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FEEDBACK CONTROL SYSTEMS FOR NON-LINEAR SIMULATION OF OPERATIONAL TRANSIENTS IN LMFBRs*

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SUMMARY

Adequate modeling of Plant Control Systems (PCS) for the study of Anticipated Transients Without Scram (ATWS) is of considerable significance in the design, operation and safety evaluation of Liquid-Metal-Cooled Fast Breeder Reactor (LMFBR) systems. In order to assess the system response to high frequency, low consequence events, the entire plant needs to be dynamically simulated. This paper deals with the description of analytical and numerical models for PCS that have been developed and incorporated into the loop version of the Super System Code (SSC-L). The importance of detailed modeling of control systems is discussed. Sample transient results obtained for a 10% ramp change of load in 40 s in the Clinch River Breeder Reactor Plant (CRBRP) are also shown.

The purpose of the plant control systems is to maintain the plant at the desired power, temperature, pressure and flow rates during startup, load changing, power operation and shutdown conditions. The Plant Protection System (PPS) remains an observer acting only to terminate any system disturbances by scram action if the plant system reaches the limit of permissible operation.

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Due to highly non-linear behavior of the plant, a linearized dynamic simulation in a frequency domain for transients where large perturbations around the steady state operating condition are to be considered, is believed to be inadequate and highly questionable; hence, a non-linear dynamics model is necessary.

The dynamic simulation of the PCS involves modeling of (1) reactor power controllers, and control rod drive mechanism, (2) primary and intermediate loop sodium flow-speed controllers, and pump drive systems, (3) feedwater, turbine throttle, bypass flow controllers and valve actuator dynamics, and (4) the plant supervisory controller.

The controller electronics is modeled by a proportional-integral-derivative (PID) controller including the dynamics of process measurement sensors and transmitters, as well as provisions for the presence of dead-bands and saturation on the controller outputs during manual and automatic modes of operation.

The reactor control rod drive mechanism is modeled by a multi-bank rod system within the framework of the first order perturbation theory.

The sodium pump drives are modeled to allow for both rheostatic (wound rotor) as well as variable frequency (squirrel cage) type speed controllers.

The PCS models have been incorporated into the SSC-L code using a rather flexible coding approach, so that the degree of sophistication as well as some design dependent variations can be easily accommodated. This provides a fast and efficient tool for the study of operational transients, confirmation of the dynamic characteristics and stability margins of the controller designs, and their possible safety-related implications (e.g., the effect of plant control systems on protection systems).

As an example of an operational transient, a 10% ramp change in load is simulated using the CRBRP design. Figure 1 shows the transient forcing function. It is observed that the load demand is ramped down from 100% to 90% in 40 s and kept constant thereafter.

The reactor power controller responds by the action of the reactor control rods (shown in Figure 2), leading to a decrease in the neutron flux level (power level) as observed from Figure 3. It is important to note that the reactivities due to the nuclear feedback effects caused by temperature and composition changes in the core were kept constant; hence, the only variation in flux is due to the control rod movement. The neutron flux level is fluctuating around the 90% demand, with the maximum deviation being less than 1%.

The flow-speed controller also responds by varying the motor torque (Figure 4), thereby adjusting the pump speed (Figure 5) and thus the flow rate (Figure 6) to the desired values according to the flow-speed control strategy, based on the near constant ΔT across the reactor core.

Results for other state variables obtained for this event, as well as results for a step change in reactivity without scram but with the controller action, will be presented along with parametric studies demonstrating the effects of different feedback cascading, control rod banking and control settings on plant system stability and response.

