

Teaching of Design in Various Academic Settings

Som Chattopadhyay
Department of Engineering
Indiana University Purdue University Fort Wayne
2101 Coliseum Blvd East, Fort Wayne, IN 46805

Introduction

Design as it refers to in the subsequent discussions is the design for strength and is taught typically in junior and senior levels of the mechanical engineering curricula at various academic settings. The typical settings that we consider are a) undergraduate teaching institutions, b) graduate research institutions and c) institutions in the third world countries where the medium of instruction is in English. The author has had the rare opportunity to teach mechanical design in a number of private and public institutions in the United States (primarily undergraduate as well as research institutions) and more recently at the American University in Cairo.

There are a number of issues that need to be addressed: they are a) content of the course, b) relevance of the course as presently taught to the student's future industrial career and c) pedagogy and as a byproduct, the issue of textbooks. We will try to address these issues as they pertain to the various academic settings. We also present a typical mechanical design pedagogical model implemented by the author at a primarily undergraduate private institution in the United States. We were able to successfully integrate the lecture and the lab modules, which provided an effective learning environment for the students.

Content and Sequence

The course in consideration is that of the design of machine elements. The content is handled in a variety of ways in different institutions. Most of the approaches proceed directly to the design of machine elements without specifically getting into the solid mechanics areas. This format is typically followed after the student has had the necessary course work in statics, dynamics and strength of materials.

Some of the institutions proceed directly into the design of machine elements. Some institutions introduce an advanced stress analysis course (advanced strength of materials) before going in to the design of machine elements. In some cases, the mechanical engineering curriculum presents a combination of basic and advanced strength of materials in a single course that precedes the course on the design of machine elements. However, most of the curricula cover the design of machine elements in a single course; some institutions do it in a typical lecture format, while some others do it in a lecture and a lab format. The author during his tenure at Villanova and Bucknell Universities taught this course as a lecture-lab format, whereas at the University of Vermont and Washington State University this was taught as a lecture only format. A notable exception is the model that has been followed at the American University in Cairo where the design of machine elements course is spread over a two-semester sequence, with both semesters taught in a lecture-lab format. This in effect spreads the topics of the design of machine elements into two separate courses, one becoming the prerequisite of the other. The educators in the Middle East note that the students are not adequately equipped with machine construction features and that most of the students do not get opportunities for a hands-on experience. Accordingly they try to address the practical aspect in more detail. This is more in line with the philosophy adopted in a majority of engineering technology programs in the United States. However in the opinion of the author the instruction for the course in mechanical design needs to be a balanced mix of theory and practice.

Within the US, as already noted, the curricula are divided as to whether to deliver the content of the design of machine elements primarily as a lecture format, or to have a combined lecture laboratory format. In the laboratory sessions (typically 3 hours a week), the students work in groups on a detailed design project in various areas of machine elements, usually culminating in the design of machineries, such as a gearbox or a power screw press to achieve certain major design goals or output. Some institutions introduce computer-aided design (CAD) and finite element analysis (FEA) packages into their lab format. This model is used at both places the author taught namely Bucknell University, as well as the American University in Cairo. The idea of using CAD is to reinforce the assembly features of the different machine elements as they fit into the overall device. The aspect of computer-aided design is addressed typically in the freshman year in most academic settings. At Bucknell University FEA package such as ANSYS^[7] is introduced in the sophomore year. Generally speaking, the students are already familiar and CAD and FEA packages before they take the course on design of machine elements, and use their background to verify the analytical calculation on deflection and stresses in machine members.

Textbooks

A few remarks on the content that appear in the textbooks need to be highlighted. Most of the textbooks, such as the ones authored by Shigley^[1], Juvinall^[2] and Norton^[3] in the first half of the text provides the solid mechanics background that is required addressing the strength issues associated with various machine elements. The text by Mott^[4] addresses the topics in a somewhat different way. The stresses and deflections due to direct tension-compression, bending and torsion are presented. The material allowable limits from various failure theories are presented as well. Then these textbooks get into the detailed assessment of various machine elements, such as, shafts, bolts, springs, gears, bearings, clutches, brakes, etc. This is the typical format followed in the textbooks that are currently in use at various US colleges and universities and also overseas.

