INTERNATIONAL RESEARCH JOURNAL IN ADVANCED ENGINEERING AND TECHNOLOGY (IRJAET) E - ISSN: 2454-4752 P - ISSN : 2454-4744
VOL 2 ISSUE 2 (2016) PAGES 582-588
RECEIVED : 06/03/2016. PUBLISHED : 15/03/2016
March 15, 2016

A PLATFORM ARCHITECTURE DRIVEN APPROACH FOR RECONFIGURABLE MACHINE TOOL DESIGN

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Abstract:

This paper addresses a reconfigurable platform based design approach of developing modular reconfigurable machine tools to provide an effective solution for product family machining in a responsive manner. Theory of modularization for reconfigurability is developed and used in the design approach. It is applied as inverse engineering over the conventional machine tools required by the part family machining to form the machining system platform. The developed method is an alternate for the existing kinematic enumeration based RMT design and has the advantage of manufacturing system level consideration in the design process.

Keywords: Reconfigurable machine tool, platform architecture, modularization for reconfigurability

1. INTRODUCTION

The Reconfigurable Manufacturing System (RMS) emerged few years ago in an attempt to achieve changeable functionality and scalable capacity. RMS is designed to provide customized flexibility to produce a part family and to cope with situations where both productivity and the ability to react to changes are of vital importance, so an ideal RMS comprehends the advances of DMS and FMS. Reconfigurable Machine Tools (RMT) are proposed to enable the RMS[1]. RMT is characterized by modularity of key components and reconfigurability.

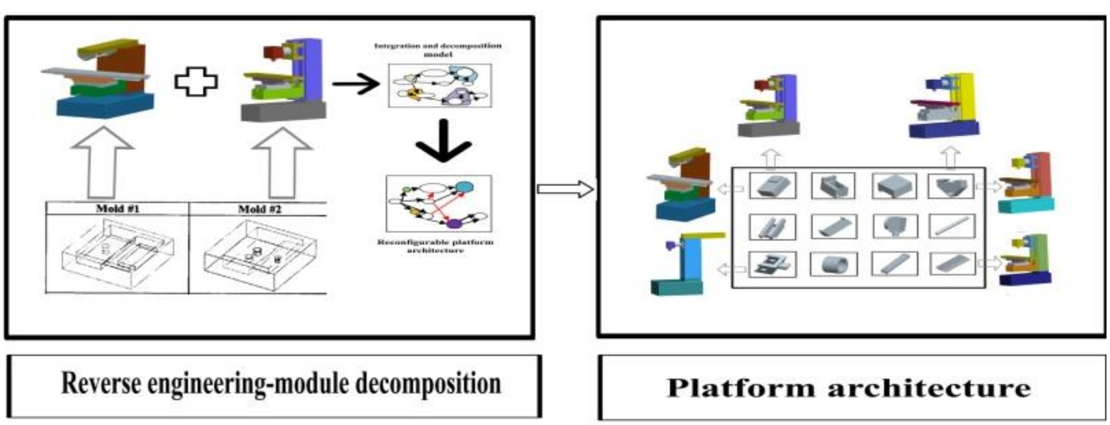

Fig.1. Proposed modular reconfigurable platform architecture generation

The RMTs are configured for a part family machining rather than configured for general functionalities as in general purpose CNCs. It has been equipped to reconfigurable within the part family for the variations with part geometry and production demand. To cope with this difficulty, it is effective to design the structure modules of the RMT as a whole from planning, throughout design and manufacturing for reconfigurability. This could be achieved in two ways, one, design RMT for a part starting from the CL data [2,3]; two, the approach proposed in this paper, by identifying candidate machine tool required to process a part family and re-engineer them to form a generic platform architecture. Having a generic reconfigurable platform architecture, various configurations capable of supporting process variations can be assembled by changing, adding and integrating the modules or even re-setting up platforms simply, and thus forming an effective reconfigurable manufacturing system rapidly and effectively. Furthermore, the platform can be used as a generic machine unit for forming a manufacturing system at low cost.

