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Optimal process parameters for parallel turning operations on shared cutting surfaces

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ABSTRACT

To enhance productivity in industrial settings, turning machines are increasingly being used with multiple turrets. This machine configuration enables parallel machining at different or at the same cutting surface using independent tools. However, there is a dynamic interaction between the cutting processes due to the waviness induced on the shared cutting surface as well as due to the dynamic coupling through the machine structure. This dynamic interaction can lead to a significant reduction of the chip removal rate compared to two conventional processes. To utilize the productivity advantage of parallel turning processes, an examination of the process-machine-interaction considering the dynamic coupling of the cutting processes is required. Hence, this paper discusses parametrization for stable processing of parallel turning operations. Therefore, time and frequency domain-based simulation models are developed and matched with experimental cutting tests. Additionally, the influence of the radial angle between the tools is investigated. This angle influences the dead time between two successive cuts for parallel turning processes on the same cutting surface. The dead time in turn directly affects the process stability limit. Thus, with the help of the developed simulation models, an optimal process parametrization for parallel turning operations can be determined.

1. Introduction

As discussed in many papers, chatter vibrations in cutting processes are a well known problem and a lot of research has been carried out to understand and model the dynamics of cutting processes to maximize the cutting capacity [1–3]. Of the various types of chatter, regenerative chatter is considered the most common [4,5]. This type of chatter can occur for processes with overlapping cuts, such as turning, milling or grinding processes. The excitation mechanism of regenerative chatter is directly connected to the background noise of the cutting forces. Small fluctuations in the cutting forces always leave a waviness on the surface of the workpiece because of the finite stiffness of the machine. If this surface waviness is cut repeatedly, the chip thickness and therefore the cutting forces vary, amplifying the process continuously [6,7].

However, the mentioned studies mostly focus on standard cutting processes. Only few research articles concentrate on the dynamics of parallel turning processes [8,9]. Nevertheless, turning machines with multiple turrets are increasingly used to enhance productivity. As described in [10] and shown in Fig. 1, parallel turning processes can occur on the same or on different cutting surfaces of the workpiece. While processing on different cutting surfaces, there is a dynamic coupling of the processes through the machine structure. Since the focus is on high-performance cutting, the workpiece dynamics are ignored. The transfer behavior of two simultaneous dynamic processes (compare Fig. 1) has been studied in the context of an analysis of the dynamics of double-spindle milling at the WZL [11].

This paper focuses on the investigation of process-machine-interaction of parallel turning operations with a shared cutting surface. Since only parallel turning operations with shared cutting surfaces are discussed in this paper, the wordings “coupled process” and “uncoupled process” refer to the structural dynamic transfer behavior of the machine structure between the tools. In this paper a parallel turning process with a shared cutting surface where the tools can oscillate independently is referred to as an uncoupled process, because there is no structural transfer behavior between the tools. This is an academic case. In real machine tools there is always a structural coupling between the tools, but the discussion of uncoupled process helps to understand the dynamics of parallel turning processes. Consequently in this paper “coupled processes” are defined as a process with structural dynamic coupling of the tools by transfer behavior. In this case, a force on tool 1 always results in a deflection of tool 2. Budak et al.

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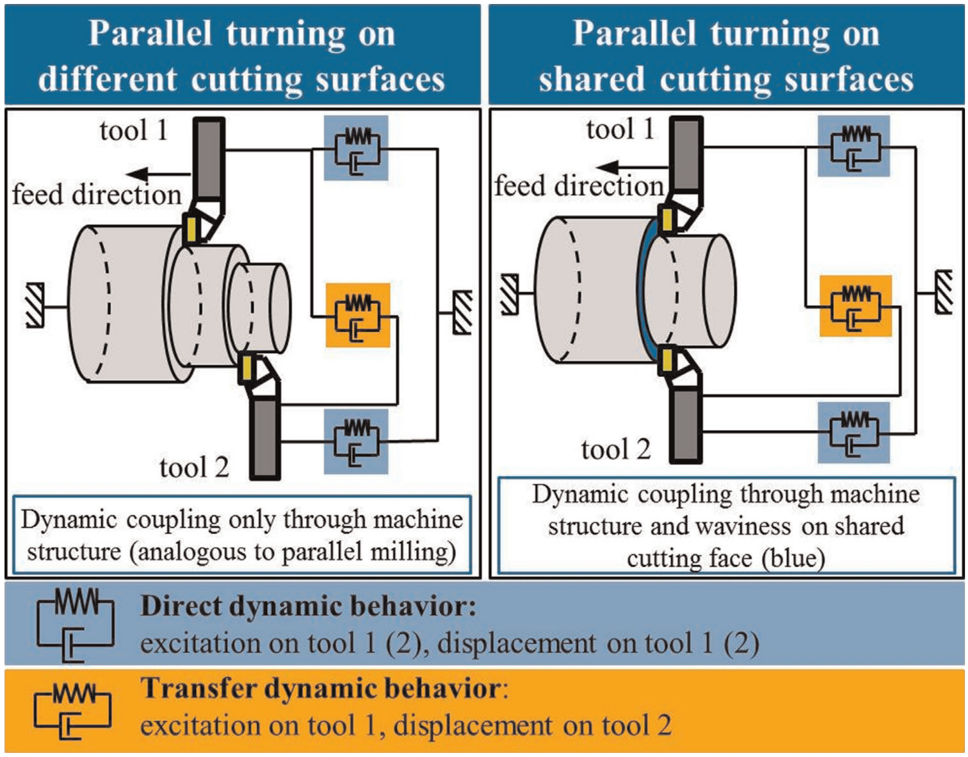

