

USING SPREADSHEET PROGRAMS IN TEACHING MACHINE DESIGN

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Abstract

This paper presents an approach on using spreadsheets to teach machine design. It also lists detailed procedures on how to implement the teaching scheme. Results show that spreadsheet programs can help students organize their design procedures. By using the characteristics of spreadsheet programs, students do not have to repeat the same calculation and can get the alternate solution of a design almost instantly when given different values on the inputs. When compared to the method taught by using calculators, students can significantly improve their performance on homework problems and tests. From teaching evaluations, their interest in taking such a course increases. In addition, instructors can give more problems to students during tests and therefore can evaluate the students' performance more objectively.

I. Introduction

When teaching a class on machine design, the instructor usually explains the equations of each design subject and then gives some examples to help students apply those equations. In most cases, students will use calculators to do homework problems and take tests. Because of the complexity of the equations as well as of the units, they usually have difficulty in getting correct answers, which decreases their interest in taking such a course.

As the use of computers has become more predominant, several textbooks are already using computers to solve some of the problems in machine design^{1,2,3,4}. When a design process is recorded as a program file in a computer, it has the following advantages for the students:

- (1) *They do not have to repeat the same tedious work of another problem if only input information is different.*
- (2) *They can get the alternate solution of a design problem almost instantaneously by using the capability of a spreadsheet program.*
- (3) *The computer program can also help them organize their solution procedures.*
- (4) *They can interpret their solutions by using the chart drawing capability available in a spreadsheet program.*
- (5) *They can turn in their homework by using electronic mail.*

Although there are some advantages, the spreadsheet program also has the following drawbacks for the students:

- (1) *They may simply open an existing file to solve a problem without exactly knowing the program capability of the file.*
- (2) *They may copy a file directly from their classmates without fully understanding the designing procedures.*

To overcome such drawbacks, students are asked to develop their own programs for homework after several examples are given. Quizzes and tests are given to evaluate students' performance in the class. When including questions of design procedures in the tests and quizzes, students will soon figure out that they need to develop their own programs and cannot rely on using the programs completely developed by other people. The following procedures are proposed to successfully implement the teaching scheme: (1) file management, (2) capability description of the program, (3) inputs, (4) design equations, (5) iteration of the solutions, and (6) quizzes, tests, and homework problems.

II. Description of the Implementation

1. File management

Good file management will help students quickly search for a developed program closest to the application. Students can use the hierarchical structure of the file management technique available in the Microsoft Windows System. As given in Figure 1, students can create a main folder called Machine Design. The main folder includes several sub folders, with each representing a design topic. Students can start their search from the main folder and reach a specific file, which is closest to their application. Also from Figure 1, if students are looking for a developed file to solve their welding problem, they will first click the sub folder of Welding. The file system will automatically prompt two folders for them to choose: (a) In-plane load and (b) Out-of-plane load. If the problem is in-plane load, the file system will automatically prompt two sub folders for them to choose: (a) Inch system and (b) Metric system. If the inch system is selected, the file system will automatically prompt several files, which have been created by the students. If students are looking for the design of factor of safety, they will choose the file entitled, " P. 16.2 – SafetyF" for their application. Students may use a Zip drive to store all the files developed in a whole semester.

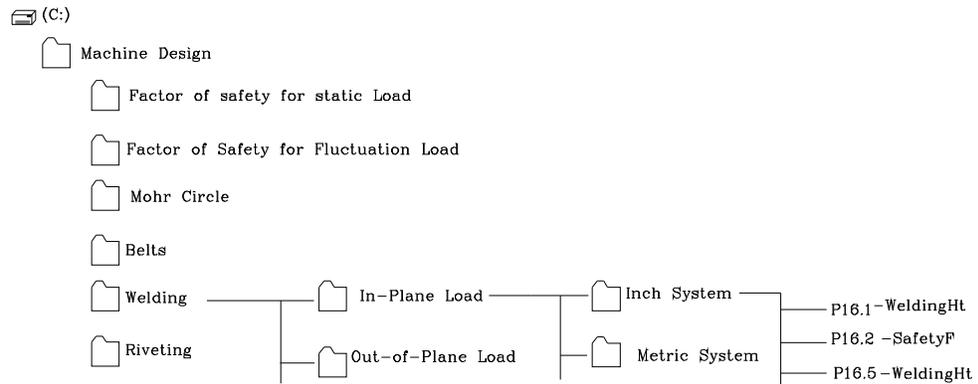


Figure 1: A hierarchical structure for the file management system.

