Structural Analysis of Steam Generator Using PC Cluster

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1. Introduction

A large-scale analysis to evaluate complex material and structural behaviors is one of interesting topic in diverse engineering and scientific fields. Also, the utilization of massively parallel processors has been a recent trend of high performance computing. The objective of this paper is to introduce a parallel process system which consists of general purpose finite element analysis solver as well as parallelized PC cluster. Then, to verify the efficiency of the established system, it was applied for structural analysis of steam generator in nuclear power plant.

2. Parallel process system

2.1 High performance PC cluster

A Beowulf style PC cluster was built for large-scale analysis. It works together through high speed network and allows the system to be viewed as a unified parallel computer system.

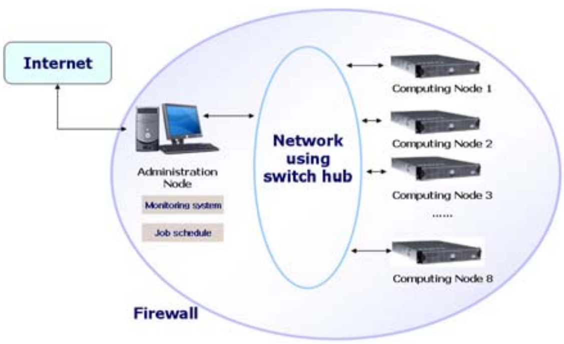


Fig. 1 Schematics diagram

In this research, the disk-based cluster was selected since it has a benefit to reduce the network loads. Fig. 1 shows a schematic diagram for configuration of PC cluster in which the relationship among administration node, hub and computing nodes are illustrated.

2.2 Features of ADVENTURE System

The ADVENTURE system consists of pre-, main- and post-processing modules that can be used in various kinds of parallel and distributed environments[1,2]. The system employs massively parallel algorithms in order to handle a huge-scale efficiently. Fig. 2 shows the schematics of the nineteen ADVENTURE modules and their execution process.

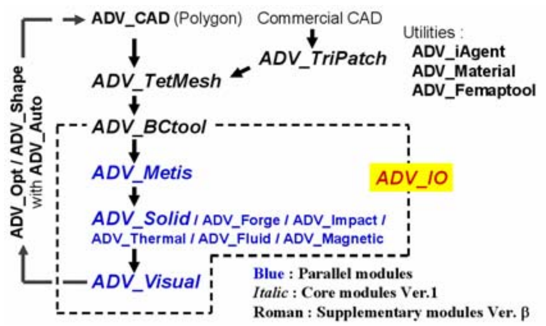


Fig. 2 Schematics of ADVENTURE modules

3. Algorithm of finite element analysis solver

In domain decomposition method (DDM), an analysis model, i.e., a finite element mesh with boundary conditions and material properties is subdivided into a number of subdomains. One of the key technologies of the ADVENTURE_Solid is a HDDM, which enables parallel finite element calculations on various kinds of computing environments. Basically in the HDDM, force equivalence and continuity conditions among subdomains are satisfied through iterative calculations such as the conjugate gradient (CG) method. Therefore, it is indispensable to reduce the number of iterations by adopting some appropriate preconditioning technique especially for solving large-scale ill-conditioned problems. The Neumann-Neumann algorithm (N-N)[3] is known as efficient domain decomposition preconditioner for structured subdomains. However, its convergence deteriorates with the increasing number of subdomains due to lack of a coarse space problem which takes care of global propagation of error.

The BDDM based N-N algorithm proposed by Mandel[4] shows that the equilibrium conditions for the singular problems on subdomains result in simple and natural construction of a coarse space problem. It has been applied to solve various phenomena[5] and there have been also several researches on parallelization of the BDDM while those were for medium scale ones such as up to one million degrees of freedoms (DOFs). Therefore, it is necessary to consider the parallelized process to get solution for large-scale problems as well.

4. Structural Analysis

Linear elastic stress analyses adopting both HDDM and BDDM algorithms were carried out for two types of models for PWR steam generator using

ADVENTURE_Solid mounted on PC cluster: the one is 6.6 million DOF model to get precise results and the other is 1 million DOF model to compare parallel performances. The model with 6.6 million DOF mesh consists of 1,349,839 tetrahedral elements and 2,206,664 nodes and the model with 1 million DOF mesh consists of 1,349,839 tetrahedral elements and 322,192 nodes.

