THE APPROACHES OF ADVANCED INDUSTRIAL ENGINEERING IN ENERGY EFFICIENCT MANUFACTURING

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This paper deals with new approaches to the development trends in the advanced industrial engineering (AIE) in energy efficient manufacturing. This integration represents a sustainable development so that more effective use of natural and energy resources are achieved and energy costs are reduced. The progress of energy efficiency improves the competitiveness of manufacturing enterprises and reduces the stress on environmental impacts of production processes. Technologies of advanced industrial engineering, new energy efficient technologies and energy efficiency standards are important for sustainability and competitiveness in production management. Energy and environment related research has contributed strongly to energy efficiency. There is also described ZIMS (Zilina intelligent manufacturing system) as a new, open and collaborative environment, supporting creativity, inventing new solutions, increasing energy efficiency and their practical implementation in the form of new innovative products.

KEYWORDS

energy efficient manufacturing, sustainable production, advanced industrial engineering, cost optimization

1 INTRODUCTION

Currently, energy efficient manufacturing will look across sectors and research programs to stimulate knowledge sharing, standardization, technologies, and actions in the thematic area for increasing energy efficiency. Investing for example in high-efficiency combined heat, power systems or technology of advance industrial engineering has the potential to save even more. In the world runs intensive research into factory of the future production system. The European Union (EU) has launched extensive research programs dedicated to factory of the future (FoF), intelligent manufacturing systems (IMS) and smart manufacturing. The aim of all these efforts is to develop a new production system using advanced technology, which will enable to satisfy demanding customer requirements in the future.

This paper is structured in the form of five main sections. The first section discusses the significant area of advanced industrial engineering in next generation manufacturing systems. Authors emphasize a new research and development platform for the development of Factory of the Future Production System, referred to as ZIMS (Zilina Intelligent Manufacturing System). The second section outlines definition of the problem statement of key priorities increasing energy efficiency. The following third section covers the description of key impacts, which can influence energy costs. Achieving higher end-use efficiency involves a great variety of technical options, because it has little visibility, or politicians, the media, or individuals looking for recognition and acknowledgement, therefore the fourth section discusses in turn the key priorities for information, communication technology enabled energy efficiency in manufacturing, and barriers of greater end-use efficiencies and future research in this area.

The main findings are then summarised in the conclusion. Response to the latest trends in the area of factory of the future production system is the emergence of new research platform, which was named ZIMS. New research and development platform was created in cooperation of CEIT, a. s., Slovakia (Central European Institute of Technology) spin off the University of Zilina, Technical University of Kosice, and technological and industrial partners. ZIMS responds to trends, in Europe are known as the Industry 4.0 [Bauernhansl 2014].

2 PROBLEM STATEMENT OF KEY PRIORITIES INCREASING ENERGY EFFICIENCY

Prof. Westkamper from the Fraunhofer Institute (Germany) developed within activities of the European Technology Platform ManuFuture - EU strategic developments that indicated as the advanced industrial engineering. Fraunhofer is Europe's largest application-oriented research organization. On factory side all sensors and control units are elements of the shops and generate informations around events. This can be called a smart factory. Real time information combined with histories and future (simulation) make it possible to realize a new generation of IT-driven factories and enterprises [Westkamper 2010]. ZIMS uses the most advanced technologies of advanced industrial engineering for the design, optimization and operation of factory of the future (FoF), especially in the area of: digital factory and digital engineering, virtual engineering, reverse engineering, digitization (3D laser scanning), rapid prototyping, virtual testing, computer simulation and emulation, etc. [Gregor 2010].

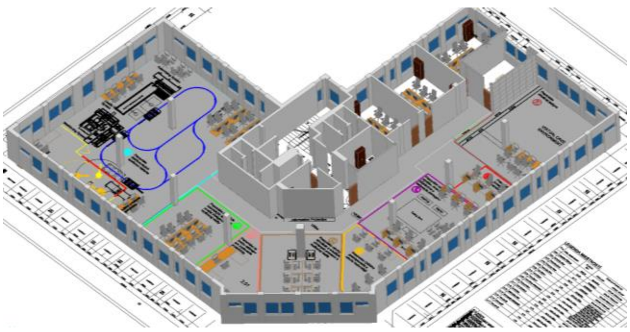

Figure 1. Layout of ZIMS (Zilina intelligent manufacturing system)

ZIMS, as a system is built in three different worlds: the real, the virtual and the digital, where their interface is created a new Cyber-Physical System (CPS) ensuring a direct integration of virtual, digital and real world. The layout of ZIMS is shown in Fig. 1.

