CONF-830609--1
BNL-NUREG-32444

BNL-NUREG--32444
DE83 006493

A MOMENTUM INTEGRAL NETWORK METHOD FOR THERMAL-HYDRAULIC TRANSIENT ANALYSIS

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Paper Submitted for Presentation at the 1983 Annual Meeting of the American Nuclear Society at Detroit, Michigan.

Work prepared under the auspices of the U.S. Nuclear Regulatory Commission.

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A new momentum integral network method has been developed, and tested in the MINET computer code.[1] The method was developed in order to facilitate the transient analysis of complex fluid flow and heat transfer networks, such as those found in the balance of plant of power generating facilities.

The method employed in the MINET code is a major extension of a momentum integral method reported by Meyer.[2] Meyer integrated the momentum equation over several linked nodes, called a segment, and used a segment average pressure, evaluated from the pressures at both ends. Nodal mass and energy conservation determined nodal flows and enthalpies, accounting for fluid compression and thermal expansion.

In MINET, a network structure was built around Meyer's momentum integral model for the flow segment. In this extended method, a system is represented using one or more flow networks, which connect to one another only through heat exchangers. Each network is composed of segments, accumulators, and boundaries. Segments contain one or more pipes, pumps, heat exchangers, and valves, each of which is represented using one or more nodes. Accumulators represent voluminous components and significant flow junctions. Accumulators and boundaries are connected by segments (see Figure 1).

In systems represented using MINET, heat exchangers are frequently shared by segments in two networks, with the flow from one segment passing through the tubes and the flow from the other passing on the outside. In order to decouple these segments during a transient time step, the tube temperatures are treated explicitly in the heat transfer calculations, and are not advanced until the end of the step.

With the segments and networks decoupled, MINET transient calculations proceed in a three step process, repeated for each network. The initial step is to march through the network segments, loading the segment matrix equation

$$\underline{\underline{A}}_S \, \underline{x}_S = \underline{\underline{B}}_S \, \underline{y}_S \quad , \tag{1}$$

and solving for the segment response matrix, $\underline{\underline{B}}_S'$ $(=\underline{\underline{A}}_S^{-1}\underline{\underline{B}}_S)$. For a segment s with N_S nodes, $2N_S+2$ linearized equations are loaded, including N_S nodal mass conservation equations, a segment momentum equation, and a total of N_S+1 donor-cell differenced nodal energy equations and segment inlet enthalpy boundary conditions. Vector $\underline{x}_S$ contains nodal interface enthalpies and flows, and vector $\underline{y}_S$ includes changes in enthalpy and pressure in the modules at the segment ends.

The second stage is to march through the network accumulators, loading the network matrix equation

$$\underline{\underline{C}}_n \, \underline{v}_n = \underline{D}_n \quad , \tag{2}$$

and solving to advance accumulator enthalpies and pressures. For a network n with N_n accumulators, N_n conservation of mass and N_n conservation of energy equations are loaded. The terms for the mass and energy entering and exiting the accumulators are evaluated using the segment response matrices, $\underline{\underline{B}}_S'$, thereby linking the accumulators.

The final step is to march through the network segments, using the solution from Eq.2 to determine vector $\underline{y}_S$. The segment response matrix, $\underline{\underline{B}}_S'$, is then multiplied by $\underline{y}_s$, and the nodal interface enthalpies and flows are advanced. After segment conditions are advanced in all networks, the heat exchanger tube temperatures are advanced.

Two features of the method provide the flexibility and speed of MINET. First, segment nodes connect only to immediately adjacent nodes, causing matrix $\underline{\underline{A}}_s$ to be banded, except for the momentum equation. This allows the storage of matrix $\underline{\underline{A}}_s$, and the solution of Eq. 1, in close-packed form, i.e., with large blocks of zeroes suppressed. Thus, the complexity of the flow network is absorbed entirely in Eq. 2, where the matrices are smaller. Second, because a segment average pressure is used, saturation properties are evaluated once per segment per step.

The MINET code has been tested against experimental data[3] and independent analysis[1,4]. In a recent extensive application, MINET was used in conjunction with the SSC code[5] to perform confirmatory analysis on the first ten minutes of a postulated natural circulation event in CRBRP (see Figure 1). Results from this analysis were compared against those obtained by the Project using the DEMO code.[6] Comparison of five key parameters (drum pressure, auxiliary feedwater and vent valve flows, and evaporator sodium outlet temperature) showed excellent agreement, with the only differences attributable to known limitations and simplifications in the DEMO analysis.[7] The MINET calculations for this complex 85 node network required 357 seconds of CDC 7600 CPU time to simulate the 600 seconds of transient time.

