Concurrent Design and Manufacturing in Vibrations and Dynamics: An Introductory Course

Jamal A. Ghorieshi and Michael W. Jennings‡
Department of Mechanical and Materials Engineering
Wilkes University, PA 18766

This paper describes student learning enhancement through transformation of teaching base from "what is being taught" to " what is being learned," by taking Vibrations and Dynamics as a prototype introductory course. Implemented throughout the curriculum, this transformation of teaching base plays the major role in satisfying *ABET 2000* criteria. The Vibrations and Dynamics course—offered in the third year of the mechanical engineering program at Wilkes University—was drastically revised from the traditional lecture, homework and paper design project. These changes include: developing, designing, prototype construction, data acquisition and processing, and testing along with oral presentation and demonstration. The main goal is for students to learn and practice engineering in a manner that is a continuing habit. In this process, students learn: (i) What is in a machine shop? (ii) what tools are necessary? (iii) how to come up with practical and useful solutions? (iv) decision making and generating alternatives in the light of incomplete and often contradictory conditions. (v) illustrate and alleviate the critical problem in a tangible manner. (vi) materials and parts selection. (vii) system assembly. (viii) applicability and ergonomics of the systems. Each group of three to four students was assigned a project with a deadline. The projects include the real world applications of the course topics such as free and forced vibrations, vibration isolators, resonance, transducers, imbalance, modal shapes, data acquisition and diagnostics, etc. Typical projects of design and construction are: a rotating fan, illustration of critical problems and solutions; velocity transducers, evaluation of the range of usability; a typical three story frame (building), resonance and mode shapes demonstration; a rotating machinery diagnostic demonstration, and more. Students learning is enhanced greatly by doing their own project and observing as other projects progress. Two of the major outcomes were brainstorming and interaction among the groups leading to innovative ideas and solutions. One of the major hurdles in this process was the demands of time both for students and faculty alike.

INTRODUCTION

The undergraduate engineering curriculum has periodically undergone structural changes to reflect the societal needs of time and to head-start the future technological innovations and learning/teaching cultures. Even though the traditional engineering education has served the nation well, nevertheless it has exhausted its effectiveness over the last two decades because of rapid changes in technology and international trade. In pursuance of answering the question: "What should be taught to engineering students?", the instructional changes intensified sharply since 1970. The engineering curriculum progressed from stand-up lecture and laboratory demonstration format to problem-solving mode, visualization, and experimentation. This paradigm shift is encouraging innovation, creativity, design, hands-on experience, solution of real world problems, interdisciplinary integration, and response to industrial, economic and social sensitivity. Major emphasis is to teach processes that lead to a life-long learning in order to lengthen the impact of college training by capitalizing on resources available. To stay competitive, these changes are becoming mandatory for every engineering institution, business, and industry. However, the responsibility of implementing this paradigm shift in curricular structure rests with the engineering faculty. Needless to say, large differences are found in faculty attitudes and views under the false pretext of academic freedom. Each institution has its own mission, paradigms, and methodology to reach aspired goals. A system thinking is necessary to implement changes at a speed comparable or yet better than with which the world around and in us is moving. This way a piece-meal approach progressing at turtle speed can be avoided. This way expensive re-training costs by the industry can be eliminated, thereby shortening the market delivery time in order to stay competitive.

There is further evidence that the students who receive industrial experience on graduation are ahead in knowledge and productivity to those who go on to graduate school directly after graduation. By the time academia senses the changes in the industry, the technology is already obsolete.

To change a focus from teaching to learning, we need to re-pose the original question as "what is being learned by engineering students?" This way we can follow the spirit of *ABET Criteria 2000* and design processes to measure the outcomes. When this process is in place, there are many anticipated benefits. Firstly, the academia will be happy that it has produced a quality product. Secondly, industry will be content that they are getting a quality product that could be put to immediate use. And last, but not least important is the fact that engineering students will find a meaning in their life on becoming productive members of industry and find excitement and enthusiasm that follows.

We have applied this new paradigm to our introductory course on Vibration and Dynamics. The processes and successes of that experiment are delineated below.

CASE STUDY DESCRIPTION

The Vibrations and Dynamic course is offered in the second semester of the junior mechanical engineering program at Wilkes University. The objective of this course is to provide an overview of free and forced mechanical vibrations in linear and non-linear systems with single and multi-degrees of freedom. Prerequisites include strength of materials, differential equations, and dynamics. The course meets three hours per week with the desired goal of providing students with a comprehensive understanding of mechanical systems and techniques that are used in problem solving process. The following course outline lists the topics:

<u>Course Outline</u>

1. Introduction to systems.

2. Free response of single-degree of freedom linear systems.
3. Free response of damped single-degree of freedom linear systems.
4. Modeling and energy method.
5. Stability.
6. Harmonic excitation.
7. Rotating unbalance.
8. General forced response.
9. Two- degree and multi-degree of freedom systems.

