Reconfigurable Manufacturing Systems (RMS): A Literature Review

*S. G. Bhatwadekar, #S. M. Ingale, $R. V. Dandage,

*Professor, #Associate Professor, Department of Mechanical Engineering, Sanjay Ghodawat University, Kolhapur, Maharashtra, India.

*bhatwadekar.sg@sginstitute.in, #ingale.sm@sginstitute.in

$Assistant Professor, Rajendra Mane College of Engineering & Technology, Ambav, Maharashtra, India. r.dandage@rmcet.com

Abstract: **Increasing competitiveness experienced by manufacturing firms is calling for cost optimization, following global manufacturing practices and responding rapidly to the changes in demands, volumes and technology. This poses serious challenges to profitability and hence sustainability of the business. Reconfigurable manufacturing systems have the potential to address these issues in a cost effective and sustainable manner because of the changeability as compared to dedicated or flexible manufacturing systems.**

This article provides a review of selected literature on reconfigurable manufacturing systems and allied technologies. It discusses the issues associated with RMS such as, reconfiguration principles, changeability, reconfigurable process plans, reconfigurable machine tools – structure and control, process planning for reconfigurable machines and product families in RMS. A short comparison between, the dedicated and flexible manufacturing systems and RMS is made. To conclude, some generic research areas for manufacturing, machine tool design, control engineering as well as computer engineering have been identified.

Keywords* — *Cost Optimization, Reconfigurable Manufacturing Systems, Changeability, Reconfigurable Machine Tools, Part Family

I. INTRODUCTION

The increasing global competition and shortening of product life cycles are resulting into increasing demand for faster responses, shortened manufacturing lead times and adaptability from the manufacturing firms. The internal challenges of reducing waste and increasing efficiency and productivity are equally tough while creating and maintaining meaningful and rewarding jobs.

Traditionally, rigid transfer lines (RTL) have been adopted for the production of limited variety of part types (one or few) to be produced in high volumes. Since in RTLs scalability is low, RTLs are usually designed according to the maximum market demand that the firm forecasts to satisfy in the future (volume flexibility); as a consequence. However, in many situations RTLs do not operate at their full capacity since their designed volume flexibility is frequently over-sized.

Volatility in market demands, changing customer's preferences and need for more products differentiation and customization have given rise to modern systems like flexible manufacturing systems (FMS), flexible assembly systems (FAS), computer integrated manufacturing systems (CIMS) and reconfigurable manufacturing systems (RMS). FMS and FAS allow in a real time manner changing machine assignments, machining or assembly processes, parts or subassemblies routing and production schedules..

The lower the sensitivity to change, the higher is the flexibility of the system. FMS offers a generalized flexibility with the help of versatile multi-capable CNC machines. However, CNCs are built before the manufacturer selects machines and process planning is undertaken to adapt the machines and the process to the part. CNCs are built with 'all' possible functionalities due to no knowledge of specific operation. This leads to "excess of capabilities" and hence blocked investments. High power, general purpose multi-axis CNC machines with large tool magazines and multiple sets of tools which are very expensive, are required for production flexibility. The flexibility is a critical issue at the stage of system design. On one side, flexibility is considered a basic necessity for companies competing in a reactive or a proactive way. However, flexibility may not always be a desirable characteristic of a system. Many times flexibility if not essential or not taken advantage of, can affect the profitability adversely. Many researchers have expressed in the relevant literature, descriptions of industrial situations where flexible manufacturing systems have unsatisfactory performance (Koren et al., 1999; Landers, 2000), cases where the available flexibility remains unused (Sethi and Sethi, 1990), or cases where the management perceives flexibility more as an undesirable complication than a potential advantage for the firm (Stecke, 1985).

