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Reconfigurable Manufacturing Systems Design Principles

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ABSTRACT

A Reconfigurable Manufacturing System (RMS) combines Dedicated Manufacturing Lines (DML) with Flexible Manufacturing Systems convertibility. Thus, it has the capacity of producing a wide range of parts, at different production levels and in conditions of high economic efficiency. To adapt rapidly and properly to needed capacity and functionality, a Reconfigurable Manufacturing System allows rapid changes in its structure, no matter if talking about hard or soft components. This paper aims to enounce and to detail Reconfigurable Manufacturing System design principles.
Key-words: *Reconfigurable Manufacturing System, machine-tool architecture, flexibility, modularity, scalability.*

1. Manufacturing Systems between Tradition and Perspectives

In the present, market demands become more and more unpredictably, products are particularizing and their life cycles are shorter. Manufacturing systems, made by one or more machine-tools and their auxiliary devices (necessary to handle the worked pieces, to do shape and dimensional verification etc.) are orderly operating to realize the pieces from a production lot in needed quantities and at required quality level. Such a system must have the capacity of adapting to economy changing requirements. Under commercial exchanges globalization conditions, the notion of prompt and particularized action became a necessary condition to manufacturing activity, if aimed to be competitive.

Traditional manufacturing systems as Dedicated Manufacturing Lines (DML) cannot face new market requirements because constitutive machine-tools were designed to do a single operation, specific to a part to be produced in a large quantity - serial fabrication type. Specialized machines lack of efficiency, under the new conditions required by market, is obvious, although they ensure a high level of security, reproducibility and efficiency and their acquisition costs is reasonably small.

From efficiency point of view, neither Flexible Fabrication Systems (FMS) can be able to successful confront the new consumers tendencies. The equipments composing these lines are Computer Numerically Controlled (CNC) and can produce a wide range of products if computer soft are adequate modified. Their attributes, received even during their designing stage (security, reproducibility and high productivity are recommending them to be used in mass production processes, but their acquisition prices are high, their reliability is smaller and they are suffering a quite rapid moral depreciation.

The adaptation of traditional manufacturing systems (DMS and FMS) to new products is slow and expensive and to ramp-up a new system more time (up to 2 years, in the case of a cutting manufacturing system) would be necessary. Same time, people investing in technological equipments have to face the risk that an expensive manufacturing system could become inefficient after a short period, because of rapid progresses from technical field.

To answer to modern market challenges, certain American researchers (Koren Y., Mehrabi M.G., Katz R., Moon Y.M., Ulsoy A.G.) suggested, [1][2], as permanent transit solution, the Reconfigurable Manufacturing Systems (RMS). These systems combine, yet from their designing phase DML high performances to FMS flexibility. Thus, production capacity can be ensured under competitive economic conditions, to a high variety of products, when relative small quantities are required. This type of systems is conceived as open/closed, to enable its upgrading, development or reconfiguration instead of been replaced or rejected.

To reach this objective, it is necessary that manufacturing system structure, no matter if talking about hard or soft components enables rapid changes to be made. Thus, Reconfigurable Manufacturing System will deliver exactly the functionality and the capacity required right in the moment when market demands are imposing it.

Manufacturing system reconfigurability is an attribute received during its design phase and it allows production capacity and system functionality adjustment, according to new market demands, by changing or re-arranging system components. By "components" we mean the whole machine-tool as well as its main parts, devices, worked pieces inter-operational transport systems, sensors and investigation devices etc.

Fig. 1 illustrates evolutions steps (D – dedicated, F – flexible, R – reconfigurable) in the case of a tool used in assembling operations.

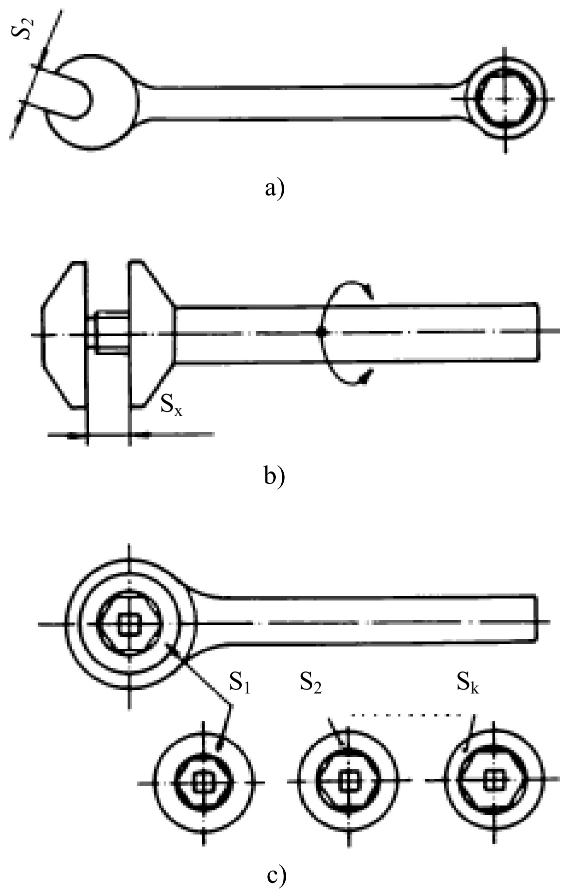

Fig. 1 – Evolution Steps in the Case of a Tool Used in Assembling Operations:
a – Dedicated (D); b – Flexible (F);
c – Reconfigurable (R).

