Time-Independent Reactor Stability Analysis using Temperature Coefficients

Michael Parnell, Dr. Pavel Tsvetkov

Introduction

Time-dependent stability analyses of reactors provide useful information on neutronics and system parameters, but have costs:

- Experience is required to operate simulators
- Detailed information on geometry, fuel, and power are needed for inputs
- Long computational times

The general stability of the reactor can be determined by using the temperature coefficient of reactivity for the fuel and the moderator.

- Depending on the ratio of these coefficients, a reactor may be unstable, completely stable, or stable depending on the gain.
- For a stable reactor, the ratio must be less than an expression which depends on the mass and specific heat of the fuel and moderator, as well as several neutronics parameters of the fuel.

An inequality was derived to determine the stability requirements, which is presented below.

Overview of Derivation

The transfer function approach to reactor analysis assumes that changes in reactivity have linear effects on neutron population, and therefore reactor temperature and power. The reactor has its own general transfer function that is coupled with feedback loops from fuel and coolant transfer functions. A block diagram of this interrelated system is provided in Figure 1 below.

- The reactor transfer function depends primarily on neutronic factors (λ, β, l*)
- The fuel and moderator transfer functions are governed by heat transfer effects (how well the energy passes to the next material, vs heating the matter itself)

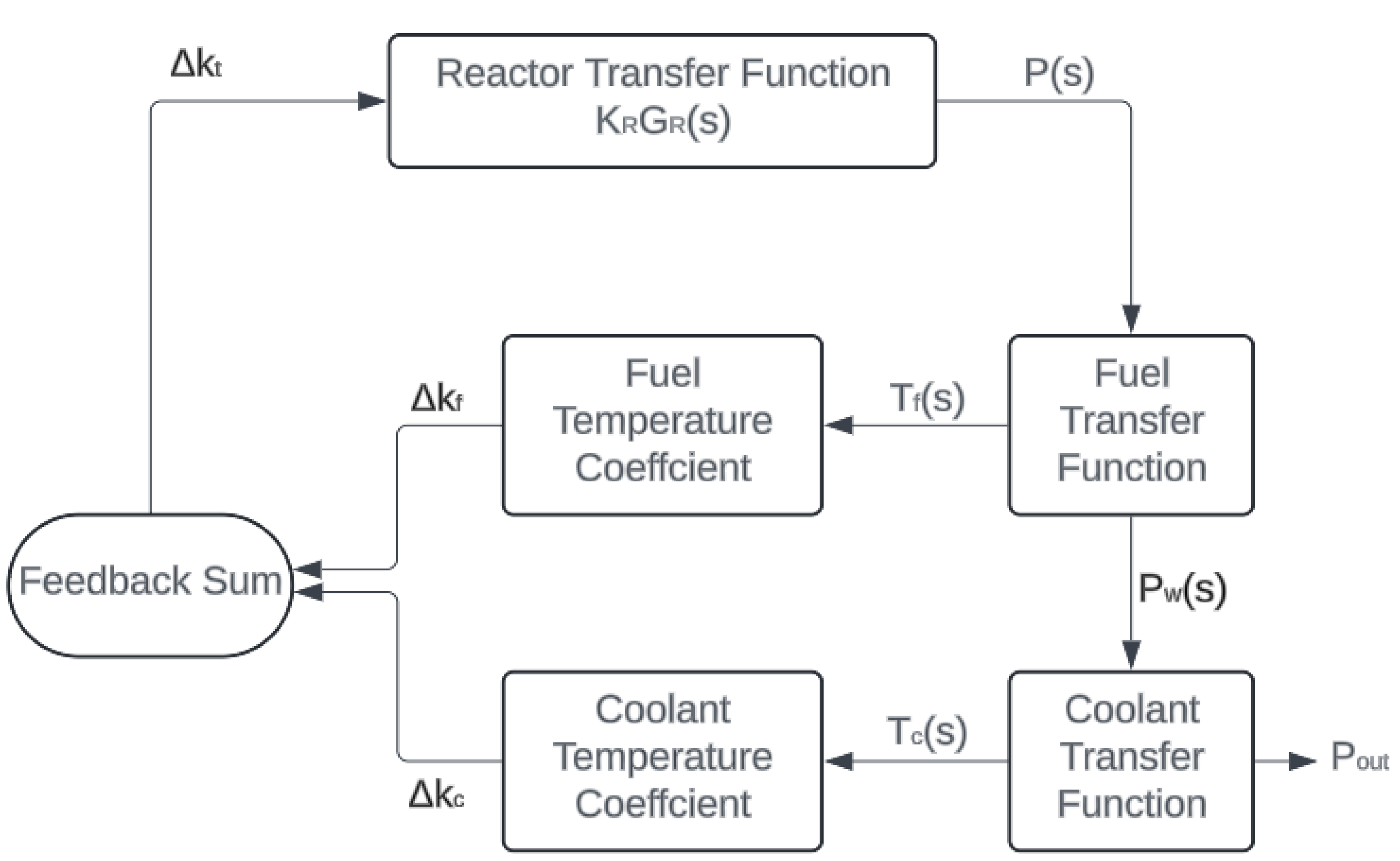

Figure 1. Sketch of temperature feedback effects from fuel and moderator.

The equations below provide the transfer functions for the reactor and the overall (fuel and coolant) temperature in Laplace notation. M and C refer to masses and specific heats of the fuel (f) and coolant/moderator (c). The α terms are the temperature coefficients, ξ is the heat transfer coefficient between the fuel and coolant, and the remaining terms are neutron parameters.

$$K_R G_R(s) = \frac{\delta n(s)}{\delta k(s)} = \frac{n_0}{l^* \cdot s} \frac{s+\lambda}{s+\beta/l^*}$$

$$K_F G_F(s) = \frac{\delta k(s)}{\delta P(s)} = \frac{\xi(\alpha_f + \alpha_c) + \alpha_f M_c C_c s}{s[\xi(M_c C_c + M_f C_f) + M_c C_c M_f C_f s]}$$

After combining transfer functions for the reactor, fuel, and coolant, along with the appropriate temperature coefficients, the following inequality is constructed that corresponds to a stable configuration.

$$\left(\frac{\xi}{M_c C_c}\left(\frac{l^*}{\beta} - \frac{1}{\lambda}\right) + \frac{M_f C_f}{M_f C_f + M_c C_c}\right)^{-1} - 1 > \frac{\alpha_c}{\alpha_f}$$

It is clear that the stability inequality does not depend on the magnitude of the temperature coefficient of either the fuel or coolant, only their ratio is significant. Therefore a plot may be developed, as shown in Figure 2, that maps the spread of temperature coefficient values that satisfy the inequality.