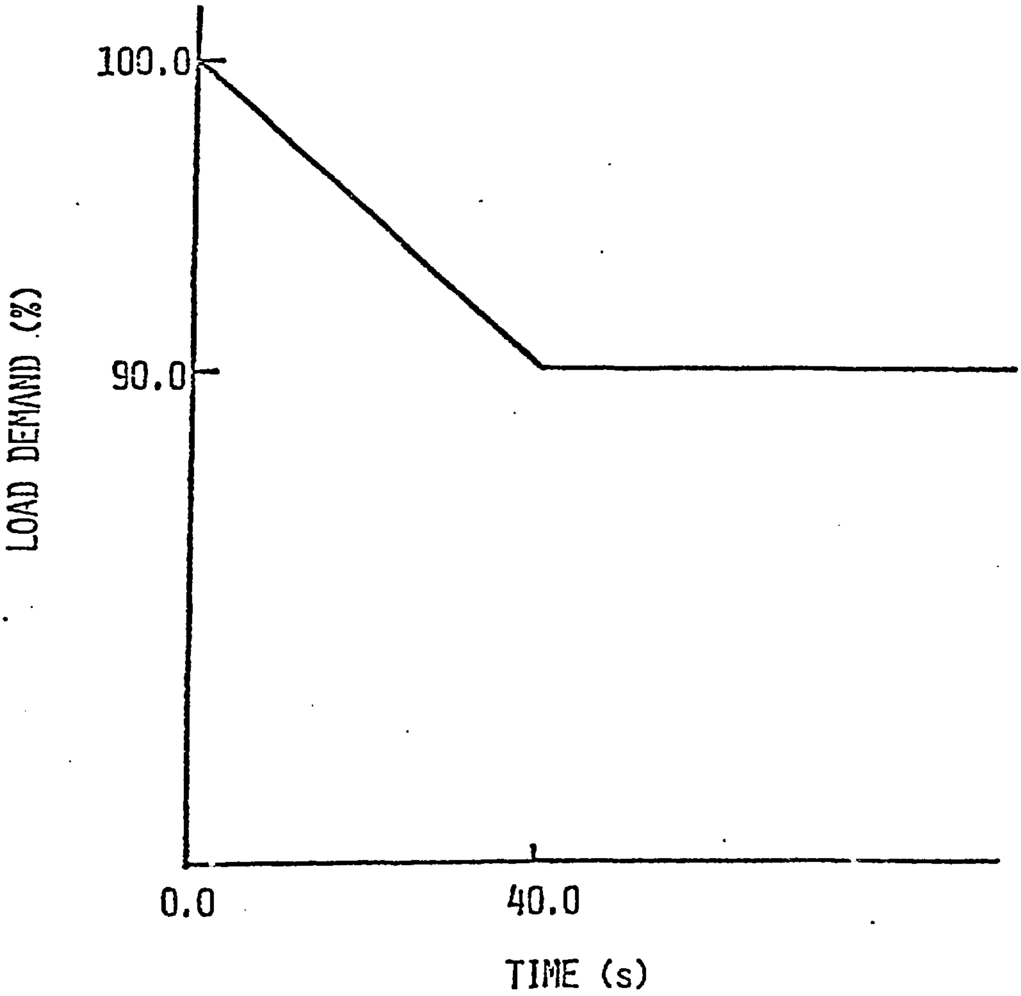

Figure 1. Variation of Load Demand as a Function of Time (Transient Forcing Function).

