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Review Article

RMS – SYSTEM OF THE FUTURE OR NEW TREND IN SCIENCE?

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ABSTRACT
Manufacturing companies in the 21st century will face unpredictable, high-frequency market changes, driven by global competition. The article presents a new concept of manufacturing systems – which address these challenges - known as Reconfigurable Manufacturing Systems (RMS). The concept began in 1999 at University of Michigan and is widely developed in many scientific publications. The paper first analyses main features of RSP. The next sections are devoted to analyze basic assumptions of RMS design and technical measures of RMS. Finally, the answer for the question if the RMS has the perspective of wide industrial implementations is discussed.

Keywords: reconfigurable manufacturing system, RMS, reconfigurability, flexibility.

INTRODUCTION

Frequent changes in the market, driven by global competition make production companies face new challenges and problems whose solutions must be cost efficient in cost and productivity [3, 8]. Aggressive competition forces adaptation to these requirements by new solutions that meet searching expectations of buyers and government regulation and legislation. High frequency of launching new products, changing production volumes and demand fluctuations are the most frequent problems that 21°C. companies face. To do this and to keep the pace of technological, economic and social changes, which have a significant impact on the progress in the organization of production, the company must react in a cost-effective, efficient and fast way [9]. A trend that emerged in modern production systems solutions shown in Table 1.

As shown in Table 1 striving for improvements in the organization of production is progressing in the direction in which the existing solutions are no longer sufficient and adequate. There is a need, which is characterized by J. Honczarenko, who wrote: "*Produce in a flexible, but in the simplest possible way and at the best price*" [4]. The basis of savings is to reduce the time needed to design, build or reconfigure production system to a minimum until its start-up and a high quality of production will be achieved. Today, lead-time becomes a bottleneck, the area reduc-

Table 1. The modern trend of development and changes of the production strategy of enterprises (own study on the basis of [4])

Present condition	Trend of development
• Priority productivity at the lowest possible level of the costs of production.	• Priority smooth flow of materials.
• The total dependency on access to a range of machinery and equipment.	• Dependency on the range of products.
• Control according to production plans.	• Control according to customer orders.
• Production of economically viable parties.	• Production takes into account the needs of customers.

ing the speed of production, from which earned income and market success of the product depends on to large extent.

As a response to emerging issues of efficiency and full use of technical resources in the production system, in 1999 at University of Michigan (United States), the concept of reconfigurable manufacturing systems (RMS) implemented was [6, 10]. RMS combines the advantages of existing, conventional production systems. The objectives set by engineers at the University of Michigan was:

- maximal reduction of the time which is needed to launch the production of a new product in the system,
- minimization of the costs associated with the design of the production system adapted to the production of a new product,
- eliminate the costs associated with excessive levels of system flexibility.

The purpose of this objective has set a framework for a new system and fully allowed to define this new paradigm. Namely, the RMS Reconfigurable Manufacturing System means the production system designed for functionality and customization for production capacity, for the tasks, arising from the changing needs of the market, by changing the structure of the system, both in terms of production equipment, and software. The system is defined as the evolutionary continuation of the existing solutions and an attempt to achieve the set objectives. Research conducted since 1999, as well as initial tests in the world, give satisfactory results, but further steps and improvements are needed.

CHARACTERISTICS OF RMS

The continuing evolution of science and technology in a natural way has led to the development of a new production system that is RMS. As already mentioned, it is the answer, and rather the exploration for recent years trend, developed according to market needs and revealing shortcomings of conventional production systems, particularly automated production lines and flexible manufacturing systems. As shown in Figure 1, RMS combines the advantages of both major systems (Dedicated Manufacturing Line – DML and Flexible Manufacturing System – FMS) into one cohesive production system.

Automatic lines (such as Dedicated Manufacturing Lines – DML) are characterized by high throughput and production of one type of products. This solution is very effective when demand for a particular offer is high and stable. Then, the rhythm and scheduled flow make them introduce to the market a large amount of one type of products that nourish it, while the level of demand is the same. In such a favorable situation DML, as referred, are cost effective, efficient and cheap (Figure 2). The problem arises when the offer ceases to have buyers or when demand falls to a level at which capacity ceases to be in full use. This situation is very common in the market, then the DML also face the need to reconfigure, which is a long and costly process. In addition, at the beginning and at the end of product life cycle demand for the product is not high enough, which makes automatic line working below its full capacity. Hence the problem of scalability of this system arises. The scalability cannot be attained

