International Journal of Interdisciplinary Innovative Research &Development (IJIIRD)
ISSN: 2456-236X
Vol. **05** Special Issue **01 | 2020**

Selection of Spindle Orientations in RMS Environment

[1]C. S. Ghadage, [2]Dr. B.S. Pabla, [3]Dr. S.S. Dhami

[1]Lecturer, Mechanical Engineering Department, Government Polytechnic, Pune,
[2]Professor, Mechanical Engineering Department, National Institute of Technical Teachers' Training and Research, Chandigarh-160019, India
[3]Professor, Mechanical Engineering Department, National Institute of Technical Teachers' Training and Research, Chandigarh-160019, India

ABSTRACT

In the current global competitive market affective cost cutting strategies constitute a major part of the total cost of the total setup, which in-turn reflects on the cost of the manufactured components? Reconfigurable Manufacturing Systems (RMS) provides a way to reduce the number of machines required in an organization by offering to rapidly change the manufacturing system configuration based on the component requirements. In this paper an attempt is made to extract geometric features of the component using a STEP format reader developed for this purpose. The geometric features are further translated into manufacturing features of the component. The manufacturing features data then is used for taking decision about spindle orientations requirement of the Reconfigurable Machine Tool.

Keywords— CAD; STEP; RMS; RMT.

1. INTRODUCTION

In this era of globalization industries are operating within the rapidly changing manufacturing environment as a consequence of the exceptional and unexpected changes in market demands. Several factors such as globalization of the economy, market saturation due to similar products and rapid advances in the process technology are concurrently contributing to these market changes. This has resulted in the division of the market in different sections and reduction in the product life cycle. Therefore, for survival and growth in the competitive world, the industry should be alert for the market changes to respond accordingly and provide higher quality products at lower cost. This in turn requires suitable manufacturing technologies.

To cope up with this new market oriented manufacturing environment the reconfigurable manufacturing system (RMS) concept was introduced [1,2,3] comprising of a modular structure of hardware and software that permits ease of reconfiguration of manufacturing facilities by changing the modules as a strategy to adjust with the market demands. The key enabling technologies for RMS are open-architecture controllers and the machines with modular structure. The modular machines have the ability to add / remove new software / hardware modules without disturbing the rest of the manufacturing system. This feature offers RMS the ability to rapidly integrate with the new technology, to adapt quickly with the production of new product classes, to adjust with the exact capacity and functionality requirements quickly with the increase, decrease or product modifications as per the changes in market demand.

2. LITERATURE REVIEW

P. Spicer et al. [4] stated the need for scalable machines and a basis for evaluating and describing them. Applicable metrics are defined, and architecture for scalable machines is presented. A design parameter based on a mathematical approach is presented to determine the optimal number of modules to be included on a modular scalable machine. U. Johannes, J. Juan and H. Sipke [5] presents a design model of reconfigurable cellular manufacturing systems that allows automated design and analysis of system configurations based on Computational Design Synthesis. The approach enables decision makers to evaluate different system performances such as costs, utilization and lead times of various designs of the system. Thus, it can help to generate an understanding of the implications of design decisions for the performance of the manufacturing system in different product demand scenarios.

Y. Koren and M. Shpitalni [6] presented the underlying principle and a rigorous mathematical method for designing and development of reconfigurable manufacturing systems which hold the advantages of dedicated manufacturing lines and flexible manufacturing systems. Discussed the core characteristics and design principles of RMS. Y. Koren, Y. M. Moon and S. Kota [7] presented a reconfigurable multi-spindle apparatus for machining of components of different part families consisting of at least two spindle head modules, a power transmission mechanism to transmit power between spindle head modules and a mechanism for reconfiguration of spindle head modules so that the multi-spindle apparatus can be reconfigured from the first configuration to second one with the change of products from first part family to the second part family. M. G. Mehrabi, A. G. Ulsoy and Y. Koren [8] identifies number of key interrelated technologies that should be developed and a numbermented to achieve the RMS characteristics such as modularity, integrability, customisation, convertibility and diagnosability. Researchers explained some of the issues related to the technology requirements of RMSs at the system and machine design levels, and ramp-up time reduction.

