RFID Integrated Adaption of Manufacturing Execution Systems for Energy Efficient Production

Rolf Steinhilper, Stefan Freiberger, Frank Kübler, and Johannes Böhner

Fraunhofer Project Group Process Innovation at the Chair of Manufacturing and Remanufacturing Technology,
Bayreuth University, Germany

Abstract

An emerging challenge for manufacturing companies is to increase the energy efficiency of their manufacturing systems in order to reduce both energy costs and overall environmental impact. Modern manufacturing execution systems must cope with the new requirements of sustainable manufacturing in addition to the conventional focus on production management. This approach shows how the digital network of manufacturing execution systems can be used to eliminate non-value adding energy consumption in the manufacturing system. Therefore, an integrated use of workstation-related information from production schedules as well as the availability of product, operator and manufacturing equipment was developed. In particular, the advantages of the radio frequency identification technology is considered, as a decentralized information source for the manufacturing execution system for product and operator induced idle and stand-by times of production machinery.

Keywords:

Energy management and efficiency; manufacturing execution system; RFID

1 INTRODUCTION

This day's resource and energy efficiency is a key-driver for innovations in technologies and products [1]. This fact is becoming increasingly important since customers are aware of the ecological impact of their machinery in the utilization phase during the product life cycle. Furthermore the European legislation already forces manufacturers to increase the energy efficiency of their products as well as the reduction of the energy consumption during the manufacturing process [2]. Upcoming technical standards and rising energy costs indicate that in future manufacturing systems and their machinery have to be reengineered to increase energy efficiency in manufacturing [3].

Especially manufacturing companies are characterized by a high consumption of energy and resources, as well as by a causing, heterogeneous plant structure. Consequently, companies have to face the challenge of controlling the continuously weight gaining proportion of energy costs of product manufacturing. This pushes for appropriate energy efficiency related reengineering measures on manufacturing equipment. Furthermore, companies have to cope with the practical issue of identifying the right equipment for energy-efficient optimization among the existing manufacturing system and to develop economically viable solutions [4].

In parallel to the activities of energy efficiency improvement, a trend for information technology (IT) oriented manufacturing equipment reengineering, like controlling migration, i.e. replacing or supplementing existing control technology by current, state of the art systems, prevails in manufacturing companies. Through the informational system integration via industrial digital networks, such as industrial Ethernet, almost all systems can be linked to modern production management software. The enabled virtual integration of manufacturing equipment extrapolate especially unused rationalization reserves through accelerated provision of information, process data recording, calculation of key performance indicators and the subsequent data analysis for continuous improvement activities [5].

This paper presents an approach on how to use existing IT company infrastructure and the horizontal and vertical information availability to establish an energy management system for the shop floor. For this purpose the architecture for an energy efficiency module within Manufacturing Execution Systems (MES) is introduced to improve resources and energy consumption situation of the manufacturing system. Through the use of wireless RFID (Radio Frequency Identification) systems, required information signals can be developed in manufacturing, which extend the scope of the system and increase their impact.

2 ENERGY CONSUMPTION AND PRODUCTIVITY

2.1 Characteristic Energy Consumption of Manufacturing Equipment

The energy consumption of manufacturing equipment during the utilization phase is based on different operating states in compliance to ISO 14955 [6]. Figure 1 shows the schematic profile of the overall energy consumption of manufacturing equipment taking into account four different operating states. A further differentiation in value adding processes, e.g. like the actual processing operation, and not value adding processes, e.g. the work piece handling task, is derived.

According to the ISO-standard a machine consist of the following component groups, which are separately analyzed according their energy consumption: Peripheral units, machine control, machine processing unit and machine motion unit. The group elements of peripheral units include the following components like units for machine cooling, process cooling, work piece and tool handling, recyclables and waste handling.

