# Enhancing the Controller Design skills in the course Linear Control Systems

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Abstract: Controller design is very essential and critical in any control systems. In order to make a system function as desired it is required to design the controller parameters appropriately and then use it in the control system. In this paper an attempt is made in enhancing the controller design skills through assignments which involves design of controller parameters and its verification using simulation. Proportional - Integral (PI) controllers and Proportional – Integral – Derivative (PID) controllers are considered in the assignment questions. Zeigler – Nichols tuning method is used to design the controller parameters and these controller parameters are plugged in the controller and the system as a whole is simulated in SCILAB simulation tool for the verification of the controller design. The assessment of the assignment questions is done using rubrics. The result of assessment shows a good percentage attainment of the design outcome.

**Keywords:** assignment; controller design; linear control systems; PI controller; PID controller

## 1. Introduction

Interconnection of different components which configures a system to obtain a required system response is a control system. The systems under control are getting complex day by day and obtaining their optimum performance is a major concern, hence control systems engineering is gaining a wide importance [1]. In order to control the process of a control system employing feedback, generally the output and reference command relationship is used as a function. In any control system the difference between the input and output is amplified such that there is a continuous reduction in the difference which aids the process which is under control. In design and analysis of a control system, the foundation is formed by the concept of feedback [2].

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The use of system analysis, modeling and systems with feedback control and its applications are majorly seen in automobile industry, vibration and sound control, industrial machinery, and many other areas of engineering [3]. This drastic and rapid growth has resulted in increasing need for students of engineering to have a thorough expertise in controller design, modeling, simulation and analysis of a feedback control system [4].

At B. V. Bhoomaraddi College of Engineering and Technology, Hubli, India, Linear Control Systems (LCS) is taught as a core course to students of Electrical & Electronics Engineering department at fifth semester. In the same semester a control system laboratory is also included which runs hand – in – hand with the theory course. Assignments are a part of the theory course assessment and the weightage for the assignment is 10% (10 marks) of the maximum score (100 marks). The following are the learning outcomes of the assignment for the course;

At the end of this assignment the students will be able to,

- Characterize the proportional, integral, and derivative terms in a controller
- Tune controller parameters to improve the performance or stability of systems, such as Automatic Generation Control (AGC) model, cruise – control system for an automobile, robot arm controller
- Explain how behavior of a system can be improved according to performance specifications, such as rise time, peak time, peak overshoot and settling time.
- Predict and show in the complex plane how pole and zero location affect system response.
- Design controllers using Zeigler – Nichols tuning method
- Analyze the complete system through simulations using SCILAB tool
- Analyze the system performance using root locus diagram

The work in this paper explains how assignments in a course can aid different skills like analysis, controller design, simulation and documentation of an engineering student. The first section of the paper gives a brief introduction as to why students should learn control systems and why analysis, design and simulation are important. The second section discusses the methodology adapted to include assignments in the course which will help students' learning. The third section talks about the implementation and results of this methodology. Discussions are taken up in the fourth section of the paper. The subsequent sections include conclusions and references.

## 2. Methodology

The course Linear Control Systems is core course of 4 credits. This course is allotted with 50 teaching hours and the breakup of this is shown below in table 1 and the Continuous Internal Evaluation (CIE) Scheme is shown in table 2.

Table 1. Course split up in terms of chapters

| Unit | Chapter | | Hours |
|---|---|---|---|
| 1 | 1 | Introduction to Control Systems | 3 |
| | 2 | Transfer function models and block diagram representations | 8 |
| | 3 | Block diagram simplification | 6 |
| | 4 | Time response analysis of first order system | 3 |
| 2 | 5 | Time response specifications | 6 |
| | 6 | Stability analysis of control systems | 6 |
| | 7 | Frequency response analysis | 8 |
| 3 | 8 | Root locus diagrams | 6 |
| | 9 | Basic principles of feedback control | 4 |

Table 2. CIE Scheme

| Assessment | Weightage in Marks |
|---|---|
| Minor Examination – 1 | 20 |
| Minor Examination – 2 | 20 |
| Assignments | 10 |
| Total | 50 |

