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An Interactive Visual Environment For Scientific Problem Solving

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Session 1566

An Interactive Visual Environment for Scientific Problem Solving

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Abstract

The feedback control laboratory is a mandatory part of the Mechanical Engineering curriculum at UNLV. The laboratory provides students with hands-on experience in control system identification, compensator design, and performance verification. The experiments are structured such that the students will learn and test problem solving strategies in feedback control. Personal computers perform process data acquisition and real-time process control by means of real time I/O boards, which interface with the plants being controlled. The main analysis and design tool is a control system design and analysis software package (VisSim) with a graphical user interface. Students enter their analytical models and designs in block diagram form.. In addition, the software supports and provides graphical output for system identification and compensator design choices, for comparisons between predicted and actual performance, and for interactive performance improvement. Students design and test compensators on the computer for water level, fluid flow, and pneumatic control systems, as well as DC-motor speed and position control systems. Root-locus, Nyquist, and state-space compensator design approaches are employed. After completing the design, the student enters the controller parameters into the real-time control program, and verifies the performance of the design by comparing actual and predicted outputs.

The control design laboratory motivates the students to become thoroughly familiar with current technology, develop experience that can be directly applied in professional practice, and gain a solid understanding of the theory governing modern control system design.

I. Introduction

The traditional control laboratory setting contains a number of experiments governed by dedicated, typically analog control units. Process data are recorded with separate instruments such as voltmeters, oscilloscopes, strip chart recorders, and data loggers. In addition, students spend much time manually recording or transferring data, drawing graphs and charts, and performing the analyses required for controller design. Inevitably, the time spent on performing these low-level chores detracts from paying attention to the more challenging problems at hand. Improved methods for integrating the recording and processing of data with design and analysis would allow students to concentrate on controller design and experimental design validation.

The benefits of interactive learning have long been recognized (Barker, 1989, and Bordogna et al., 1993). Karayanakis (1993) describes the benefits of graphical block diagram modeling for control instruction. Examples of innovative applications of graphical control system design and their experimental implementations are found -among several others- in papers by Kim (2001), Mueller (2001), and D'Andrea (2001).

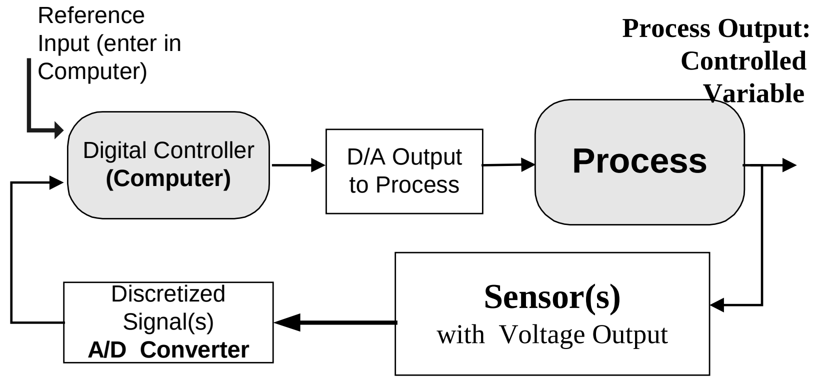


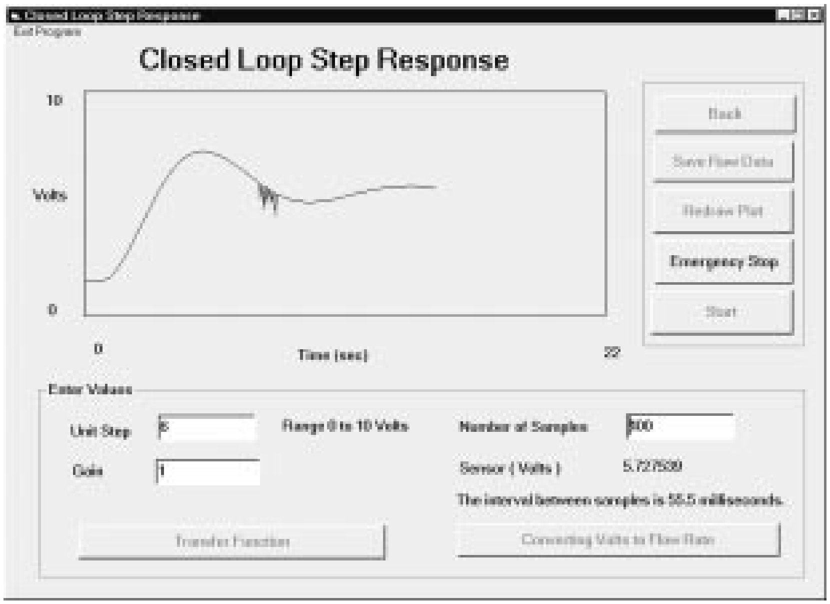
Figure 1 Configuration of Control Experiments