Smart Factory – is built as an agile system that is able to adapt rapidly to changing customer requirements. Intelligent features, automation, and robotics, reconfiguration, automatic control, simulation and emulation technologies are used to create rapid change [Gregor 2008].
Virtual Factory – virtualization technology and data integration are used to represent the dynamics of real enterprise. Virtual factory represents cyber feature of real enterprise and virtual representation of all its elements. It uses data from sensors, actuators, video and audio information, biometric data, etc. In real time creates a virtual image of functioning of enterprise.

Digital Factory – digitalization and digital technologies are used to integration of all activities within product life cycle and production systems. Digitizing, modeling, simulation and emulation are used to understanding of comprehensive manufacturing processes and creation of new knowledge, which is used for optimization of real production systems. [Gregor 2015]. ZIMS also represents a pilot project of intelligent manufacturing systems, which is composed of workplaces that communicate with each other through holon [Marcan 2013]. Holons form comprehensive holarchy.

This section will explain how to setups for achievement energy efficiency in manufacturing, which are essential conditions for cost optimization. Analysis of problem statement results shows the following key priorities, which can influence increasing energy efficiency. These priority items should be prioritized:
- intelligent lightweight construction,
- multi-material design,
- intelligent energy management,
- miniaturisation of dimensions.

2.1 Intelligent lightweight construction
For example, there is an intelligent lightweight construction of new cars (see Fig. 2). Intelligent lightweight construction results in lower fuel requirements and higher performance. Depending on the model, especially lightweight materials are used for the individual parts that make up the body shell, for example, aluminium in the front end and chassis [Kohar 2014]. This saves an immense amount of weight while simultaneously guaranteeing extremely high stability and excellent passive safety. Light materials like aluminium, the most modern magnesium alloys and carbon-fibre reinforced plastic are used. Carbon-fibre reinforced plastic is a high-tech material that's particularly suited to vehicle manufacture – it's just as stable as steel, but about 50 % lighter.

Figure 2. Intelligent lightweight construction

2.2 Multi-material design
Different design strategies are possible depending on the situation.

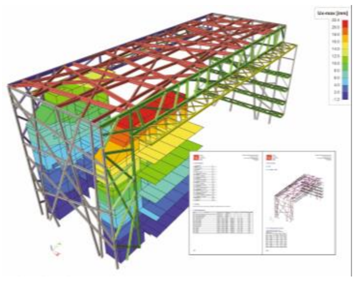

Figure 3. Multi-material design

The designer may develop a new material, he may adapt an existing material, or he may define a combination of materials. Examples of multi-material design are shown in Fig. 3.

2.3 Intelligent energy management
Tomorrow's energy efficient manufacturing will require additional processing power at all levels of its infrastructure. Most wireless sensor nodes presently powered by batteries:
- battery replacement is costly,
- self-powered sensors and actuators offer maintenance-free lifecycles and are environment-friendly [Rakyta 2014].

Alternative power sources are being developed:
- solar, vibration, rotation, temperature, organic material,
- may use a capacitor as a buffer when system not in use,
- low power technology complements these developments and provides low power intelligence [Magvasi 2013].

Integration of energy efficiency in manufacturing trough intelligent energy management is shown in Fig. 4.

Figure 4. Intelligent energy management

2.4 Miniaturisation of dimensions
Miniaturization of part (see Fig. 5) is a strong draw in many types of consumer products, but it can be taken too far. For example, mobile phones could be shrunk to the point where keypads and displays would be difficult to use [Slamkova 2010].

Increasingly, product designers are challenged to provide easy-to-use man-machine interfaces despite higher product complexity and shrinking control-panel real estate. Many electronic devices have already reached a near optimal form factor.

