STEP-based CAD/CAPP integration for finish machining operations.

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STEP - BASED CAD/CAPP INTEGRATION FOR FINISH MACHINING OPERATIONS

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Abstract: This chapter presents various CAD/CAPP integration methodologies adopted in Feature Recognition Module (FRM) of a "Finish Machining – Computer Aided Process Planning system" (FM-CAPP). The FRM contains three sub modules to process the inputted STEP AP203/214 data of a 3D CAD model. They are (i) Interfacer developed for STEP AP203/214 formats (IFST) (ii) Feature Identifier (FI) and (iii) Machinable Volume Identifier for Finish cut (MVI). Methodologies are explained for all the three sub modules to recognize features of type normal, interacting, tapering, interacting-tapering and curved base. Finally, a case study is presented to validate the adopted integration methodology.

Key words: finish machining, STEP AP203 /214 formats, feature recognition

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1. Introduction

In Computer Aided Process Planning (CAPP), work on feature recognition for prismatic parts has focused mainly on identifying the machinable volume as a whole. Generally, machining a part starts with a rough cut in which the bulk of the material is removed in the form of simple blocks (Hebbal., S.& Mehta., N.K (2001, 2002), Hebbal.,S (2004), Nagaraj., HS. &Gurumoorthy., B. 2002). The remaining finish cut volume has to be identified separately to complete the machining of the feature. A schematic representation of machinable volume for rough cuts and finish cuts is shown in Fig.1 for through step, blind step and through slot.
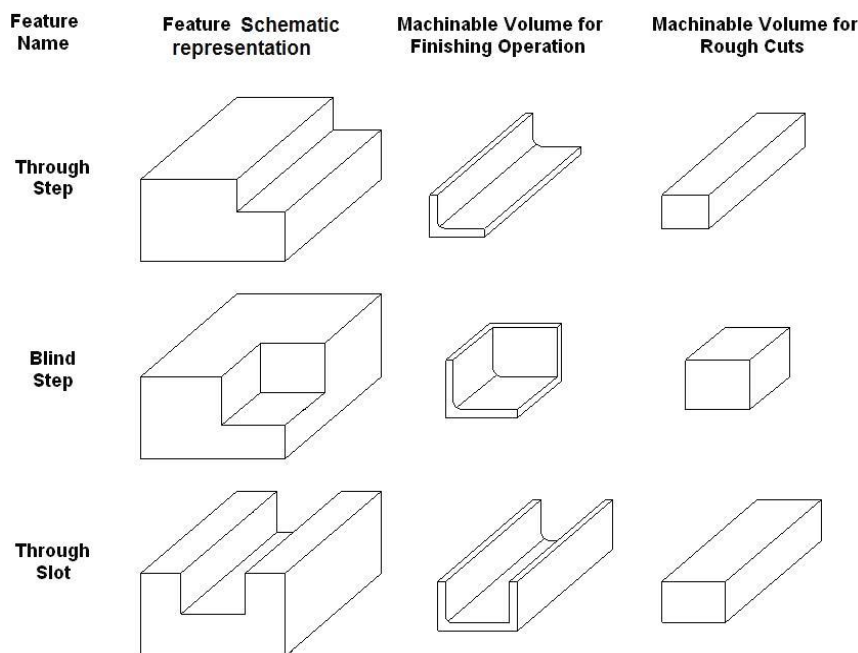

Fig. 1. Schematic representation showing machinable volume for rough & finish machining operations

From the machining point of view, this finish cut machinable volume forms the crux of the machining as it contains the details of surface finish and tolerance linked with the final dimensions. This finish cut machinable volume is often complex in shape as it is bounded by the simple shape of the rough cut on one side and the final shape of the feature on the other. The complexity while identifying this volume is more pronounced when the features of complicated cross sections such as tapering features, interacting features, and features with curved bases and their interactions are present in the part.

This is mainly required when the present problem on finish cut is dealt with. Hence in order to perform the above tasks, in this research a STEP based CAPP system named "Finish Machining - CAPP" (FM-CAPP) as shown in Fig. 2 is developed for finish cuts to generate process plans automatically for prismatic parts. In this work STEP AP203/214 is chosen as the AP224 format dealing with process planning data provides only the description of features and not about the geometrical and topological relations which is required for the complete recognition of features

and their finish cut machinable volumes. The FM-CAPP system consists of three modules, namely (i) Feature Recognition module (FRM), (ii) Machining Planning Module (MPM) and (iii) Setup Planning Module (SPM). In this chapter the FRM module is explained to cover the scope of this book. The forth coming sections explain the FRM module of the FM-CAPP system.

While presenting the details of the FRM module, the following sections are dedicated to explain the methodologies in each sub module. (i) Section 2 explains the details for InterFacer Developed for STEP AP203/214 formats (IFST) (ii) Section 3 concentrates on Feature Identifier (FI) module for feature recognition process and explains in detail the methodologies employed for recognition of manufacturing features (iii) Section 4 describes the Machinable Volume Identifier for finish cut (MVI) of the feature recognition module and provides the various methodologies adopted to calculate the finish cut machinable volume (iv) Section 5 presents an case study of a industrial prismatic part and briefly explains the developed methodologies and (v) Section 6 is reserved for conclusions.
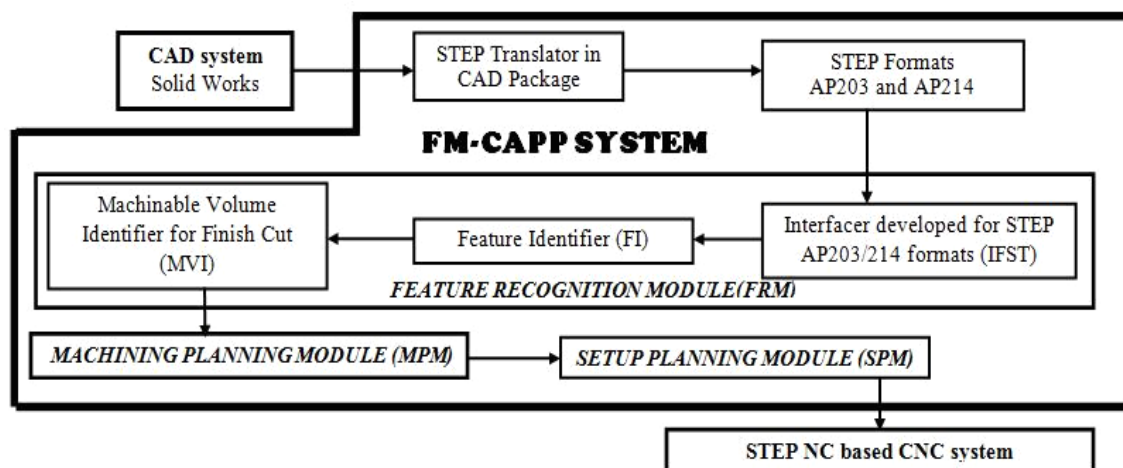

