11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
E. Oñate, J. Oliver and A. Huerta (Eds)

OPTIMIZED-AUTOMATED CHOICE OF CUTTING TOOL MACHINING MANUFACTURING FEATURES IN MILLING PROCESS

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Key Words: *Milling process CAPP, Automatic Tool selection, Operation sequence, Optimization.*

Abstract. In manufacturing industry, selection of a proper cutting tool is the most critical activity in achieving a better product quality and in controlling the overall cost of manufacturing. In this paper we present an automated and optimized cutting tools selection system for milling process. This modular platform is used to automatically, supplies, CAD / CAM system by appropriate cutting-tools required for the machining of manufacturing features extracted by an automatic feature recognition system for prismatic parts based on a method we have developed called “Frontier Faces of Base Face” (FFBF). Data-tools were collected from recent rotating tools Machining Handbook of world's leading manufacturer of tools Sandvik Coromant. A demonstrative sample, of extracted manufacturing feature, is presented to illustrate the correctness of optimized choice of milling tools and machining operation sequences, and to validate the methodology.

1 INTRODUCTION

Process planning is an activity that consists in selecting the necessary processes, tools, appropriate parameters and operation sequencing to manufacture a part. The traditional way to solve process-planning problems is to leave it to the manufacturing experts that translate the global geometry of the part into a group of machining features well adapted to a defined machining process, relying on their own experience. This manual approach is time consuming and, usually, not consistent as the quality of the process plan depends on the planners’ experience [1, 2]. Disadvantages of manual approaches led to development of automated approaches that aimed to reduce the probability of errors and inconsistencies. Computer Aided Manufacturing Process Planning is one of the most important advances in the area of manufacturing engineering which plays a critical role, linking Design and Manufacture. CAPP determines automatically the use of available resources, including machines, cutting inserts, holders, appropriate machining parameters such as cutting speed, feed rate, depth of cut, and generates automatic sequences of operations and instructions to convert a row material into a required product with good surface finish [3]. The production cost of a manufacturing component depends upon cost of workpiece material, tooling cost, and recurring expenses. Thus, it is clear that the only scope to reduce the overall cost of a workpiece is to focus on the tooling cost and machining time. Selecting an optimum insert, optimum cutting conditions, and optimum sequences affect directly the workpiece cost [1].

More than one hundred CAPP systems have been reported in the literature. However, the link between CAD and CAPP systems is still not integrated as desired [4]. On one hand, the data of the neutral files such as STEP, IGES generated by CAD systems consist of geometric and topological information, these data cannot be used for direct application to process planning since CAPP systems require part form feature information, not geometric and topological information, CAD is usually geometry-based, whilst CAPP/CAM are feature-based and domain-dependent, which results in unsatisfactory practical implementation, or a common weakness of CAPP systems [5]. On the other hand, Geometrical and Dimensional Tolerancing (G&DT) and surface roughness and technological data required for downstream applications are not embedded in the geometric model for the most of the current CAD systems, which are lacking of appropriate data structure to admit them. CAD models seem to include these data as seen in the drawings, nonetheless, these data are not real attributes of CAD models but simply represented as text on the drawing [6]. Another problem is presented at the tool selection stage, a broad range of tools is available to suit various practical applications and machining systems. As a consequence, the tool/process designer has to wade through voluminous machining data handbooks and catalogs of cutting tools with different materials, coatings, geometry, and chip-groove configurations for high wear resistance and effective chip breaking. Consequently, process planners are forced to choose and recommend suboptimal cutting conditions [7].The aim of this paper is to select adequate cutters and inserts for prismatic manufacturing. At a first stage, features with their attributes are extracted from STEP AP203 Ed2 [8]. Features are extracted by a feature recognition system based on a method called “Frontier Faces of Base Face” [9]. At a second stage, features, their dimensional parameters and technical data such as surface roughness and G&DT are analyzed for cutting tool selection purposes. Data-tools were collected in Microsoft ACCESS from recent rotating tools Machining Handbook of Sandvik Coromant [10].The proposed methodology and system architecture are addressed in the following sections.

2 LITERATURE REVIEW

Mookherjee & Bhattacharyya [11] Used an expert system for tool selection, which automatically selects the appropriate milling cutters and inserts as well as turning inserts, the material and the geometry, based on the requirement of the user. The elements that influence the tool selection are: workpiece material, the entering angle of the cutter, type of application surface roughness, machine tool characteristics, coupling systems, etc. Cutting conditions such as cutting speed and initial feed, depth of cut are selected from the machining handbook according to the grade of insert. Kumar & Rao [12] developed a system for selecting optimum tool geometry and cutting conditions using surface roughness prediction model for end milling. The system provides analytical models, based on experimental results for obtaining a surface roughness model using the response surface methodology. The primary factors related to cutting tools influencing the surface roughness of medium carbon steel are cutting speed, feed, radial rake angle and nose radius. A mathematical models thus developed are further utilized to find the optimum process parameters using genetic algorithms. Veeramani & Gau [13] described a two-phase methodology for selecting an optimal set of cutting-tool sizes to machine a 2.1/2D pocket, taking into consideration of geometric constraints as well as processing time information. In the first phase, a new concept called the Voronoi mountain is employed in order to calculate the removed material volume that can be machined by a specific cutting-tool size, the material volume that will subsequently remain to be machined, and the cutter-paths (and corresponding processing times) for each cutting-tool. In the second phase, a dynamic programming approach is applied for optimal selection of cutting-tool sizes on the basis of the processing time. Shunmugam & Reddy [14] proposed and system based on the genetic algorithm (GA) for selecting optimal conditions in multi-pass face-milling. The choice of tools is done to yield minimum total production cost while considering technological constraints such as allowable speed and feed, dimensional accuracy, surface finish, tool wear and machine tool capabilities.