This work defines platform-based design of reconfigurable machine tool as creation of a stable modular-based architecture that can be rapidly extended, customized for a range of machining application, and delivered to customers for quick deployment and configure or reconfigure to their changing needs within the specified range of machining application. Aiming at developing the technological basis, a method of modularization for reconfigurability is proposed across a family of machine tools based on functionality, module commonality and configuration similarity. The present work uses inverse-engineering approach as detailed in Fig. 1. In this approach, the conventional machine tools are integrated and decomposed at their The difficult problem is how to bring and control the adoptability of modules for ‘part family customized reconfigurability’, and to reduce the number of modules in the platform architecture.

With the above situation as background, the objective of paper is to propose a new method for machine tool structure modularization and module design to show new possibilities in machine tools with better reconfiguration potential. Towards the platform design approach, Mori developed a method with multi-machining technology where RMT is defined as platform architecture and the reconfigurations are done by choosing candidate modules at each level [4]. A novel generic modular reconfigurable platform (GMRP) is proposed in [5]. It offers hybrid manufacturing capabilities, modularity, reconfigurability and adaptability to provide agile, responsive system. In a research, the reconfigurability of machine tool has been studied for agility of the machining system and a design frame work has been suggested for such RMTs [6].

2. MODULARIZING FOR RECONFIGURABILITY

2.1. Commonalities in machine tools

Commonality will be must criteria for module realization in platform based approach [7]. In machine tools, the module interaction is less complex and is characterized with few and standard interfaces. Hence, the modularization is limited to functional interactions, inturn, simple physical interactions. It changes the sense of commonality that is different from regular modular product design.

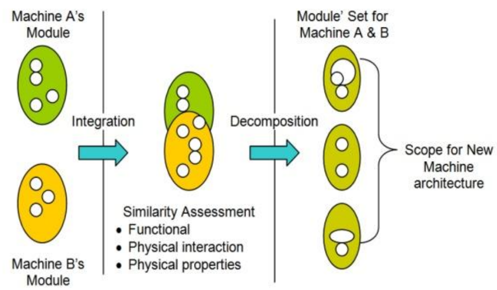

Fig. 2. Proposed decomposition strategy for modularization

The commonalities in machine tool structure are functional commonality, physical interface (connection) commonality, physical characteristic commonality (load bearing capacity). It is obvious that mere load bearing capacity of a structural module can be a decisive factor for module realization in machine tool modular design. For example, a column with sliding functionality can be decomposed to base and slide, and the base can be used for 'other functionalities'. Thus the load bearing capacity and the unused faces of the column are used as a source to make reconfigurability. The decomposition strategy for modularization is detailed in Fig.2.

2.2. Proposed Decomposition Approach

The criticality lies in estimating the similarity and deviation. An improved function structure which shows functions, interfaces and structural properties is used for this purpose. It is used to read the adjacent modules function and physical interfaces. Estimation of similarity and deviation between modules or sub-systems help in selecting functional scope of the modules or sub-assemblies for the decomposition process. Moreover, this approach will add system level consideration to the modularization process.

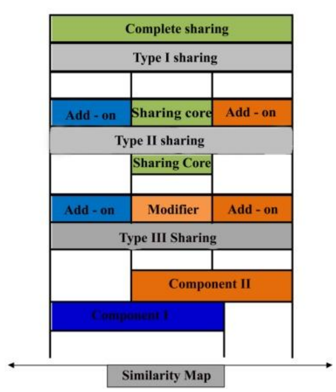

Fig. 3. Similarity mapping of system, sub systems and modules

The aim is to increase the share-ability among the modules or sub-systems in the considered machine tools to achieve reconfigurability. The overlapping of functions results in sharable core module and the deviation ends in add-on modules. decomposition problem.

