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A Multi-Institutional Interdisciplinary Distance Controls Experiment: Bringing Engineering and Engineering Technology Students Together

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Abstract

The University of Kentucky (UK) Extended Campus Programs in Paducah along with Murray State University (MuSU) have developed the first experiment in what is expected to become a sequence of projects involving students in mechanical engineering technology enrolled at MuSU and mechanical and chemical engineering students at UK. This collaborative effort involves utilizing the design skills of the UK students to develop transfer functions required to model and design a control system for an Electrohydraulic Actuation (EHA) position control apparatus located in the Motion Control Laboratory on the MuSU campus. MuSU students use their hands-on skills to develop the hardware system and implement the control scheme. Students at UK and MuSU then jointly (via the Internet) operate the equipment, conduct experiments, report observations, troubleshoot problems, and evaluate both success and failure. In addition to the practical experience in controls education, students at both campuses learn about the sort of interaction engineers and technologists typically have in the workplace and develop an appreciation for their symbiotic professional relationship. Future work will involve students from both institutions working together in close contact, further developing the understanding and appreciation of the roles each will fill in the future; extending the projects to include systems of interest to chemical engineers; and involving students located at the main campus of the University of Kentucky in the projects.

1. Introduction

An educational pilot program, related to control system design, implementation, and analysis, was completed in Fall, 2001. It involved collaboration between the electromechanical engineering technology department at Murray State University in Murray, KY, and the mechanical[1] and chemical[2] engineering departments at the University of Kentucky College of Engineering Extended Campus Program in Paducah, KY. The project included development of a fully functioning Electrohydraulic Actuation (EHA) position control system as a class project for engineering technology students at

MuSU, and testing and analysis of the system by remote operation, via the Internet, as a class project for UK engineering students in Paducah. One primary goal of the project was to determine the feasibility and practicality of arranging course projects at both institutions involving collaboration between engineering students and engineering technology students. Although there were a number of technical hurdles encountered during this initial effort, the pilot program was successful in demonstrating the potential of the concept as a tool for providing non-collocated engineering and engineering technology students with an educational experience, based on an industry model, which familiarizes the students with differences in typical job functions between engineers and technologists, while also providing them with lab experience based on actual industrial controls software and hardware. A secondary goal of this project was to demonstrate the feasibility of concurrent engineering by remotely utilizing equipment and software via current telecommunications technology.

Other work involving remote laboratory experiments in controls education has been undertaken, as reported, for instance, in Gillet, et al.[3]. Another example related to on-line laboratory education is an on-line controls lab[4] in the chemical engineering department at the University of Tennessee at Chattanooga, which can be accessed and used remotely by anyone with Internet access. In the work reported in this paper, the concept of using the Internet for remote operation of lab equipment is extended to allow for collaboration between engineering and engineering technology students at two different institutions.

2. MuSU / UK Relationship

The UK Extended Campus program in Paducah, KY, is located approximately an hour's drive from MuSU. The UK Extended Campus Program offers bachelors degrees in mechanical and chemical engineering. MuSU offers engineering technology degrees in a number of disciplines, one of which is electromechanical. MuSU also offers an engineering physics degree. The UK Extended Campus program has four full-time faculty in mechanical engineering, and four full-time faculty in chemical engineering. Also, several MuSU faculty members have a joint appointment with UK, and they teach some of the courses at the UK program in Paducah. This arrangement provides opportunities for convenient collaboration between faculty at UK and MuSU. In the work discussed in this paper, one primary focus is the extension of the collaboration to the students of both institutions.

3. Engineering / Engineering Technology Professional Relationship

While there is significant overlap between the job functions of engineers and engineering technologists, there are also significant distinctions. The differences in the expected job functions are reflected in the curricula of the degree programs. It seems that the different strengths of engineering programs and engineering technology programs at universities can be exploited through collaboration between engineering and engineering technology students to enhance the educational experiences for students in both programs. Typically, an engineering technology student develops an excellent background, beyond that of a typical engineering student, in hands-on implementation of system hardware, such as control system hardware, through lab work. Engineering students tend to gain a more in-depth mathematical background.

