International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 8 No. 1 Sep. 2014, pp. 307-319

http://www.ijias.issr-journals.org/

# Manufacturing Computer Aided Process Planning For Rotational Parts. Part 2: A New Approach for Optimizing Multiple Interpretations of Interacting Features Based on Manufacturing Rules and Metal Removal Principals

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**ABSTRACT:** Automatic Feature Recognition (AFR) has played a crucial role linking Computer Aided Design (CAD) activities and Computer Aided Process Planning (CAPP) activities. For the purpose, many methods have been developed to recognize form features from CAD files, taking into account features interactions. Among one of the most efficient approaches that can handle features interactions is the Cell-based volume decomposition approach. However, on the one hand, this method suffers from computational combinatorial explosions when multiple interpretations of sets to remove volumetric features from a same part are generated. On the other hand, not all interpretations are rational from a machining point of view in the real manufacturing environment. This paper describes a new approach to eliminate the undesirable interpretations of features, according to manufacturing rules and metal removal principals. A Features Suppression system is elaborated, and which consists in adding or removing material rings matching to some volumetric features of the part. By this way, the part and the stock are modified, and the number of interacting features that are used to generate multiple interpretations of features is remarkably reduced. A simple example part has been processed through this paper to validate the approach.

**KEYWORDS:** Automatic Feature Recognition, Features Interactions, STEP, CAD/CAPP/CAM, Optimization, Turning Process.

## 1 INTRODUCTION

Due to the high industrial competitiveness, manufacturing companies are forced to produce high quality products at the lower possible cost. Process planning is an activity that consists in selecting the necessary tools, machines, processes, operations and instructions, to transform industrial materials from raw materials into finished parts, according to the requirements of the designer. The traditional way to solve process planning problems is to leave it to the manufacturing experts, who translate the global geometry of the part into a group of machining features, well adapted each to a defined machining process, relying on their own experience and knowledge of production facilities, equipment, their capabilities, and tooling. As a part may contain many features, proper sequencing of machining these features is crucial in achieving efficient and high-quality manufacturing of the part [1]. This manual approach is time consuming and also considered as a poor use of engineering skills, because of the high clerical content in most of its functions [2]. To overcome these issues, and to ensure significant reduction of time needed for elaboration of manufacturing process planes, manufacturing companies need more automation from design activities to manufacturing activities, ensuring an easier, a faster and a flexible workflow [3]. As the design process is reinforced by many Computer Aided Design tools, Computer Aided Process Planning (CAPP) has evolved to simplify and improve process planning, and achieve more effective use of manufacturing resources. In the recent years, the integration of Computer Aided Process Planning (CAPP) has received significant attention, since it represents the main bridge between Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM). One of the core tasks in CAPP systems is to extract and identify the information such as machining features directly from a CAD neutral file, because CAD systems do not provide part feature information. Thus, in order to insure an efficient interfacing between CAD and CAPP systems, feature recognition is one of the most competent approaches.

Over the past decade, automatic feature recognition has steadily advanced, and many commercial feature recognition systems have appeared in the marketplace. However, most of current feature recognition systems have not yet been significantly implemented in real industrial activities [4]. The majority of these systems can interpret and process only isolated features, but proper handling of interacting features often has a wide range of consequences and effects on a feature model, in the way it is to be interpreted and utilized in process planning activities. On the one hand, feature interactions can cause feature validity to be violated because they not only change the predefined feature geometric form and its topology, but also alter its attributes such as Geometric Dimensioning and Tolerancing (GD&T), or even completely leads to the suppression of some features surfaces [5]. From a machining point of view, the machining of certain features may accidentally destroy the necessary entities such as fixturing surfaces, locating surfaces, and supporting surfaces required for machining other features [6]. As a result, it is hard to identify features and hard to sequence them properly in process planning. On the other hand, despite the fact that some robust methods such as Convex Decomposition and Volume Decomposition methods have been developed so as to handle features interactions, these methods are computationally intensive [7]. A large number of possible combinations of cells (up to n!) have led to an enormous time complexity. Adding to that, not all the interpretations of interacting features were reasonable from a machining point of view [8].

In the literature, in volume decomposition approach, generating multiple interpretations of interacting features, and creating new form features is done by extending material surfaces of the interacting features until the stock [7], [8], [9]. The data used to build these new features are only form feature information: geometric, dimensional and topological data extracted from a CAD neutral data file such as STEP [10]. Besides, Geometric Dimensioning and Tolerancing (GD&T), economic and technological constraints, are not taken into account during feature recognition and especially generation of multiple interpretations of interacting features. These tolerancing requirements and constraints are usually used by downstream activities such as automatic tool selection, adding to features and operations sequencing. When we talk about multiple interpretations of interacting features, we talk about multiple combinations that correspond to all the possible sets of machining features that can be recognized from the part. It represents multiple ways to decompose the total machinable volume into features volumes. It is known that GD&T and economic and technological constraints create implicitly precedence between features, which can lead to the elimination of some combinations for which the order to machine features violates precedence constraints. However, extraction of GD&T data from CAD systems has been a major problem. These data are embedded as a drawing in the most of CAD systems [11]. Thus, the only scope to reduce the number of multiple interpretations of interacting features, without recurring to (GD&T), economic and technological constraints, is to focus on eliminating all the interpretations of interacting features that are not reasonable from a machining point of view, by unifying machining parameters according to manufacturing rules and metal removal principals [12], and which is the main objective of this manuscript.

