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CO-DEVELOPMENT OF PROCESS PLANNING AND STRUCTURAL CONFIGURATIONS CONSIDERING MACHINE'S ACCESSIBILITY IN A RECONFIGURABLE SETUP

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ABSTRACT
Manufacturing System has been evolved over the years to accommodate major design variations. To respond to these high frequency variations and to stay competitive, there is a need of having such type of manufacturing system that could cope with market trends and design changes efficiently. Product's design and its manufacturing capabilities are closely related, thus the manufacturing system should be customized to cater all the design changes with suitable manufacturing capabilities. Reconfigurable Manufacturing system has been recommended for the turbulent market conditions because of its flexible and changeable nature. This research work is based on the co-generated model in which optimal machine configurations are generated through the application of optimization technique. Based on these configurations, system is tested for reconfiguration in case of production changeovers. Considering the relevant change drivers the degree of reconfigurability in any case of application can be achieved through proposed algorithm. 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), Alternative process plans (APPs), Flexible manufacturing system (FMS), Reconfigurable process planning (RPP), Genetic algorithms (GA), Dedicated manufacturing system (DMS).

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Contribution/ Originality

This study contributes in the existing literature of reconfiguration in a manufacturing system. Considering the parameters mentioned in eq.1 makes this approach generic, reliable and cost effective. Selection of operation and its sequence has given better flexibility and scalability through the application of MOGA. Actual resources (machining and assembly setups) can be obtained using this approach by measuring extent of reconfiguration for production changeovers.

1. INTRODUCTION

Reconfigurable Manufacturing System (RMS) has revolutionized the manufacturing industry. It has been integrated from some of the valuable features of Flexible Manufacturing System (FMS) and Dedicated Manufacturing System (DMS): flexibility from FMS and multi tool operation from DMS [1, 2]. In this perspective a lot of research is in progress in the field of reconfigurable process planning (RPP). The industrial requirement is to have such a system that could reduce the cost and enhance the product's quality in parallel. Thus with the objective of minimizing the cost and product's manufacturing time, this research work is based on the generation of optimal machine configuration for producing different features of a part. Machine accessibility is one of the key elements in generating structural configurations. It allows the tool to reach the surface of the manufacturing part.

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An evolutionary optimization approach has been adopted to search optimal process plan by minimizing certain parameters.

Process planning is basically a bridge between the design and manufacturing. RPP deals with the variations in process planning, due to which the need of adding or removing different machines and modifications in their structural configurations may arise [3, 4]. Many researchers are focusing on the concept of co-evolution or co-generation from last few years [4-6]. In this instance, Tolio, et al. [7] concluded from a survey that the changes in product, processes and production system are interlinked. One of the improved algorithms of machine configuration was proposed by Maaz and Baqai [8] in which Machine Adaptive Retain ability Approach was proposed to select process plan by comparing the previously employed process plan with the proposed process plan considering kinematic configurations. Optimality is not assured in calculus techniques, for this purpose evolutionary optimization techniques are being established over the past few years. Selection of candidate machines by integrating process plans and scheduling specifications simultaneously rather than two separate functions was proposed by Bensmaine, et al. [9]. Azab and Naderi [10] focused on sub family sequencing and parts in each sub family sequencing to model the problem of production scheduling. Although several papers are related to RMS, but few of them has discussed co-generation paradigm. There is a need to accommodate process planning and scheduling issues simultaneously. This would result in significant reduction in product's lead time and manufacturing cost.

2. PROPOSED METHODOLOGY

Since this paper is concerned with minimizing the cost and time in terms of machining capabilities, thus proposed methodology is divided into two stages. In the first stage, the algorithm for generating alternative process plans and machine configuration is presented. Second stage of the methodology is related to optimization through the application of multi objective genetic algorithm.

2.1. Process Plans and Machine Configuration

Process planning is categorized in two different levels: feature sequencing and operation sequencing. Feature sequencing is high level process planning which is related to minimization of tool and setup changes. On contrary, operation sequencing determines the order in which selected operations are to be performed while satisfying the constraints established for different features of part family [11]. In the presented work both level of process planning has been considered to get a reliable and cost effective process plan. Alternative process plans (APPs) have been generated from the proposed algorithm considering specific constraints: Precedence constraints, Datum constraints, Geometrical constraints and Technological constraints. The above mentioned constraints are to be satisfied while manufacturing any product. The inputs required are operations and the precedence relationship between these operations. The algorithm shown in 'figure 1' starts with the major step i.e. grouping of operations in a matrix based on the precedence between operations. Randomly select an operation, if it satisfies the zero precedence checks condition, saves it and assign next operation. If the precedence between operations satisfies, go to next step else return back to zero precedence check. Now check repeatability, if the selected operation is already in the saved array then discard this operation and randomly select another operation. Check size of saved array, if it is less than total no. of operations, return to precedence check, else save the generated process plan in a matrix. Repeat the algorithm till all possible process plans for different features of same part family generated. Machine's structural configuration is generated on the basis of orientation required to generate any particular feature of the part family. Depending upon the machine's accessibility and tool approach directions, machine's kinematic configurations have been generated for each process plan. This algorithm is applied on part Couvercle De Vileberequin (CDV) whose specifications are mentioned in Annex. The results of the proposed algorithm are discussed in later section to explore the optimized process plan through optimization technique.