2. Capability description of each program

As mentioned above, one of the drawbacks of using computers to solve design problems is lacking in understanding the exact applicability of each program, especially when many program files have been developed. Therefore, a description of the capability of each program is recommended. Students may type such comments at the top of their files. For example, in the topic of welding, students may write the following Capability Description to a file:

This program is designed to solve welding problems under the following processes:

- (1) *The program can only be applied to a static in-plane load.*
- (2) *The program is good for both inch and metric systems.*
- (3) *If only the yielding strength of the welding material is given, the theory of maximum shear is used to convert the yielding strength to allowable shearing stress.*
- (4) *When providing the input information of the welding seams and external load, a coordinate origin for the welding system must be chosen.*
- (5) *Output of the program is the factor of safety.*

Students are encouraged to read such comments to ensure that they open the exact file for their application. These comments are particularly critical during the final exam when many program files have been developed.

3. Inputs

Incorrect inputs to a program will yield incorrect solutions. Using the characteristics of spreadsheet programs, the input area can be emphasized by filling it with different colors so that students will check every input block before reading the solutions. Usually the inputs are given from the problem itself and/or the tables from material properties, such as Young's modulus, Shear rigidity modulus, yielding and ultimate strengths, load factor, stress concentration factor, etc. As given in Figure 2, each block number reminds students to give the correct unit. Students can also insert a figure, such as the one from Figure 3, to help themselves understand the meanings or symbols during their inputs.

Power (HP)	RPM on Driving Sheave	RPM on Driven Sheave	Friction Coef.	Load Factor, K	Gravity Const. (in/s ²)
20	450	350	0.25	1.8	386

Figure 2: Emphasis of the input unit on each block.

4. Design equations

Design equations make up a major part of machine design. As given in Figure 4, since typing equations are difficult to read, students can insert a comment on each block by specifying the Equation Number in the textbook.

All functions available in the spreadsheet software, such as SUM, MAX, IF, AVERAGE, etc., can be applied to formulate design equations, which are typed in sequence according to the design procedures.

For example, in V-belt design, the following equations are typed in sequence:

- (1) *Pitch radius of the driving sheave.*
- (2) *Pitch radius of the driven sheave.*
- (3) *Center distance between the sheaves.*

OD1, in tbl 10.1 p. 321	OD-PD (Table 10- 1) on p.321	Weight w, lb/in (table 10-10 on p. 321)	R1, in, pitch radius	R2, in, Pitch Radius, Eq.10.1	OD2	c dist, Eq. 10.11 on p. 324	Alpha, rad, Fig. 10.2 of p.318
6	0.05	0.0044	2.975	5.78472222	11.81944444	14.80972	0.190878
6.9	0.05	0.0044	3.425	6.85972222	13.36944444	17.03472	0.19105
8	0.05	0.0044	3.975	7.72916667	15.50833333	19.75417	0.191207
10.6	0.05	0.0044	5.275	10.2569444	20.56388889	26.18194	0.191449
14	0.05	0.0044	6.975	13.5625	27.175	34.5875	0.19163

(b) speed reduction

Figure 3: A drawing inserted to explain the symbols of the inputs.

- (4) Angle of the belt with respect to centerline.
- (5) Total length of the belt.
- (6) Wrap angle on driving sheaves.
- (7) Centrifugal force of the belt based on its angular velocity.
- (8) Force on the tension side of the belt.
- (9) Force on the slack side of the belt.
- (10) Resultant load on belts including Load Factor.
- (11) Load capacity of each belt.
- (12) Total Number of belts required.

