Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 55 (2016) 164 – 169

www.elsevier.com/locate/procedia

5th CIRP Global Web Conference Research and Innovation for Future Production

Electric Load Management on Machine Tools

Eberhard Abele, Philipp Schraml*, Daniel Moog

Institute of Production Management, Technology and Machine Tools, Technische Universität Darmstadt, Otto-Berndt-Str. 2, 64287 Darmstadt, Germany

* Corresponding author. Tel.: +49 6151 16-20288; fax: +49 6151 16-20087. *E-mail address:* schraml@ptw.tu-darmstadt.de

Abstract

Today, the need for a more economic handling of energy in the production context is urgent. Moreover, structural changes in the energy market are taking place due to a growing share of renewable energy sources in power generation. These circumstances require solutions to reduce and flexibilize the electric load demand of production facilities.
Machine tools are subject to a wide range of applications. Besides, they integrate diverse cross-sectional technologies. Therefore, research results regarding the optimization of the load demand of machine tools can serve as a basis for the optimization of the power intake of numerous production machines.
In this context, the paper at hand presents a two-step approach to optimize the electric load demand of machine tools in productive state. In a first step, a potentials analysis is carried out to identify modules suitable for load demand control. Additionally, the amount of achievable peak load reductions through managing the load for a specific use case (primary process and designated machine tool) is determined. The potentials analysis considers the load demand of auxiliary modules of a machine as well as the module-specific control mode and internal operational concept. If a sufficient potential can be detected, the actual optimization of the load profile of the machine in productive state is carried out in a subsequent step. The optimization process seeks to incorporate the independently controlled auxiliary units into a global control concept. The aim of the optimization is to find an operating schedule for the considered auxiliary units leading to a cumulative load profile featuring desired load objectives. These load objectives can be peak minimization, flexibilization, or smoothing.

Peer-review under responsibility of the scientific committee of the 5th CIRP Global Web Conference Research and Innovation for Future Production

Keywords: *energy control; load management; machine tools*

1. Introduction

Energy costs cover a significant share of annual operating costs [1]. Increasing energy prices, political goals and regulations, as well as risen public awareness [2] demand for a more economic handling of energy in the production context. In research on machine tools, this is reflected in a focus on increasing the energy efficiency of machine tools, which can e.g. be achieved through the use of more efficient components [3].

Nomenclature

LRP_{abs}	absolute load reduction potential	in kW
LRP_{rel}	relative load reduction potential	in %
P^{targ}	target load demand	in kW
P_{c}	power rating of machine tool	in kW
P_k	mean load demand of module k	in kW
P_{n}	nominal load of machine module	in kW
P_t^{fix}	fixed load demand of drive system	in kW
$x_{t,k}$	binary switching state variable	–

Peer-review under responsibility of the scientific committee of the 5th CIRP Global Web Conference Research and Innovation for Future Production
doi:10.1016/j.procir.2016.08.046

Another possibility to energetically optimize machine tools is through load optimization. Three measures to do so are peak load minimization, load flexibilization, and load smoothing. Each of these measures features different benefits depending on the area of application.

Decreasing the maximum load demand of production machines, i.e. minimizing peak loads, can allow for a lowering of the connected load of machines. In return, this generates reduced infrastructure requirements [4]. Particularly, connector cables as well as power transformers may be dimensioned smaller, which can result in monetary savings [5]. Furthermore, common tariff structures in Germany's industry typically provide that a share of the total electricity cost is calculated based on the maximum obtained load amount over a defined period of time (e.g. month, year) [6]. Therefore, if peak loads are kept at a minimum over tariff-relevant time periods, electricity costs can be saved.

With the increasing share of renewable energy sources in the total electricity mix, volatility in power generation is expected to increase. Hence, dynamically reacting to demand fluctuations becomes more challenging [7]. A demand-sided load flexibilization can contribute to the synchronization with a volatile energy supply profile and have a stabilizing impact on the power grid [8]. In this context, load flexibilization can have monetary benefits for companies when new tariff structures accounting for the change in the energy market are being established [9].

Load smoothing increases the predictability of load profiles, which can be beneficial for energy data monitoring as well as the loading and utilization of energy storage capacities (energy buffer management).

Against this background, the paper at hand presents a two-step approach to optimize the electric load demand of machine tools. In particular, the approach focuses on the load optimization in productive state since research on this topic has only been conducted scarcely [9] and unexploited potential is evident.

2. Load management on machine tool level

Today, production machines commonly feature a high degree of automation. Especially machine tools are standardly equipped with integrated control solutions, comprising a numerical control (NC), and a Programmable Logic Controller (PLC) [10]. The availability of such control units offers the possibility to influence or manage the power intake of machines automatically over entire operation cycles.

Initial forms of load management applications on machine tool level are control-based standby managers. These applications follow the objective to reduce the load demand of machines in non-productive periods. Within the project *MAXIEM*, a machining center was equipped with such a software-based standby management [11]. Upon occurrence of specified trigger events, e.g. completion of operation, the control unit turns off peripheral components. Thereby, the machine tool is shifted into a state of a reduced load demand. In the example of a 3-shift serial production, the annual energy demand can be reduced by 23 % with this strategy. Similar control optimizations are discussed in [3], [12], and [13].

In [14], an approach for modelling machine tools facilitating the self-optimization of their energy demand is presented. Particularly, the concept aims at reducing idle power and total energy consumption by minimizing the energy waste related to excessive medium supply.

The aforementioned approaches aim at minimizing the mean load demand of machine tools through load alternation in non-productive states. However, research on the optimization of the power demand of machine tools during productive periods has only been conducted by very few authors.

In [15], an intelligent frequency converter was developed. On the one hand, the unit acquires current module-specific energy demands. On the other hand, it controls the load demand through communication with modules of one or multiple machines to avoid peak loads above a defined threshold.

In [16], it is shown how the load profile of machine tools can be controlled during productive state without negative impacts on productivity or process safety. It is argued that load profiles of machine tools are constituted of a base load share corresponding to determined processes and of a flexible load share corresponding to non-determined processes. Determined processes are default by the operation specific NC code, which defines the working states of the motor spindle and the feed axes. Non-determined processes serve auxiliary functions and are typically executed by peripheral components such as coolant lifting pumps. In that regard, non-determined processes are controlled independently from the primary determined processes. Due to this autonomous nature, the non-determined load demand is suitable to be flexibly controlled within certain constraints without negatively affecting the primary process.

Concluding, load demand control on machine tools during the productive state is a fairly recent research field. None of the investigated publications addresses the issue of load management on a single machine tool under quantitative aspects. Furthermore, a ready-to-implement optimization strategy for machine controls under energy-related aspects is not provided. Both of these issues are addressed by the developed approach, which will be presented in the following sections.

3. Load management approach to optimize the electric load demand of machine tools

During the execution of manufacturing processes, the main control unit addresses the individual modules with the main objective to almost exclusively suffice primary process requirements. Until this date, machine tool controls are not designed to additionally incorporate energy-related objective functions such as the minimization of the total power intake at any given time during the productive state [17]. Instead, the activation of the various modules by the main control unit is carried out independently, thus resulting in non-minimal load profiles during process realization.

To optimize the peak load demand of machine tools during the productive state, a two-step approach was developed. In a first step, a potentials analysis is carried out. This is done to identify and classify modules which are suitable for a load demand control. Besides, the achievable peak load reduction through the implementation of a load management for a