3. RECONFIGURABLE MACHINE TOOL

Y. Koren and S. Kota (1999) [9] invented the Reconfigurable Machine Tool (RMT) shown in Fig.1, having machine tool assembly which can be easily reconfigured to perform single or multiple machining processes simultaneously on a work-piece so that this machine has exact functionality required to perform a given set of machining tasks with improved productivity feature of Special Purpose Machine tools. The invention allows quick changes in the machine structure and quick conversion of the machine by relocating the basic building blocks of the machine. The Machine consists of a table on which a raw work-piece is to be mounted and one or two support units which carry at least one single-axis spindle unit. The spindle units can be easily removed or attached to the support units and are easily movable along the support units to perform machining operations from various positions and orientations relative to the work-piece. On each spindle which is computer controlled to rotate the tool having a linear stroke along its axis of rotation, a desired cutting tool can be added. All the support units are reconfigurable, which can be easily repositioned to different locations and orientations about the work-piece. The table has a flat top mounted on the column, which is secured to the base. It has translational motion along the horizontal and vertical direction relative to the column, and the column may also be telescopic capable of providing for vertical linear movement and rotary movement to the table relative to the base. It can also be pivoted at the top of the column to allow it to be tilted or angled relative to the base.

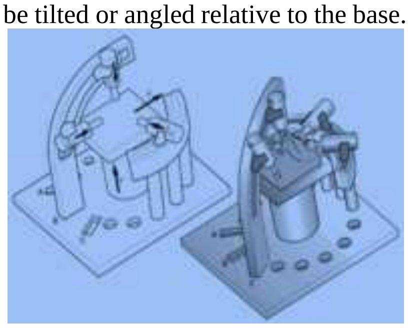

Fig.1: Reconfigurable Machine Tool

4. RMS CORE CHARACTERISTICS

RMS is designed using the hardware and software modules which can be integrated quickly and consistently. To accomplish these design objectives, RMS must encompass a number of key features called as RMS core characteristics such as modularity, integrability, customization, scalability, convertibility, and diagnosability [10]. These characteristics must be applied to the design of production systems comprising machines, machine controllers, and their control software.

5. RMT SPINDLE ORIENTATIONS

The methodology implemented in the present work to decide the RMT spindle orientations consists of five major steps which are listed as follows:

- Generate a CAD Model for the part.
- Create a STEP file from CAD Model.
- Extract geometric features data from the STEP file.
- Manufacturing Features Recognition.
- Decide RMT spindle orientations.

5.1Generate CAD Model

Three types of CAD models have been widely used by the researchers for part modelling, i.e., wire-frame model, surface model, and solid model. Parts are represented by points, lines and curves in wire-frame models. In surface model parts are represented by their bounding faces and each face has edges and vertices on it. Surface models provide a better graphic interface than wire-frame models. A solid model is a superior approach for creating 3D models. Constructive Solid Geometry (CSG) and Boundary Representation (B-rep) methods find wide acceptance among the researchers for part modelling in CAPP [11]. This has made authors to think use of 3D CAD model suitable for part modelling.

In this paper 3D CAD Model for a cylindrical part as shown in Fig. 2 is generated using two different CAD systems, namely CATIA and CREO. The CAD Model selected has six features such as plain surface, cylindrical surface, through cylindrical hole, rectangular groove, semicircular groove and edge chamfer.

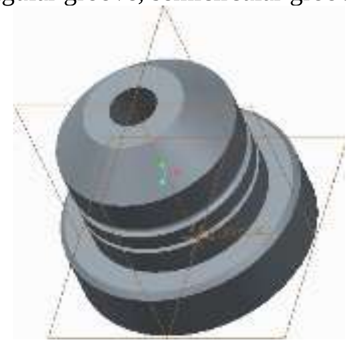

Fig. 2: CAD Model

5.2 STEP File

STEP (Standard for Exchange of Product data) is the precise computer interpretable representation of product data, which offers the resource of an efficient information exchange between product design and different manufacturing activities as well as it provides compatibility with different CAD systems. It uses the data modelling language EXPRESS to specify the product information to be represented that enables precision and consistency of representation. A part of STEP file is shown in Fig. 3.

Fig. 3: STEP File.

The STEP file starts with ISO-10303-21 and ends with END-ISO-10303-21. It is divided into two distinct sections which are header section and a data section. The header section includes information such as file name, date, CAD software used, etc. The DATA section is the most important part of the STEP file consisting of a number of correlated or independent statements. These statements describe different components of drawing such as face, edge, point, etc. The statements in the data section gives a series of entities used to describe the information of product. The structure of sentences is as follows:

#Instance Name = Entity Name (Attribute 1, Attribute 2, . . .);

The Instance Name is a positive integer used to represent the statement number starting from one and continues in sequence up to the last statement. The Entity Name is a self illustrative reserved word such as ADVANCED_FACE, ORIENTED_EDGE, PLANE, LINE, CARTESIAN_POINT, CYLINDRICAL_SURFACE, etc., which gives information about different geometrical features of the product. The attribute may be referring to instance name, value, string, coordinates of a point, etc.

