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Three-dimensional modeling of deep hole vibratory drilling dynamics

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Abstract

In this work, a new three-dimensional approach to the numerical dynamics modeling of drilling processes with a special elastic device contributing to the tool's axial self-oscillations excitation on specified machining regimesis being proposed.The numerical model considers the possibility of self-oscillations excitation in the system due to the regeneration mechanism of cutting.Sufficient axial vibration amplitude causes fragmentation of chips, which significantly facilitates chip removal from the cutting zone and causes a positive influence on machining process quality. On the other side, in the *device-tool-workpiece* system along with the axial vibrations,lateral vibrations in other directions can be excited, which results in a distorted polygon-like shape of the drilled hole. Time realizations of *device-tool* system motion, machined surface configuration and the shape of the drilled hole were obtained for different machining regimes as simulation results.The proposed approach to the modeling and obtained results may be used in designing devices for vibratory drilling and to the rational machining regimes selection in the drilling of deep holes with application of such devices.

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Keywords: vibratorydrilling; cutting dynamics;finite element method;self-excited vibrations;geometric modeling.

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1. Introduction

Realizationofvibratorydrillingprocesswithself-excitedoscillationsrequiresdesigningandapplicationofa specialdevice – avibratorydrillinghead, which is a transitional element between the machine spindle and cutting tool (drill). Drilling head design should provide transmission of a primary cutting motion torque, stated tool fixation stiffness in the axial direction for excitation of self-vibrations during machining on determined regimes, sufficient bending stiffness for prevention of undesirable lateral vibrations excitation. Sufficient axial vibration amplitude causes fragmentation of chips [1], which significantly facilitates chip removal from the cutting zone, and causes a positive influence on machining process quality. On the other side in the *device-tool-workpiece* system along with the axial vibrations can be excited in other directions. Particularly, lateral bending vibrations of a tool and the elastic device's elements may lead to a whirling motion of the drill, which results in a distorted polygon-like shape of the drilled hole.

Approaches to the investigation of the drilling process stability presented in the previous studies can be divided into two main groups: stability analysis in the frequency domain and the time domain models. The first group was devoted to the analytical analysis of the delay differential equations (DDE) with the assumption continuity of instantaneous uncut chip thickness. Stability of the drilling process is investigated in works of Ema and Ismail [2-5] considering only lateral vibrations. In [6,7] Altintasproposed stability model taking into account up to four degrees of freedom of the elastic tool (axial vibrations, torsional vibrations, lateral vibrations in two orthogonal directions) with the use of a beam model.In the methods from the second group direct modeling of the drilling process in the time domain is conducted. In [8] time domain drilling model with geometrical algorithm, based on radial depth buffer method, considering four degrees of freedom is presented. Stability of the vibratory drilling processis investigated in [9] by Guibert.In this paper, it is proposedthat a three-dimensional approach to the numerical modelling of drilling dynamics in full formulation using the author's program 3DCUT [10] be carried out.

In this work, three-dimensional modeling of the drilling process with the application of a vibratory drilling head with a well-known design [11] is conducted. In this case, the main goal is to define zones of rational machining regimes, where axial self-oscillations are excited, while undesirable lateral and torsional vibrations are insignificant in the dynamic system.

2. Proposed approach

The proposed numerical model of cutting dynamics includes a three-dimensional geometric modeling algorithm based on the modified depth buffer method, finite element model of the *self-vibratory drilling head-tool* system (fig. 1), and phenomenological cutting force model. This numerical model considers the possibility of self-oscillation excitation in the system due to the regeneration mechanism of cutting.The general approach to the modeling of three-dimensional machining dynamics is fully described in work [10].

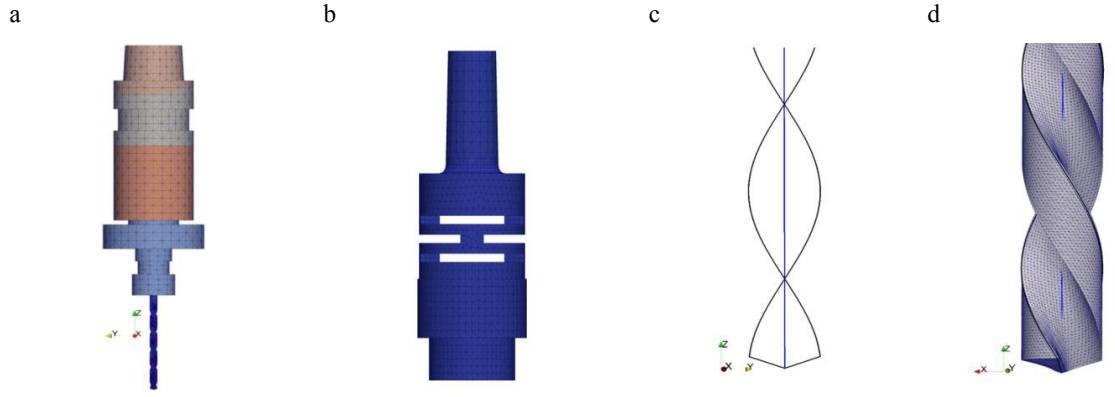

Fig. 1.Finite element model of drilling head and its super-elemental mesh (a); model of spring element (b); geometric model of drill (c), linked with its finite element model (d).