122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #12762

Modeling and Control of a Tungsten-Bulb Heated Incubator: Teaching Controls Theory in a General Engineering Program

Dr. Jason Yao, East Carolina University

Dr. Jianchu (Jason) Yao is an Associate Professor with the Department of Engineering at East Carolina University (ECU), Greenville, North Carolina, USA. He received a B.S. and M.S. degrees in electrical engineering from Shaanxi University of Science and Technology, China, in 1992 and 1995, respectively, and the Ph. D. degree in electrical engineering from Kansas State University in 2005. He served as a controls engineer in China from 1995 to 2000. His current research interests include wearable medical devices, telehealthcare, bioinstrumentation, biosignal processing, and control systems. His educational research interests are laboratory/project-driven learning and integration of research into undergraduate education. Dr. Yao is a member of the American Society of Engineering Education and a senior member of Institute of Electrical and Electronics Engineers (IEEE).

Modeling and Control of a Tungsten-Bulb Heated Incubator: Teaching Controls Theory in a General Engineering Program

Most engineering students consider controls theory challenging because of its mathematical intensity. Frequency domain controls concepts (Nyquist criterion, magnitude/phase margin, etc.) are often perceived as more difficult by many students because the connection between these theoretical concepts and their physical significance is distant. In the general engineering program at East Carolina University, a comprehensive project, *Using the Frequency Method to Design an Incubator Temperature Control System for a Waterfowl Park,* has been developed to address this issue.

During the course of the five-week project, students are required to model the thermal dynamics of Tungsten incandescent bulbs and a glass incubator in MATLAB; characterize the frequency response of the incubator; design a compensator with SIMULINK based on the plant's frequency response; and evaluate the system performance. Having a sense of a real application, the students were motivated and enthusiastic to tackle difficult theory that they otherwise would be reluctant to attack. Most of them were able to actively seek answers to challenging questions in the project and successfully completed the design task.

Learning outcomes were measured by analyzing student project reports and their responses to survey questions. Assessment results from the first two trials of the project show that this integrative project worked well for the general engineering students; not only they were able to connect abstract control theory to tangible applications and design control systems to meet requirements, they also observed how other subject knowledge (in this case, thermal and heat transfer) is applied to model practical processes, gaining a greater level of enthusiasm towards the general engineering curriculum. Their ability to use MATLAB and SIMULINK was also considerably improved.

Modeling and Control of a Tungsten-Bulb Heated Incubator: Teaching Controls Theory in a General Engineering Program

I. Introduction

While basic concepts in controls theory, such as stability, steady-state error, and transient performance, are fairly straightforward, analyzing and designing control systems poses greater challenges to most of undergraduate students due to the extensive mathematics involved. Control systems design via frequency responses (Bode plots and Nyquist diagrams) appears more forbidding to students than its time-domain alternatives (root locus methods, etc.) due to the loose connection between the frequency domain parameters (e.g., magnitude/phase margins) and system performance parameters. Grasping the difficult frequency analysis skills, however, is essential for electrical engineering (EE) students to sufficiently prepare them for future jobs. Creative instruction approaches are desired in order to efficiently deliver frequency-domain controls design methods.

In order to gain insight into how the engineering educational community has been teaching controls from the time-domain and frequency-domain, the author conducted a comparative literature review. "Controls", along with "Root locus" and "Bode plot" respectively, were used as keywords to search the *IEEE Transaction in Engineering Education* and the *ASEE Annual Conference Proceedings*. The results from this quick review, as summarized in Table I, indicate that, in both sources, more efforts on time-domain methods were reported than those on frequency-domain methods, confirming the discrepancy between the existing efforts in the time- and frequency domain. Moreover, few publications returned from these two searches directly addressed the abovementioned concern [1-9].

TABLE I Time- and Frequency-Domain Controls Teaching: a Quick Literature Review

Keywords	**Source 1***	**Source 2***
"Controls" and "Root Locus"	272	94
"Controls" and "Bode Plot"	128	75

*Source 1: IEEE Transaction in Engineering Education; Source 2: ASEE Annual Conference Proceedings

The project presented here, *Using the Frequency Method to Design an Incubator Temperature Control System for a Waterfowl Park*, aims to facilitate student learning the topic of frequency response based control system design through a "learning-by-doing" approach. In this project, students were asked to design an incubator temperature control system with 60 W Tungsten incandescent lamp bulbs working as the heat source. Through the project, students learn how to model dynamic systems (thermal systems in this case) to obtain their frequency responses and design compensators via gain/phase margins. The five-week project was offered in a senior electrical engineering concentration course in a general engineering program.

The paper starts with the introduction of the general engineering curriculum structure and the course background, then describes the project goals, objectives, and brief procedures, followed by the effectiveness evaluations, results and discussion, and concludes with observations and future improvement opportunities. Most of the project technical details, survey questionnaire, and assessment rubrics are included in the paper as appendices.

