Process Planning for Reconfigurable Manufacturing System for Mould/Die Making

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Abstract— **For efficient manufacture of moulds and dies and in order to meet the unstable market situation, a well organised reconfigurable manufacturing system is required. The geometric features of moulds and dies are not the same as discrete parts. They are contained elements on a block of steel and are usually in the form of contours, slots, corners, slope faces, curved surfaces and cavities. A lot of techniques are found in literature for process planning of manufacturing system of discrete parts but that of bodies similar to moulds and dies are quite rare. In this research, different techniques from literature are combined to form the process planning of a reconfigurable manufacturing system for mould and die making, which may also be applicable to similarly complex bodies. A technique was developed based on the weight of precedence factors to form a machining precedence order, which can be used to formulate the route sheet that is unique for manufacturing of moulds and dies and other similar complex bodies. A reconfigurable machine layout in which the developed process planning can be applied is also developed.**

Keywords-process planning; mould and die; manufacturing system; precedence; machine cell.

I.   INTRODUCTION

Manufacturing process planning can be defined as the sequence of procedures, plans and machining processes and parameters that are necessary to transform raw materials or components into a final and specific end products (finish goods) based on the design specifications at the least cost and with acceptable quality [1, 2, 3]. The process plan specifies what raw materials or components are needed to produce a product, and what processes and operations are necessary to transform those raw materials into the final product [4]. In general, a process plan contains routes, processes, process parameter, machines, set-ups and tools required for production of parts [5].   Process planning is the link between the computer aided design (CAD) and computer aided manufacturing (CAM) in computer integrated manufacturing (CIM) [6, 7, 8, 9].

Because of some intrinsic contents of process planning for the case of reconfigurable manufacturing systems, a holistic technique is required for it. Reference [10] presents group technology (GT) as a very good technique to be employed in

this regard. GT is an approach to manufacturing and engineering management that helps manage diversity by capitalising on underlying similarities in products and activities [11, 12]. One of the major applications of the philosophy of group technology is the formation of machine cells or manufacturing cell (cellular manufacturing); these cells are dedicated to the production of a set of part families. The major design objectives associated with cellular manufacturing are to (1) reduce setup times; (2) avoid as much as possible, intercellular movements of parts; (3) minimise investment in new equipment; and (4) maintain acceptable machine utilisation levels [13]. In the context of moulds and dies where the features to be machined are all on the surface of a solid block of steel (or other suitable materials), a special technique has to be devised for their reconfigurable manufacturing. This forms the basis of the present research. Moulds and dies are composed of functional and support components [14, 15]. Functional components are the cavity, core inserts and punches while the support components are the standard parts which assure the overall functionality of the tooling assembly. As pointed out in reference [15], the use of standard die and mould components is required to reduce the manufacturing time to the time needed for machining core and cavity, and the punch and the die. Manufacture of moulds and dies can be classified into three main machining operations: roughing operation, semi-finishing operation and finishing operation [14]. For machining to be feasible, efficient and of high quality, the sequence should obey the precedence relations intrinsic to the features contained in the cavity and punch [16]. These precedence relations are usually imposed by technological and some other requirements of the feature [17]. As simply mentioned in reference [18], "the sequence of machining the features of a part is an important task in process planning".

According to reference [19] cellular manufacturing requires three planning activities that can be modified to suit reconfigurable manufacturing systems; they are as follows:
(1) Grouping of machines into manufacturing cells (otherwise known as cell formation). In the present work, machine cells are formed based on frequently machined features,

which are pockets, holes, slots and steps [20, 8]. Other features are a combination of two or more of these. This implies that four basic machine cells are formed: for pocket making, for hole making, for slots making and for step making.

(2) Assignment of parts to specific machines (known as machine loading). Since manufacturing in moulds and dies involves creation of features on the same block of steel, appropriate machine layout takes care of this activity.

(3) Scheduling of the part families in each of the manufacturing cell. Sequencing of machining operation based on machining precedence constraints takes care of this activity in moulds and dies manufacturing system.

Therefore, in the manufacture of a mould or a die, a blank block of steel enters the manufacturing system and all the features are machined out in succession based on precedence constraints and it comes out at the end of the manufacturing cells as a machined mould or die. This type of reconfigurable manufacturing system cell is similar to pure flow shop manufacturing cells [21] and it resembles the traditional flow shops. It is also very similar to the focused cellular manufacturing (FCM) described in reference [22].