The course includes semester long home work's and quizzes, three tests, plus a comprehensive final, and a semester long project.

NEW TECHNIQUE IMPLEMENTATION

The teaching transformation predominantly takes place in the method of course assignments and its implementations. This is discussed as follows:

I) Subjects

- Why are the topics and sub-topics important? Why should they be studied? How do the problems develop and evolve?
  What are the reasons behind the mathematical modeling? What resources are needed? How the approximate solutions compare with more realistic behavior obtained from computer aided design or experimentation on the real system?
- What is the best possible technical solution and what is the compromised solution under the given constraints (including non-engineering constraints)?

II) Assignments:

- Real world problems.
- Industry sensitive problems.
- Generating and evaluating alternatives in order to pick a solution.
- Critical thinking and anticipated innovative solutions in different set of constraints.
- Use of engineering tools (hardware and software) in problem solving and evaluating alternatives by changing parameters.
- Use of measuring devices such as accelerometer, velocity and displacement transducers, dynamic signal analyzer, and data acquisition instruments and packages in order to test the designed outcomes.
- Working with the machine shop personnel and equipment to implement the design.

III) Design Projects:

The students work in groups of three to four to stress the importance of team work. Each group is assigned a design project. These projects are chosen based on the conditions that may occur in industrial site or industrial requirements. Requirements of a project include: developing, designing, constructing, testing, and finally an oral presentation along with a written report. The prototype design projects are:

1. Rotating Unbalance:

   To illustrate how unbalance occurs in rotating machinery and how to damp-out the vibrations and hence avoid resonance.

2. Velocity Transducer:

   What vibration measurement devices are? How are these made? How do these function? When and how they should and can be used?.

3. Three Story Shear building:

   How structures may oscillate? What are the theoretical, computational, and experimental ways of determining the dominant mode of vibrations? What are the consequences of oscillations at resonance frequency and how to alleviate them?

4. Rotating Machinery Diagnostics:

   How to diagnose the vibration induced by defects in a machine, such as bearing defects, misalignment, and looseness, etc.?

Generally, time spent on the projects varies from 60% to 90% of that spent on theoretical lecture and is done primarily at students own schedule with deadlines for milestones indicated; however, advising is available from instructor, access to the mechanical design laboratory and computer aided design laboratory is provided, and arrangements of supervising the students in the machine shop in the absence of resident machinist are made.

Following is a summary of the prototype projects:

Project One–Rotating Unbalance

In this project, students designed and constructed a rotating-fan-platform assembly which consisted of a fan manufactured by Rotron Inc. attached to a base. This unit was then connected to a fixed mounting surface by means of a spring and damper. A mass was attached to one blade of the fan thus introducing rotating unbalance to the system. the system response was then modeled so as to select an adequate spring-damper combination to compensate for the unbalanced condition. Illustrations are shown in Fig. 1.

Project Two–Velocity Transducer

Students on this project fabricated and calibrated a velocity transducer. This involved conversion of voltage readings produced by the transducer into corresponding velocity values. The design of the transducer was completed so as to facilitate monitoring velocity at a specified range. Computer-aided data acquisition was employed by using a program known as DTVEE to analyze and calibrate the transducer. The system was modeled so that the inherent values of the transducer could be chosen to achieve the desired velocity range. This included mass, damping coefficient, and stiffness. The problem was approached from two directions: empirical calculations, and experimental data obtained through the data acquisition. Illustrations for the transducer are shown in Fig. 2.

Project Three–Three-Story Shear Building

This project involved the design, construction of a three story building model and analysis through experimental and theoretical means. The model was constructed on campus in the machine shop. It consisted of nine inch long aluminum rods with a diameter of 0.25 inches for the vertical supports and 5”x 5”x 0.125” aluminum plates for the floors. An accelerometer was utilized to determine the response of each floor to an impact load. Students determined the natural frequency of the building through experimental data from the transducer, mathematical analysis, and computerized modeling with ANSYS software. Mode shapes and natural frequencies for various loading conditions were presented in written and oral presentations. The Matrix Method was employed for mathematical computation. Plots generated in ANSYS were used to demonstrate the mode shapes at each loading condition. accelerometer data was analyzed and plotted from a Hewlett Packard Model 1200A Oscilloscope. A simplified diagram of the model is shown in Fig. 3.