3 PROPOSED METHODOLOGY

3.1 Manual approach proposed by the manufacturer for tool selection in milling process

Cutting tools consist of two main components: the milling cutter and cutting insert. The objective of the manual approach of tool selection is to determine several parameters for the milling cutter, such as cutter type, coupling type, pitch, cutting diameter and so on. For the insert, parameters to determine are the insert size, insert grade, parallel land, geometry, and finally cutting conditions. The rotating tools Machining Handbook of Sandvik Coromant is divided into three main categories, milling, drilling, and boring. In this paper, we present the methodology of cutting tool selection for milling process.

The first step consists in selecting cutting tools is to select the cutter type which depends on the type of operation to perform. There are four major operations proposed by the manufacturer, face milling, shoulder milling, profile milling and slot milling. For each operation, a number of cutter types is available including recommended ones. The second step consists in selecting the material to be machined which lead to select an insert parameter representing the material that the insert can machine. The third step concerns selection of cutter pitch. The pitch influences the productivity, stability, consumed power and has to be adapted to the material to machine. The manufacturer proposes three different cutter pitches, coarse pitch, close pitch, and extra close pitch. As examples, the coarse pitch is the first choice for instable operations requiring a reduced cutting force, the close pitch is selected to increase productivity and the extra close pitch is selected for roughing and finishing operations of ISO K materials. The fourth step consists in selecting the coupling type which depends on clamping possibilities available in the milling center. The fifth step concerns selection of the insert geometry depending on the application. The manufacturer gives three geometries, geometry L for finishing, geometry M for semi finishing, and geometry H for roughing applications. Taking the fact that the material to be machined and the geometry of the inset are chosen, the insert grade can be selected according to these parameters. In the last step, cutting conditions such as maximum depth of cut (ap), the maximum chip thickness (hex), feed per tooth (fz) and cutting speed (Vc) can be determined. Maximum depth of cut is given for each insert size. For example, recommended depth of cut for inserts with 8mm of size is 5,5mm. To perform and efficient cut, the maximum chip thickness must be chosen according to the type of the cutter. Initial values of max chip thickness and recommended values of feed per tooth are given according to each type of cutter and suitable insert size and geometry. Recommended chip thickness is also given for each insert grade. Recommended cutting speeds can be determined according to four parameters, insert grade, the type of

