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Reconfigurable Manufacturing Systems on New Product

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Abstract

This paper presents theoretical knowledge obtained from literature sources of reconfigurable manufacturing systems as a new class of systems. The article compares reconfigurable manufacturing systems structure with that of traditional flexible lines. Next it defines the core characteristics and design principles of reconfigurable manufacturing system their relationships between each other and classification of manufacturing systems. This paper highlights the impact of reconfigurable manufacturing system on new product design in global manufacturing systems of the research and development of intelligent solutions in the technological process.

Keywords: reconfiguration, manufacturing systems, modularity, flexibility, product

Introduction

Changing manufacturing environment characterized by aggressive competition on a global scale and rapid changes in process technology requires to create production systems that are themselves easily upgradable and into which new technologies and new functions can be readily integrated [1].

To stay competitive, manufacturing companies must use systems that not only produce their goods with high productivity, but also allow for rapid response to market changes and consumer needs. A new manufacturing capability that allows for a quick production launch of new products, with production quantities that might unexpectedly vary, became a necessity. Reconfigurable manufacturing system (RMS), offer this capability.

Reconfiguration is an engineering technology that deals with design of production machines and manufacturing systems for cost-effective, rapid reconfigure to quickly respond to market changes. If the system and its machines are not designed at the outset for reconfiguration, the reconfiguration process will prove lengthy and, therefore, impractical. The reconfigurable manufacturing system is, therefore, a responsive manufacturing system whose production capacity is adjustable to fluctuations in market demand and whose functionality is adaptable to new products [2].

RMS - a new class of systems

This new type of manufacturing system, which we call the reconfigurable manufacturing system, will allow flexibility not only in producing a variety of parts, but also in changing the system itself. Such a system will be created using basic process modules-hardware and software- that will be rearranged quickly and reliably. These systems will not run the risk of becoming obsolete, because they will enable the rapid changing of system components and the rapid addition of application-specific software modules. This system will be open-ended, so that it can: (i) be continuously improved by integrating new technology, and (ii) be rapidly reconfigured to accommodate future products and changes in product demand rather than scrapped and replaced.

The definition of a reconfigurable manufacturing system is as follows according to [3]:

A reconfigurable manufacturing system (RMS) is one designed for rapid adjustment of production capacity and functionality, across a product family, by rearrangement or change of its components (hardware and software).

Other definition of a reconfigurable manufacturing system is, therefore, as follows according to [4]:

A Reconfigurable Manufacturing System (RMS) is designed at the outset for rapid change 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 in regulatory requirements.

As shown in Figure 1, there are many aspects of reconfiguration. These include various configurations of the production system (e.g., serial, parallel, and hybrid), reconfiguration of the factory communication software, configuration of new machine controllers, building blocks and configuration of modular machines, modular processes, and modular tooling.

There are a number of key interrelated enabling technologies that should be developed and implemented to achieve the goals of reconfigurable manufacturing systems.

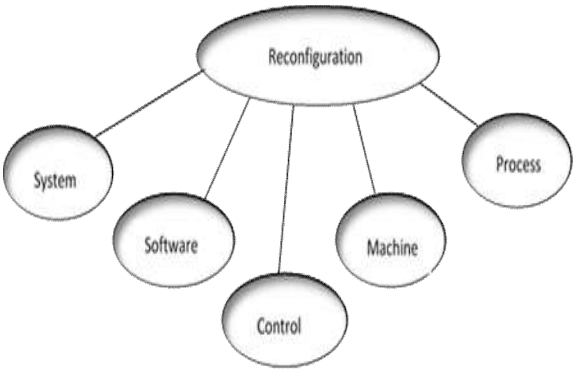

Figure 1 Aspects of reconfiguration for reconfigurable manufacturing system

Reconfiguration characteristics and principles

Reconfigurable manufacturing systems are marked by six core reconfigurable characteristics, as summarized below [5].

Customization (flexibility limited to part family). System or machine flexibility limited to a single product family, thereby obtaining customized flexibility.

Convertibility (design for functionality changes). The ability to easily transform the functionality of existing systems and machines to suit new production requirements.

Scalability (design for capacity changes). The ability to easily modify production capacity by adding or subtracting manufacturing resources (e.g. machines) and/or changing components of the system.

Modularity (components are modular). The compartmentalization of operational functions into units that can be manipulated between alternate production and schemes for optimal arrangement.

Integrability (interfaces for rapid integration). The ability to integrate modules rapidly and precisely by a set of mechanical, informational, and control interfaces that facilitate integration and communication.

Diagnosability (design for easy diagnostics). The ability to automatically read the current state of a system to detect and diagnose the root causes of output product defects, and quickly correct operational defects.