The main contribution of this paper is to formulate a process planning technique that can be utilised when developing a reconfigurable manufacturing system for moulds and dies and similar complex bodies. Other process planning techniques available in literature may not be applicable to these types of products because formation of different features on the same block of steel (or other materials) must respect some precedence orders. The work is therefore dependent on proper sequencing of machining activities.

II. THE PROPOSED APPROACH

The proposed approach was developed bearing in mind that generation of features of moulds and dies are dependent on one another, a phenomenon referred to as the precedence constraint. It considers the machine layout in each manufacturing cell to be formed based on the machining precedence constraints. Consequently, interconnectivity of these manufacturing cells is expected to be made reconfigurable as discussed later in this paper, with respect to Figures 4 and 5. This is ensured by incorporating routing flexibility in the manufacturing cell configuration [23]. It does not necessarily mean that each machining operation will have to be contained in one cell, the number of cells within the machining operation will depend on the number of machines required to complete the operation. The two basic requirements of efficient group technology cells, according to reference [24], are cell compactness and cell independence. Proximity and ease of communication between the operators within a cell are also of utmost importance [25]. Like any other engineering design, manufacturing cell design proceeds through a logical sequence of steps. At each step, the designers make compromises between conflicting requirements or technical limitations. The first activity in the proposed approach is the sequencing of the machining. Once

the machining sequencing is accomplished, it is on this basis that the machine arrangement in the cells will be done.

The process of sequencing machining activities can be done according to the following steps:

Step 1: Decomposition of cavity shapes into machining features.

Step 2: Identification of suitable machines for the production of each feature.

Step 3: Consideration of factors for precedence.

Step 4: Categorisation of the factors, for example: as essential, very important, important, less important and not important.

Step 5: Drawing of table of precedence. This step is utilised to generate a route sheet.

Step 6: Decision making on the layout of the facility. Machine layout can be in U-shape, a straight line, or some other arrangements. The important factors here are inter-connectivity in terms of time, space and information [25] and the constraint that the manufacturing system must be reconfigurable.

It would be necessary to first identify an appropriate technique for creating the sequence of the operation based on precedence constraint. This starts with the step 1 as above.

A. Decomposition of cavity shapes into machining features

Volume decomposition in conventional machining is the breaking or division of a complex volume into simpler or primitive volumes. These simpler volumes are composed into composite volumes and then identified as machinable volumes in a feature-based manufacturing system [26]. Three heuristic-based methods presented in reference [26] that exist for achieving volume decomposition are design model generation, heuristic slicing and extension of heuristic slicing to curved surfaces. Another decomposition approach was presented in reference [18]; their approach highlighted a process consisting of three steps namely: maximal volume decomposition, selection and conversion. Either of the two approaches is suitable for the present work but it should be noted that decomposition in mould and die manufacture is influenced by factors, some of which, according to reference [27], are (1) complexity of the part/product, (2) manufacturability of the individual mould component, (3) disassembly considerations and (4) tool accessibility of the boundary of the mould components (machinability). Depending on the above factors, a two-piece mould or a multi-piece mould is achieved. A two-piece mould comprises a cavity and a core while multi-piece mould comprises more than two disassembled mould members. The number of pieces of the mould is determined by the number of parting surfaces that are necessary to be formed in order to accommodate the complexity of the part. The presence of undercuts on the moulded parts further compounds the complexity of the part and hence increases the number of parting surfaces. Decomposition of the shape is therefore a compromise of all the factors that contribute to determining the number of pieces of moulds that will be needed to produce the part. The task of decomposition of shape can therefore be approached from the viewpoint of optimisation of the parting direction. The information from CAD of the mould or die can be employed for the

decomposition of the shapes using the Kohonen self-organising feature map neural network presented in reference [28]. Reference [29] presented another automatic feature extraction system that makes use of information from CAD. The system is called an automatic feature extraction system (AFES) and it consists of three modules namely: a data file translator, a part form feature classifier and a manufacturing operation selector.

If the decomposition is meant for an improved or a new product (mould or die), in which an existing manufacturing system will be employed for its production, in other words, which will require the reconfiguration of an existing manufacturing system, the decomposition of the product should be done with reference to the old product. This is necessary so that the existing manufacturing system will be suitable for the new product with minimum alteration on the existing manufacturing system.