This paper is organized as following: In Section 2, we describe previous works on Automatic Feature Recognition and features sequencing. Section 3 briefly describes a feature recognition system for rotational parts which adopts STEP AP203 Ed2 as an input. Section 4 provides details about a new concept of Features Suppression, based on the work done by Ersan Aslan [12], and which consists in eliminating the unwanted combinations by adding or removing material rings corresponding to some volumetric features of the part, according to manufacturing rules and metal removal principals. In section 5, we give an overview of a Features Generator system capable of generating multiple interpretations of interacting features. Section 6 treats machining features sequencing. In section 7, a simple workpiece is presented for explanation of the proposed methodology. Finally, concluding remarks and recommendations are presented in Section 8.

## 2 LITERATURE REVIEW

- Automatic Feature Recognition (AFR)

There have been many previous attempts leading to the development of successful feature recognition methods for manufacturing purposes, and which can be broadly classified into many approaches: graph-based, hint-based, convex volume decomposition, volume decomposition-recombination, rule-based, and other methods.

Graph-based approaches are most efficient in recognizing canonical instances of feature patterns, but generally cannot handle interacting features and multiple interpretations [8]. Rahmani & Arezoo [4], made a hybrid graph based and hint-based analysis techniques to recognize interacting features for prismatic parts. The graph-based aspect of the current approach is aimed at extracting feature hints, but the feature is completed geometrically. This method uses an AAG which is decomposed to limit and organize the search space for feature hints. Hints, in sub-graph forms, are extracted from the decomposed graph components. A completed volume is then generated for each feature hint using geometric and topological properties of the part.

Convex decomposition and maximum volume decomposition methods are more robust in handling features interactions, but are computationally intensive, and lead to a large number of possible features interpretations. Wang & Kim [7], described a hybrid feature recognition method capable of handling interacting features for prismatic parts, and which combines three feature recognition technologies: graph-based, convex volume decomposition, and maximal volume decomposition method. These methods are combined so as that they mutually complement each other's capabilities, without compromising performance and completeness. The graph-based method (GRP) efficiently simplifies the volumetric connectivity of the resulting part. The maximal Volume Decomposition method (MVD) removes features with toroidal faces, while addressing MVD's combinatorial complexity. Negative Feature Decomposition method (NFD) handles interacting features, and generates rich feature information. Anomalies caused by MVD's maximal volume growing have been identified, and are cured by introducing limiting half-spaces.

Jaider and El Mesbahi [9] developed a feature recognition system for rotational parts by taking STEP file as an input to the system. The first module of this system uses the rule-based approach for recognizing both isolated and interacting features. This module consists in analyzing geometric and topological data extracted from STEP AP203 Ed 2 data file, and recognizes each feature according on certain pre-specified rules that are characteristic to the feature. The second module takes the recognized features, and uses a circular volume decomposition approach to generate multiple combinations of possible machining features. For each combination, an order to build features is well defined. Each Feature is built by extending its material surfaces until the stock or material surfaces of the part. It has been concluded that this system is reliable in recognizing turning features and generating multiple interpretations of interacting features, nevertheless, according to manufacturing rules and metal removal principals applied in real manufacturing environment, it is no use to generate some interpretations of features, for which the order of machining these features is not reasonable.

- <u>Machining features sequencing:</u>

Liu & Wang [1] used a hybrid approach combining both knowledge-based rules and geometric reasoning rules to determine feature sequence for prismatic parts with interacting features. The developed approach consists of three steps. The first step involves determining machining precedence constraints by a set of defined knowledge-based. These precedence constraints can be classified as Fixture interactions, Tool interactions and Tolerance/datum interactions. In the second step, machining features are grouped into setups based on determining a primary locating direction of a setup, and the appropriate machining features are grouped into the setup according to their tool approaching directions (TADs). In the last step, features are sequenced within each setup through geometric reasoning. The advantage of this approach is that both manufacturing interactions and geometric interactions can be handled simultaneously during feature sequencing.

Ersan [12] developed a system that aimed to extract information from DXF files to determine features existing on rotational parts, machined on horizontal machining centers. During features extractions, and by applying production rules, some features are modified based on analyzing their neighborhood. The definition of process neighborhood should be considered as an obligation for maintaining of tools, shortening of tool path and part programming and preventing of tool crashing into the part material. By this way, machining parameters are unified, new features were re-created and new processes were established. The processes are put into order according to manufacturing rules and metal removal principles, becoming prior and secondary. The number of factors starts with 100, which belongs to facing. The bigger confident factor describes the first process to be performed. This system is powerful when isolated features occur, however, it cannot handle multiple interpretations of interacting features.

## 3 AUTOMATIC FEATURE RECOGNITION FROM STEP AP203 ED2

### 3.1 GEOMETRIC AND TOPOLOGICAL DATA EXTRACTION

Being an emerging international standard protocol for the exchange of technical product data, STEP is a text file containing strings and entities that describe geometrically and topologically 3D models. The high level of description in STEP is the shell. A Closed-shell is a topological item that is constructed by joining faces along edges. A face in STEP file is denoted as ADVANCED_FACE, characterized by its surface type, and bounded at least by one loop of edges. Each loop is formed by a set of edges connected by vertex points, each vertex point, circle center, cylinder center, and so on, is marked by its coordinates. As cited implicitly above, the STEP file starts with a string CLOSED_SHELL and ends with coordinates of points, such as vertex points coordinates and circle centers coordinates. Extraction of geometric and topological information is done according to the hierarchical structure of STEP file, where C++ language is used to locate various strings and entities in the STEP file, and to store them in a database in such a way that the extracted data are coherently ordered. The command string::size_type loc = str.find( " CONICAL_SURFACE ", 0 ) is an example of one of the functions that can be used to locate a specified text string.