As per the college norms minor examination – 1 and 2 are subjective examinations and are conducted as per the schedule given in advance which accounts for a total of 40 marks out of 50 marks of CIE. The remaining 10 marks are allotted for assignments. In the course LCS, the assignment given includes design of controller parameters (manual calculations), programming (coding), analysis, simulation and documentation. The class which underwent this course had strength of 80 students and the assignments were to be submitted as a pair. Students were asked to find a partner to pair up with them to complete the assignments. No rules were imposed on team formation, students were given the freedom to form pairs themselves without any conditions. The assignment submissions were done using an app called 'Edmodo', which is an online platform majorly used to discuss, share and learn from peers.

## 3. Implementation and Results

A total of six questions were given to the students in the form of assignment. These questions had to be solved using the learning's from the class as well as extra reading from different resources. The assignment questions were available with the students at the beginning of the semester in the lesson plan copy. The students were asked to take up these questions after the completion of chapter 5, so that by then they will have understood many important concepts of the course which will help them to solve the assignment by applying the learning's from the course. Students were asked to take up the first two questions of the assignment and they had to do their submission online within 10 days. The remaining four questions one by one where given after the completion of subsequent chapters and their submission was also online. The submission link would get closed itself on the last day of the submission and if a team still wants to do the submission they have to send a request to course owner online and then it would be the course owner's decision to accept or reject their submission. Online submission of assignments made students complete their assignments in time.

The following are two sample assignment questions and students' solution to those questions;

A. PID Controller design:

Figure 1 shows the Automatic generation control (AGC) model of a isolated power system area. The system parameters are: $K_{ps}$=100;$T_{ps}$=30; $K_{sg}$=$K_t$=1.0; R=3.0; B=1, $T_{sg}$=0.4, $T_t$=0.5.

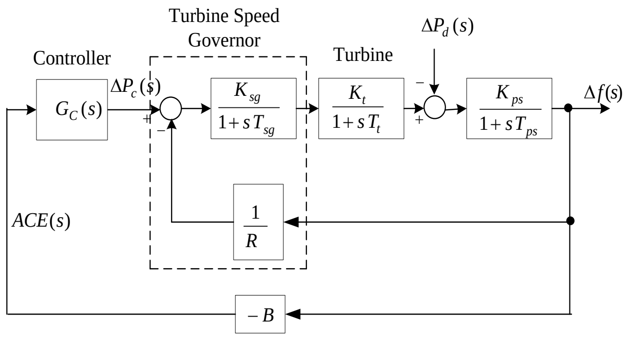


Fig. 1 Automatic Generation Control Model

i) Develop the X-COS model of the system

ii) Using time-response simulations, design a P, PI and PID controllers by applying Ziegler-Nichols tuning method (Employ a step change in load demand $\Delta P_d$ by 0.01 pu)

iii) Obtain time response and compare the performance of P, PI and PID controllers in terms of various time-response specifications