II. Course Background

General Engineering Curriculum Structure

The Electrical Engineering (EE) concentration, started in 2011, is the newest addition to the Department of Engineering at East Carolina University. Prior to the launch of the EE concentration, a survey was administered to the Department Industry Advisory Board members and other professional stakeholders. The survey results highlighted that the local industrial workforces need employees with skills in two particular EE areas: power and controls.

Established in 2004, East Carolina University's general engineering program was established to train well-rounded employees for business and industry employers in eastern North Carolina [10]. In order to achieve the goal of training general engineers with specialized skills, a curriculum structure consisting of an engineering core curriculum and concentration-specific courses was implemented.

Constrained by the broad nature of a general engineering program, only two courses (*ENGR2514— Circuit Analysis* and *ENGR3050—Sensors, Measurements, and Controls*) in the core curriculum introduce EE topics and two others have some EE content (*ENGR1016—Introduction to Engineering Design* and *ENGR2050—Computer Application for Engineers*). Out of these EE-related courses, *ENGR3050* is a hybrid course that covers two major topics: Instrumentation and Controls, each of these topics usually deserves one or more courses in a specialized EE program. Although special instruction designed for the general engineering curriculum exposes students to all the necessary topics and achieves the outcomes, the coverage of EE subjects is limited for EE concentration students who need to gain more insight in the controls topic. Therefore, a second controls course has been included in the EE concentration curriculum, providing students with a more systematic study of controls theory.

Project-Driven Instruction

Teaching a "customized" course in such a specially structured curriculum demands a great level of creativity. A "project-driven" instructional approach, for example, was developed to organize and teach the abovementioned hybrid *Instrumentation and Controls* course [11]. In this course, "two major design projects were developed to cover fundamental concepts in the instrumentation and controls areas. The first project was a thermometer design project that requires the student to design a thermistor-based digital thermometer. The second project was a coupled-tank level control system design project." [11] Instrumentation and controls concepts, analysis methods, and design approaches are closely tied to the two projects. Student feedback showed that the students appreciated the real-world related projects and believed that the project helped them make connections between theories and their applications. From the instructor's perspective, this "project-driven" approach serves as a good vehicle to efficiently cover controls concepts, mathematical theory, and computer simulation tools (MATLAB). Encouraged by this success, the author is determined to adopt the same philosophy and incorporate another design project in the EE concentration course *EENG4510—Control Systems Design,* to facilitate student learning.

The *EENG4510—Control Systems Design* Course

The students have been exposed to most of the important concepts (e.g., transfer functions, transient/steady-response, stability, poles/zeros and their impact on system performance, PID, etc.) from the ENGR3050 course in the general engineering core. This EE concentration course is designed to provide EE concentration students with a more solid theoretical background. Topics covered in this course include root locus analysis and design in time domain, frequency response analysis and design (with Bode plots), and digital control system fundamentals. While design via root-locus (moving trace of closed-loop poles) seems to be relatively intuitive, most of the students found the connection between the frequency response parameters and system performance distant. A viable solution to address this issue is to reinforce the frequency response skills with real-world examples that require students to go step-by-step through the design process with meaningful goals and help them grasp the mathematically intensive concepts from the "learning-by-doing" experience.

At the course level, the project presented in this paper closely supports many course learning objectives. Upon the completion of the course, students are able to:

1. Describe control system transient response, steady-state error, stability and how the location of the poles and zeros of the system affect the system's behavior.
2. Sketch the Nyquist diagram and Bode plots of a system, by hand and with MATLAB®.
3. Determine the gain/phase margin of a system from its Bode plots and Nyquist diagrams.
4. Interpret control system Bode plots and Nyquist diagrams.
5. Use Bode plots to design lag compensation and lead compensation to achieve desired system performance.
6. Use MATLAB® and SIMULINK® to aid in control system analysis and design.

III. Method

General Project Design Considerations

Several general strategies were employed when this comprehensive design project was first initiated. First of all, the project is supposed to help students understand the abstract frequency domain control concepts (Bode plots, gain/phase margins, etc.) that they see for the first time. The application idea should be interesting and simple so the students understand the project and are encouraged to learn the subject content. Secondly, the students have a course (*ENGR3012—Thermal and Fluid Systems*) in the core curriculum, where they have gained knowledge in both thermal and fluid systems. Since they completed the "Coupled-tanks Level Control Project" in the core course ENGR3050 (which is the control of a fluid system), a thermal-related control problem will be ideal to show students a different application that is well connected to their background. Lastly, the "Coupled-tanks Level Control Project" was mostly hands-on work with no theoretical simulation; a project that emphasizes computer simulation will be the most beneficial to these EE students. Biological systems, like the egg hatching process here, show significant rhythmicity and are often dominated by powerful circadian rhythms. This biological aspect, however, is not accounted for in the project in order to make the modeling of the thermal system manageable at the undergraduate level.