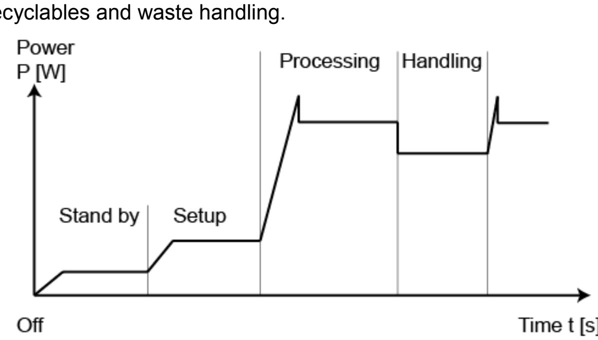

Figure 1: Schematic power profile of discrete manufacturing process.

Machine processing units are e.g. main spindle of a turning machine, tool spindle of a machining centre, slide of a press, draw cushions of a press machine. Motion units are e.g. linear axes of a turning machine, linear and rotary axes of a machining centre, mechanical, electrical, hydraulic, or pneumatic device of a machine tool, or a combination thereof.

In compliance to the ISO-standard, table 1 shows an application of the system using a metal-cutting machine tool. The matrix includes a recommendation of the component activity regarding the operation state condition and a further subdivision in value and not value adding tasks.

Operation state / Component	Off / not value adding	Setup / not value adding	Stand by with peripheral units on / not value adding	Ready for operation and idle / not value adding	Processing / value adding
Mains	Off	On	On	On	On
Machine control (PLC)	Off	On	On	On	On
Peripheral unit (cooling system)	Off	On	On	On	On
Machine processing unit (main spindle)	Off	On no machining	Off	Hold	On, machining
Machine motion unit (rotary axis)	Off	On	Off	Hold	On

Table 1: Machine state and component matrix.

This structure allows a consumption-based analysis of energy input of individual manufacturing equipment and serves as a starting point for component-related measures of reengineering.

For evaluating the energy efficiency of an entire system in discrete manufacturing, the equation listed in Formula 1 is used [7]. It indicates how much energy for the product manufacturing is needed.

$$E_{eff} = \frac{Processed\ piece}{Energy\ input} \tag{1}$$

Recent studies show that a remarkable proportion of the total energy consumption of manufacturing equipment is caused during non-value-added machine states like idle and stand by [8]. These consumers are often process-independent peripheral components such as the cooling system and material or chip conveyor [9]. The actually required energy consumption for machining on factory level represents 12 % compared to the total power [10].

2.2 Productivity of Manufacturing Equipment

The productivity of manufacturing equipment is defined as the ratio of produced parts to the related time of production [11].

$$Productivity = \frac{Processed\ pieces\ per\ period}{\text{Operation time per period}} \tag{2}$$

The effectiveness of manufacturing equipment is reflected in ensuring the required availability and its optimal utilization and an optimum in the use of resources and energy.

In practice the equipment productivity, enabled by the energy consumption described in section 2.1, is limited by several factors. Losses in the productivity are possibly connected with the machinery itself, caused by technical malfunctions or in correlation with organizational disturbances like failures in the production order schedule or material shortages. Both are resulting in equipment downtimes [12]. The connection between the technical feasible productivity and the actual produced quantity of parts is shown schematically in figure 2. The typical progress of productivity increases continuously during ramp-up until the manufacturing equipment reaches its predetermined value. During downtimes the productivity goes back to zero.

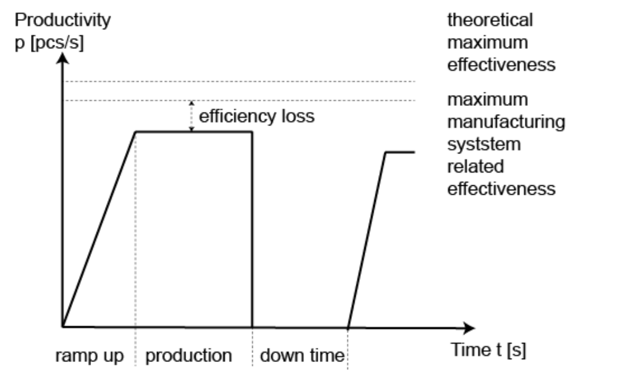

Figure 2: Schematic productivity profile of a discrete manufacturing process.