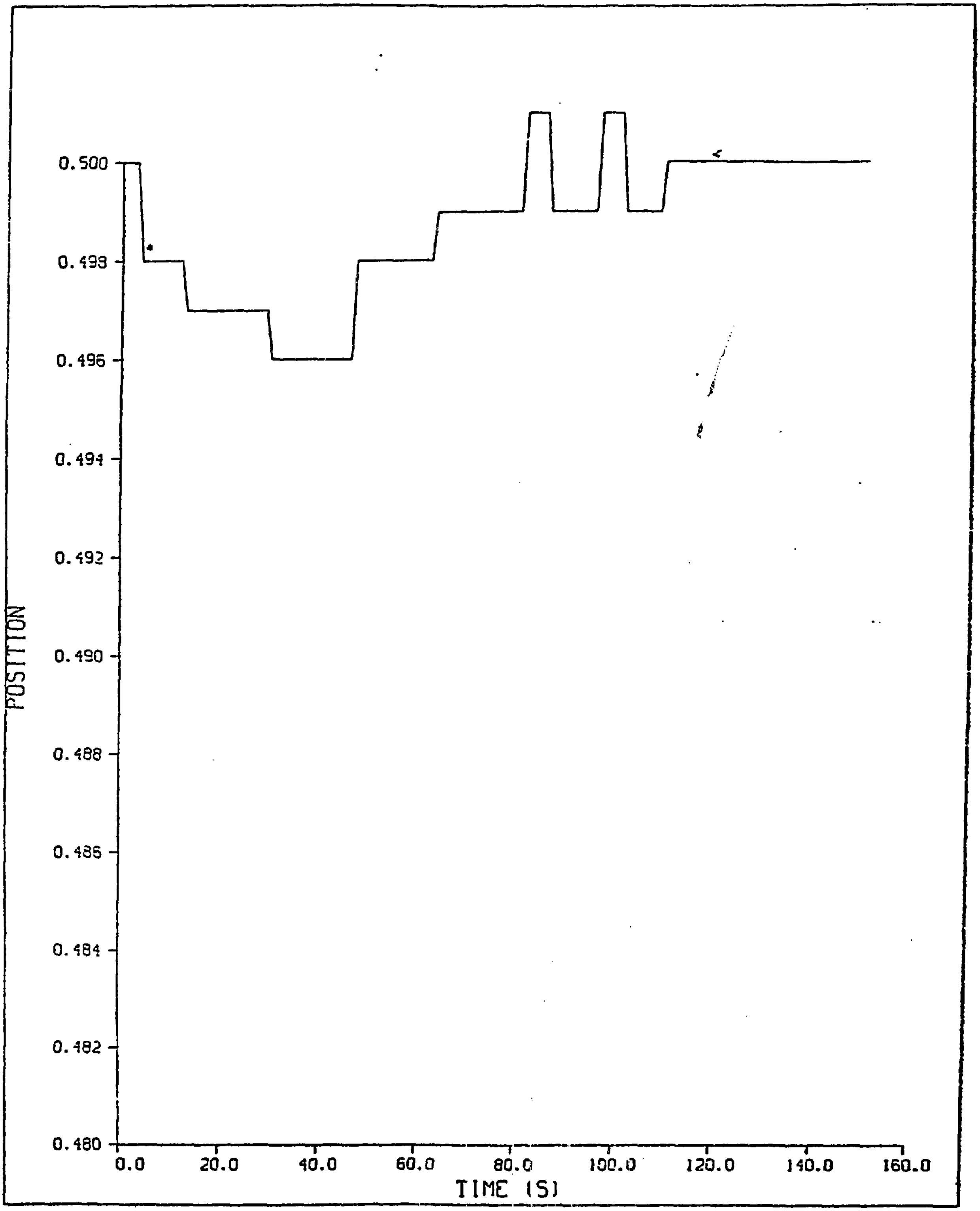

Figure 2. Fractional Withdrawal of Reactor Control Rod (Fine Rod)