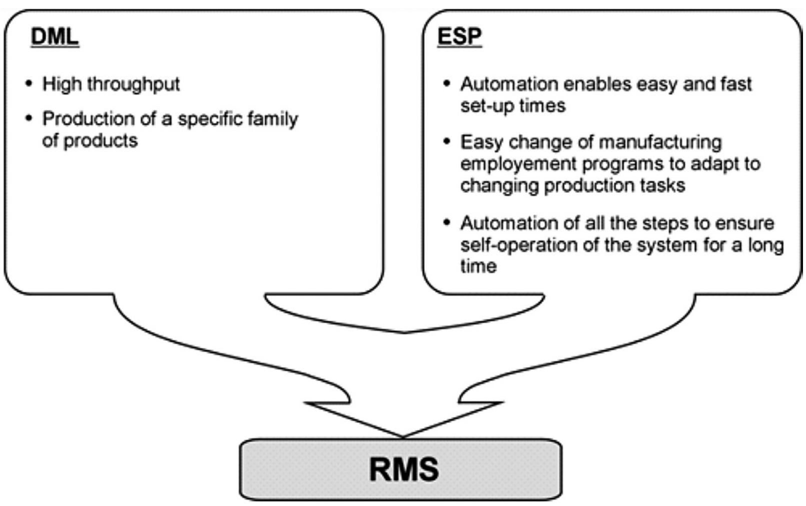

Fig. 1. Advantages of conventional manufacturing systems combined by the RMS

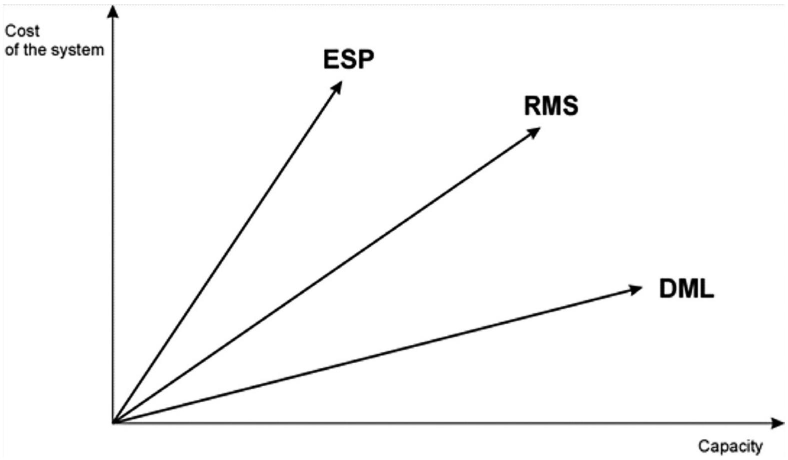

Fig. 2. The costs of RMS, FMS, DML compared with a production capacity (own study based on [3])

due to the machines suitable for the production of one type of products.

Scalability is achieved by the FMS system which is able to produce various kinds of products with variable and adjustable frequency. So it uses the work of multi-functional machines which, at the time of purchase, are suitable for diverse production and equipped with a set of spare parts and modules. However, due to general-purpose machine tools for FMS, its throughput is much lower, and the cost of plant and machinery does not always aligned to its profits. High costs cause many companies not to choose FMS, and even make the system be unaffordable for them. Therefore, it is relatively rare as a solution used in production.

The combination of the two systems, their main advantages, with non-performances elimination clarified certain characteristics to be met by the new system. Thus, the RMS is characterized by these six factors: diagnosability, scalability, convertibility, rationality, modularity, integrity [1, 2]:

- **Modularity** – means that the technical solution is designed and built with the prepared individual parts or assemblies, "*which as modules, [are] often different from each other with embodiments, reached by a combination of various general features of the system*" [4]. Modularity allows easily change of the structure, conservation of modules or their improvement. This solution reduces the cost and adapts the system to the market demand for product.
- **Integrity** – is the ability to quickly and efficiently integrate the modules into a cohesive system. It is possible by combining mechanical, computer and control connections of individual elements. The integrity at the machine-level considers the possibility of such a combination, which aims at shaping the machine according to the current need. The integrity of the system means development of the system, so that, the machinery, transport equipment and other items through appropriate drivers to operate efficiently as a whole.
- **Rationality** – means a strict focus on the flexibility, adapted to market needs. It is a key element distinguishing RMS from FMS, which often generates unnecessary costs through the part of system's flexibility. RMS uses different tools in the same machine, which reduces costs and increases productivity. As it is shown in Figure 1 RMS is designed for a particular narrow family of products manufacturing, which distinguishes it from flexible systems.
- **Convertibility** – the ability to adapt quickly the functionality of the system, its equipment and drivers, in order to adapt to new market needs. The rate of changes in the system is a prerequisite for its efficiency and profitability, for this reason retooling methods should be adjusted to the needs: conventional and modern, including quick machine calibration.
- **Scalability** – means adaptation of production capacity level according to the needs. This change is made in two ways: first by changing the ability of the individual elements of production, either by full or partial reconfiguration of the system. Scalability having a close reference to variability, can also be considered as a machine or system scalability.
- **Diagnosability** – this is system's ability to read, detect and diagnose (the state of the ma-