The goal of the project is to design a temperature control system for an incubator for a local waterfowl park (http://shwpark.com/). The students first conduct a literature review and find the acceptable temperature range for egg hatching. They are then tasked to use 60 W Tungsten incandescent bulbs as a heat source to maintain the temperature in a 3m × 1m × 1m glass incubator within the required range as the external temperature changes with the day/night cycle. The project consists of five primary steps:

1. With the SIMULINK thermal model of a house provided, modify this model for the thermal dynamics of the lamp bulbs (simplified as a glass sphere with a diameter of 10 cm and a thickness of 0.5 mm) and the incubator whose thickness is 10 mm.
2. Find the step and frequency response of the temperature control system with one bulb.
3. Determine the desired open loop gain (which in this case is the number of bulbs) from the steady-state-error.
4. Follow the procedures specified in [12] to design a lag compensator that ensures the overshoot is also in the acceptable range.
5. Simulate and evaluate the system performance of the entire system (SIMULINK model).

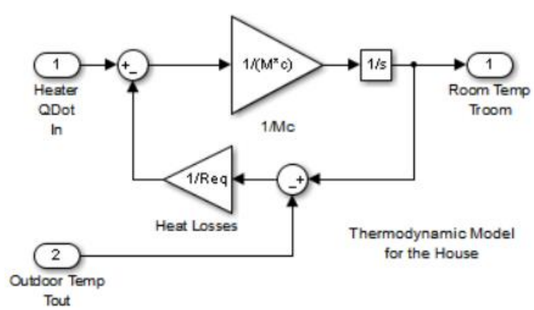


Figure 1. Thermodynamic model for a house [13].

More details of the project assignment are included in Appendix I.

Assessment/Evaluation and Results

Since the start of the EE concentration, the project has been offered twice: the first time to a small group of five students and the second time to fourteen students. The project appeared challenging to both student groups due to two factors: the extensive background theory that they encounter for the first time and the requirement to use new computer simulation tools (e.g., SIMULINK) with little practice. Most of the students from the first group were unable to complete the project (partially due to pitfalls existing in the newly developed project notes). However, assessment results from the second group showed substantial success; all fourteen students were able to complete the project tasks and submit the project report on time. Most of the students were able to design the temperature control system properly and keep the incubator temperature change within the acceptable range. Student learning was assessed with three major components: (1) student self-evaluation survey, (2) assessment against the project learning outcomes using the report, and (3) assessment of two ABET outcomes. Details of the three components are provided as follows:

a. Student Self-Evaluation

The end-of-project survey included questions with five-level Likert scale (with 5 representing Strongly Agree and 1 representing Strongly Disagree) responses to collect information in three categories: (1) students' general perception on the project (interestingness, motivation, etc.), (2) their opinion on how the project helped them learn the subject content (e.g., controls concepts and methods), and (3) their opinion on how the project helped them learn the computer tools (e.g., MATLAB and SIMULINK functions). The complete survey questionnaire is included in Appendix II. TABLE II compiles the survey results.

TABLE II. Student Self-Evaluation with End-of-Project Survey

	Mean	**Mode(s)**	**Standard Deviation**
Student General Perception			
1. Interesting and motivating	3.6	3	0.99
2. Sense of accomplishment	3.5	3, 4	0.87
3. Understand impact of engineering practice	3.5	4	1.12
Control Theory			
1. Solve engineering problems	4.0	4	0.86
2. Thermal system modeling	3.5	2, 3, 4, 5	0.97
3. Steady-state-error from Bode	3.8	5	1.09
4. Gain and phase margins	3.8	4	0.83
MATLAB Skills			
1. Like MATLAB/SIMULINK	4.0	4	0
2. MATLAB programming	4.4	4	0.48
3. Design control systems with MATLAB/SIMULINK	3.8	4	0.97
4. Apply new MATLAB/SIMULINK capacities	4.0	4	0

b. Project Learning Objectives Assessment

As stated in the project handout in Appendix I, the students are expected to achieve a set of specific learning objectives, listed as follows:

1. Research and find acceptable temperature range for waterfowl hatching.
2. Model the dynamics of the tungsten bulb and the glass incubator using MATLAB.
3. Build the thermal dynamics models of the tungsten bulb and incubator using SIMULINK.
4. Obtain the open loop step response of the incubator system with SIMULINK.
5. Characterize the frequency response of the incubator system with SIMULINK.
6. Determine the system open loop gain to meet the steady-state-error requirement.
7. Design the temperature control compensator via the frequency response method.
8. Evaluate the temperature control system performance through time and frequency domain.

Students individually wrote a report summarizing their research, analysis, and design work. In order to measure learning objectives, corresponding parts of the project report were assessed using rubrics defined towards each objective. These rubrics use a ranking scale of 1—5, with 5 representing the best (student achieved learning objectives by clearly reporting the corresponding content in the write-up) and 1 representing the poorest (the write-up shows that the student made no progress in corresponding learning objectives). Learning objectives assessment results are reported in TABLE III.

