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Original article

Machine tool simulation based on reduced order FE models

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Abstract

Numerical simulations of the behavior of machine tools are usually based on a finite element (FE) discretization of their mechanical structure. After linearization one obtains a second-order system of ordinary differential equations. In order to capture all necessary details the system that inevitable arises is too complex to meet the expediency requirements of real time simulation and control. In commercial FE simulation software often modal reduction is used to obtain a model of lower order which allows for faster simulation. In recent years new methods to reduce large and sparse dynamical systems emerged. This work concentrates on the reduction of certain FE systems arising in machine tool simulation with Krylov subspace methods. The main goal of this work is to discuss whether these methods are suitable for the type of application considered here. Several Krylov subspace methods for first or second-order systems were tested. Numerical examples comparing our results to modal reduction are presented.

MSC: 65F30; 70J10; 70J50

Keywords: Model order reduction; Simulation; Krylov subspace; Moment matching

1. Introduction

The integrated simulation of machine tools consists of two major parts: the structural model of the machine tool representing its reaction on certain control inputs on the one hand and the control loop generating those inputs on the other hand. The reaction of the mechanical structure on control inputs is described by a system of FE semi-discretized partial differential equations. After linearization one obtains a system of ordinary differential equations of second order

$$M\ddot{x}(t) + D\dot{x}(t) + Kx(t) = Fu(t), \quad y(t) = C_v\dot{x}(t) + C_p x(t), \tag{1}$$

where $M, D, K \in \mathbb{R}^{n\times n}$, $F \in \mathbb{R}^{n\times m}$, $C_v, C_p \in \mathbb{R}^{q\times n}$, $x(t) \in \mathbb{R}^n$, $u(t) \in \mathbb{R}^m$, $y(t) \in \mathbb{R}^q$. Here Rayleigh damping is considered, that is, the damping matrix D is proportional to the mass matrix M and the stiffness matrix K: $D = \alpha \cdot M + \beta \cdot K$, where α and β are real parameters which are chosen by the experience of the design engineer and lie between 0 and 0.1. The system matrices are large, sparse and non-symmetric. All of this accounts for unacceptable computational and resource demands in simulation and control of these models. In order to reduce these demands to acceptable computational times, usually model order reduction techniques are employed which generate a reduced order model

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