Project Four–Mass-Spring Model

In this project, a group of students chose to characterized the vibrations of two metal beams where one was made of aluminum and the other of steel. The scope of the project included: identifying the natural frequency, quantifying internal damping, determining strength characteristics of the materials, finding density and weight, material behavior under stress, and response to transient and steady-state excitation.

Testing carried out on the simply supported beams included: analysis of forced excitation using an accelerometer and a Hewlett Packard Model 1200 oscilloscope, sonic velocity testing, oscillation with variation of mass and stiffness, and determination of weight and density. Empirical calculations were completed using a combination of general equations found in Strength of Materials and Engineering Vibrations textbooks. This included manipulating equations involving the Magnification Factor and the Logarithmic Decrement.

A detailed written report of the project was compiled including: printouts of the data gathered with the accelerometer, tabulated data gathered from testing, all calculations, and graphs created in Excel illustrating the various properties of the material that were defined in the project scope. This project demonstrated to students that variation does exist in generally accepted values of material properties and challenged them to pursue methods of verification through vibration characteristics.

Project Five–Rotational Machinery Analysis

The final project summarized required a group of students to analyze multi-degree of freedom systems. This included design and construction of a rotational vibration simulator which could be used to demonstrate various defects which generate unacceptable levels of vibration in rotating systems. This model demonstrated vibration caused by: bearing defects, misalignment, and looseness. An illustration of the simulator is shown in Fig. 4.

A 1/3 hp Dayton electric motor was coupled to a shaft supported by Dodge pillow block bearings. Slots in the bearing housings allowed for horizontal movements via jacking bolts to move the shaft out of alignment. Initial alignment was obtained using dial indicators and machining the mounting base where the bearings were fastened. Looseness was demonstrated by leaving the set screws loose that lock the bearing race to the shaft. An outer race defect was placed in one of the bearings in the machine shop. After the demonstrator was made operational, data was collected by the students with a Data Line Data collector and analyzed with Emoniter and Mechanalysis software. Both the data collector and the software are products of Entek Corporation.

Spectrums generated in the software were plotted with the ordinate having values of amplitude. Acceleration readings were converted by the software into velocity with units of inches per second. The abscissa values were frequency with units of CPM. These units were chosen because of the ease at which they could be correlated with RPM of the motor used to drive the demonstrator. Normal plots were compared with plots of the defects. Analysis functions of the software were utilized to demonstrate how these particular defects could be found if unknown in rotational machinery. A presentation and report was prepared by the students detailing procedures and learnings of the entire project. Typical sample plots are shown in Fig. 5 and Fig. 6.

RESULTS

This experimentation illustrates that an introductory course could be used to impress upon students the importance of the subject that they study and its applications. Furthermore, it prepares students with a strong knowledge that they could build on over their career. In this experiment students learned:

- The role that vibration has in our daily life.
- What transducers are, how they are made and used?
- What data to collect using data acquisition package and how to evaluate and use the data?
- How failure due to vibration occurs, and how to alleviate them?
- How vibrations are taken into account in designing machinery or structures.
- How to diagnose problems and find the *best possible solution*?

Another result that is of particular interest, which surfaced in the process of completing the assigned design projects, was that each group was cognizant of other group's projects and helped each other. Often phrases such as " it's easier to ...", or " it's cheaper to ...", or " can't do it ...", or " can't use...", or " it isn't easy to install...", or " it doesn't look good..." , were heard. It was witnessed that students cooperate with other groups and even lend helping hand where needed. The students get involved with collective brains storming. This helped in:

- feasibility study,
- various manufacturing options,
- cost effectiveness,
- evaluation of various solution options,
- system user-friendliness.

EVALUATION

The students with this background will be able to function well in an entry level job in the field of mechanical vibration and do problem solving in either modal analysis or machinery diagnostics without recourse to retraining by the employer. This indicates that this method of teaching has the best result.

REFERENCES

‡Also at Procter and Gamble, PA.

