24.536 Reactor Experiments

Lab #4 Description/Procedure: Measuring and Interpreting Feedback Effects within the UMLRR

Objective

The purpose of this experiment is to develop and validate a model to represent the inherent feedback effects within the UMass-Lowell Research Reactor (UMLRR). In particular, all the lab exercises to date have been performed at low power (or during subcritical operation) with the intent of minimizing the effects of the inherent temperature and xenon feedback effects on our reactivity measurements and our overall observations of zero-power (or feedback-free) reactor dynamics. Now, for this lab, the feedback effects are the primary focus area, so all the reactor sequences studied will highlight one or more of the different feedback mechanisms that are inherent to all thermal reactor systems. Several prior reactor sequences will be studied using archived data to help develop, rationalize, and quantify a proposed feedback model, and two new reactors sequences will be performed to help confirm/validate the model. Combined, the exercises performed here should give a good understanding of how to model the various inherent feedback mechanisms and how they affect real reactor operations.

Introduction/Overview

Inherent negative feedback is quite common (and often an absolute requirement) for most real systems as a way of limiting operation to regions where the performance of the system is not seriously degraded and to guarantee that public safety is not compromised. In nuclear systems, inherent stability to reasonable changes in power or temperature perturbations is achieved if all the reactivity feedback mechanisms are negative -- meaning that an increase in power or temperature leads to a decrease in reactivity, which leads to a decrease in power, and so on. In thermal reactor systems, the primary feedback mechanisms are related to the fuel and coolant temperatures and to the buildup and decay of xenon within the system. In this lab exercise, we study how these feedbacks affect operation of the UMass-Lowell research reactor (UMLRR). In particular, a combination of calculations and separate-effect tests within the reactor are studied to try to quantify the individual fuel and coolant reactivity coefficients and the xenon feedback reactivity component specific to the UMLRR. With this information, a "feedback model" will be proposed and tested as part of the overall laboratory exercise.

Because of the number and length of the reactor runs needed to isolate and quantify the various feedback components, several reactor sequences were designed and run prior to the current lab, and these are discussed and analyzed using archived reactor data as part of the pre-lab portion of this overall exercise. In addition, since no direct measurements of the fuel temperatures or in-core coolant temperatures are available, a simple mathematical model is discussed and used to develop a working relationship between reactor power (and coolant flow rate) and the core-averaged fuel and coolant temperatures for both the forced and natural convection modes of operation. Using an appropriate combination of the empirical data and the mathematical model, we should be able to develop a crude but reasonable "feedback model" for the UMLRR. Finally, during the actual in-lab portion of this exercise, we will run a couple of new reactor sequences that should provide a rigorous test of the specific "feedback model" developed here -- as well as clearly demonstrate that negative feedback and reactor stability are indeed inherent features of UMLRR operations.

The two sequences to be run during the lab involve natural convection and forced convection operation and our goal is to evaluate how well our dynamics model with inherent feedback actually represents real operation of the UMass-Lowell research reactor (UMLRR). In particular, a relatively long reactor sequence (2.5 - 3.0 hours) that includes both natural and forced convection flows and a number of reactivity perturbations (and power transients) will be designed and implemented as a test of our overall simulation capability. This test sequence is similar in nature to the one conducted as part of Lab #3 (see Ref. 1), where we compared a feedback-free kinetics model to actual operation of the UMLRR. Those tests, however, were conducted in forced flow mode with $P(t) < 30$ kW so that there would be negligible feedback effects within the system. The purpose of the current lab, in contrast, is to highlight these nonlinear interactions. Thus, the reactor sequence will include high power operation to initiate the production of xenon, and both natural convection and forced flow operation so that both the fuel temperature and coolant temperature effects can be evaluated. If designed properly, this reactor sequence should clearly illustrate how the nonlinear interactions between power level, temperature, and xenon buildup affect reactor behavior, and also serve as a great test of the simulation model that has been developed as part of this course.

The background theory for our study of feedback effects is thoroughly discussed in Refs. 2-6. In particular, the integration of a simple feedback model -- that includes both temperature and xenon feedback effects -- within an 11-equation dynamic simulation model of the UMLRR was discussed in some detail in class, and a summary of the mathematical model is available in Ref. 6. In this lab exercise, we will evaluate how well the model actually represents real operation of the UMass-Lowell research reactor (UMLRR).