The interactive control laboratory seeks to overcome hardware limitations, eliminate manual record keeping and data processing, and make GUI (Graphical User Interface) analysis and design tools for control systems available during and after the lab. The user can easily move and exchange data between application elements. All real time control and recording functions reside in the computer and are software-programmable. Thus, a wide range of control laws as well as open-loop and closed-loop testing functions can be generated and executed at will. As is appropriate for a first control laboratory, continuous methods are practiced wherever possible. Since the time constants of the experiments are generally at least 100 times larger than the computer sampling rate, continuous methods can be applied without observing a performance degradation.

The VisSim software package offers easily learned GUI modeling tools as well as easily configurable tools to access data files and other software tools such as Mathcad and Matlab. VisSim was used in our control laboratory for control system modeling and model validation. A number of convenient nonlinear block elements permits the rapid assessment of the effects of nonlinearities observed during experimentation.

Figure 2 Flow Experiment: A Pneumatic Servovalve controls the water flow rate, measured by the magnetic Flowmeter at right. The plant is approximately described as a linear second order system.

The control lab comprises physical experiments on DC-servomotors, fluid flow, thermal, hydraulic, and pneumatic plants. Each experiment is controlled by a computer through a data acquisition board. Among analytical methods covered are root locus and frequency response methods for analysis and compensator design, state space compensator design, and system identification from experimental frequency response records. Students perform their assignments on PC's. All computers are networked within the engineering college. Figure 1 illustrates the configuration of the experiments, which communicate with the process through a data acquisition board with D/A and A/D capabilities.



Unit Step 6

Gain 1

Number of Samples 400

Sensor (Volts) 5.727539

The interval between samples is 55.5 milliseconds.

Figure 3 Flow Experiment: Closed-Loop Step response

II. Approach

2.1 Real Time Control System Software: The controller software for the experiments was developed in Visual Basic. The student encounters a Graphical User Interface (GUI) which guides him/her through the experimental process. The GUI software presents conceptual information about the experiment, its configuration and procedures. The software communicates with the process through manufacturer-supplied software drivers. Experimental results are displayed in graphical form during and after the experiment. Lastly, the student can save experimental records in a data file for further analysis: Fig.2 shows the flow control experiment. Figure 3 (Proportional control) illustrates the interactive process: The student enters the process parameters, such as the controller gain, number of samples etc, and starts the experiment.

2.2 Software for Control System Design and Analysis: The VisSim simulation and analysis software was chosen for modeling, analysis, and comparison between experiments and theory.

Linear Mathematical Modeling – Introductory courses in automatic control typically employ linear mathematical modeling in the form of transfer functions and linear state space equations. The information flow between control loop components such as plant and controller is typically modeled in the form of a signal flow or block diagram. Block diagram concepts are readily understood by the students, and they prefer block diagram modeling in a GUI format over more mathematical approaches.

III. Laboratory Experiments

The controls lab begins with introductory sessions to train the students in the use of VisSim for dynamic system modeling, simulation, and graphical presentation of results. In the subsequent experiments students import the experimental records into VisSim and compare the results with their analytical models. The comparison between experiments and linear theory shows clearly the limitations of linear modeling, as well as the need for the student to understand each experiment at a high level of detail. Fig. 4 illustrates the detail required for the DC motor speed

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control model. The interested reader may view the lab assignments for the undergraduate controls lab at: http://www.me.unlv.edu/coursenotes/control/control.htm.