RMS allows changeable functionality and scalable capacity (Koren, 2006) by physically changing the components of the system through adding, removing or modifying machine modules, machines, cells, material handling units and/or complete lines. RMS is designed for rapid changes in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality within a part family in response to sudden changes in market or regulatory requirements, with the goals of exactly the capacity and functionality needed, exactly when needed. Key characteristics of the RMS are modularity, integrability, customization, convertibility, scalability and diagnosability. Modularity, integrability and diagnosability reduce the configuration time and effort; and customization, scalability and convertibility reduce reconfiguration cost. These characteristics can reliably reduce lifetime cost by enabling a system to change constantly during its lifetime, ‘‘staying alive’’ despite changes in markets, consumer demand, and process technology. Figure 1.1 illustrates the costs involved in enhancing the capacities of the three manufacturing systems

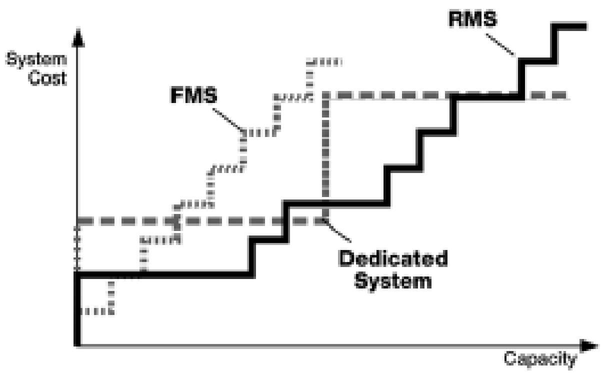


Fig. 1.1: Manufacturing system cost v/s capacity (Koren et al., 1999)

II. ISSUES IN RMS

2.1 Reconfiguration Principles: Reconfigurable manufacturing systems are designed according to following reconfiguration principles (Koren & Shpitalni, 2011): (a) An RMS system provides adjustable production resources to respond to unpredictable market changes and intrinsic system events:

• RMS capacity can be rapidly scalable in small increments.

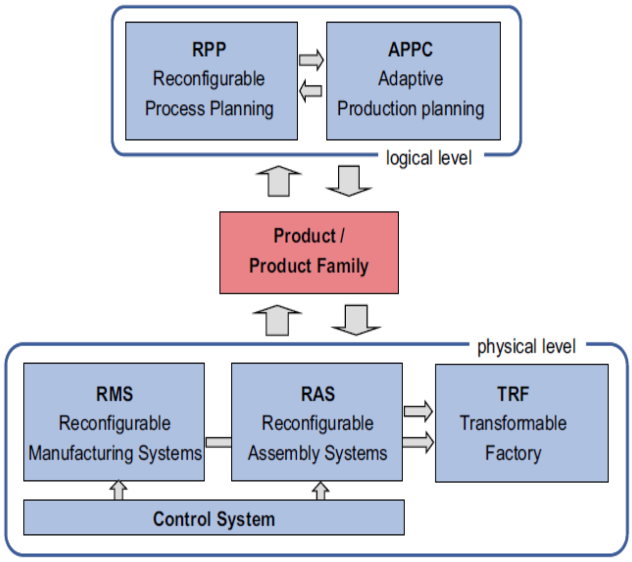
• RMS functionality can be rapidly adapted to new products.

• RMS built-in adjustment capabilities facilitate rapid response to unexpected equipment failures.

(b) An RMS system is designed around a product family, with ‘just enough’ customized flexibility to produce all members of that family. (c) The RMS core characteristics should be embedded in the system as a whole, as well as in its components (mechanical, communications and control) to be able to derive the true benefits.

2.2 Changeability: Product life cycle starts with the initial system design and synthesis according to the specified objectives and constraints followed by modeling, analysis and simulation, and then the final design is realized, implemented and used in production. The manufacturing system undergoes re-design and reconfiguration, throughout its operation, as new requirements emerge and changes are required; aimed at meeting the requirements of the changed environment.

Changeability has been proposed as an umbrella concept that encompasses many aspects of change on many levels within the manufacturing enterprise (Wiendahl et al., 2007). Changeability is defined as the characteristic to implement early and envisaged adjustments of the factory’s structures and processes on all levels, due to change impulses, economically. Objectives of changeability are defined as, product flexibility, operation flexibility and capacity flexibility. Figure 2.1 depicts the scope of such changeability; while figure 2.2 shows the enablers of the changeability,