### 3.2 AUTOMATIC FEATURE RECOGNITION

Taking the fact that geometric and topological data are extracted from the STEP file, these data are analyzed by the rule-based approach in order to identify each feature according on certain pre-specified rules that are characteristic to the feature. In this paper, the recess feature illustrated in Fig. 1 has been chosen for explanation of above rules. It must be noticed that the coordinate system that was adopted is YZ, Y for the diameter, and Z for the length since it is the same axis taken In CNC machining operations.

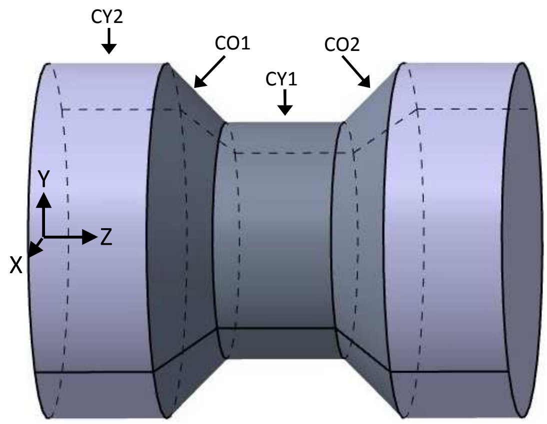


***Fig. 1. A cylinder containing an angled recess feature***

The set of heuristic rules used to describe recognition of this type of recess depicted above is as following:

**Rule 1**:
The STEP data must contain two CONICAL_SURFACEs (CO1, CO2) and two CYLINDRCAL_SURFACEs (CY1, CY2) having different diameters, and circle centers of the cylinder with minor radius lie between four circles centers of the cylinder with major radius.

**Rule 2**:
X and Y coordinates of cylinders centers, tapers centers and circles centers must be the same, and Z coordinate may be different.

**Rule 3**:
X, Y, Z coordinates of each taper center and two circles centers of the cylinder with minor radius are same.

**Rule 4**:
The left taper to the minor cylinder must be a right hand taper (major radius at the left end of the cone), and the right taper to the minor cylinder is a left hand taper (major radius at the right end of the cone). The angle of taper is equal to the last value in the line of CONICAL_SURFACE in the STEP text file. The depth of the recess is equal to the difference between the big and the small radius of cylinders.

**Rule 5**:
Edge curve construction of CYLINDRICAL_SURFACEs and CONICAL_SURFACEs must be; line, circle, line circle, or; circle, line, circle, line.

**Rule 6**:
Every CYLINDRICAL_SURFACE and CONICAL_SURFACE shares two common linear edges with another of the same type.

**Rule 7**:
Circles with minor radius of tapers and circles of the cylinder with minor radius are same. Circles with major radius of tapers and four circles among eight of the cylinder with major radius are same.

The system for feature recognition processes a database of fifty predefined manufacturing features and capable of recognizing external features, internal features, and special features such as threads.

## 4 FEATURES SUPPRESSION

After recognizing turning features, an analysis is made to handle interacting features, since when many interacting features occur, multiple combinations of features to be removed from the stock in order to machine a same workpiece are generated, which can lead to a computational combinatorial explosion. For the purpose, we have developed a Features Suppression system, to reduce the number of combinations generated by a Feature Generator system, by adding and removing material rings to the part and from the stock respectively. The advantage of this method is that the part is simplified and interactions between the suppressed features and the remaining features are avoided. This Features Suppression system is based on the work done by Ersan [12], which treats unification of machining parameters for rotational parts according to manufacturing rules and metal removal principals, and which consists in defining priority of the processes based on analyzing neighborhood of some features.

### 4.1 FEATURES SUPPRESSION BY ADDING MATERIAL RINGS TO THE PART

In this step, a judicious analysis is done to neighbor surfaces of some usual turning features. Features processed in this sub-section are: grooves, recesses, tapers, rounds and chamfers.

- **Neighborhood of grooves and recesses**

From the point of manufacturing rules applied by experts in the real manufacturing environment, two cylinders having a same diameter will be machined sequentially, which causes long tool path into blank diameter of the groove. Hence, when a groove lies between two cylinders having the same diameter (Fig. 2a), these cylinders are unified to form a new cylinder length, and a groove is stored to be performed after machining that new cylinder. Otherwise, a material ring corresponding to the groove dimensions, topology and geometry can be added to the part. This is done by extending an adjacent cylindrical surface (ADVANCED_FACE) to the groove by a length matching to the length of the blank diameter of the groove. It must be highlighted that all geometric and topological data related to the groove, and the cylinder are modified or deleted from STEP text file. For example, ADVANCED_FACEs representing the two plans and the cylinder with minor radius that form the groove of Fig. 2a, loops, circular edges, vertex points, and so on, are deleted from STEP file. In the case when neighbor cylinders of the groove have different diameters (Fig. 2b), the cylinder with minor radius is extended until reaching a material surface representing a plan of the groove.