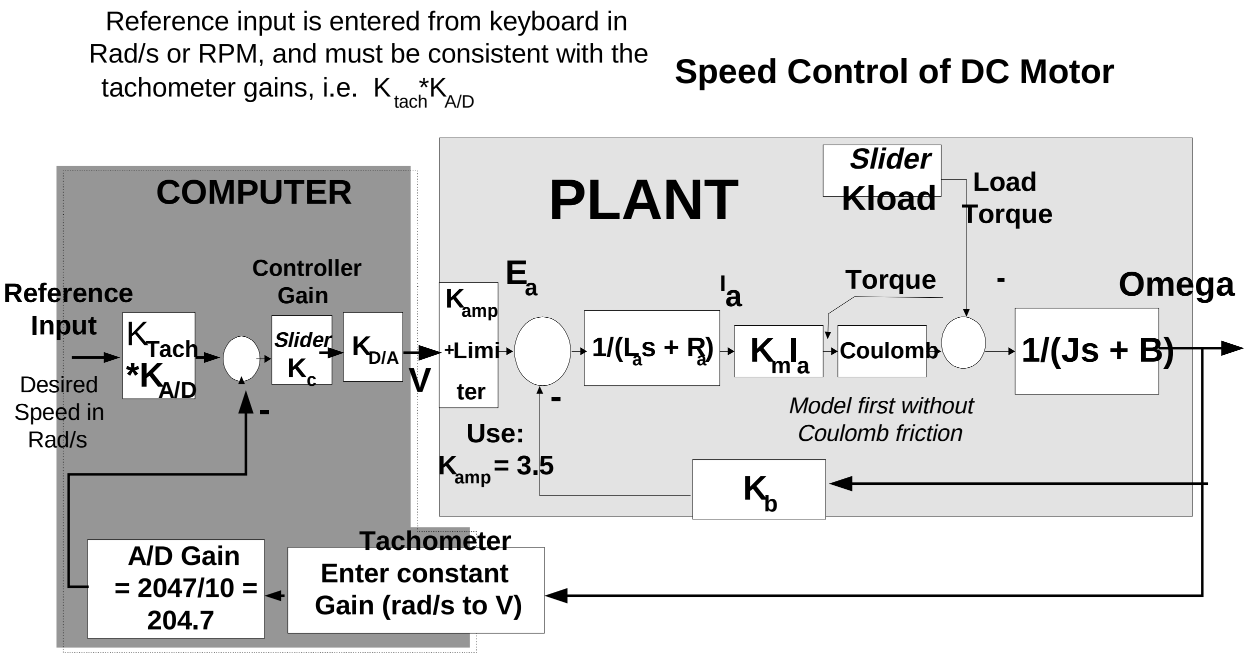

Figure 4 Detailed Block Diagram of DC Motor Speed Control

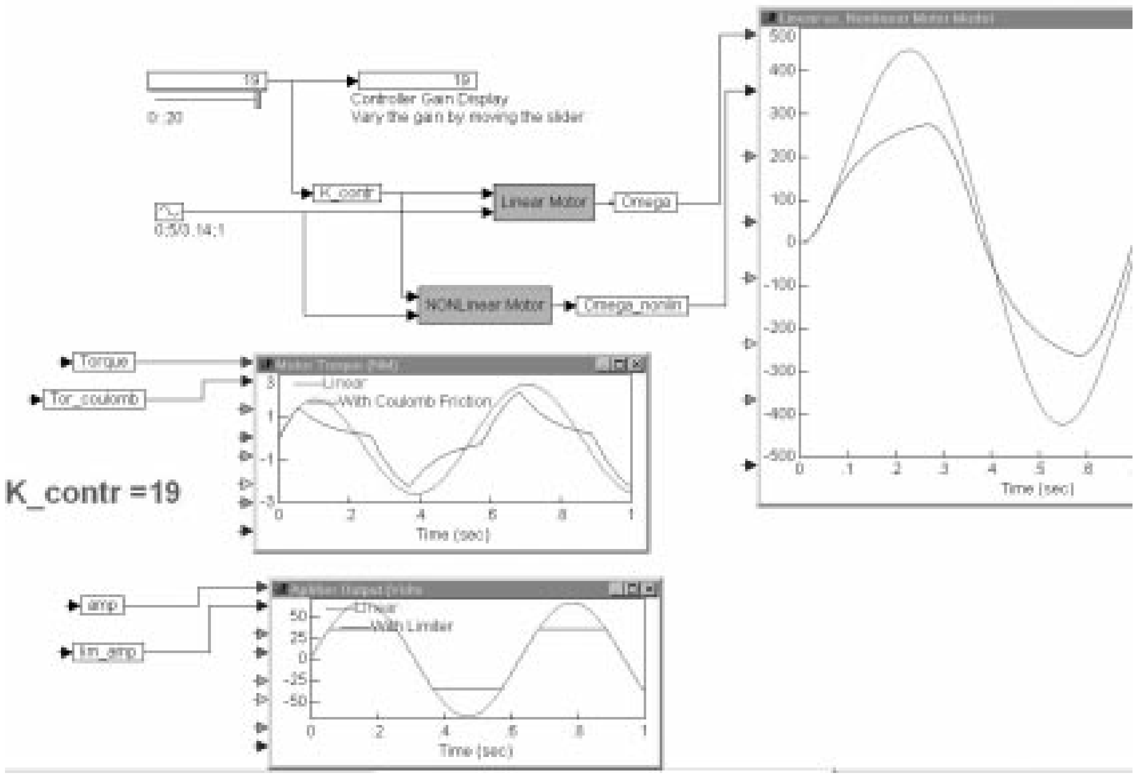

Figure 5 Evaluation of Nonlinearities: Limiter and Coulomb Friction

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Nonlinear Modeling, Identification, and Experiments – The scope of linear models is limited by nonlinearities such as finite power to the process and Coulomb friction. Both effects can be demonstrated on the DC motor as well as other experiments. Fig. 5 shows a comparison of open-loop linear and nonlinear DC motor models. The nonlinear models were obtained by augmenting the linear transfer function model by a limiter (max. amplifier output voltage) and a Coulomb friction block to model drive shaft friction. Both nonlinear effects are visible in separate parts of Fig. 5. In the lab, students are asked to build nonlinear plant models based on manufacturer-supplied data sheets, and to validate the models experimentally. Fig. 6 compares the step response of the open-loop linear model with the equivalent experimental record. The noise visible in the experimental record is mostly the result of Coulomb friction on the motor shaft.

