24.536 Reactor Experiments and 407.403 Advanced Nuclear Lab

HW #8: "Integral Blade Worth Curves" Pre-lab Exercises

Introduction

The purpose of Reactor Experiment #3 is to become familiar with various techniques for measuring blade worths curves within the UMass-Lowell Research Reactor (UMLRR). In particular, this lab exercise addresses three different experimental techniques that can be performed, but actual data for generating a blade worth curve will be taken live for only the Inverse Kinetics method -- and the other methods will be illustrated using archived reactor data (as part of your post-lab work). In addition, an effort will be made to help validate the simple point kinetics model (with no feedbacks) that has been used to illustrate the various reactor operations scenarios addressed so far this semester, and also to formally benchmark the recently-implemented Inverse Kinetics capability at UMass-Lowell. Combined, the exercises performed as part of this lab should give a good understanding of basic reactor kinetics (with no feedbacks) and the various techniques used for measuring the integral worth curves for a real reactor.

Upon completion of this experiment, the student should have a better understanding of various methods for measuring the integral worth curves for a real reactor, and have more confidence in our ability to predict the feedback-free behavior of a reactor via numerical solution of the point kinetics equations. In addition, you will also have your first introduction to the use of inverse kinetics to measure blade worth curves and to help better view/interpret the overall system dynamics. HW#8 emphasizes these general topics and helps you plan for the actual lab that will take place during a subsequent class meeting. The specific tasks and deliverables for this pre-lab assignment are described below:

Task 0: Review/Study the Lecture Notes, Examples, and Associated Reference Materials

Before starting the formal tasks listed below, you should be sure that you have a good understanding of the main topics under study and be familiar with the overall experimental procedure to be followed for Reactor Lab #3. In particular, for this pre-lab HW, you should carefully review the following documents (these are available in the course Dropbox folder):

1. J. R. White, "Integral Worth Curves: Theory and Measurement Techniques," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell. Also included in this discussion is a series of Matlab routines to illustrate the three methods discussed here. These files are available within the ***bw_stable_period_demo.zip***, ***bw_inverse_rate_demo.zip***, and ***bw_inverse_kinetics_demo.zip*** files.
2. J. R. White, "Inverse Point Kinetics," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell. Also included in this discussion is a Matlab demo (see the ***invkin_demo.zip*** file) that illustrates/validates the basic method.
3. J. R. White, "Reactor Lab #3 Description/Procedure: Measuring Integral Blade Worths Curves within the UMLRR," part of a series of procedures used within the 24.536 Reactor Experiments course at UMass-Lowell.

You will also want to browse through the following set of Lecture Notes as additional background concerning the operator form of the neutron balance equation and for some brief introductory concepts on the subject of first order perturbation theory (these are also available in the course Dropbox folder):

4. J. R. White, "The Multigroup Neutron Balance Equation," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell.
5. J. R. White, "The Weight Function," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell.

And, finally, you may also want to take a look at the following files that document the blade calibration procedure used routinely within the UMLRR prior to 2013:

6. J. R. White, "Blade Worth Calibration within the UMLRR," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell. This set of Lecture Notes also provides documentation for the **blade_worth_gui** Matlab program.
7. J. R. White, "Analysis of the Blade #4 Calibration Experiment #1 Performed on August 15, 2005," part of a series of Demos & Expts. available at www.nuclear101.com.

Task 1: Answer several general questions concerning the background theory and the specific methods to be illustrated as part of the Integral Blade Worth Curves lab.

Answer each of the following questions/problems fully and include your responses, calculations, and Matlab simulations, as needed, as part of your complete package for HW#8.

Problem 1: Briefly identify the three methods discussed for measuring the integral rod or blade worth curves in a real system. What are the advantages/disadvantages of each method?

Problem 2: The theoretical development of the "ideal integral rod worth curve" uses some concepts from First Order Perturbation Theory (FOPT). As part of our brief introduction to the topic of FOPT, we introduced the concept of an "adjoint operator". What is the adjoint to the second derivative operator -- that is, if $H = d^2/dx^2$, what is H^* assuming that the "boundary terms" vanish?

Problem 3: Continuing with the subject of FOPT, write out both the forward and adjoint diffusion equations for the usual 2-group thermal reactor problem (i.e. with no upscatter and $\chi_1 = 1.0$ and $\chi_2 = 0.0$), and identify the key differences in these sets of equations. Also identify what is meant by the term "self adjoint" and determine if the 2-group equations satisfy this condition -- and be sure to explain why or why not.

