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SUMMARY

BWR THERMOHYDRAULICS SIMULATION ON THE AD-10 PERIPHERAL PROCESSOR*

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INTRODUCTION

Nuclear power plant simulations utilizing recently developed thermohydraulics codes such as TRAC and RELAP-5, are affordable only in a limited way to a few large institutions with access to major, government-supported computing centers.

This presentation demonstrates the feasibility of simulating plant transients and severe abnormal transients in nuclear power plants at much faster than real-time computing speeds in a low-cost, dedicated, interactive minicomputer. This is achieved by implementing advanced modeling techniques in modern, special-purpose peripheral processors for high-speed system simulation. The results of this demonstration will impact safety analyses and parametric studies, studies on operator responses and control system failures and it will make possible the continuous on-line monitoring of plant performance and the detection and diagnosis of system or component failures. The high-speed simulation capability of the developed interactive system is required for mitigating effectively the consequences from accidents by predicting the outcome of operator actions before they are taken.

Crucial to the nuclear power plant simulation is the simulation of the Nuclear Steam Supply System (NSSS). The feasibility demonstration reported here consists (i) of implementing, on a selected minicomputer, an advanced

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thermohydraulics model for the NSSS dynamics in a BWR system, (ii) of comparing the computed results from the minicomputer with those of a large CDC-7600 main-frame computer, executing the same thermohydraulics model, and (iii) of establishing thereby computing accuracy and speed.

SIMULATION TECHNIQUES

Mathematical Models. Effective simulation of two-phase flow is achieved in part by matching flow model complexity with available detail of empirical information for constitutive relations. Thus, a four-equation model was chosen to predict one-dimensional, nonhomogeneous, nonequilibrium two-phase flow. Only two, namely the vapor mass and the mixture energy conservation equations, are integrated as partial differential equations by volume-averaging over each of the 55 computational cells in the system and by integrating the resulting ordinary differential equations with respect to time. The third equation, the mixture mass balance, is analytically converted into a volume flux divergence equation and simply integrated along the flow paths by numerical means. The fourth equation, the momentum balance, is analytically integrated along closed contours through each of the three core channels and through the recirculation loop. The resulting contour momentum balances are ordinary differential equations and integrated to yield the individual loop momenta. A single, system-averaged pressure is computed from global mass and energy equations and used to predict thermophysical coolant properties everywhere. This and the contour integration of the momentum balance affords the computational decoupling of the momentum balance from mass and energy balances while retaining completely the effects of gravity on the momentum balance.

Relative phasic velocities are computed from the slip model by Bankoff-Jones[1]. Nonequilibrium vapor generation is modeled in two parts, one for wall heating and the other for flashing and condensing. Standard correlations[2] are employed for nonboiling and boiling wall heat transfer. Form losses and two-phase flow effects for wall shear are accounted for. Polynomial fits are used to represent thermophysical and transport properties.

Acoustic effects in the steam lines are computed with a dynamic model for adiabatic compressible vapor. The radial and axial fuel temperature distributions are predicted from a lumped-parameter model for each of the 12 axial flow channel segments. A point kinetics model is used first to start the simulation program and will be replaced later by one-dimensional transient neutron kinetics predictions.

Model selection and its analytical optimization, as described above, contribute significantly to the simulation efficiency. The special features of the peripheral processor employed require scaling and suggest the use of high-speed table interpolation. Scaling and precomputing of multi-dimensional table entries reduced sharply the required number of arithmetic operations during simulation and thusly increased even further the simulation efficiency.

Special-Purpose Computer. The selected parallel processor AD-10 of Applied Dynamics International has been specifically designed for fast, efficient integration of ordinary differential equations. This special-purpose peripheral processor is being programmed through a PDP-11/34 host computer, by using the high-level, modular state-equation oriented simulation language MPS-10. The AD-10 processor can interact directly with other digital computers (array processors or general-purpose computers), with instrumentation, color-graphics terminals, recorders, oscilloscopes or with other AD-10 processors. Each AD-10 provides for up to 128 on-line interactive channels for I/O transmission.

The AD-10 processor has six synchronized (10MHz), special-purpose microprocessors for arithmetic and logical operations, each equipped with its own instructional memory and executing in parallel while broadcasting data to each other and to interleaved data memory via a 20 MHz Multibus.

The computing speed in the AD-10 processor is due primarily to its architecture, namely: the parallel processing in six microprocessors, pipe-line architecture (seven stages in the Arithmetic Processor ARP), the interleaving of data memory, synchronous broadcasting of data, hard-wired arithmetic for function generation and a combination of fixed and floatng point arithmetic with 16 and 48-bit word lengths. Computing speed is also accelerated by the use of efficient integration algorithms and multi-dimensional table interpolations which eliminate a large number of arithmetic operations without loss of accuracy.

RESULTS

The feasibility demonstration performed at BNL showed that the AD-10 can simulate a licensing base transient ten times faster than the transient proceeds and more than 100 times faster than the CDC-7600 main-frame computer which utilized also the benefits from converting the partial differential equations of mixture mass and momentum balances into volume flux divergence and contour momentum equations, respectively.

The reference transient is a turbine trip from full power, followed by reactor scram, but aggravated by disabled control circuitry for steam bypass, for safety and relief valves and for recirculation pump trips. The frequency and amplitude characteristics of this transient are typical of most plant transients and abnormal events and therefore typical of the integration step size limitation which is most frequently imposed by boundary conditions and system responses.

Computing Capacity. The 55-node, four-equation model formulation for the

NSSS thermohydraulics required the currently available instructional memory of one AD-10 processor. A new software version for the AD-10 will double that memory allocation. A second processor has been dedicated to simulate, in parallel, neutron kinetics, conduction and systems controls.

Computing Accuracy was established[3] by comparing results from the AD-10 with those of the CDC-7600 main-frame computer. The agreement is good. The adequacy of 15-bit precision for computing derivatives was established by comparing the full 15-bit precision results with computations obtained with 13 and 14-bit precision. No differences could be detected.

Computing Speed. The AD-10 requires 78 microseconds per integration step, the CDC-7600 required two milliseconds. The AD-10 is ten times faster than real-time and 110 times faster than the CDC-7600. The overall speed multiplier of 110 is composed of a factor between three and five due to analytical model optimization and function generation, and a factor between approximately 20 and 50 entirely due to the features of the AD-10, including its interactive capabilities.

CONCLUSIONS

Modern, special-purpose peripheral processors are fast, accurate and cost-effective to outperform large main-frame computers in the simulation of transients in nuclear power plants.

REFERENCES

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