B. Identification of suitable machines for the production of each feature

Decomposition activity in step 1 leads to well defined features. This enables a clear identification of manufacturing operations that can be used to generate the defined features and subsequently the suitable machine for each of the operations. Now based on the similarity of the manufacturing operations of the features, the features are then classified into families so that a common machine can be allocated to them. This leads to the formation of machine cells. Both activities are collectively referred to as group technology.

C. Consideration of factors for precedence

This may vary depending on the nature of production at hand. Some of the basic factors of precedence irrespective of the nature of production are listed below.

1) Technological factor of the part [30]: With reference to Figure 1, the two parts are composed of two features: a step and two holes. The corresponding machining for both of them are milling and drilling (and boring). But because of the fact that the hole in part P2 is located right on the step makes it a necessity that the step be milled first so as to be able to locate the position for the drilling of the holes. Such precedence is a technological requirement. There is no such requirement in the case of P1 where any of the features can be created first.
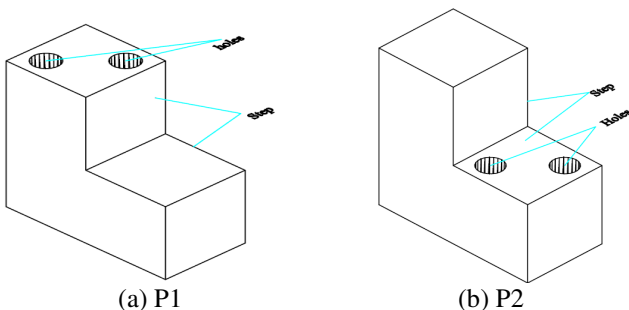

(a) P1   (b) P2
Fig. 1: Two different parts with identical features.

Cases like the one described above are common in the fabrication of moulds and dies and therefore it is a very important factor that should be taken into consideration in their process planning. Technological factor can also be related to forces of machining process. This is because forces developed during machining can deform the workpiece, tool and fixture. These deformations may result in unsatisfactory quality of the part or in tool breakage [31]. Therefore the machining of any feature whose formation will cause or aid deformation on the workpiece or the tool is sequenced accordingly. This factor is also referred to as non-destruction and accessibility constraint [6].

2) Geometric factors: These are concerned with tolerances and the relationships between features. This factor is used to impose a precedence constraint if a feature serves as datum to another (for example, parallelism, perpendicularity, position, runout and so on) or if a feature will have direct contact (gripping) with the work-holding device in the course of machining other features in such a way that it may cause defects on the surface that is gripped. In the case of the former, the feature that is used as datum is machined to specification before any other features. In the case of the later, enough tolerance is provided on the feature that is to be gripped if it has to be machined before other features, for the purpose of perpendicularity or parallelism.

3) Economic factor: This factor has to do with setting precedence to reduce the cost of production. Using Figure 2 to illustrate this factor, the Figure consists of two features- a step and a slot. Two things will come into play here; tool life and quantity of material removed in each operation. Both features can be produced by milling operation but different orders of production have different tool life.
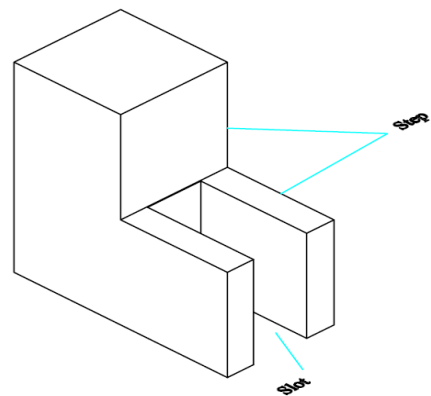

Fig. 2: Example of manufacturing order influence on manufacturing cost

A compromise needs to be reached among these factors. Sometimes preference has to be given to a particular factor with respect to the others for feasibility reasons. At this juncture the set of knowledge based rules and geometric reasoning rules presented in reference [16] can be applied to solve any ambiguity that may arise. There also exist

some volumetric feature interactions between various manufacturing features that can contribute to setting machining precedence; details of these are given in reference [31].