Fig. 2. Overview of the proposed system

2. InterFacer developed for STEP AP203/214 formats (IFST)

Extraction of necessary B-Rep data required for feature recognition is considered as one of the main task while integrating Computer Aided design (CAD) with Computer Aided Process Planning (CAPP). This section concentrates on developing a standard interfacing methodology for a standard neutral format known as Standard for Exchange of Product Data (STEP).
The flow diagram of the Interfacer for STEP AP203/214 formats as developed in the present work is shown in Fig.3. It contains a main module comprising AP203/214 Database (APD), Hierarchy Tree Tracer (HTT), Hierarchy Tree Database (HTD), STEP file ID storage (SIS), STEP File ID Access Module (SIDA) and Temporary Storage (TS). Six hierarchical modules (Hierarchical Level I-VI) with the separate sub modules serve to extract the geometrical and topological ID's from the STEP formats. The interfacer works on the principle of subdivision and extraction of entities present in the STEP file for the recognition of manufacturing features. The details of various modules developed are based on the geometrical and topological

entities present in the STEP formats. Already the details for these entities are easily available in many handbooks (STEP Application Handbook. 2000). Hence, only the working procedure is presented for easy understanding of the reader.
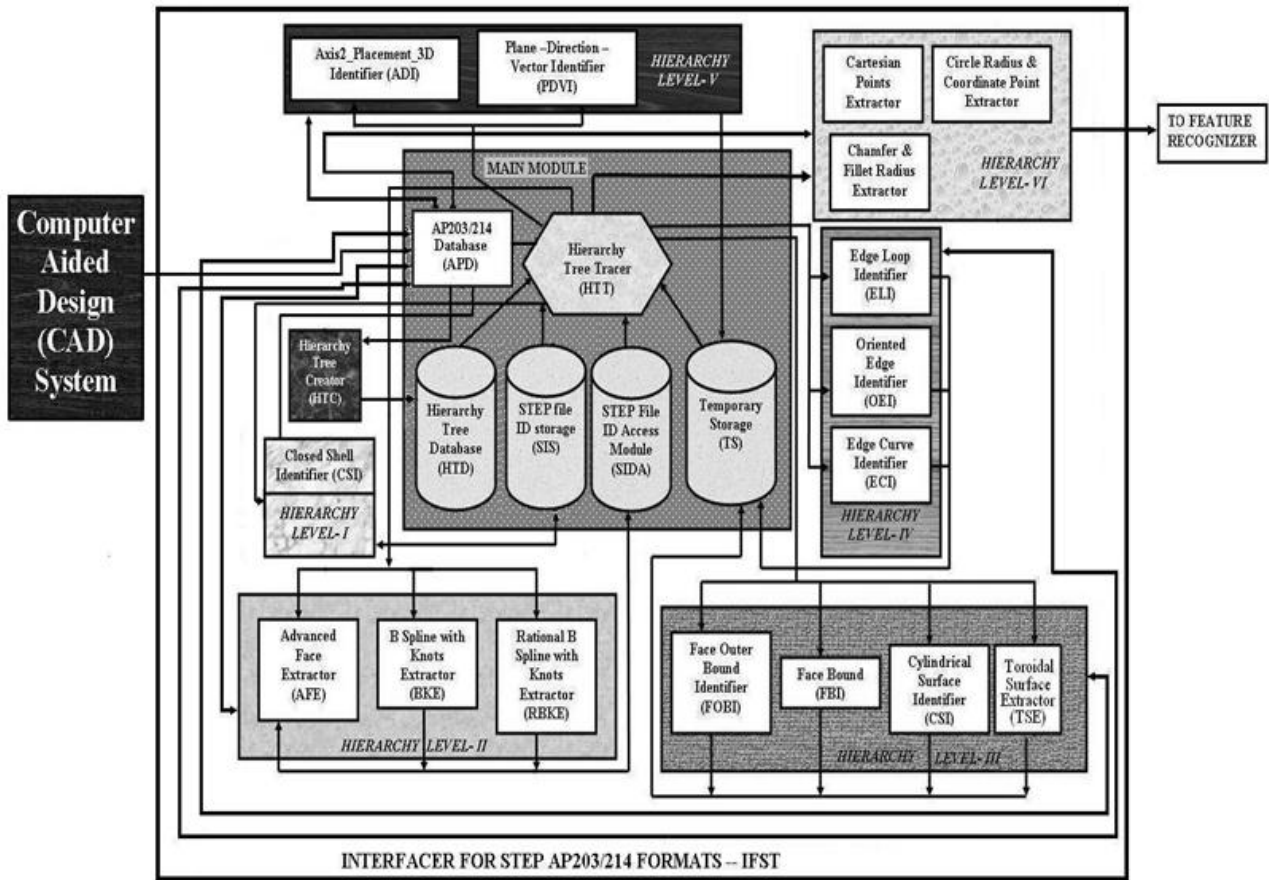

Fig. 3. Interfacer for STEP AP203/214 formats (IFST)

The Hierarchy Tree Creator (HTC) uses this file from APD and identifies the geometrical and topological entities of the part. Then it matches the hierarchy tree of the prismatic part based on the previously stored hierarchy trees in the Hierarchy Tree Database (HTD). Generally, the hierarchy tree contains different entities to represent the 3D model. The hierarchy levels represented in STEP AP203 and AP214 formats for the part and the general details of these entities are available in [14]. The HTC can generate 3 different types of hierarchy trees to trace the information required to reconstruct the prismatic part. HTD can also be accessed manually for storing the hierarchy trees. However, in the present research, 3 hierarchy trees developed are sufficient to extract the information for considered features. After this process, the Hierarchy Tree Tracer (HTT) uses the information from the HTD and activates the consecutive (Hierarchical Level –I, II, III, IV, V) modules. This is achieved by HTT, after storing the ID's (Identification Numbers) information inside the STEP file ID storage (SIS). Based on this, the initial activation starts from the Closed Shell Identifier (CSI) of Hierarchy Level –I. Then the trace ID's from CSI are stored in SIS. The HTT now traces the new ID's inputted from CSI in SIS and searches the STEP file stored in APD. Whenever the entities represented in Hierarchy Level- II are detected, the following sub modules are activated (i) Advanced Face Extractor

(AFE) (ii) B Spline with Knots Extractor (BKE) and (iii) Rational B Spline with Knots Extractor (RBKE).

Again the ID's extracted from these modules are stored in SIS and the HTT traces the Hierarchy Level – III entities by utilizing the APD. It then activates the third level sub modules namely (i) Face Outer Bound Identifier (FOBI) (ii) Face Bound Identifier (FBI) (iii) Cylindrical Surface Identifier (CSUI) and (iv) Toroidal Surface Extractor (TSE). As more number of entities and ID's are linked with Hierarchy Level – III, the usage of SIS is stopped and the Temporary Storage (TS) becomes functional. Now, the HTT utilizes the information from the TS and detects the entities present in Hierarchy Level – IV. Consequently, the following sub modules are activated (i) Edge Loop Identifier (ELI) (ii) Oriented Edge Identifier (OEI) and (iii) Edge Curve Identifier (ECI). Then the Hierarchy level – V module is activated by HTT by using the data stored in TS. The sub modules Axis_3D_Placement Identifier (ADI), Plane Direction & Vector Identifier (PDVI) stores the details of the Hierarchical level –V entities present in the STEP files and stored in the TS. Finally, the details required to reconstruct the part namely cartesian points, circle radius, chamfer and fillet details are extracted by (i) Cartesian points Extractor, (ii) Circle Radius & Coordinate Points Extractor and (iii) Chamfer & Fillet Radius Extractor. The final details are then sent to the feature recognizer to recognize the manufacturing features. The various modules that are accessed and used in IFST are presented in the cases study in section 5.

After the extraction of necessary data from the STEP formats, the IFST passes the information to the next sub module FRM for identification of the features with normal, tapered and curved base cross sections. The next section explains how the data is utilized to identify the features using the syntactic pattern recognition methodology.

3. Feature recognition of prismatic parts with normal, tapered and curved base cross sections

The initial implementation to develop a feature recognizer has been already completed by (Hebbal., S. 2004) for rough machining by adopting a DXF format. The rough machined part and the final part details from the STEP AP203/214 formats extracted by the interfacer (IFST) described in previous section are inputted to the feature recognizer, which adopts the syntactic pattern recognition technique to recognize the part features present in the rough machined part and final part. In this research, a feature recognizer has been developed which is capable of identifying the combinations of different shapes of features differentiated on the basis of slot, step and pocket/hole. The feature recognizer is capable of recognizing 30 normal features and with 9 types of tapers. The names of 30 normal features and 9 types of tapers are coined by following the schematic representation given in Fig.4.