2. Domains of Use

Conform to those shown in Fig. 2, DML have a very high production capacity but, same time, a limited functionality [1]. They are efficient from costs point of view as long as they are manufacturing a small number of parts and the demand on market overtakes the offer. Frequently, in the case of saturated markets and under global concurrence increased pressure, dedicated manufacturing lines are constrained to function below their maximum capacity and, in many cases they cannot realize the profit anticipated at the moment when investments started.

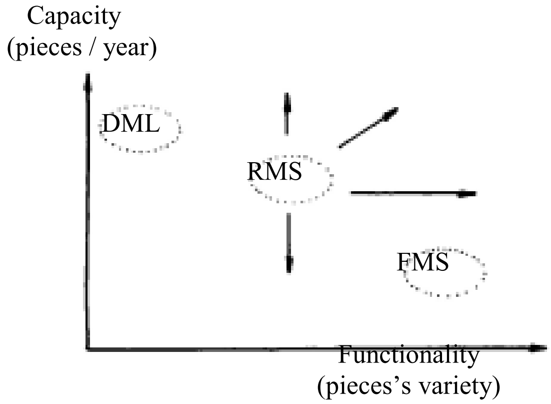

Fig. 2 – Manufacturing Systems Optimum Domain of Use:

DML – Dedicated Manufacturing Lines;
FMS – Flexible Manufacturing Systems;
RMS – Reconfigurable Manufacturing Systems

Yet since designing stage, FMS are conceived with functionality and capacity levels much over estimated necessary, when prospecting the market. From logical point of view, such a solution is equivalent to „buy an object whose utility is expected in the future". In this case, invested capital is blocked on short term and effective realized profit is small.

In the case of Reconfigurable Manufacturing Systems, disadvantages above exposed are eliminated. When designing a RMS, reconfigurable hard and soft parts are used. Thus, system's or equipment's functionality and capacity can be adjusted in time, related to the demand on market.

The Reconfigurable Machine-Tool (RMT) is Reconfigurable Manufacturing System's essential element. These structures were defined, as principle, for the first time in 1999 by researchers Koren, Y. and Kota, S. from the Engineering Research Center for Reconfigurable Manufacturing Systems at the University of Michigan [9].

Some researchers (Suh, N. P. and Doubel, H.) anticipated these tendencies from machine building industry. Thus, the structural design principle was enounced based on functions division criterion, [4]. According to it, an equation of designed structure, connecting functional requirements vector to machine-tool constructive parameters, through a matrix, was written [3]. In [6] work, authors are studying RMT problematic, having as main idea their de-composition into distinct parts. Specific aspects concerning modules inter-changeability and standardization are also analyzed.

As it results from [7] and [8], Reconfigurable Manufacturing Systems designing process should be grounded on a set of principles to allow manufacturing system adaptation to the new manufacturing requirements. In this purpose, when designing RMT as RMS integrated element, the substitution / addition of certain modules or existing modules reciprocal positions change must be provisioned.

3. Design Principles

An ideal RMT possess six core characteristics: modularity, integrability, customized flexibility, scalability, convertibility, and diagnosability (fig. 3).

These characteristics, which were introduced by professor Yoram Koren in 1995, apply to the design of whole manufacturing systems, as well as to some of its components : reconfigurable machine-tools, their controllers and also to the system control software.

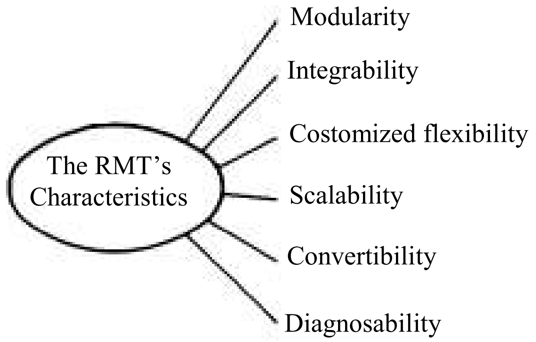

Fig. 3 – The characteristics of an ideal RMT

Modularity. In a reconfigurable manufacturing system, many components are typically modular (e.g.. machines, axes of motion, controls and tooling). When is necessary, the modular components can be replaced or upgraded to better suit new applications. Modules are easier to maintain and update, thereby lowering life-cycle costs of systems. The fundamental questions when designing with the modular approach are: what are the appropriate building blocks or modules and how should they be connected to synthesize a functioning whole?

