Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 67 (2018) 75 – 80

www.elsevier.com/locate/procedia

11th CIRP Conference on Intelligent Computation in Manufacturing Engineering, CIRP ICME '17

A multi-level procedure to evaluate the energy flexibility potential of production machines

Richard S.-H. Popp[a,*], Corinna Liebl[a], Michael F. Zaeh[a]

[a]*Technical University of Munich, Institute for Machine Tools and Industrial Management (iwb), Boltzmannstr. 15, 85748 Garching, Germany*

* Corresponding author. Tel.: +49 89 289 155 88; fax: +49 89 289 155 55. *E-mail address:* Richard.Popp@iwb.mw.tum.de

Abstract

With the recent increase in the use of renewable energies, such as photovoltaic and wind energy, both manufacturing companies and energy providers are confronted with an increasingly volatile energy supply, caused by alternating weather conditions. Quantitative models are needed to assess new strategies that can be applied to the circumstances of the volatile energy supply by manufacturing companies on a profitable basis. Most quantification models consider only individual production levels, so that a uniform assessment over several levels is not given. The approach presented in this paper expands an existing single-level quantification model for the application to further factory levels. Based on a simple example of a machining manufacturing, the energy flexibility potentials, quantified by key figures, are derived.

A key point for the energy flexible operation of production machines is to ensure productivity and product quality. As the manufacturing industry is striving to maximize the utilization of its machines, a consideration of the energy flexibility potentials over the utilization ratio of the machines has been performed. This approach focusses on energy flexibility potentials which can be executed on short notice. Scheduling of energy demands via production planning, with lead time e.g. more than a day, is, however, not taken into account.

Peer-review under responsibility of the scientific committee of the 11th CIRP Conference on Intelligent Computation in Manufacturing Engineering

Keywords: Machine tool; Energy efficiency; Energy flexibility

1. Introduction

In future, the controllability of the energy demand will obtain an increasing importance, caused by the growing market share of renewables that are mainly based on wind and solar power. These sources induce a high dependency of energy availability on weather conditions. To compensate for this, the energy consumers (e.g. factories) can be encouraged by new tariff structures that refund a flexible energy demand.

But also a self-sufficient energy supply is a possibility worth considering for manufacturing companies. Resulting from the rapid evolution of the energy market, the investment costs for systems that generate renewable energy have decreased in recent years, especially for solar power [1].

In the past, companies were very cautious to operate production machines according to the energy availability due to their high requirements concerning productivity and reliability. Nevertheless, machines of a high utilization have a huge potential to adapt their power demand to the energy availability [2].

In this paper an existing model to quantify the energy flexibility potential for production machines will be extended and adapted for a multi-level application. Therefore, it is possible to directly compare the various potentials of different factory levels.

Companies can thus obtain a detailed statement of the potential of their machines and provide strategic decisions whether and at which factory level an energy-flexible operation can be carried out. An economic evaluation of the achieved potential can be performed on the basis of the procedure in [3].

2. Energy flexibility of production machines

Within this paper, energy flexibility potentials are focused that can be executed on short notice. These are called *real-*

Peer-review under responsibility of the scientific committee of the 11th CIRP Conference on Intelligent Computation in Manufacturing Engineering
doi:10.1016/j.procir.2017.12.179

time energy flexibility potentials and can be performed e.g. on the machine and the subordinated components level to adapt the energy demand according to the prevailing energy availability.

Several approaches for modeling energy flexibility exist within the literature. In the field of manufacturing, universal as well as more specific methods and strategies have been developed to estimate the potential of the energy flexibility. Besides sole technical evaluations [2, 4, 5], economic indicators have also been derived [6]. In the following, special attention will be given to approaches, which relate to metal-cutting manufacturing.

A state-based approach for quantifying the potential of energy flexibility is presented in [7]. By performing measures, like the adaption of process starts or machine scheduling, the energy demand can be slightly synchronized to external circumstances. Although a detailed analysis is proposed taking a large number of factors into account, neither the evaluation of the energy flexibility of production systems with quantified values of flexible energy nor an application on different production levels is possible.