There should certainly be advantages for engineers in developing a better understanding of hands-on implementation of, for instance, control system hardware. Also, there should certainly be advantages for engineering technologists in developing a deeper mathematical background. Of course, there are limits on the number of courses that can be fit into a four-year degree program. Therefore, it seems that collaboration between students in the two programs may be an effective, mutually beneficial means for expanding the knowledge base for all involved. Further, because the expected job functions are often different in the workplace for engineers and engineering technologists, development of collaborative course projects that are structured to illustrate the typical workplace functions of engineers and engineering technologists can help students to better understand the typical role for graduates of their degree program in an industrial setting.

3. Pilot Program Project Overview

As mentioned previously, there were a number of technical hurdles encountered during the pilot program that reduced the time available for student involvement in this initial effort. Among other things, significant problems were encountered related to system communications involving a Virtual Private Network (VPN), which was required for accessing the Allen-Bradley hardware, installed at Murray, remotely from Paducah with Rockwell Automation software installed on a client computer in Paducah. Successful resolution of these matters required considerable time and effort on the part of Information Technology (IT) personnel at both institutions.

In this first effort, there was not interaction between the students at MuSU and UK, but the Murray students did implement the control and EHA system hardware, and the Paducah students did observe the remote operation of the system, and take data from the tests and perform mathematical analysis of the results.

The EHA system used is an industrial grade system supplied by the Parker Hannifin Corporation. The control system consists of Allen-Bradley industrial hardware and Rockwell Automation control software. The EHA position control system consists of a single-rod double-acting hydraulic cylinder, a linear potentiometer attached to the end of the cylinder rod, a Parker D1FS proportional valve, an A-20 amplifier board, and an Allen Bradley Control Logix 5550 industrial Programmable Logic Controller (PLC). The control software is Rockwell Automation Control Logix 5000 with trending capability. The physical system layout is as shown in Figure 1. The basic operation of the system is that the valve is commanded to spool position setting an orifice opening. This orifice opening then translates the amplifier command signal to a hydraulic fluid flow output. The flow is then integrated in the hydraulic cylinder, which translates to velocity of the piston rod. The potentiometer then provides the second integration to open loop position. The plant, being the piping, cylinder and load, is typically a 5th or 6th order response system, however these systems typically have a 2nd order dominant mode and are readily approximated by a 2nd order model. A complete description and analysis can be found in the text by J. L. Johnson[5]. This particular system did not have a sufficient load and therefore is 1st order open loop. The control loop is closed in the PLC using a classical Proportional, Integral, Derivative (PID) control algorithm. Once the loop is closed the system then becomes a 2nd order response system using proportional gain only. This was the system that was used for this pilot program.

A highly simplified system block diagram, reasonable for the purposes here, for closed-loop operation, is as shown in Figure 2. Details of block diagrams, Laplace transforms, and other issues related to system analysis will not be included here, as numerous controls textbooks, such as the text by Nise[6], are available with in-depth discussions. In Figure 2, G(s) is the plant transfer function, Y(s) is the piston position, X(s) is a valve opening position, R(s) is the command input signal (r(t) is a specified piston position as a function of time), and $G_c(s)$ is a selected compensator transfer function. The valve opens and allows fluid to flow, which moves the piston in the cylinder. The plant transfer function, G(s), relates piston position, Y(s), to a valve opening position, X(s). If the piston mass is negligible, then G(s) can be approximated as a transfer function in the form:

$$G(s)=\frac{Y(s)}{X(s)}=\frac{A}{s^2+Bs} \quad (1)$$

The mechanics of hydraulic cylinders will not be overviewed here, but the constants, A and B, depend on parameters such as hydraulic fluid bulk modulus, piston area, effective entrained fluid volume, and other system constants. References are available with detailed discussions (see, for instance, <u>Marks' Standard Handbook for Mechanical Engineers</u>[7]). Based on this transfer function, for open-loop operation, a unit step input for x(t) causes the piston <u>velocity</u>, v(t) (where V(s)=sY(s)), to approach a constant, equal to A/B. If the system is initially stationary with the valve closed, and then the valve is opened to some constant position in a step fashion, the piston will translate at a constant velocity (after a very short duration transient decays), until it impacts the end of the cylinder and is restrained from further motion.