Future miniaturization will focus more and more on increasing a product's sophistication, performance, and market penetration [Krajcovic 2013].

Figure 5. Miniaturisation of dimensions

3 ANALYSIS OF KEY IMPACTS, WHICH INFLUENCE ENERGY COSTS

Realising cost-effective energy efficiency potentials will be beneficial not only for individual energy consumers, but also for the economy as a whole [Micietova 2014]. For example, saved energy costs can be used to produce energy-saving domestic goods and services. In following section of the paper are described key impacts, which can influence energy costs. Seven key impacts are listed here:

- remanufacturing technologies,
- intelligent engineering with specialised materials,
- implementation of new technologies - nanotechnologies,
- integration of functions - adaptronic, sensors, actors,
- reduced process chains - near net technologies, near net shape production,
- process capability - waste, scrap, defects,
- recycling technologies,
- reconfigurable enterprise (RE).

3.1 Remanufacturing technologies

The globalized economy is strongly influenced not only by economic cycles but also a rapid change in customer behavior, which result in turbulences [Gregor 2009]. The changes in human behavior are arising as a consequence [Dulina 2014]. Business community should continually find new ways to respond to these incentives. One of the effective solutions is the use of reconfigurable manufacturing systems (RMS).

Remanufacturing (see Fig. 6) is generally seen as the most environmentally friendly of end of life treatments for a retired product. If the remanufactured product can be considered a substitute for a new product, then a credit is usually claimed for the avoided resource use and emissions associated with the new product production.

The biggest savings is generally from the avoided new materials production, but the difference between new manufacturing and remanufacturing can also be significant [Koren 2011].
At the same time, remanufactured products generally sell for about 50-80% of the new product. Hence remanufacturing can be seen as a win-win; it saves money (for the consumer) and it saves the environment.

Figure 6. Remanufacturing technologies

The purpose of reconfigurable manufacturing systems is a rapid adjustment of production capacity and functionality with respect to quick response to generating circumstances. The main task of manufacturing system reconfigurability lies in hardware and software components changing [Micieta 2015]. Reconfigurable manufacturing systems are proposed (of several authors) as a solution to unpredictable fluctuations in market demand and market turbulence [Westkamper 2010].

An example of an innovative development using the latest Internet of things technologies is an autonomous logistics system developed in the framework of research ZIMS [Gregor 2011].

This system uses the logistics towing units Aurora, from the company CEIT (Central European Institute of Technology). These autonomous towing units were developed in the base of the requirements of the automotive industry, in cooperation with Volkswagen, Slovakia. The resulting solution is the Modular reconfigurable logistics system. As is shown in Fig. 7, the system uses automatic identification of towing units position, custom navigation, monitoring and control system, which is integrated to the production planning system.

Figure 7. Modular Reconfigurable Logistics System

3.2 Intelligent engineering with specialised materials

Intelligent engineering is focused on quality controlling, material properties evaluation as well as institutions is focused on progressive materials production (such as biomaterials, optic wires, micro electric elements, intelligent materials, etc.

3.3 Implementation of new technologies - nano, graphene

Graphene sheets could be used for touch screens (see Fig. 8), just like the ones currently used for credit card terminal signature pads. It's less brittle, less expensive, and performs better than the material currently used for signature pads.

Research and development of new technologies deal with several global workplace today. Most progress is made in the context of collaborative research of Intel (Jason Campbell - Intel Research Lab Pittsburgh) and Carnegie Mellon University (S. Goldstein, morwe TC) in the USA, who started about ten years ago. The aim of their research is to develop a computer chip as big as a grain of sand.

But maybe the most exciting new applications on the horizon for graphene take advantage of its inherent anti-bacterial property. It's super-light and allows a great deal of light to pass through it, so it could be incorporated into anti-bacterial bandages, clothing and other textiles that resist bacterial growth, and even food and live tissue packaging. It seems almost possible that graphene is poised to become the plastic of the future [Gajitz 2015]. Today's scientists and engineers are finding a wide variety of ways to deliberately make materials at the nanoscale to take advantage of their enhanced properties such as higher strength, lighter weight, increased control of light spectrum, and greater chemical reactivity than their larger-scale counterparts [Coliseum 2011].

