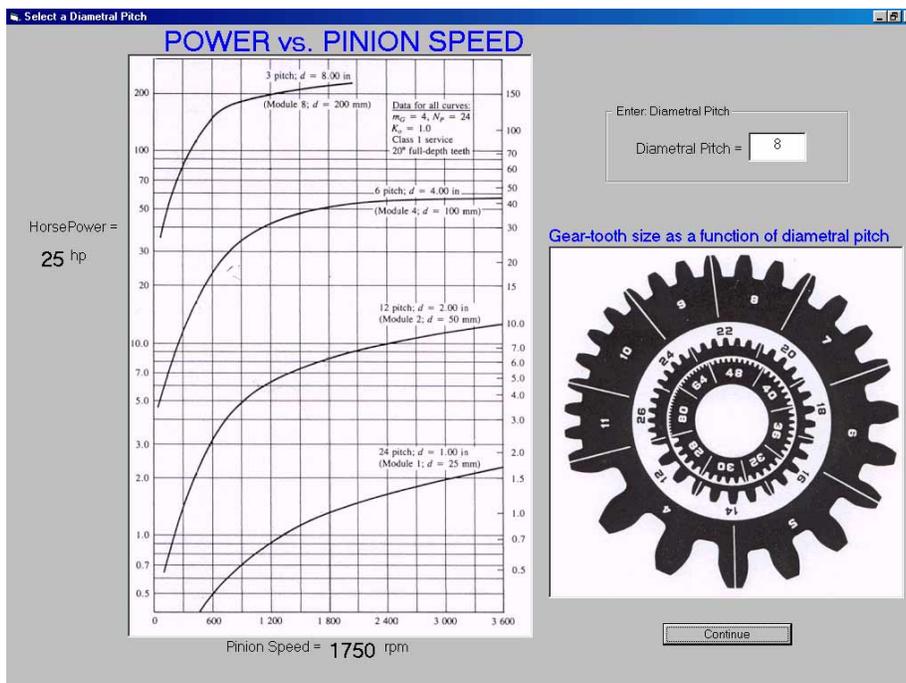

FIGURE. 1

SPUR GEAR DESIGN INPUT FORM

FIGURE. 2

DIAMETRAL PITCH FORM

next form. The next form calculates the tangential and radial forces on the pinion and gear. The forces are automatically calculated and are shown in the figures on the form, therefore the user knows what the force are and where they are applied. The next few forms calculate different specifications of the gear drive system such as the pitch diameter, center distance between pinion and gear, and the pitch line speed of the pinion and gear. Some of the forms do calculations and give an output with a figure to show what the output means. Other forms show tables or graphs and have the user select or determine the input value to be used in later forms or calculations. All forms are designed to assist the user in determining the factors or feature values needed to determine the output value. As an example, the overload factor, K_o, is determined from the following form shown in figure 3. The recommended overload factors are shown based on the type of power source and the driven machine[2]. The overload factor is a safety factor based on loads that may exceed the calculated tangential force due to load variations. The user enters the overload factor in the text box as shown. This form gives the user information in a table to

FIGURE. 3
OVERLOAD FACTOR FORM

determine the required value for their specific application. One advantage of visual basic is the ability to have figures, tables, graphs, and charts as a part of the program as shown in figure 3. This allows the program to be self-sufficient. If the program did not have this capability, the user would have to refer to a gear reference book and find the required value and input the value in the program. The next form calculates the load distribution factor, K_m, shown in figure 4. The load distribution factor, K_m, is based on many different factors. The width of the gear, the quality of the gear, and the mounting of the gear, influence the way the load is distributed to the gear teeth. The following equation calculates the load distribution factor[1].

$$K_m = 1.0 + C_{pf} + C_{ma} \qquad (5)$$

where C_{pf} = pinion proportional factor
         C_{ma} = mesh alignment factor

