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22.921 – Nuclear Power Plant Dynamics and Control

Problem Set #3

The questions that follow are taken from two papers that appeared in Nuclear Science and Engineering. These are:

(1) Application of the 'Reactivity Constraint Approach' to Automatic Reactor Control – NSE 98, pp. 83-95, 1988. This paper is referred to as NSE 98.

(2) Considerations in the Design and Implementation of Control Laws for the Digital Operation of Research Reactors, NSE 110, pp. 425-444. This paper is referred to in NSE 110.

You should have received both of these papers as handouts.

1. Figure 1 of NSE 110 illustrates the fission process.

   a) What are the three possible paths for production of neutrons?

   b) What are the relative yields of each path? (Hint: The sum of the yields must be 100%. What is the value of $\overline{\beta}$?)

2. The denominator of the dynamic period equation contains three terms. (See eqn (11) of NSE 98)

   a) Provide a concise explanation of the physical meaning of these quantities. Which are proportional to the prompt neutron population and which to the delayed neutron population?

   b) Which of these three terms can be changed on demand? Does this suggest an argument for choosing one of these quantities as the control signal for a reactor controller? What is that argument?

   c) Compare the denominator of eqn (11) of NSE 98 with that of eqn A.1 of NSE 98. Which is the easier to program in a digital controller? Why?

3. Figure 1 of NSE 98 shows that the effective multi-group decay parameter, which is a weighted average of the precursor concentrations, varies with the reactivity. Why? (Hint: See middle portion of Figure 2.)

4. The value of the standard multi-group decay parameter is 0.1 s^{-1} and the net reactivity present in a reactor is 100 mbeta. The control rods are not moving $(\dot{\rho} = 0)$ and asymptotic conditions $(\dot{\lambda}_e = 0)$ exist. Refer to eqn A.1 of NSE 98 with ℓ^* set equal to zero.

   a) What is the reactor period?

   b) By what factor will the reactor power increase in thirty seconds? (Hint: Refer to eqn (1) of NSE 98. The quantity T(t) is essentially the reactor power. Integrate eqn (1) for a constant period.)

c) What is the minimum rate of reactivity insertion needed to halt the power increase instantly (i.e., $\tau = \infty$)?

5. What is meant by the expression "feasibility of control"?

6. Refer again to Figure 1 of NSE 110. The neutron lifetime is defined here as the time for a neutron to be born from fission, thermalize, and cause a fission. The lifetime for prompt neutrons in typically $1 \cdot 10^{-4}$ s. That for delayed neutron is $(1/\lambda_e)$ where λ_e is the standard effective multi-group decay parameter. A typical value of λ_e is 0.08 s^{-1}.

   a) Why are delayed neutrons essential to reactor safety? (Hint: What is the lifetime of an average neutron?)

   b) Why do delayed neutrons cause difficulty in the design of reactor controllers?

7. Four tasks are involved in the approach that humans use to achieve control. These are planning, prediction, implementation, and assessment. (See p. 2 of NSE 110.)

   a) What is meant by each of these tasks?

   b) Which one(s) can be done via analog equipment?

   c) Which one(s) can be done by digital equipment? What are the challenges in doing these digitally?

8. Two of the major difficulties in the design of reactor controllers have been the non-linear term in the first kinetics equation ($\rho(t)n(t)$ where $\rho(t)$ is a function of $n(t)$) and the difference in response times of the prompt and delayed neutrons. The period-generated control approach overcomes these problems. How? (Hint: See Section V.A of NSE 110.)

9. Why does NSE 110 advocate (on p. 15) the use of both a period-generated control law and a supervisory controller? The latter would be based on the concept of feasibility of control (i.e., reactivity constraints).

10. List the advantages and disadvantages of P-I-D (proportional-integral-derivative) control laws and those of model-based control laws.