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Optimal Framework for reconfiguration of manufacturing setups using Non Dominating Sorting Genetic Algorithms

[Eram Asghar, Aamer Ahmad Baqai, Ramshah Ahmad, Nazish Liaqat]

Abstract— **The concept of reconfigurable manufacturing system has emerged drastically as it reduces the product lead time and meets with the market demand efficiently. The performance of a manufacturing system lies on a set of planning and scheduling data incorporated with the machining capabilities keeping in view the market demands. The proposed work focuses on the formulation of an optimal framework for production over part families. Machine's kinematic configurations are generated considering tool's degree of freedom. The application of non-dominating sorting genetic algorithms over machine configurations makes this approach more reliable. A case study has been presented to illustrate the application of proposed model based on the technological constraints.**

Keywords—*Reconfigurable manufacturing system (RMS)), Multi objective Genetic Algorithm (MOGA), Non dominating Sorting Genetic Algorithms (NSGA), Couvercle De Vileberequin (CDV*), *Corps de Pompe a Huile moteur(CPHC).*

I. Introduction

Manufacturing companies started facing unpredictable market fluctuations in the start of 20^{th} century. Due to the unexpected demands, product design needs to be modified accordingly. The shorter product life cycle are urging the manufacturers to modify their systems to the frequent design changes. Thus there is a need of a reconfigurable model to accommodate all the design changes with customized flexibility and capacity. Reconfigurability is an engineering technology that deals with the design and manufacturing system to make required modifications to respond cost effectively to market changes. The concept of RMS was introduced to sustain in global market by rapid adjustment and modification of production capacity and system functionality in reaction to abrupt market demands. In this research work reconfiguring methodology has been introduced to switch the production from one part to another through the application of non-dominating sorting genetic algorithms.

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II. Related Work

In RMS field, research is being in progress for the development of changeability enablers to adjust and rebalance the system configuration depending upon the requirement. Changeability concept allows the change enablers at different levels of any industry to sustain the life cycle of manufacturing system. Responsiveness is required at different levels in manufacturing system in terms of changeability and scalability. Reduction in product cost and responsiveness can be observed by customizing the machining capabilities at product design stage and then the reuse of these capabilities at reconfiguration stage [1,2]. One of the major contributions in configuration selection was carried out by Youssef and ElMaraghy [3]. It is a novel approach for the selection of machine configurations in two phases. In phase one, near optimal configuration is selected considering different demand scenarios using real coded GA and Tabu Search (TS). The second phase deals with discrete optimization to search the optimal configurations from the ones that were produced in the phase one. Reconfigurable Machine Tool (RMT) is modular type of machine tool having the characteristics like convertibility, integrability and modularity [4]. These characteristics of RMS allow mass customization and rapid response to the product design change. Machine kinematic configurations are generated from the set of functional requirements and process plans in order to design RMTs as stated by Moon and Kota [5]. Another approach was proposed by K.K Goyal [6] for optimal assignment of machine in parallel setups. In this approach optimal configurations are generated through an optimization technique of non-dominating sorting NSGA and adopted TOPOSIS ranking theory. This approach leads to the machine tool reconfiguration by adding or subtracting machine modules going through different performance measures. NSGA-II technique has also been used by Abderrahman et al [7] in the selection of optimal machines from the set of candidate machine configurations. In this research work multi product case with high degree of freedom can be considered as future work. With the idea of co-evolution the machine configurations can be used for different product designs over and over again preserving the feasibility of the system for a long period of time. P.Mohapatra et al [8] proposed the method to bridge the gap between scheduling and setup planning by grouping the machining features on the basis of tool approach directions (TAD), adopted NSGA –II and fuzzy set theory to get the best pareto optimal solution. Recently, Ahmed Azab et al [9] proposed a methodology in modeling of large problems which include sub family sequencing and parts in each sub family to minimize the maximum completion time using mathematical programming software. Reconfigurable Manufacturing Systems are built to effectively respond to

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market changes. Although plenty of work exists on the issues of RMS but a wide scope of study is still required in all fields of RMS. To have real implementation of RMS, a reconfigurable framework is required through which production around a part family can be made possible with minimum machine capabilities.

III. Proposed Methodology

The proposed optimized reconfigurable model is required that should be intelligent enough to track and accommodate the design modifications and system requirements. In reconfigurable manufacturing environment, machines exist in different configurations with customized flexibility allowing the rapid change of machine configuration. Each machine consists of various modules providing different tool and orientations of parts. Configuration changeover depends upon the machine's visibility for that particular operation.

A. *Optimal Machine Configuration*

Machine's structural configuration is generated on the basis of orientation required to generate any particular feature of the part family. The inputs of this algorithm are alternative process plans and possible tool approach directions. Depending upon the machine's accessibility and tool approach directions, machine's kinematic configurations have been generated for each process plan (see figure 1).