Experimental Procedure

As implied above, the reactor run for this lab will involve two separate, but similar, reactor operations sequences, with a transition from natural convection to forced convection operation between the two operational modes, as follows:

Phase I: Sequence of Movements with the Regulating Blade -- Natural Convection

1. The reactor should be at about 5 kW with the RegBlade in Auto Mode at about 12 inches withdrawn. The primary and secondary pumps should both be off. The system should be stable in this state for several minutes to assure steady state operation.
2. Ask the reactor operator to go to Manual Mode and to perform the pre-planned sequence of movements of the RegBlade to achieve the desired P(t) profile. This sequence should involve 3 or 4 movements of the RegBlade while in natural convection mode, both outward and inward, to add positive and negative reactivity as needed to generate a good test case. The interval lengths will likely be much longer than in the Lab #3 sequence used to test a feedback-free model -- since now we need to give time for the feedbacks of interest to become significant. During actual operation, try to keep as close as possible to the planned sequence and timing of the blade movements -- although some flexibility is okay here since, during the post-analysis phase, the simulations will be updated with the actual times and positions that were used during actual reactor operations.

   The constraints on reactor operation during this phase include keeping $P(t) < 80$ kW, keeping the stable reactor period well above 60 seconds (probably in the 90 – 120 seconds range), having the last step induce a power decrease as a transition to the Phase II analysis, and making this happen within about 60 minutes of operation. This phase will be complete when the reactor power reaches 5 kW after the last RegBlade movement.

Note: Be sure to design the last step of this phase of operation to be a power decrease so that the reactor approaches the proper state for the next phase of operation. Doing this will save some operations time in the transition step between Phase I and Phase II.

Transition from Phase I to II: Turn on Primary Pump

The last step from Phase I should involve a reduction in power. Watch this operation carefully and, when the power level reaches about 5 kW, ask the reactor operator to go into Auto Mode to hold the power at this level.

After auto-mode operation at 5 kW for a few minutes (to assure that steady state has been reached), ask the reactor operator to switch to Forced Flow Mode and, with the RegBlade still in Auto Mode, to turn on the primary pump. This "pump-on" transient will induce a positive reactivity spike due to the colder water that will be drawn into the core. The RegBlade should automatically respond by inserting itself further into the core to compensate for the positive feedback reactivity in its attempt to keep the power level approximately constant during the transient. You should carefully observe and record operations during the "pump-on" transient, paying particular attention to power level, RegBlade location, and the core inlet and outlet temperatures. Can you explain what has happened? Does the system behave as expected? What is the new RegBlade position after stabilization? Can you predict/rationalize the observed result quantitatively?

Phase II: Sequence of Movements with the Regulating Blade -- Forced Flow

1. Make sure that the system is stable in the forced convection state at about 5 kW for several minutes to assure steady state operation before starting Phase II operations.
2. Now ask the reactor operator to go to Manual Mode again and to perform the pre-planned sequence of movements of the RegBlade to achieve the desired P(t) profile while in forced convection mode. This sequence will involve another 2 or 3 movements of the RegBlade while in forced flow mode with similar constraints as above, except now we want to keep $P(t) < 800$ kW. Note also that the last interval of the sequence should not take the system subcritical via blade movement, since we want to let the inherent feedbacks shutdown the reactor on their own. In particular, the system should be observed without further external action for at least 20-30 minutes after the last RegBlade movement so that the xenon effect can be clearly identified. The total length for the full reactor sequence (Phases I and II) should be no more than 3.0 hours or so.
3. Once you have sufficient data, this lab sequence is complete, and you should notify the reactor staff that you are finished and thank them for their assistance during the lab.

References

1. J. R. White, “Lab Description/Procedure: Measuring Integral Blade Worths Curves within the UMLRR,” one of a series of labs for the Reactor Experiments course at UMass-Lowell.
2. J. R. White, “Temperature Related Reactivity Coefficients and Feedback,” part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell.

3. J. R. White, "Xenon Poisoning in Thermal Reactors," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell. This set of Lecture Notes also serves as documentation for the **xenon_gui** code.
4. J. R. White, "Steady-State Temperature Profiles in a UMLRR Fuel Channel," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell. This set of Lecture Notes also serves as documentation for the **sstemp_umlr_gui** code.
5. J. R. White, "Reactivity Feedback Effects -- Part I: Prediction, Measurement, and Interpretation," one of a series of PowerPoint Lectures for the Reactor Experiments course at UMass-Lowell.
6. J. R. White, "Reactivity Feedback Effects -- Part II: Prediction, Measurement, and Interpretation," one of a series of PowerPoint Lectures for the Reactor Experiments course at UMass-Lowell.