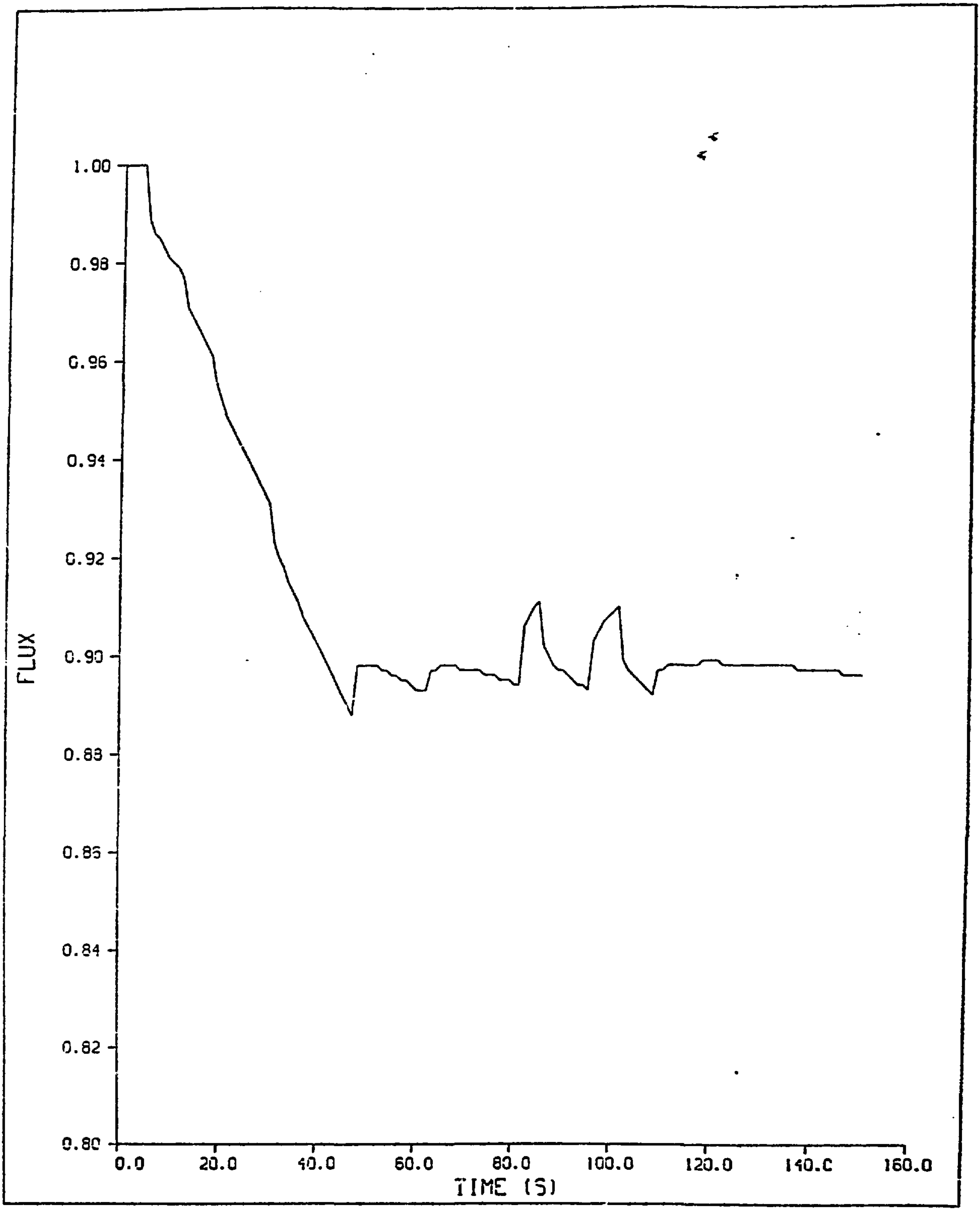

Figure 3. Variation of Neutron Flux Amplitude (or Power) as a Function of Time

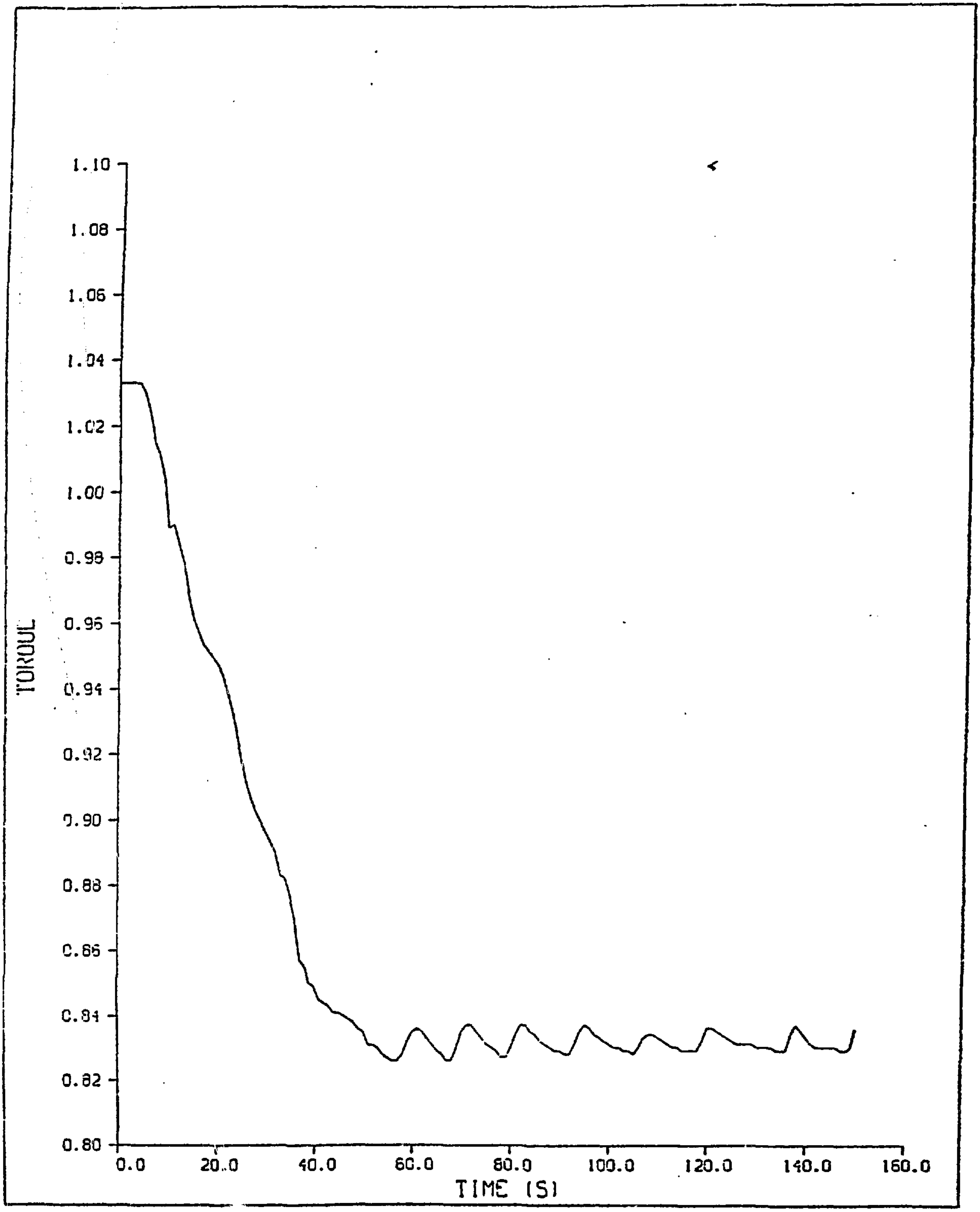

Figure 4. Variation of the Main Motor Fractional Torque as a Function of Time (Primary System)

