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Tuning of tool dynamics for increased stability of parallel (simultaneous) turning processes

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A R T I C L E I N F O

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A B S T R A C T

Parallel (simultaneous) turning operations make use of more than one cutting tool acting on a common workpiece offering potential for higher productivity. However, dynamic interaction between the tools and workpiece and resulting chatter vibrations may create quality problems on machined surfaces. In order to determine chatter free cutting process parameters, stability models can be employed. In this paper, stability of parallel turning processes is formulated in frequency and time domain for two different parallel turning cases. Predictions of frequency and time domain methods demonstrated reasonable agreement with each other. In addition, the predicted stability limits are also verified experimentally. Simulation and experimental results show multi regional stability diagrams which can be used to select most favorable set of process parameters for higher stable material removal rates. In addition to parameter selection, developed models can be used to determine the best natural frequency ratio of tools resulting in the highest stable depth of cuts. It is concluded that the most stable operations are obtained when natural frequency of the tools are slightly off each other and worst stability occurs when the natural frequency of the tools are exactly the same.

1. Introduction

Twin turret turning centers and mill-turn machines with a lower turret offer capability to use two cutting tools in turning. Simultaneous (parallel) turning operations, where two turning tools simultaneously machine a workpiece, can be employed on these machines for increased productivity. It is also possible to employ parallel turning on standard lathes using special tool holders which can take two turning tools. An example of such adaptation is presented in the following section.

When two tools are in operation, dynamic interaction between them may result in stability problems and advantage of using more tools may be compromised if process parameters are not set properly. Therefore, it is quite important to involve a stability model in planning stage for selection of the most productive process parameters. Moreover, the model can be used as a tool to tune the dynamic properties of each tool such as stiffness and mass for increased productivity.

The stability of single tool turning processes has been studied in detail by many researchers. The initial works on turning stability used one dimensional stability formulation [1–6]. Later, Rao et al. [7] and Ozlu and Budak [8] extended the stability formulation to 3D for increased accuracy. However, there are only a few studies on parallel turning process stability. Lazoglu

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et al. [9] formulated a parallel turning process in time domain where each tool cuts a different surface. Through simulations, they demonstrated that parallel working tools decrease the stability limits of each other. Ozdoganlar and Endres [10] developed a parallel turning process on a modified vertical milling machine where two turning tools cut different surfaces. They developed an analytical stability solution which was applicable to symmetric systems only. Ozturk and Budak [11] modeled the parallel turning process where two turning tools cut the same surface simultaneously. They showed the stability could be increased due to dynamic interaction between the tools creating an absorber effect on each other.

The previous works on the optimization of parallel machining operations have been mainly on sequencing of these operations [12–14]. On the other hand Tang et al. [15] developed an optimization tool that considers constraints such as cutting forces, spindle power and tool life in parallel turning, but ignored chatter stability limits.

From literature review, it was identified that there is a need for stability models that cover wider application areas in parallel turning. Moreover, optimization studies need to consider stability of process. The developed stability models in the paper can be used to select the best process parameters for given tools. In addition, they can also be used as a guide to tune dynamic properties of tools to optimize the absorber effect on each other for increased productivity.

In this paper, a common modeling approach for stability of two cases is presented. In the first case, a special tool holder which can hold two cutting tools is employed on a standard turning center. Since the cutting tools are on the same holder, there is a direct dynamic coupling between the tools. In the second case, turning tools are clamped on independent turrets. Hence, there is no direct dynamic coupling between the tools, but they dynamically interact through the workpiece. Formulations for these two cases are presented in the next section. In Section 3, the procedure developed for generation of stability diagrams is explained. The stability limit predictions of the presented model are demonstrated for different cases and simulation results are compared by experimental data in Section 4. In Section 5, two methods that can be used to tune the dynamic properties of cutting tools for higher stability, hence higher productivity, are explained.

2. Formulation of dynamics of parallel turning

Stability formulations for two cases are presented in this section. In the first case, two turning tools are clamped on a special tool holder as shown in Fig. 1(a). The tools move together since they are on the same turret; but they cut different surfaces on the workpiece. In the second case, two turning tools are clamped on different tool holders which are on different turrets on a twin turret turning center as presented in Fig. 1(b). Although the turrets can move independently, they cut the same surface on the workpiece when there is no relative motion between them. The dynamics of each case is analyzed in the following sections.

2.1. Two turning tools on the same turret

Fig. 2 represents the cutting process where two turning tools on the same turret machine different surfaces on a workpiece. The tools move together in the feed direction, and the tool that cuts the workpiece first is numbered as tool 1. Cutting depths of each tool can be different; a_1 and a_2 represent the cutting depths of tool 1 and tool 2, respectively. In order to keep stability formulation in one dimension and focus more on the effects of parallel machining, the tools are considered to have no side cutting edge or oblique angles. Due to the lack of side edge cutting angle, only displacements of the tools in the feed direction affect the regeneration mechanism. Each tool can be modeled as being attached to a rigid surface of the machine with springs (k_1, k_2) and damping elements (b_1, b_2) as shown in Fig. 2. Moreover, there are dynamic interactions between the cutting tools which is represented by spring and damping elements (k_{12} and b_{12}). Due to this interaction, the process is dynamically parallel, i.e., dynamic cutting forces on each tool affect dynamic displacements of the other. The dynamics of the workpiece can easily be included in the formulation. However, it is neglected here since the workpiece is considerably rigid with respect to the cutting tools along its longitudinal axis, i.e., the Z-axis.

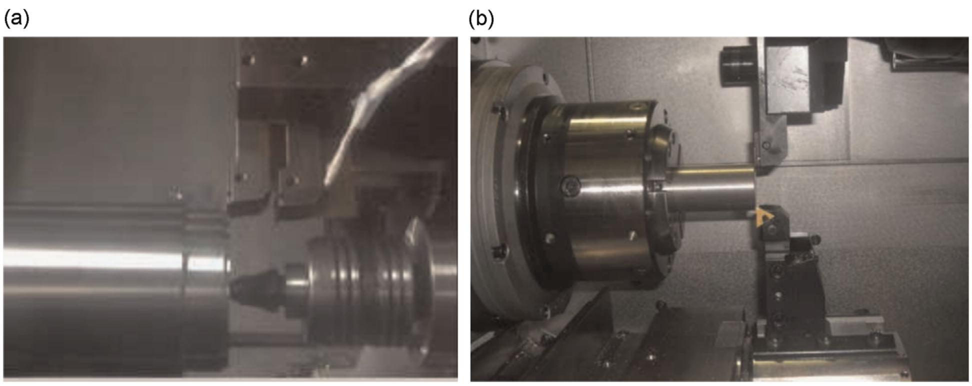

Fig. 1. Parallel turning cases: (a) two turning tools on same turret and (b) two turning tools on different turrets.