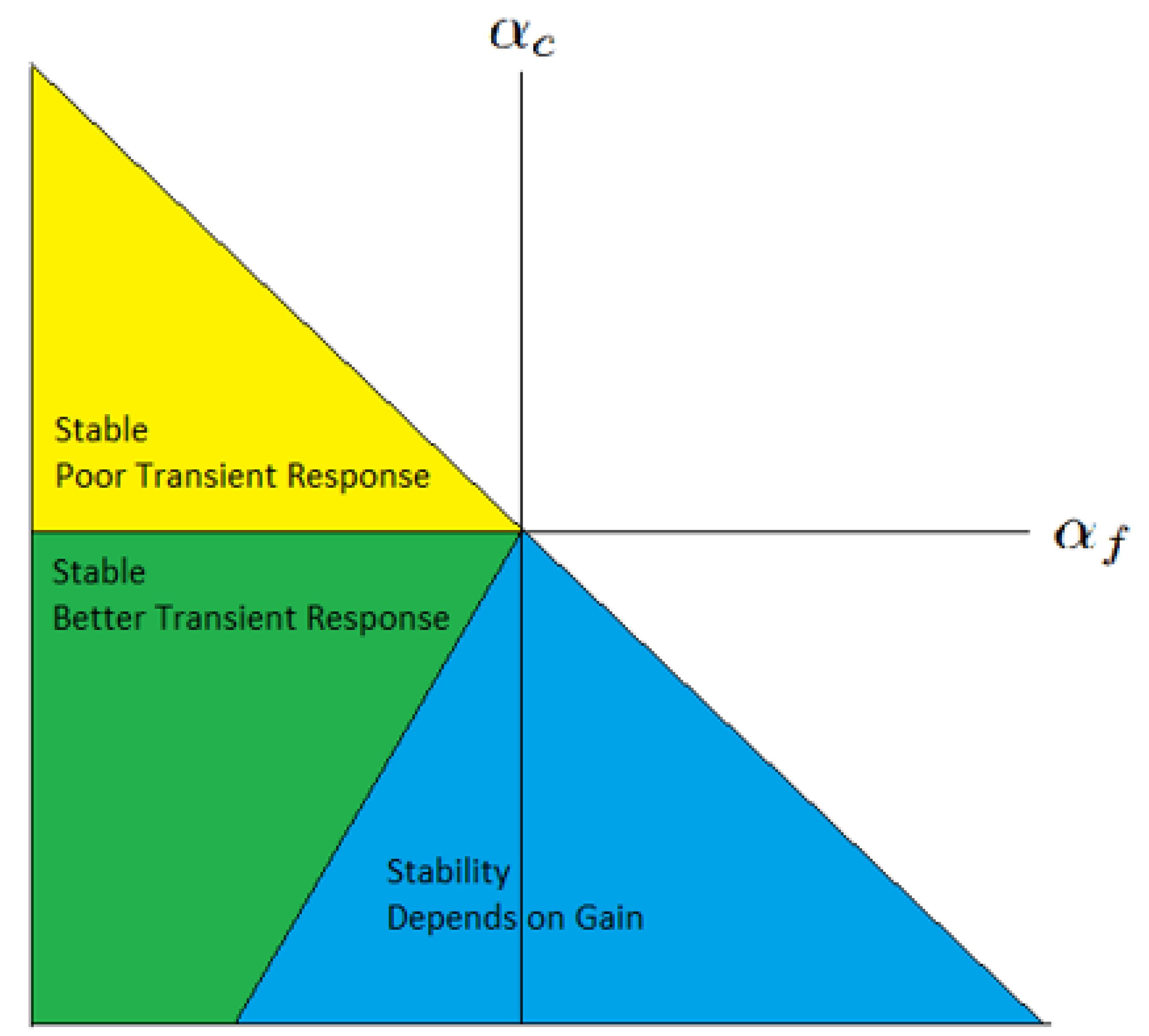

Figure 2. Plot of stable, semi-stable, and unstable regions as function of α values.

Applications

This analysis was used to evaluate the stability of the Molten Salt Reactor Experiment (MSRE), an experimental system operated at Oak Ridge National Lab in the 1960s. Few investments have been made in MSRs in the last 60 years, so the data from the MSRE is the most current experimental information available. The MSRE was built with the following characteristics:

- Fluid fuel salt containing ^{233}U: 1448 kg with specific heat of 1983 J / (K · kg)
- Fixed graphite moderator: 3687 kg with specific heat of 1757 J / (K · kg)
- Total heat transfer coefficient between fuel salt and graphite: 36000 W / K
- Temperature coefficients (Δρ/K): $-1.1034 \cdot 10^{-4}$ for fuel, $-0.5814 \cdot 10^{-4}$ for graphite

Inserting these parameters into the derived stability equation satisfies the inequality, so this method of analysis confirmed the stability of the MSRE.

Future Work

The next reactor to be analyzed is the Molten Salt Research Reactor (MSRR), a future reactor being designed by a nationwide-partnership led by Natura Resources. Analyses thus far have focused on MSRs, but can be applied to many types of reactors, especially next-generation systems. The following steps of this endeavor may involve the creation of a centralized database of current and proposed reactor designs, so stability ranges of different systems can be easily compared.

References

Shultz, M.A., "Control of Nuclear Reactors and Power Plants", 2nd Edition, (1961).

Texas A&M Engineering Experiment Station

Natura Resources SUSTAINABLE ENERGY

TEXAS A&M UNIVERSITY Department of Nuclear Engineering