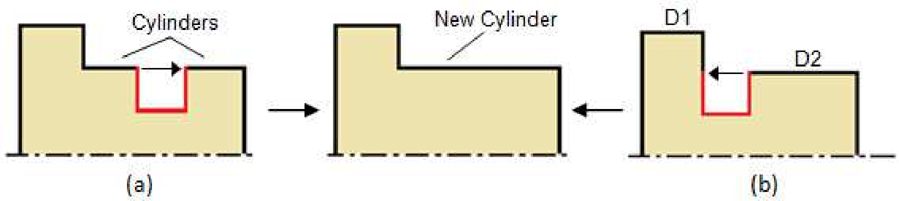


*Fig. 2. Rings addition for grooves*

In the case of nested grooves (Fig. 3), material rings addition is done by the same manner, starting from small diameters to big diameters, and repeated until that no groove remains in the workpiece. Material rings addition for grooves can be applied also for many types of recess and nested recess, such as angled recesses and filleted recesses. It seems clear that the order to add material rings corresponding to recesses and grooves is the contrary order to machine these features.

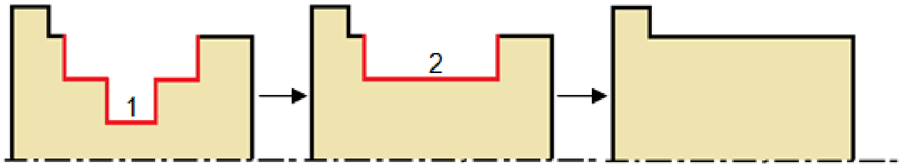


*Fig. 3. Rings addition for nested grooves*

- **Neighborhood of tapers**

Concerning tapers, author [12] has described how to create a new cylinder based on neighborhood between cylinder and taper, by extending the cylinder. However, the cylinder may interact with other neighbor features. Features interactions generate multiple interpretations of features, as a result, the length of that new cylinder may take many values (Fig. 4). Thus, it is preferable to add a material ring from the taper, in such a way that the neighbor minor cylinder to the taper becomes a simple shoulder feature, formed by joining a plan and a cylinder along a circular loop. By this way, the shoulder can interact easily with other simple features (Fig. 5). In this case, a material ring is formed by creating two virtual surfaces (Fig. 6). The first surface is obtained by extending the neighbor cylinder with major radius by the length of the taper. The second surface is a plan bounded by two loops. The inner loop of that plan is the same loop formed by circles with minor radius of the taper. The outer loop of that plan is the same loop formed by two circles of the extended cylinder.

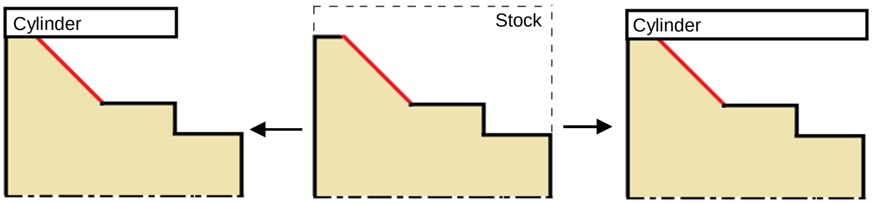


*Fig. 4. Cylinder created from a taper (Ersan, 2005)*

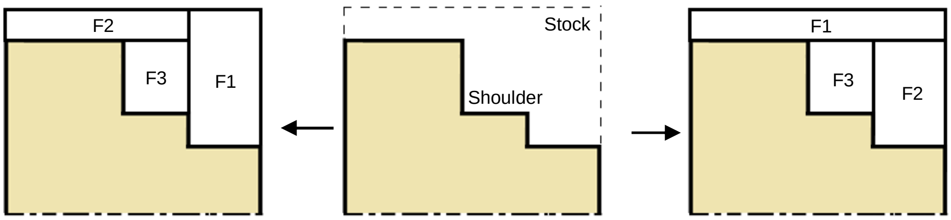


*Fig. 5. Some interacting features resulting after adding a ring to the taper*

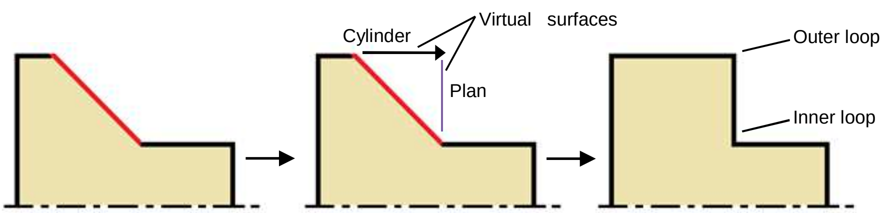


*Fig. 6. Ring addition for a taper*

- **Neighborhood of chamfers and rounds**

It is known that adjacent surfaces of a chamfer are almost a plan and a cylinder. Author [12] has explained how to create a cylinder neighbor to a chamfer, for which the length is calculated by the sum of the old cylinder length and the first chamfer length. However, the neighbor face to the chamfer was not treated. Adding to that, the adjacent face and the adjacent cylinder to the chamfer can interact between each other and with other features. As a result, the length of that new cylinder, and the diameter of circles that form the outer loop of the face may take many values (Fig. 7). Thus, it is advantageous to add a material ring from the chamfer in order to facilitate handling of interacting features adjacent to the chamfer (Fig. 8).