For closed-loop operation, the compensator transfer function, $G_c(s)$, could be selected as a classical PID controller:

$$G_c(s)=K_P+K_D\,s+\frac{K_I}{s}=\frac{K_D\,s^2+K_P\,s+K_I}{s} \quad (2)$$

In this effort, a simple proportional gain ($K_P>0$; $K_D=K_I=0$) was used in several step response tests, and for these cases, the closed-loop transfer function can be written:

$$\frac{Y(s)}{R(s)}=\frac{AK_P}{s^2+Bs+AK_P}=\frac{\omega_n^{\,2}}{s^2+2\varsigma\omega_n\,s+\omega_n^{\,2}} \quad (3)$$

where . is the damping ratio for the system, and T_n is the undamped natural frequency. For a system with the transfer function in Equation 3, it is clear that a step response, in theory, has zero steady-state error. Also, since A and B are system constants, and the system operator is free to select a value for K_P, increasing K_P increases the system natural frequency and decreases the effective damping ratio (increases the overshoot).

As long as the system is underdamped (.<1), the damping ratio can be estimated based on the percent overshoot (%OS) of the step response[6]:

$$\zeta = \frac{-\ln(\%OS/100)}{\sqrt{\pi^2 + \ln^2(\%OS/100)}} \tag{4}$$

Then, based on the peak time, T_P, the undamped natural frequency can be calculated[6]:

$$\omega_n = \frac{\pi}{T_P\sqrt{1-\zeta^2}} \tag{5}$$

Therefore, from a measured response to a step input, with a selected proportional gain, K_P, the unknown system parameters can be approximated.

P-I control (K_D =0) was used in two frequency response tests. With K_D=0, the closed-loop transfer function can be written:

$$\frac{Y(s)}{R(s)} = \frac{AK_P s + AK_I}{s^3 + bs^2 + (AK_P)s + AK_I} \tag{6}$$

If r(t) is sinusoidal: $r(t) = P\sin(\omega t)$; then the response is be given by: $y(t) = Q\sin(\omega t - \phi)$, where Q is the response magnitude, and N is the phase angle of the response with respect to the input. Well-known standard analysis techniques are available[6] for predicting the magnitude and phase angle of the response for a system with the transfer function in Equation 6, assuming a sinusoidal input.

Once the MuSU students built the system, testing was done remotely from Paducah. A web cam was directed at the piston extension so that the UK students could see the actual motion, in real time, resulting from command inputs. Command inputs were entered in Paducah by accessing the Allen-Bradley software residing on a computer at MuSU.

4. Results

The system was run in open loop, with the input, x(t) (valve opening), applied as a step input. Two cases were run. The piston position vs. time was measured. An example result plot is shown in Figure 3, which tends to confirm that the transfer function in Equation 1 is reasonable, as the piston displacement approximates a ramp function (after decay of initial transients), so the piston velocity is a constant (until the piston reaches the end of the cylinder).

The system was then run in closed-loop, with simple proportional gain compensation, $G_c(s)=K_P$. One response case is plotted in Figure 4, with $K_P=2.0$. A subsequent case, plotted in Figure 5, with $K_P=2.5$, shows the expected effects of increasing K_P. The increase in K_P produced an increase in frequency of oscillations and increase in overshoot, due to a decrease in damping ratio, . .

The input and response for a case with sinusoidal input are shown in Figure 6. The expected sinusoidal response, with a phase and magnitude different from the input, is clearly illustrated in Figure 6.

The UK students were able to calculate reasonable estimates for system parameters based on the results. The experiment exposed the UK students to remote operation of the control system, which is the common mode of operation in industry. It also provided them with exposure to industrial quality equipment. Further, it provided good examples to reinforce system analysis methods learned from the textbook.

5. Future Work

Based on the success of the pilot program, it is concluded that all significant technical difficulties have been resolved. The feasibility and practicality of implementing course projects at both MuSU and UK involving collaboration between engineering students and engineering technology students has been demonstrated. A more in-depth course project is now planned for the students during the fall semester of 2002. It will involve teams composed of combinations of UK and MuSU students. Final plans will be completed during the summer of 2002.