. **Fig. 2.1: Scope of changeable manufacturing**

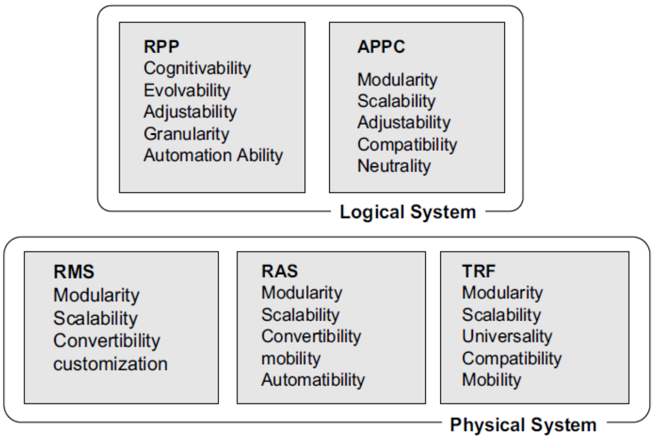


Fig. 2.2: Enablers of changeable manufacturing sub-systems (ElMaraghy & Wiendahl, 2009)

2.3 Reconfigurable process plans: There are key enablers for achieving reconfigurable process plans and correspondingly matching techniques for their efficient recreation when needed, (ElMaraghy & Wiendahl, 2009). These enablers are listed in the following text.

•**Cognitivability:** The ability to recognize the need for and initiate reconfiguration when pre-requisite conditions exist. This ability is imparted on process planning through the use of some artificial intelligence attributes.

•**Evolvability:** The ability to utilize the multi-directional relationships and associations between the characteristics of product features, process plan elements and all manufacturing system modules capable of producing them.

•**Adjustability:** The ability and representation characteristics that facilitate implementing optimally determined feasible and economical alterations in process plans to reflect the needed reconfiguration.

•**Granularity:** The ability to model process plans at varying levels of detail in order to, readily and appropriately, respond to changes at different levels (e.g. in products, technologies and systems).

•**Automation ability:** The availability of complete knowledge bases and rules for process planning and reconfiguration, accurate mathematical models of the various manufacturing processes at macro- and micro-levels, as well as meta-knowledge rules for using this knowledge to automate the plan reconfiguration

2.4 Reconfigurable Machine Tools (RMT): A conceptual designing of a reconfigurable machine tool is shown in figure 2.3. An RMT will have mechanical passive and active modules. Active modules create motion by drives or other adaptive elements, whereas passive modules have static and supporting function.

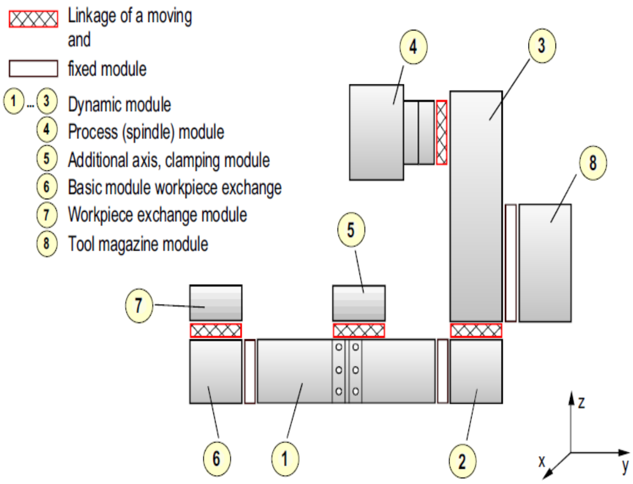
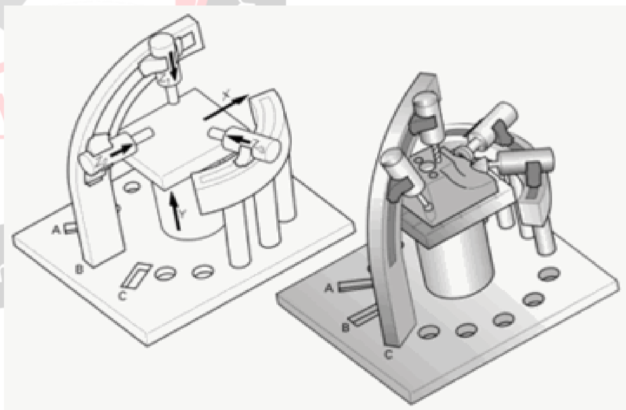