3.1 Concepts adopted for feature recognition
A brief overview of all the basic concepts adopted for feature recognition of prismatic parts have already been presented in an earlier DAAAM conference

(Hebbal.,S & Mehta., NK. 2001). Moreover, all these standard concepts such as pattern primitives and strings are well known and can be referred from standard sources (King Sun., Fu. 1982). Also, the methodology to determine the normal and tapered is a general 3 step procedure where the points are projected towards their parallel faces and the collinearity is calculated. Then the decision is made as tapered if the points are not collinear. The concept has already been given in (Arivazhagan., A. et al., 2009) and can deducted from standard mathematical text books.

By using these methodologies, the Feature Identifier (FI) generates the data in the text file and passes the information to the next module namely the Machinable Volume Identifier for Finish cut (MVI) for further processing. In the next section the details of MVI have been presented for calculation of finish cut volumes.
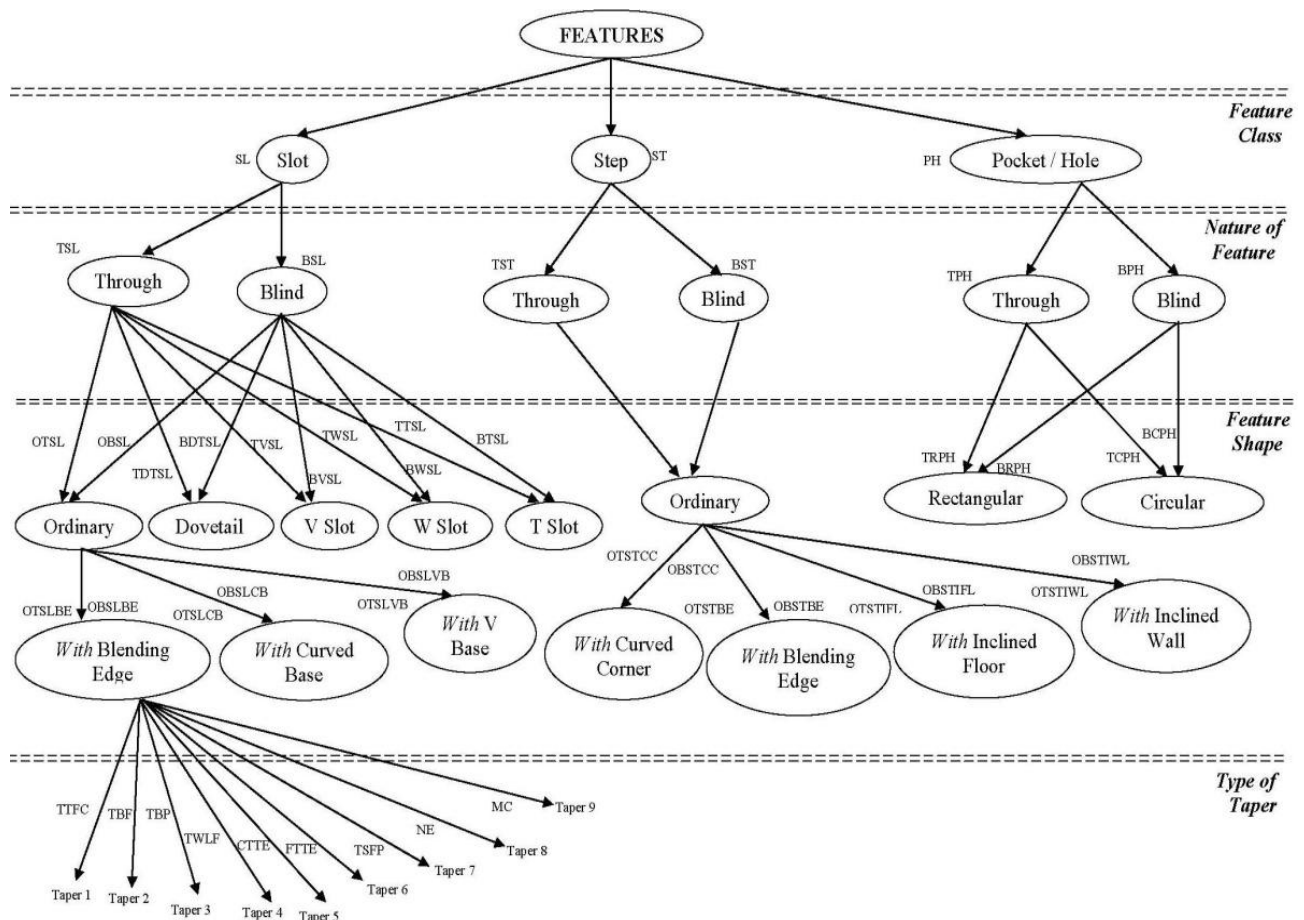

Fig. 4. Schematic representation of hierarchy tree of features

4. Machinable Volume Identifier for Finish Cut (MVI)

As shown in Fig.5, the output data of the feature recognizer in terms of edge loop data, edge and vertex data, coordinate points and plane information serves as the input for the MVI. The MVI consists of nine sub modules to calculate the machinable volume. The following three sub modules constitute the primary part in MVI and are directly connected with the output module of the feature recognizer:

(i) Edge Loop Extractor (ELE): The ELE module extracts the information of features regarding the edge loops, dimensions, location planes, and their interactions.

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(ii) Edge and Vertex Extractor (EVE): The EVE module extracts the details of the edges and vertices along with the coordinate points of the features.

(iii) Deductor for Rough and Final part (DRF): The DRF module separates the information of rough and final part which is required for generating strings and finish cut machinable volume calculation.