TABLE III. Achievement of Learning Objectives

	Mean	**Mode(s)**	**Standard Deviation**
1. Requirement research	4.4	5	0.77
2. Thermal system modeling	4.1	4, 5	0.79
3. SIMULINK model	4.1	4, 5	0.79
4. Open-loop response	4.1	4	0.67
5. Frequency response	4.1	4, 5	0.79
6. Determine open loop gain	4.4	5	0.64
7. Compensator design	3.4	3	0.77
8. Performance evaluation	3.9	3, 4, 5	1.00

c. ABET Outcome Support

According to the department ABET assessment plan, this course is supposed to provide assessment data for two ABET outcomes (Outcome f: ethics and Outcome h: impact). These two outcomes were assessed through the incubator design project. To assess outcome h, the students were asked to conduct research and find out how their design may harm the embryo and lead to possible hatching defects if the steady-state-error or the overshoot of the temperature are outside the acceptable range. Outcome f was assessed by checking their report to evaluate how closely they had kept design consequence in mind at different design stages over the duration of the project. Specifics of the assignment and assessment rubrics are included in Appendix III. TABLE IV summarizes the results of the two ABET outcomes.

TABLE IV ABET Outcomes Supported by the Design Project

	Mean	**Mode(s)**	**% of >=4**
Outcome f: ethics	2.73	2	54.6
Outcome h: impacts	3.64	4	100

IV. Discussion

In their responses to the open-end questions, some students reaffirmed the difficulties existing in designing control compensator through the frequency response approach. Many students expressed their excitement on being able to learn integrative and powerful software such as SIMULINK, although some believed that more help for this new tool, such as a tutorial, needs to be provided. A closer examination of the data in TABLE I reveals that students felt the project helped them learn computer design tools (average score 4.05) and controls theory (average of 3.78). An interesting yet surprising point can be drawn from TABLE I: while the responses to the short answer questions clearly demonstrated that they appreciated the opportunity of learning controls through this real-world project, the general perception of the project (motivating, interesting, sense of accomplishment, etc.) receives the lowest scores (average 3.53) compared to the other two categories. Several logistics issues occurred during the project, such as computer crashes and MATLAB license incompatibility, changed and delayed the original schedule and might have adversely influenced the students' perception.

The assessment results for each project learning objective show that, overall, the students performed well on the learning outcomes (average score: 4.06), with researching control specification (Objective 1) and obtaining open loop gain (Objective 6) from steady-state-error the best (4.4)and performed poorly on the controller design and system evaluation (scored 3.4 and 3.9, respectively). These results demonstrate that, generally, the students accomplished modeling and analysis tasks better than design and evaluation tasks. Regarding the lag compensator design, some students completed the design using the root locus method, instead of the required frequency response method. This observation confirmed that the former comes to students more naturally.

Results from the ABET outcome assessment are consistent with the project learning objective assessment. After research, the students understood the impact of their design work (average score: 3.64 out of 4); exposing eggs to temperatures outside the desired range for an elongated period of time can cause failed hatches, altered hatch time, and birth defects. However, many of the students failed to refer to this requirement at various design stages (average score: 2.73 out of 4). While one cannot conclude from these results that those students conducted experiments unethically during the project, it does necessitate the need to remind the students to keep profession ethics in mind throughout their daily engineering practice.

Examining the objectives/outcomes assessment results helps to identify opportunities to improve the project in the future. For example, the students did not think the project helped them with thermal dynamics modeling (score rated 3.5, significantly lower than other items). Adding a project element that requires the students to validate the physical model may help: students are asked to research and find the temperature of the Tungsten filament and glass bulb surface and to compare these research results with the outputs from the SIMULINK thermal models. Also, those learning outcomes related to compensator design are expected to improve when clearer instructions are provided in the project and frequency- and time-domain methods are clarified.

V. Conclusion

This paper presented an undergraduate-level course design project, where students are tasked with designing an incandescent lamp bulb-heated incubator temperature control system that keeps egg hatching temperature safe. The students used MATLAB and SIMULINK tools to model the thermal dynamics of Tungsten incandescent bulbs and a glass incubator, characterized the frequency response of the two thermal processes, and designed the compensator from the Bode plots. Student learning was assessed through student self-evaluation and project reports. Results from the first two rounds show that this real-world project can effectively facilitate student learning, making the intricate frequency methods easier to understand. The paper also identified several areas that can improve the student learning experience, making it more appealing in future offerings.

References

[1] Fei-Yue Wang. The exact and unique solution for phase-lead and phase-lag compensation. IEEE Transactions on Education, Volume: 46 , Issue: 2.

[2] Teixeira, M.C.M. ; Assuncao, E. On lag controllers: design and implementation. IEEE Transactions on Education, Volume: 45 , Issue: 3.

[3] Cavicchi, T.J. Phase margin revisited: phase-root locus, bode plots, and phase shifters, IEEE Transactions on Education. Volume: 46, Issue: 1.