Besides the aim of increasing energy efficiency of manufacturing equipment the effort considering an increased effectiveness as well as the reduction of technical and organizational losses in efficiency are dominating the measures of reengineering [5].

3 FRAMEWORK FOR THE MES INTEGRATED ENERGY EFFICIENCY OPTIMISATION

3.1 Initial Power and Productivity Profile Analysis

To evaluate the applicability related control measures for reducing not value adding energy demand, a simultaneous analysis of both power consumption as well as the associated manufacturing equipment productivity is performed as shown in Figure 3.

Therefore two assessment criteria Q_1 and Q_2 are established which evaluate the energetic behavior of each component j with respect to prioritize the non-value adding operation states i. Initially, the condition Q_1 is checked. It indicates whether in a downtime of the equipment a power consumption of the analyzed system component j is present.

$$Q_{1_{i,j}}: p_{(t1)} = 0 \wedge P_{i(t_1)} > 0 \tag{3}$$

If condition Q_1 is valid for the component j, the indicator Q_2 will be assessed subsequently. Q_2 describes the ratio of the average energy consumption of a non value adding operation state of the component j to the average energy consumption during a processing operation.

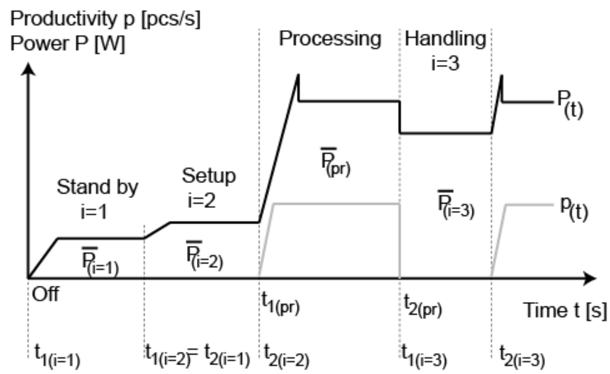

Figure 3: Productivity and power profile analysis.

$$Q_{2_{i,j}}: \frac{\overline{P_i} = \frac{1}{t2(i) - t1(i)} \int_{t1(i)}^{t2(i)} P_{(t)_i} dt}{\overline{P_{pr}} = \frac{1}{t2(pr) - t1(pr)} \int_{t1(pr)}^{t2(pr)} P_{(t)_{pr}} dt} \quad (4)$$

To ensure the comparability, the value Q_2 is normalized to the range [0, 1]. If the value of the criteria Q_2 approaches 1, the difference between the average energy consumption during the value adding process and the average energy consumption of related non-value added states i is high. This indicates a high potential for optimization and thus a high priority based on the underlying condition before.

However, if Q_2 is close to 0, the difference between the average energy consumption during the production process and the average energy consumption of related non-value added states i is low. This indicates a modest potential for optimization and thus a low priority based on the underlying condition before.

The assessment factors Q_1 and Q_2 serve as decision support criteria for the selection of the components with high efficiency potential.

3.2 Architecture of the Energy Efficiency Module

A Manufacturing execution system (MES) is defined as a shop floor control system which includes either manual or automatic labor and production reporting as well as online inquiries and links to tasks that take place on the production floor [5]. MES creates a vertical integration of information by connecting manufacturing equipment with its sensor-based process data at the lowest hierarchical level all the way up to the business divisions and their ERP systems. Figure 4 shows the MES embedded IT infrastructure. The horizontal integration of information is the exchange of data at the manufacturing equipment level. This data is transmitted via the related digital shop-floor network, which is also connected to the MES [13].

The implementation of the described approach increases the energy efficiency based on immediate real-time control of electrical manufacturing equipment including the equipment's components connected to the MES. The control consists of a unit to turn a device or process on or off and for more complex processes, advanced multivariable control functions are applied.