chine and poor quality production). It also includes taking immediate corrective action. Diagnosing recognized in terms of poor quality of manufactured parts is critical. This is due to the fact that frequent change of the system or individual modules, forces equipment calibration and quality of manufactured products verification. The time required to perform these activities will largely determine usefulness and profitability.

The design of the system described with the above features, makes such a system fully adapted to the changing market needs and demand fluctuations, and its modular design makes it efficient and cheap. The aforementioned characteristics define a new, different from the FMS and DML, class of Reconfigurable Manufacturing Systems (RMS).

DESIGN AND CONSTRUCTION AND TECHNICAL MEASURES OF FMS

Before the problem of design and commissioning RMS will be discussed, as well as using technical resources in modular structure of individual machines and entire system, it should be noted that the proposed system will not always be the best solution. If a producer wants to apply, he should start with the analysis connected with desirability of application of RMS to a specific product. It is evident that the demand for some products is constant over long periods of time, then the implementation of the production can be the best by using DML. It is not necessary choosing RMS, or FMS. Therefore, the first essential step in the design of the system is the analysis of the purpose of implementation [7].

After decision of using RMS, the next step is to design a reconfigurable system. Its configuration, defined as a set of machines (including controllers, means of transport and connections between them) is to comply with the six, already mentioned, characteristics: modularity, integrity, rationality, convertibility, scalability, and diagnosability. The machine consists of modular machining centers and modular machine. To design a system which is to meet reconfigurable conditions, the input must be gathered (what is shown in Figure 3), and identified all the failures connected with the completeness and proper configuration of the existing system (a whole as well as individual modular units and the modules themselves).

Therefore, system designing requires, not only the selection of appropriate components of modules, but also continuous the analysis of their optimality and the possibility of improvement. Design of the new RMS system, as well as reconfiguration of an already existing, can be extracted, in order to adapt to market needs.

The problem of monitoring and control in the designed system is a separate issue. The physical connection of the modules is not enough (although is problematic due to the efficient connection of the modules of specific interfaces, mechanical (its construction, drives, hydraulics, electrical and electronic) for their efficient work. Control of complex systems requires precise algorithms of their control and combine them into a single database. In addition, large number of modules, generates a large number of different system configurations and connection units, from serial to parallel through mixed ones. For example, five machines have 16 different con-

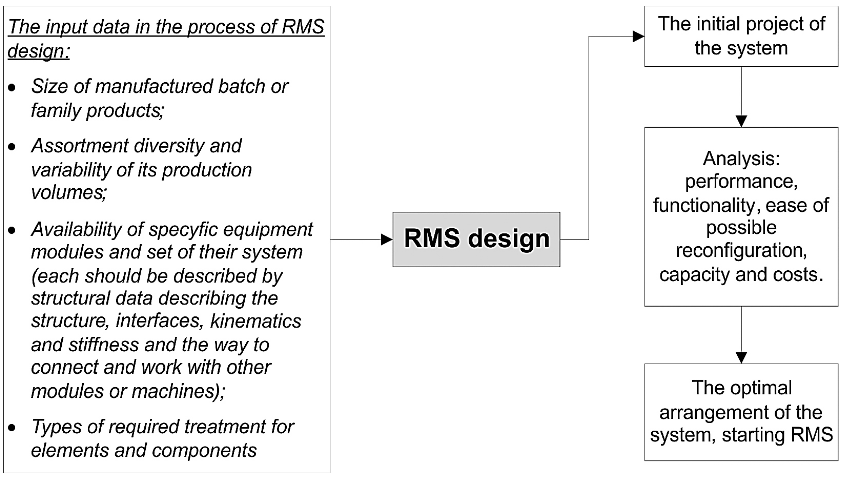

Fig. 3. RMS design stages (*own study based on* [9])

figurations, that is, for n-machine 2^(n +1) configurations. An efficient system should be able to choose an optimal configuration and control it so that all the production is both efficient and qualitatively adequate. Master RMS control system integrates into a coherent whole, therefore, the work of individual modules on machines connected in a structured system whose devices are designed for their measurement, control, and transportation of materials, products and intermediates. Thus, the problem is based on open controlling (open-architecture), which is characterized by several important features [5]:

1. Openness in the choice of hardware – thanks to modularity various components can be changed without the need to replace the entire set. This solution is far cheaper than standard solutions.
2. Openness of CNC operating systems for compatibility – allowing import of the existing standard software.
3. Openness of input – output configuration interfaces.
4. Openness for manufacturers' machines – by the opportunity to display individual wishes and settings.

Only the development of a standard for manufacturers of modules and equipment allows to develop RMS paradigm and make the production much cheaper for efficient control and combining standardized components from different companies.

The condition of modularity in the design of the system includes both the system as a whole coherent and logical structure, as well as the construction of various machinery and equipment [11]. Only the design of the system allows to reduce costs and fast start-up production of new products.

TECHNICAL MEASURES OF RMS

The key element which determines manufacturing system reconfigurability is the technical equipment – and especially machine tools. There are two types of machine tools included to manufacturing subsystem of RMS:

- Reconfigurable machines,
- Modular-machining centres.

Reconfigurable machines are modular devices that can be easily adapted to individual needs, by changing, adding or removal of individual functional modules. Such machines are created by consumers postulate of the principles of lean – machining for lean – production, so the installation of base units in these machines is easy for operators, does not require highly skilled personnel. For example, tasks of machining different elements are applied to a modern lathe (apart from the typical turning operations) processing elements of different shape, such as smooth and threaded holes, windows, gouges, grooves. In this way, almost all the element processing, including turning, drilling and milling, is performed by a single device, which greatly reduces both the time of manufacture (no storage between positions, unnecessary transport between devices) as well as costs.

Modular-machining centers are defined as CNC machines, whose structure provides the ability to run a large number of different machining treatments, using different tools in order to get the item for the most trimmed part (if possible-completely).

Modular design brings mutual benefits for producers and buyers of equipment listed in Table 2.

As shown above, modular design of the system and machine construction provides tangible benefits that make the trend in science, which is the

Table 2. The benefits for producers and buyers, resulting from the use of a modular machine tools (own study based on [4])

Producer	Buyer
• Investment in commercial products and technological - construction documentation is done only once (the next contract renewal of existing offers).	• The possibility to make changes in a using system, its development, and removal.
• Additional work on the design documentation are provided only for individual customers.	• Quick replacement and repair of defective parts. (Availability of the elements on the market).
• It is to prepare production schedules, production is stabilized.	• Short term of supply of whole systems and individual modules.
• Production of the modules can be done regardless of the order in batches of production that minimizes costs.	• Facilitating and acceleration the design work (using CAD), by having many modules and components database.
• The division of batch production scheduling allows subsequent modules storage and assembly.	• Ability to create custom modules and solutions from the range.

RMS, begins to grow rapidly in the direction of an isolated system which is efficient and cost effective market response to the needs of customers.

Machining centers and reconfigurable machine tools are not separate elements, but form a coherent whole in the RMS through wired and wireless connections, which are effectively controlled by the master control system, together with monitoring devices and transport.

CONDITIONS OF RMS APPLICATION IN MODERN COMPANIES

Reconfigurable production is the latest development trend in the wider field of integrated production systems. Here are examples of its applications, which, can be termed as the RMS, but they are significant steps forward in field of reconfigurability [3]:

- 1976 "Molins System 24" – flexible and integrated system developed by Mr. Williamson, in order to ensure greater productivity. Machining centers were combined into an automated, touched system to machining elements prepared on pallets.
- 1972 Aurebach – plant system of production is M250/02 CNC. It was equipped with two three-axis machining centers, but the service was performed manually from a central operator station.
- 1977 – Trial Tskuba factory in Japan, containing modular machines and assembly robots to produce the kind of party with assistive devices, which improve the flow of pieces by the production process.