5.3 Geometric Features Extraction

The feature extraction from STEP file is nothing but to extract geometry and topography information of the 3D model from data section. Sequential search approach is used to scan the file to search the required feature data of the component. At the start, program search for the key word CLOSED_SHELL in every statement of the STEP file and identify the unique statement containing this key word. The attributes in this statement give links to entity ADVANCED_FACE which gives further links for the data related to different bounding surfaces of the component. The data about start point, end point, length and direction of lines; centre point, radius and the axis of circles on the bounding surfaces are obtained by searching the statements in hierarchy obtained from the links provided by the attributes of the different entities in hierarchy from ADVANCED_FACE. This is the basic information necessary for different manufacturing activities stored in a STEP file, which provides information for feature recognition. The features extracted from STEP file give information regarding size, shape and location of different surfaces of the finished component in 3D space which are nothing but the geometric features. A STEP file is created for the CAD model and this STEP file is used as an input to the STEP format reader [12]. STEP format reader is a computer program which reads part geometric information in STEP file and output of a program gives the information about component geometric features such as plane, cylindrical surface, conical surface, etc.

5.4 Manufacturing Features Extraction

A Methodology developed in this research work to extract manufacturing features from the geometric features is based on the number of geometric features with same start point along the axis of the component. The flowchart for manufacturing features extraction from geometric features of the component is shown in fig. 4. The steps are as elaborated in brief as follows:

5.4.1 One Geometric Feature

When there is only one geometric feature located at any point on the axis such as cylindrical surface or toroidal surface or conical surface, then the corresponding manufacturing feature is turning for cylindrical surface, forming/contour turning for toroidal surface and taper turning for conical surface.

5.4.2 Two Geometric Features

When there are two geometric features located at any point on the axis, then one of them will be a circular plane which may or may not contain face bound edge. If they are located at the start point on the axis, then the circular plane does not contain face bound edge. The Second geometric feature will be toroidal surface or conical surface or cylindrical surface having a common edge with the face outer bound edge of the circular plane. For the circular plane the manufacturing feature is facing/parting and for toroidal surface or conical surface or cylindrical surface the corresponding manufacturing feature is forming/contour turning or taper turning or turning. If they are located at intermediate point along the axis of finished part then the circular plain will be one of the geometric features and it will contain a face bound edge. Locate face outer bound and face bound edge of this circular plane; one of them will be the part of the preceding geometric feature. If face bound edge is part of the preceding geometric feature, then geometric feature containing face outer bound edge will decide the next manufacturing feature and vice versa. It may be toroidal surface or conical surface or cylindrical surface and the corresponding manufacturing feature is forming/contour turning or taper turning or turning.

5.4.3 More Than Two Geometric Features

The steps adopted to decide manufacturing features when more than two geometric features are located at any point on the axis are listed below:

1. When more than two geometric features has same start point on the axis, then one of them will be a circular plane with face bound edges. When these features are located at the start or end point of the component and circular plane is with interior edges, then the first manufacturing feature is facing provided that raw material length is equal to finished part length plus machining allowance at start point and end point, otherwise when raw material is a continuous bar stock then manufacturing feature at start point is facing while at the end point is parting.
2. Select face outer bound edge of the circular plane and locate the surface containing this edge, which is bounding surface. The exterior surface may be cylindrical surface or conical surface or toroidal surface and the corresponding manufacturing feature will be turning or chamfering / taper turning or forming.
3. For each face bound edge on the circular plane extract its position, dimension and type i.e., curved or straight.
4. Take one of the face bound edge and locate interior plane/surface containing this face bound edge, which is inside the bound volume. The interior plane/surface is always in the bound volume and it indicates finished surface of the component. It is bounded by face bound and interior edges. Enlist all the face bound edges and check whether any one of the face bound edge is face bound edge of the circular plane of the component located between start point and end point of the component. Remove such a face bound edges if any from those circular planes.
5. Identify next interior plane/surface comprising common interior edge with interior plane/surface located in the previous step and continue identification of new plane/surface having a common interior edge with previous plane/surface, until the newly identified interior plane does not have any common interior edge with a previous interior plane/surface.
6. The Interior Planes / surfaces located in steps 4 and 5 are assigned to a group called group of interconnected planes / surfaces on the basis of common edge. These planes / surfaces clubbed together in sequence provide surfaces of the finished part as well as the size and shape of the manufacturing feature. For example, when face bound edge is a circle, interior surface containing this edge will be cylindrical / conical surface and the next interior surface comprising common interior edge with this surface is cylindrical / conical surface. The group of such interior surfaces clubbed together will give cylindrical hole or conical hole as the manufacturing feature. When the face bound edge is a straight line and the interior plane containing this straight line is a plane parallel to the axis. In this case, two additional planes and one cylindrical surface parallel to the axis are identified in succession with common interior edge with previous plane. Here the cylindrical surface and three planes clubbed together will give manufacturing feature keyway. If the cylindrical surface is corresponding to the face outer bound edge on the plane, then the keyway is on the outer diameter of the shaft. If the cylindrical surface is corresponding to the face bound edge on the plane, then the keyway is in the hole.
7. Repeat steps 4 to 6 to locate manufacturing features for each face bound edge on circular plane which is not included in the interior plane/surface of the detected manufacturing feature.

