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Energy efficient machining with optimized coolant lubrication flow rates

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Abstract

Nowadays, reducing the energy consumption is an important step to optimize machine tools. In general use, high pressure pumps of inner cooling lubricant supply are dominant energy consumers in machine tools and thus offer great possible savings. This paper presents and discusses several approaches to optimize the energy consumption of machine tools by controlling and reducing the coolant flow rate. Measurements of the machine power input show total saving potentials of up to 37 percent, while investigations of tool wear examine the aspect of technological risks. The feed rate is identified as a significant influencing factor, which interacts between the tool wear and and the optimal lubrication flow rate in milling and drilling operations.

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Keywords: Energy efficiency; sustainable manufacturing; coolant lubrication; tool life

1. Introduction

Energy costs have come into focus of metalworking industry in the last decade since they have increased continuously and account up to 20 percent of total cost of ownership for machine tools nowadays [1]. However, energy efficiency measures should not be at the expense of accuracy, dynamic and reliability, which are still the dominant indicators for the productivity of machine tools. Apart from directly economic aspects ecologically motivated incentives are also becoming increasingly significant since the industry sector has a 42.6 percent share of world electricity consumption [2]. Due to climate change and its aftermath on our society, politics have become aware of industry's impact on primary energy consumption and thus carbon emissions in the past few years. As a consequence, several political restrictions have come up that force manufacturers and users of machine tools to reduce their energy consumption [3,4].

High pressure cutting fluid pumps were identified as main consumers in a large number of investigations [5,7]. However, Klocke et al. show that the power-demanding high-pressure technology can yield overall energy savings. For the investigated turning process, a significant increase of the achievable cutting speed shortens the primary processing time by 50 percent and therewith the energy amount per workpiece by 40 percent without influence on tool wear [8]. Sangermann shows possibilities to reduce the hydraulic power at a constant level without increasing tool wear [9]. Nevertheless, Rief et al. present drilling operations for example, where conventional flood cooling has advantages in tool life and energy efficiency over high pressure technology [10]. In general, a transferability of existing results is hardly possible because of a wide range of influencing parameters [11]. Further investigations are required to get a profound knowledge of the effects on the machining process [8,9,11]. From the environmental point of view, it must be the goal to achieve maximum productivity with minimum energy input that mainly depends on pressure and flow rate [8]. The latter is applied to be the crucial parameter for all main tasks of cutting fluid (cooling, lubrication, chip transport and in some cases chip control) [11]. It can be ensured by implementing a flow rate control as shown in [6]. In comparison to a

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conventional pressure control with a regulating valve, it offers considerable energy savings in machining centers. The power demand of the cutting fluid unit which is equipped with a 40 bar pump for the inner coolant supply, was reduced by 32 percent in a demonstration process. Thereby, especially in drilling operations, the pressure and thus the energy consumption are automatically lowered because of the reduced flow resistance in idle times.

The approach of the work presented in this paper is an extension of the flow rate control shown in [6,12]. An additional lowering of pump power can be realized by a need-based selection of flow rate setpoints. These values must be chosen accurately with regard to actual process parameters to avoid losses of productivity or increased tool wear. Therefore, the effect between flow rate and tool wear was investigated for different process types. By means of a need-based flow rate supply the energy saving potential was determined experimentally on a modified machining center. The studies were conducted in collaboration with the companies DMG MORI SEIKI, Sandvik Coromant, Grundfos and Bosch Rexroth Interlit.

2. Experimental setup

Two representative machine tools are chosen for the investigations. Milling and drilling operations are considered as well as cylindrical turning and grooving. The material for all experiments is duplex steel (1.4462).

