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Modelling of robotic drilling

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Abstract

Recently, industrial robots are increasingly used in machining activities such as drilling, milling and grinding operations. However, due to their low stiffness and anisotropic behavior, the robotic drilling may lead to some circularity, position or perpendicularity errors. In this paper, two robotic drilling models are proposed. The first one focuses on the cutting process where the chip section is discretized and computed at each step. The second model takes into account the stiffness of the robot at hand. Some additional developments are carried out in order to analyze the elasto-static behavior of the robot while drilling.

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Keywords: Machining, drilling, robotic;

1. Introduction

The increasing competitiveness between companies requires means of production which meet an expected functionality at a reduced investment cost. This financial rationalization encourages industrial robotic to compete with machine as regards tasks for which the volume of the workspace is large and does not require a great accuracy (up to 0.1mm).

Robotic drilling is a complex task regarding the complex modelling of the process and the behavior of an industrial robot. In fact, a bit has different active area and so, a set of parameters which evolves during the drilling. These operations stress the industrial robots and disturb its accuracy. We observe then a static and a dynamical deformation of the robot depending on the stress frequency (See Fig.1). Firstly, a static error occurred due to a thermal deformation [1] and gravitation regarding the posture. A specific calibration is often proposed by manufacturers or a calibration in situ allows not to consider it (or to reduce its influence). Secondly, we observe an elastic deformation due to the process, the inertial forces and a natural oscillation due to the kinematics. This aspect is deeply studied in the literature and allows to compensate 90% of the real deflection [2].

The task to be carried out has 5 dimensions characterized by the position of a point and the orientation of the tool axis. The degree of functional redundancy is 1. This degree is represented by the angle of reorientation of the end effector around the tool axis of the drilling bit. Many contributions exploit this redundancy in order to find the posture with the higher stiffness [4,5,6]. Other approaches focus on the workpiece placement

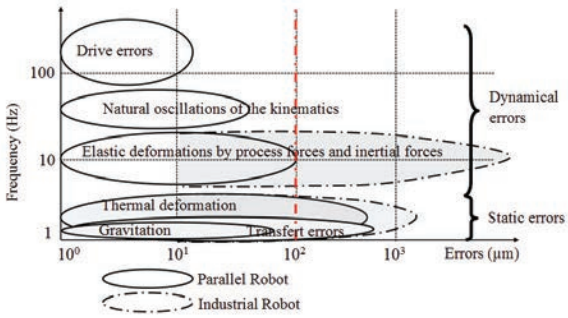

Fig. 1. Summary of inaccuracy factors, their amplitudes and frequencies[3]

[7], the robot placement optimization [8], the force limitation with an orbital drilling [9] or the stability prediction via modal analysis [10]. The objective of these works is limiting the impact of the process on the robotic architecture to improve the quality. Moreover, in order to eliminate some specific behavior such as the sliding movement (staking) due to the low stiffness of serial robot, high-bandwidth force feedback [11] has been presented as a method for high-precision drilling. It has been observed by [12] that with a 2D vision system, an accuracy of 0.1mm can be reached for robotic drilling which correspond to the accuracy standard of robotic drilling. These works, following the approaches, show that the accuracy of robotic drilling is between 0.1mm to 2mm depending on the conditions (sensors, robot posture, robot stiffness,...). The behavior of the robot must be improved to answer more specifically to the needs of customers in terms of accuracy and quality.

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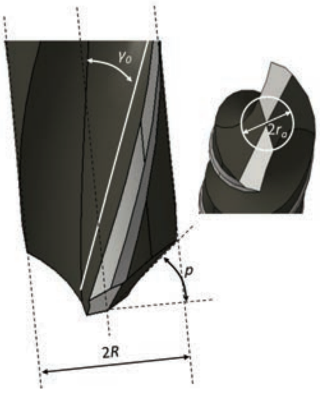