These three modules are in turn connected with the Syntactic Pattern Recognizer (SPR). The SPR contains a Syntactic Pattern Strings Database (SPSD) where strings and the shapes of machinable volumes are stored. Input to the SPR is from the DRF module. The SPR is directly connected with the Finish Cut Volume Identifier (FCVI) which in turn is connected to a Checker Subsystem. The Checker Subsystem contains three modules namely (i) Dimensional Checker (DC) (ii) Coordinate Plane Checker (CPC) and (iii) Extra Volume Checker (EVC). These three modules check the dimensions, plane locations and interactions before the calculation of finish cut machinable volume. Finally, the FCVI displays the output of MVI on the Graphical User Interface (GUI).
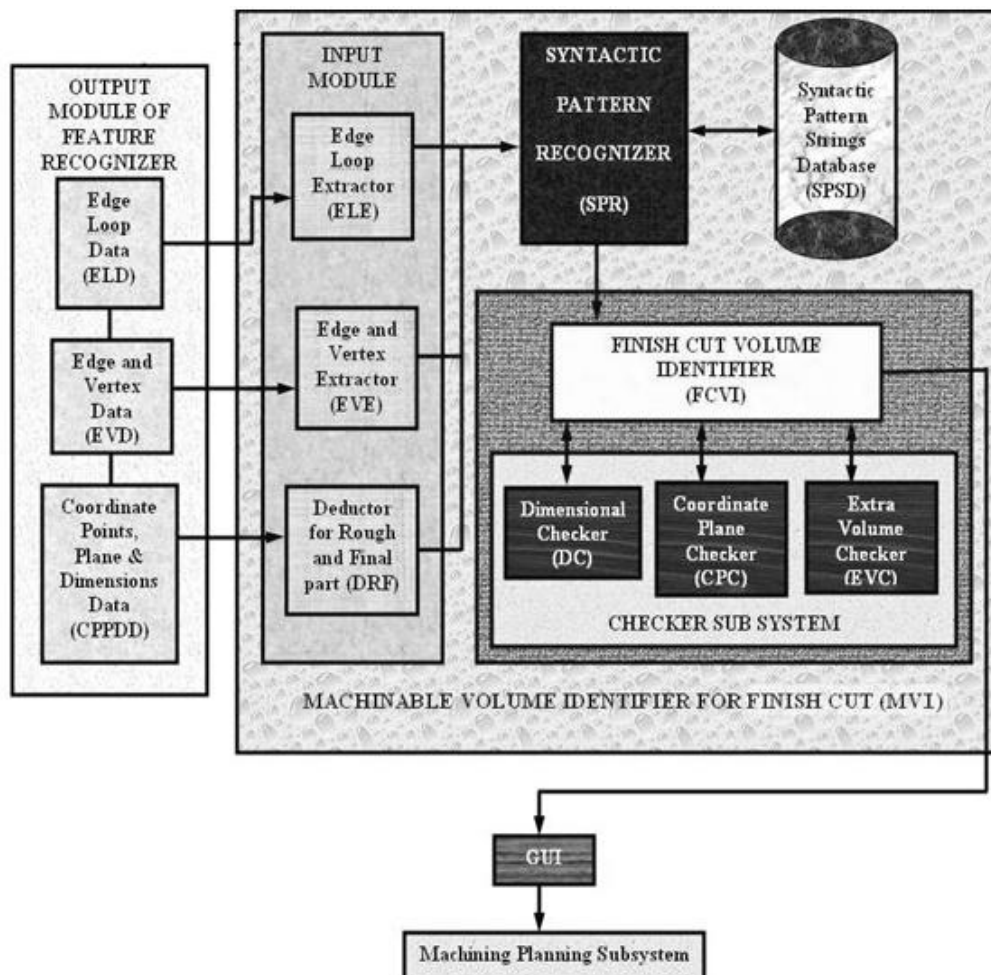
Fig. 5. Block diagram of the feature recognition module in FM-CAPP and machinable volume identifier for finish cut (MVI)

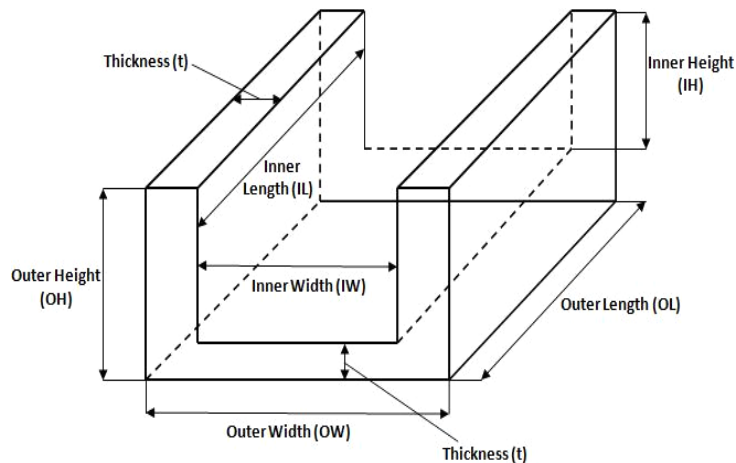*4.1 Machinable volumes for finish cut operations and grouping of features*

Fig. 6. Machinable volume details for a through slot

S.No	Name of the 'feature-type' and number of applicable features	Characteristic parameters : (edges (e) , face (f), parallel face (pf), radius (r), fillet radius (fr), curved base (cb), curved corners (cc), chamfer (c))
1	Through step - 21	e - 4
2	Through slot - 21	e - 6
3	Blind step - 21	e - 3; pf- 1
4	Through slot with filleted corners - 6	e - 6; fr- 4
5	Through slot with blending edge - 14	e - 10
6	Through V slot - 12	e - 4
7	Through slot with V- base - 7	e - 8
8	Through rectangular pocket with filleted corners - 2	e - 8; fr - 8
9	Blind slot - 21	e - 3; pf - 1
10	Through slot with curved base - 14	e - 6; e-cb - 2
11	Through step with blending edge - 14	e: 6
12	T-slot - 14	e: 14
13	Through rectangular hole - 12	e: 8
14	Stepwithcurvedcorner - 10	e - 6 ;cc - 2
15	Through step with filleted corners - 6	e - 6; fr - 2
16	Chamfer - 12	e - 6; c-e - 2
17	Through circular hole - 10	e-r : 2

Tab. 1. Explanation to the 17 'feature-types'

While calculating machinable volumes, there may be many combinations of features in a prismatic part including those with interactions of normal features and tapered features. Hence, during this process, standard dimensional details are used to describe the volume. They are length (l), width (w), height (h) and thickness (t). Further to describe the machinable volume's inner and outer dimensions the following notations has been introduced: (i) Outer Length (OL) and Inner Length (IL) (ii) Outer Width (OW) and Inner Width (IW) (iii) Inner Height (IH) and Outer Height (OH) and (iv) Thickness (t) is the value obtained by deduction of the rough machined part from the final part. Basically, there are 17 basic 'feature-types' methodologies which are able to identify all the features considered in this research. Table 1 shows 17 basic 'feature-types' to identify the finish cut volume.

4.2 General methodology to identify the features and calculation of finish cut machinable volume

The steps applicable to the present work are discussed below:

4.2.1 Steps for calculation of finish cut machinable volume

Steps to identify the shape of the finish cut machinable volume

Step 1: Identify the shape of the finish cut machinable volume by separating the information of rough machined part and final part.
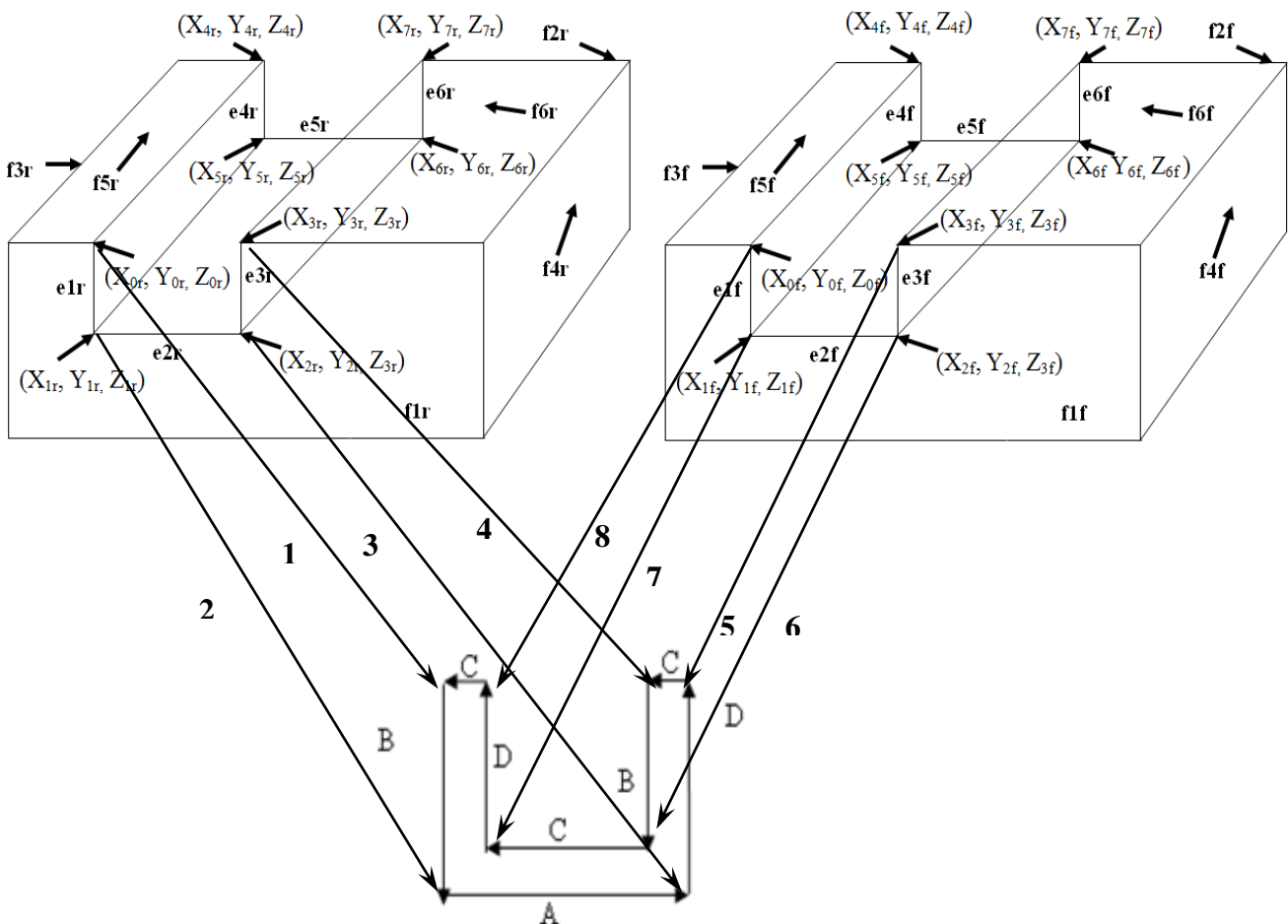