[4] Fabiana Manzo, Vassilios Tzouanas, and Enrique Barbieri. Modeling and Control of Heat Integrated Distillation Columns: A Case Study. 2012 American Society of Engineering Education Annual Conference.

[5] Chiu Choi, Undergraduate Controls Laboratory Experience. 2004 American Society of Engineering Education Annual Conference.

[6] Michael Rider, Juliet Hurtig, John-David Yoder. Providing Hands on Experiences In A Mechanical Engineering Controls Systems Course. 2004 American Society of Engineering Education Annual Conference.

[7] Design analysis of phase lead compensation for typical laser guided missile control system using MATLAB Bode plots, 10th International Conference on Control, Automation, Robotics and Vision, 2008. ICARCV 2008.

[8] Mustafa Guvench, Sam Gile, and Shafaat Qazi. Automated Measurement of Frequency Response of Electrical Networks, Filters and Amplifiers. 2001 American Society of Engineering Education Annual Conference.

[9] Peter Woolf, Barry Barkel. Process Control: A Relevant Approach. 2006 American Society of Engineering Education Annual Conference & Exposition.
[10] Kauffmann P., Rogers R., Lunsford P. A Case Study: Development of a Practice Oriented Engineering Program with Implications for Regional Economic Development, Proceeding, 2004 ASEE Annual Conference and Exposition, Nashville, Tennessee.
[11] Yao, J., & Limberis, L. A Project-Driven Approach to Teaching Controls in a General Engineering Program. 2008 Annual American Society of Engineering Education Conference, Pittsburg, MA, USA.
[12] Nise, Norman. Control Systems Engineering, Wiley. ISBN: 978-0470547564
[13] Mathworks, Inc. http://www.mathworks.com/help/simulink/examples/thermal-model-of-a-house.html

EENG 4510— Advanced Control

Project #2: Modeling and Design of an Incubator Temperature Control System

Objectives:

1. Research and find acceptable temperature range for waterfowl hatching
2. Model the dynamics of the tungsten bulb and the glass incubator using MATLAB
3. Build the thermal dynamics models of the tungsten bulb and incubator using SIMULINK
4. Obtain the open loop step response of the incubator system with SIMULINK
5. Obtain the frequency response of the incubator system with SIMULINK
6. Determine the system open loop gain to meet the steady-state-error requirement
7. Design the temperature control compensator via the frequency response method
8. Evaluate the temperature control system performance through time and frequency domain

Introduction:

Sylvan Heights Waterfowl Park (http://shwpark.com/) hatches many bird species. An incubator that can maintain proper temperature, humidity, and ventilation is crucial in order to successfully incubate these little lives. Packaged in safe glass envelop, tungsten light bulbs are naturally convenient heating elements used for incubating purposes. During the next weeks, you are tasked to design a temperature controls system using a MATLAB tool SIMULINK. Specifically, you will complete the following tasks:

1. Research and determine the egg hatching temperature requirement
2. Model the bulb and the incubator (math and thermal)
3. Build the bulb and the incubator subsystems in SIMULINK
4. Characterize the frequency response of the plant: the two subsystems cascaded with the incubator temperature going back to the bulb subsystem
5. Determine the response of the plant when in a unity negative feedback
6. Determine the number of bulbs to meet the steady-state error requirement
7. Plot the frequency response of open-loop system with the new gain (the number of bulbs)
8. Determine the compensator via frequency response method to improve transient response
9. Plot the frequency response of the compensated system Gc(s)*G(s)
10. Simulate and evaluate the system

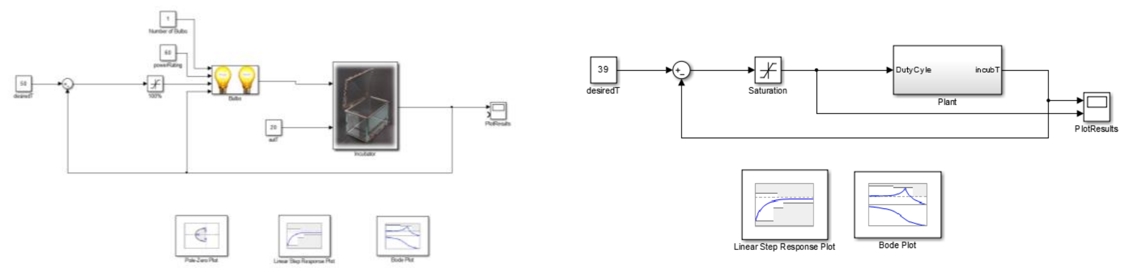
Design specifications:

- Physical dimensions of the incubator: L x W x H = 3m x 1m x 1m
- Temperature range: determined by your research
- Bulb rating power: 60 W

Tasks:

In this project, you are expected to complete the following tasks, each of which is provided with detailed instructions.