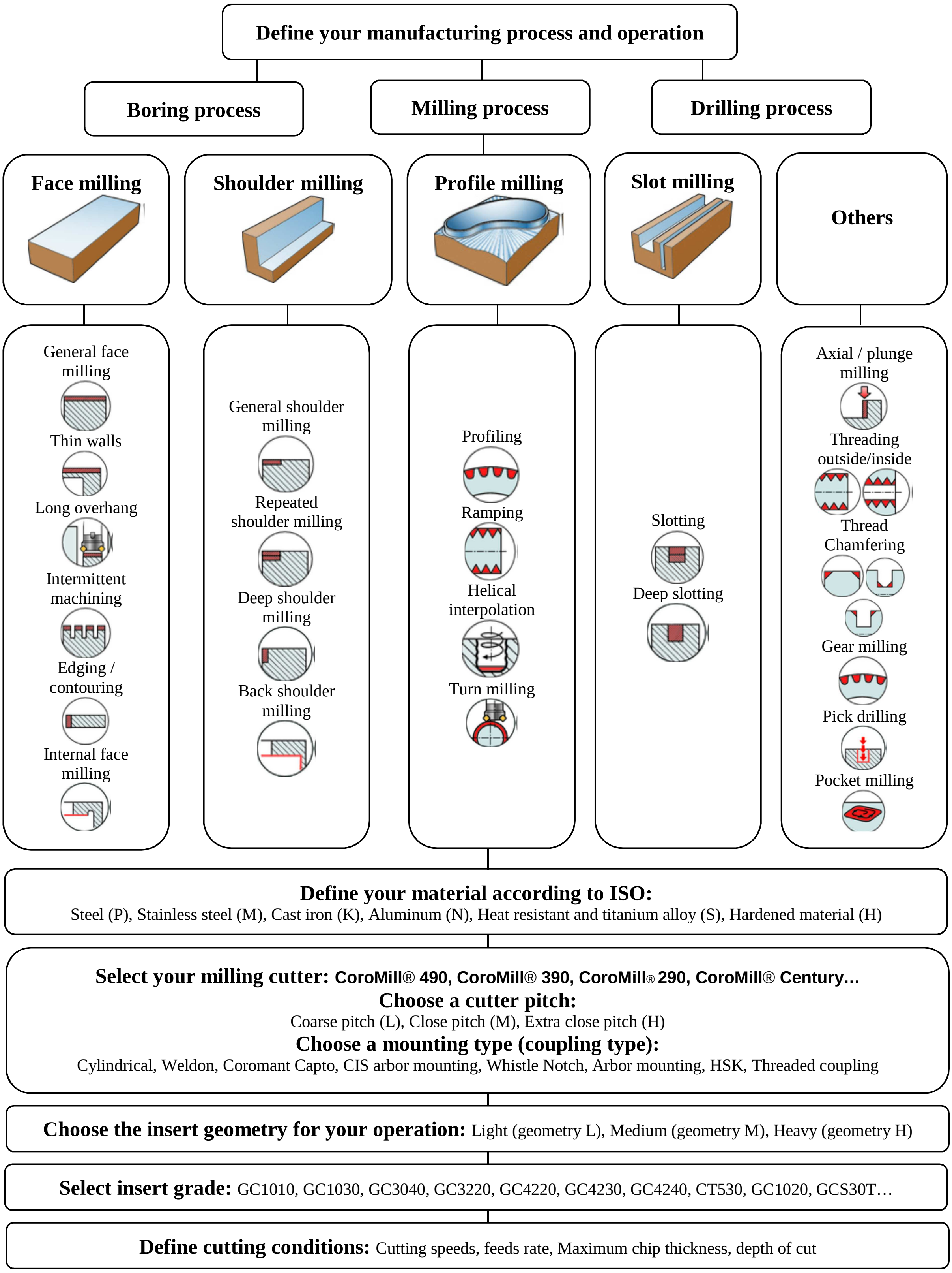


Figure 1: Flowchart of the manual approach for milling tool selection

material, its specific cutting force kc and its Brinell Hardness. To clarify the method of choice of tools proposed by the manufacturer, we gathered the major steps that lead to a choice of cutters and inserts for a given operation, and which are depicted in the flowchart of Fig.1.

It is clear that the manual method proposed by the manufacturer for the choice of cutting tools presents some drawbacks and difficulties. On the one hand, the choice of cutters and appropriate inserts according to the manufacturer's manual choice depends on several parameters and criteria, as well as on the expertise of the user who must manually select these parameters and criteria through the machining handbook in order to achieve a choice of tools for a given application, which is time consuming. The manufacturer provides a recommended choice of cutting tools, but the optimization of the machining process can follow several alternatives. On the other hand, for best efficiency of CAPP systems, the integration and management of cutting tools is important since they represent the most dynamic resources. In CAPP systems, the treated parts are broken down to manufacturing features. However, manufacturers of tools such as Sandvik Coromant not follow the concept of features. The choice of tools depends essentially on the operations to be performed, and not on features to manufacture. This problem can be resolved if the tool selection is performed automatically for manufacturing features, which is the aim of this paper and that is addressed in the following section.

3.1 The proposed methodology for automatic tool selection for manufacturing features

3.1.1 Automatic feature recognition (AFR)

In a previous work, we have focused on the development of an automatic feature recognition system for prismatic parts which adopted the Standard for the Exchange of Product model data (STEP), defined as the international standard ISO 10303-203. The system recognizes manufacturing features by using a Chain of Faces and Base of Faces CF-BF graph. A library which consists of milling-pre-defined manufacturing features is elaborated to enable the automatic extraction. A feature is modeled by a series/parallel association of Opened Chain of Faces OCF or Closed Chain of Faces CCF that rest on a Base Face BF. The feature is considered perfect if all Faces that participate in constitution of OCF/CCF are a blank face, else it is an Imperfect Manufacturing Feature IMF resulting of interactions with at least one feature. In object to establish new virtual Faces to satisfy this necessaries condition, a judicious analysis of orientation of Frontier Faces FFR that rest on FB is performed. Creation of new virtual faces by extending their material surfaces until the blank and/or material surfaces of the part leads to generate multiple interpretations of interacting features. The technique is tested on a several parts taken from literature and result gives a good satisfaction. Possible combinations of features generated by the system for an example part are depicted in Fig.2.

It is clear from Fig.2 that dimensional parameters of features are different for both combinations. In other word, the machining time required for removing the machined material volumes that represents manufacturing features is different. Adding to that, in each combination an order to machine features which is the same order in which features are built, is defined. This, leads to the generation of multiple process plans. At this stage, we cannot predict which combination will lead to the optimal process plan. Hence, introducing an optimized selection of tools, an optimized machining time and a sequence optimisation can plumb to the selection of an optimal process plan for an optimal combination of features.