In some of the countries, such as India, the textbooks that are used also follow the same pattern. However some of the deficiencies appear in the traditional texts. First of all, one needs to address the issue of structural materials. Most of the textbooks cover the content with the fundamental assumption that the materials are linearly elastic, homogeneous and isotropic. This pretty much eliminates a broad class of materials of construction namely plastics, polymers and composites which are finding increasing use as structural materials. So as educators, we must address these issues to a certain extent, as it relates to the design of machine elements. The aerospace and automotive industries are currently using materials that are often stretched beyond the elastic limit, necessitating the use of plasticity. Furthermore, an isotropic behavior is manifest in composite materials that need to be addressed in the curriculum. Aside from these considerations, the aspect of materials selection is seldom addressed.

GENERAL CURRICULUM ISSUES

It is the opinion of the author that there is a definite need to include the basic elements of materials selection before one embarks on the aspect of strength design of machine elements. This outlook needs to be introduced early on in the design curriculum. A few books address this aspect, notably by Ashby^[5] and Farag^[6]. At the American University in Cairo, the materials selection course is introduced at the senior level but is not tied to the course on the design of machine elements. However, very few curricula in the United States have the course on materials selection and if they do, there is no adequate tie-in with the mechanical design course. For example, the author had the opportunity to teach the course on Material Selection in Mechanical Design at the University of Idaho, which was a stand-alone course in the senior year of the Mechanical Engineering program. The author is not aware of other institutions in the United States that specifically cover the topic of material selection as a separate course. Some recent textbooks on the design of machine elements address this aspect, e.g. Collins^[10]. Dieter's^[11] text, although not a text on design of machine elements, addresses this issue as well.

*Proceedings of the 2004 American Society for Engineering Education Annual Conference and Exposition
Copyright © 2004, American Society for Engineering Education*

Another aspect that is not specifically addressed in the design of machine elements is the issue of fatigue and its relationship to fracture mechanics. Such a treatment is rarely followed in most curricula and there is an absolute separation of materials science and mechanical design. Earlier programs on materials science in the United States and overseas have essentially focused on metallurgy and micro-structural aspects. It is the opinion of the author based on his extensive industrial experience primarily in the power generation industry, that new development in fracture mechanics and its relationship with fatigue should be emphasized in the current design curriculum. Furthermore, the life cycle issues of design should be continually brought into perspective as one proceeds to design machine elements.

A significant feature that is often not addressed is the current trends in miniaturization and the impact of nanotechnology and micro-electromechanical systems (MEMS). Some the curricula in the United States are now focusing some attention on this aspect but rarely it is integrated with the design of machine elements. The issues of how does one go about designing machine elements at micro-scale and how the curriculum could be built around that perspective need to be explored in some detail. Another feature that needs to be addressed is the fact that most of the design calculations that were performed in the past for the design of machine elements using a closed form strategy does not necessarily apply for machine or structural elements with complicated geometry or composed of advanced materials and subjected to time varying loads. Therefore it is imperative that some numerical solution be emphasized early on in the curriculum. The use of some general-purpose finite element program such as ANSYS ^[7] and Pro- Engineer ^[8] has proved to be beneficial in finding deflection and stresses. Such evaluations should be applied to the design of machine elements, if resources are available. However this discussion relates to linear elastic material behavior only, and indeed a large number of design calculations such a representation is adequate. Moreover, there is nonlinear behavior due to large displacements, large structural deformations, plastic deformations, etc. In such cases, one has to deal with a detailed finite element numerical solution along with the corresponding challenges of interpreting the calculated stresses and deflections and comparing with the appropriate allowable stresses. Indeed as we come across new classes of materials, this aspect presents a great deal of challenge. Therefore, a general awareness needs to be provided to the students on the numerical solution using finite elements (or other methods) for analyzing structural deformation and stresses. It is to be realized that due to complexity in material behavior, especially in problems with anisotropy and inelasticity, the classical closed form treatment of deflections and stresses is neither practical nor valid. There also should be a renewed look at the curriculum, which based on presenting machine elements that are rarely designed in the work place situations. For example, gears are rarely designed for strength in current industrial settings. Instead, gear drives, which are standardized, are usually picked from a manufacturer's catalog. This is process is similar to the one followed in the selection of bearings in a course on the design of machine elements. In fact, more emphasis should be placed on how the various machine elements are assembled in a piece of machinery rather than looking at a particular machine element in great detail.

This aspect is very rightfully understood at the American University in Cairo where a great deal of emphasis is placed on machine construction. The role of a 3-dimensional CAD package is invaluable in its ability to bring appreciation and insight into how various mechanical elements are combined in typical machinery.