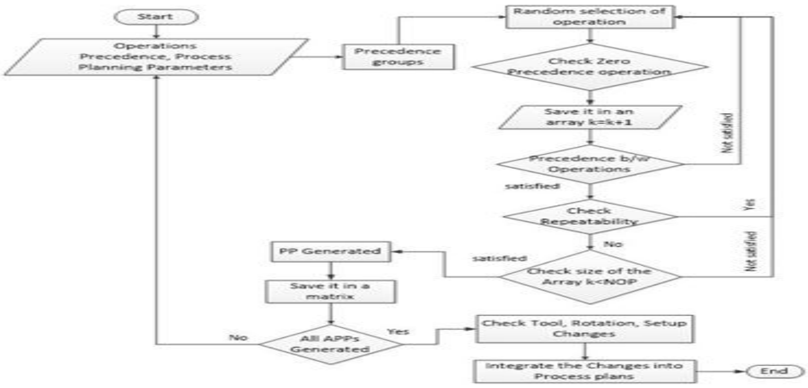

Figure-1. Algorithm for APPs

2.2 Optimization

This section aims at the automatic generation of optimal process plan minimizing different parameters of process planning. The parameters which are taken into account are: part rotation, tool and set up changes, spindle degree of freedom subject to precedence and technological constraints. As calculus based techniques have limited search region, evolutionary optimization technique has been adopted. GA's are the powerful global search algorithm and was introduced in 1975 by John Henry Holland. Population size of candidate solution is user defined but it affects the performance and scalability of GA's. Small population size may result into premature convergence and large population size takes unnecessary computational time [12]. Thus in the proposed approach population is updated to increase randomness and search region which guarantees the convergence of genetic algorithm into feasible region. The output of the proposed algorithm is the optimized process plan and machine's structural configuration. Starting with the following steps to evolve the solution to search the optimal process plans.

Step1: Initializing Population

Initial population of all possible APPs is generated. GA parameters (population size, stopping criteria) and process plans generated are the inputs.

Step2: Fitness Evaluation

Fitness evaluation of the whole population generated based on the fitness criteria shown in Eq-1.

$$f(x) = f(T_i, S_i, R_i)$$

$$f(x) = \min(\sum_{i=1} T_i . w1 + {}^{n}\sum_{i=1} S_i . w2 + {}^{n}\sum_{i=1} R_i . w3 + {}^{n}\sum_{i=1} dof_i . w4) \quad \text{(Eq-1)}$$

$$w1 = 0.25, w2 = 0.25, w3 = 0.25, w4 = 0.25$$

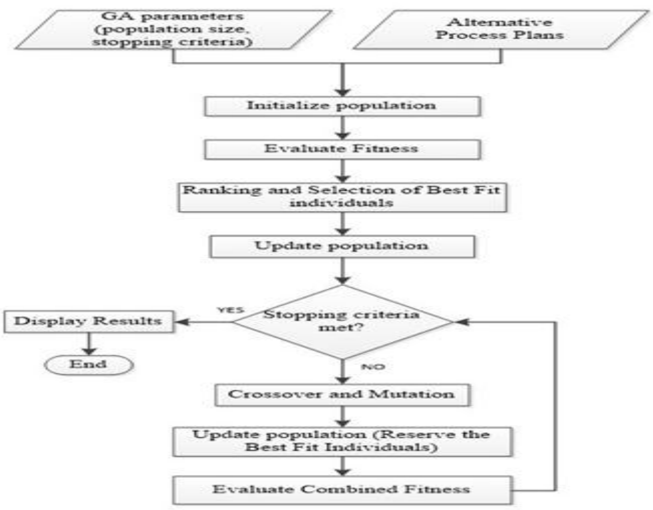

Figure-2. Multi Objective Genetic Algorithm

In the presented work, equal weights have been assigned to each objective to avoid conflict. Preference can be given to any particular objective according to requirement.

Step3: Selection

The idea of selection is to prefer the best fit individuals and discard the weak ones. The individuals after evaluating the fitness are ranked. The ones having better fitness are preferred for next generation to produce children i.e. to make new combinations.

Step4: Update Population

Reserve the best fit solutions from the population. Updating population avoids premature convergence and diversifies the search region.

Step5: Recombination

By recombining the portions of good individuals, there is a possibility to get better combinations. Recombination accelerates the search in population. There are many methods to accomplish recombination. To achieve better performance and better combinations, properly design crossover mechanism is required. Many crossover mechanisms have been developed which includes: uniform crossover, cycle crossover, order based crossover, partially matched crossover [12]. Position wise crossover has been used in the current methodology. The working of the cross over operator is shown in 'table 3' and 'table 4'.