Fig. 7. Generation of strings

Sub Step1.1: From the output of the feature recognizer, the ELE and EVE separate the information regarding the edge loops, edges, vertices, planes, dimensions.

Sub Step1.2: The DRF separates the details of the edge loops, vertices and co-ordinate points for the rough machined and final part.

Sub Step1.3: The arranged data of rough machined and final part are passed to the SPR for the generation of strings that are compared with the pre-defined syntactic pattern strings stored in the SPSD database to identify the shape of the machinable volume. This step is elaborated with a suitable example in the next paragraph.

Explanation to Sub Step 1.3: String generation proceeds in an anticlockwise direction from the top left hand corner using the predefined vectors (www.designrepository.org) obtained from standard handbooks (King, Sun, Fu. 1982). For generating the strings, the vertex points of front face edges of the rough machined feature and the final feature are transposed and connected to form a closed figure as shown Fig.7. Similarly, the string is generated for the back face of the feature. For the example part of Fig.7, the string of the finish cut machinable volume is read as "BADCBCDC". Now to determine the shape of the machinable volume the strings of the front and back faces are compared with the predefined strings stored in the strings database.

Steps to check whether the features are interacting or non-interacting

Step 2: Identify whether the features are interacting or non-interacting

Using the information extracted from the ELE, the FCVI check whether the features are interacting. For this, the procedure adopted by (Hebbal., S.& Mehta., N.K (2001, 2002) (given below) is used. The general steps for feature interaction are as follows:

Sub Step 2.1: Initially, identify the feature as 'through' or 'blind' by applying the concept of edge loops.

Sub Step 2.2: Check whether the face belongs to Perfect Quadrilateral (PQ) category by identifying the connecting face of the feature between the parallel edge loop or parallel face.

Sub Step 2.3: If all the faces are of PQ category then assign the feature as 'feature with no-interaction'.

Sub Step 2.4: If the type of face belongs to Complex Polygonal (CP) Face or Face With a Cavity (FWC), then assign the feature as interacting feature.

Sub Step 2.5: Now for the detected face of CP or FWC category, with the help of edge loops, check whether it is 'through' or 'blind'.

Sub Step 2.6: Perform the same check for other connecting faces.

Sub Step 2.7: Finally, by analyzing the face contained in the main feature, confirm the features that are interacting with it.

Due to page restrictions of this chapter, explanations for these general steps are not given here. Further, it is explicit that these details can be deduced by considering an example part containing interacting features. If interested, the reader is suggested to obtain further details from the author through anemail request.

Steps to reconstruct the interacting feature

Step3: Reconstruct the interacting feature as a sum of the constituent features.

Basically, an interacting feature is obtained by machining of the constituent features. Therefore, prior to calculation of the finish cut volume of an interacting feature, it is necessary to reconstruct the interacting feature as a sum representation of the constituent features. This is implemented in the following sub steps.

Sub Step 3.1: From the EVE collect the details of edges, vertex points, and coordinate points of the interacting feature.

Sub Step 3.2: Reconstruct the feature by joining the vertex points of parallel edges omitting the presence of the additional feature.

Sub Step 3.3: Pass the reconstructed feature to FCVI for calculation of machinable volumes.

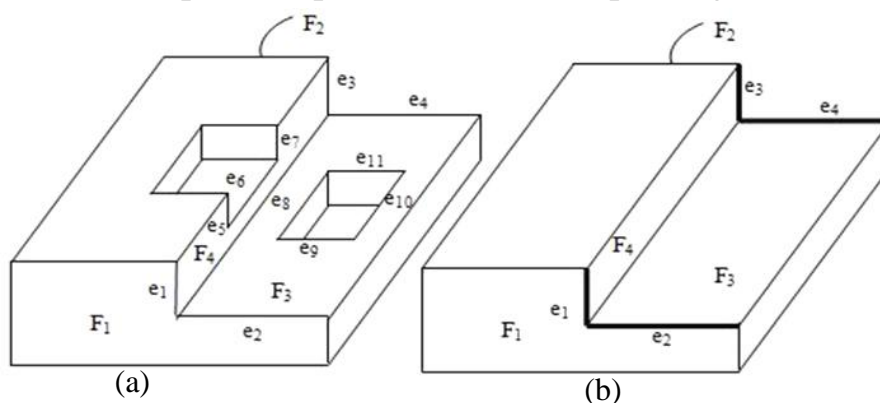The above sub steps are explained with the help of Fig. 8a and 8b.

Fig. 8. Example prismatic parts with interacting features

Explanation to Sub Step 3.1: In Fig.8a, the feature 'through step' is interacting with two features. The edges related to it are (e1, e2) and (e3, e4) and the vertex points are e1 (VP1, VP2), e1 (VP2, VP3), e3 (VP4, VP5) and e4 (VP5, VP6). The corresponding coordinate points are: VP1 (X1,Y1,Z1), VP2 (X2,Y2,Z2), VP3 (X3,Y3,Z3), VP4 (X4, Y4, Z4),VP5 (X5,Y5,Z5) and VP6 (X6,Y6,Z6),.

Explanation to Sub Step 3.2: The feature is reconstructed by connecting the parallel edge loops: (i) the vertex points of edge e1 are connected with parallel vertex points in edge e3. (ii) Similarly, the vertex points of edge e2 are connected with the parallel vertex points in edge e4.

Explanation to Sub Step 3.3: After reconstruction the feature is ready for calculation of machinable volumes. The reconstructed edges are highlighted as dark lines and shown in Fig. 8b.

The next step is to determine the feature type based on the number of edges, faces, fillet radius etc and to calculate the finish cut machinable volumes. The general methodology applicable to this procedure is given in the next section.

Steps to calculate the finish cut machinable volume

Step 4: Calculate the finish cut machinable volume by identifying the suitable 'feature type' specific methodology based on the number of edges, faces, fillet radius, chamfer radius etc.

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Sub Step 4.1: For the obtained shape of the finish cut machinable volume, the EVE provides the number of edges, faces, fillet radius and chamfer radius associated with the feature.

Sub Step 4.2: Based on number of edges, faces, fillet radius and chamfer radius, identify the appropriate 'feature type' (Table 1).