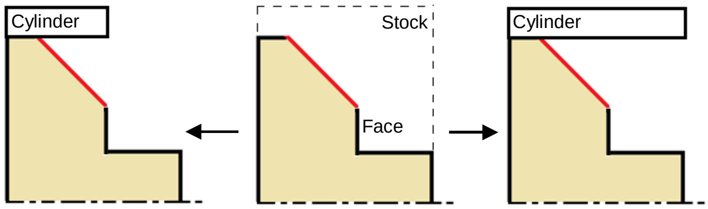


***Fig. 7. Cylinder created from a chamfer (Ersan, 2005)***

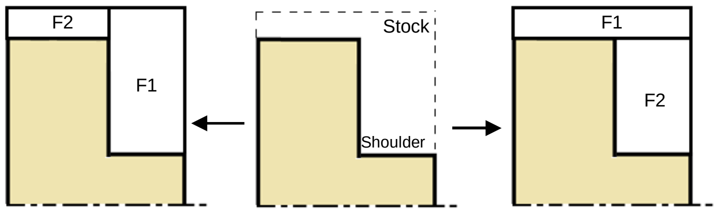


***Fig. 8. Interacting features resulting after adding a ring to the chamfer***

In this case, a material ring is formed by extending adjacent surfaces to the chamfer (Fig. 9). The adjacent cylinder to the chamfer is extended by the first chamfer length, and the adjacent face to the chamfer is extended by the second chamfer length.

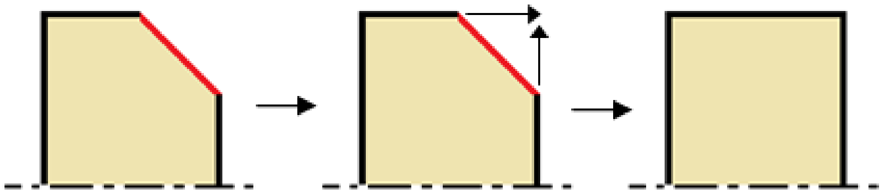

***Fig. 9. Ring addition for a chamfer***

Material rings for rounds are also created by extending adjacent surfaces to the round. The difference between rounds and chamfers is that both adjacent surfaces to the round are extended by the round radius.

#### 4.2 FEATURES SUPPRESSION BY REMOVING MATERIAL RINGS FROM THE STOCK

It is known that workpiece zero point is generally taken on the face in CNC machining operations. So, facing is considered to be the first operation in any turning process. The second operation is considered as the operation from stock diameter to the maximum diameter of the finished product [13]. Thus, it will be necessary to remove the face and the cylinder features from the stock cylindrical bar, if they exist, in order to avoid interactions between the face and the cylinder with maximum diameter with other features. A face feature exists, if the difference between the length of the stock and the final part length is different to zero. Besides, a cylinder exists if the difference between the diameter of the stock and the final diameter of the finished part is different to zero. The face and the cylinder can be removed by extending the face until the stock, and followed by extending the cylindrical surface with maximum diameter until the extended face (Fig. 10). And then, a cylinder to the face and a hollow cylinder to the cylinder with maximum diameter are removed from the stock. By this way, the length of the new cylindrical stock bar becomes smaller by the length of the removed cylinder to the face, and the diameter of the new stock becomes smaller by the difference between the old stock diameter and the maximum diameter of the part.

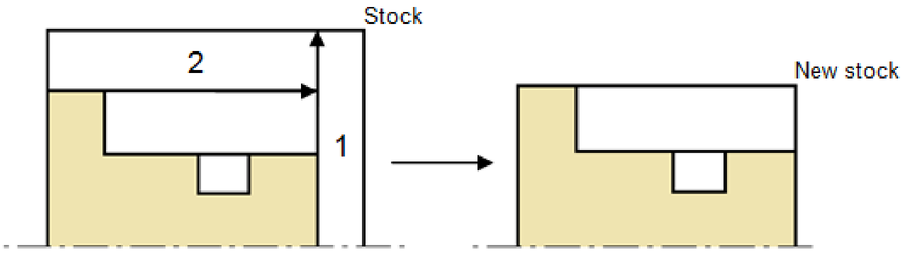


*Fig. 10. Suppression of the face and the cylinder features from the stock*

### 4.3 Features Combinations Elimination

The workpiece of Fig. 11 is taken on one hand, to recapitulate and to clarify the methodology above for adding and removing material rings, and on the other hand, to explain and to show how systematically, the number of multiple combinations resulting from interacting features is reduced. The workpiece in divided into two regions, internal region and external region since the maximum diameter for both internal and external features, is at one end of the part [9], [14]. Each region must be treated separately in order not to confuse interactions between features from different regions.