The first testing machine is a machining center DMG DMU 65 monoBLOCK® for milling and drilling operations (Fig. 1), that is equipped with a cutting fluid unit made by Bosch Rexroth Interlit. Its screw pump for high pressure supply is frequency converted and hence represents the best available technology concerning energy efficiency. It achieves a maximum pressure of 80 bar and a maximum flow rate of 31.9 l/min. An additional implementation of flow rate sensors enables a flow rate control of the inner cutting fluid. By means of the G-code, the operating mode can be switched from pressure control to flow rate control. Additional NC commands specify the setpoint values that are transferred by a PROFIBUS connection to the frequency converter of the pump. Fig. 1 shows the energy distribution of this machining center for a demonstrator machining process with a constant pressure of 80 bar. In this case, the frequency converted high pressure pump requires 46 percent of the total energy input and thus offers most potential savings. The cutting tools for drilling and milling are of type SANDVIK CoroMill® and CoroDrill®.

The second machine tool is a GILDEMEISTER CTX 520 L® lathe for the regarded cylindrical turning and grooving applications and contains a centrifugal pump made by Grundfos. It is frequency converted and pressure controlled and achieves a maximum pressure of 20 bar and a flow rate of 50 l/min. The turning tools used are of type SANDVIK T-Max® P and CoroCut® Q and contain jets for directed coolant fluid supply.

3. Tool wear

The influence of the variation of the volume flow rate of the coolant on the tool life time is investigated for external cylindrical turning and grooving on the lathe and for side milling and drilling on the machining center.

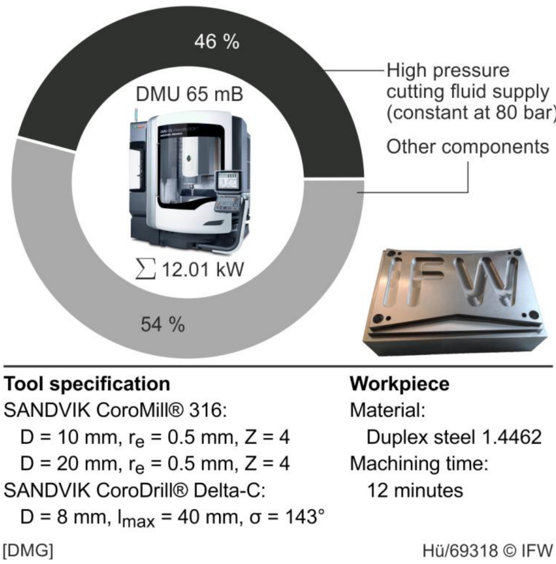

Fig. 1. Testing machine tool DMU 65, workpiece and energy consumption.

3.1. Wear investigation on a lathe

The influence of volume flow rate of the coolant on the tool life time is analyzed for external cylindrical turning. Therefor the tool wear is investigated by measuring the width of flank wear land (VB) with respect to the cutting length of the tool (Fig. 2). VB = 300 µm is assumed to be the terminal width of flank wear land which indicates the maximum cutting length for a given tool.

The cutting tests are performed for five equally distributed volume flow rates in the range of 2.2 to 6.8 l/min, the machining parameters are given in Fig. 2. In Fig. 3 the trend of VB with increasing cutting lengths l_c are shown for variable volume flow rates. It can be seen that the maximum cutting length is comparable for flow rates in the range of 4.5 to 6.8 l/min but decreases rapidly for smaller flow rates. Consequently, the flow rate for this machining process can be reduced to 4.5 l/min without affecting the tool life time. This is addressed as minimum required flow rate.

Subsequently, it was analyzed how the process parameters affect the minimum required flow rate by increasing the cutting speed and the feed rate separately, which is shown in Fig. 4. It compares the maximum cutting length for variable volume flow rates and process parameters. It becomes evident that the tool life time – indicated by the maximum cutting length – is decreased with increasing feed rate and cutting speed but the minimum required flow rate is independent of the process parameters.

3.2. Wear investigation on a machining center

After demonstrating the existence of a minimum required volume flow rate of the coolant for turning processes this finding is to be confirmed for more complex machining