Fig. 2.3: Arrangement of a machine tool with a modular design

(G. Pritschow et. al, 2009)

Reconfigurable machine tool structures: In a reconfigurable machine tool system, many components are typically modular (e.g., machines, axes of motion, controls, and tooling (Fig. 2.4). When necessary, the modular components can be replaced, swapped or upgraded to make the configuration compatible with the new applications. New configurations of machine tools can be created to meet the processing demands of individual parts from families (Fig. 2.5). Landers et al. (2001) have discussed systematic design tools that have been recently developed for RMTs and illustrated examples to compare RMTs to traditional types of machine tools.



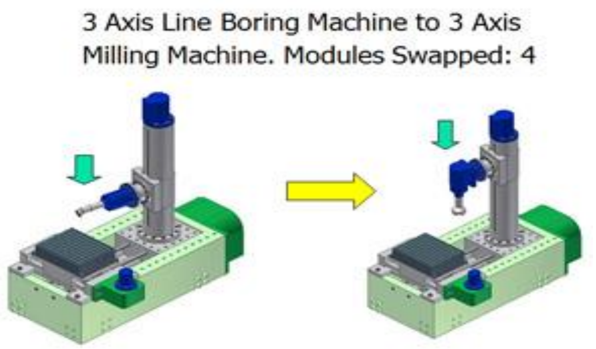


Fig. 2.4: Modularization of production functions (processing units) (Rod Hill, 1999)

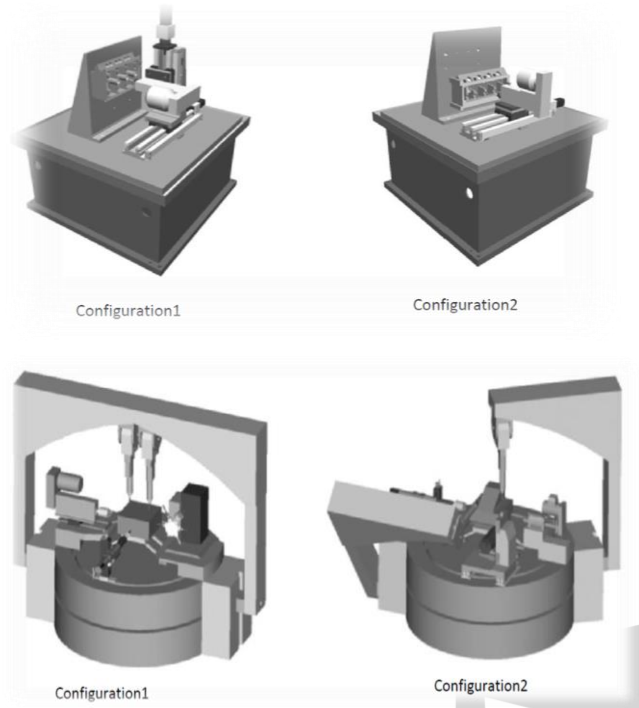


Fig. 2.5 Reconfigurable machines by replacing machine modules and using integrated reconfiguration functions

Configurable control systems: Similar to the physical modularity necessary for providing the functional (processing) capabilities, an RMT must have modularity in its control features too. This ensures the availability of 'just adequate' control features of the software. Some well-known research activities concerning open multi-vendor platform-based configurable control systems include, OMAC (Open Modular Architecture Controls) in the North America, OSEC/FAOP (Open System Environment for Controllers/FA Open Systems Promotion Forum)(earlier JOP) in Japan or OSACA (Open System Architecture for Controls within Automation) in Europe (G. Pritschow et. al, 2009)

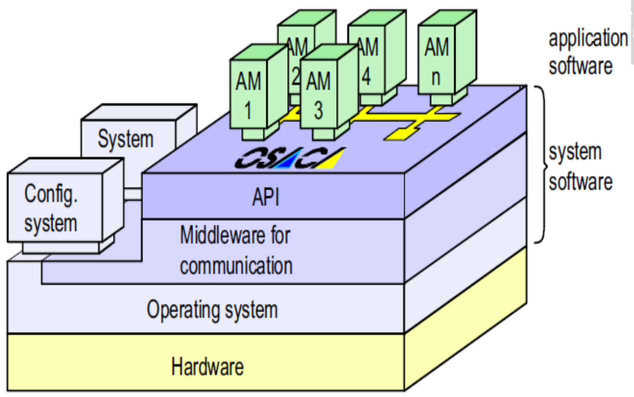


Fig. 2.6: Configuration of an OSACA platform for open architecture, adaptable and reconfigurable control system

The control software components may be developed on different hardware platforms (nodes). The interfaces between these components must be vendor-independent, connected by a transparent and standardized communication system.