The basic plans for the fall project are to have the UK students design a relatively simple hydraulic system that produces desired rotational motion of a disk, and to have the MuSU students build the system. As a prerequisite for the control system design course, UK mechanical engineering students complete a systems modeling course. Therefore, at the start of the controls course, they are already familiar with free-body diagrams and the writing of system equations. They will be given an initial brief introduction to feedback control concepts, and given specifications for a number of desired system parameters, such as natural frequency and damping ratio, assuming some simple control law, such as a simple proportional gain, with the system operated as a unity negative feedback system. Time will not allow in-depth, start-to-finish design work, so the students will be provided a basic system layout. They will complete the system design through system analysis, making the necessary calculations to specify required parameters. The MuSU students will communicate directly with the UK students, through email and team meetings conducted via Instructional Television (ITV). In one of these meetings, the UK students will make a formal presentation to the MuSU students outlining specifically the system design. They will provide the MuSU students with all information needed to build the system. The MuSU students will then actually build the system, and make a formal presentation to the UK students describing their efforts.

Late in the semester, once the system is built, the UK students will be provided various desired system response specifications. For instance, they may be told that the system is required to track a step input with minimum response time and zero steady-state error, so they will need to develop a compensation scheme that meets these goals. Also, desired frequency response characteristics will be provided, and the compensation specified must meet these specifications. Another formal presentation by the UK students to the MuSU students will be required, outlining the basics of the control system design, including some of the mathematical background, such as block diagram representation of the system, block diagram reduction to determine closed-loop transfer function, and prediction of system response to a known input based on solving the system equations in transfer function (Laplace transformed) form. The MuSU students will then test the system in-house at Murray, and confirm the system meets the specs. They will then make a presentation of results of the tests to the UK students. For added practical experience, the UK students will perform the set of tests through remote operation of the system from Paducah.

UK chemical engineering students in Paducah also have access to a potentially remotely controlled process apparatus. The device, a Process Plant Trainer from Armfield, Ltd.[8], consists of a multi-loop process involving level, flow, and temperature control. While primary use to date has involved a PID controller connected to the system, an Allen-Bradley PLC is available for use with the simulator. The required network hardware will be added to the simulator to enable remote access. Faculty from MuSU and UK will coordinate a project requiring contributions from students at both sites to design and implement an appropriate control method for a specified operating mode for the simulator. This exposure to a chemical process system should prove useful to the MuSU students, many of whom will likely find employment in a chemical plant. UK chemical engineering students will benefit from this cross-disciplinary project in the same manner as their mechanical engineering counterparts.

6. Summary

A successful pilot program has been completed related to controls education in engineering and engineering technology programs. Technical issues related to remote operation of a hydraulic position control system were resolved. From this initial effort, it was concluded that mutually beneficial collaboration between UK engineering students and MuSU engineering technology students can be included in controls courses in both the UK engineering program and the MuSU engineering technology program. Plans have been developed to extend the concept to semester long, team-oriented course projects in controls courses both at UK and MuSU. It is expected that the collaboration can be very helpful in providing the UK students with a better understanding of physical realization of the types of systems they study in their controls textbook, and it can also be very helpful to the MuSU students in developing a better understanding of the mathematical basis for the control system designs which they implement using their hands-on skills. Also, both groups of students should develop an appreciation for the overlap and the distinctions between typical job functions of engineers and engineering technologists. In addition, both groups should benefit from experience in working with industrial quality systems (both hardware and software), in a manner consistent with common industry practice, i.e. remote operation of the system.

7. Acknowledgements

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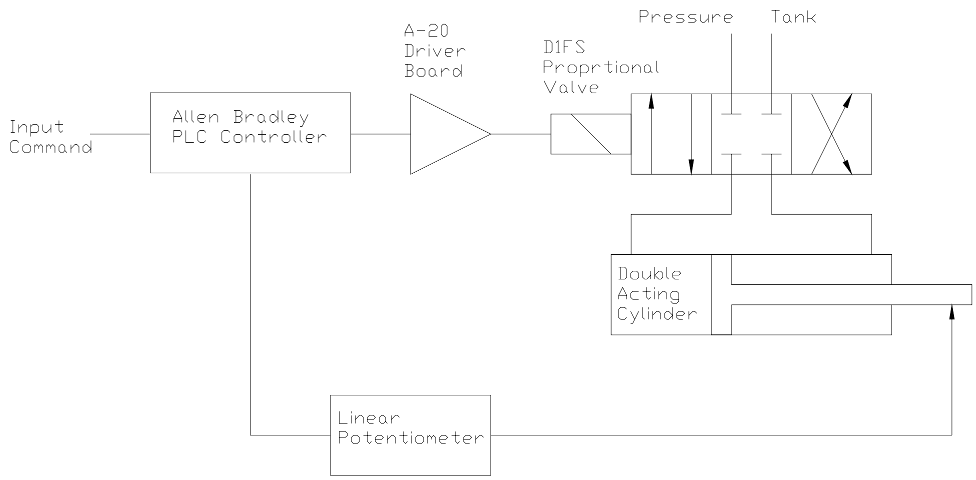

Figure 1: Control system sketch.

