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Application of spindle speed increaser as sustainable solution to upgrade machine tools

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Abstract

Due to varying machine operations, cutting material and feed motion of the respective milling machine, a wide range of spindle speed is required. Modern machine tools are therefore occasionally equipped with two spindles to cover a wider application scope. Especially while increasing the cutting removal rates for soft materials like aluminium alloys, outdated machine tools fail to provide high spindle speed. Spindle speed increasers (SSI) are possible solutions in order to flexibly increase the cutting removal rates of milling machines. In this paper, the state of the art of SSI is investigated regarding its application in different milling machines and with respect to resource and energy efficiency. Therefore, based on the respective machining operations, spindle input and milling machine, a selection methodology is provided to prove the feasibility of the application of existing SSI. This allows estimating the sustainable benefit on theoretical basis.

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Keywords: machine tool upgrade, spindle speed increaser

1. Introduction

In order to develop a resource efficient way of upgrading conventional outdated milling machines the authors propose an approach of applying add-ons within the Collaborative Research Centre (CRC) 1026 B5 project. This approach is aiming at enhancing specific functions of the respective machine tool in a flexible manner. Fig. 1 shows

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an accuracy increasing add-on as sustainable solution to compensate the positioning deviations of a Deckel FP4NC milling machine (thereafter: FP4) in x- and y-plane [1].

Fig. 1. Deckel FP4NC milling machine (a) accuracy increasing add-on; (b) productivity increasing add-on

High Speed Machining (HSM) plays a vital role in automotive, aircraft and mould industry. By increasing the spindle speed a reduction of the specific cutting forces and temperature has been experimentally observed [2]. The achievable cutting removal rates range mainly between $Q_w = 150 - 1{,}500\ cm^3$ and cutting velocities v_c up to $10{,}000\ min^{-1}$ are reached [2]. Cutting conditions play a major role to reduce the energy consumption and thus increase the machining efficiency. Kianinejad et al. compared the energy consumption of an outdated FP4 and a newer DMG DMU50 milling machine under varying cutting conditions. The objective was to identify the factors, which limit the achievable removal rate for different tools, processes and materials. The results obtained show that, especially for finishing processes, the maximum possible spindle speed was the bottleneck for the maximum achievable removal rate. Altogether, it was found that the outdated machine tool has about 40 % higher specific energy consumption during cutting operation. Due to limited maximum spindle speed and spindle power, the outdated machine tool is not able to reach higher removal rates. The energy efficiency is further limited while machining materials, which allow even higher cutting speeds than offered by FP4 such as aluminium alloy [3].

Nomenclature

a_e	cutting width
a_p	cutting depth
D	tool diameter
F_{cmz}	average cutting force
f_z	feed per tooth
h_m	average chip thickness
κ	pressure angle
k_c	specific cutting force
K	correction factor (K_V: cutting velocity, K_{Ver}: tool wear, K_γ: chip thickness)
m	slope
n	spindle speed
φ_s	cutting arc angle
Q	cutting removal rate
z	number of teeth

In order to increase the machining productivity several actions took place. Rangarajan and Dornfeld conducted a case study to identify an optimum angle for face milling and roughing [4]. A kinetic energy recovery system (KERS) has been simulated and presented as a worthy solution to enhance the energy efficiency of machine tools. The simulation results have shown that the use of KERS results in 5 - 25 % power reduction [5]. Mori et al. experimentally measured the impact of cutting conditions on the power consumption. By varying cutting speed, feed