Selection of basic modules and the way they are connected allow for the creation of systems that can be easily integrated, diagnosed, customized, and converted. Reconfigurable Machine Tool with a modular structure, containing spindle modules that can be reconfigured to allow different machining operations are presented in [9].

Integrability is the ability to integrate modules rapidly and precisely by a set of mechanical, informational, and control interfaces that enable integration and communication. At the machine level, axes of motions and spindles can be integrated to form machines. Integration rules allow machine designers to relate clusters of part features and their corresponding machining operations to machine modules, thereby enabling product-process integration. At the system level the machines are the modules that are integrated via material transport systems (such as conveyors and gantries) to form a reconfigurable system. To aid in designing reconfigurable systems, system configuration rules are utilized.

Customization is the ability to design system/machine flexibility just around a product family, obtaining thereby customized flexibility, as opposed to the general flexibility of FMS/CNC. This characteristic drastically distinguishes RMS from flexible manufacturing systems (FMS), and allows a reduction in investment cost. It enables the design of a system for the production of a part family, rather than a single part (as produced by DML) or any part (typical FMS). In the context of RMS, a part family is defined as all parts (or products) that have similar geometric features and shapes, the same level of tolerances, require the same processes, and are within the same range of cost. The definition of the part family must ensure that most manufacturing system resources are utilized for the production of every member part. The RMT configuration must be customized to fit the dominant features of the whole part family by utilizing the characteristic of customized flexibility. Customized flexibility for the part family allows the utilization of multiple tools (e.g., spindles in machining) on the same machine, thereby increasing productivity at reduced cost without compromising flexibility.

The convertibility defines the ability to easily transform the functionality of existing systems, machines, and controls to suit new production requirements. System convertibility may have several levels. Conversion may require switching spindles on a milling machine, or manual adjustment of passive degrees-of-freedom changes when switching production between two members of the part family within a given day. System conversion at this daily level must be carried out quickly to be effective. To achieve this, the RMT must utilize not only conventional methods such as off-line setting, but it should also contain advanced mechanisms that allow for easy conversion between parts, as well as sensing and control methods that enable quick calibration of the machines after conversion.

Scalability means to easily change production capacity by rearranging an existing manufacturing system and/or changing the production capacity of reconfigurable stations. Scalability is the counterpart characteristic of convertibility. Scalability may require at the machine level adding spindles to a machine to increase its productivity, and at the system level changing part routing or adding machines to expand the overall system capacity (i.e., maximum possible volume) as the market for the product grows.

Diagnosability is the ability to automatically read the current state of a system for detecting and diagnosing the root-cause of output product defects, and subsequently correct operational defects quickly. Diagnosability has two aspects: detecting machine failure and detecting unacceptable part quality. The second aspect is critical in RMS. As production systems are made more reconfigurable and their layouts are modified more frequently, it becomes essential to rapidly tune (or ramp-up) the newly reconfigured system so that it produces quality parts.

4. Conclusions

The reconfiguration science will form the basis for a vital production technology in this era of global market competitiveness – that it will involves into entirely new manufacturing field with enduring benefits for the economy and society.

Some of the key research issues in machine level design are:

- develop a reconfiguration design theory based on a systematic synthesis of machine modules and their associated processes;
- design reconfigurable machines, constructed from a set of generic modules, which enable the machining of a family of parts;
- create integration tools that can quickly configure discrete logic control systems;
- develop self-calibration, self-diagnosis techniques for machine tools and their spindles.

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Principii de proiectare a sistemelor de prelucrare reconfigurabile

Rezumat

Sistemul de fabricaţie reconfigurabil (RMS) combină performanţele ridicate ale liniilor de maşini specializate (DML) cu convertibilitatea sistemului de fabricaţie flexibil (FMS). Astfel, are capacitatea de a prelucra o varietate de produse şi volume de producţie în condiţii de înaltă eficienţă economică. Pentru a se adapta rapid şi exact la capacitatea şi funcţionalitatea de care este nevoie, sistemul de fabricaţie reconfigurabil permite schimbări rapide în structură, indiferent că este vorba de componente hard sau soft. Scopul acestei lucrări, este de a formula şi a detalia principiile de proiectare ale sistemelor de fabricaţie reconfigurabile.

Principes de projectations pour les systèmes de fabrication réconfigurables

Résumé

Le système de Fabrication Reconfigurable (RMS) combine les hautes performances des Lignes de Fabrication Spécialisées (DML) à la convertibilité du Système de Fabrication Flexible (FMS). Ainsi, il a la capacité de réaliser une variété de pièces et de volumes de production, dans des conditions de grande efficience économique. Pour s'adapter rapidement et précisément aux capacité et fonctionnalité nécessaires, le système de fabrication reconfigurable permet des changements rapides dans sa structure, soit qu'il s'agit des components hard ou soft. Le but du ce travaux est de formuler et de détailler le principe du conception pour les systèmes de fabrication reconfigurable.