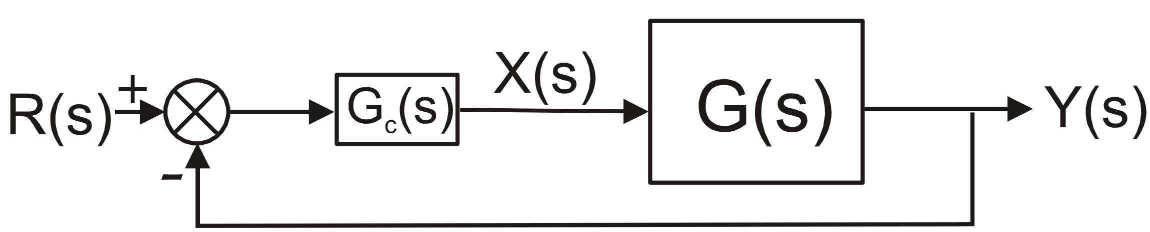

Figure 2: System block diagram for the configuration of steps 3 and above.

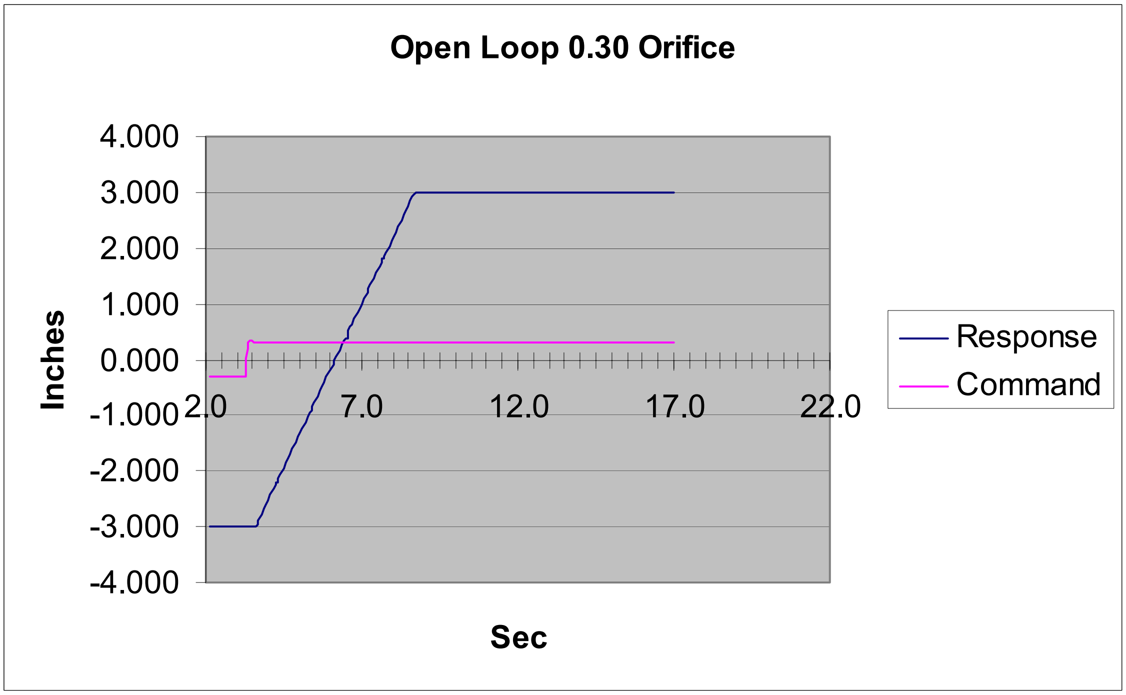

Figure 3: Open-loop system response with a valve position step input.