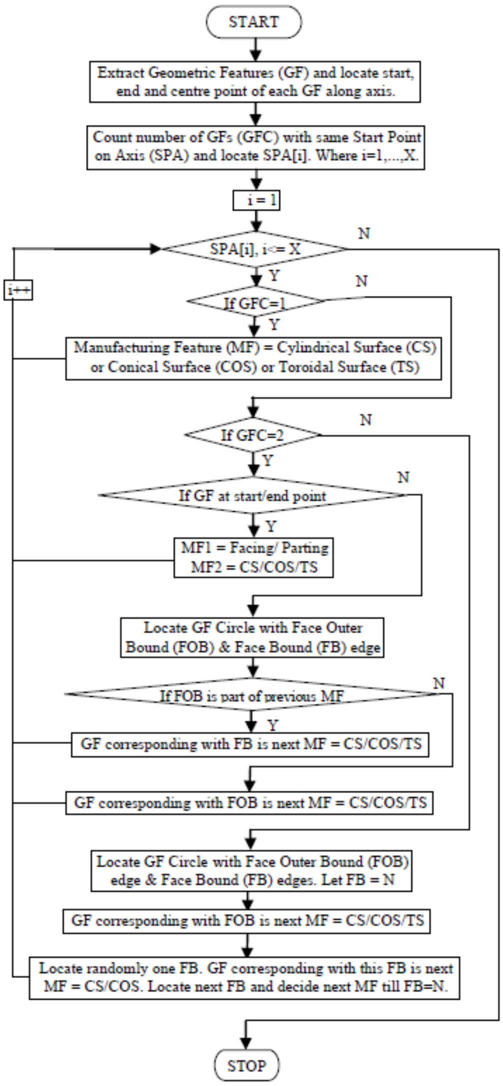

Fig. 4: Manufacturing features extraction flowchart

5.5 Decide RMT Spindle Orientations

The RMT consists of the machine base, table, vertical support or horizontal support or both vertical and horizontal support. The power spindles are mounted on vertical and horizontal support [9]. The prismatic part is clamped on table and cutting tools are mounted on the power spindles while the

Table 1: RMT Spindle Orientations

Sr. No.	Manufacturing Feature	Required RMT Configuration								
		Location of		Power Spindle			Table Movement Parallel to Axis			
		Raw Material	Cutting Tool	Location	Motion	Axial Movement	X	Y	Z	Rotary
1	Facing, Turning, Taper Turning, Chamfering, Grooving and Forming	Power Spindle	Table Slide	Horizontal Support	Rotary	No	Yes	Yes	No	No

cylindrical part is clamped in the clamping device fixed on the power spindle mounted on the horizontal support and the cutting tool is clamped on the slide mounted on table. The slide has two motions, one parallel to the axis of power spindle and another perpendicular to the axis of power spindle.

Once the manufacturing features are extracted, the next step is to decide the RMT spindle orientations. The RMT spindle orientations will depend on the type of manufacturing feature processed on the part and the part type that is prismatic or cylindrical part. The objective of this research paper is to determine the RMT spindle orientations required for cylindrical component. Every extracted manufacturing feature has its dimensions, axis placement and location in 3D space. The manufacturing features data is used to recognize the location of raw material and cutting tool; power spindle location, motion type and movement; and table linear movement parallel to x, y and z axis as well as rotary movement about a vertical axis. The RMT configuration required for different manufacturing features for the example CAD model is given in table 1.

6. CONCLUSION

In this paper an attempt has been made to decide the RMT configuration required for cylindrical parts. A generic STEP reader is developed to extract the geometric features of cylindrical components using a STEP file created from the CAD model and tested for different CAD models developed from PROE and CATIA. The output of a STEP reader is used to recognize the manufacturing features of the component which are used to decide the RMT spindle orientations needed to process the component. The data of manufacturing features and the RMT spindle orientations can be used as input to Computer Aided Process Planning in RMS environment.

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