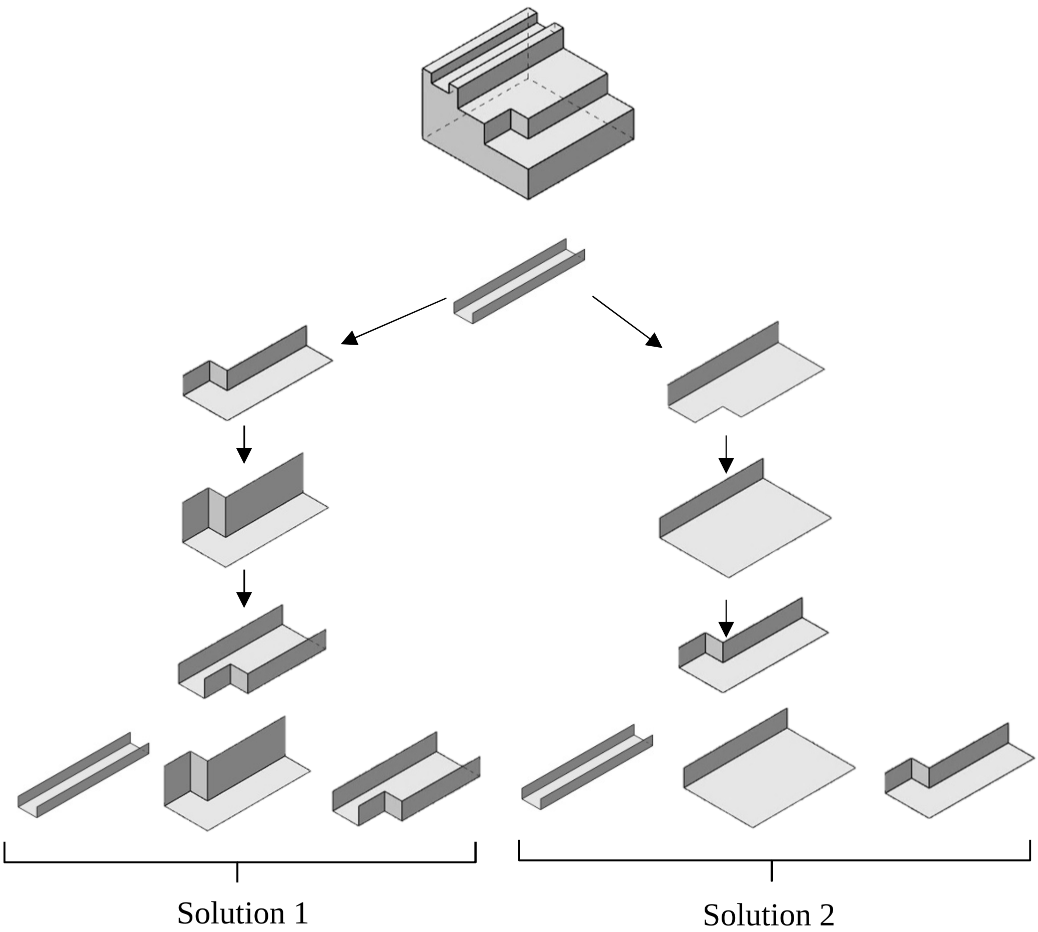


Figure 2: The two possible combinations of interacting features for a simple part

To achieve a complete representation for a process-planning, GD&T and surface finish need to be complete and correctly represented according to the requirements of the machining features. Then, it is important for the machining feature model to get the geometric tolerances in order to create relationships between features and reference datum for the machining processes. Therefore, one of the main tasks in the feature conversion is to extract and convert each geometric tolerance to its related feature as an attribute. When feature interaction happens, the features concerned will be altered both in geometry and dimensions, which lead to alterations or deletions of some feature surfaces and boundary edges, but with the original feature geometry and GD&T in the database without modifications [15]. Before extracting and converting GD&T from design features, it is advisable to explain how G&DT are embedded in STEP AP203 Ed2 data file.

As know, a shell in STEP file is formed by joining surfaces (denoted as ADVANCED_FACEs) along edges. E.g. a cylinder is formed by joining four ADVANCED_FACEs, two cylindrical surfaces and two planar surfaces. Example of a cylindrical surface of a cylinder is given by the following record in STEP file:
#149=ADVANCED_FACE('Corps principal',(#148),#97,.T.) ;

In order to define the portion of the geometry the GD&T information relates to, at first the corresponding geometric element has to be identified, this is assumed to be an ADVANCED_FACE. Next, a SHAPE_ASPECT will be defined so that the face can be related to. The link between the SHAPE_ASPECT and the ADVANCED_FACE is created by an entity of type GEOMETRIC_ITEM_SPECIFIC_USAGE.

The next step is linking the ANNOTATION_OCCURRENCE to the geometry. This is done using a DRAUGHTING_MODEL_ITEM_ASSOCIATION, which references the global DRAUGHTING_MODEL, the ANNOTATION_OCCURRENCE in question and the SHAPE_ASPECT that identifies the portion of the geometry that the annotation relates to. Surface roughness related to the ADVANCED_FACE cited above (#149) is given through the entities which are given by in STEP the following records:

#2343=GEOMETRIC_ITEM_SPECIFIC_USAGE('','GDT',#2342,#24,#149) ;
#2345=DRAUGHTING_MODEL_ITEM_ASSOCIATION('','',#2342,#257,#1761) ;
#1761=ANNOTATION_OCCURRENCE('Rugosit\X2\00E9\X0\.2',(#1760),#1758) ;
#1758=GEOMETRIC_CURVE_SET('surface
roughness',(#1762,#1765,#1768,#1771,#1776,#1779,#1798,#1816,#1822,#1855,#1873)) ;

Where #1762…#1873 denote polylines. A polyline is a line created by a series of short straight line segments. The entity polyline is defined in Part 42, and already known in AP214 / AP203 Ed2 standard. Using this type of entity, each GD&T feature and 3D annotation can be exported as a GEOMETRIC_CURVE_SET of polylines, circles and TRIMMED_CURVES where the basis curve is a circle (circular arcs). Polylines are defined by a list of CARTESIAN_POINTS. Taking the fact that G&DT and surface roughness related to each feature surfaces are known, extraction and conversion of G&DT can be resolved by applying the method developed by Gao et al. [15], which consists in locate each tolerance of the component to the corresponding feature, and convert the virtual datum elements in the design model into recognizable elements for the machining application.