**Solution:**

(i) X – COS model

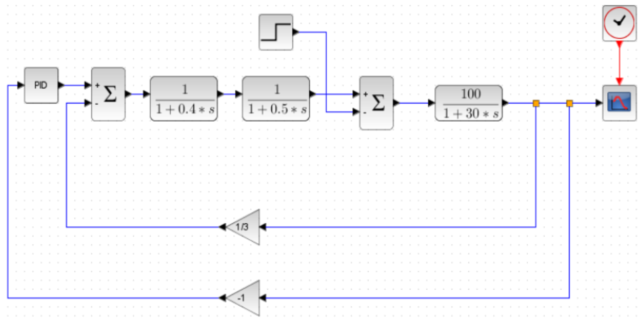


Fig. 2 X – COS model of AGC

(ii) P, PI and PID Controller gains

**P controller gain is given by:**

i) $K_p = 0.5 \times K_{cu} = 0.5 \times 1.052 = 0.526,$ $K_p = 0.526$

**PI controller gain is given by:**

i) $K_p = 0.45 \times K_{cu} = 0.45 \times 1.052 = 0.4734,$ $K_p = 0.4734$

ii) $K_i = 1.2\frac{K_p}{T_u} = 1.2\frac{0.4734}{2.8} = 0.2028,$ $K_i = 0.2028$

**PID controller gain is given by:**

i) $K_p = 0.6K_{cu} = 0.6 \times 1.052 = 0.6312,$ $K_p = 0.6312$

ii) $K_i = 2\frac{K_p}{T_u} = 2\frac{0.6312}{2.8} = 0.4508,$ $K_i = 0.4508$

iii) $K_d = \frac{K_p T_u}{8} = \frac{0.6312 \times 2.8}{8} = 0.22092,$ $K_d = 0.2209$

(iii) Time response and comparison

P – Controller

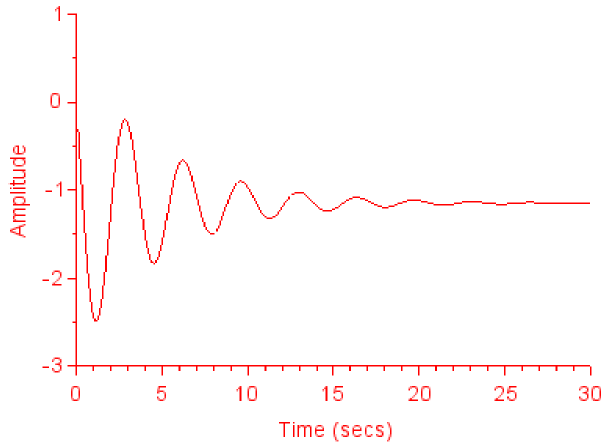


Fig. 3 System response with P – Controller

PI – Controller

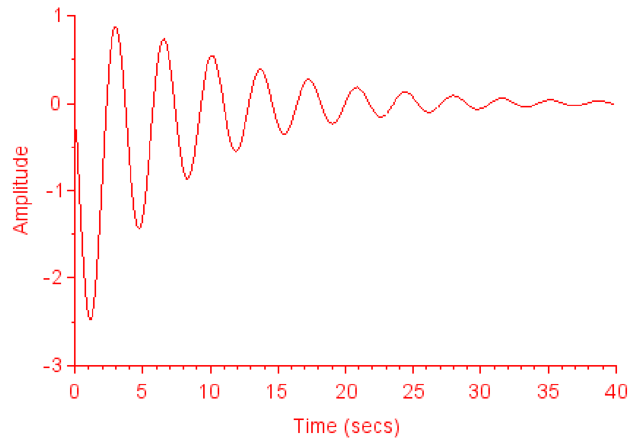


Fig. 4 System response with PI – Controller

PID – Controller

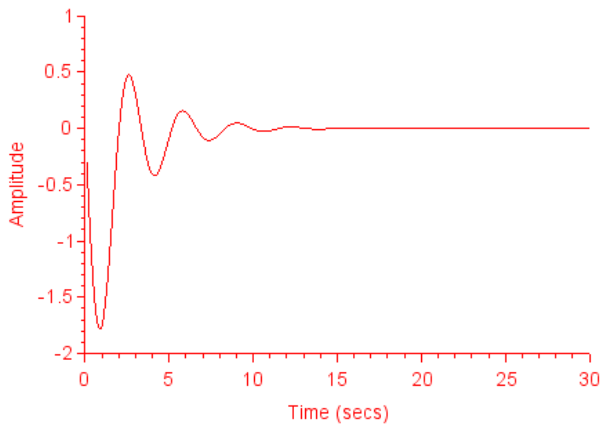


Fig. 5 System response with PID – Controller

Table 3. Result Comparisons

| Time Response Specifications | Controller | | |
|---|---|---|---|
| | **P** | **PI** | **PID** |
| Peak Value | 1.04 | 1.25 | 1.6 |

| | | | |
|---|---|---|---|
| Rise Time (sec) | 0.654 | 0.914 | 0.654 |
| Settling Time (sec) | 22.5 | 40 | 10.5 |
| Peak Overshoot (%) | 66.7 | 25 | 30 |