Fig. 1. Parallel turning with shared cutting surfaces.

were able to demonstrate substantial changes in process stability of parallel turning processes compared to conventional processes with one tool [9]. The theory to describe process instabilities due to chatter is based on the idea of a closed loop control with machine and process models and discusses the following phenomena. Due to a minimal disturbance in the process, the cutting force on tool 1 varies. This results in a vibration of the tool due to the dynamic compliance of the machine structure. A waviness is cut onto the workpiece surface. This waviness reaches the second tool after a dead time $T_{d,12}$ and dynamically excites this tool. In turn a waviness is cut by the second tool, which reaches the first tool again after another dead time $T_{d,21}$. This mutual excitation is illustrated by an interaction model in Fig. 3. Thus, the dead time is defined as the duration the work piece needs for the rotation between two consecutive tool engagements. For conventional turning processes, the dead time is the time for one rotation of the work piece. For parallel turning processes with the same cutting surface, the dead time depends on the radial angle between the tools α (compare Fig. 2).

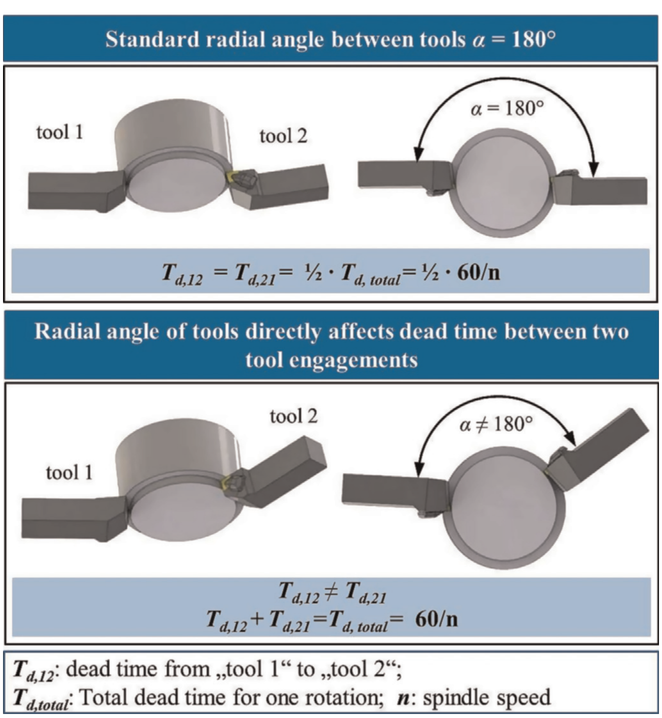

Fig. 2. Influence of the radial angle on the dead time.

It is evident that the stability behavior of the system is affected by changes in the dead times ($T_{d,12}$ and/or $T_{d,21}$) [12]. The dead times can be varied either by changing the spindle speed n or by varying the radial angle between the tools α. The aim of the developed approaches at the WZL is the prediction and simulation of optimal spindle speeds and angle parameters to maximize the cutting capacity. Therefore, the modeling is presented in detail in the next section.

2. Modeling the dynamics of parallel turning processes

For the prediction of process stability limits of parallel turning processes (depending on the spindle speed n and the radial angle between the tools α), both a model in the time and in the frequency domain have been developed at the WZL. The model in the frequency domain provides a high computational performance, allowing for rapid calculation of numerous combinations of spindle speeds and angular positions. The time domain model provides a detailed examination of the excitation and chatter initiation phase. Moreover, modeling of a continuous change of the radial angle α is planned. This results in a time-variant dead time (similar to permanent active spindle speed variation), which can no longer be simulated using only frequency domain methods.