In summary, a new momentum integral network method has been developed, and tested in the MINET code. The method facilitates the representation of complex fluid flow and heat transfer networks, including the compression and thermal expansion, and has exhibited excellent computational speed.

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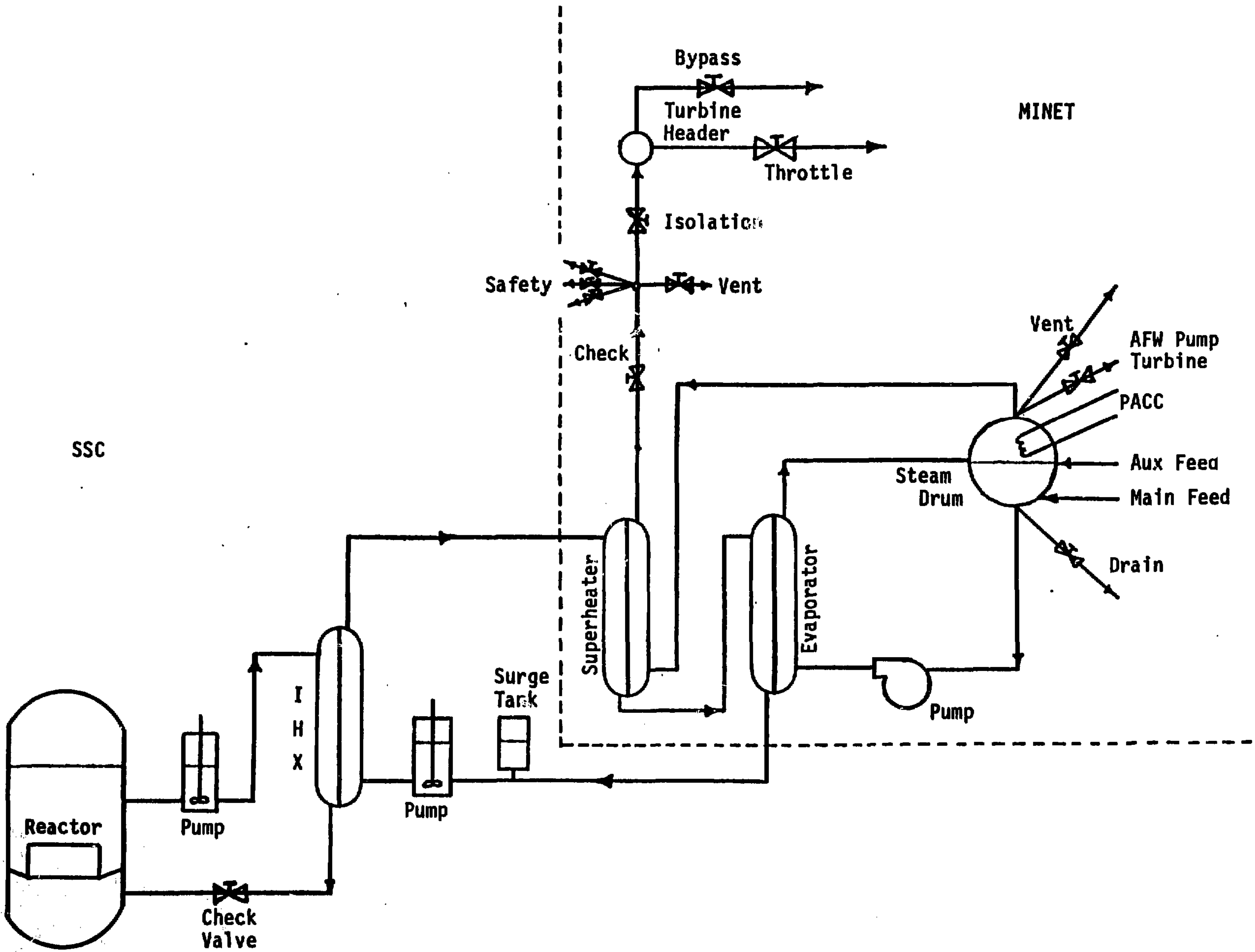

Figure 1. Clinch River Breeder Reactor Plant (CRBRP) Representation Using SSC/MINET