Figure 8. Flexibler touchscreen and dynamic analysis and simulation of material

3.4 Integration of functions - adaptronic, sensors, actors

Adaptive structure technology, briefly called adaptronic, is an innovative, new cross sectional technology for the optimization of structure systems. The adaptive structure technology is based on functional integration by combining conventional structures with active material systems, which extend classical load-bearing and form-defining structure performance by including sensor and actuator functioning. In connection with suitable adaptive controller systems, adaptive structure systems can adapt to their respective operational environment optimally.

3.5 Reduced process chains - near net technologies, near net shape production

Near net shape production is concerned with the manufacture of components, whereby shaping is realized mostly by no chipping manufacturing techniques and finishing by cutting is reduce to a minimum. Near net shape manufacturing involves such objectives as reducing the number of process stages, minimizing costs, and guaranteeing enhanced product quality.

3.6 Process capability - waste, scrap, defects

By employing the statistical process control techniques, in an automated, real-time fashion, many of customers also report they are able to simultaneously:

- Increase product quality.
- Improve production capacity.
- Reduce product waste, scrap, etc.
- Enhance productivity.

The process, which involves waste for the production of energy, is named as waste-to-energy and energy-from-waste. This is a process, which recovers energy from the waste materials, and in which energy is gained through the process of combustion directly or sometimes fuel is produced from waste, which is the source for energy.

3.7 Recycling technologies

Recycling technologies provides innovative solutions to help producers achieve financial gains through turning mixed waste into a valuable resource. The specialized recycling machines (for examples discs screens separators, shredders, bag openers, glass cleanup systems, over belt magnets and eddy current separators) integrate and improve your recycling system needs. Recycling equipment can also be used for more specific applications such as recycling plastics, cardboard recycling and compactors for waste transfer station.

Reducing energy waste in manufacturing enterprises helps reduce manufacturing costs, and helps keep our industries competitive. But energy waste isn't as easy to identify and address as scrap material that can be swept off the manufacturing enterprise floor and repurposed. Many manufacturers simply don't see wasted energy, because they're not looking for it. Or, as is more often the case, they don't have knowledge or the means to address the problem.

3.8 Reconfigurable Enterprise

Rapid changes in customer requirements are manifested through new market opportunities in different regions, geographical areas or in the global space. A successful enterprise must be able to change their internal and external parameters, and to adapt to the rapid changes in the business world. If it is possible for reconfigurable production equipment to create reconfigurable production systems, the set of such production systems, accompanied by reconfigurable control software is allowed to create reconfigurable manufacturing enterprise (RE - Reconfigurable Enterprise).

Internal level of reconfigurable enterprise requires a new organizational structure, supporting business culture, fast communication system and cooperation with customers and suppliers.

On the external level, reconfigurable enterprise is the ability to form strategic alliances with other enterprises in order to gain a competitive advantage. When the market shifts usually enterprise cannot immediately change their skills. Strategic alliance improves the ability of the enterprise in a quick reconfiguration and accelerating response on market changes.

Professor Y. Koren from the University of Michigan identifies the following characteristics of reconfigurable manufacturing systems:

- Variability: The possibility of modifying of the manufacturing system in order to produce the proposed products.
- Modularity: Decomposition of the service functions in process units, which can be interchanged within alternative production programs.
- Integrability: Quick and transparent modules integration (mechanical, information and control interfaces).
- Customization: Design of the manufacturing system flexibility or machine around a specific product family.
- Scalability: Changes in the current production capacity by adding or removing of system components in order to increase current performance.
- Convertibility: Change in the current functionality of used components and control systems.
- Reusability: Re-use of modules in the system elements. System elements, which are ended the life due to excessive wear.
- Energy efficiency: Achieving of energy efficient p rocesses by interchanging of the system components and change the system performance.
- Environmental safety: Use of alternative energy sources for production [Koren 2010].