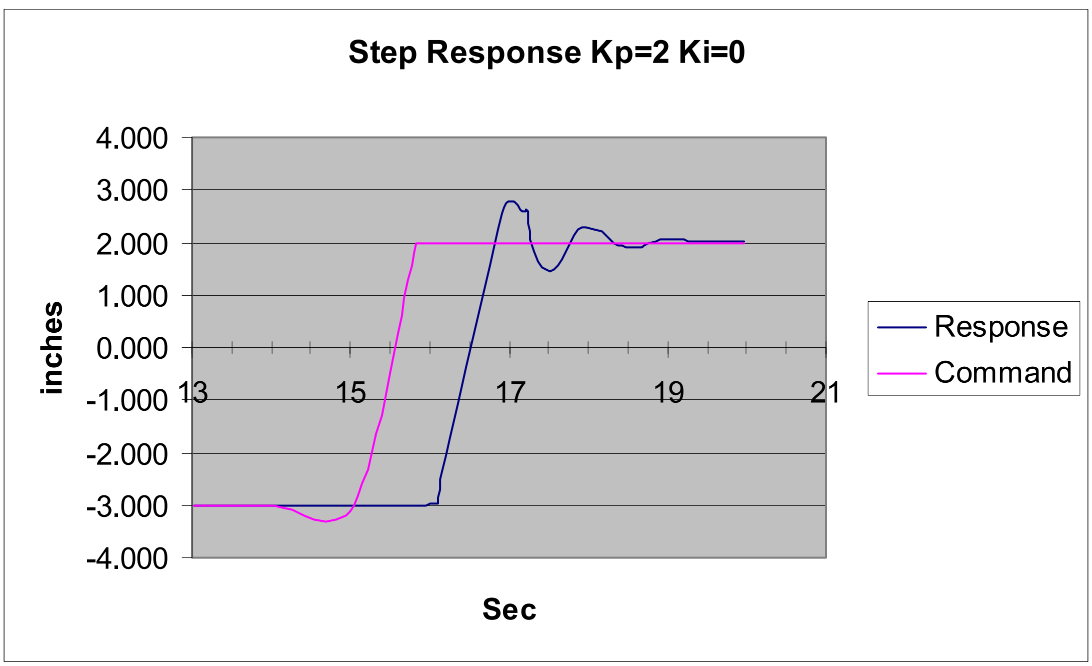

Figure 4: Step response with K_p=2.

