The New Dynamic Systems Sequence at Kettering University

Ram S. Chandran and Janet Brelin-Fornari
Department of Mechanical Engineering
Kettering University

Abstract

This paper describes the development and restructuring of courses in the Dynamic Systems Sequence implemented in the Department of Mechanical Engineering at Kettering University. The proposed courses in Dynamic Systems, two in the series, combine three previously offered courses. The emphasis is on a multi-disciplinary approach to systems engineering and includes a hands-on laboratory experience, computer simulation, and theoretical analysis as a single experience in a studio environment. This approach allows the students to develop and exercise the underlying theory to real world system problems.

Introduction

In the recent curriculum reform implemented at Kettering University, the number of total program credits for graduation was reduced from 180 to 160. The restructuring was done as a part of university wide curriculum reform initiated after reviewing feedback from interested constituency, assessment data, and analysis of future trends. This effort took approximately two years. A careful and systematic approach to curriculum reform was utilized by the Mechanical Engineering faculty to maintain the quality of education while reducing the total number of credits to graduate. The Mechanical Engineering credits needed for graduation was decreased from 96 to 76 credits, plus 4 credits for an undergraduate thesis (which is engineering based). It may appear that the final curriculum adopted was diluted. The real outcome, was the integration of basic math and science courses into the Mechanical Engineering curriculum as well as the integration of related engineering courses. The overall emphasis was a multi-discipline approach to solving engineering problems.

One example of the integration of courses at Kettering University was within the Dynamics Systems Sequence. In the previous curriculum, Mechanical Vibrations, Systems Modeling, and Control Systems were taught as separate courses, each required for graduation. In the new curriculum, these three courses have been integrated into two courses, again, both required for graduation. Many universities currently teach the three courses in the Dynamics System Sequence as separate courses; some universities offer Control Systems as an elective. Other universities have attempted to integrate the Dynamics Systems Sequence[1]. This paper will show how integration was achieved at Kettering University. The reformed courses are titled Dynamic Systems I and II. An outline of these two courses is included in Appendix A.

The Courses

Dynamic Systems I (MECH 330) is a junior level, four credit hour course. There are four hours of classroom contact with the class meeting twice a week for two hours at a time. This course introduces students to mathematical modeling of multi-discipline systems which include mechanical, electrical, and/or hydraulic components. The mechanical examples in this course are mainly from vibrations, but its similarity to electrical and hydraulic systems is also emphasized. Modeling is conducted via bond graphs and Newton's Laws (force and energy balance). The course relies on the use of the software package MATLAB/SIMULINK to teach system simulation and the understanding of system behavior in the time domain. The pre-requisites for this course are: Dynamics, Differential Equations and Laplace transforms, Electrical Circuits(introductory level), Matrices and Numerical Methods, and Fluid Mechanics.

The course can be divided into two parts: (1) mathematical modeling and (2) analysis and synthesis of simple systems. The modeling portion consists of bond graphs as applied to multi-domain systems and development of system models in state vector format. The students are also taught the classical approach to mechanical system mathematical modeling using force/moment diagrams and energy balance (Lagrange's Equation) methods. Analysis, design, and synthesis are approached using hand calculations and the software package MATLAB/ SIMULINK. Students calculate parameters such as natural frequency, damping constant, time constant, and characteristic equation. Using the software, the students simulate system response and study the system characteristics such as transient and steady state response in the time domain. With the application of these skills, the students complete design projects which evaluate system performance with the variation of critical parameters. An example of a simulation assignment for MECH 330 is located in Appendix B.

Dynamic Systems II (MECH 430) is a senior level, four credit hour course with the class meeting three times a week, twice for a two hour lecture session and once for a two hour laboratory experience. The mathematical modeling techniques learned in MECH 330, are used to develop control system models. Subjects covered include negative and positive feedback, system performance characteristics, block diagrams, and transfer functions. The students learn methodologies to design controllers such as PI, PD and PID. The improvement of system performance is addressed using various analytical and computational techniques such as root locus. Most of the systems analyzed are multi domain in nature. The students simulate system response and evaluate its performance characteristics both in time and frequency domains. Again, the simulation software package used is MATLAB/SIMULINK. An example of a final project assigned for Dynamic systems II (MECH 430) is given as an example in Appendix C. Only a portion of the work completed by the students is shown. The students had performed initial parameter evaluations using hand calculations. Then the students used MATLAB/ SIMULINK tools to simulate the system and designed the controller using root locus techniques.