The advantages of reconfigurable production systems which offer to businesses are their ability to rapidly adapting to the new range of products, so-called ramp up time. Ramp up time is a period of time that a new reconfigurable production system needs to attain stable, planned production parameters, for example production volume, continuous production time, quality, etc. Reconfigurable manufacturing system supports the development of new hardware and software. Hardware is represented mainly by developments such production equipment which use the modular concept and offers new possibilities for rapid changes in their structure (configuration). Software development is represented by open control architecture (open architecture control).

4 RESULTS - KEY PRIORITIES FOR INFORMATION AND COMMUNICATION TECHNOLOGY ENABLED ENERGY EFFICIENCY IN MANUFACTURING

Result was identified to the significant barriers, primarily market imperfections that could be overcome by targeted policy instruments as prevent the realization of greater end-use efficiencies. These barriers of greater end-use efficiencies are shown in Fig. 9.

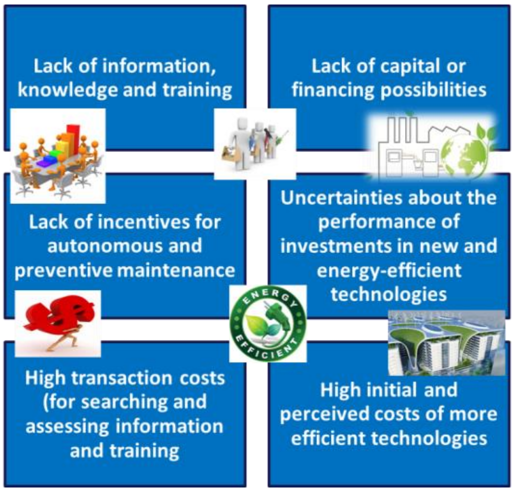

Figure 9. The barriers of greater end-use efficiencies

To gather a better understanding of the current state of research and gap analysis of research and technology development activities specific to information and communication technology usage for energy efficiency in manufacturing the study was realized. The main categories served as the basis for structuring the work within this study. These main categories were:

- Tools for energy efficient design and production management: performance estimation, modeling, production management, design.
- Tools and equipment for intelligent control: automation and control equipment, monitoring and diagnosis equipment, quality of service (best-effort services), wireless sensor networks.
- Energy management and energy standardization: standards of the country, energy policy, energy audit.
- ISO 50 001: 2011 Energy management system, Requirements with guidance for use - the purpose of this International Standard is to enable organizations to establish the systems and process necessary to improve energy performance, including energy efficiency, use and consumption. The purpose of this international standard is to enable organizations to establish the systems and processes necessary to improve energy performance, including energy efficiency, use and consumption. [ISO 50001 2011].
- User awareness & decision support: performance management, visualization of energy use, behavioral change, enterprise resource planning.
- Support of information and communication technology: technology of advanced industrial engineering (e.g. digital factory, virtual reality, augmented reality, automation), management execution system, artificial intelligence, intelligence control.

Key research challenges and priorities for information and communication technology enabled energy efficiency in manufacturing are presented for each of the main categories:

- process integration,
- system integration,
- process virtualization,
- interoperability,
- standardization,
- knowledge management.

In the next section will be described concept of energy efficiency oriented manufacturing. This concept includes four steps.

1. step: Energy planning and measurement (to set energy efficiency manufacturing metrics, planning and benchmarks).

2. step: Energy implementation and control (monitoring and control of energy efficiency in manufacturing are important for energy management because more integration with systems using real-time data for operational monitoring and facilitating strategic decisions regarding energy efficiency and production line performance system to monitor energy consumption, or automation systems should include software to monitor processes and energy consumption).

3. step: Reconfiguration of energy system (from the perspective of sustainability, the relevant objectives of reconfigurable manufacturing systems are:

- to reduce the wastes through the reuse of manufacturing resources,

– to reduce energy cost through the optimization of manufacturing processes and system reconfiguration.

4. step: Checking and improvement (the results of implementation of this new concept of energy efficiency oriented manufacturing will lead to future research plans. There is a need to search for opportunities, not only in undertaking energy saving technical actions, but also in introducing of reconfiguration of system requirements.