ILLUSTRATIONS

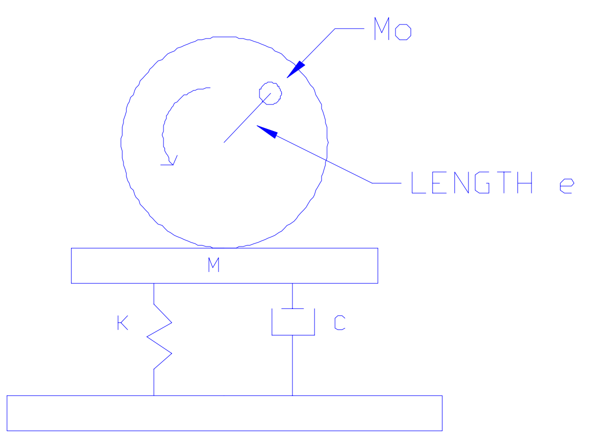
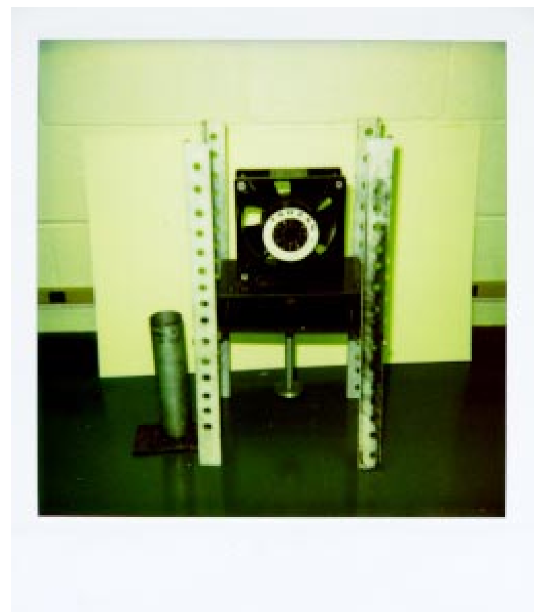


FIGURE 1: ROTATING UNBALANCE SPRING-DAMPER SYSTEM



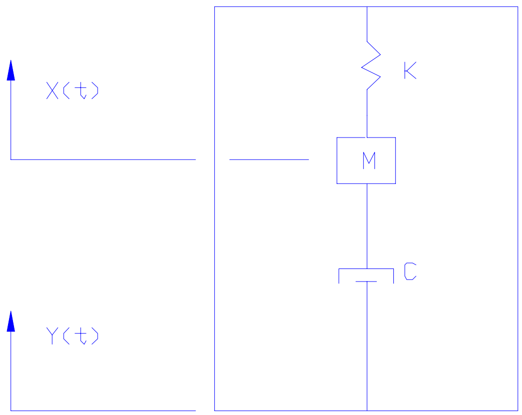


FIGURE 2 SCHEMATIC OF VELOCITY TRANSDUCER

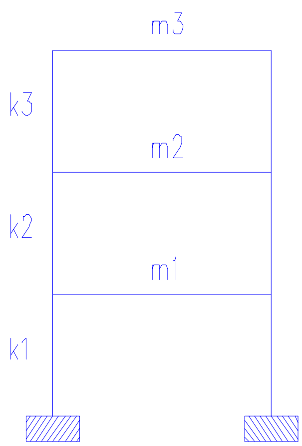
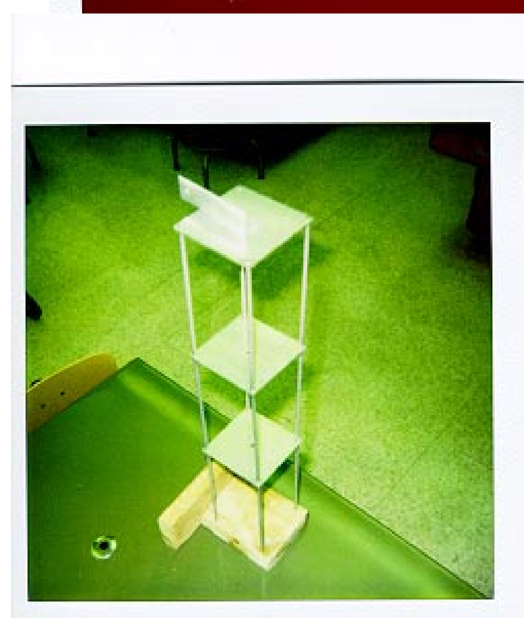