Figure 1. Algorithm for Optimal Machine Configuration

Mostly optimization of engineering designs are carried out through evolutionary algorithms which are stochastic global search methods inspired by natural evolution. These algorithms are basically inspired from different natural phenomena and make use of the best character of that phenomenon. As discussed earlier, this algorithm searches the global optimum solution and because of its extreme robustness the probability of getting the minimum global solution increases. GA's are the powerful global search algorithm was introduced in 1975 by John Henry Holland. It is method of searching the best solution from population to population by using the natural selection. The major difference of GAs from other search techniques is its initialization of random solutions called population and each individual in a population is chromosome representing the solution to the problem [10]. Multi objective Genetic Algorithms (MOGAs) are the extended form of single objective GAs. Non dominating sorting genetic algorithms (NSGA) works by minimizing each objective first and then by computing the overall fitness of the objectives as a single objective function leads towards the single optimum solution. In most of the multi objective problems, a set of solutions exist from the large search region which is superior from other solutions in the search space, these solutions are called pareto optimals or non dominated solutions [11]. If in case, no solution in the feasible region is better than other, then any of the solution is acceptable. Sometime designers are interested to get all alternative solutions for this reason the concept of pareto optimality is used for multi-criteria optimization. The idea behind this algorithm is to rank the solutions according to their non domination count to get a set of pareto optimal solutions. Non dominated solutions are those which are not dominated by any other solution in the feasible design space [12]. The aim of this research work is to minimize the machine capabilities and reconfigure the production system optimally. Therefore considering the criteria of tool change, set up change and part rotation the genetic algorithms have been applied.

IV. Results and Discussion

The developed model has been evaluated applied on two case study parts CDV and CPHC belonging to same part family. Specifications of these parts are mentioned in annex. The tool axis available depending upon the machine's visibility and its movement for different features of process plans are presented in the schematic diagram of process plan depicted in figure 2.

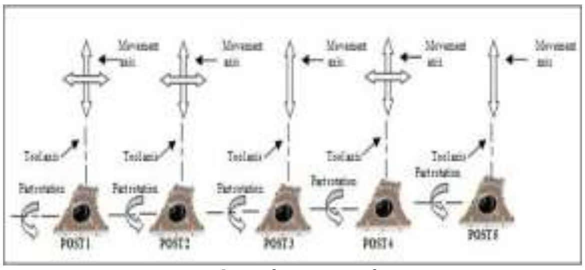

Figure 2. Tool Configuration of Master Part

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TABLE I: Optimal Machine Configuration for CDV

Ops	Machine Configurations						Spindle Angle of Rotation		
	X	-X	Y	-Y	Z	-Z	α	β	ϒ
OP3	0	0	1	0	0	0	- 90	0	0
OP1	0	0	0	0	0	1	0	0	0
OP12	0	0	0	0	0	1	0	0	0
OP7	0	0	0	0	0	1	0	0	0
OP5	0	0	0	0	1	0	0	180	0
OP6	0	0	0	0	1	0	0	180	0
OP8	0	0	0	0	1	0	0	180	0
OP4	0	0	0	0	0	1	0	0	0
OP2	0	0	1	0	0	0	-90	0	0
OP9	0	0	0	0	1	0	0	180	0
OP10	0	0	0	0	0	1	0	0	0
OP11	0	0	0	0	0	1	0	0	0
OP13	0	0	0	0	0	1	0	0	0
OP14	0	0	0	0	0	1	0	0	0

TABLE II: Process Planning Parameter CDV

No of setup changes	4
No of Tool changes	10
Part rotation	4
Spindle degree of freedom	7

The configurations obtained from the master part are compared with all possible combinations of machine configurations. As a result minimum machine configuration is generated for CPHC and the system is adjusted for production accordingly. These configurations and process planning parameters are shown in table 3 and 4.

TABLE III: Optimal Machine Configuration for CPHC

Ops	Configurations						Spindle Angle of Rotation		
	X	-X	Y	-Y	Z	-Z	α	β	ϒ
OP1	0	0	1	0	0	0	-90	0	0
OP5	0	0	0	0	0	1	0	0	0
OP6	0	0	0	0	0	1	0	0	0
OP13	0	0	0	0	0	1	0	0	0
OP2	0	0	1	0	0	0	-90	0	0
OP7	0	0	0	0	0	1	0	0	0
OP14	0	0	0	0	0	1	0	0	0
OP3	0	0	0	0	0	1	0	0	0
OP4	0	0	0	0	0	1	0	0	0
OP20	0	0	0	0	0	1	0	0	0
OP15	0	0	0	0	0	1	0	0	0
OP21	0	0	0	0	0	1	0	0	0
OP8	0	0	0	0	0	1	0	0	0
OP22	0	0	0	0	0	1	0	0	0
OP23	0	0	0	0	0	1	0	0	0
OP9	0	0	0	0	0	1	0	0	0
OP24	0	0	0	0	0	1	0	0	0
OP10	0	0	0	0	0	1	0	0	0
OP11	0	0	0	0	0	1	0	0	0
OP12	0	0	0	0	0	1	0	0	0
OP16	0	0	0	0	0	1	0	0	0
OP17	0	0	0	0	0	1	0	0	0
OP18	0	0	0	0	0	1	0	0	0
OP19	0	0	0	0	0	1	0	0	0
OP25	0	0	0	0	0	1	0	0	0
OP26	0	0	0	0	0	1	0	0	0
OP27	0	0	0	0	0	1	0	0	0
OP28	0	0	0	0	0	1	0	0	0