Since a large proportion of the energy consumption of production equipment is connected with non value adding operating states, e.g. product handling, relevant conditions, which exclude a value adding operation, will be evaluated in a logical interpreter unit.

Therefore a centralized information deployment in relation to the operation state-specific energy consumptions and the differentiation in value adding processes is established. In general, a work station with manually operated manufacturing equipment cannot be in the value adding operation state if one of the conditions listed in Table 2 (A, B, C, D or E) is present. If the system is part of a manufacturing line and depending on other equipment, the available information provided through horizontal integration about the equipment connected before and after is included as additional conditions into the interpretation process.

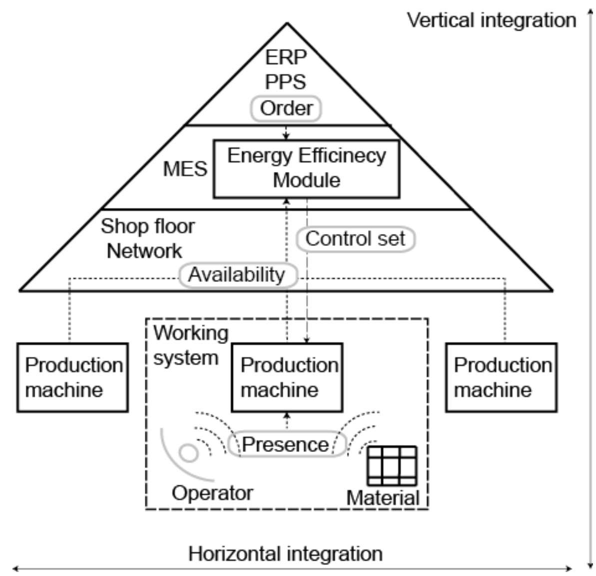

Figure 4: Energy efficiency MES Module.

The information on the conditions A, B and E can be achieved as an integral part of MES and must not be additionally provided. While the presence information of the machine operator and the material or work piece has to be taken additionally to the System.

Condition	Information source
A: No production order	PPS; vertical integration
B: Machine down time (planned or unplanned)	Machine control; vertical integration
C: No operator present	Presence; RFID
D: No material or work piece present	Presence; RFID
E: No availability of connected production equipment	Machine control; horizontal integration

Table 2: Conditions and related information source.

In this context the following logical condition will be checked by the MES energy efficiency module:

$$IF \quad A \vee B \vee C \vee D \vee E \quad THEN \quad \overline{Production} \quad (5)$$

According to the interpretation the second step of the energy efficiency module is preceded immediately. This includes an energy-oriented control of the connected manufacturing equipment and their individual components in form of customized control functions $\mathrm{f_i}$.

The control function will be individually adapted to the triggering condition A, B, C, D or E to specifically regulate the equipment components or to fully switch them on and off. The selection of control measures will be individually set up for each component in order to obtain no influence on plant productivity.

To keep the implementation effort for the control functions manageable a pre selection of relevant components considering the criteria $Q_{1_{i,j}}$ and $Q_{2_{i,j}}$ is recommended.

For forwarding of control commands to individual manufacturing equipment control the system makes use of the Object Linking and Embedding for Process Control (OPC) standard.

3.3 Presence Detection and Information Generation through the Use of RFID

In order to generate information signals depending on the presence of a machine operator (condition C) or the absence of material (condition D), RFID systems can be applied. RFID systems use radio waves to identify items or people automatically. These systems consist of RFID tag and a transceiver. The latter emits a field of electromagnetic waves by an antenna, which is absorbed by the tag. The absorbed energy is used to power the tag's microchip. A signal including the tag identification number is sent back to the reader. Those passive RFID tags work on the basis that they absorb the power from the reader and use this to empower the microchip and re-emit a signal. Active tags contain a battery, which powers the chip and transmits to the reader [14].