1. Research and determine the egg hatching temperature requirement.
   Go online and research the temperature requirement for egg hatching. Answer the following questions: What is the desired temperature? What is the allowable temperature range? And what may happen if the temperature is not well controlled?
2. Build the bulb and incubator thermal models in SIMULINK.
   a) First read and make sure you understand the MATLAB house thermal model provided by Mathworks, Inc. To open the model file, type "edit('sldemo_househeat_data.m')" in your MATLAB command window. Save it in a different name so that you don't accidentally make changes to the original file. Refer to the webpage: http://www.mathworks.com/help/simulink/examples/rmvd_matlablink__137f787244c9729ab43473118cdc7a7c.html. Refer to Figure 1 and 2 when reading the m.file.
   b) Modify the house parameters in the m.file to reflect the provided dimensions of the incubator. Save all the changes. After this file is run, the values of all the parameters will be in the MATLAB workspace and SIMULINK can use these values in the model built next.
   c) Build the incubator model in SIMULINK, using thermal parameters defined in the .m file. The subsystem should have two inputs: heat (power) flowing in "Q_{in}" and the outside temperature "T_{out}"; one output: the air temperature in the incubator "T_{incub}". Mask the model as a subsystem.
   d) Add the calculation of the bulb parameters R_f, R_b, C_f, C_b, and *ReqBulb* into the same .m file.
   e) Build the bulb thermal model using Equation (10) and the thermal parameters defined in the .m file. Refer to Figure 4. The subsystem should have four inputs: "Number of Bulbs", "Bulb Power Rating", "Duty Cycle", and "Incubator Temperature"; and one output: "Heat Out". Mask the model as a subsystem. When building the bulb model, note that the heat out to the incubator is the heat loss of the bulb(s), which is similar to the heat loss in the house model.
3. Characterize the frequency response of the plant, which is the cascade of the bulb subsystem and the incubator subsystem, with the incubator temperature connected back into the bulb subsystem (see Figure 1). Note that this back connection is part of the thermal interaction. It is NOT part of the feedback control we are trying to design. Here a "Saturation" block is added to limit the duty cycle to 100%. You need to mask the details of the plant in order for the next steps. At this point, use only 1 bulb.



(a) (b)

Figure 1. The plant in a unity negative feedback. The details of the plant are masked in (b).

a) Referring Figure 2, add a Bode plot to the SIMULINK model; check “Show Plot”; select the input signal as the input of the bulb (which is the filament turn-on duty cycle), and the output signal as the output of the incubator (which is the incubator temperature).

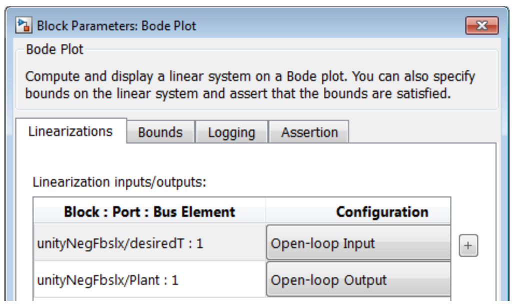


Figure 2. Signal configuration to get the open-loop frequency response.

b) Run the simulation for 3 hours (3*3600) and save the Bode plots.

c) Read the phase margin and gain margin from the Bode plots.

d) Can we determine the settling time, peak time, and steady-state error from the Bode plots? If yes, find them. If not, explain why not?

4. Determine the step response of the plant when the plant is in a unity negative feedback

a) Similar to the Bode plots, Step-Response plots can be obtained (referring Figure 3). One thing that’s different: select the incubator temperature as the signal and configure it as “Complementary Sensitivity” in order to get the step response of the **closed-loop** system.

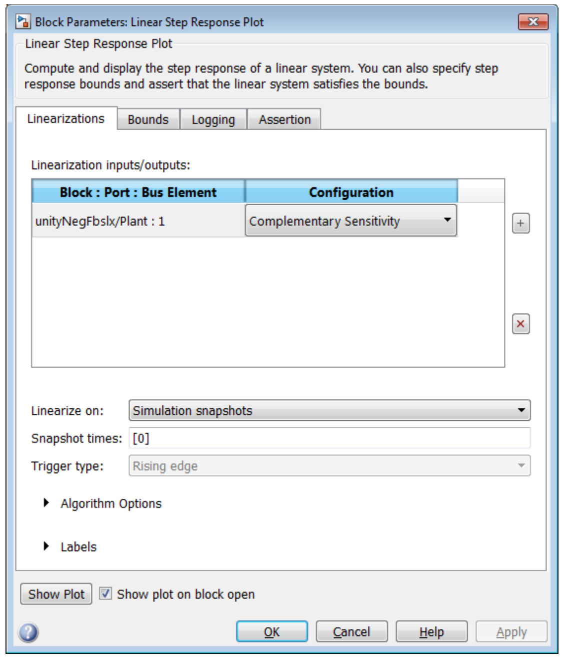


Figure 3. Signal configuration to get the closed-loop step response.

b) Record transient response and steady-state response (P.O., peak time, settling time, and steady-state error).

c) Compare the steady-state error found from the Bode plot and the step response.