Taking the fact that all G&DT, and surface roughness related to each surface of the part are extracted and technological and economic constraints are recognized. This plumbs to the creation of precedence between surfaces of the part. Thus, precedence constraints between features are placed in a well-known matrix of precedence called PMatrix in order to generate at least one process plan. Multiple process plans are obtained in the case when operations having equal machining sequence (they have no prior geometric, dimensional, economical or technological constraints) exist. So in this case the choice cutting tools depends on the experience of the designer respecting logical manufacturing constraints such as sequentially of operations having the same type of cutting tools (avoids the tool change) and optimization of tools travel distance. Once process plans are generated, the number of combinations of interacting features can be reduced due to precedence constraints generated between features. Thereby, only the remaining process plans for the combinations that respect these constrains will be addressed in automatic cutting tool selection module.

Taking the fact that geometric and topological data of features, intrinsic G&DT of features, G&DT between features, and surface roughness related to each surface of features are extracted, these features with their attributes are used as input data to the system of automatic tool selection.

3.1.2 Architecture of the database of milling cutting tools

Before introducing the new concept of automatic choice of cutting tools, it was necessary to collect from the catalog of Sandvik Coromant [10], all inserts and cutters including their designations and parameters, cutting conditions and materials grades. For the purpose, a relational database was seized with Microsoft ACCESS and which is composed of several tables, a table of inserts and their attributes, a table of cutters and their attributes, a table of materials, a table of inserts grade, a table of cutting conditions and so on. These tables are connected by relational links in such a way that relations between data of the manufacturer are respected. For example, the inserts table is connected with cutter table since the tool size and type of insert must correspond with the seat size and type of the cutter. This structure will be useful for the automatic extraction of all data necessary to select appropriate tools for a given feature.

3.1.3 New concept based on manufacturing features for the selection of cutting tools

In the literature, the majority of authors are based on recommendations made by the manufacturers to select tools for desired operations [9, 16]. Despite the fact that many authors use the feature-based approach, the choice of tools is made from catalogs by selecting the operation that can achieve the feature [1]. This choice is generally depending on the operation to be performed, such as face milling, shoulder milling, slot milling, groove milling and pocket milling, and depends of the experience of the user. This prompted us to develop a new approach based on features for selecting cutting tools. After a rigorous study of the catalog of the manufacturer, we have developed a system in which all inserts and cutters that can insure the realization of each manufacturing feature are selected depending on many criterias, rules and manufacturing design assumptions. As a result, the choice of tools becomes almost automatic for the manufacturing features. After giving a brief description of the philosophy of the system, the step which follows consists in explaining how tools are selected taking into account the data of manufacturers on one hand, and on the other hand, data of part features. The architecture of this system is limited to milling process (boring and drilling are not included) and can be outlined in the flowchart of Fig.3.

When a feature is generated, its attributes and parameters are transferred to a rules-based systems and decision systems that analyze these data on one hand. On the other hand, this system searches what is the parameter or what are the parameters to be determined for cutters and inserts adding to that the determination of cutting conditions, according to each parameter of the feature. The parameters of the feature can be described as following:

- Feature type
- Intrinsic G&DT of features
- Surface roughness of features surfaces
- Material of the workpiece
- Dimensions of the feature

The determination of each parameter related to cutting tools according to feature parameters respects machining design assumptions, recommendations of the manufacturer and some concepts based on the literature. Analysis of each features parameters and the determinations of some major cutting tools parameters are explained us following:

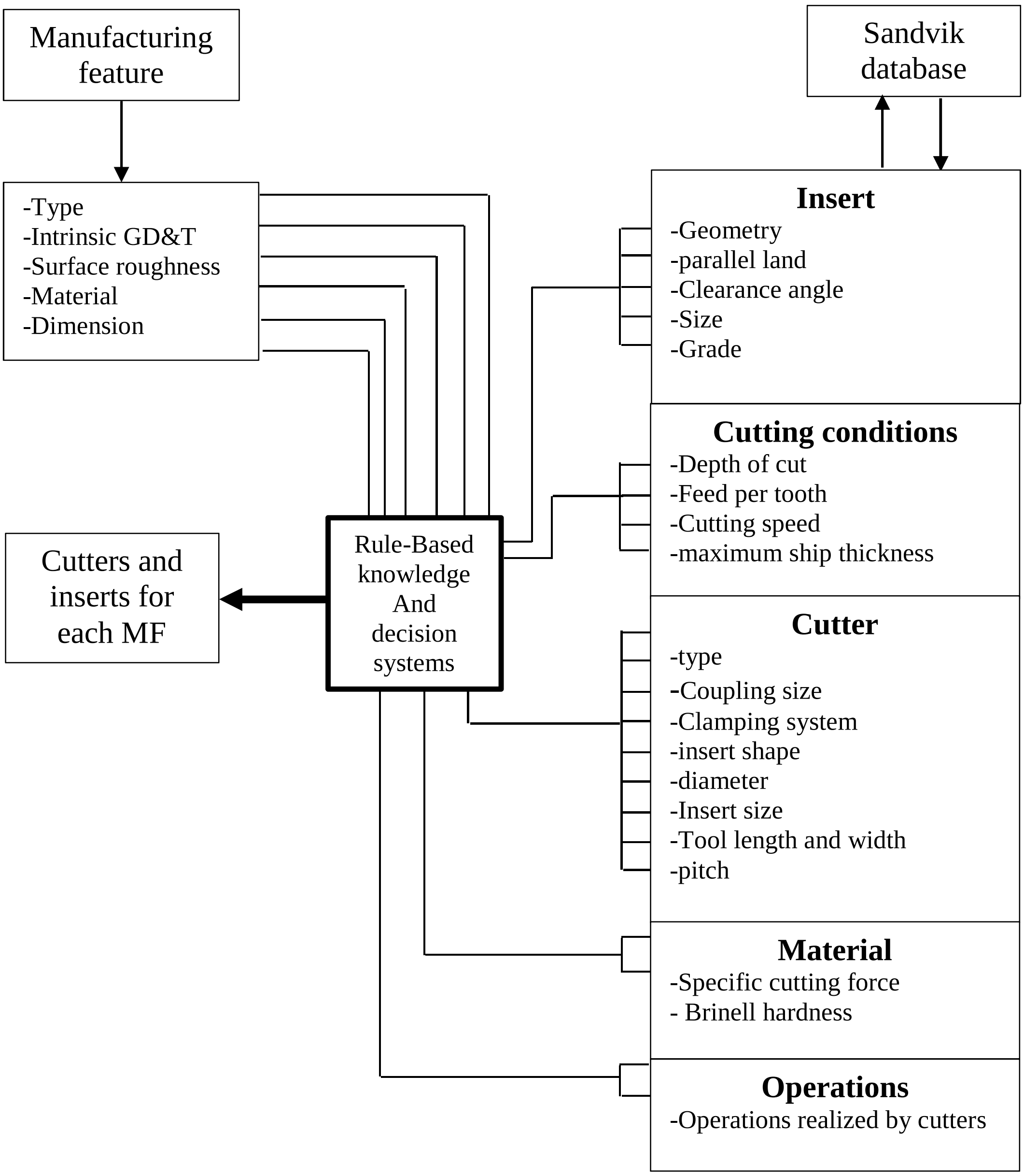


Figure 3: flowchart of automatic tool selection based on manufacturing features

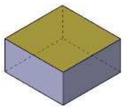
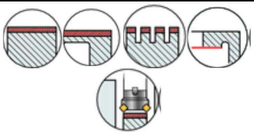
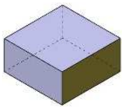
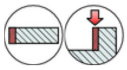
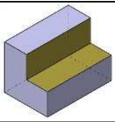
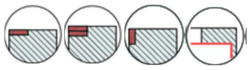
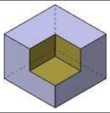
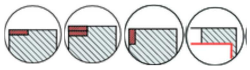
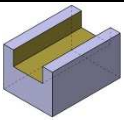
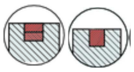
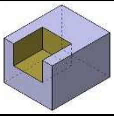
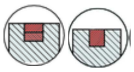
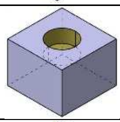
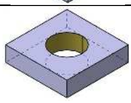
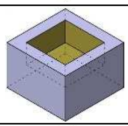
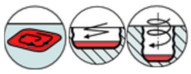
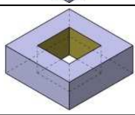
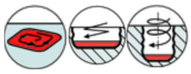
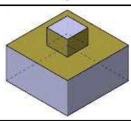
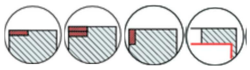
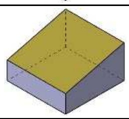
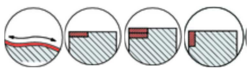
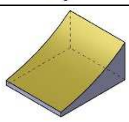
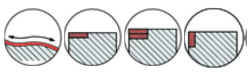
- The type of the feature is the most critical parameter that implicitly determines the type of the cutter and the type of insert. The manufacturer gives groups of cutters and their suitable inserts including recommended ones according to the operation to be performed. So, it is necessary to affect operations to features in order to achieve a choice of cutters and inserts for the feature. Machining features can be divided into two categories, simple features and complex features. Simple features are realized by using one machining operation, for example, a face and a shoulder can be performed by face milling and shoulder milling respectively. A groove is formed by a grooving operation. Thereby, operations proposed by the manufacturer can be affected directly to the feature to ensure its machining. Complex features require at least two machining operations such curved surfaces and freeform surfaces (features), which require roughing and profiling operations. These types of surfaces are called Multiple Operation Surface (MOS) and have been already cited in the literature [17]. Thus, all operations that can insure the machining of each feature are affected to the feature, and then, all types of cutters are affected to the features that can machine. It must be noticed that features that need two operations requires two groups of cutters and inserts. If any inserts or cutters are repeated, they are deleted from a group to avoid redundant.