Customization, scalability and convertibility [5] are critical reconfiguration characteristics. Modularity, integrability and diagnosability allow rapid reconfiguration, but they do not guarantee modifications in production capacity and functionality. Customization, an essential RMS characteristic, is based upon design for a part family or a product family, a concept already mentioned by other researchers [6]. The six key RMS characteristics reduce the time and effort of reconfiguration, and consequently enhance system responsiveness. 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 [5].

Reconfigurable manufacturing systems are designed and operate per a set of basic principles given below. The first three principles are the core principles that define a reconfigurable system. The others are secondary principles that assist in designing a cost-effective RMS.

1. The RMS contains adjustable production resources to respond to imminent market needs.
   - RMS capacity is rapidly scalable in small, optimal increments.
   - RMS functionality is rapidly adaptable to the production of new products.
   - RMS inbuilt adjustment capabilities facilitate rapid response to unexpected equipment failures.
2. The RMS is designed around a part/product family, with just enough customized flexibility needed to produce all members of that family.
3. To enhance the responsiveness of a manufacturing system, RMS core characteristics should be embedded in the whole system as well as in its components (mechanical, communications and controls).

4. The RMS contains an economical mix of flexible and reconfigurable equipment with customized flexibility, such as reconfigurable machines whose functionality and productivity can be readily changed when needed.
5. In general, systems with many alternative routes to producing a part are more reconfigurable, but they require higher investment cost in tooling and in material-handling systems.
6. The RMS possesses hardware and software capabilities to respond cost effectively to unpredictable events (market changes and machine failure).

As is shows in Figure 2, there are six key characteristics in a reconfigurable manufacturing system (RMS), namely, modularity, integrability, customization, convertibility, scalability and diagnosability. Also, as explained above, to implement design methodology, the five principles of separation, unification, connection, adaptation and reusability, are the reference to achieve the six characteristics of RMS. Upon the five RMS design principles, it is noticeable that the relationship between six characteristics and five principles is a key to understand the RMS design methodology [6, 7].

The relationship of principles and characteristics chart is showed below in Figure 2.

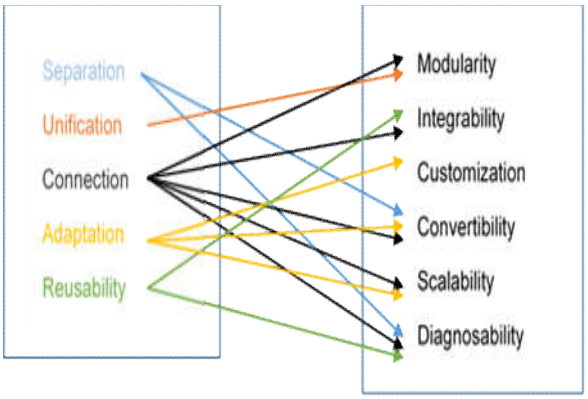

Figure 2 Relationship of principles and characteristics for RMS

Comparison of flexible and reconfigurable manufacturing systems

Every manufacturing enterprise, and, in turn, its manufacturing systems, should have three goals: produce at low cost, enhance product quality, and possess capabilities for rapid response. Reconfigurable systems are focused on achieving the third goal – responsiveness, and achieving it at low cost and rapid time. As we will show, manufacturing systems that use reconfigurable components and architectures can offer much greater benefits to manufacturers than traditional manufacturing systems. These include adjustable rates of productivity and flexibility, along with new tools for designing systems and getting production up and running are a hallmark of reconfiguration design that improve the time-to market and provide production at precisely the quantities needed, and at the lowest possible cost [2].

Current traditional manufacturing systems that are mainly dominated by dedicated and flexible systems, are not able to meet the market responsiveness requirements at reasonable cost, as explained below [2].

Dedicated manufacturing lines (DML), or transfer lines, are based on fixed automation and produce a company's core products or parts at high-volume. Each dedicated line is typically designed to produce a single part (e.g., specific engine block) at high production rate. When the volume is high, the cost per part is relatively low. Therefore, DMLs are cost effective as long as market demand matches the supply; but with increasing pressure from global competition, there are many situations in which dedicated lines do not operate at full capacity, and thereby create losses. Of course, producing product variety is impossible with a DML, and therefore their role is decaying in modern manufacturing.

Flexible manufacturing system (FMS) consist of computer numerically controlled (CNC) machines and other programmable automation and can produce a variety of products on the same system [1]. Despite this advantage, however, our survey shows that flexible systems have not been widely adopted, and many of the manufacturers that bought FMSs are not pleased with their performance [2]. Drawbacks of FMSs are that they require more expensive machines than DMLs, and because of the single-tool operation of CNC machines, the production rate of FMSs is very small compared with their DMLs counterparts. In addition, the production capacity of FMSs is usually lower than that of dedicated lines, and they are not designed for a quick change in their capacity, namely, they are not responsive to market changes [2].