At the end of the 1970s FMS's began to develop, which halted the development of a reconfigurable systems. Since mid-1990's RMS trend has been growing-systems that are able to react to market changes quickly, with providing desired functionality and capacity at any time. Several documented projects, describing the problem, however, in a general way, have been completed. The European Union has drawn up a report on the European system of machine tools, which states that if the machines are designed and built in a modular way then they can specialized in different modules, rather than be complete systems. System integrators will build a complete system of modules. This strategy, as the report states, requires a distribution of machine tools for autonomous functional units, which are based on a plug - and-play basis and can be used according to specific, contract needs. Several projects have been completed in this way. These include:

- Modular Synthesis of Advanced Machine Tools (MOSYN) – the project realized by the University of Hannover, focusing its research on the specification of machine configuration according to different customers' needs.
- Special Research Program 467 – a project of the University of Stuttgart, in which one of the objectives was the development of machining systems, which, thanks to reconfigurations could increase its functionality, as well as the ability of the production. This project was to combine short-term adaptation to the changing conditions of machine tools production and fluctuations in demand.
- 1996 – Engineering Research Center of the University of Michigan (in cooperation with the National Science Foundation and 25 manufacturing companies) implement the concept of RMS, which are investigated and developed to this day, for example by yielding patent for reconfigurable machine tools.

The above examples indicate, not only the scientific trend, that theory concerning contemporary research on the development of production systems and technological for manufacturing of machinery which has set, but also the direction of specific actions, which is undertaken in order to create an optimal system: adapted to the changing environment – reconfigurable manufacturing system.

CONCLUSION

Strong evolutionary trend of the development of production systems cause the solutions which help companies keep up with market changes in a quick and cost-efficient way are still searched for. Therefore, a start-up of system is a key issue for the purpose of staying competitive. Today the time from a product idea to a full capacity production must be cost-effective and reduced to a minimum, with constant search for new ideas, proposals and solutions (Figure 4).

Previous proposals for production systems has begun to show their lack of adaptability to the changing environment. Development trend, based upon FMS and DML, develops in a key direction, which is modularity: the entire system, individual, machinery and components. Modular-

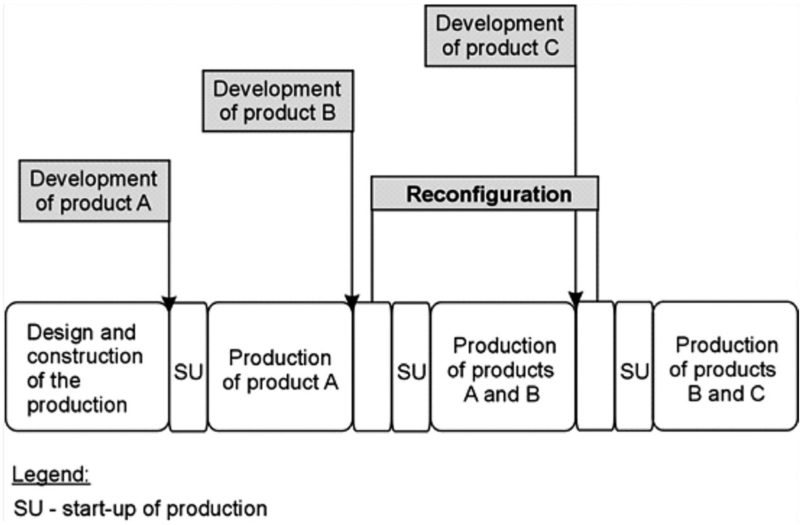

Fig. 4. The product life cycle on the market today (own study based on [6])

ity is a challenge for today's designers, as well as for the manufacturers in the field of engineering of manufacturing, because it means normalization and standardization of solutions, such as base units and pieces of equipment. It is a wide-ranging problem involving functional elements in a compact system. This problem develops on the underlying substrate links: mechanical, electrical, electronic and control: algorithms of signal flowing through reconfigurable modular system of libraries – still dilated databases. Will RMS become the new solution, fully accepted and implemented in modern enterprises? Reconfigurable system, according to the principles, meets all the expectations of flexible, low-cost and easy to use production. It is admitted, that RMS is only the first step, created by the assumptions, whose shortcomings cannot be seen yet. No companies, based on the system, confirms the difficulties in the implementation of this paradigm. Previous research, produce positive results also raise the idea that, what today is still learning, based on the examples, in the future can become a reality – a natural next step in the evolution of production systems. All things considered Reconfigurable Manufacturing System is a trend and direction in which manufacturing industry growing rapidly today.

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