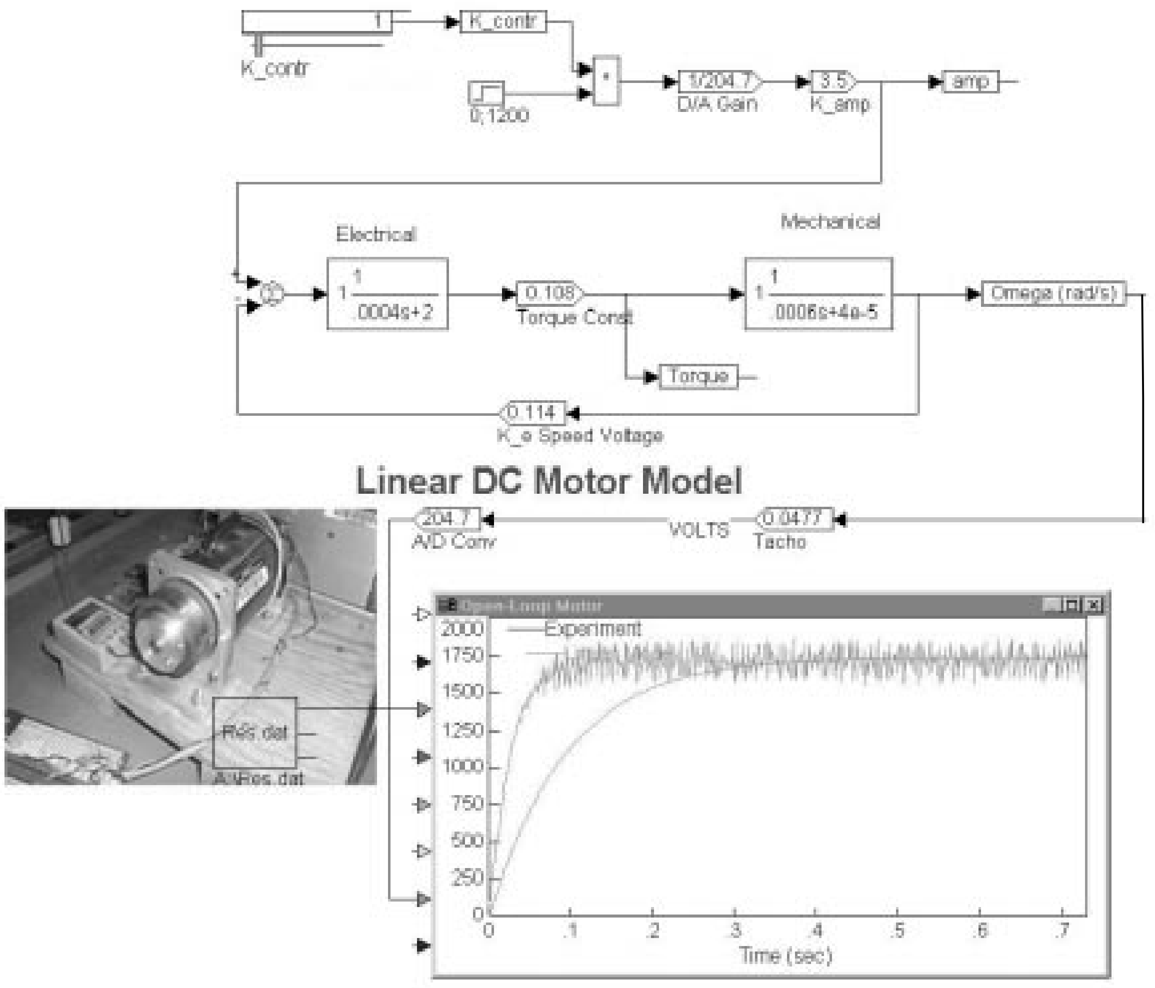

Figure 6 DC Servomotor Speed Control: Comparing the linear model with the experiment. The inserted photograph shows the experiment.

When the actuator operates in its linear range, the closed loop DC motor experiment agrees reasonably well with the linear model (Fig. 7). At larger controller gains the amplifier reaches its output limit, see Fig. 8.

