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Analysis of the Energy Consumption of Fluidic Systems in Machine Tools

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Abstract

Power losses in machine tools are converted into thermal energy warming up components such as rotary table, tool holder, linear guide rails etc., and the machine tool structure. Due to this temperature change, thermo-elastic deformations of the machine tool structure occur which directly influence the position of the tool center point (TCP). Consequently, the accuracy of the machine deteriorates during the production process. The warmed-up parts or components need to be cooled; therefore, fluidic systems, such as cooling system, are installed to prevent this effect. In order to reduce the occurring thermo-elastic deformations and to enhance the production quality it is necessary to minimize the heat input. Previous research projects mainly focused on the energy demand of the machine tool and its main drives, reducing the energy consumption by developing more efficient components, and control strategies. However, the energy consumption of the fluidic systems has not yet been described in detail. Therefore, a detailed analysis of the existing fluidic system structures and their energy demand is necessary in order to ensure a uniform temperature distribution of the machine tool at minimal energy consumption.

The main goal of this paper is to analyze the energy consumption of the fluidic system exemplified by two demonstrator machines. This investigation will help obtain the information concerning the energy demand of the fluidic system for these two different machines. This makes it possible to predict the consumed energy and the thermal behavior of the machine tool and its fluidic systems. Furthermore, the Energy consumption can serve as a reference for developing new system structures.

Firstly, the paper describes the two different demonstrator machines with a special focus on their fluidic systems. Secondly, the methodology of the measurement to measure the energy consumption of the whole machine and of the fluidic systems is shown. Lastly, with the aid of experimental investigations the energy consumption of each machine is calculated and discussed for a defined process.

As a result of the investigation, the energy distribution of the fluidic systems for both machines is determined. This knowledge serves as a reference for further investigations, for example, the cooling system. The first steps of the network-based simulation strategy are illustrated. These network-based models are helpful for future investigations regarding new structuring concepts such as the decentralization of the fluidic systems.

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Keywords: Energy consumption; Fludic systems; Machine tools; Thermo-elastic deformation; System structure; Modeling and simulation

1. Introduction

In the field of production technology, machine tools represent a relevant part of the machine equipment in a company. Depending on the manufacturing, machine tools require up to 68 % of a company's total energy demand [1]. During the production processes, e.g. drilling, cutting, or milling, a part of electric and mechanical energy (energy losses) is converted into thermal energy. Due to the temperature change, a thermo-elastic deformation of the machine structure occurs. This deformation directly influences the TCP and, consequently, the precision of the machine while the production process deteriorates. The fluidic systems, such as the cooling system, are essential elements for controlling these thermo-elastic deformations. They can be divided into cooling system, cooling lubricant system, hydraulic system and lubrication system. On the one hand, some of them allow for heat dissipation from the overall machine tool structure as well as from the main components in order to reduce the temperature gradient and to homogenize the temperature distribution. On the other hand, the fluidic systems themselves are essential energy consumers and, therefore, a significant

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heat source within the machine tool. Previous studies were carried out in [2, 3] to analyze and determine the energy consumption and the energy distribution at the machine tools. However, these are concerned with decreasing the energy consumption of the components of the machine tools through constructive measures as well as developing a shutdown control of components during waiting times. However, the energy consumption of the fluidic systems has not yet been described in detail. Therefore, a detailed analysis of the existing fluidic system structures and their energy demand is necessary to increase the efficiency of the machine tools at uniform temperature distribution. With the aim of higher productivity and accuracy, machine tools are faced with the challenge of having a higher energy consumption and losses influencing the accuracy negatively due to increasing thermo-elastic deformations [4].

The main goal of this paper is to analyze the energy consumption of the fluidic system for two demonstrator machines. The first demonstrator machine is type DBF630, whereby this machine is used mainly for heavy-duty cutting. The second demonstrator machine is type DMU80 eVo linear and is used for high speed cutting. This investigation will help to obtain information about the energy demand of the fluidic system for these two different machines. This makes it possible to predict the consumed energy and the thermal behavior of the machine tool and its fluidic systems. Furthermore, the energy consumption can serve as a reference for developing new system structures. The investigation does not serve as a comparison between the two machines.