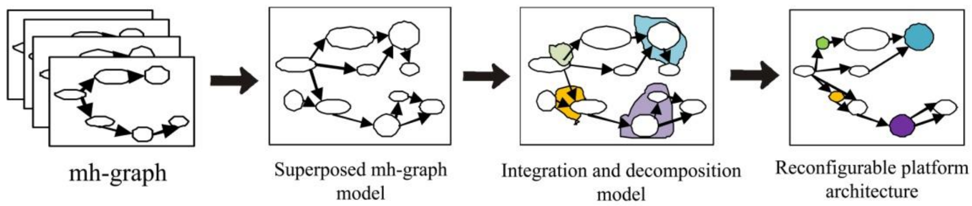

Fig. 4. Modularization for reconfigurability

Similarity analysis determines the commonalities between two machines. It also indicates the deviation and the possibility of convertability from one to other. Similarity analysis and convertability analysis have to be done at various levels starting from components to whole system. The criteria used for analyzing are functional, physical interface, physical characteristic sharings and shape, size and strength Similarities of modules are used to select modules for the decomposition. Three possible types of share-ability (similarity) between two products have been possible as fig.3.

3. PROPOSED MODULARIZATION FOR RECONFIGURABILITY

Outline of the proposed modularization procedure is detailed in Fig. 4. The approach assumes that selected machine group for machining the part family is available. As first step of the procedure, modules and their interactions of target machine tools are described in graph structure. Graph representation is preferred for its simple construction and ease of implementation. An attributed multi-point hypergraph representation proposed in [8] is used and each target machine is modeled as a graph.

3.1. Dependency and Sharability Analysis

In the next step, similar modules are identified with their connectivity to the neighbors using error tolerant graph matching [9]. The graph matching algorithm process two or more graphs to find and list similar modules, sub-assemblies. The error, allowed deviation, in the matching is used to maximize the similarity by allowing added functions or interfaces. The details of the algorithm are left as it is beyond scope of this paper.

3.2. Modules Development

The next task is to maximize the similaritywithin the components, modules and sub-system with the proposed modularization approach. The result is convertibility analysis (feasible conversions of module for reconfiguration purpose). The graph representation has the advantage of re-writing which is controllable via external constraints [8]. The conditions of added functions, add-on functions, function distribution between modules and the other decomposition criteria will form the graph re-writing constraints.

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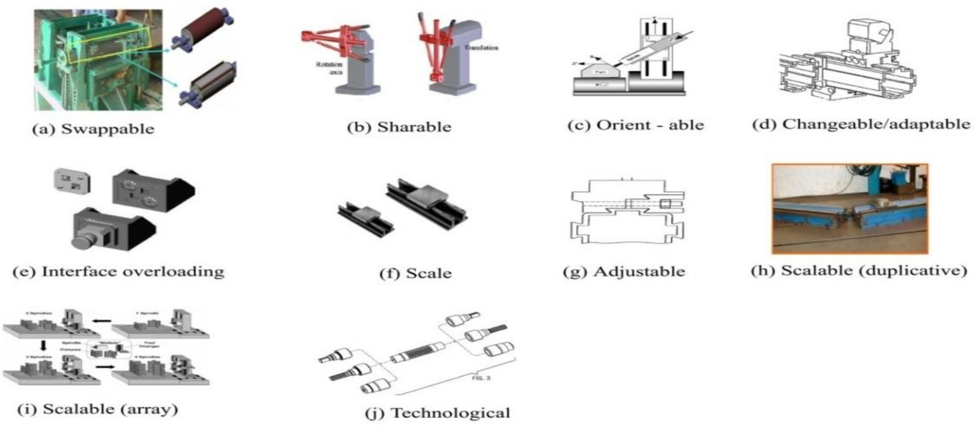

Fig. 5. Types of reconfigurability

application of alternate graph re-writing rules form alternate paths and each of them mean different module formation (preparation of module for reconfiguration) starting from the single seed. The final graph means a generic multifunctional module. These generic multifunctionalmodules (graphs)are decomposed (again graph re-writing) for solid specification module based on the proposed decomposition strategies. Reconfiguration opportunities, types of modularity (listed in Fig.5.) are used to configure the modules. These module development steps are repeatedly applied to successive resultant sub-modules up to meaningful pendant components to achieve a stable modular structure.

