Estimation and Simulation of the Nonlinear Dynamic Properties of a Boring Bar

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In this paper, an initial investigation of the nonlinear dynamic properties of clamped boring bars is carried out. Two nonlinear, single-degree-of-freedom models with different softening spring nonlinearities are introduced for modeling the nonlinear dynamic behavior of the fundamental bending mode in the cutting speed direction of a boring bar. Also, two different methods for the simulation of nonlinear models are used. The dynamic behavior in terms of frequency response function estimates for the nonlinear models and the experimental modal analysis of the clamped boring bar is compared. Similar resonance frequency shift behavior for varying excitation force levels is observed for both the nonlinear models and the actual boring bar.

1. INTRODUCTION

In industries where metal cutting operations such as turning, milling, boring, and grinding take place, degrading vibrations are a common problem. In internal turning operations, vibration is a pronounced problem, as long and slender boring bars are usually required to perform the internal machining of workpieces. Tool vibration during internal turning frequently has a degrading influence on surface quality, tool life, and production efficiency. At the same time, such vibrations result in high noise levels.

An extensive number of experimental and analytical studies have been carried out to study boring bar dynamics. However, most research has usually been carried out on the dynamic modeling of cutting dynamics and usually concentrates on the prediction of stability limits.[1–5] In a study concerning the motion of the boring bar, it was stated that clamped boring bars may display nonlinear dynamic behavior.[6] Later, a more thorough investigation concerning the clamping conditions of the boring bars,[7] confirmed this assumption regarding nonlinear dynamic behavior.

When it comes to nonlinear modeling of the clamping of tools, Yigit et al.[8] examined and modeled a reconfigurable machine tool structure including weakly nonlinear joints in consideration of their cubic stiffness. They used a sub-structuring method called nonlinear receptance coupling and validated the method with experimental data from such a structure. Thus, referring to the literature review, it seems as if little work has been done on the identification and modeling of the nonlinear dynamic properties of a clamped boring bar. Knowledge regarding nonlinear dynamic properties of a clamped boring bar may be utilized in the modeling of dynamic properties of boring bars in order to provide increased accuracy in such models. Hence, it seems to be important to be able to identify the nonlinear dynamic properties of a clamped boring bar.

Nonlinearities may be caused by several different factors. Common sources of nonlinearity are, for example, the contact phenomena, in which elements of a system during dynamic motion come into contact with the surrounding environment due to a large displacement, which, in turn, creates a new set of boundary conditions. Another example is friction in joints, or sliding surfaces and large forces, and/or deformation that cause the properties of the material to behave in a nonlinear manner, for example plastic deformation.[9] This paper presents an initial investigation of the nonlinear dynamic properties of boring bars. Two nonlinear, single-degree-of-freedom models with different softening spring nonlinearity have been introduced in order to model the nonlinear dynamic behavior of the fundamental bending mode in the cutting speed direction of a boring bar. Two different methods for the simulation of nonlinear models are used, that is, the Runge-Kutta method, implemented in MATLAB,[10] and the digital filter method.[11] The dynamic behavior in terms of frequency response function estimates for the models and the actual clamped boring bar have been compared.

2. MATERIALS AND METHODS

2.1. Experimental Setup

The experimental setup and subsequent measurements were carried out in a Mazak SUPER QUICK TURN - 250M CNC turning center. The CNC lathe has a spindle power of 18.5 kW and a maximal machining diameter of 300 mm. The distance between the centers is 1005 mm, the maximum spindle speed is 400 revolutions per minute (rpm) and the center also has a