Sub Step 4.3: Apply the 'feature type' specific methodologies to calculate the finish cut machinable volume by deducting the rough machined part from the final part.

Explanation to Sub Step 4.1: If the feature is 'through slot' and the shape of the identified finish cut machinable volume is as shown in Fig.8, then the number of edges are six, 3 from the edge loop EL1 (e1, e2, e3) and 3 from the edge loop EL2 (e4, e5, e6).

Explanation to Sub Step 4.2: Here, three edges are identified in both the front and back faces. The 'feature types' having three edges on front and back faces are 'through slot', 'blind slot', and 'through slot with curved base' (S.No.2) in Table 4.0. As the feature under consideration has neither a curved base nor a parallel face, it is decided that the given feature matches with the feature type 'through slot'.

Explanation to Sub Step 4.3: The calculation of machinable volume by deduction of the rough machined part from the final part is carried out in the following steps:

(i) Identify the length (l) of the machinable volume by deducting the parallel edges of the edge loops representing the feature in rough part and final part. The calculated length from the rough part constitutes the IL and that from the final part constitutes OL.

(ii) Identify the height (h) of the machinable volume by deducting the vertices of the edges constituting the side faces of the feature in rough part and final part. This value for the rough machined part represents IH and the same for the final part represents OH of the machinable volume.

(iii) Identify the width (w) of the machinable volume in rough part and final part by deducting the vertices of the edges constituting the base of the feature. This value for the rough machined part represents IW and the same for the final part represents OW of the machinable volume.

(iv) Identify the thickness (t) of the machinable volume by deducting the edges of the rough machined part from the final part. This value represents the thickness of the machinable volume in relevant plane and direction.

Step5: Display the final results with the dimensional details of the machinable volumes.

4.3 Description of 'feature-type' specific methodologies for finish cut machinable calculation

This section presents the details of finish cut machinable volume calculation for one sample feature type "Through Slot with blending edge" from among the '17' listed in Table 1.

Fig.9. (a) represent a rough machined part by means of edge loops and faces. The following edge loops are highlighted in rough machined: El1r (e1r, e2r, e3r, e4r,

e5r) & El2r (e6r, e7r, e8r, e9r, e10r). The final part is not shown as it contain the same shape but including the finish cut volume and with a sub script 'f'. The machinable volume contains length (l) width (w), thickness (t), height (h) as their dimensions to represent the volume. The methodology adopted to calculate these dimensions for this feature type is as follows.

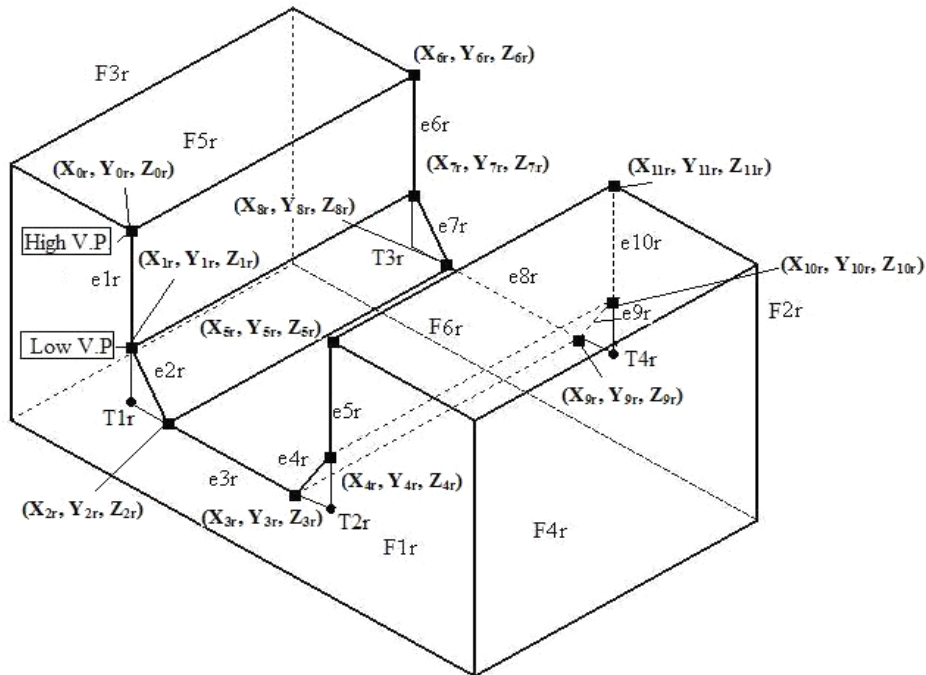### 4.3.1 Feature-type: through slot with blending edge

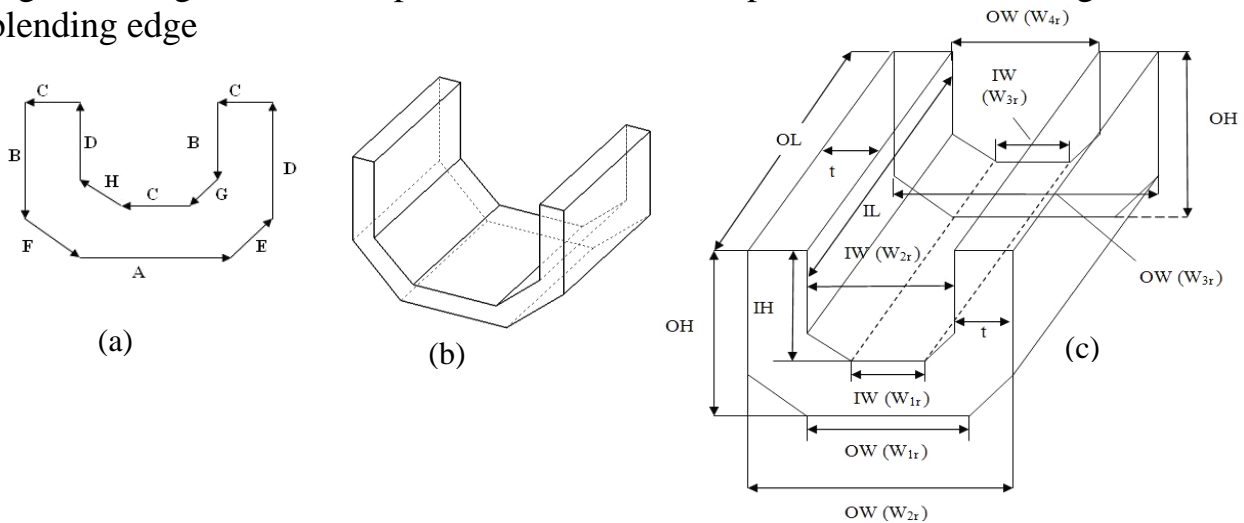Fig. 9. Rough machined part and Schematic representation of through slot with blending edge

Fig. 10. Pre-defined vector &machinable volume for through slot with blending edge with the dimensional details

Calculation of dimensions of through slot with blending edge

Initially the strings are generated for the front and back face by following the predefined vector as shown Fig.10a. The generated string for this feature type is "BFAEDCBGCHDC". The details of machinable volume and the pre-defined vector direction are also shown Fig.10 (a), (b) and (c).