The laboratory for MECH 430 is currently under development and is scheduled for a pilot term in Summer of 2002. The laboratory includes approximately five experiments focusing on mechanical, electrical, and hydraulic control system problems. At least two experiments emphasize multi domain systems. The students will mathematically model and simulate a system and the response will be correlated to experimental hardware performance. Subsequently, system performance enhancement will be addressed using both the simulation and the hardware. The laboratory will be organized for groups of students limited to three members.

Discussion

These two courses are challenging both from the point of teaching and learning. The simulation tools are extensively used in the lecture class to understand system behavior and parameters influencing the same. This is one of the primary reasons for using the studio environment[2] for teaching these courses. Students are required to do a number of simulation assignments during the term which culminates in a design project wherein they design a controller using simulation. With the addition of the lab in MECH 430, a portion of the design project will be to correlate the simulation using experimentation.

As is often the case with integrated courses, currently no textbook is available. A custom textbook[3] was developed in collaboration with Wiley and Sons, combining sections of three textbooks dealing with Vibrations, Systems Analysis and Control Systems. The book has been under evaluation for the past three terms. Initial student response has not been encouraging, therefore, additional material is under development to be included on the course web page (under development). Topics will include refresher mathematics and dynamics.

The initial assessment indicates that on average, 81% of the MECH 330 students "highly agree" that the course objectives were met, whereas approximately 55% of the MECH 430 students responded as "highly agree". The 55% rating should improve with the inclusion of the laboratory experience. Feedback from the students regarding course content has been positive, but those who co-op in the field of vibrations are searching for a more intense study of mechanical, vibrating systems. To address this issue, a mezzanine level course in Vibrations may be added to the curriculum as an elective. The use of MATLAB/ SIMULINK within the two courses has been widely accepted by the students. Subsequently, the students are using the software in other courses.

Conclusions

In this paper, the status of a new integrated sequence in Dynamic Systems developed and offered by the Department of Mechanical Engineering, Kettering University, Flint, MI is presented. This integrated sequence was needed to accommodate the reduction of the total number of credits hours required to graduate. The three courses that were offered in the previous curriculum were combined into two courses with emphasis on multi domain systems. Simulation tools, such as MATLAB/SIMULINK, are used to facilitate learning. A laboratory has been constructed for the second of the two courses and will be implemented in Summer 2002. A custom textbook was assembled for these courses with the help of Wiley and Sons.

References

[1] Gretar Tryggvason, Michael Thouless, Deba Dutta, Steven L. Ceccio and Dawn M. Tilbury, " The New Mechanical Engineering Curriculum at the University of Michigan", Journal of Engineering Education, July 2001.

[2] Patrick Little and Mary Cardenas, "Use of "Studio" Methods in the Introductory Engineering Design Curriculum", Journal of Engineering Education, July 2001.

[3] Dynamic Systems I and II, MECH 330 and MECH430, Kettering University, Wiley Custom Services, 2001.

RAM S. CHANDRAN is an Associate Professor of Mechanical Engineering at Kettering University in Flint, Michigan. He received his B.E., and M.Tech., degrees from India and his Ph.D., from Monash University, Australia. He actively pursues research in the areas of Fluid Power servo systems, System dynamics, Modeling, Simulation and Controls.

JANET BRELIN-FORNARI is an Assistant Professor of Mechanical Engineering at Kettering University in Flint, Michigan. She received her BS from University of Nebraska, MS from University of Michigan and Ph.D. from University of Arizona. She actively pursues research in the areas of Dynamics and Biomechanics.

Appendix A - Dynamic Systems I and II Course Descriptions and Learning Objectives

MECH 330: Dynamic Systems I
2001 Catalog Data: Credit 4 (4-0-4)
Prerequisites: Dynamics, Differential Equations & Laplace Transforms, Circuits, Fluid Mechanics, and Numerical Methods & Matrices.

This is a first course in System Dynamics. The object of this course is to provide a mathematical understanding of physical systems and components. The focus is on multi-discipline approach. Construction of mathematical models of systems with Bond-graph, Newton's Laws (Force/Moment and Energy Balance), and computer simulation using software tools is emphasized. Application of modeling techniques to understand the behavior of free vibration (damped and undamped), forced vibration for harmonic excitation, and systems involving multi-degrees of freedom, including applications such as vibration absorbers will be discussed.

