The Use of Calculation Software In Undergraduate Machine Elements Instruction

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Abstract

Education in the principles and practices of the design of machine elements inherently involves numerous topics such as gears, shafts, bearings, keys, clutches, brakes, springs, and many more. Furthermore, each topic requires students to perform extensive calculations to specify design parameters and to analyze the performance of a proposed design. The design of each component must address the interfaces with mating components. Many alternative designs must be considered to work toward the optimum system. Accomplishing these tasks within a typical undergraduate course or curriculum places heavy demands on students and instructors in terms of time limitations and the ability to manage the process. The use of calculation software can facilitate this process and allow students to produce more robust designs. This paper will outline the advantages of employing industry-standard calculation software within undergraduate curricula on mechanical design. The presenter is the author of a popular textbook on machine elements in mechanical design as well as two others in applied fluid mechanics, and applied strength of materials. Over 30 years of experience in writing technical textbooks gives a good perspective on the movement of state-of-the-art technology from research and industry sources into effective undergraduate curricula. The new 4th edition of the author's book *Machine Elements in Mechanical Design*, published by the Prentice Hall Company in Upper Saddle River, New Jersey, includes the new ***MDESIGN*** software from the German company, TEDATA, designed for use in the United States. TEDATA is the producer of the successful European software ***MDESIGN mec.***

Introduction

The design of machine elements inherently involves extensive procedures, complex calculations, and many design decisions. Data must be found from numerous charts and tables. Furthermore, design is typically iterative, requiring the designer to try several options for any given element, leading to the repetition of design calculations with new data or new design decisions. This is especially true for complete mechanical devices containing several components, as the interfaces between components are considered. Changes to one component often require changes to mating elements. Use of computer aided mechanical design software can facilitate the design process by performing many of the tasks while leaving the major design decisions to the creativity and judgment of the designer or engineer.

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Author's Background

The author of this paper is a professor emeritus of engineering technology at the University of Dayton in Dayton, Ohio. He started his academic career in 1966 teaching a variety of courses in the Mechanical Engineering Technology program and he continues to teach to this day. Besides the course in Design of Machine Elements, he has taught most of the major courses in the program and has contributed to the development of the curriculum and laboratories. He served as associate dean for six years and as department chair for twelve years.

He is the author of three textbooks, all published by the Prentice Hall Publishing Company, a unit of Pearson Education, Inc., based in Upper Saddle River, New Jersey.[1, 2, 3] His first book was published in 1972 and he has continued to generate new books and new editions since that time. The books are designed for undergraduate courses that emphasize the application of the principles of mechanical design.

Design of Machine Elements Software

Each copy of the new 4th edition of *Machine Elements in Mechanical Design* includes a CD-ROM containing ***MDESIGN***, an extensive set of 28 calculation modules developed by the German company, TEDATA. Derived from the very successful ***MDESIGN mec*** software produced for the European market, the U.S. version of ***MDESIGN*** employs standards and design methods that are in typical use in North America. Many of the textual aids and design procedures come directly from the author's book, *Machine Elements in Mechanical Design.*

Topics for which the ***MDESIGN*** software can be used as a supplement to the book include:

Statically Determinate Beams	Statically Indeterminate Beams
Combined Stresses and Mohr's circle	Shaft Design and Analysis
Column Analysis	Column Design
V-belt Drives	Standard Roller Chain Drives
Spur Gearing	Helical Gearing
Bevel Gearing	Wormgearing
Parallel Keys	Woodruff Keys
Ball and Roller Bearings	Plain Surface Bearings
Power Screws	Fasteners
Bolted Connections	Welded Joints
Helical Compression Springs	Helical Extension Springs
Helical Torsion Springs	Short Shoe Drum Brakes
Long Shoe Drum Brakes	Band Brakes
Cone Clutches and Brakes	Plate-Type Clutches and Brakes

Special icons are placed in the book at places where use of one of the 28 modules in the software is pertinent.