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Height (h): Height (h) is defined as the distance between the base to top point in a feature. While calculating the height of machinable volume, it is necessary to calculate a temporary point parallel to the base of the feature as the features belonging to this 'feature type' contain a blending edge. The procedure to calculate the temporary point is as follows:

Calculation of temporary points for the rough machined part: In Fig.10a, the points are calculated for the blending edges e2r and e4r located in the front face F1r. For the edge e2r, the following edges in XY plane are considered: (i) e1r with V.P. (X1r, Y1r, Z1r) and (ii) e3r V.P. (X2r, Y2r, Z2r). The temporary point is calculated by drawing two perpendicular lines from the V.P. (X1r, Y1r, Z1r) and V.P. (X2r, Y2r, Z2r). Then the intersection point of both the lines is taken as the temporary point. The calculated point is T1r = (X1r, Y2r, Z2r). Similarly for other blending edges, the following points are calculated. (i) For the blending edge e4r, T2r = (X4r, Y3r, Z3r) (ii) For the blending edge e7r, T3r = (X7r, Y8r, Z8r) (iii) For the blending edge e9r, T4r = (X10r, Y9r, Z9r)

Calculation of height for rough machined part: In any edge (e (i)) the starting point is taken as the Highest VP and the end point is taken as the Lowest VP. These two points are schematically represented in Fig.11 for the edges e1r and e1f.

Height (h) = [Diff. of e1r] + [Low. V.P. of e1r – T1r] = [(X0r, Y0r, Z0r) - (X1r, Y1r, Z1r)] + [(X1r, Y1r, Z1r) - (X1r, Y2r, Z2r)] = IH.

Similarly, the following combinations are also used to calculate the IH of the machinable volume (i) [Diff. of e5r] + [Low. V.P. of e5r – T2r] (ii) [Diff. of e6r] + [Low. V.P. of e6r – T3r] and (iii) [Diff. of e10r] + [Low. V.P. of e10r – T4r]

Length (l): Length (l) can be defined as the distance covered between front and back point in a part.

Calculation of length for rough machined part: To calculate the length (l) of the machinable volume the following edges in the rough machined part are considered: (i) e3r and e8r. These edges are shown in Figures 11.

Length (l) = e3r-e8r = [(X2r,Y2r,Z2r)(X3r, Y3r, Z3r) – (X8f, Y8f, Z8f)(X9f, Y9f, Z9f)] = IL

Width (w): Width (w) can be defined as the distance between two parallel points in the feature. As the feature is having a blending edge, the values of width have to be calculated separately for the base and the top. Hence, the values of the width for IW comprise w1r, w2r (for the base) and w3r, w4r (for the top). The values of the width for OW comprise w1f, w2f (for the base) and w3f, w4f (for the top). The schematic representation indicating these notations for the finish cut machinable volume is given in Fig. 5.17c. In order to calculate the Width (w) of the machinable volume the following parallel edges as shown in Figures 11 are considered: (i) e3r, e8r, e1r, e6r, e5r, e10rr and (ii) e3f, e8f, e1f, e6f, e5f, e10f.

Calculation of width for rough machined part:

W1r = Diff. between VP of e3r = IW= [(X2r, Y2r, Z2r) - (X3r, Y3r, Z3r)]

W2r = Diff. between V.P of e8r = IW= [(X8r, Y8r, Z8r) - (X9r, Y9r, Z9r)]

W3r = VPof e1r – VP of e5r = [(X0r, Y0r, Z0r) - (X5r, Y5r, Z5r)] = IW or

W3r = VPof e1r – VP of e5r = [(X1r, Y1r, Z1r) - (X4r, Y4r, Z4r)] = IW

Similarly, the following combinations are also used to calculate the IW of the machinable volume (i) W4r = VPof e6r − VP of e10r (ii) W4r = VPof e6r − VP of e10r

Thickness (t): Thickness can be defined as the amount of material obtained when deducting similar edges of rough machined feature from the final feature.

e1r-e1f = [(X0r, Y0r, Z0r) (X1r, Y1r, Z1r)] - [(X0f, Y0f, Z0f) (X1f, Y1f, Z1f)];
e2r-e2f = [(X1r, Y1r, Z1r) (X2r, Y2r, Z2r)] - [(X1f, Y1f, Z1f) (X2f, Y2f, Z2f)];
e3r-e3f = [(X2r, Y2r, Z2r) (X3r, Y3r, Z3r)] - [(X2f, Y2f, Z2f) (X3f, Y3f, Z3f)];

Similar procedure is followed to calculate the OH, OL, OW from the final part
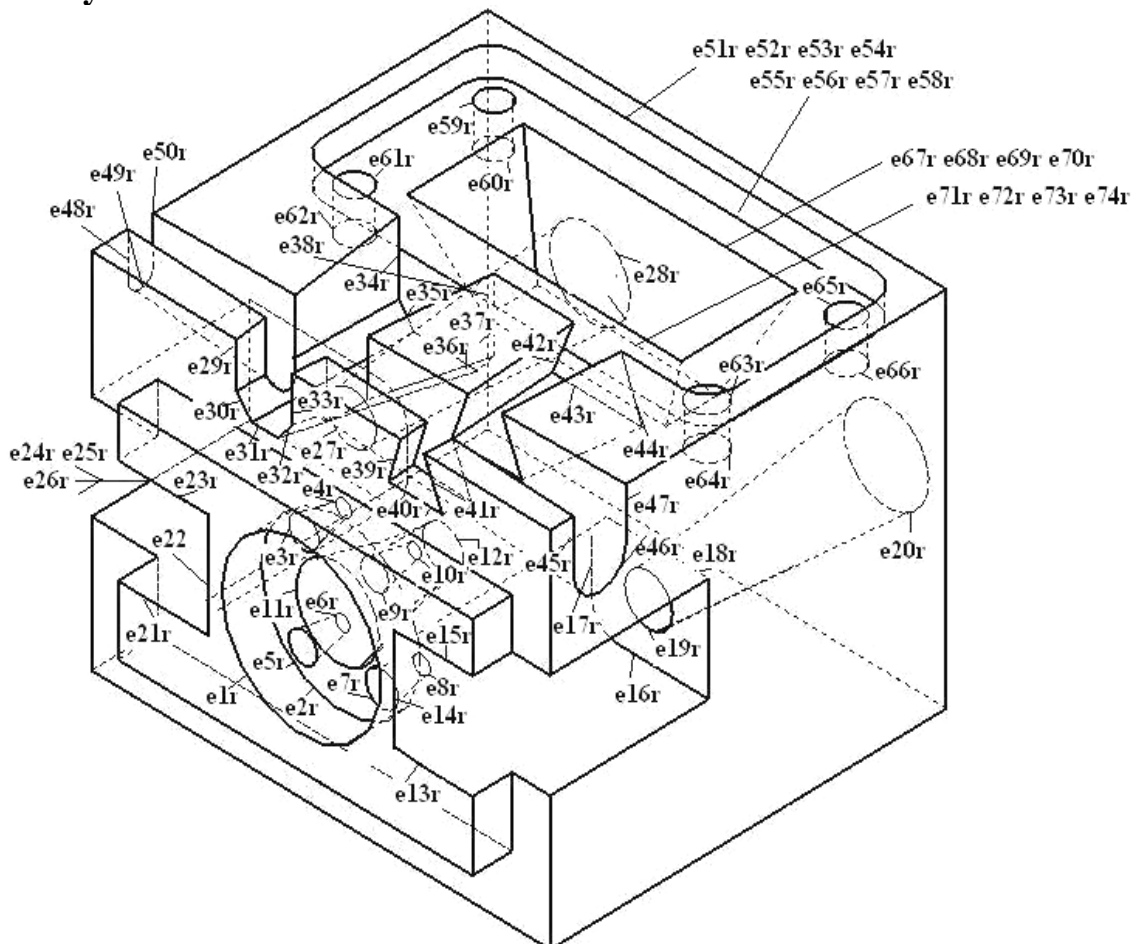
5. Case Study