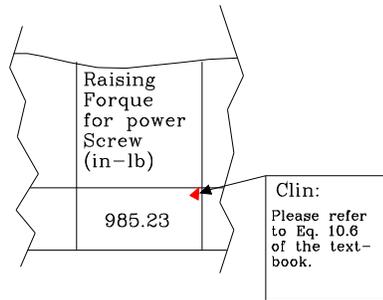


Figure 4: A comment for each equation block.

The main reasons that the equations must be typed in sequence are: Step (4) is derived from Steps (1) through (3); Step (5) is derived from Steps (3) and (4); Steps (8) and (9) are derived from Steps (6) and (7); Step (10) is derived from on Steps (8) and (9); Step (12) is based on Steps (10) and (11).

This example shows that a spreadsheet program can easily organize design equations in the correct order and, therefore, can help students avoid the mistakes made when using calculators.

5. Iteration of the solutions

The solutions of each design problem can be obtained or interpreted by using the following four major characteristics available in a spreadsheet program: (1) Change input condition, (2) Copy and paste, and (3) Go Seek.

(1) Change input condition

In many cases, students or designers seek alternate solutions for a design problem when the design environment changes. After a spreadsheet program has been developed, students can get an alternate solution almost immediately by changing the input condition. For example, in welding design, designers can select different welding materials, different welding configurations, and different factor of safety when the design environment changes. By simply changing the input conditions, students can obtain alternate solutions almost instantly.

(2) Copy and Paste

“Copy and Paste” is another effective method of generating alternate solutions. The input variable for an equation can be classified as either a constant or a variable⁵. If the input is a constant, students add “\$” in front of each block number when typing the equation. If the input is a variable, they do not have to type “\$” in front of each block number. For a simple example, according to Newton’s second law,

$$F = ma$$

students are asked to calculate the force F when a mass m is experiencing different accelerations a . Since the mass is always a constant, a prefix of “\$” is required when typing the block number of mass in the Equation F. Since the acceleration will be a variable, no “\$” is required when typing the block number of the acceleration in the Equation F.

In machine design, the following examples use the capability of “Copy and Paste”:

- (a) *In flat-belt design, what is the resultant stress on the belt when using different sizes on the diameter of the driving sheave?*
- (b) *In V-belt design, what is the number of belts required when using different types of V belts?*
- (c) *In clutch design, how many pairs of clutches are required when considering different sizes on the inner diameter of the plate?*
- (d) *In spring design, what are the properties of a spring when using different commercially available materials?*

Figure 5 shows the results of using “Copy and Paste” to get alternate solutions for the clutch design. A figure plot available in spreadsheet programs explains the relationship between the actuating forces on each plate when the number of plates changes.

(3) Go Seek

As in the example of Equation Force, students can also apply the “Go Seek” function from the “Tool” menu of the Excel to seek the value of acceleration when a force is given. In machine design class, numerous applications of “Go Seek” can be applied to solve different tasks, such as given in the following cases:

- (a) *In V-belt design, what is the size of the diameter of the driving sheave when the maximum allowable stress of a flat belt is given to perform a power transmission?*
- (b) *In shaft design, what’s the diameter of a torsion bar required when the transmission power is changed?*
- (c) *What preload is required for a fastening system when the factor of safety is specified?*
- (d) *In riveting design, what is the size of the rivet diameter when using a different factor of safety?*