Basic Features of *MDESIGN*

The ***MDESIGN*** software is a useful tool for problem solving and design. The software is very user friendly and each module contains several textual and graphical aids that explain the technical bases on which the module is constructed and the data that must be entered by the user. Input screens prompt the user to define the problem and to make basic design decisions. There are links to additional help screens for some of the input variables to provide explanations of the types of choices available and to assist the user in making appropriate choices. Furthermore, embedded databases for some variables allow the user to select values rather than searching for other sources of data. An important example is the inclusion of an extensive set of data for the strength and stiffness properties of materials in many modules. Values for some variables that would normally be found from charts and tables are calculated automatically by algorithms built into the software.

Several modules contain extensive data bases that allow the user to consider multiple optional designs and compare them to select the more optimum choice. Some modules also provide a parametric analysis feature.

After all necessary data are entered, the user applies the Calculate feature to cause the module to perform the required analyses. Some modules provide an initial calculation procedure while searching embedded databases to determine a set of possible choices that meet design requirements. For example, in the *Chain Design* module, the program searches databases for the power transmitting capacity of every combination of chain size, sprocket size, and number of strands of chain, and generates a list of designs that have a sufficiently high design power rating. The user then selects a suitable design and the program completes the calculation and produces the output in an easy to read format. Input and output can be reported in several different units selected by the user. Conversions, if needed, are automatically accomplished by the software.

The output always contains lists of pertinent input values and computed results. Many modules augment the basic output with graphical displays of the results and pictorial views of the element being designed.

In a few modules, it is not possible to ensure that every proposed solution will meet all design requirements. In such cases, the output includes cautionary comments advising the user to redesign the element.

Users must first ensure that the software is appropriate to the nature of the problem to be solved. While the 28 modules cover a wide range of applications within the field of machine design, not every problem can be solved.

Caution on the Use of Software in Undergraduate Instruction

For centuries, many types of computational aids have provided powerful tools for designers. However, there are simultaneous cautions pertaining to their use in instruction. It has long been recognized that the inclusion of calculation aids in engineering design instruction carries the danger that the student or novice user will make undetected errors or inappropriate choices that lead to erroneous results and unacceptable designs. This comment goes back to the days when slide rules were first used to make basic calculations. An error in manipulating the slide rule's many scales or in determining the correct order of magnitude of the result could lead to a dangerous error. Electronic calculators offered improvements but allowed other forms of errors to occur, such as incorrect data entry or improperly calculated arguments for functions. Using spreadsheets or computer programming in any language in instruction has its own set of difficulties, allowing students to make inaccurate calculations to many decimal places.

A computer-age term that has emerged to describe such difficulties is, "Garbage in, garbage out." This means, of course, that if incorrect data are provided or if incorrect computer code is created, the results will always be useless and they will at times be very dangerous if they are relied upon.

For this reason, the following cautionary statement is included in the design of machine elements textbook that includes the ***MDESIGN*** software:

> ***We emphasize that users of computer software must have a solid understanding of the principles of design and stress analysis to ensure that design decisions are based on reliable foundations. We advise that the software be used only after mastering a given design methodology by careful study and practicing manual techniques. Then, data with known results can be applied to the software as a check on the understanding of the program's input and output.***

Examples of the Use of the *MDESIGN* Software in Instruction

This section describes a few of the modules included in the ***MDESIGN*** software and how they can be used in undergraduate instruction.

Gearing Group:

Separate modules are provided for **Spur Gearing, Helical Gearing, Bevel Gearing,** and **Wormgearing.** Each module basically follows the procedures described in the author's book that is patterned after standards of the American Gear Manufacturers Association (AGMA). Input data include the diametral pitch, number of pinion teeth, input speed, output speed, certain material factors, overload factor, reliability factor, and others depending on the module. The program provides guidance for the quality number and the specification of the number of teeth in the gear and its face width. The geometry factors for bending and pitting resistance are computed by the program for some modules, while others require the user to input those using tables and charts from the book or from charts reproduced in the help screens. Outputs include actual output speed, sizes of pertinent geometric features, forces on gear teeth, and tooth stresses. The acceptability of stresses is evaluated by the program with suggestions for the types of materials to be specified. Multiple designs can be tried very quickly to work toward an optimum final result.