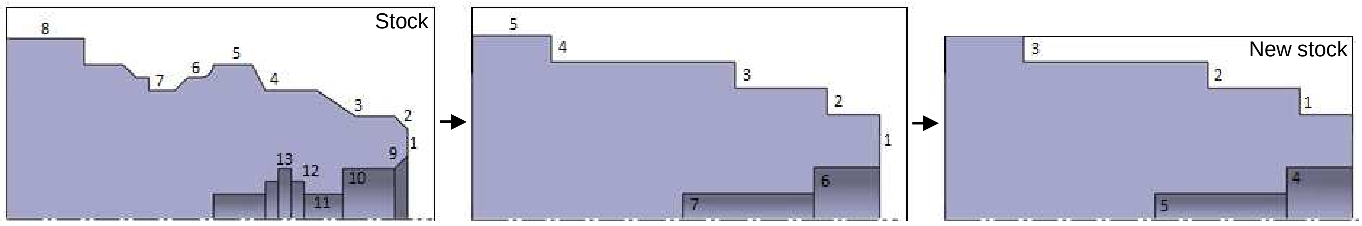


*Fig. 11. Simple workpiece*

For the workpiece left in the figure above, eight features are interacting for external turning, and five interacting features for internal turning. Taking the fact that chamfers represent covering features, the chamfers 2 and 9 are excluded from interactions. This means that 7! Combinations of features to machine the external shape of the part are resulting by external features, and 4! Combinations are resulting by internal features. By applying the method of material rings addition, shoulders 3 and 4, face 1 and the adjacent cylinders to chamfers are modified. Recesses 6 and 7 are excluded from interactions with other features such as the shoulder 5. The same case for grooves 12 and 13. This means that the number of combinations is reduced to 5! combinations for external turning, and 2! combinations of internal turning. By removing the face 1 and cylinder 5 from the stock, the number of combinations is reduced to 3! combinations for external turning. It must be noticed that all material rings that were added to the part or removed from the stock, that correspond to machining features, are stored in a database, since they will be used for machining features sequencing. So after covering the workpiece by adding material rings matching to features processed in section 4.1, and after reducing dimensions of the stock cylinder by removing the face and the cylinder with major radius from it, the modified part and the remaining features will be addressed in the Feature Generator system, also, the new stock will be used to generate possible interpretations of interacting features.

## 5 Features Generator

Before describing the methodology followed for generating new manufacturing features, it will be important at this stage to define the following terms: Perfect Manufacturing Feature (PMF), and Imperfect Manufacturing Feature (IMF). A PMF is simply an isolated feature, for which frontier surfaces of the feature surfaces are blank surfaces. Whereas, an IMF is an interacting feature, wherein, at least one frontier surface of the feature surfaces is not a blank surface. Thus, the Features generator system analyses frontier surfaces of each feature surfaces, to locate the IMF that will be used to build new manufacturing features. Construction of a new manufacturing feature (MF) is based on extending material surfaces of the IMF until blank surfaces of the part. By this way, an IMF is transformed to a PMF. Once a feature is built, it is removed from the stock, and after, material surfaces of a following feature are extended until the last new stock. The operation is repeated until that the stock becomes the final part. It must be noticed that the order in which features are build, is the same order in which features are machined. For the example part of Fig. 12, only one combination to build features in a specific order is illustrated, many combinations are valid.

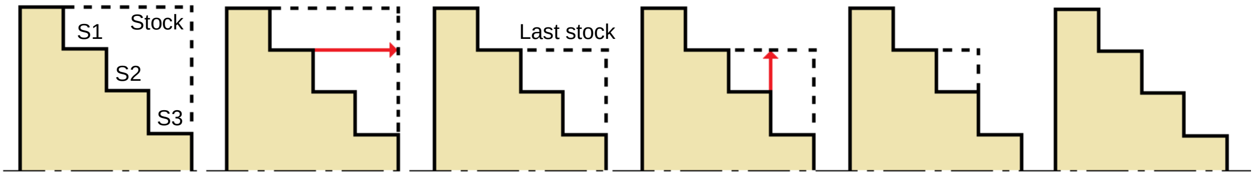


*Fig. 12. Generation of features by extending their material surfaces until the stock surfaces*

Combinations of features can be obtained according to the number of IMF. If the number of intersecting imperfect manufacturing features is N, there are N! combinations to build N features. Otherwise, there are N! manners to machine N features. So, after construction of new perfect manufacturing feature, which are considered as isolated features, the Features Generator is called to extract new dimensional parameters of features. These features are also stored in the same database where material rings were stored.

## 6 MACHINING FEATURE SEQUENCING FOR PROCESS PLANNING

It must be observed that all the stored features are in an incorrect order from a machining point of view. Features are put into order according to metal removal principles, becoming prior and secondary and usability of the tool for many features as given in Table 1. The features below have got confident factors to put them in order [12]. The number of factors starts with 100, which belongs to facing, the bigger confident factor describes the first process to be performed. Facing is followed by longitudinal turning of the maximum diameter of the part. Both these features belong to the removed features from the stock. Next, features to be performed are features of a combination among those generated from interacting features by the Feature Generator system, which are simple shoulders that can be also classified as cylinders with a same confident factor (90).

In our system for feature recognition, a shoulder can be identified as a junction between a plan and a cylinder (Fig. 13a), or between a conical surface and a cylinder (Fig. 13b). We can consider that a taper is the association of a simple shoulder (junction of a plan and a cylinder) and a material ring to the cone (Fig. 13c). Thus, it will be advantageous to unify this ring and the simple shoulder in a single roughing operation [13], with respect of the priority of process, and taking into consideration features interactions. Taking the taper shown in Fig. 14b. Due to features interactions, the ring to the taper can be associated only with one feature respecting machining passes.

- If the adjacent cylinder (1) to the taper is extended first, then, the ring is unified with the adjacent shoulder (2) of Fig. 14a, in a single roughing operation.
- If the adjacent face to the taper is extended first, then, the ring is unified with the adjacent cylinder (2) of Fig. 14c, in a single roughing operation.

Taking the fact that the previous features are removed from the stock, features that were added as material rings to the part are machined according to their confident factors. As cited above in Section 4, the order in which nested grooves and nested recesses are added to the part from small to big diameters, is the contrary order to machine these features.