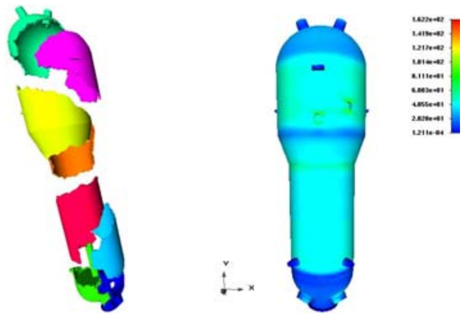


Fig. 3 Domain decomposition and von Mises stress distributions of steam generator

The steam generator structural analysis results using ADVENTURE_Solid were compared to the corresponding reference solutions to verify the applicability of parallelized finite element analyses. The reference analysis was performed by using ANSYS. The finite element mesh was composed of 58,479 eight node hexahedral elements (SOLID45 in ANSYS) and 77,590 nodes. As shown in fig.4, the two types of evaluation results were almost same.

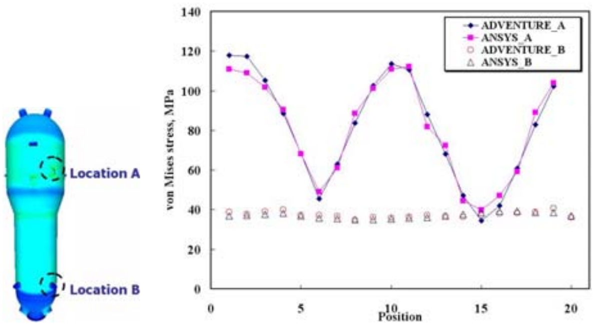
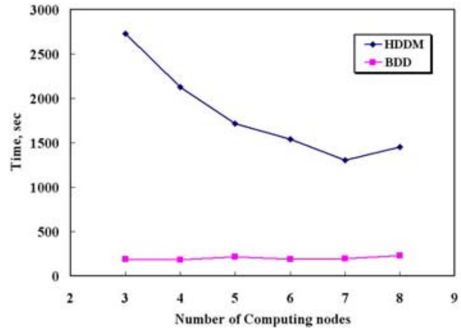
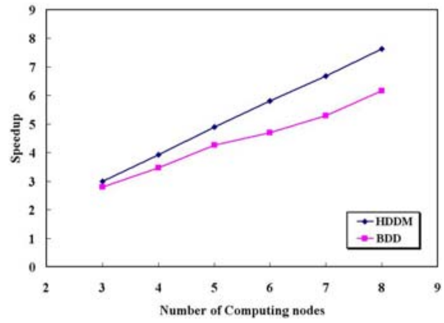


Fig. 4 Comparison of stress analysis results from ADVENTURE_Solid and ANSYS

Fig. 5(a) shows comparison of consumed time according to number of computing nodes. When using three computing nodes, the analysis time adopting HDDM was about fourteen times longer than that of BDDM while six times longer for eight computing nodes. Fig. 5(b) represents comparison of speedup according to number of computing nodes. In cases of analyses adopting HDDM, the parallel efficiencies were almost 97% for total computation time. However, the differences of speedup owing to finite element analysis algorithms were increased when four computing nodes were used.



(a) Number of computing nodes vs. Time



(b) Number of computing nodes vs. Speedup

Fig. 5 Performance of parallel processing

5. Conclusion

A parallel process system which consists of general purpose finite element analysis solver as well as parallelized PC cluster was established. Prototypal three dimensional full structural analyses of simplified steam generator under internal pressure were carried out using the parallel process system. The evaluation results using 6.6 million DOF mesh agreed well to the corresponding reference solutions. Parallel performances were examined using steam generator model with 1 million DOF mesh. Thereby, the efficiency of parallel performance of HDDM was higher than that of BDDM. The average speedup of HDDM was 97% while that of BDDM was 83%.

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