D. Categorisation of the factors using Likert scale

Because of non-availability of a technique that can be employed for categorising these factors in literature, a heuristic form of technique such as Likert scale rating is formulated. The Likert-type scale is an ordered, one-dimensional scale from which respondents choose one option that best aligns with their view. Each feature is examined against the factors of precedence explained above and considered individually with respect to the facilities (machines, tools and fixtures) on ground to categorise them on a three point Likert scale. Three point Likert-type scales are used in the present work. 3 points weight is given to "essential", 2 points weight to "important" and 1 point weight to "not important". The sum of the weights for the features determines their machining positions i.e. feature with the highest weight takes the first position and the one with lowest weight takes the least position. In a situation where two or more features have equal weight, the procedure is repeated on these ones until they stand out relative to each other. To illustrate this, a particular product (mould or die) shall be considered, having six features F1, F2, F3, F4, F5 and F6 decomposed. These six features are examined with respect to technological factor, geometrical factor and economic factor and the rating is done as shown in Table 1.

Table 1: Allocation of Likert weight to precedence factors for the features

Feature / Factor	F1	F2	F3	F4	F5	F6
Technological weight	3	2	3	1	2	1
Geometrical weight	2	2	3	2	2	1
Economical weight	3	2	2	1	2	1
Total	8	6	8	4	6	3
Position	1st	3rd	1st	5th	3rd	6th

In the examination of the features with respect to these factors to determine the Likert weights, experience and expertise is highly required. That is why engineering collaboration and negotiation as suggested by [32] should be employed during every stage of the design of a manufacturing system. This means that every stake holder (the engineers, designers, managers, machine operators, accountants etc.) in the manufacturing system should be involved at every stage of decision making. For example, if there is a tie between two factors, i.e. technological and geometrical factors, it takes expertise and experience for someone to resolve it by making recommendation on fixture or otherwise. For instance if a

feature serves as a datum for another one and this same feature has to be gripped for that other feature to be machined, the simple solution to this may be to recommend an electromagnetic holding device which should not have destructive impact on the surface of the feature during machining. This recommendation will further determine the weight of the economic factor.

E. Drawing of table of precedence

The last row in Table 1 is used to generate the route sheet and consequently the machine arrangement and hence the table of precedence. The ties in features F1 and F3, and F2 and F5 are resolved by repeating the entire procedure for each pair separately as mentioned earlier. The procedure described above is depicted in the algorithm shown in Figure 3.
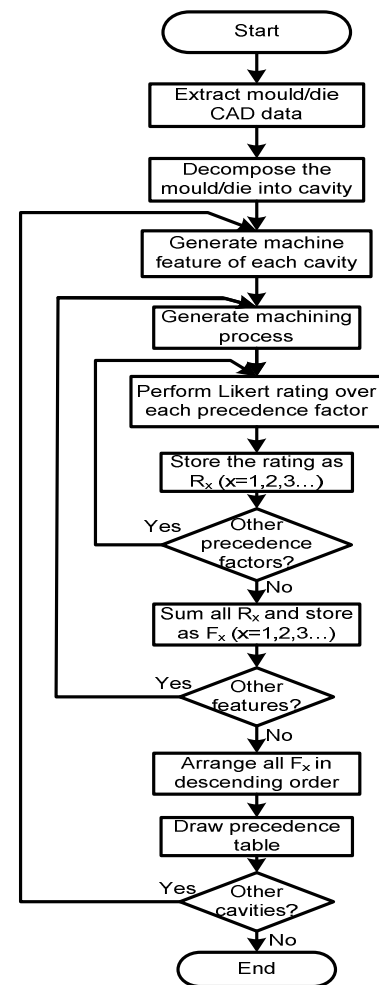

Fig. 3: Algorithm of the machining precedence constraint order

F. Decision making on the layout of workstations/facilities (machines, fixtures and material handling system)

The effect of workstations/facilities layout cannot be overemphasised as it was said to be one of the key areas which have a significant contribution towards manufacturing productivity in terms of cost and time in a manufacturing