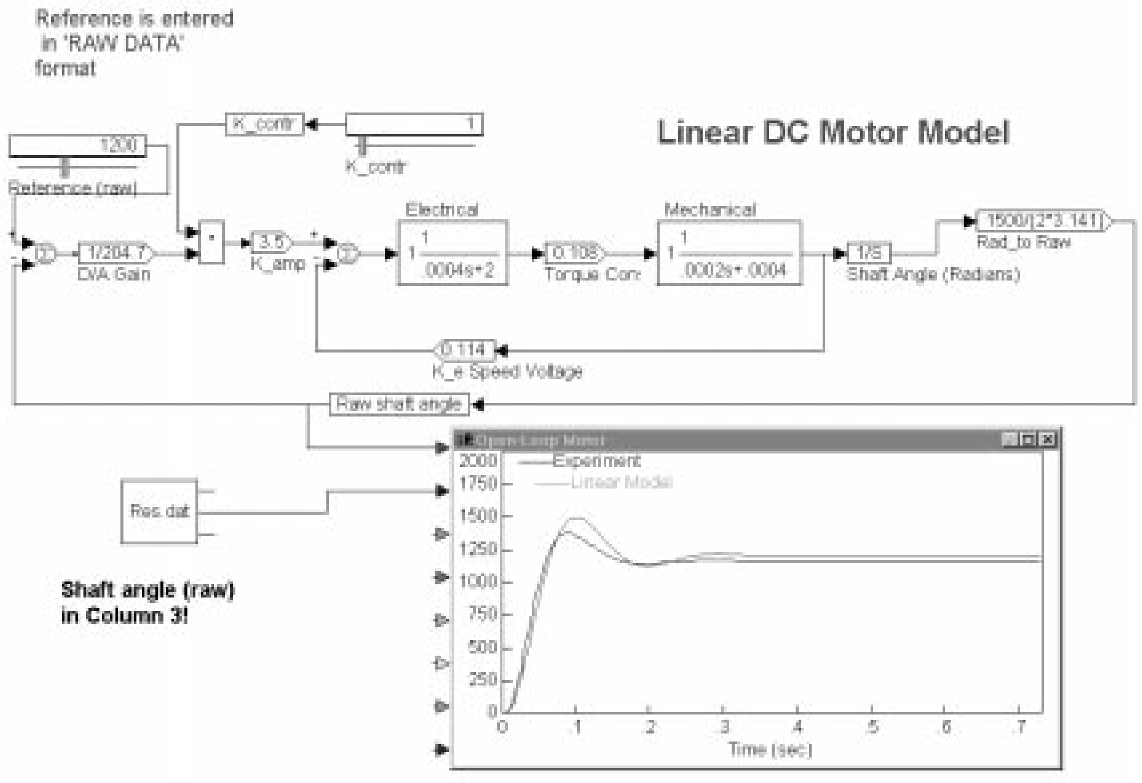

Figure 7 Closed Loop P-Control of DC Motor Shaft Angle, Gain K = 1. Comparison between experiment and simulation model.

Lead Control – Students design a lead controller according to closed loop eigenfrequency and damping specifications. Although linear theory is employed, the lead controller equation must be discretized and entered into the lab PC as a difference equation. Since VisSim does not have a discretization tool, a small Mathcad routine is employed to generate the difference equation as a function of lead pole, zero, and sampling rate. The Mathcad program encodes Tustin's (trapezoidal) discretization. In Fig. 9, the lead design and the experimental record (represented as A:\res.dat) are compared.

Identification – An experimental identification of plant dynamics (transfer function) is performed by recording the frequency response experimentally, followed by an FFT analysis of the recorded plant frequency response. Fig. 10 shows the time-domain frequency response. The magnitude portion of the resulting Fourier transform is displayed in Bode format. Since the recorded signal contains considerable noise, only the lower frequencies (to approx. 1 Hz) yield useful information. Fig. 11 presents a comparison of the recorded frequency response with third and second order linear plant models. Here, the second order model yields the best approximation.

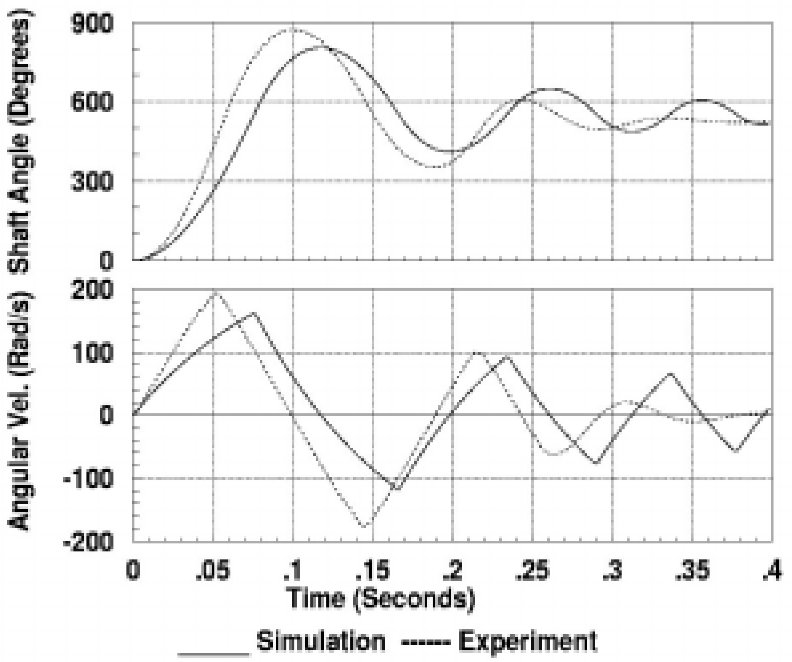

Figure 8 DC Servomotor, Gain K = 5: Amplifier Limiting causes poor agreement with the linear model.