B. Design assignment:

Figure 6 shows the T.F model of a servo controlled joint of a robot arm employing PI controller. It is now required to design the PI controller for optimum system response. The system parameters are: Gear ratio (n)=1/20; $R_m$=21; $L_m$=2; $K_T$=38; B=1.0;J=2.0;$K_m$=0.5;

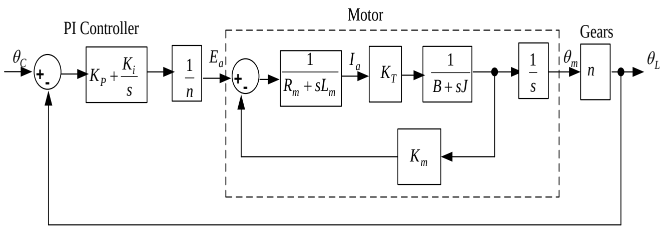


Fig. 6 Model of a servo controlled joint of a robot arm

(i) Show that the plant T.F is $\frac{\theta_L(s)}{E_a(s)} = \frac{0.475}{s(s+1)(s+10)}$

(ii) With $K_i$=0, use RH criterion and determine the ultimate gain ($K_{PU}$) and period ($T_U$) at which the system exhibits sustained oscillations. Verify this by developing a SCILAB program/XCOS model and obtaining a step response for step input ($\theta_c$).

(iii) Using Ziegler-Nichols tuning method, design PI controller.

(iv) Verify the above design by SCILAB/XCOS simulations and measure the time response specifications.

**Solution:**

(i) Transfer Function proof

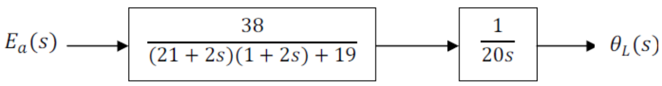


Fig. 7 Reduced block diagram

$$\frac{\theta(s)}{E_a(s)} = \frac{38}{(21+2s)(1+2s)+19} * \frac{1}{20s}$$

$$= \frac{38}{(20s)(4s^2+44s+40)}$$

$$= \frac{38}{80s^3+880s^2+800s}$$

$$= \frac{0.475}{s^3+11s^2+10s}$$

$$\frac{\theta(s)}{E_a(s)} = \frac{0.475}{s(s+1)(s+10)}$$

(ii)

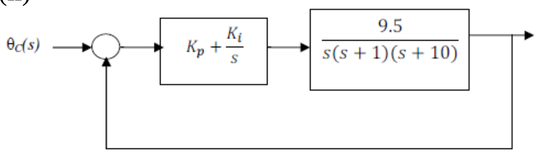


Fig. 8 Reduced block diagram

Characteristic equation: $s^3 + 11s^2 + 10s + 9.5K_p = 0$

Table 4. Routh – Hurwitz array table

| | | |
|---|---|---|
| $S^3$ | 1 | 10 |
| $S^2$ | 11 | $9.5K_p$ |
| $S^1$ | $(110 - 9.5K_p)/11$ | 0 |
| $S^0$ | $9.5K_p$ | 0 |

Since, $K_{CU}$ is the value of $K_P$ that results in sustained oscillations it requires that