Table-1. Parent Sequences

P1	A	B	C	D	E	F	G	H	I	J
P2	J	H	G	C	E	F	D	B	A	I

Table-2. Child Sequences

C1	A	B	C	G	E	F	D	H	I	J
C2	J	H	G	C	D	E	F	B	A	I

Step6: Mutation

This operator randomly selects two individuals and swaps them to maintain diversity. Random individuals from each child obtained in step 5 (shown in 'table 4') are mutated to enhance the efficiency of genetic algorithm. The mutated sequences are shown in 'table 5'.

By the application of GA, individuals having the best fitness are obtained. Best fitness means having minimum changes of tool, setup, part rotation and spindle degree of freedom. GA gives best fit process plans along with their corresponding kinematic configurations.

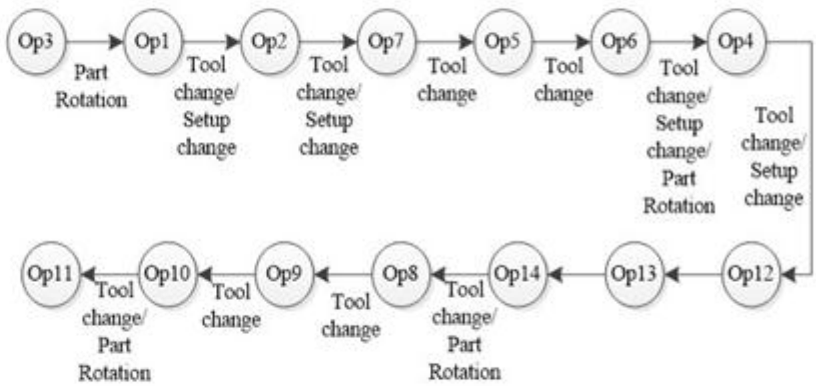

Figure-3. Graphical Representation of Process Plan

3. CASE STUDY AND RESULTS

To explain the working of developed algorithms, analysis has been carried out on different features of CDV. The developed optimization technique of genetic algorithm has been implemented on master part to get optimized process plan (shown in figure 3).

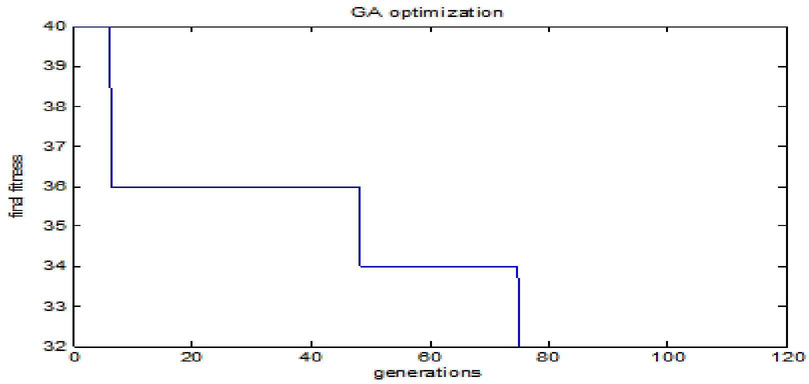

Figure-4. Convergence of Genetic Algorithm

The graph shown in 'figure 4' demonstrates that optimized process plan obtained after 75 generations for part CDV.The converegance in graph shows that the fitness function reaches to minimum optimal value with the increase in generations. The optimized process plan obtained through multi objective GA is presented in 'table 7' along with its corresponding kinematic configurations.

Table-7. Kinematic Configurations

PP	3	1	2	7	5	6	4	12	13	14	8	9	10	11
K.Cs	+y	+y	+x	-z	-z	+z	-z	-z	-z	-z	+z	-z	-z	-z

The above case study shows that by applying the proposed approach optimum process plans and corresponding machine's kinematic configurations can be achieved for reconfiguration changeability extent. The proposed methodology is more practical and generic in the way that it has the ability to cost effectively reconfigure the system. The presented algorithm can manufacture the part family with minimum production change over time and optimal machine capabilities.

4. CONCLUSION AND FUTURE WORK

Different approaches have been developed in past for generating process plan and machine configuration in a fixed machine structure. In proposed approach an application of multi objective genetic algorithms optimized the reconfigurable system by the selecting the optimized process plan from a set of alternative process plans. Integration of machine's kinematic configuration of each process plan according to machine's visibility and accessibility gives the possible machine's capability. Future works can be extended for parallel setups, different manufacturing costs and time can also be taken into account to obtain optimal reconfigurable framework.

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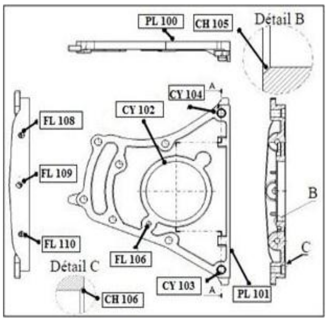
Annexn



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