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Keeping a factory in an energy-optimal state

Sylvia Wahren[a,b,]*, Eduardo Colangelo[a], Alexander Sauer[b,c], Jörg Mandel[b], Jörg Siegert[a]

[a]Institute of Industrial Manufacturing and Management IFF, University of Stuttgart, Nobenst. 12, Stuttgart, 70569, Germany
[b]Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Nobelst. 12, Stuttgart, 70569, Germany
[c]Institue for Energy Efficiency in Production EEP, University of Stuttgart, Nobelst. 12, Stuttgart, 70569, Germany

* Sylvia Wahren. Tel.: +49-711-970-1115; fax: +49-711-970-1002. *E-mail address:* syt@iff.uni-stuttgart.de

Abstract

The energy performance of individual machines and peripheral processes in a production system is, for the main part, not sufficiently known. The ECOMATION project aims at solving this problem by developing methods to measure and illustrate energy consumption and save energy in manufacturing processes. A holistic approach enables operators to continuously monitor a factory's energy consumption, based on two control loops: one at the shop floor level (including main processes and peripheral systems) and the other at the factory level, the two loops being interlinked in an additional step. The approach allows for the bidirectional exchange of data between the resources of both main process and peripheral processes and the higher management level. Classical approaches usually consider only the main process at machine level, even though a significant percentage of energy is required by the peripheral systems. The aim of the approach is to keep the manufacturing system in an energy-optimal state.

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1. Introduction

Rising energy prices and an increasing awareness of limited resources and their sustainable use prompts ever more manufacturing companies to strive for an energy-efficient production that, leads to lower costs [1]. An important issue in production organization is the energy-efficient planning and control of production, with a particular focus on machine scheduling [2]. Machine scheduling allocates production orders to available machines, considering quantitative and time restrictions. About 17% of the life cycle costs of a machine tool account for energy costs [3]. The annual energy consumption of cutting machine tools amounts to 150,000 kWh [4]. This shows that the energy-efficient control of machines should not be disregarded.

ECOMATION creates new opportunities for planning production, taking into account energy efficiency, and for intervening during production through control measures.

For a sustainable and energy-efficient production, a holistic approach across different layers and levels of the control hierarchy is compulsory. ECOMATION addresses the issue of planning and control on the following levels: factory control level (capturing the whole factory), machine level (capturing machines as a resource), electric component level (capturing single components in a machine) and process level (capturing single process steps, such as cutting). Only such a multilevel approach allows for identifying energy losses and addressing them by appropriate measures. As the goal is to control energy consumption in the manufacturing process and the process peripherals and to increase energy efficiency through automation, the project is called ECOMATION. The syllable "ECO" refers to economically and ecologically motivated efficiency, while "MATION" refers to enabling resource efficiency through automation

Control loops have been developed for the factory control level which enable, for example, an energy-efficient scheduling of machinery. For the lower levels (machine level, electric component level, and process level), specific control loops were developed which support an energy-efficient operation of machines. Taking into account the actual situation, such a control loop selects the ideal machine parameters and the operational state.

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The approach is designed to enable energy-efficient control across all indicated levels and within the hierarchy. By using consumption models at all levels, predictions can be made for an optimum control. The following article presents a holistic approach for different areas of production planning and control as well as for the machine level, which demonstrated by an operating state optimizer.

2. Initial situation and State of the Art

Current projects want to increase the efficiency of a single machine or process and provide an optimal design of process chains. They develop and implement concepts to support the manufacturing industry in the reduction of energy consumption. These approaches often inform only about consumption sources, including the temporal consumption structure. Factories, however, are complex systems. The "energy" factor takes various forms and energy is used in different areas of a factory. Energy can be produced (energy generation), has to be distributed, will be ‘consumed’, can be recovered, and is lost (energy losses). The focus here is on energy conversion and distribution in a factory. A major part of energy will be used by peripheral applications and processes in non-value added sectors [5]. Engelmann shows, in an example of car body manufacturing, that peripheral applications such as exhaust ventilation systems, lighting equipment, and air supply account for 50 percent of total energy consumption in the building. For this reason, it is imperative to take peripheral systems into account [5]. According to Schenk and Wirth [6], three levels of peripheral systems can be distinguished. This approach has been adopted by ECOMATION.

Müller also deals with the energy-efficient planning and operation of factories. He developed methods and checklists in the field of energy efficiency of factories, as well as management and target systems related to energy efficiency [7]. These universal methods can be partially applied to the specific problem. Müller focuses on energy-efficient factory planning and includes planning activities such as system analysis and system design. Another difference is that ECOMATION accomplishes the control of energy consumption through operations planning measures, an aspect not considered by Müller.

Production planning and control includes measures required for the production of an order, for instance by job planning [8]. Reinhart et al. selected different fields of action for production planning and control which result in a reduction of energy consumption. These fields are: energy-optimized sequence of production orders, selection of an energy-optimal resource (machine with minimal energy consumption), harmonization of energy consumption, accumulation of buffer and idle times, and definition of an energy-optimal batch size [9]. Production planning and control influences the energy performance of a factory (energy consumption) particularly by the selected resource and the determination of target time.

Also the use of software system for material flow simulation is a possible approach to verify energy-oriented goals in manufacturing systems [10]. One approach provides Putz et al. [11]. He developed a framework for energy-sensitive production control (manufacturing execution system) to support an energy-sensitive material flow simulation. This framework includes the enterprise control level, the manufacturing control level and the manufacturing level. The software solutions implemented in the afore-mentioned levels can contribute to a decreased energy utilisation.

As ECOMATION is complemented by a comprehensive methodology for energy-efficient operation, an actual operating optimum can be achieved. The approach allows the identification of efficient resources based on an optimal control of consumers. Subgoals are:

- detecting the energy consumption of processes, equipment and components,
- predicting energy consumption for various types and use cases,
- automated, situation- and requirement-oriented optimal control parameters and processes that have an impact on energy consumption based on energy control loops at machine level, as well as
- ensuring a company's energy efficiency by remote power control loops in planning and control.

3. Basic Methodology

3.1. General approach

To continuously control a factory and keep it in an energy-optimal state, the first thing to do was to create models of the main processes and the peripheral systems. Then, the modeled resources were linked to specific status-based energy profiles. For example the following machine conditions are possible: off, warm up, wait, work, error, save. Interfaces served to connect the models to the shop floor to allow their parameterization by the recorded field data. The model is connected ‘bottom-up’ to the management level. The superior management level records, for example, data on machine status, loading times and consumption. The basics and the implementation of the modeling approach are illustrated in [12]. Figure 1 shows the general approach, particular the planning and optimization logic.

First of all, the status available for each resource was used for modeling the resources and the energy demand was calculated for each status. An interface between shop floor and model allows for the integration of field data (energy consumption values). In addition, the times are defined, i.e. how long the status lasts and when it occurs. This information can be derived from the standard times set out by operations planning.

With a view to the shop floor, i.e. the manufacturing resources, several optimizers for the manufacturing processes and the machine components were developed to control the machines and the machine components in an energy-optimal manner. These optimizers are united in the so-called machine-level control-loop.