RFID is an automatic identification technology which is already used in the supply chain of many companies but is also gradually applied to the core of manufacturing processes [15]. By adopting the technology on the shop floor, the exact real-time presence information that is obtained from RFID systems, can be integrated seamlessly into the energy efficiency module of the manufacturing execution system [16]. In particular, the electromagnetic field of a 13.56 MHz system with passive RFID tags will be used for the presence detection. Depending on the antenna and the production environment these systems can achieve a reading distance up to 7 meter. This fits the specifications for the work station.

In order to generate the information for the energy efficiency module the machine operator as well as the used material respectively the work piece conveyor have to be equipped with a transponder. The reading device for this transponder has to be positioned close to the related production machinery. By means of the electromagnetic field (generated by the antenna of the reading device) a presence area around the work system is created. If the transponder enters this area, a signal is generated by the reading device. The presence area size depends on the response field strength. The response field strength is the minimal value, at the maximum distance between transponder and reading device, when the supply voltage is still enough to power the transponder. The supply voltage has to be adjusted depending on the production environment to reduce interference. The switching limit respectively the response field strength is set by the reading device [14].

The information about presence of a machine operator or the absence of material, acquired with the RFID system is sent through the equipment MES interface via the network infrastructure to the energy efficiency module and can be used for the condition interpretation described in section 3.1.

4 ASSESSMENT OF THE ENERGY SAVING POTENTIAL OF AN INDUSTRIAL CLEANING MACHINE

The initial power and productivity analysis and the derivation of the achievable savings potential were carried out on industrial cleaning equipment. The system includes a washing process by the three cleaning steps, spraying, flooding and ultrasonic adding up to a total nominal power of 91 kW.

For measurement of the electrical consumption of selected components in the various operating states, a data acquisition system with single-ended analog input, and a sampling rate of 10 ms per channel was applied.

The analog current signals were generated by inductive current sensors. The used devices are in the measuring range of 10, 25, 50, 75 ampere. The voltage was recorded via a conventional voltage divider. To determine the component-based energy consumption, the energy data was recorded by the following system components with the specified sensors:

1: Ultrasonic cleaning device, nominal power: 2 kW; Sensor: 10 A

2: Cleaner treatment, nominal power: 1 kW; Sensor: 10 A

3: Vacuum pump, nominal power: 2.5 kW; Sensor: 10 A

4: Heating, nominal power: 9 kW; Sensor 50 A

5: Hot air heating, nominal power: 20 kW; Sensor: 75 A

6: Flood-injection pump1; nominal power: 3 kW; Sensor: 10 A

7: Flood-injection pump2; nominal power: 3 kW; Sensor: 10 A

8: Flood-injection pump3; nominal power: 7.5 kW, Sensor: 50 A

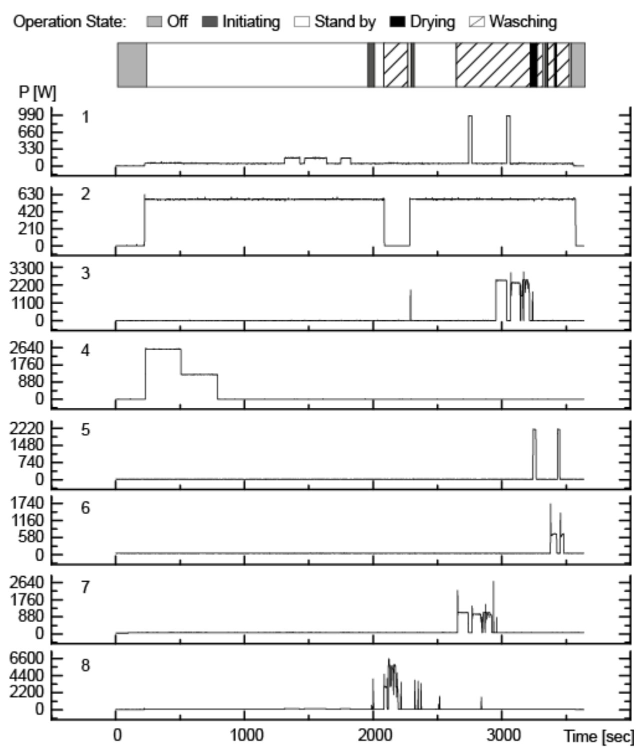

Figure 6: Component related energy consumption of an industrial cleaning machine.