Chapter 2 gives an overview of the fluidic systems and their function for both demonstrator machines. In Chapter 3 the methodology for measuring the energy demand of the whole machine and its fluidic system is illustrated. By measuring the electric power, the energy consumption of the machines for a defined process is evaluated and the energy distribution regarding the different fluidic systems is shown.

Nomenclature

E_{el}	electric energy (J)
$i_{1,2,3}$	phase current (A)
P_{el}	electric power (W)
t	time (s)
$u_{1N,2N,3N}$	virtual star voltage (V)
$u_{12,23,31}$	virtual delta voltage (V)

2. Fluidic systems in DBF630 and DMU80

The first experimentally analyzed demonstrator machine in Fig. 1, type Scharmann DBF630 (machine 1), has three linear feed axes with ball screw drive (X, Y, Z) and one rotary feed axis (B). The additional U axis is used only for the turning process and is inactive during the drilling or milling processes. The spindle of machine 1 is a gear spindle with two gear steps. In gear step 1, the spindle rotation speed ranges to 1200 min^{-1}, and the transmission ration is i1=8.2080. In this step, a high cutting performance due to high torque of 1700 Nm could be applied. In gear step 2, the spindle rotation speed ranges to 3500 min^{-1}, the transmission ration is i2=1.5. So the spindle speed range can be varied by the transmission ratio and by motor through the frequency converter. The overall driving power of the machine is 35 kW [5].

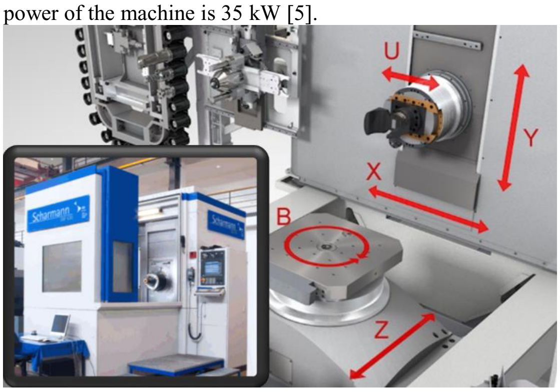

Fig. 1: Schematic representation of axes configuration of DBF630 (machine 1).

Fig. 2 presents the second demonstrator machine DMU80 eVo linear (machine 2). This machine has three feed axes with linear direct drives (X, Y, Z) and two rotary feed axes (B, C). The maximum spindle speed is 18000 min^{-1}, and the driving power amounts to 35 kW (S2) or 25 kW (S1). Accordingly, the driving performance of the torque amounts to 130 Nm (S2) or 87 Nm (S1). The spindle speed can be controlled only by the motor which is combined with a frequency converter.

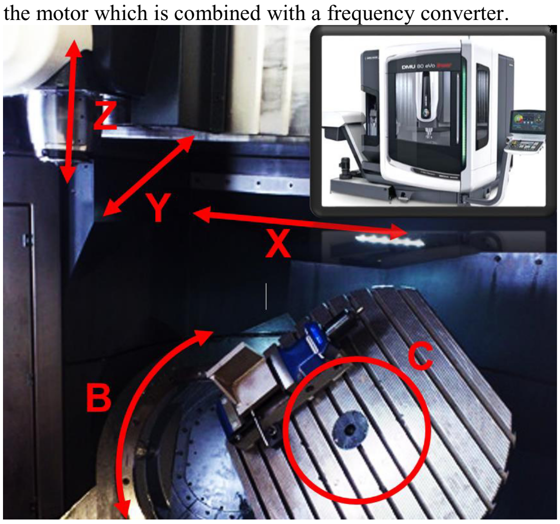

Fig. 2: Schematic representation of axes configuration of DMU80 (machine 2).

Table 1 summarizes the technical data and the properties of machine 1 and machine 2. Both machines differ in their speed range and torque so they can be used for different application tasks such as heavy-duty cutting (with low speed and high torque in case of machine 1) or high speed cutting (with high speed and low torque in case of machine 2). The demonstrator machines 1 and 2, as mentioned before, have four main fluidic systems (cooling, cooling lubricant, lubrication and hydraulic system). In the following sub-chapters the functions of their fluidic systems are described.