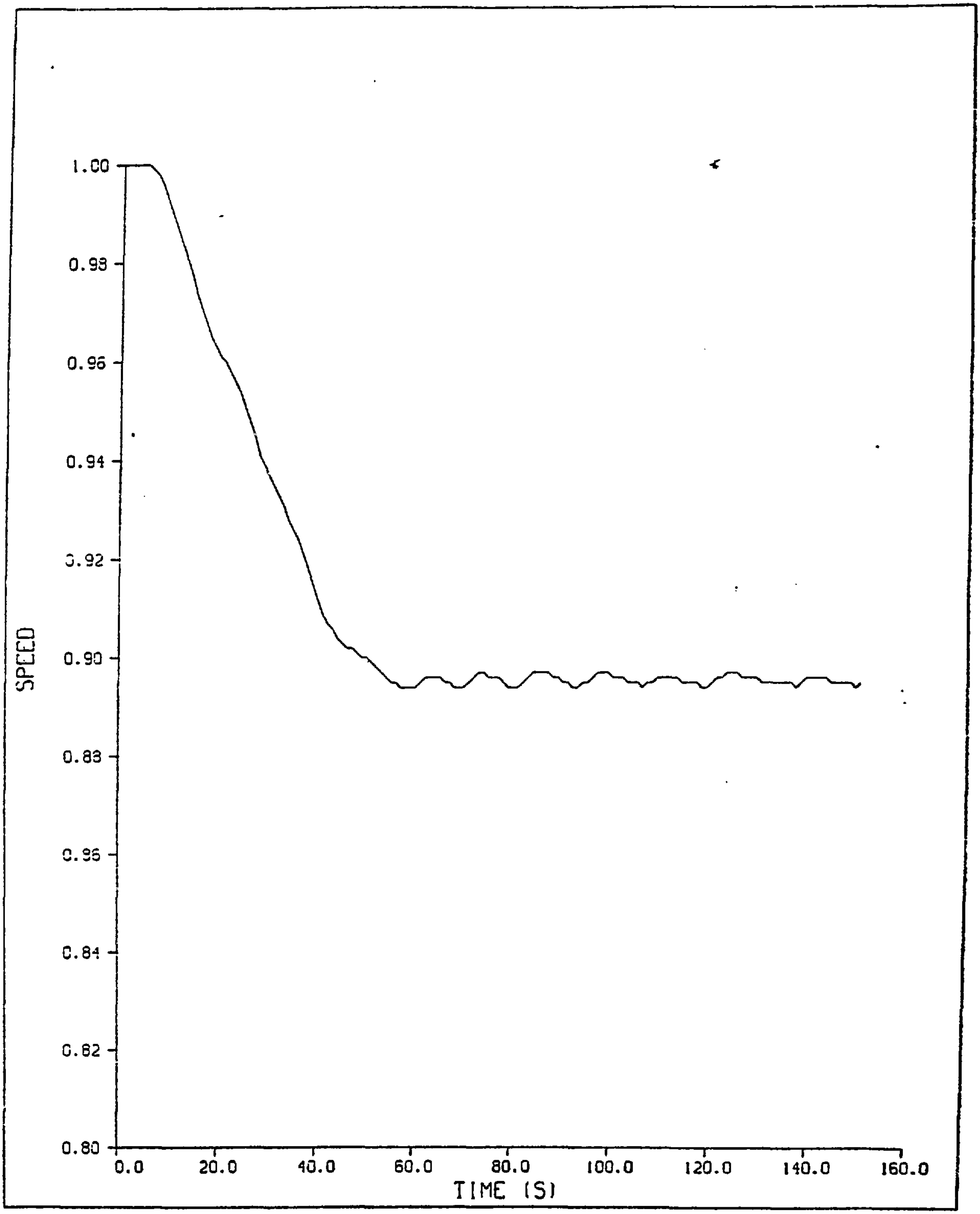

Figure 5. Variation of Primary Pump Fractional Speed as a Function of Time