*Table 1. Features and their confident factors for machining purposes (Ersan, 2005)*

| Feature name | Confident factor | Feature name | Confident factor |
|---|---|---|---|
| **Face** | 100 | **Angled recess** | 50 |
| **Cylinder** | 90 | **Filleted recess** | 40 |
| **Taper** | 80 | **Groove** | 30 |
| **Chamfer** | 70 | **Thread** | 20 |
| **Fillet and round** | 60 | **Parting off** | 10 |

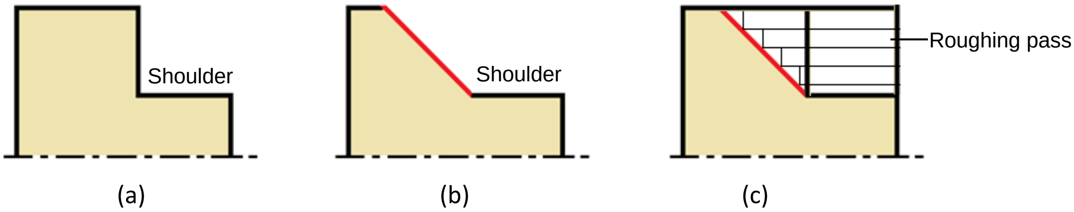


*Fig. 13. Classification of a shoulder*

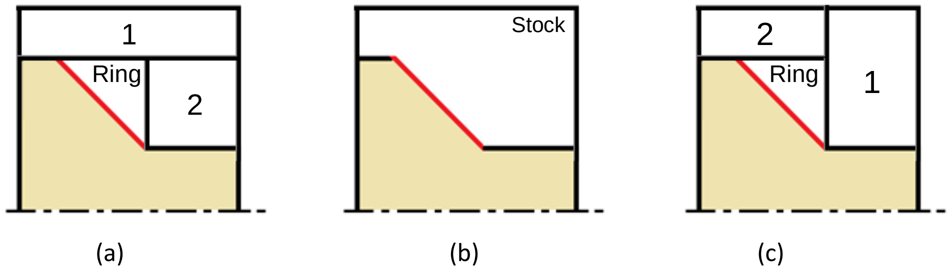


*Fig. 14. Association of the ring to the taper with enveloping features*

## 7 CASE STUDY

In this section, we took the same example part shown in Fig. 11. This part is used on one hand, to clarify the method for generating new manufacturing features from interactions between features, and on other hand, to recapitulate the chronological order in which features are sequenced for machining, based on their confident factors.

After extraction of geometric and topological data of the part from STEP AP203 Ed2 data file, these data are analyzed by the Automatic Feature Recognition system to extract features. The Feature Suppression system eliminates some features by adding material rings to the part, and stores them in a database. Other features are removed from the stock and also stored in the same database. The Features Generator system takes the new stock, the modified workpiece, and the remaining features (three shoulders) as input. After distinguishing between PMF and IMF, material surfaces of IMF are used to build new PMF. Taking the fact that three shoulders are recognized, 6 (3!) combinations to machine the external shape of the part are generated. For each combination, the order in which features are modified and their surfaces are extended until the stock to form PMFs, is the same order in which features are machined. Two combinations are similar since features are the same in a dimensional point of view. Thus, only five combinations remain. To machine the internal shape, two combinations are generated. This means that the total number of combinations to machine the part is equal to the product of numbers of combinations for external turning and internal turning. Thus, ten combinations are generated as illustrated in Fig. 15. At a last stage, the Features Generator system stores the generated features and their new dimensional parameters in the database.