Course Learning Objectives
1. Model simple engineering systems involving at least two disciplines-such as electrical-mechanical, mechanical-fluid, mechanical-electrical-fluid combinations. Develop the linear state equations in matrix form, simple block diagrams, and simple transfer functions.
2. Analyze the system performance in the time domain using Laplace/inverse Laplace transform solutions for simple cases. Evaluate eigenvalues and characteristic equations.
3. Evaluate the system performance characteristics, such as stability, based on accepted matrices.
4. Simulate the system performance in the time domain using accepted professional simulation tools such as MATLAB/SIMULINK.
5. Design simple systems to meet performance objectives using modeling and simulation techniques detailed in the course.

Computer usage:
Basic computer skills and familiarity with MATLAB/SIMULINK.

Appendix A (continued)

MECH 430: Dynamic Systems II
2001 Catalog Data: 4 (4-2-4)
Prerequisite: Dynamic Systems I

This is a second, follow up, course in System Dynamics. The objective of this course is to provide an understanding into basic principles and methods underlying the steady state and dynamic characterization of feedback control systems. The focus is on multi-discipline approach as in the previous course. Construction of mathematical models of systems using Bond-graphs, block diagrams and development of transfer functions and state space models is emphasized. System performance is studied mainly using computer simulation (both in time and frequency domains) software tool(s). Design of control systems is attempted using the same computer simulation tools. Introduction to some advanced topics in control systems is also provided.

Course Learning Objectives:

1. Model simple engineering systems involving multiple feedback loops. The system will include at least two disciplines, such as electrical-mechanical, electrical-fluid-mechanical combinations.
2. Analyze the system performance in time and frequency domains using Laplace/inverse Laplace transform solutions for simple cases. Evaluate the characteristics equations.
3. Evaluate the system performance characteristics, such as stability, based on accepted matrices in time and frequency domains.
4. Simulate the system performance in time and frequency domains using accepted professional simulation tools, such as MATLAB/SIMULINK.
5. Design simple controllers, such as P, PI, PD and PID, for systems to meet performance objectives using the modeling and simulation tools, such as MATLAB/SIMULINK, detailed in the course.

Computer usage:
Basic computer skills and familiarity with MATLAB/SIMULINK.

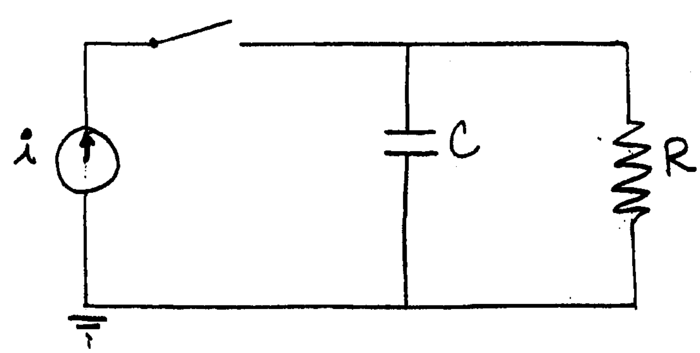
Appendix B - Example of Dynamic Systems I Simulation Assignment

MECH330
Lab 2

Draw a bond graph, complete the causality, develop the state equation, and the transfer function of the electrical circuit shown below. Using Simulink, plot the current at the capacitor versus time and the voltage at the resistor versus time for an input of 5 amp applied to the circuit with the switch closing at time = 0 seconds (constant input of 5 starting at time = 0). What is the time constant for the circuit? How long will the circuit take to reach 98.2% of its final value? The value of the resistor, R, = (your group number) * 100 Ω and the value of the capacitor, C, = 150 microfarads (μf).

Hand in:

- Bond graph with causality
- State equation formulation
- Block diagram formulation (i.e. Laplace transforms for transfer function)
- Print of block diagram from Simulink
- Print of Current v. Time for the capacitor
- Print of Voltage versus time for the resistor
- Calculation of the time constant for Voltage v time response
- Calculate how long it will take the resistor to reach 98.2% of its final Voltage value and indicate on the Voltage v Time graph that the value calculated corresponds to the plotted information.