Reconfigurable manufacturing system (RMS) is a modern system that bridges the gap between the DML and the FMS. RMS design is focused on producing a particular family of parts rather than an infinite range of parts limited only by the machine's

geometric and operational envelope, as is the case with FMS. The RMS trades a bit of flexibility for higher throughput. While a RMS does not provide the general flexibility that FMS offers, it can have just enough flexibility (i.e., functionality) to produce the whole part family for which it was designed. Therefore, the RMS has the advantages of both FMS and DMLs without their drawbacks [3].

More importantly, an RMS includes added advantages that neither of the others possesses. RMS is designed to "reconfigure," to grow and change within the scope of its lifetime, and so it can respond to market changes quickly [9]. In other words, the RMS is designed for changes in its production capacity (the number of products it can produce) and in its functionality (which provides the capability to produce new parts and products) in ways that do not affect its overall robustness or reliability. Reconfiguration allows an RMS to achieve throughput approaching that of a DML but allows it to produce simultaneously several products.

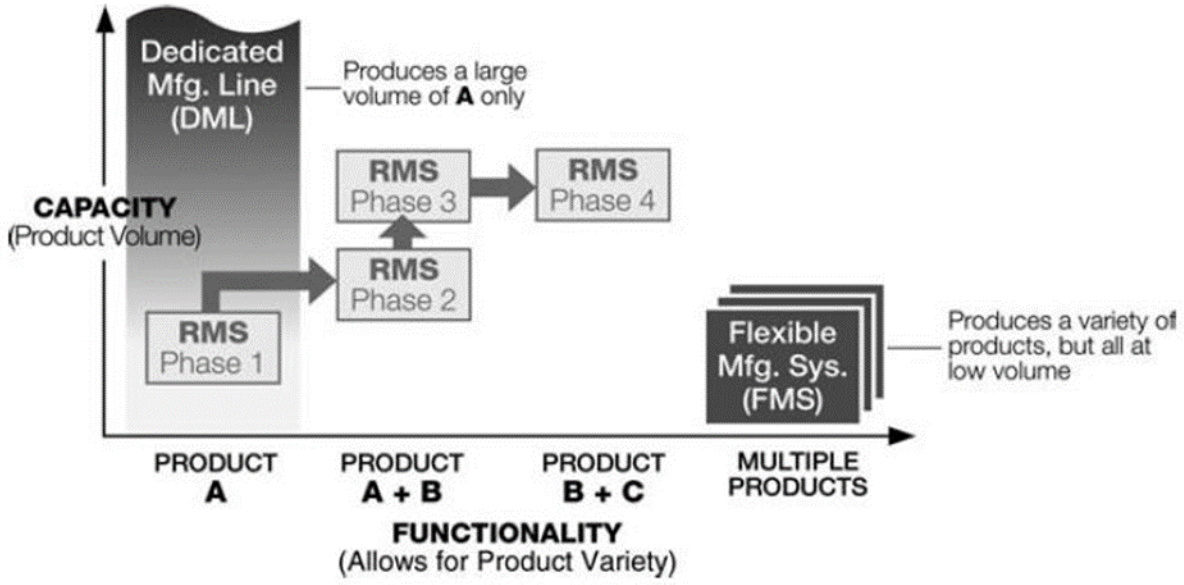

Figure 3 Changes in RMS during its lifetime in response to new product [9]

Figure 3 shows the advantages that RMS represents. In this example, the RMS is initially built to produce only Product A. After some time, the system is reconfigured to produce Product B as well. However, since this requires overall higher production output, the system capacity must be higher (phase 2). As the market for Product B grows, more production units are added to the RMS (phase 3). Finally, after a few years, Product A is phased out completely but a new Product C is introduced; the RMS can fulfill all these requirements (phase 4) in Figure 3 without a major redesign of the system. The RMS is designed at the outset so that adding capacity can be done cost-effectively, and the system alterations needed to produce new products are done just as easily [9].

The key feature of RMS is that, unlike a DMS and an FMS, its capacity and functionality are not fixed. The RMS will be designed using reconfigurable hardware and software, such that its capacity and/or functionality can be changed over time and unlike other manufacturing systems, it does not have a fixed hardware/software. It is clear that current trends in open-architecture control (reconfigurable software) and in modular machines (reconfigurable hardware) are key enabling technologies for RMS. Reconfigurable manufacturing systems will not be more expensive than flexible manufacturing systems or even dedicated transfer lines. Unlike the other types of systems, the RMS aims to be installed with the exact production capacity and functionality needed, and may be