Component \ Operation state	Off / not value adding	Initiating / not value adding	Stand by / not value adding	Drying / not value adding	Washing / value adding
					Q1
1: Q2	0,01	0,09	0,12	0,09	1
2: Q2	0,04	0,99	0,99	1,00	1
3: Q2	0,08	0,08	0,08	0,41	1
4: Q2	0,01	0,01	0,01	0,01	1
5: Q2	0,03	0,03	0,03	0,78	1
6: Q2	0,02	0,06	0,02	0,60	1
7: Q2	0,02	0,14	0,14	0,14	1
8: Q2	0,08	0,16	0,20	0,15	1

Table 3: Analysis results.

The component related energy consumptions as shown in Figure 6 are used to determine the quality criteria Q_1 and Q_2 introduced in Section 3.1. In this application, the washing process is defined as the value adding operation due to the fact, that this step fulfills the requirements of the customer and increases the rewarded product value. All other operation states are defined as not value adding. The determined values for the quality criteria are shown in table 3.

Then, for each component their control function f_i was defined. The achievable relative energy savings, based on the total energy consumption of the system was calculated.

For the considered components a resulting total stand by energy saving potential of 60 % can be achieved by implementing the MES module and the selective component control. The control conditions for the stand by state are: 1: turn off; 2: power reduction up to 50 % according used cleaning media; 3: turn off; 4: power reduction to 50 %; 5: turn off; 6: turn off; 7: turn off; 8: turn off. To avoid extending the response time from stand by state to washing, the heating and cleaner treatment is not fully turned off.

In this use case, the RFID transponder can be attached to the cleaning basket. This requires a special transponder type resistant to temperature and chemical- cleaning agents.

5 CONLUSION AND FUTURE WORKS

The developed procedure represents an approach to use the MES related IT infrastructure of manufacturing companies for a continuative reduction of non value adding energy consumption of connected manufacturing machinery. Furthermore the effectiveness of the system can be increased by integrating RFID technology as a related decentralized presence information source. Therefore this work supports manufacturing companies to increase their energy efficiency with manageable efforts. The introduced machinery analysis based on the energy demand in different operation states, indicates the effectiveness which can be achieved by connecting it to the system.

A first practical check of the potential energy savings on an industrial cleaning machine showed that at least 60 % of the non value adding energy consumption during the stand by state can be avoided by connecting the machine to the introduced MES energy module.

A next step is to improve the performance of the interpretation and control system of the MES energy module by integrating knowledge based decision making system. The task of this system is to predict the duration and impact of the non value adding operation states regarding the available information sources. For instance such a system extension would support to classify machine break downs based on the interpretation whether it’s a serious failure like a bearing damage or just an inadvertently checked photoelectric barrier. The MES energy module can individually decide which energy mode should be initiated with respect to the machine availability both on the broke down equipment and all inter-connected machines.

Finally the implementation of the procedure in further use cases will additionally optimize the procedure especially regarding its portability and significance on various manufacturing processes.

6 ACKNOWLEDGMENTS

The presented research work is partially financed by the Bavarian Ministry for Economic Affairs, Transport and Technology as a supporter of the project Green Factory Bavaria and the German Federal Ministry of Education and Research (BMBF). The research and development project MINMISE – Minimierung nicht wertschöpfender Energieaufwände durch energetische Anlagenoptimierung in KMU is funded by the German Federal Ministry of Education and Research (BMBF) within the Funding Action “SME – Innovative: Resources and Energy Efficiency” (funding number 02PK2266 – 02PK2269) and managed by the Project Management Agency Karlsruhe (PTKA). The author is responsible for the contents of this publication.”