Appendix C - Portion of Student Design Project from Dynamic Systems II

Motor Design Part 3 – PID Controller

The objective of this final portion of the motor simulation project was to design a PID controller for the motor. A certain value of percent overshoot was selected, which gave a value of zeta. The open loop transfer function of the system was evaluated, and MATLAB was used to generate the root locus plot. Determining the intersection points of the root locus and the constant zeta lines allowed us to find the additional zero required for the derivative portion. Then, another root locus plot was constructed for the new transfer function, and again the intersection points were found. This allowed us to obtain all the values for the PID controller.

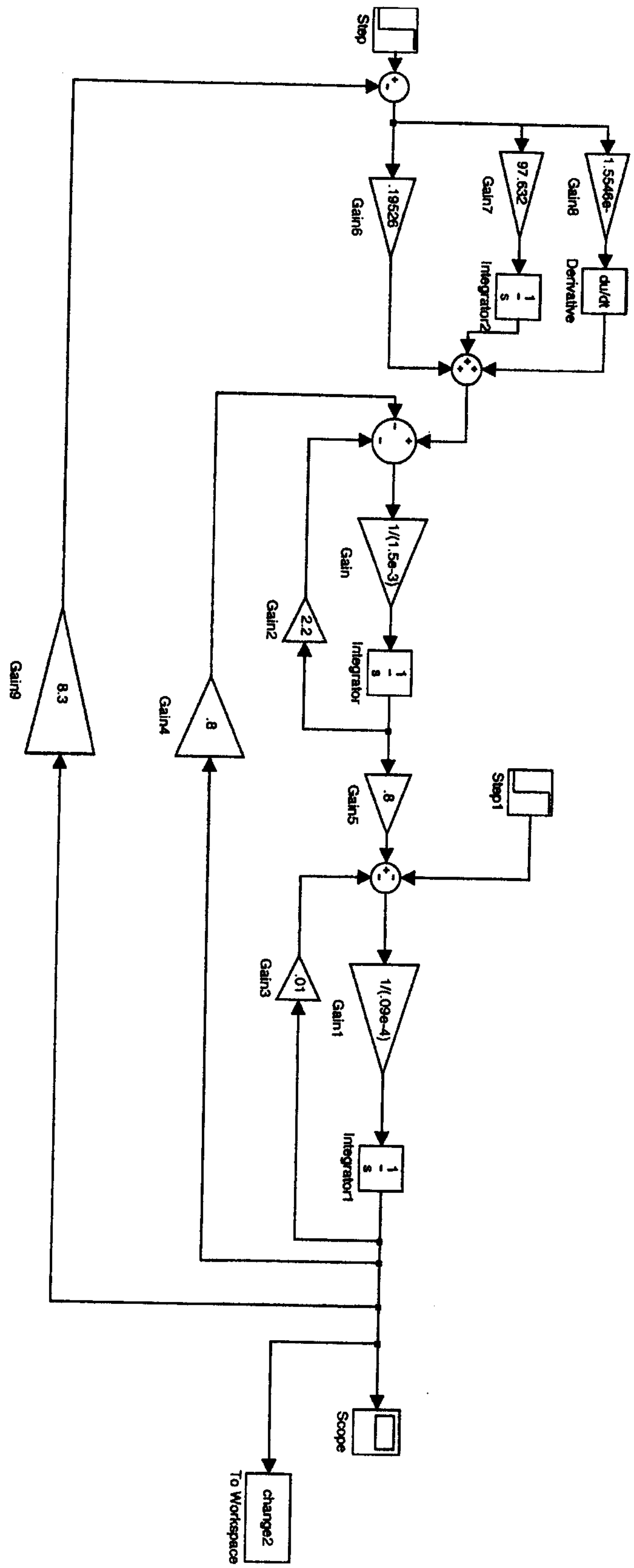
The designed value of overshoot for our system was selected to be 20%. The final plot of the output (see attached) was used to calculate percent overshoot after the designed controller was put in place. This yielded a percent overshoot of approximately 21.3%. This indicates a good correlation.

Please refer to attached calculation sheets for details.

Attachments:

Calculation sheets (4 pages)
Root locus plots (2 pages)
Final block diagram (1 page)
Motor output (1 page)

Appendix C (continued)



Appendix C (continued)