Fig. 2. Bit modeling parameters

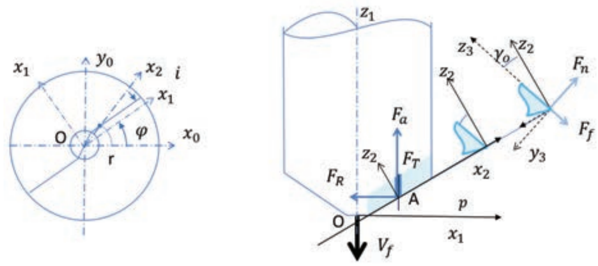

Fig. 3. Cutting forces inside the frames

Literature highlights ways to optimize the accuracy. For the current study, the paper deals with the influence between the drilling process and the elasto-static behavior of the robot [13]. Drilling modelling aims to characterize the thrust and the torque [14,15,16]. In our study, we want to use it to predict the accuracy of the robot regarding the process stress [17]. The consideration of these modelling is relevant in robotic drilling since the tool axis direction may not be constant during the drilling operation. The paper is organized as follows : section 2 presents drill modelling, section 3 defines the robot modelling, section 4 presents the interaction between the drilling process and the robot behavior, section 5 gives the conclusion and the perspective of the paper.

2. Drill modelling

The prediction of the thrust and torque is based on a generalized mechanics model including cutting specific coefficients [18]. Drilling bit has several active area which acts on the part with a set of parameters. In this paper, we focus specifically on the following (see Fig. 2) :

- Point angle p
- Cutting Angle γ_0
- Indentation area r_a
- Drilling bit radius R
- Advance speed V_f
- Cutting specific coefficient K_{fp_i} and K_{np_i}
- Surface of chip section A_c
- Feed per tooth f_z
- Tool Center Point TCP at point O

2.1. cutting modelling

Considering the cutting modelling, we consider that the bit interacts with the part following oblique, indentation and margin area.

2.1.1. Interaction with the oblique cutting

To evaluate the wrench force, explained at TCP point, $w_a = \{F_a; M_a\}$ during oblique cutting, we introduce the cutting specific coefficient K_{np_i} and K_{fp_i}.

$$\begin{cases} F_n & = & K_{np_0} \cdot A_c(f_z, dr) \\ F_f & = & K_{fp_0} \cdot A_c(f_z, dr) \end{cases} \tag{1}$$

Cutting forces are represented inside the Fig. 3. F_n and F_f (See Eq.1) are defined in the frame R_3. R_3 is defined from R_2 with the angle γ_0 following z_2. R_2 is defined from R_1 with the angle p around y_1. R_1 is defined from R_0 with the angle φ around z_0. A relationship must be defined to explain the wrench at point A defined at the middle of the cutting edge. The objective is the evaluation of F_x, F_y and F_z and their contribution following F_a axis force and F_r radial force defined in the frame R_1 (See Eq.1 and Eq.2).

$${}^{R_1}F = \begin{pmatrix} cos(p) & 0 & sin(p) \\ 0 & 1 & 0 \\ sin(p) & 0 & cos(p) \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\gamma_0) & sin(\gamma_0) \\ 0 & -sin(\gamma_0) & cos(\gamma_0) \end{pmatrix} \cdot \begin{pmatrix} 0 \\ -F_n \\ -F_f \end{pmatrix} \tag{2}$$

$$\begin{pmatrix} F_x \\ F_y \\ F_z \end{pmatrix} = \begin{pmatrix} -sin(p) \cdot (F_n \cdot sin(\gamma_0) - F_f \cdot cos(\gamma_0)) \\ -F_n \cdot cos(\gamma_0) - F_f \cdot sin(\gamma_0) \\ (F_n \dot{s}in(\gamma_0) - F_f cos(\gamma_0))cos(p) \end{pmatrix} \tag{3}$$

This equation is true taking into account that p and γ_0 are independent from r, K_{np_0} and K_{fp_0} are considered as constant. It exists a 2^{nd} cut-edge leading to the cancellation of the radial force and it doubles the axial force. It leads to the Eq.4.

$$F_a = 2 \cdot F_z = (F_n \cdot sin(\gamma_0) - F_f \cdot cos(\gamma_0)) \cdot cos(p) \tag{4}$$

With the introduction of the cutting specific coefficient inside the relation, we can write :

$$F_a = 2 \cdot F_z = 2 \cdot (K_{np0} \cdot sin(\gamma_0) - K_{fp0} \cdot cos(\gamma_0)) \cdot cos(p) \cdot (\frac{R - r_a}{cos(p)} \cdot f_z) \tag{5}$$