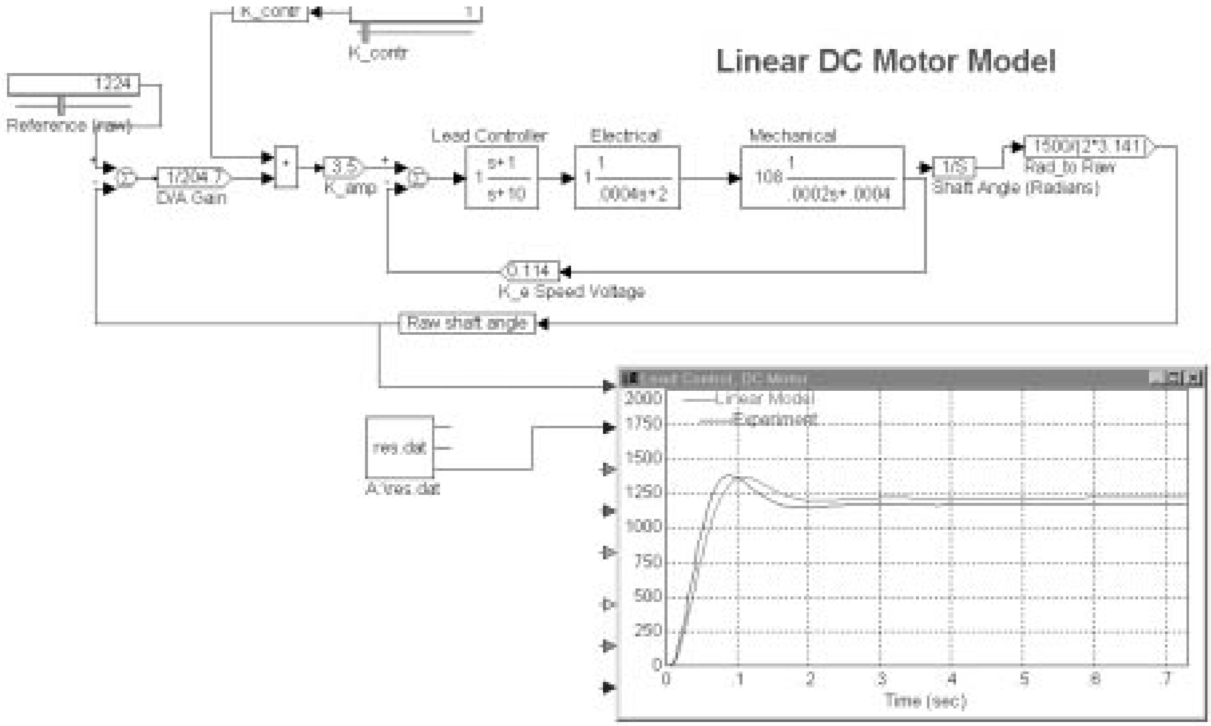

Figure 9 Closed Loop Lead Control of DC Motor Shaft Angle, Gain K = 1. Comparison between experiment and simulation model.