The software program calculates the pinion proportional factor and the mesh alignment factor. The results are placed in the label box along with the face diameter shown in figure 4. The student can verify the values graphically by looking at the two graphs[1] shown. The type of gearing unit is selected as an option. The user can see how changing the type of gear unit affects the mesh alignment factor. The higher the precision gear unit the lower the safety factor required, which means the lower the load distribution factor. The following is the steps showing how the student determines this value without the use of the software program. The student would find the pinion proportional factor and the mesh factor in two graphs found in the machine elements book. They would use the face width of the gear and the face width divided by the pitch diameter of the gear to determine the pinion proportional factor from the graph. The student would then determine the type of gear unit used from the application or problem given. There are four options for the type of gear units. The open gear unit, which is not as accurate to extra-precision enclosed gear units, which are very accurate. The choice of unit is based on the application or problem given. The mesh alignment factor could be specified from the graph by using the face width of the gear along with the type of gear unit used. The machine elements book provides two equations to calculate both the pinion proportional factor and the mesh
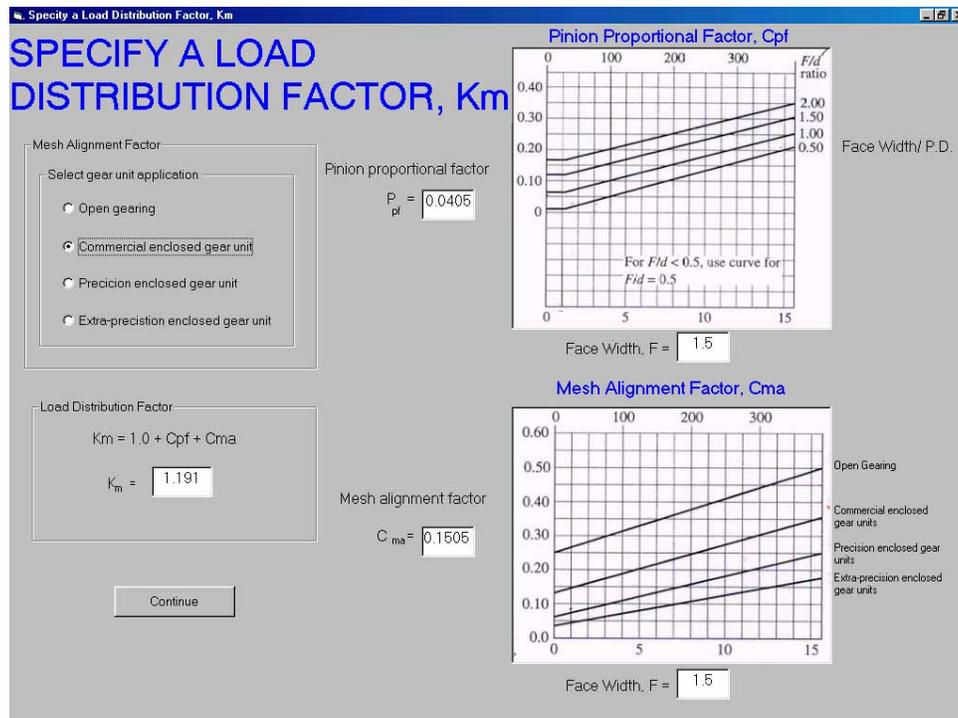

FIGURE. 4
LOAD DISTRIBUTION FACTOR

alignment factor, but most students prefer to determine the values graphically. The load distribution factor is then calculated based on both the pinion proportion factor and the mesh alignment factor using equation 5. The remainder of the factors and variables for equations (3) and (6) are determined using similar means. Once all the factors and variables are determined

the program calculates the allowable bending stress and the allowable contact stress based on equations 3 and 6 respectively. The last step would be to select a material based on the allowable stresses. Figure 5 shows the form used to select a material based on the allowable bending stress[2]. As can be seen in this form the allowable stress for the pinion and the gear are shown and Brinell hardness value needed for this stress. The Brinell hardness number is used only if selecting a through-hardened material. The user has five material choices, plastic, bronze, iron, through hardened steel, and case hardened steel. By selecting any of these options a material list appears on the right side of the form. In figure 5 the case hardened material option is selected. This brings up a list box with all the recommended steel materials and a list box of hardness options. The user selects the steel material that exceeds the allowable bending stress or hardness calculated. This is done for both the pinion and gear. The last couple of forms

FIGURE. 5
MATERIAL SELECTION BASED ON ALLOWABLE BENDING STRESS

summarize the inputs and outputs to allow the user to print out all the data. The user can print out information from any form that has a print command on it, an example of one of the output forms[2] is shown in figure 6.