4.1 The key options for energy management positioning

Energy saving positioning determines energy policy of the enterprise. We can identify three options for energy saving positioning in the industrial enterprises:

– a way to solve particular problems of power supply service. Such positioning implies that energy conservation goals to provide solution to the problems related to rectifying defects in industry's power supply service. It can result in lowering industry's energy consumption, reduction in energy consumption associated with production of certain types of goods, etc.,
– a way to increase the industry's performance in investment development programs. Energy conservation in that case is regarded as one of many business lines to increase the industry's performance, together with delivering production technology innovation, upgrading operating machinery, adapting advanced materials, etc. The effect of energy saving declares itself in growing production and commercial performance of the enterprise,
– a way to solve strategic problems of corporate development. Energy saving and efficiency is considered as a strategic direction to increase competitiveness of the enterprise. Therefore, successful task solution in this field exercises a dominant influence on the corporate strategic targets. The requests for initialization of energy management activities are listed in Table 1.

Possible positions of energy efficiency in an industry	**1. To solve certain power supply problems**	**2. To improve enterprise efficiency**	**3. To address enterprise strategic issues**
Methods	Brainstorming ishikawa diagram, affinity diagram, etc	Method of advanced industrial engineering , virtual reality, digital factory, etc	Swot analysis, PEST analysis, project management, etc.
Result assessment	Rectify defects identified in enterprise energy supply, optimize energy saving	Increase production and economic performance Boost financial and economic indicators of enterprise	Meet the shareholders demands and achieve enterprise strategic aims
Period of changes	Short-term	Medium-term	Long-term
Funding of expenses	External and internal sources, project payoff period equals 1-2 years	External or internal sources, project payoff period is up to 6 years	External or internal sources, project payoff period is up to 10 years
Control techniques	Project paperwork	Program control (set of projects)	Strategic management
Scope of variation the expectation	Rather narrow/ clearly defined range	Rather wide/ varies according to expectations	Global/ varies according to expectations

Table 1. Key option for energy management positioning

5 CONCLUSIONS

This paper presents study of key priorities for information and communication technology enabled energy efficiency in sustainable manufacturing in sustainable production and description of key impacts and priorities, which can influence energy costs. Therefore, new methods, tools and technologies for increasing energy efficiency in manufacturing are still in the process of development. Further research intends to specify the concept and to develop a demonstrator for using these methods by next case studies. In further research, results should be transferred into industrial practice. The aim of the research is to determine visions, key research topics, barriers, impacts, key business scenarios and priorities, which can influence energy costs with low associated investment costs. New sources of productivity growth in the following stages of development will be certainly artificial Intelligence (AI), application of knowledge-based systems and intelligent holonic solutions. Nowadays, behind closed doors of research laboratories runs stormy and secret research on humanoid robots that take over the entire service area in the production factory. Already in the 18th century designed by Elli Whitney principle of modular construction products. Modularity is gradually transferred to the area of tools, machines, production lines and production systems. Enterprises are developed modular. Tools and technologies of digital factory are provided support for designing modular enterprise that integrates global business space, way of plug and work. Thus complicated and sophisticated systems require entirely new approaches to their design and testing. Advanced industrial engineering is focused on three main subgroups:

– industrial networks,
– adaptive production,
– digital engineering [Micieta 2014].

What has been done by the University of Zilina, Faculty of Mechanical Engineering, Department of industrial engineering (KPI) for the issue of development of Advanced industrial engineering? KPI in cooperation with partners works on:

– implementation of targeted networking research and development potential for the development of national technology platform Manufuture – CEIT (Central European Institute of technology),
– solving complex research projects of the basic and applied research and development carried out extensive cooperation with industry. Within the research activities is developed own concept of Zilina intelligent manufacturing system (ZIMS),
– systematically education and trainings of specialists in the field of advanced industrial engineering (AIE) – is developed own concept of Learning university,

- creating own concept of Digital Factory - Zilina (support of industrial development).

The ambition of future research work and project is to design and develop a new practical concept of reconfigurable logistics system and on its prototype check the possibilities of its putting in the automotive and electronics in industry.

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