$K_{CU} = K_P = 11.578$

$T_U$ =1.99sec

i) $K_P = 0.45 \times K_{CU} = 0.45 \times 11.052 = 5.210$

ii) $K_i = 0.5 \times (K_{CU}/T_U) = 2.923$

SCILAB modeling of the system

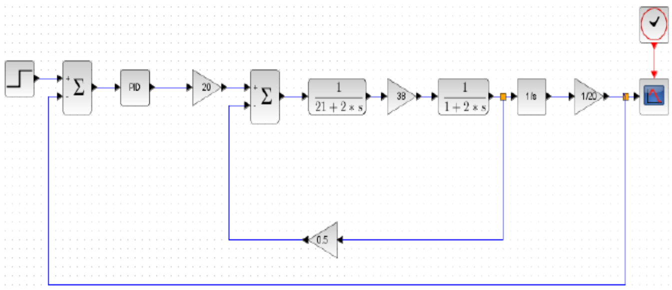

Fig. 7 SCILAB model of robot arm

PI – Controller

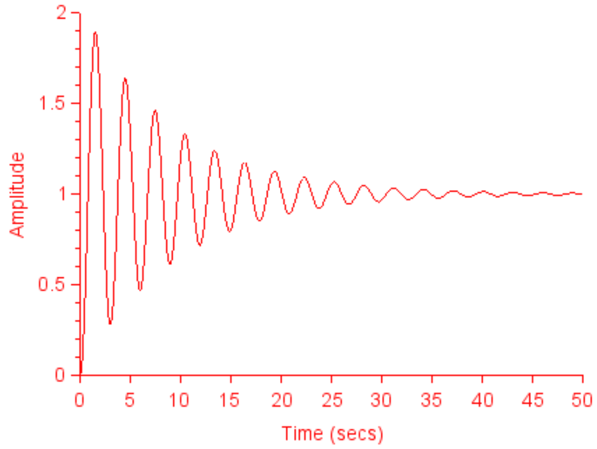


Fig. 8 System response with PI – Controller

Table 5. Time response specifications

| | |
|---|---|
| Peak Time (sec) | 2.0 |
| Rise Time (sec) | 1.65 |
| Settling Time (sec) | 48 |
| Peak Overshoot (%) | 10 |

The above two examples show the solutions to the given assignment questions submitted by the students. The assessment of the assignment submission was done using detailed rubrics [5]. These rubrics were shared with students well in advance and they were asked to work on the assignment questions keeping rubrics as the reference. The students were assessed on different aspects like

- analysis of the given problem statement,
- controller parameters design,
- verification by system simulation using SCILAB,
- documentation

The course instructor assessed the assignments by meeting the team's one after the other individually. The assignment was evaluated for 10 marks and the detailed breakup of these 10 marks and the rubrics are shown in table 6.

Table 6. Assignment Evaluation Rubrics and marks split up

| **Total : 10Marks** | **Weightage** | **Criteria and marks (Excellent)** | **Criteria and marks (Good)** | **Criteria and marks (Needs Improvement)** |
|---|---|---|---|---|
| **Analysis** | **20% (2M)** | Understand and solve the given problem thoroughly (2) | Understand the problem but fail to solve the problem (1) | Fail to understand the given problem (0) |
| **Controller Parameter Design** | **30% (3M)** | Design all the controller parameters following the method (3) | Design few of the controller parameters following the method (2) | Makes an attempt but unable to design the controller parameters (1) |
| **Modern Tool usage (Simulation)** | **30% (3M)** | Simulate the system and analyze all the results (3) | Simulate the system but fails to analyze all the results (2) | Makes an attempt but fails to simulate the given problem (1) |
| **Documentation** | **20% (2M)** | Prepares the document without errors (2) | Prepares the document with minimum errors (1) | Prepares the document with many errors (0) |

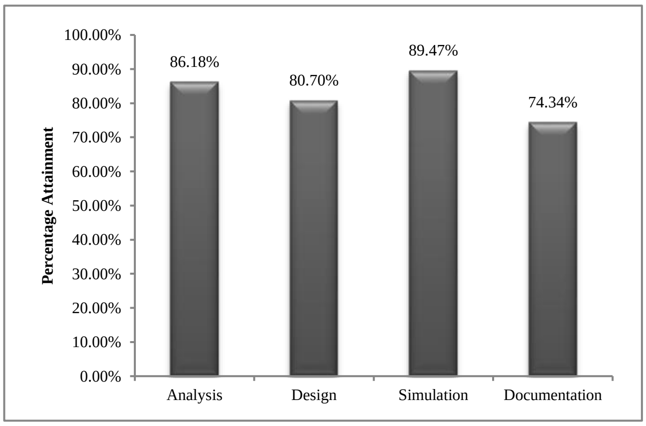


Fig. 9 Attainment of various parameters (Analysis, Design, Simulation and Documentation)

After assessing each teams work and allotting them marks for their work as per the rubrics, the attainment of analysis, design, simulation and documentation was done and it is as shown in Fig. 9. Out of all the four parameters which were being assessed, simulation is the parameter with the highest attainment of 89.47%. Following this the parameter analysis attainment is 86.17% and that of parameter design is 80.7%. The parameter documentation's attainment is the least with 74.34%.