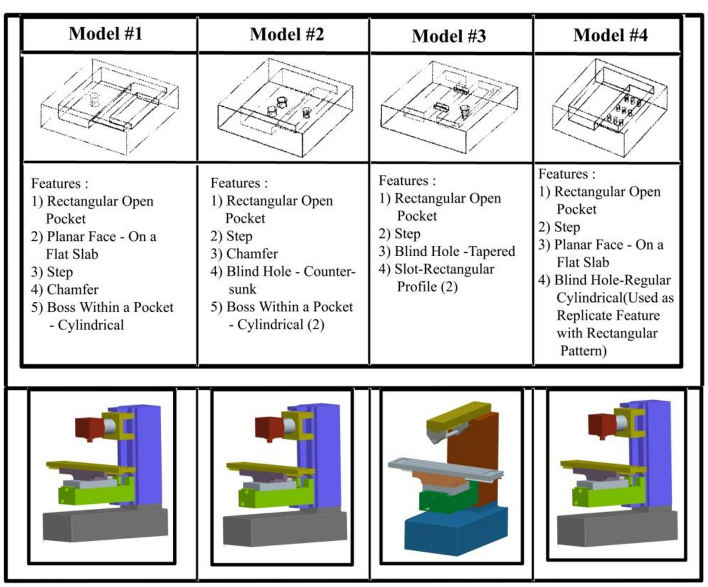

Fig. 6. Exemplary parts and corresponding machining system

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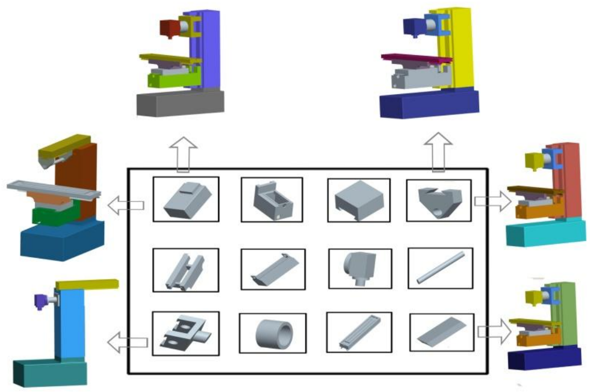

Fig. 7. Reconfigurable platform architecture generated based on proposed methology

3.3. Platform development

The candidate machine graph and the modules formed by (graph re-writing) rules of module construction will form the reconfigurable platform architecture. It is a superimposed hyper-graph whose alternate path specifies the machine tool reconfiguration. It results in modules and their interaction to form platform with scope for reconfigurability. The new paths in the graph mean new machine configuration with entirely different functionality from the candidate machine tools considered in the process.

4. CASE STUDY

The parts with their machining features, operation requirements and selected candidate machines selected for the case study are detailed in Fig 6. These roughly consist of 19 functional modules, such as column, various slide, various spindle, table, drives, and bases. A complete similarity is found in knee assembly. The column module has knee sliding function and strength sharing in both the configuration whereas it shows variation in machining unit holding and drive unit mounting. Machining unit shares functions at machining end but shows variation in receiving rotational input and physical connection with column.The modules are redesigned based on the design theory proposed. Salient points in the design are full length running slide, drive unit mounting that satisfy both the configuration, a slide on top of the column to fix machining unit carrier and a fixing interface (in the side face) for spindle arm. The slide in the column is adjusted to take knee or slide which allows both spindle slide configuration and knee type configuration. This will allow the column to take horizontal orientation which carry cross slide assembly and form entirely different configuration. Similarly, the spindle is added with interface to take rotation motion from both top and aside face. A directional changing mechanism is added as add-on assembly for rotational motion input from the side. The vertical sliding motion is alternatively considered in the spindle carrier and adds to the platform as an alternate module for vertical sliding function. Sliding and rotation modifiers are introduced as functional adopter for the spindle module. The platform is added with swing (rotation modifier) module to provide orientation possibility to the spindle. The developed platform along with possible machine tool configurations is shown in Fig.7. Finally the modules are optimized for the loading condition arises with candidate machine tool configurations.

CONCLUSION

A theory of modularization for reconfigurability is developed and used for reconfigurable platform design of RMT. The method will help in forming reconfigurable modular platform architecture of a part family machining system. Various RMT modularity types are captured and used in the modularization process. The similarity at the module, assembly and sub-system level of RMT is increased by applying modularization approach developed which includes machining system level consideration. The method can be improved by adding additional conditions and constraints to the modularization process. A systematic computational algorithm can be developed to accomplish the proposed platforming method.

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