Generating a Control Configuration:, The "building plan" for a manufacturing unit is used as a basis for the generation of a required control configuration. (Fig. 2.7)

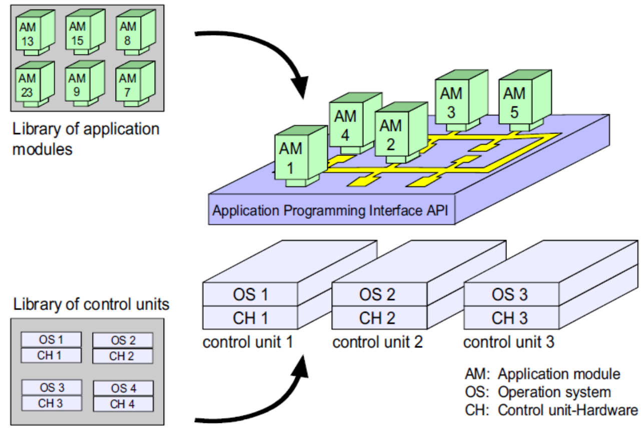


Fig. 2.7: The instantiated components on the platform

2.5 Process Planning for Reconfigurable Machines: The selection of the different types of machine(s) and their appropriate configurations to produce different types of parts and features, according to the required machine capabilities, is a fundamental building block in generative planning of manufacturing processes (Shabaka and ElMaraghy, 2007). The machine structure is represented as kinematic chains that capture the number, type and order of different machine tool axes of motion, which are indicative of its degrees of freedom and ability to produce certain geometric features as well as the size of workspace (Fig. 2.8). Operations are represented by a precedence graph and grouped according to the logical, functional and technical constraints.

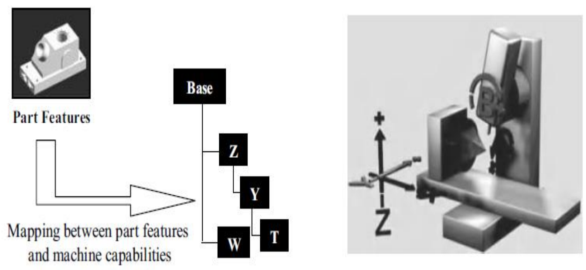


Fig. 2.8: Mapping between part features and machine capabilities (Shabaka and ElMaraghy, 2007)

2.6 Product families in RMS: In RMSs, products are grouped into families, each of which requires a system configuration. The system is configured to produce the first family of products. Once it is finished, the system is reconfigured in order to produce the second family, and so forth. Therefore, the effectiveness of an RMS depends on the formation of the best set of product families. Galan et al. (2007) have proposed a methodology for grouping products into families, which takes into account the requirements of products in RMSs. It consists of implementation of (i) modularity matrix through a product-part matrix and level of product modularity, (ii) commonality matrix to identify products that share some parts, (iii) compatibility matrix, which maps the compatibility of each product against all others, (iv) reusability matrix depicting the use of existing product components to manufacture a new product type and (v) product demand matrix grouping products with similar demands to select a machining system with similar capacity.

Design of components for reconfigurability: Components with identical functionality but difference in some features may require different routes. Two components with identical functionality using same raw material, but with different features, may not be processable on the same layout. Relocating some of the differentiating features on the two components can make them processable on any of the route. The basic idea of selecting component designs makes component routes more similar. This in turn minimizes the number of potential relocations of machines needed for system reconfiguration efforts. To select component designs, the cost at the worst case of system reconfiguration for each alternative component design, is used as a measure, (Gun Ho Lee, 1997).