FIGURE 3 SCHEMATIC OF THREE STORY SHEAR BUILDING



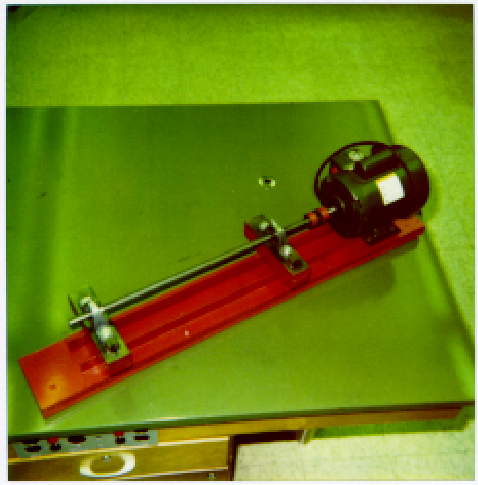


Fig.4 Rotating Simulator

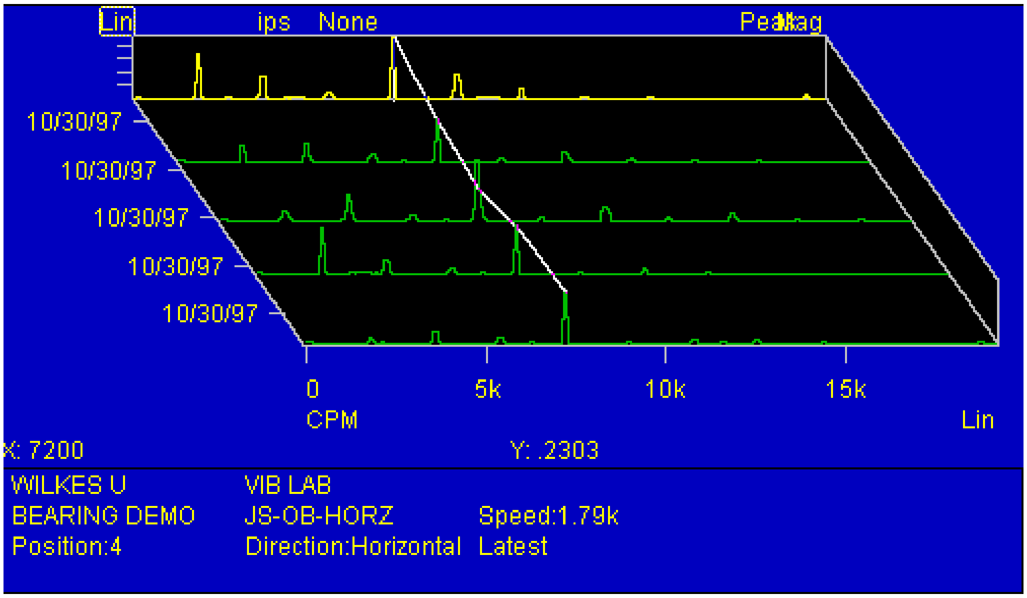


FIGURE 5: WATERFALL MAP

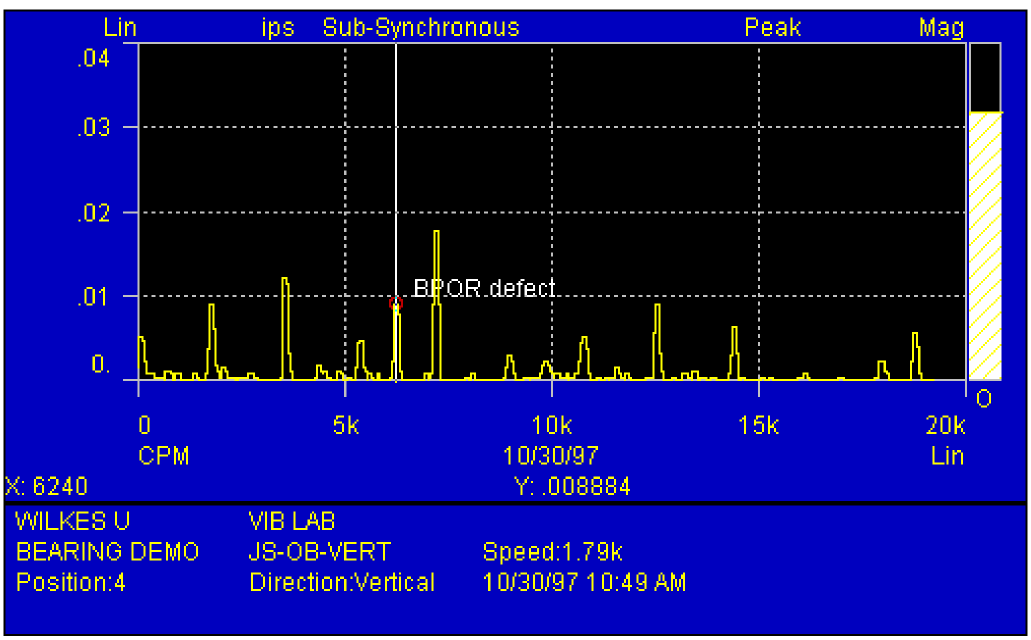


FIGURE 6: DEFECTIVE BEARING