- Depending on the surface roughness and GD&T related to each feature surfaces, a number of applications is assigned, for example, a feature having surface roughness of 0.8 (Ra = 0.8) have to be machined in three applications, roughing, semi-finishing, and finishing application. The manufacturer gives a tool geometry which depends on the type of application and the material to be machined. For example, the geometry PH is dedicated for roughing (H) of steels (P). In finishing operations, surface roughness is also influenced by some parameters depending on the surface generated. For example, for axially generated surfaces, surface roughness is influenced by the feed per revolution and the wiper land. To generate a good surface, it is important to ensure that the feed per revolution (fn) is less than 80% of the parallel land (bs). It must be known that extra close pitch cutters increase the feed per revolution, the larger the diameter cutter, the greater the feed per revolution, requiring a larger parallel land. For Radially generated surface, surface roughness is influenced by a compromise between feed per tooth and the cutter diameter (D). Which is given by Eq. (1).

$$Rt = fz^2/4D \tag{1}$$

- Depending on the material of the workpiece, the type of application and the type of the cutter and its suitable type of insert, which are assumed already selected, the insert grade may be determined. The manufacturer gives the designations of materials and their characteristics such as Specific cutting force and Brinell hardness. Depending on the insert grade and the type of material, the manufacturer gives the maximum chip thickness and the recommended cutting speed. Initial values of maximum chip thickness and recommended values of feed per tooth are given according to each type of cutter and suitable insert size and geometry.
- Dimensions of the feature such as depth of the feature and wide/length affect the choice of the type the cutter its diameter respectively. The diameter of the cutter is used to calculate the cutting speed taking into account recommendations proposed by the manufacturer that should not be violated. The depth of the feature is an important parameter that leads to the choice of an insert size. For example, if a feature depth is 8mm, and two insert sizes of 8mm and 14mm are available, there are two ways to machine the feature, in one pass with a 14mm insert size since it authorizes a maximum depth of cut of 10mm, or in two passes with a 8mm insert size because it authorizes a maximum depth of cut of 5,5mm. It is can be deduced from this example, that the insert with a bigger size will be used one time but it is the expensive one. Contrary, the insert with a small size will be used for two passes. The number of passes performed by an insert affects its tool life. Thus, the tool life/ insert size ratio presents an important parameter leading to the choice of an optimal insert size

Table 1: Example of the construction of one table

MF	Surfacic feature	Appropriate operations	Example of appropriate cutters	Suitable inserts/type of cutters head
Horizontal face			CoroMill 490***	490
			CoroMill 390**	R390
			AUTO-FS***	SBEN-SBEX
			CoroMill 331***	N331.1A- RCKT- RCHT
			CoroMill 290*	R290
Vertical face			CoroMill 390***	R390
			CoroMill 290**	R290
			Coromill 316***	316
Through step			CoroMill Century***	R/L590
			CoroMill 790***	R790
			CoroMill Plura***	R216- R215
			CoroMill 331***	R/L331.1A- RCKT- RCKT
Blind step			CoroMill 490***	490
			CoroMill 290**	R290
			CoroMill Plura iLock***	R216
			CoroMill 331	RCKT
Through slot			CoroMill 329***	329
			CoroMill 210*	R210
			CoroMill 327***	327
			CoroMill Ball Nose*	R216
Blind slot			CoroMill 328***	328
			CoroMill 300**	RCHT- RCKT
			T-MAX Q-cutter***	N151.2-330.20
			CoroMill 316***	316
Blind hole			CoroMill Plura***	R216
			CoroMill 316***	316
Through hole			CoroMill Plura***	R216
			CoroMill 316***	316
Blind pocket			CoroMill 316***	316
			CoroMill 390***	R390
			CoroMill 200	RCKT- RCHT
Through pocket			CoroMill 316***	316
			CoroMill 790***	R790
			CoroMill 210***	R210
Boss			AUTO-FS***	SBEN- SBEX
			CoroMill 300*	R300
			CoroMill Plura	R216
			CoroMill 331***	R/L331.1A
Slope face			CoroMill 300***	R300
			CoroMill Ball Nose***	R216
			CoroMill 790**	R790
			CoroMill 210*	R210
Freeform surface			CoroMill 390*	R390
			CoroMill 316***	316
			CoroMill 200**	RCHT- RCKT
			CoroMill 690***	690

according to the depth of the feature.

It must be known that some parameters related to tools such as the coupling size and type, and the pitch of the cutter are selected manually by the user, which is advised to choose these parameters according to his necessities. Once the system has determined all parameters related to the inserts and cutters, adding to cutting conditions for each feature, and taking the fact that each parameter is coded by at least one letter or one number, it searches through the database of catalogued tooling matches. Once such a match is determined the system stores the code key of each tool in another database. Table 1 encompass all milling features, appropriate operations, cutters and their suitable insert, cutters head, that can be used to perform the machining of each feature. Cutters with three starts are recommended ones.

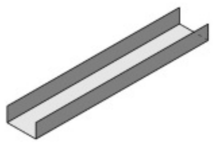
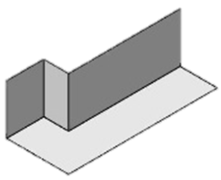
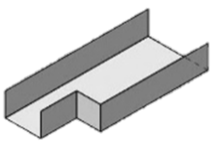
4 CASE STUDY