5. Determine the number of bulbs to meet the steady-state error requirements

   a) Find the open loop gain that meets the steady-state error requirement. In order to do this, you need to find the static error constant first.

   b) Determine, with analytical calculation, the number of the bulbs required to satisfy the steady-state error requirement. That is, we adjust the open-loop gain by changing the number of bulbs used in the incubator.

   c) Plot the frequency response of the open-loop system with the new gain (the new number of bulbs). Plot the step response of the closed-loop system with the new gain. This is similar to tasks 3 and 4, but the number of the bulbs is different.

   d) Observe the overshoot of the closed-loop system with the new gain. Is this overshoot still in the safe temperature range for egg hatching?

6. Determine the compensator via the frequency response method to improve overshoot (referring Figure 4).

   a) Find ζ and phase margin ϕ_M from the desired overshoot.

   b) Follow the procedures discussed in class to determine the lag compensator Gc(s).

   c) Plot the frequency response of the compensated system Gc(s)*G(s).

   d) Observe the new gain/phase margin.

   e) Evaluate the system performance and verify that the requirements are met. Otherwise, modify the compensator to ensure that is the case.

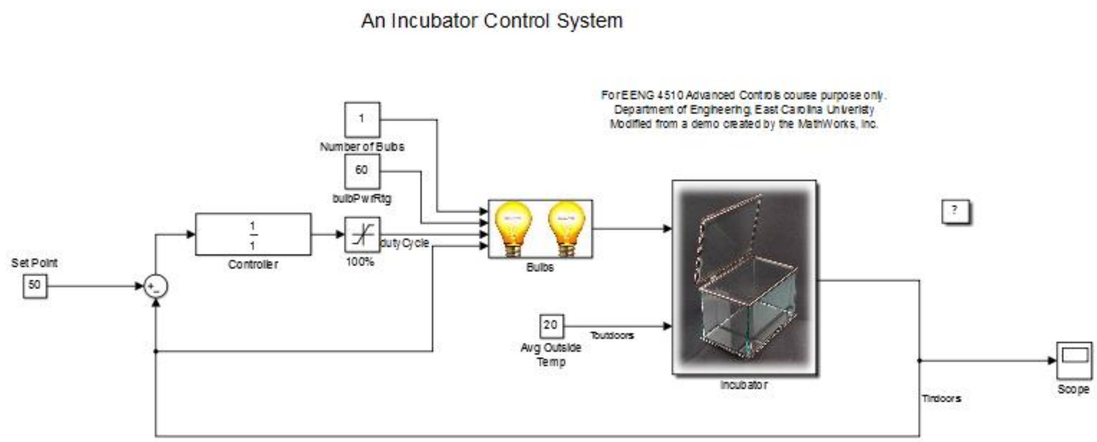


Figure 4. The closed-loop system, including the designed compensator.

Progress and Milestones:

Since the project is lengthy, here is a progress plan with milestones in order to manage your project. You are required to turn in your deliverables for my review. I will provide feedback.

- Week 1: Learn about the system and the tool; model the incubator thermal dynamics.
  <u>Deliverables</u>: a paragraph with answers to all the questions (include any references you might have) and a *.m file that models the incubator. (Due 10/24)
- Week 2: Build the SIMULINK Model of the system and analyze the open-loop system through both frequency (Bode plot and Nyquist diagram) and time domain (step response).
  <u>Deliverables</u>: masked models for the two subsystems (tungsten bulb and glass incubator) and the plant model (with the two subsystems cascaded). Bode plot, step response plots, and interpretation of these plots. (Due 10/31)
- Week 3: Determine the number of bulbs required to satisfy the steady-state error requirement; design the compensator to satisfy other performance requirement.
  <u>Deliverables</u>: write up of the approach to determine the number of bulbs required; write up of how the compensator is designed. (Due 11/7)
- Week 4: Simulate the new closed-loop system; evaluate the final system.
  <u>Deliverables</u>: simulation results and interpretation. (Due 11/14)
- Week 5: Complete the entire project and write report.
  <u>Deliverables</u>: Final report. (Due 11/24)

(f) Graduates of the Engineering Program will demonstrate the understanding of professional and ethical responsibility.

In the final course design project, the students were asked to design a temperature control system for waterfowl egg hatching. The design work should have the hatching condition in mind and evaluation of the system should be conducted against these requirements, and comments of the results should be thoroughly referred to the requirements (part of the assignment description included below).

==

Sylvan Heights Waterfowl Park (http://shwpark.com/) hatches eggs of many bird species. An incubator that can maintain proper temperature, humidity, and ventilation is crucial in order to successfully incubate the little lives. Packaged in safe glass envelop, tungsten light bulbs are naturally convenient heating elements used for incubating purposes. During the next weeks, you are tasked to design a temperature controls system using a MATLAB tool SIMULINK. Specifically, you will complete the following tasks:

1. Research and determine egg hatching temperature requirement

Go online and research the temperature requirement for egg hatching. Answer the following questions: What is the desired temperature? What is the allowable temperature range? And what may happen if the temperature is not well controlled?