TABLE IV: Process Planning Parameters of CPHC

No of setup changes	8
No of Tool changes	24
Part rotation	0
Spindle degree of freedom	4

The output of the proposed algorithm shows minimum axis of spindle rotation for each operation. The optimum machine configurations for the master part CDV are shown in table 1 along with the spindle rotational angles and process planning parameters are shown in table 2. It is evident from table 2 that minimum changes have been obtained through the application of MOGA.

The above case study shows that by applying the proposed approaches, an optimized reconfigurable framework can be obtained. This framework includes: optimum process plans, optimum machine's kinematic configurations and reconfiguration changeability extent. RPP represents important changeability enablers for product and manufacturing system evolution. It cost effectively manages the change in product and modify the system accordingly.

Conclusion and Future Work

This research work is concerned with the development of an integrated approach for modifying the setup according to the variations in product design. Application of NSGA yields the system towards global optimum. The presented algorithm can manufacture the part family with minimum production changeover time and optimal machine capabilities. This work can be extended for multiple and parallel setups. Extension of the same algorithm by increasing the number of parts, this would add the versatility in the system.

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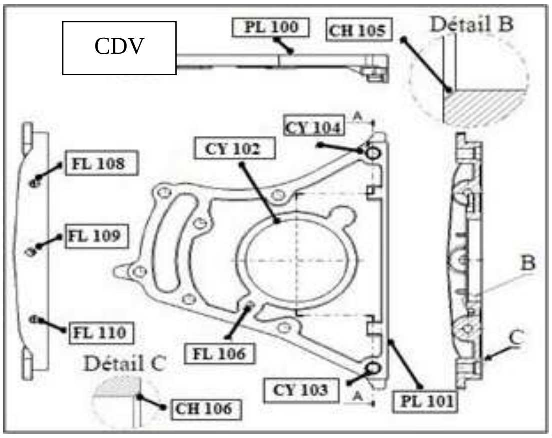
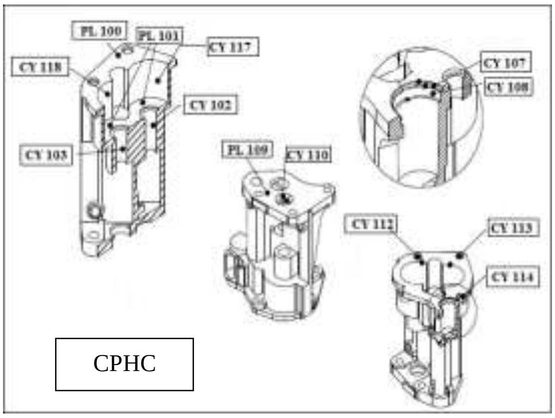
Annex.



Operation Data for Part CDV			
Features	Operations	Op ID	TAD
PL 100	Rough Milling	1	+x , +y , -z
PL 100	Finish Milling	2	+x , +y , -z
PL 101	Rough Milling	3	+z , +y
PL101	Finish Milling	4	+z , +y
CY 102	Drilling	5	+z , -z
CY 102	Reaming	6	+z , -z
CY 103	Drilling	7	+z , -z
CY 103	Reaming	8	+z , -z
CY 104	Drilling	9	+z , -z
CY 104	Reaming	10	+z , -z
FL 106	Drill	11	-z
FL 108	Drill	12	-z
FL 109	Drill	13	-z
FL 110	Drill	14	-z



Operation Data for Part CPHC			
Features	Operations	OP ID	TAD
Pl 100	Rough Milling	1	+x , +y , -z
Pl 100	Finish Milling	2	+x , +y , -z
Pl 101	Rough Milling	3	-z
Pl 101	Finish Milling	4	-z
Pl 109	Rough Milling	5	+x , +y
Pl 109	Finish Milling	6	+x , +y
Cy 107	Drilling	7	-z
Cy107	Boring	8	-z
Cy 107	Reaming	9	-z
Cy 108	Drilling	10	-z
Cy 108	Boring	11	-z
Cy 108	Reaming	12	-z
Cy 110	Drilling	13	-z
Cy 110	Boring	14	-z
Cy 110	Reaming	15	-z
Cy 117	Drilling	16	-z
Cy 117	Boring	17	-z
Cy 118	Drilling	18	-z
Cy 118	Reaming	19	-z
Cy 102	Drilling	20	-z
Cy 102	Boring	21	-z
Cy 102	Reaming	22	-z
Cy 103	Drilling	23	-z
Cy 103	Reaming	24	-z
Cy 112	Drilling	25	-z
Cy 113	Drilling	26	-z
Cy 114	Drilling	27	-z
Cy 115	Drilling	28	-z