The developed systems for feature recognition and automatic tool selection have been applied to the simple workpiece shown in Fig. (2). The material of the workpiece is taking to be steel (P). After designing the part with CATIA V5, the physical STEP AP203 Ed2 file is generated, and then, at a first stage, feature recognition is applied. Three features are identified, the groove F1 which is a simple feature considered as a perfect manufacturing feature. A complex manufacturing feature F2 composed by two interacting features, which are a through step and a blind step. And a simple feature F3 which can be identified as a through step since only two faces of this feature are blank faces. The system for feature recognition generates two combinations resulting by interactions between F2 and F3. For tool selection, each combination is treated separately by the automatic tool selection system. In this example, we have treated only one combination of features. Taking the fact that features are identified, surfaces of each feature are known, and geometric and technical data related to each surfaces of each feature are stored. In this example, we have taken surface roughness of 1µm for surfaces of all features for simplification and in order to generate tools for roughing, and finishing operations for all features. At a second stage, features parameters are transferred to the system for cutting tool selection, and parameters of tools are determined. For each feature, a number of tools is selected. For the huge number of more than 400 inserts and cutters generated by the system, we have limited insert size to 8mm for 331 and 490 inserts, to 9mm for 327, and to 11mm for 390 inserts, the coupling type is limited to cylindrical shank for CoroMill 331, CoroMill 490, CoroMill 390 cutters. Since cilandrical shank coupling is not available for CoroMill 329, Arbor coupling is chosen. Cutters diameters are limited to 40mm for CoroMill 490 and CoroMill 390, to 100mm for CoroMill 329. Cutters head diameters are limited to 25mm for CoroMill 316, and to 20mm for CoroMill Plura. Concerning applications, some inserts are not available for roughing operations, such as CoroMill 331. Thus we have chosen inserts for semi-finishing operation in this case despite the fact that the system has generated roughing operation for the groove F1.Table 2 illustrates the selected inserts, cutters, and cutters heads for each feature and for each application.

5 CONCLUSION

In this paper, we first gave an overview of the method we have developed regarding the recognition of machining milling features. This step is crucial for the integration of CAD / CAM systems. When several interacting features arise, several combinations of features are generated, and for each combination, an order of features machining is well defined by the feature recognition system. This number can be reduced if we take into consideration the GD&T and economic and technological constraints that create precedence between features, and thereafter, some combinations are deleted and will not be processed by the system of cutting tool selection. The method of cutting tool selection we have developed introduces a

Table 2: Tools generated by the new approach for each feature of the example part

Features	Cutters	Applications	Inserts/head
 F1	**CoroMill 331:** R331.32-080A32EM R331.52-080A32EML R331.52-080A32EMR R331.35-080A32EM100	Finishing	N331.1A-08 45 08H-NL-GC1012 N331.1A-08 45 08H-W-GC1025L R/L331.1A-08 45 30H-WL-GC1025 R/L331.1A-08 45 15H-WL-GC1025 R/L331.1A-08 45 23H-WL-GC1025 R/L331.1A-08 45 30H-WL-GC1030 R/L331.1A-08 45 15H-WL-GC1030 R/L331.1A-08 45 23H-WL-GC1030
		Semi-finishing	N331.1A-08 45 08H-PM-GC4230 N331.1A-08 45 08M-PM-GC4230 N331.1D-136508E-PM-GC4240 N331.1D-136520E-PM-GC4240
	CoroMill 327: 327-16B18SC-09 327-16B32EC-09 327-16B45EC-09 327-16B64EC-09 392.ER327-11 09 022 392.ER327-16 09 022 392.ER327-20 09 022 392.ER327-25 09 022	Finishing and Roughing	327R09-18 15002-GM-GC1025 327R09-18 20002-GM-GC1025 327R09-18 25002-GM-GC1025 327R09-18 30002-GM-GC1025 327R09-18 15001-GMM-GC1025 327R09-18 20002-GMM-GC1025 327R09-18 25002-GMM-GC1025 327R09-18 30002-GMM-GC1025 327R09-18 11000-GM-GC1025 327R09-18 13000-GM-GC1025 327R09-18 16000-GM-GC1025
	CoroMill 329: 329-100Q22-E 329-100Q22-F 329-100Q22-G 329-100Q22-H 329-100Q22-J	Finishing and Roughing	N123E2-0200-0002-CM-GC1125 N123F2-0250-0002-CM-GC1125 N123G2-0300-0002-CM-GC1125 N123H2-0400-0002-CM-GC1125 N123J2-0500-0002-CM-GC1125
 F2	**CoroMill 490:** 490-040A32-08M	Finishing	490R-08T308M-PL-GC1030
		Roughing	490R-08T308M-PH-GC4240
	CoroMill 390: R390-040A32-11M R390-040A40-45M	Finishing	R390-11 T3 08E-PL-GC1030 R390-11 T3 08M-PL-GC1030
		Roughing	R390-11 T3 10M-PH-GC4240
 F3	**CoroMill 316**	Finishing	316-25FM850-25010L-GC1030
		Roughing	316-25SM550-25010P-GC1030 316-25SM550-25015P-GC1030 316-25SM550-25020P-GC1030
	CoroMill Plura	Finishing	R215.36-20060-AC38L-GC1620
		Roughing	R216.34-20050-CC32P-GC1640

new concept of selecting cutting tools based on manufacturing feature. Tools are selected taking into account all the parameters relating to features generated by the system for feature recognition. Through the parameters of each feature, the system determines the parameters for cutting tools. Once all parameters of tools are determined, several series of letters and numbers that represent the tool parameters are stored. The system searches through the database of manufacturer codes that correspond to these coded series. Thereafter, tools are stored in another database related to each feature.

it is clear that this new concept will facilitate on the one hand the selection and integration of tools in CAPP system, and secondly, reduce the time required to find appropriate tools through the catalog for a given operation. However, this method results in most cases to several inserts and cutters with different sizes. It must be highlighted that the size of insert and the depth of cut present crucial parameters affecting the total machining time, which is also influenced by the tool change time, by tool travel time, and operation sequencing. These issues will be addressed in a future work.

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