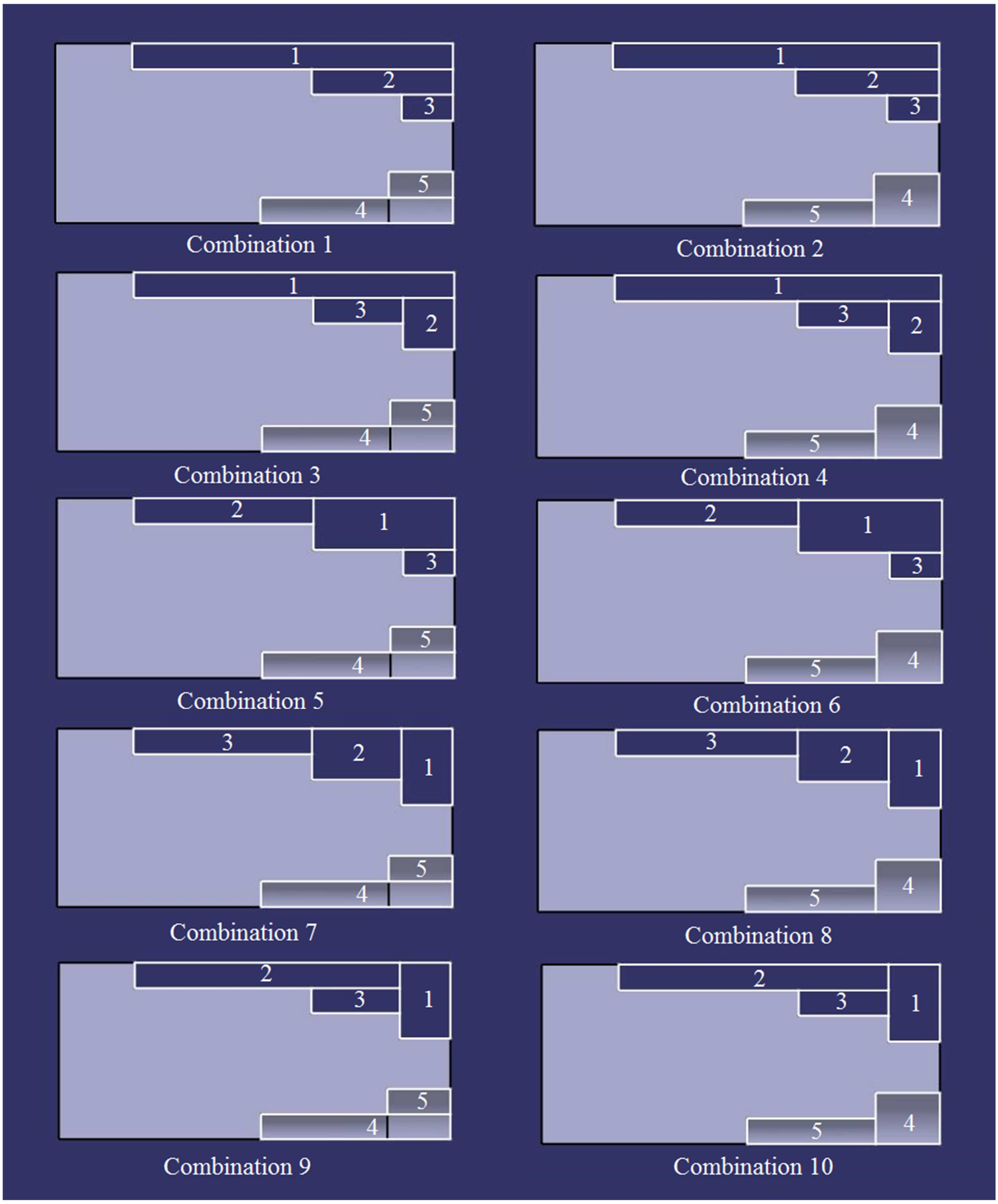


*Fig. 15. Combinations of features generated by the Feature Generator system*

It must be noticed that sequencing of features that were generated by the Feature Generator system was not treated. However, all combinations are valid. For this reason, and for explanation, we chose combination 1 to illustrate the chronological order in which all stored features are machined (Fig. 16).

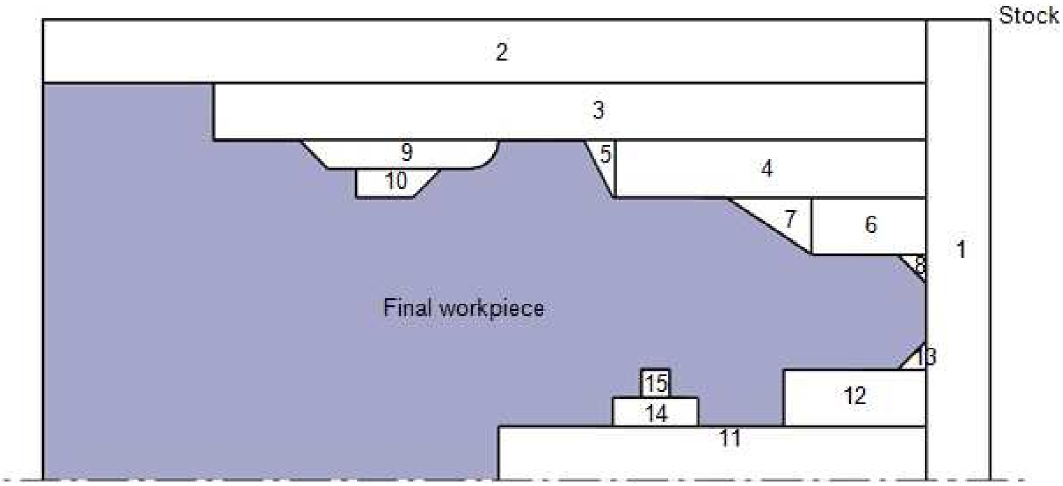


*Fig. 16. Chronological order to remove machining features from the stock*

## 8 CONCLUSION AND RECOMMENDATIONS

In the present work, we have introduced a new methodology interlinking CAD and CAPP systems, based on features recognition for rotational parts. The Automatic Feature Recognition system extracts geometric and topological data of the part from STEP AP203 Ed2 to recognize manufacturing features. According to manufacturing rules, some features such as grooves and recesses are excluded from features interactions and can be added as materiel rings to the part, to avoid interactions with other features. Others such as end faces and the cylinder with maximum diameter of the part are deleted from the stock, according to metal removal principles. As a result, the number of combinations generated by the Features Generator system (FG) is reduced. The new stock, the modified workpiece, and the remaining features are transferred to the Feature Generator system, which analyses the transferred features and builds new features from material surfaces of interacting features, by extending their material surfaces until black surfaces of the new stock. All features that was added to the part or removed from the stock, adding to the new features generated by the FG system, are stored in a database. Finally, the stored features are sequenced for process planning purposes according their confident factors.

It is clear that despite the fact that the number of combinations of interacting feature is remarkably reduced, the Features Generator system can give multiple combinations when many interacting shoulders occur, which can lead to a computational combinatorial explosion, and time consuming at tool selection stage. The combination 1 of Fig. 15 has been chosen purposely, since it respects an economic constraint that consists in organizing machining passes for a lower machining time. Thus, it will be benefic to take into consideration economic and technological constraints, Geometric Dimensioning and Tolerancing (GD&T) during generation of multiple interpretations of interacting features. Taking the fact that surfaces of each feature are known, GD&T, economic and technological constraints create precedence between surface of the part and then, between features. By this way, some combinations of feature for which the order to machine features violates these constraints will not be processed, and only the remaining combinations will be transferred to downstream activities such as automatic tool selection. These issues will be addressed in a future work.

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