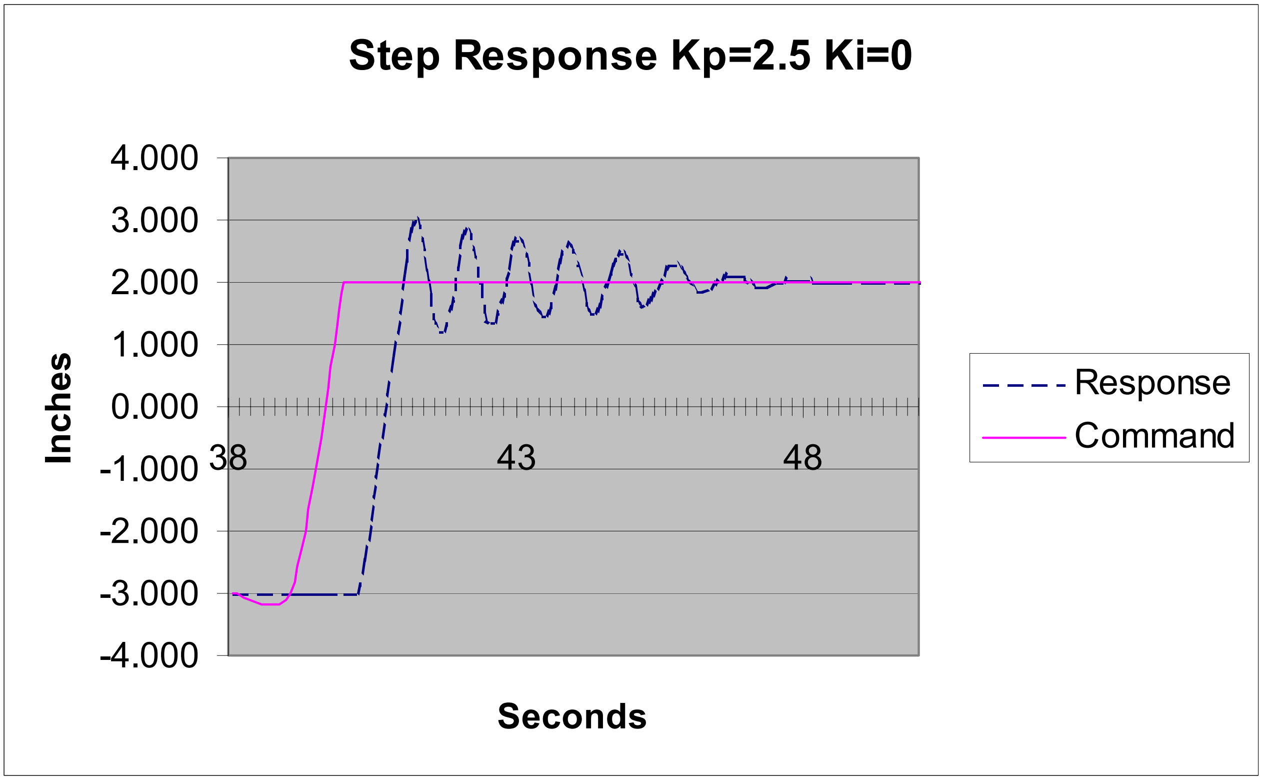

Figure 5: Step response with K_p=2.5.

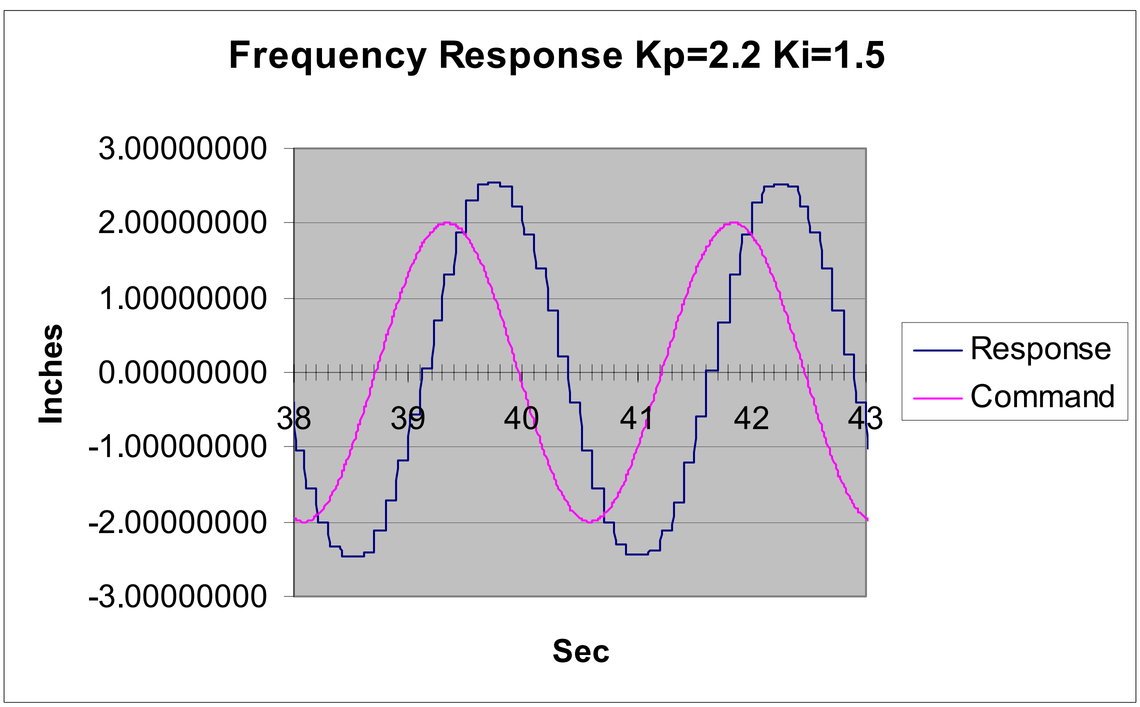

Figure 6: Frequency response with K_p=2.2, K_I=1.5.

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