Apart from all these it is our job as educators in mechanical design to prepare students for their future roles as practicing engineers where a multifaceted approach to design is generally adhered to. Typically these graduates serve as designers performing designs of various components by primary sizing calculations and looking at the bigger picture of the components in the overall system. Such designers often interface with specialists in the area of thermal and structural analyses. Some of the training provided in the mechanical design course is useful to structural analysts in a number of ways. However the aspect of numerical solution becomes increasingly important to the people groomed to be structural analysts.

Finally, the students should be made aware of the fact that the design for strength is a feature that is not deterministic but indeed stochastic. Such a treatment is presented in a handful of textbooks but is hardly employed in the conventional design pedagogy. Indeed, statistical consideration enters into the problem from the standpoint of variability in dimensions, loads and in material stress limits. Each of these parameters has a statistical variation, which could be characterized in terms of the respective means and standard deviations. The students need to be cognizant of the fact that the notion of the factor of safety that is used in design is one in which this variation is accounted for in practice. Additionally, this is a feature that very crudely accounts for the statistical variation in the dimensions, loads and material properties. [See *e.g.* [9]] It is gratifying to find that such an appreciation is gradually gaining ground in the design curricula in both the United States and overseas engineering programs.

Description of a Lecture-Lab Pedagogical Model for Mechanical Design

In this model, that the author experimented with the junior level mechanical engineering students at Bucknell University during the spring of 2003, the lectures and the lab went hand in hand. The course consisted of three one hour lecture sessions and a three-hour lab/design session per week. After providing the necessary background for designing mechanical elements in terms of mechanics of materials including fatigue, the various mechanical elements were introduced in this prescribed sequence based primarily on the design of a speed reduction system. The project problem that the student teams needed to work on was presented. The problem was to design a two-step speed reducer in which the first reduction was to be accomplished through single reduction spur gears and the next step through a choice of either a chain drive or a belt drive. The input shaft speed and power level was specified as well as the desired output shaft speed.

Couplings were to be provided between the input and output gear shafts. In addition there would be a clutch between the motor and the gear input shafts and a brake at the output end. The outline of the project is illustrated in Figure 1. The lectures were built around the project problem. First element that was introduced was the shaft. The students were taught how to design shafts as a beam under combined bending and torsion. This was followed by the design of bearings; both the journal and