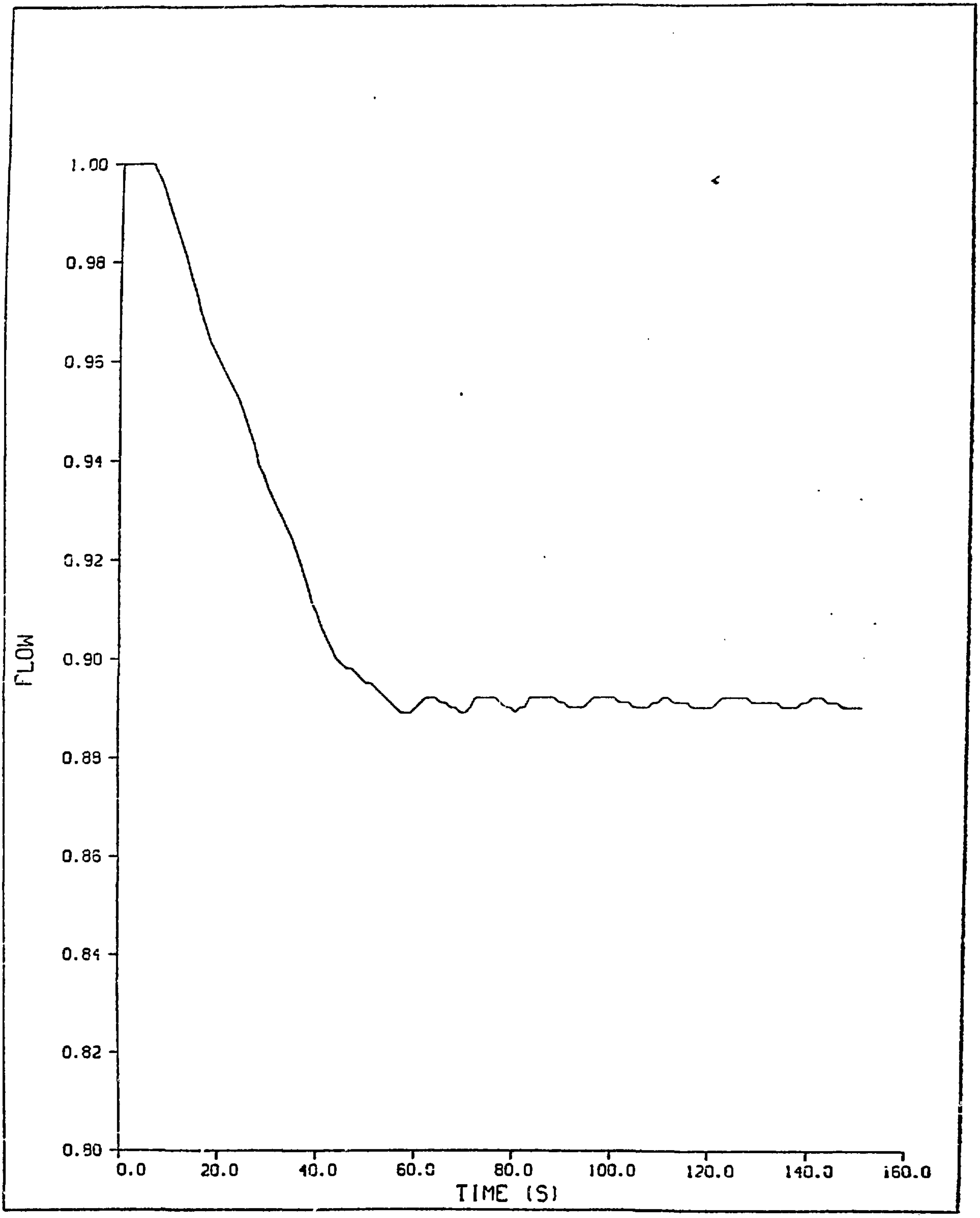

Figure 6. Variation of Reactor Inlet Nozzle Fractional Sodium Flow Rate as a Function of Time