==

4 (Superior): The student's design and evaluation of the control system referred to the egg hatching temperature requirements. The analysis comments on the system performance were thorough and rational.

3 (Satisfactory): The student's design and evaluation of the system mostly referred to the egg hatching temperature requirements. The analysis comments on the system performance were reasonable.

2 (Below Expectation): The student's design and evaluation of the system largely referred to the egg hatching temperature requirements with significant oversights. The analysis comments on the system performance were biased.

1 (No Progress Shown): The student's design and evaluation of the system didn't refer to the egg hatching temperature requirements. The analysis comments on the system performance were either unreasonable or missing.

(h) Graduates of the Engineering Program will demonstrate the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

In the final course design project, the students were asked to was to research and determine the egg hatching temperature requirement (part of the assignment description included below)

==

Sylvan Heights Waterfowl Park (http://shwpark.com/) hatches eggs of many bird species. An incubator that can maintain proper temperature, humidity, and ventilation is crucial in order to successfully incubate the little lives. Packaged in safe glass envelop, tungsten light bulbs are naturally convenient heating elements used for incubating purposes. During the next weeks, you are tasked to design a temperature controls system using a MATLAB tool SIMULINK. Specifically, you will complete the following tasks:

2. Research and determine egg hatching temperature requirement

Go online and research the temperature requirement for egg hatching. Answer the following questions:: What is the desired temperature? What is the allowable temperature range? And what may happen if the temperature is not well controlled?

==

4 (Superior): The student was able to find sufficient information about the temperature requirements for egg hatching and the consequence if the design fails to meet these requirements.

3 (Satisfactory): The student was able to find most of the information about the temperature requirements for egg hatching and the consequence if the design fails to meet these requirements.

2 (Below Expectation): The student was able to find some information about the temperature requirements for egg hatching and/or the consequence if the design fails to meet these requirements.

1 (No Progress Shown): The student was unable to find the temperature requirements for egg hatching or the consequence if the design fails to meet these requirements.

SURVEY: Laboratory Design Project—Incubator Temperature Control Design

1. **This design project improved my ability to use math to solve engineering problems.**

Strongly disagree	*Disagree*	*Neutral*	*Agree*	*Strongly agree*
1	2	3	4	5

2. **This design project improved my MATLAB programming skills.**

Strongly disagree	*Disagree*	*Neutral*	*Agree*	*Strongly agree*
1	2	3	4	5

3. **Knowledge from thermodynamics and heat transfer from Engineering Core Curriculum helped me when working on this project.**

Strongly disagree	*Disagree*	*Neutral*	*Agree*	*Strongly agree*
1	2	3	4	5

4. **This design project helped me understand how thermodynamics and heat transfer knowledge is applied in process modeling and control.**

Strongly disagree	*Disagree*	*Neutral*	*Agree*	*Strongly agree*
1	2	3	4	5

5. **After this design project, I am able to find steady-state error of a system from its Bode plots.**

Strongly disagree	*Disagree*	*Neutral*	*Agree*	*Strongly agree*
1	2	3	4	5

6. **After this design project, I am able to understand magnitude and phase margins of a system.**

Strongly disagree	*Disagree*	*Neutral*	*Agree*	*Strongly agree*
1	2	3	4	5

7. **After this design project, I am able to use MATLAB and Simulink to model, analyze, and design control systems.**

Strongly disagree	*Disagree*	*Neutral*	*Agree*	*Strongly agree*
1	2	3	4	5

8. **After this design project, I am able to apply more MATLAB and Simulink capacities.**

Strongly disagree	*Disagree*	*Neutral*	*Agree*	*Strongly agree*
1	2	3	4	5

9. **After this design project, I like MATLAB and Simulink as a design tool.**

Strongly disagree *Disagree* *Neutral* *Agree* *Strongly agree*
1 2 3 4 5

---

10. After this design project, I fully understand the impact of my engineering practice.
Strongly disagree *Disagree* *Neutral* *Agree* *Strongly agree*
1 2 3 4 5

---

11. Completing this design project gives me a sense of accomplishment.
Strongly disagree *Disagree* *Neutral* *Agree* *Strongly agree*
1 2 3 4 5

---

12. This design project was interesting and motivated me to learn.
Strongly disagree *Disagree* *Neutral* *Agree* *Strongly agree*
1 2 3 4 5

Please comment on the following questions.

1. **Please describe the part(s) of this design project that you liked the MOST.**

2. **Please describe the part(s) of this design project that you liked the LEAST.**

3. **Please include at least three things you learned about MATLAB/SIMULINK from this project.**

4. **Please suggest at least one thing to improve this design project.**

5. **Provide below if you have any other comments.**