A real-time energy flexibility control method for aligning interlinked manufacturing systems to an energy supply by renewables has been proposed in [8]. For this execution control, no forecasts of energy availability are necessary in order to adapt the operation times of production machines. Although the target is to maintain the throughput time, the described scenarios allow for a lower productivity and a higher inventory in order to achieve energy flexibility goals. Different performance indicators were derived in order to present the method's potential. The publication considers the possibilities on the machine level by using existing buffers between process steps. A similar approach using a real-time strategy by disruption management was proposed in [9]. In both, an evaluation of the component level and a comparison of component and machine level is not performed.

Detailed studies on energy flexibility of machine tools were carried out by [10, 11]. A strict focus was placed on the component level in order to avoid negative effects on productivity. A transfer of the evaluation models to the machine level has not been carried out yet.

The research activities presented within this section focus on methods for evaluating the energy flexibility of production systems on single levels, mainly on the machine and component level. A direct comparison of two different production levels has not been carried out. Thus, there is as yet no decision-making basis for manufacturing companies to decide whether and at which factory level an energy-flexible operation can be performed productively. This paper presents a procedure to evaluate the potentials on two production levels and the behavior of both levels over a varying utilization ratio of the production machines.

3. Single-stage evaluation model

3.1. Adaption of the existing quantification model

In [12] a model was presented, which allows for the quantification of energy flexibility potentials on the component (resp. aggregate) level for all intermittently operating systems. For this purpose two key figures have been identified, which are already sufficient to describe the potential of each individual system:

- Flexible energy E_F: The amount of electrical energy that can be shifted in time without compromising productivity and process reliability.
- Energetic time of use t_D: The corresponding time, by which the flexible energy can be shifted under the same restrictions.

The model was developed further by continuing evaluations and investigations. While there has been a limitation of validity to approximately the same length of active and passive periods, the consideration is applicable to any ratios of the time periods. For clarity, the factors f_P for the buffer expansion and the previous performance profile E_P (cf. [12]) are now neglected. These can be inserted again according to [12].

The revised calculation shows that the flexible energy is now independent of the type of the current state (see eq. 1). In addition, the amount of the parameters of both measures (*interruption of the active state* and *early start of the active state*) is identical. This applies analogously to the energetic time of use (see eq. 2). In addition, the value is always positive, since the energy demand is not retroactively variable.

$$E_F = \left(\bar{P}_{curr} - \bar{P}_{targ}\right) \cdot 0.5 \cdot \min(\bar{t}_{curr}, \bar{t}_{targ}) \quad (1)$$

$$t_D = 0.5 \cdot \max(\bar{t}_{curr}, \bar{t}_{targ}) \quad (2)$$

$\bar{P}$: mean power demand of a state (current or target state)
$\bar{t}$: mean duration of a state (current or target state)
curr : current state of the regarded component / machine
targ : target state, initiated by a measure

The re-evaluation of the coolant lifting pump of a machine tool now shows a clear agreement between the adapted model and the measured values. In figure 1, the values for the two measures of the early start (fig. 1 left) and interruption (fig. 1 right) of the active state are shown. The dashed line shows the tuples of E_F and t_D at different points in time t_{exec} of the execution of the measure.

The assumption that the measures are carried out statistically at half the time of the respective initial state ($t_{exec} = 0.5 \cdot \bar{t}_{curr}$) must deviate from the general case in order to determine the line of modeled values.

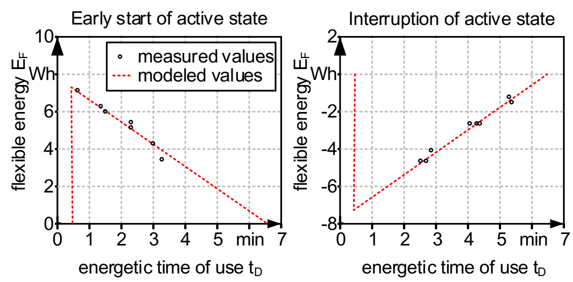

Fig. 1: Comparison of measured and modeled energy flexibility indicators.