upgraded (in terms of both capacity and functionality) in the future, when needed [2, 9].
The main components of RMS are CNC machines and Reconfigurable Machine Tools (RMTs) - a new type of modular machine with a changeable structure that allows adjustment of its resources (e.g., adding a second spindle unit). In addition to RMTs, also reconfigurable controls that can be rapidly changed and integrated in open-architecture environment are critical to the success of RMS [2].
A reconfigurable machine tool (RMT) can therefore be designed to perform the necessary machining operations on all the members of the part family with reconfiguration to the machine tool itself [7, 9]. That means that the RMT can cost-effectively produce a whole family of parts, even part styles that haven't been called for yet, with equal precision and reliability [7].
There are two basic objectives in RMT design. These objectives are:
1. To increase the production rate for the machine by adding machining devices (…exactly the capacity needed),
2. To adapt the functionality of the machine by changing its geometry to fit the production of a new member of a family of parts (…exactly the functionality needed) [2, 9].
The architecture of RMS can be hierarchically structured as shown in Figure 4. On the system level Reconfigurable Machine Tools (RMT) are linked into sequential or parallel production lines [2, 10].

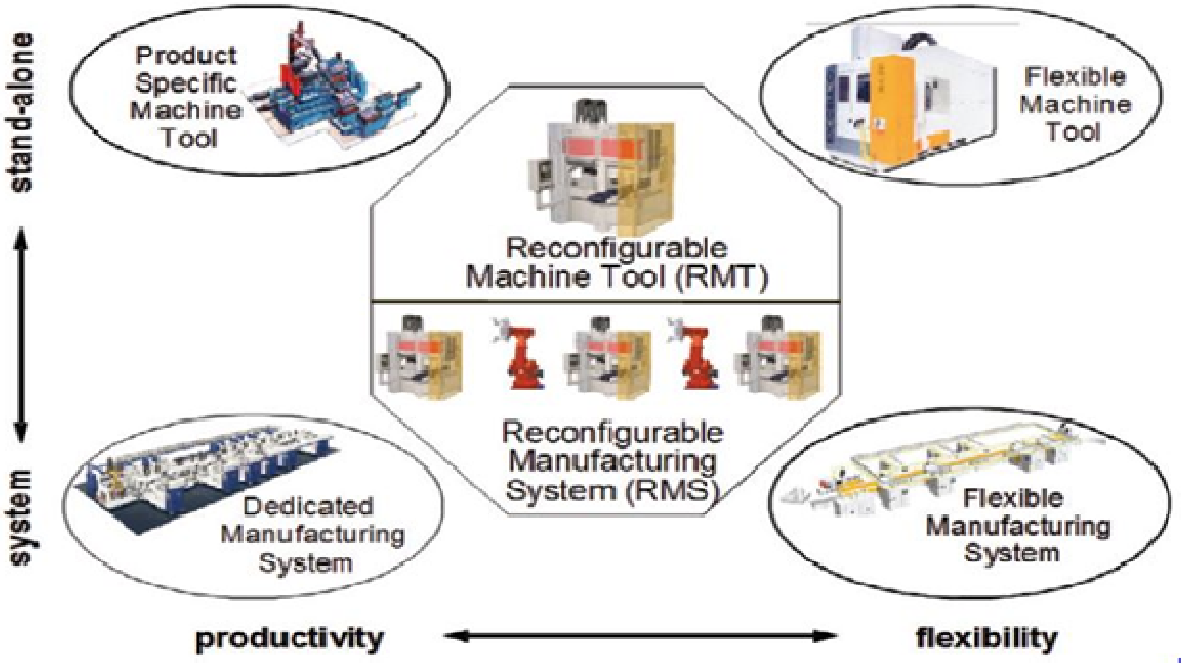

Figure 4 Classification of Manufacturing Systems [10]

A system designed per these principles constitutes a new class of systems – a Reconfigurable Manufacturing System (RMS). The RMS is designed to cope with situations where both productivity and the ability of the system to react to change are of vital importance. The invention of the RMS is documented in US Patent #6,349,237 [8].

Conclusion

Manufacturing companies in the 21st century face increasingly frequent and unpredictable market changes driven by global competition, including the rapid introduction of new products and constantly varying product demand. To remain competitive, companies must design manufacturing systems that not only produce high-quality products at low cost, but also allow for rapid response to market changes and consumer needs. Reconfigurable system is a novel engineering technology that facilitates cost effective and rapid responses to market and product changes. All these changes are driven by aggressive competition on a global scale, customers who are more educated and demanding, and a rapid pace of change in product and process technology [2, 5].

Global economic competition and rapid social and technological changes have forced manufacturers to face a new economic objective: manufacturing responsiveness (i.e., adaptation of the manufacturing system to market conditions). To respond to these challenges a new type of manufacturing system, a Reconfigurable Manufacturing System, is needed. Reconfigurable manufacturing systems are quite different than the current manufacturing technologies (i.e., dedicated manufacturing lines and flexible manufacturing systems) in that they are designed at the outset with adjustable resources in order to provide exactly the capacity and functionality that are needed, exactly when needed.

Acknowledgements

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