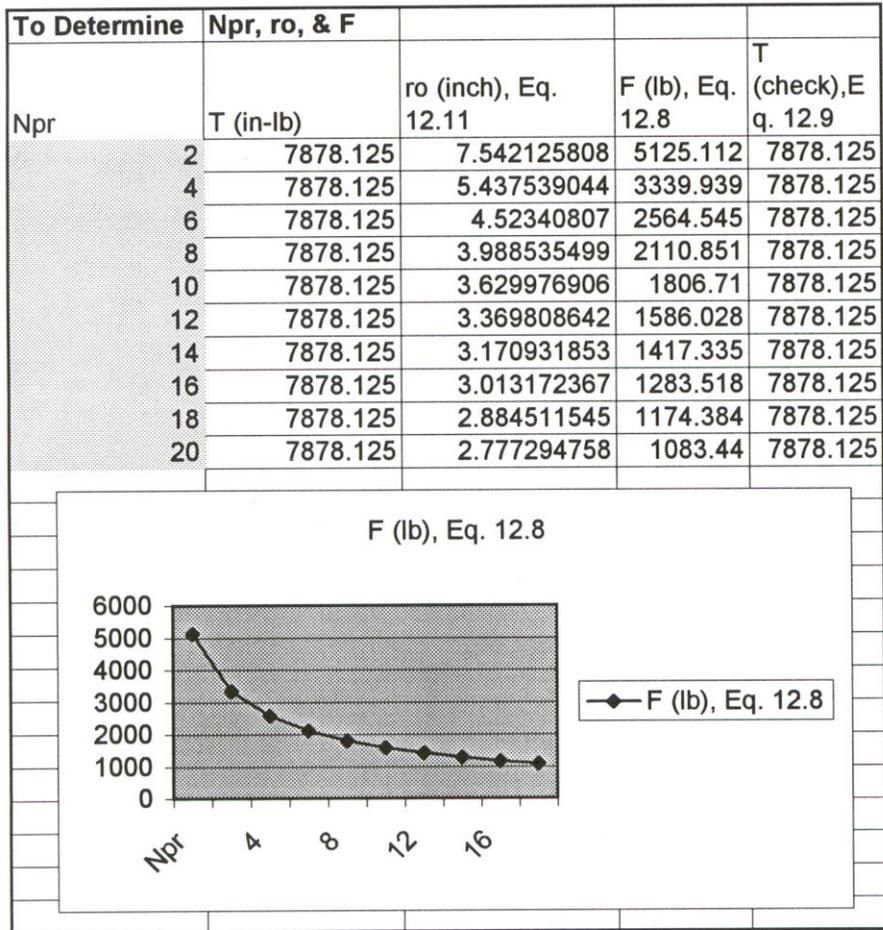


Fig 5: Copy and Paste with figure plot in clutch design.

6. Quizzes, tests, and homework problems

Students are given regular homework assignments, requiring use of the spreadsheet analyses, to familiarize themselves with their applications and the effect of changing variables. They generally submit their homework assignments through electronic mail, which the instructor grades and discusses with them either in class or through electronic mail. Quizzes are regularly given between tests to insure that students understand the procedures of how to develop the spreadsheet programs. It was found early on that, without periodic quizzes, students would not study the reading materials, memorizing only their homework applications, and their performing poorly on tests. Quizzes and tests

went beyond merely looking for answers from among the program files, and included conceptual questions from the reading materials to ensure that students study the entire design procedures. Early comparisons of their spreadsheet analysis method of teaching the course to the traditional method indicate the ability to expose the students to more types of machine design problems in class and on tests, as well as more complex problems. Students could also readily see the effect of changing several variables. It is believed that students develop a better understanding of machine design considerations.

III. Summary

Using spreadsheet programs will definitely help Engineering Technology students organize their solution processes in a course in machine design, which requires much computational work. Students can avoid making mistakes when using calculators and, therefore, increase their interest in taking such a course. Spreadsheet programs are especially effective in obtaining alternate solutions, which are commonly seen in machine design. Although students may have to spend a lot of time in creating a new file, the program usually can be easily modified to solve different problems under the same topic.

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Biography

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Gary R. Crossman, Associate Professor of Mechanical Engineering Technology at Old Dominion University, Norfolk, Virginia, has 31 years of experience in engineering technology education. He holds a Bachelor's degree from the U.S. Merchant Marine Academy and a Master of Engineering degree from Old Dominion University. He has been very active in the Engineering Technology Division and the Engineering Technology Council of ASEE, holding several positions in ETD, including chair. He has also been active in TAC of ABET, as a commissioner and the American Society of Mechanical Engineers.