Ball and Roller Bearings Module:

This program aids in the specification of a commercially available ball or roller bearing from extensive databases for 16 different types of bearings from two widely known manufacturers, FAG and SKF. The user selects the preferred type, and provides data for radial and thrust loads, speeds, desired hours of life, and size limitations. User specified factors are also entered such as Viscosity Grade for the lubricant to be applied (typical choice is 68); Operating Temperature (typical choice is 40˚C); and Contamination Factor (typical choice is 1.0). The program then produces a list of possible bearings, organized in order of the bore size. The user selects one and the program completes the calculation of performance, giving the projected life of the bearing in hours that is compared with the desired life. Subsequent trials may be done quite quickly to work toward an optimum design.

Helical Compression Springs Module:

The method for the design of helical compression springs illustrated in the author's book is used in this module. The user supplies values for forces and lengths, end type, wire type, type of service (light, average, severe), and initial estimates of the mean diameter of the spring and the design shear stress (typically in the range from 80 to 140 ksi). The program determines an appropriate wire diameter, computes the actual stresses, and outputs the geometry of the spring. Allowable stresses for several types spring wire materials are automatically calculated as a function of spring wire diameter and the type of service. The modules for **Helical Extension Springs** and **Helical Torsion Springs** use similar approaches.

Power Screws Module:

The procedures described in the author's book are implemented by this program to design a power screw with Acme threads having a 14 1/2˚ thread angle. The user enters data for the load to be moved, the distance traveled, and the time to move the load. The material for the screw is selected from lists of alloys of steel, aluminum, cast iron, copper, bronze, and zinc. The strength data are automatically entered by the program. The design value for the coefficient of friction is entered. The output includes the dimensions of the standard Acme screw threads. The program checks the tensile stress in the screw and the shear stress in the threads. The minimum length of engagement of the threads with a nut is reported. The program also computes the torque required for raising and lowering the load, the efficiency, the linear speed of the nut, the rotational speed of the screw, and the power required for driving the screw. If the screw is loaded in compression, it should be analyzed for column buckling using the ***Column Analysis*** module.

Column Analysis Module:

Centrally loaded straight or crooked columns and eccentrically loaded straight columns are analyzed. Input data required are: column length, end fixity, material, cross section shape and dimensions, amount of crookedness if any, and amount of eccentricity of the line of action of the load if any. Output for straight, centrally loaded columns includes critical buckling load and allowable load. Output for crooked and eccentrically loaded columns includes maximum stresses. For eccentrically loaded columns, the maximum lateral deflection of the column is also computed.

Statically Determinate Beams Module:

This is a very extensive beam analysis program that allows the application of loads in virtually any direction including concentrated forces, distributed loads, concentrated moments, and torques. It offers visualization of the beam, its supports, and its loading pattern. It is useful for any type of machine element or structural member loaded as a statically determinate beam. Output includes shearing force and bending moment diagrams, stresses due to bending and vertical shear, deflections, and slopes of the loaded beam. The **Shaft Design and Analysis** module uses similar approaches with augmented consideration of stress concentrations pertinent to shafts.

Conclusion

This paper has described the use of the ***MDESIGN*** software in undergraduate instruction in the design of machine elements as it would be used with the author's textbook, *Machine Elements in Mechanical Design*, 4th edition, 2004. The advantages are noted while also identifying cautions that must be exercised to ensure correct use of the software. Examples of some of the 28 modules in ***MDESIGN*** were discussed.

References

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