IV. Conclusion

This program allows the student to design and analyze a spur gear system. The program allows the student to select a gear material based on the allowable bending stress and allowable contact stress. The program is fairly long with about twenty forms to go through to select a material. Even though the program is long, it is straight foreword to use. Many factors are not only based on the input data but are sometimes selected based on experience. The user should have some background in gear design. While this program is used in an academic environment, it could also

be used in industry to design and analyze gears. The program simplifies the design process by organizing all the inputs and calculations in an easy to understandable fashion. The user can therefore benefit by learning the process of the gear design and understand how the inputs are
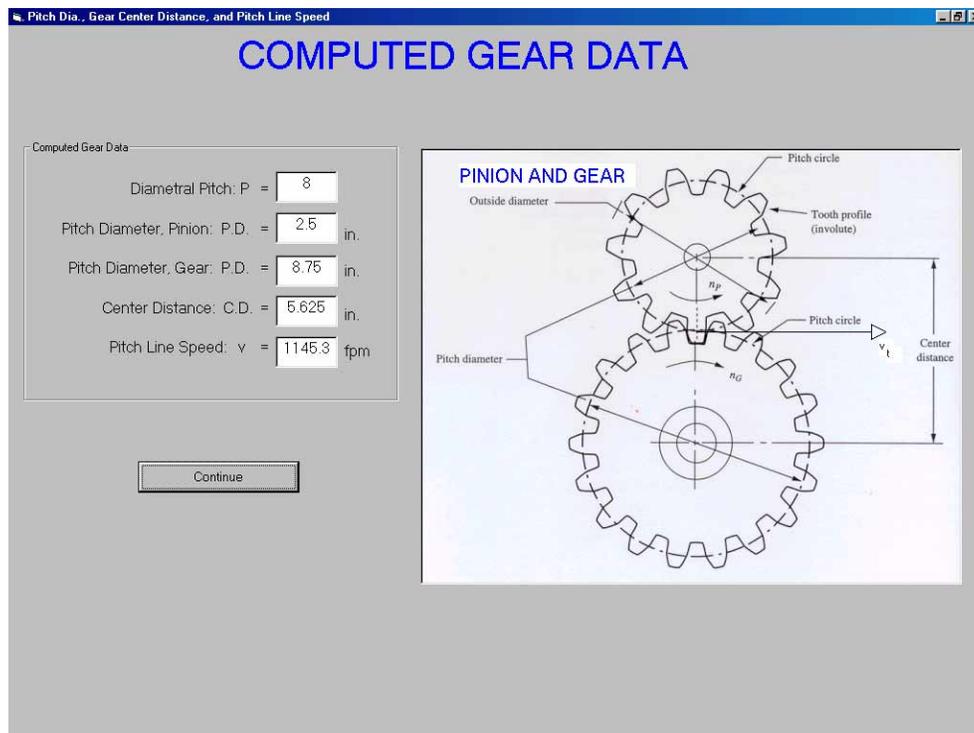

FIGURE. 6
COMPUTED OUTPUT GEAR DATA

determined and what the outputs mean from the program. The gear analysis process is long and is done in an iterating manner. This means the user may go through the gear design analysis two or three times to get the best results. The program allows the user to go through the design process multiple times quickly and easily.   The software has not been used in the machine elements course. I hope to use it by the spring semester of 2001 if all the permissions required are granted. So at this time, I do not have any student feedback. A future item of interest will be assessing the programs impact on student learning.

Bibliography
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