III. Future Scope

RMS offers combined benefits of dedicated and flexible manufacturing systems. It is necessary to develop a way of thinking and new computer aided technologies to cope up with the issues of designing part families, alternative processing routes, mapping product features with processing modules, generating part programs for operations designed thus, algorithms to create new machine configurations quickly and their physical creations, Reconfigurable machine tools provide a feasible alternative for manufacturing scenarios where processing requirements change over the life-time of the machine tool. However there is a need for designing methodologies for structural validation and diagnosability for quality issues. There are the issues of optimizing the inventories of machine or processing modules for a given production volume and variety. The research efforts need to be multi-disciplinary to derive the synergistic advantages.

IV. Conclusion

There has been a significant literature about RMS, both in volume and variety of issues, published in the last couple of decades. This review article has attempted through selected literature, to discuss the various issues involved in the implementation of RMS such as, reconfiguration principles, changeability, reconfigurable process plans, reconfigurable machine tools – structure and control, process planning for reconfigurable machines and product families in RMS. It also compares briefly, the dedicated and flexible manufacturing systems with RMS. Researchers and practicing engineers in the fields of core manufacturing, machine tool design, control engineering and computer engineering working in a synergistic manner have huge opportunities to develop the technology and systems for implementing RMS in the long run. Some general research areas have been identified in the end.

REFERENCES

[1] G. Pritschow, K-H.Wurst, C. Kircher and M. Seyfarth, 2009, Changeable and Reconfigurable Manufacturing Systems, Ed. H. El Maraghy, Springer Series in Advanced Manufacturing, Springer-Verlag London Limited..

[2] Gun Ho Lee, 1997, Reconfigurability Consideration Design of Components and Manufacturing systems, Int J Adv Manuf Technol (1997) 13:376-386).

[3] H. ElMaraghy & H.-P. Wiendahl, 2009, Changeable and Reconfigurable Manufacturing Systems, Ed. H. El Maraghy, Springer Series in Advanced Manufacturing, Springer-Verlag London Limited..

[4] Koren Y., 2006, General RMS Characteristics. Comparison with Dedicated and Flexible Systems. In: Dashchenko A.I. (ed) Reconfigurable Manufacturing Systems and Transformable Factories. Springer Verlag, Berlin/ Heidelberg, pp 27–46.

[5] Koren Y., Heisel U., Jovane F., Moriwaki T., Pritschow G., Ulsoy G., Van Brussel H., 1999, Reconfigurable Manufacturing Systems. Ann CIRP 48/2:527–540

[6] Koren, Y. and Shpitalni, M., 2011, "Design of reconfigurable manufacturing systems", Journal of Manufacturing Systems, doi:10.1016/ j.jmsy. 2011.01.001

[7] Landers R.G., 2000, A new paradigm in machine tools: Reconfigurable Machine Tools. Japan-USA Symp on Flex Autom, Ann Arbor, Michigan.

[8] Landers, RG, Min, BK & Koren, Y, Reconfigurable Machine Tools, CIRP Annals – Manufacturing Technology, 2001

[9] R. Galan_, J. Racero, I. Eguia, J.M. Garcia, 2007, A systematic approach for product families formation in Reconfigurable Manufacturing Systems, Robotics and Computer-Integrated Manufacturing 23 (2007), 489–502

[10] Rod Hill, 1999, RMT-Patent Drawing.gif, Graphic Designer at the University of Michigan - Engineering Research Center at the University of Michigan - Ann Arbor

[11] Shabaka A.I., ElMaraghy H.A., 2007, Generation of Machine Configurations based on Product Features. International Journal of Computer Integrated Manufacturing (IJCIM) 20/4:355–369, Special Issue

[12] Sethi A.K., Sethi S.P., 1990, Flexibility in Manufacturing: A Survey. Int J Flex Manuf Syst 2:289–328

[13] Stecke K.E., 1985, Design, planning, scheduling and control problem of flexible manufacturing systems. Ann Oper Res 3:1–12

[14] Wiendahl H.-P., ElMaraghy H.A., Nyhuis Zäh P.M.F., Wiendahl H.-H., Duffie N., Brieke M., 2007, Changeable Manufacturing – Classification, Design and Operation. Annals of the CIRP 56/2:783–809