7 REFERENCES

[1] Lang-Koetz, C.; Pastewski, N.; Schimpf, S.; Heubach, D. (2010): Resource efficiency as a key-driver for technology and innovation management: Dealing with an emerging trend in technology intelligence, in: International journal of technology intelligence and planning 6, No.2, pp.164-184.

[2] European Union (2009): Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products.

[3] Steinhilper, R.; Slawik, S.; Pentzlin, F.; Boehner, J. (2011): Increasing energy efficiency by remanufacturing and reengineering, in: Proceedings of Eco Design 2011 International Symposium, Kyoto, Japan, pp.206-212.

[4] Steinhilper, R.; Freiberger, S.; Kübler, F.; Boehner, J. (2012): Development of a Procedure for Energy Efficiency Evaluation and Improvement of Production Machinery, in: Leveraging Technology for a Sustainable World: Proceedings of the 19th CIRP Conference on Life Cycle Engineering, Dornfeld, D. A. and Linke, S. B. (eds.), Berkeley, USA, pp. 341-346.

[5] Cottyn, J.; Landeghem, H.; Stockman, K.; Derammelaere, S. (2009): A Method to Align a Manufacturing Execution System with Lean objectives, in: International Conference on Production Research, Wang, G. and Wong, T. (eds.), Shanghai, China, pp. 211-217.

[6] Objectives ISO 14955-1 (2011): Design methodology for energy-efficient machine tools, working draft commented, comments discussed, committee draft until 2011-05-15.

[7] Thiede, S. (2012): Energy Efficiency in Manufacturing Systems, in: Sustainable Production, Life Cycle Engineering and Management, Herrmann, C., Kara, S. (eds.), Berlin, Germany.

[8] Linke, B.; Overcash, M. (2012): Life Cycle Analysis of Grinding, in: Leveraging Technology for a Sustainable World: Proceedings of the 19th CIRP Conference on Life Cycle Engineering, Dornfeld, D. A. and Linke, S. B. (eds.), Berkeley, USA, pp. 293-298.

[9] Brecher, C.; Bäumler, S.; Jasper, D.; Triebs, J. (2012): Energy Efficient Cooling Systems for Machine Tools, in: Leveraging Technology for a Sustainable World: Proceedings of the 19th CIRP Conference on Life Cycle Engineering, Dornfeld, D. A. and Linke, S. B. (eds.), Berkeley, USA, pp. 239-244.

[10] Quilligan, F.; Upton, C. (2012): Visual Decision Support for Energy Aware Production Planning, in: Towards Implenting Sustainable Manufacturing: Proceedings of the 10th Global Conference on Sustainable Manufacturing, Seliger, G. and Kiliç S. E. (eds.), Istanbul, Turkey, pp. 453-458.

[11] Zandin K., Kjell B., (2001): Maynard's Industrial Engineering Handbook.

[12] Garcia, M.; Santos, J.; Arcelus, M.; Viles, E. (2011): A Framework Based on EWW and Wireless Technology for Improving Overall Manufacturing Operations, in: Proceedings of the International Conference on Advances in Production Management Systems, Stavanger, Norway, pp. 132-139.

[13] VDI, Richtlinie 5600 (2007): Manufacturing Execution Systems, Beuth Verlag, Berlin.

[14] Keskilammi, M.; Sydänheimo, L.; Kivikoski, M. (2003): Radio Frequency Technology for Automated Manufacturing and Logistics Control. Part 1: Passive RFID Systems and the Effects of Antenna Parameters on Operational Distance, in: International Journal of Advanced manufacturing Technology, pp. 769-774.

[15] Dirk H. (2004): Mapping and localization with RFID technology, in: Proceedings of the 2004 IEEE International Conference on Robotics & Automation, New Orleans, USA, pp. 1015-1020.

[16] Jiwei, H.; Hexu, S.; Tao, L.; Zhaoming, L. (2008): The Design of Manufacturing Execution System Based On RFID, in: Power Electronics and Intelligent Transportation System, pp. 8-11.