system [33]. The workstations are laid out in order according to a route sheet generated from the table of precedence. It is necessary to design from inception an initial manufacturing system configuration (i.e., the arrangement of manufacturing workstations/facilities) that will be favourable for easy reconfiguration. Four types of layouts are presented in reference [34]: (a) straight line, (b) U-shape, (c) serpentine and (d) loop. The configuration concepts introduced in reference [35] are: (a) pure serial, (b) pure parallel, (c) parallel without crossover, (d) parallel with crossover, (e) hybrid and (f) variable process. None of these seems to satisfy all the six core characteristics and principles of reconfiguration [36, 37]. With the help of the process plan proposed above and necessary types of manufacturing flexibility built-in, a reconfigurable manufacturing system such as the one shown in Figure 4 can be achieved.
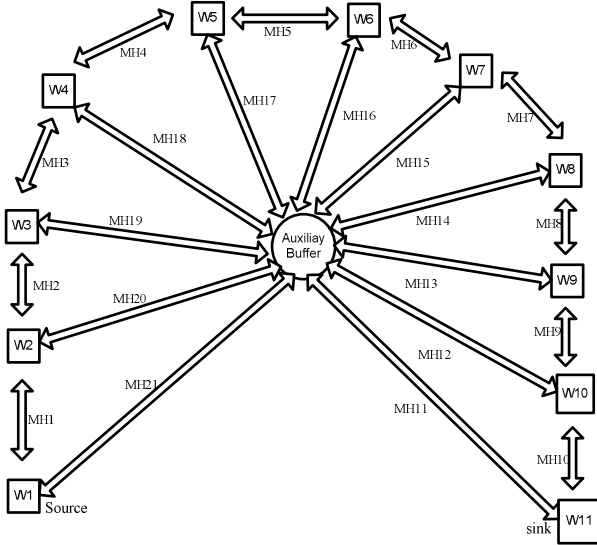

Fig. 4: Proposed reconfigurable manufacturing system
Legend: MH = Material-handling device, W = Workstation
(Machine, Measuring table, cleaning device, etc.)

The number of machines and the complexity of the manufacturing system with possible reconfiguration analysis (market analysis) will determine the number of workstations and material handling devices. From the various definitions of reconfigurability found in literature, manufacturing system reconfiguration can be achieved in the following six basic ways: Machines reconfiguration, layout rearrangement, removal/bypass of machine(s), replacement of machine(s), addition/insertion of machine(s) and backtracking [38, 39, 36, 40]. From the layout shown in Figure 4, a workpiece can be routed from any workstation to any other workstation via the material handling device that connect them directly or via the auxiliary material handling system. Reconfiguration is achieved by activation of the relevant and deactivation of the appropriate material handling system. This configuration gives room for easy machine bypass and connection between a machine and any other machine. If it happens that the manufacturing of a new product requires an arrangement of workstations in the following order: W1-W2-W6-W5-W8-W9-W4-W3-W10-W11, the following auxiliary material

handling devices will have to be activated: MH20, MH16, MH17, MH14, MH13, MH18, MH19 and MH12. The reconfigured manufacturing system will no more be U shaped but rather a serpentine layout [34] as follows: W1-MH1-W2-MH20-MH16-W6-MH5-W5-MH17-MH14-W8-MH8-W9-MH13-MH18-W4-MH3-W3-MH19-MH12-W10-MH10-W11, as shown in Figure 5.

It should also be noted that bidirectional rather than unidirectional material handling devices will achieve better results in terms of manufacturing system reconfiguration.
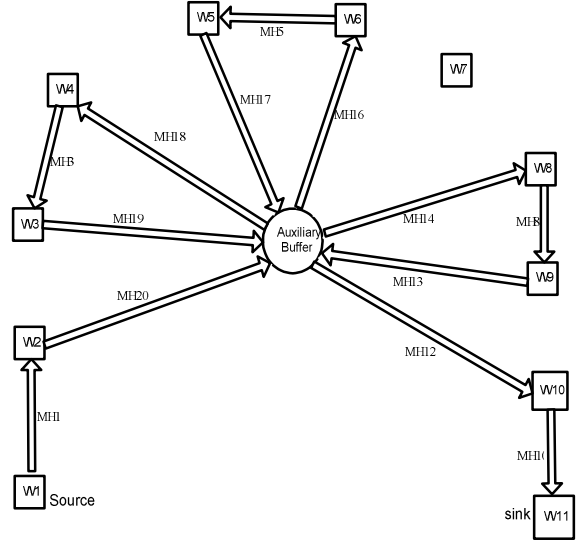

Fig. 5: Reconfigured manufacturing system

III. CONCLUSIONS AND RECOMMENDATION FOR FURTHER WORK

The major design objectives associated with cellular manufacturing as mentioned in the introduction section are satisfied by this work. The process planning guideline presented in this paper is basically for mould and die manufacturing and it will fulfill all these stated objectives. Further work is needed in the area of automatic control of the material handling systems to reduce the setup time during reconfiguration. This should specifically be focused on the bypass of machines, backtracking, repeat, in-sequence and accommodation of more than one type of material handling device.

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