Three Parallel Computation Methods for Structural Vibration Analysis

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Three parallel algorithms, based on existing sequential methods for vibration analysis, were developed and evaluated for the solution of three example problems on a parallel computer. The three methods—Lanczos, multisectioning, and subspace iteration—maintain reasonable accuracy in the computation of vibration frequencies and show significant reductions in computation time as the number of processors increases. An analysis of the performance of each method was carried out to determine its strengths and weaknesses and to identify the key parameters that affect its computational efficiency.

Introduction

THE determination of the fundamental (lowest) natural frequencies and associated mode shapes is a key step used to uncover and correct potential failures or problem areas in most complex structures. However, the computation time taken by finite-element codes to evaluate these natural frequencies is significant, often the most computationally intensive part of structural analysis calculations. There is a continuing need to reduce this computation time. This study addresses this need by developing methods for parallel computation.

Since Von Neumann (sequential) computers are approaching their limit of computation speed due to physical constraints (speed of electricity), a new generation of parallel scientific computers is being introduced to increase computation power by increasing the number of processors. With such parallel computers, time-consuming calculations of vibration analysis (i.e., matrix factorization) can be performed using many processors operating in parallel. However, methods that perform well on sequential computers do not necessarily perform well on parallel computers. For that reason, the NASA computational structural mechanics (CSM) initiative began the development of new parallel algorithms to speed up structural analysis computations on the emerging class of parallel computers.[1-5] The work described herein extends this previous work.

The objective of this paper is to describe and evaluate the performance of three parallel computation methods developed for the solution of structural vibration problems on a parallel computer. The three methods are the Lanczos method, subspace iteration, and sectioning.[6-15] To evaluate their performance, each method was used to solve representative vibration analysis problems on a parallel computer.

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Methods for Vibration Analysis

The solution of structural vibration problems has become more complex as the structures to be analyzed, such as aircraft and flexible space structures, have increased in size and complexity.[6] The usual objective of a vibration analysis is to find a few of the lowest vibrational frequencies and the associated mode shapes of a structure. The approach is to solve the structural eigenvalue problem

$$Kx = \lambda Mx \tag{1}$$

where K and M are symmetric, positive-definite stiffness and mass matrices, respectively, x is the displacement vector (the eigenvector), and λ (the eigenvalue) determines the frequency. In this study, three parallel methods have been developed and tested on representative problems of present and future interest. The method of subspace iteration is included in this study as programs based on it are in widespread use throughout the engineering community for eigenvalue extraction.[6] The Lanczos method is included as an emerging competitor of subspace iteration.[6,15] A method based on sectioning is amenable to parallel solution of the standard eigenvalue problem,[15] so its suitability as a parallel method for the generalized eigenproblem is studied here. Methods based on Jacobi, block Jacobi, and QR transformations are not included since they solve for all eigenvalues. For our applications, only a few of the smallest eigenvalues are required. A brief description of each method follows.

Lanczos Method

The Lanczos method, a technique to solve Eq. 1, involves transforming the original large eigenvalue problem into a small, easier-to-solve problem.[11] The major calculation tasks in the Lanczos method include decomposition of the stiffness matrix and the solution of the system of equations by a forward solution followed by a backward solution. The elements