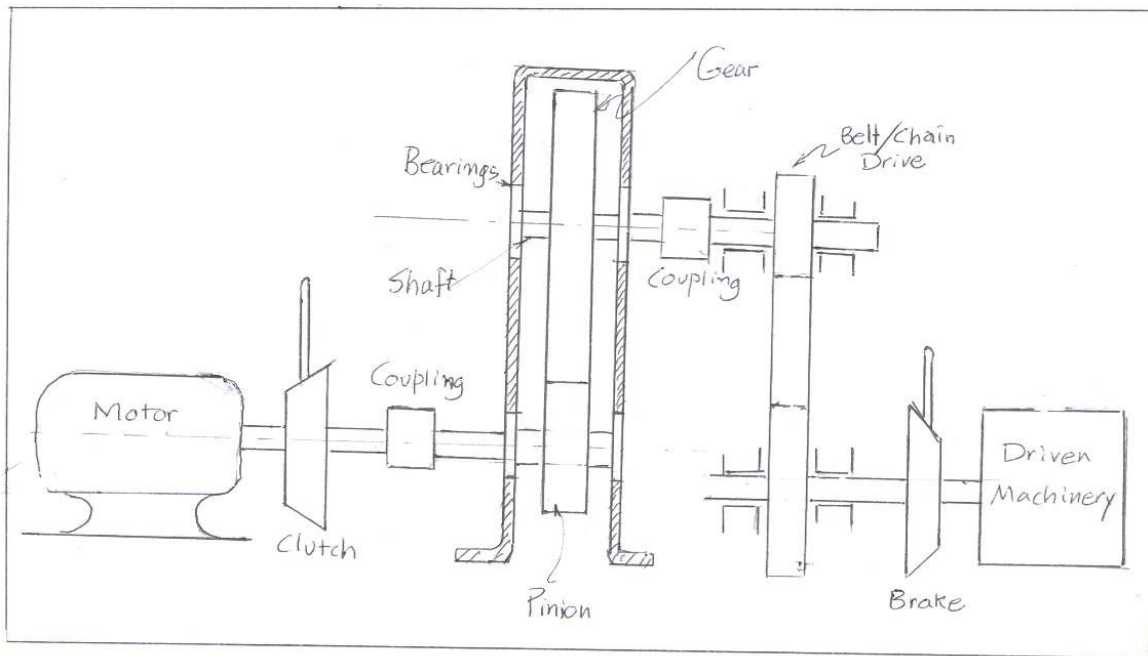


Figure 1: Layout for the Mechanical Design Student Project

the rolling element bearings were covered. Gears were introduced next with coverage limited to spur gears only. In the lab sessions the students first designed the gears and then using the forces and torques exerted by the gears, designed the shafts, the bearings and the couplings.

The students then had to design both journal and ball bearings for supporting the shafts, the topics of which were covered in the lecture sessions. The shafts had to have variable cross-sections along their axes to economize material and also to match up with the bearing and coupling bore sizes. Once the shaft dimensions were finalized, the students determined the deflections of the shafts by a finite element code such as ANSYS^[7] using a series of beam elements. The students then designed the belt drive and the chain drive (they had to design both options for the second step of speed reduction). The lecture sessions for belt and chain drives of course, preceded the design of those elements. The lecture sessions were then devoted on mechanical springs, which were subsequently followed by, clutches and brakes. The final job of the student teams was to design the clutch and the brake for this machinery.

Discussions and Conclusions

In this paper the author has outlined his experience teaching the course on design of machine elements at various academic settings both within the United States and in the Middle East. A number of deficiencies in the pedagogy have been noted and suggestions provided. The intent of the author is not to have a total restructuring of the program, but to include some essential elements in the curriculum. The textbooks can address these problems to a very large extent, and there is a need to have new texts in this area. It is interesting to note that some of the current texts have already started to expound on this subject. For example, Shigley and Mitchell^[1] address the issue of stochastic approach in design. Collins^[10] and Dieter^[11] address the issue of material selection. The overall curriculum needs to have elements of computer-aided design both in terms of computer graphics as well as finite elements to address structural design of complex structures that the students would use in their professional careers and also to verify numerically the solution of classical mechanics problems that are solved in a closed form. The entire curriculum needs to have a modern and a novel outlook and the impact of new areas such as nanotechnology and MEMS and associated concepts of miniaturization need to be addressed.

A model lecture-lab format has been successfully implemented by the author in his teaching of the course on design of machine elements. In this specially designed course, the lab sessions and the lectures go hand in hand with the lecture. This has been very effective as judged by the student response.

Bibliography

- [1] Shigley, J. E., Mischke, C. R., *Mechanical Engineering Design*, Seventh Edition, New York, McGraw Hill, 2003.
- [2] Juvinall, R. C., Marshek, K. M., *Fundamentals of Machine Component Design*, Third Edition, New York, John Wiley, 2003
- [3] Norton, R. L., *Machine Design: An Integrated Approach*, Second Edition, Upper Saddle River, N.J., Prentice Hall, 2000.
- [4] Mott, R. L., *Machine Elements in Mechanical Design*, Fourth Edition, Upper Saddle River, N.J., Prentice Hall, 2003.
- [5] Ashby, M. F., *Material Selection in Mechanical Design*, New York, Pergamon Press, 1992.
- [6] Farag, M. M., *Material Selection for Mechanical Design*, Upper Saddle River, N.J., Prentice Hall, 1997.
- [7] *ANSYS Version 8.0*, ANSYS, Inc., Canonsburg, PA, 2003
- [8] *Pro/ENGINEER*, PTC, Needham, MA, 2003
- [9] Steffen, J. R., Hayes, L. T., Wiedemeir, D. W., Tennyson, S., "Introducing Reliability Concepts in Machine Design" *Proceedings of the 1998 ASEE Annual Conference*, pp. 902-909.
- [10] Collins, J. A., *Mechanical Design of Machine Elements and Machines*, New York, John Wiley, 2003.
- [11] Dieter, G. E., *Engineering Design: A Materials and Processing Approach*, Third Edition, New York, McGraw Hill, 2000.

SOM CHATTOPADHYAY teaches freshman engineering courses at Indiana University-Purdue University, Fort Wayne, Indiana. He received his Ph.D. in Mechanical and Aerospace Engineering from Princeton University. His areas of research interest are design theory and methodology, pressure vessel design/analysis, and dynamics of mechanical and electromechanical systems