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Control of a multi degrees functional redundancies robotic cell for optimization of the machining stability

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Abstract

Productivity in robotic machining processes can be limited by instability phenomena resulting from the interaction between robot dynamics and cutting conditions. The robot dynamic behavior and consequently the machining stability vary within the workspace, due to the changes of the robot posture. Therefore, the chatter in machining robot depends on cutting parameters and as well as the robot configuration. Hence, each posture of the robot has its own stable cutting conditions. Moreover, along a machining trajectory, the robot can follow an infinite number of postures in its configuration space, due to the redundancies offered by the overall kinematic chain of the robotic cell. This paper deals with the control of the multi degrees functional redundancies of the ABB IRB6660 robotic cell for optimization of the machining stability.

Keywords: dynamic modeling, machining robot, stability prediction, functional redundancy;

1. Introduction

The technological advances enable robots to perform different manufacturing tasks as welding, polishing and machining operations. Industrial machining robots are used to increase the flexibility and reduce the costs of production. This is why industrials trend to replace machine-tools by robots in the machining process is constantly increasing. Nowadays, industrial robots have been specifically developed for machining, which aims to a shorter machining cycle time and higher productivity. These parameters in machining robot are limited by the low rigidity of the robot structure and chatter phenomena. Chatter is a self-excited type of vibration that occurs in metal cutting. Under specific machining conditions, chatter may occur and grow rapidly, which can cause the cutting tool failure or damage the machine components.

Altintas [1] presents the regeneration of waviness (Fig.1) as the most powerful source of chatter and self-excited vibration. The regenerative chatter vibration system can be represented by the block diagram in Fig.1a.

Chatter in robotic machining is not only affected by machining parameters, but also the robot configuration. S. Mejri et al. [2] and L. T. Tunc et al. [3] experimentally studied the effect of the end-effector position on robotic machining dynamic behavior. They observed significant change of the robot dynamic behavior due to the changes of the robot configuration.

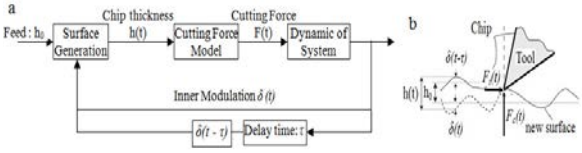

Fig.1. (a) Block diagram of regenerative chatter vibrations (b) chip thickness variation in regenerative chatter

The robot can be piloted to follow a machining trajectory where different joint space configurations are feasible for the same end-effector position, due to its kinematic redundancy. A robot is redundant when the end-effector freedom degrees are less than the joint space freedom degrees (active joint number). The redundancy increases the accessible volume and capability to avoid obstacles in a robotic task. Several researchers have reported their studies to improve the robot

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behavior using the advantages of redundancy in robotic machining. Different criteria are defined to manage the redundancy such as stiffness improvement, accuracy, etc. A. Olabi et al. [14] optimize the robot configurations in a machining trajectory by taking as criteria the minimization of the gap between the actual and the desired geometry of the machined parts. Subrin et al. [5] consider the singularity avoidance as criteria to manage the robotic redundancy.

In this paper, the distance from stability limit in machining operation is the criteria to optimize through the control of the robot posture.

The ABB IRB6660 industrial machining robot has a hybrid structure with a serial part (with three active joints q_4, q_5 and q_6) and a parallel part (two active joints q_2 and q_3) with three passive joints (q_{p1}, q_{p2}, q_{p3}) as shown in Fig. 2.

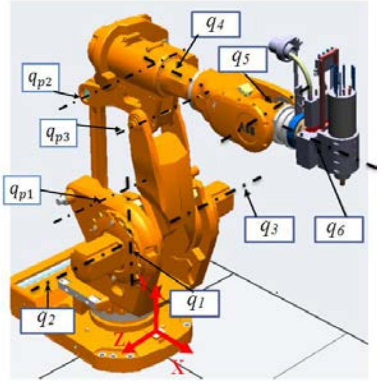

Fig.2. ABB IRB6660 industrial robot

The joints stiffness of the ABB IRB6660 robot are identified experimentally by K. Subrin et al. [6]. They applied a methodology developed by C. DUMA et al. [4] for the joint stiffness identification.

Table 1. Joint stiffness values [6]

Axe1	Axe2	Axe3	Axe4	Axe5	Axe6
10^6	2×10^6	2×10^6	4×10^5	4×10^5	4×10^5 N.m/Rad

A numeric model of the ABB IRB6660 industrial machining robot has been developed by applying the flexible joints and body approach.

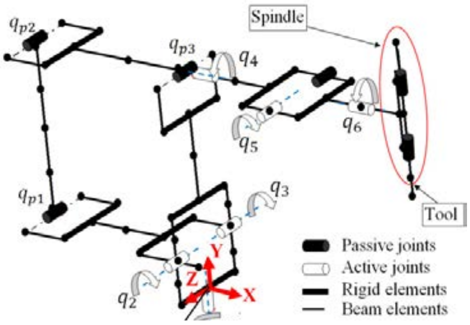

Fig.3. Robot modeling by 3D beam elements [7]

In order to consider the flexibility of the robot links, they used Matrix structural analysis method (MSA). In this method, each robot body is modeled by a 3D (three dimensions) beam elements combination. The ABB IRB6660 robot model is composed of an assembly of 3D beam elements as presented in Fig. 3.

It provides an adaptive dynamic model for posture changes during robotic machining operations. The numerical model was readjusted by a calibration procedure on the basis of experimental results [7]. The dynamic model of the robot is integrated in the machining block diagram shown in Fig. 1.

S. Mousavi et al. [8] have shown the influence of robot displacements on the structure modal properties (frequency and mode shapes), and then the robot vibrations behavior.

The changes in robot dynamic behavior in the workspace allow optimizing the robot configurations regarding machining stability conditions using functional redundancy in robotic machining.

In this paper, the second section present the machining operation with one and then with two functional redundancies and their effect on machining stability. The experimental machining tests with one functional redundancy and then two functional redundancies are realized to confirm numerical results.

Nomenclature

a_r	radial tool engagement
a_p	axial depth of cut
F(t)	Cutting force
h_0	static chip thickness
h(t)	dynamic chip thickness
K_t	tangential cutting pressure
m	joint space dimension
N	tool's cutting edge number
n	operation space dimension
r_s	structure redundancy degree
r_f	functional redundancy degree
r_c	cinematic redundancy degree
t	task space dimension
ω_c	chatter frequency
X_w, Y_w, Z_w	local coordinate attached to the workpiece
X_7, Y_7, Z_7	local coordinate attached to the end-effector
X_0, Y_0, Z_0	global coordinate attached to the robot base

2. Stability prediction in robotic machine with redundancy

Three types of redundancy can be identified in the litterateurs [9]:

- Structural redundancy: a serial robot manipulator has a structural redundancy when joint space dimension *m* is larger than the operational space dimension *n*.

$$r_s = m - n$$

- Kinematic redundancy: a serial robot manipulator has a kinematic redundancy when joint space dimension *m* is larger than the task realized degree *t*.