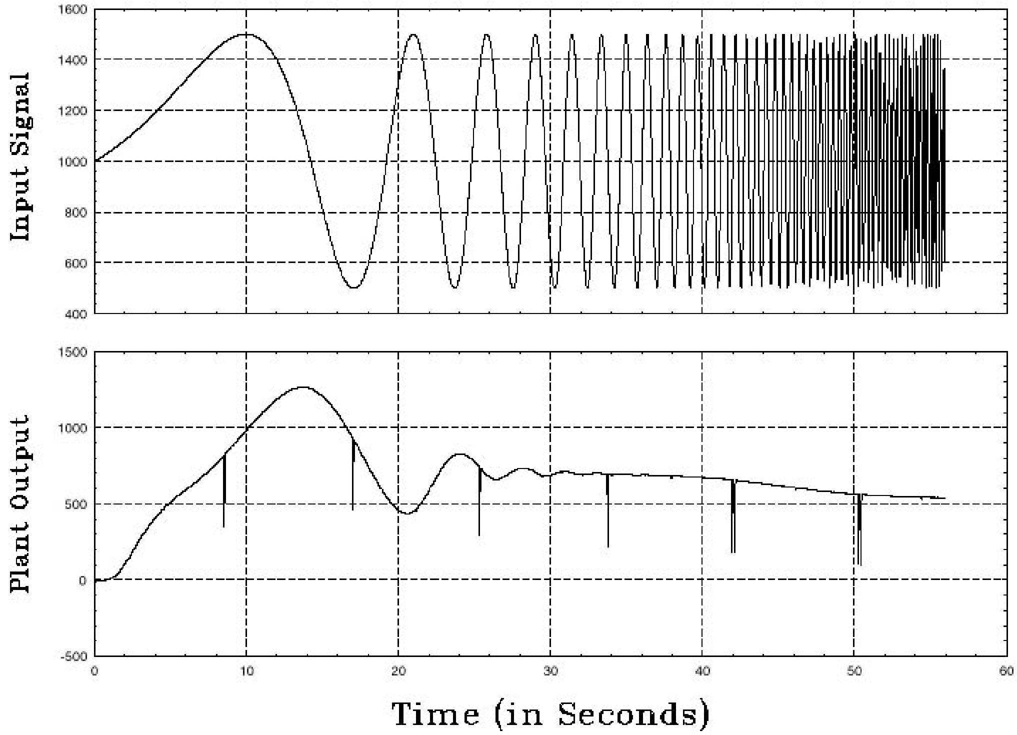

Figure 10 Experimentally recorded Frequency Response of the Flow Plant of Fig. 2. Upper Segment: Input Signal. Bottom: Flow Meter Signal. The spikes resulted from signal noise.

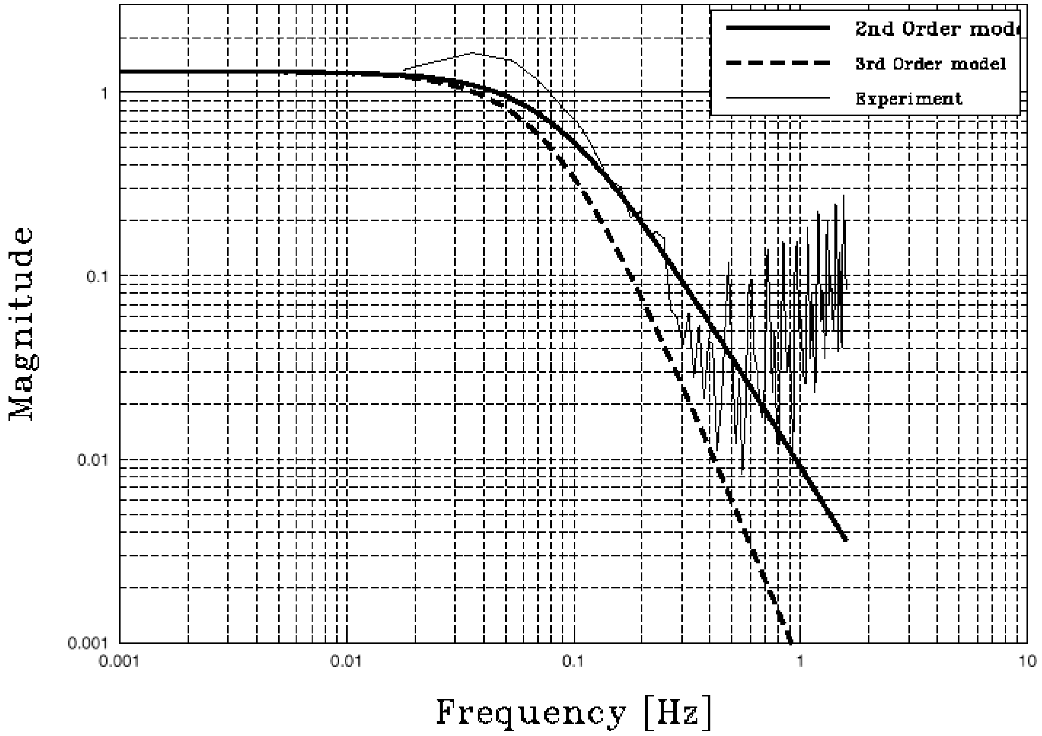

Figure 11 Bode Plot (Magnitude vs. Frequency) of the Frequency Response of Fig. 10. The comparison with two possible linear plant models shows that the plant is best approximated as a second order linear system.

IV. CONCLUSION

An interactive control systems laboratory for undergraduate instruction based on real time data acquisition and control and GUI modeling and analysis with VisSim software has been presented. The laboratory seeks to free students from low-level record keeping and analysis, and focuses on the application of the design and analysis concepts presented in the lecture. The laboratory scope includes advanced analysis and design. The laboratory integrates experiments on control systems with interactive analysis, design, and performance verification, using PC- and work station based GUI tools. Computer simulation, design, and real time process control are performed during the course of the lab. Student responses to the laboratory were quite favorable, with the GUI control system modeling most frequently mentioned as an advantage for developing in-depth understanding.

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