Problem 4: In the theoretical development of the "ideal integral rod worth curve" we showed that, assuming "1-group theory for a bare 1-D homogeneous critical reactor of height H", the ideal integral worth distribution is given by

$$\rho_w(z) = \rho_w(H)\left(\frac{z}{H} - \frac{1}{2\pi}\sin\frac{2\pi z}{H}\right)$$

Your job here is to **formally derive this result** showing all the details and assumptions involved. In doing this you can start with the statement "that the worth of a material inserted to an axial depth z within the reactor is proportional to the product of the forward and adjoint fluxes integrated over the perturbed domain" and, for 1-group theory, this statement can be written mathematically as

$$\rho_w(z) = \alpha \int_0^z \phi^*(z')\Delta\Sigma_a(z')\phi(z')\,dz'$$

where α is the proportionality constant and ϕ^* is the adjoint flux.

Problem 5: Briefly discuss what is meant by the term "inverse problem" and relate this concept to the solution of a typical reactor kinetics problem. Note that this should be a general discussion -- that is, no formal equation or model development is needed here!!! I just want a general overview of the topic…

Problem 6: In discussing the practical implementation of the Inverse Kinetics Methods within the UMLRR, a problem with "reactivity drift" was mentioned. Briefly identify the cause of this issue and the limitations it imposes on the application of the method.

Task 2: Develop a sequence of RegBlade movements for the Phase I portion of the upcoming experiment.

As discussed in class, your primary pre-lab task for this experiment is to do a formal Matlab simulation and develop a preliminary plan for the Phase I sequence described in the Experimental Procedure section of Ref. 3. This simulation should have several distinct calls to the ***ode15s*** ODE solver (and associated point kinetics function file) which solves the point kinetics equations for the planned movement of the RegBlade. Each interval should involve a short ramp (up or down) followed by some period with the RegBlade held constant -- to allow time for the power to increase or decrease, as appropriate. The design procedure should involve deciding how many intervals to include, the magnitude and direction (out or in) of the blade movement, and the duration of the interval with no blade movement.

Things to consider in designing a suitable procedure with P_o = 7-8 kW include the following:

The Goal:

To design a reactor operations sequence that represents a rigorous test for evaluating the accuracy of our feedback-free point kinetics simulations and the effectiveness of the inverse kinetics algorithm.

The Limitations/Constraints:

a. Keep the total simulation time around 40-60 minutes -- to keep the actual experimental time to a reasonable value.

b. Keep any positive periods well above 60 seconds to assure safe reactor operation -- you should probably aim for between 90 – 120 second positive periods. The minimum negative period is automatically around 80 seconds -- even so, the rate of negative insertion is not a safety issue anyway...

c. Keep the maximum power level at any point in time below 25 kW so that feedback effects are indeed negligible.

d. Have at least three sequences of RegBlade movement followed by a movement-free interval at the beginning of the Phase I sequence where $P(t) > 0.5$ kW -- so that "reactivity drift" is not an issue with the inverse kinetics method.

e. And, finally, have at least one interval where you deliberately try to show the "drift" in the measured $\rho(t)$ predicted by the inverse kinetics method (as discussed in Refs. 1-2). **Note:** This should probably be the last interval in your full sequence since a significant "drift" can affect subsequent measurement accuracy for $\rho(t)$. Of course, you will not see this effect in the simulations, since the idea is to actually show this "drift" once we do the real reactor run -- so be sure your last simulation interval addresses this subject!!!

Documentation and Submission of HWs

In general, I expect a professional, well-written, semi-formal report for each HW assignment in this course. Please refer to HW#1 regarding the format for each HW assignment in this course -- **they should all be done and submitted in a similar fashion!!!**

For this HW, you will need to include your discussions for Task 1 Problems 1 - 6 , and the Matlab code, results, and discussions for Task 2. As done previously, please put everything together, including all your Matlab m-files, in a single zip file -- **only one zip file per HW please** -- and **email this to me before 4 pm (UML time) on next Sunday**...

Note: I will review your Task #2 simulation before the actual lab class to decide what sequence (or possibly a combination of steps) will be performed during the live lab session. Just before the actual lab, we will review the selected Phase I sequences (so be prepared to discuss these) and we will make a collective decision on how to proceed for the actual reactor run. Only one sequence will be performed during the actual reactor lab -- this could be selected from a single group entry or I may try to combine several student suggestions into a single "class" sequence. I will have to wait to see what you propose as part of your HW #8 assignment…

Good luck and have fun…