## 4. Discussions

The main aim of this assignment is to provide the students with hands – on approach of doing engineering which results in increased student participation in the process of learning, enhanced proactive and critical thinking, improving communication skills. The strategy used for assessment to closely monitor the students learning and performance, included course instructors rigorous observation of students' behavior in the class and their involvement. The assessment plan was strategically designed and prepared to measure the attainment of the learning outcomes by the student.

The attainment of the parameter simulation is the highest because most of the students could relate the theoretical concepts studied in the class and verify them using simulation, hence they were experimenting with simulation considering different cases which enhanced their simulation skills. Few teams failed to learn simulation and were unable to complete the assignment. The least attainment is of the parameter documentation and this is because many students did not spend much time working on the reports. Most reports had issues with text alignment, text font, text size, poor visibility of graphs, etc. At the end of the assignment submission each student gave a feedback which essentially included ten questions addressing about the ease/difficulty in assignment, comfort level in using the simulation tool, designing controller parameters and others. A total of 65 students gave the feedback out of 80 students. The following section discuses the student feedback.

**Feedback analysis**

- Was the assignment for the course Linear Control Systems a good learning experience? 96.72% of the class said 'YES' and 3.28% of the class said 'NO'.
- Were you overloaded with the assignment questions? 45.76% of the class said 'YES' and 54.24% of them said 'NO'.
- What type of assignment do you prefer? 18.33% said 'Writing', 31.67% said 'Hardware', 40% said 'Simulation' and 10% of the class said 'Quiz'.
- What changes in the assignment questions should be made? 31.67% said 'Reduce the number of questions', 21.67% said 'Reduce the complexity of the questions', 1.67% said 'Increase the complexity of the questions', 35% said 'The number of questions are correct' and 10% said 'Increase the complexity of the questions'.
- How comfortable are you in using the SCILAB tool? 33.33% said 80 – 100%, 58.33% said 60 – 80%, 5% said 40 – 60% and 3.33% said 20 – 40%.
- To what extent were you able to apply the learning's of theory taught in class? 20.34% said 80 – 100%, 64.41% said 60 – 80%, 11.86% said 40 – 60% and 3.39% said 20 – 40%.
- Rate your learning through the assignment for the course Linear Control Systems? 21.67% said 80 – 100%, 68.33% said 60 – 80%, 6.67% said 40 – 60% and 3.33% said 20 – 40%.
- To what extent did the simulation help you in understanding the concepts better? 31.67% said 80 – 100%, 56.67% said 60 – 80%, 10% said 20 – 40% and 1.67% said 20 – 40%.
- How confident are you in using the SCILAB tool in other subjects or project work? 32.20% said 80 – 100%, 59.32% said 60 – 80%, 5.08% said 40 – 60% and 3.39% said 20 – 40%.
- How comfortable are you in designing the controller parameters for a given system after having done the assignment? 25% said 80 -100%, 60.71% said 60 – 80%, 12.50% said 40 – 60% and 1.79% said 20 – 40%.

## 5. Conclusions

This paper discusses the implementation of assignments in the course Linear Control Systems. It is seen that with this assignment students have gained different skill sets like analysis, design, simulation and documentation. The attainment of the parameters analysis, design and simulation is better in comparison with the parameter documentation. There is scope for improvement for the parameter documentation and can be improved by provided templates for report submission.

**Acknowledgement**
The author would like to thank the Head of the department and Dr. S. R. Karnik, Electrical and Electronics Engineering of KLE Technological University, Hubli, for providing the necessary support to carry out the work.

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