Fig. 11. Rough & final part NEW_DEMO_US showing internal features

In this section to illustrate the application of the developed FRM module and in the process to validate its various modules and sub modules, the prismatic part shown in Fig.11 is taken as a case study. It is a modified representation of the original part NEW_DEMO_US (Zhu, H. &Menq, CH. 2002) downloaded from a design repositoryyobtained from NIST. The part has been re-modelled for this research separately as rough machined part and final part with tapered and interacting features. The re-modeled part contains 19 features with 11 tapered-interacting features and 8 normal features. The details of the features with their feature codes as defined in our feature recognition database are as follows: (i) Five "Circular Blind Pocket / Hole

S.No	Level in the Hierarchy Tree	Entity Name	Module(s) activated in the Interfacer (IFST)	Feature Name & Feature Code (Feature Identifier FI)	Details of Finish Cut Machinable Volume (mm) and Machinable Volume Identifier (MVI)
		Interfacer developed for STEP AP203/214 formats		Feature Identifier (FI) and Machinable Volume Identifier (MVI)	
1	HL-I	CLOSED_SHELL	CSI	BCPHNE – FT2	All features / machinabel volumes are similar in size and shape.4 Features in face F53 ; l = 15mm; t=3mm; 2 Features in face F54 & F55 ; l = 90mm; t =2.8mm;
	HL-II	ADVANCED_FACE, BOUNDED CURVE	HTT, AFE, BKE, RBKE	OBSLFC – FT3	l = 75mm; t = 4mm; w =29.4mm, 37.4mm; h= 40.5mm, 44.4mm
2	HL-III	FACE_OUTER_BOUND, FACE_BOUND, CYLINDRICAL_SURFACE, TOROIDAL_SURFACE	HTT, FOBI, FBI, CSI, TSE	OTSLCBNE – FT7	h = 18.7mm, 16.3mm; t = 2mm; l = 173.6mm; w =9.6, 5.6mm;
3	HL-IV	EDGE_LOOP, ORIENTED_EDGE, EDGE_CURVE	ELI, OEI, ECI	BRPHNE – FT8	length (l) = 35.02mm; width (w) =103.84, 68.33m; 96.84mm, 61.33mm; thickness (t) =3.5mm; height (h) =43.97mm, 19.62mm; 12.62mm, 36.97mm
4	HL-V	EDGE_CURVE, AXIS2_PLACEMENT_3D, DIRECTION, VECTOR	ADI, PDVI	OTSLBENE – FT6	l = 69.1mm; w = 22, 17.23, 31.8mm, 23.9, 21.2, 35.8mm; h= 20.9, 31.4, 34.26, 22.9, 33.4, 30.8mm; t = 2mm
5	HL-VI	CARTESIAN_POINT	Cartesian Points Extractor	TDSLNE – FT5, RBPHFC – FT4	h = 13.5, 17.7, 15.5, 19.7 mm; t = 2mm; l= 69.1mm; w = 18.15, 31.1, 20.4, 34.1mm; All features / machinable volume are similar in size and shape. so is also similar.l = 15mm ; t = 2mm

Tab. 2. Output from the FRM Module for the prismatic part NEW_DEMO_US

[OCBHP]" ,(ii) Seven "Blind Circular Pocket Narrowing at the End (OBCPNE)" , (iii) Two "Ordinary Through Slot having Fillet at the Corners (OTSLFC)" , (iv) One "Rectangular Blind Pocket / Hole having Fillet at the corners (ORBPHFC)", (v) One "Blind Dovetail Slot Narrowing at the End (BDSLNE)", (vi) One "Ordinary Blind Slot with Blending Edge Narrowing Towards the End (OBSLBENTE)" , (vii) One "Ordinary Through Slot with Curved Base Narrowing at the End (OTSLCBNE)" , (viii) One "Rectangular Blind Pocket Narrowing at the End (RBPNE)". Fig.12 a & b represents all the 19 machinable volumes for the prismatic part. The output after adopting the above explained methodologies is presented in Table 2.
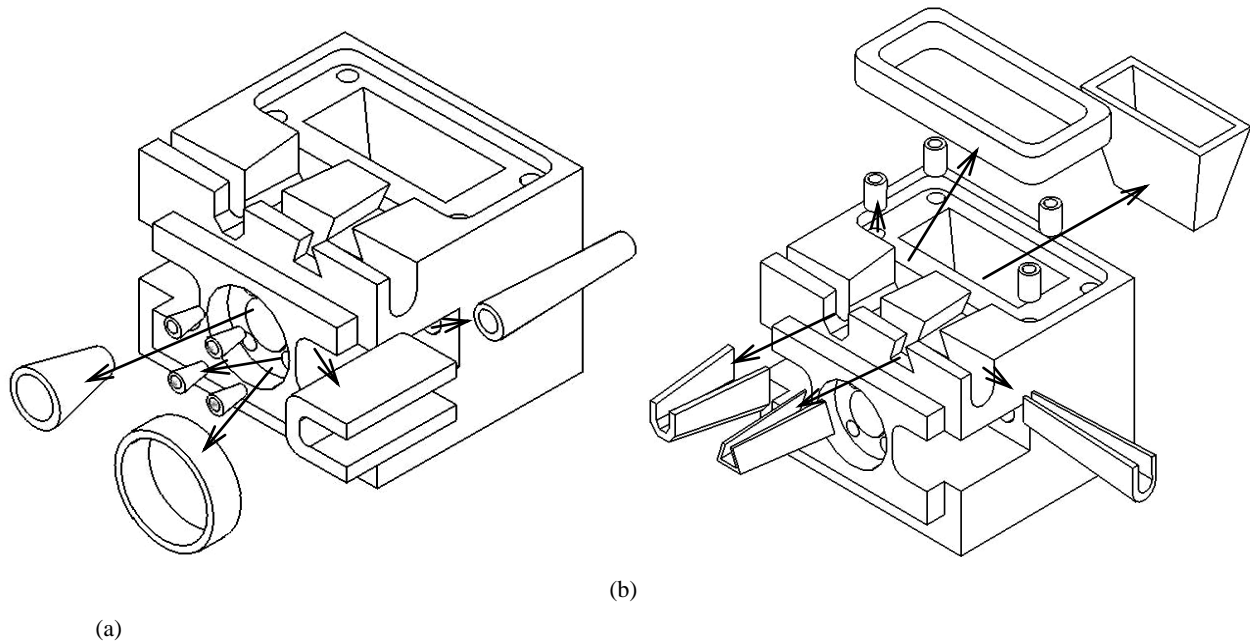

(b)

(a)

Fig. 12. Complicated prismatic part with its hierarchy tree

6. Conclusions

The basic initiative behind this approach is to identify the finish cut volume left after rough cut using STEP AP203 and AP214 formats. After an extensive literature review it become clear that no such work has been reported so far in the domain of CAPP. For this an Interfacer (IFST), Feature Identifier (FI) and Machinable Volume Identifier for finish cut (MVI) are developed to identify features and to calculate the finish cut machinable volumes by deducting the edge loops of rough machined part (obtained from the rough machining CAPP system) from the final part. The FRM module inside the FM-CAPP system identifies the finish cut machinable volumes for all the features of normal tapered and curved base cross sections. For all normal and tapered features the MVI identifies one relevant methodology or more than one methodologies (for features having combination of more than one taper) from among the 17 'feature type' specific methodologies developed for finish cut machinable volume identification. The methodologies are coded by using C and C++ programming language running in VC++ compiler. The part details of some standard industrial prismatic parts were inputted manually into the FRM module and tested for

its capability. The FRM module recognized and created the necessary output within minimal amount of time. By identifying the finish cut machinable volume it is possible to produce a prismatic part with the specified tolerance & surface finish mentioned in the design and to select the suitable machining processes and operations inside the machining planning module. Further to add with, in the future it is planned to extend the capability of FRMfor features having free form surfaces which include B-Splines & Bezier surfaces and their interactions.

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