Development of Complex Feature Extraction System from Prismatic Parts Using Hybrid Algorithms

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Abstract In the current scenario most of the industries want to produce superior quality products with less production time and manufacturing cost to full fill the customer needs. The integration of computer-aided design (CAD) and computer-aided manufacturing (CAM) attain the industry's needs. However, the integration of CAD and CAM is most difficult task and facing lot of challenges. Feature recognition (FR) is the key link between integrate CAD and CAM and overcome the issues present in it. This paper presents a development of complex feature extraction system to extract different features like slant edges, bends, fillets, and chamfers from prismatic parts. A hybrid automatic feature recognition algorithm (HAFRA) combination of milling feature extraction algorithm (MFEA) and cylindrical feature extraction algorithm (CFEA) is proposed to identify the complex features using STEP file and then validation of the algorithm is done through case study. The developed hybrid automatic feature extraction system is well suited to extract the complex features from prismatic parts and thereby improve the downstream applications like process planning, CAPP, CAE, CAM, CAI, etc.

Keywords FR · CAD · CAM · Features · STEP file and hybrid algorithm

1 Introduction

Day by day computer revolution in manufacturing industries rapidly increasing. Most of the manufacturing industries are used computers to design the required products with superior quality, high durability, less manufacturing time with reduced cost and high production throughput. In this manner integration of computer-aided design (CAD) and computer-aided manufacturing (CAM) plays a vital role. However, the

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integration of CAD and CAM is most difficult task and having lot of issues due to lack of proper interfacing between them. The feature recognition (FR) is a key link to integrate CAD and CAM and also acts as an interface between design and manufacturing activities. Most of the researchers carried out their research on development of automatic feature extraction algorithms to extract various features for downstream applications like computer-aided process planning (CAPP). In this way, an automatic feature extraction system is developed to recognize form features by using logical geometrical rules [1]. In addition, various issues present in feature recognition is clearly addressed and developed a hybrid approach (i.e., combination of hint-based and volume decomposition) to extract intersection features [2]. Moreover, identified different manufactured features by using reverse engineering approach [3]. The extraction process contains three phases feature reconstruction, feature extraction, and feature translation. Furthermore, a novel approach is designed to recognize primitive features in the depressions of a polyhedral machining parts by using graph-based approach [4]. A new approach to identify prismatic part features by using logical rule-based approach [5]. Classification of cylindrical and milling features based on their characteristics and developed a multi-feature extraction system to extract cylindrical and milling features by applying logical rules and concave and convex relations [6].

Furthermore, a novel approach is developed to identify 2.5D prismatic part features based on machining of pre-defined features in the database [7]. A new technique (i.e., light-ray virtual method) is established to recognize machining features [8]. A hybrid approach (combination of graph-based and hint-based) is developed to extract intersecting milling features [9]. Classified free form features like passage, protrusion, slot, and compound features based on their geometrical properties and features are recognized by using attributed adjancy graph (AAG) method [10]. Moreover, some amount of research work has been done on automatic feature recognition of constant thickness metals like sheet metal components. Classified deform features on sheet metal based on their topological properties and features are extracted by using graph-based approach [11]. A new technique (Basic deformation feature graph) is developed to identify deform features like dimple, wall, jog, louver, rib, bead, etc. [12]. Further bit amount of research work has been attempted on extraction of casted features by using automatic feature extraction systems. A new approach is addressed to identify casting and forging part features by using volume decomposition method [13].

However, very limited work has been done on identifying inclined plane features and edge fillet features in matching parts. This paper presents a new algorithm is developed to extract milling and cylindrical features on inclined planes and edge fillets by using combination of logical rules and concave and convex relations. The implementation and validation of algorithm via in house developed JAVA program is used. The rest of the paper is segregated as follows; automatic feature extraction methodology is explained in Sect. 2. Implantation and validation of the algorithm is executed via example in Sect. 3. Discussion and feature construction theory is addressed in Sect. 4. Finally, conclusions are mentioned in Sect. 4.

2 Methodology

The hybrid AFR algorithm is developed to extract various milling features like pocket, blind pocket, through hole, and fillet of a 3D model object created by CATIA software version 5.

The proposed hybrid AFR algorithm is ability to identify the features on inclined plane. Moreover, HAFRA act as a key link between CAD and CAM. In addition, HAFRA minimizes the manufacturing cost as well as stored the product information throughout its life cycle without damage of product attributes data. The milling feature extraction process from 3D modeled object is illustrated in Fig. 1.

2.1 Milling Feature Extraction Algorithm (MFEA) from B-Rep Data

Initially, the required product is created by using CAD software. The product model is transformed into neutral file is known as STEP AP-214 file. Which plays a major role to interface between CAD and CAM. Then after boundary representation (B-rep) data extracted from STEP files by using geometric data extraction algorithm (GDEA) [5]. Further, B-rep data given as an input to MFEA as shown in Fig. 2, to extract milling feature information based on concavity relation approach. The following steps have been adopted to execute the MFEA.

Step 1: Extraction of B-rep data from STEP AP-214 file.

In this step, geometrical entities viz., plane, line, circle, edge, edge loop, inner bound, outer bound, etc. extracted by using geometrical extraction algorithm (GDE) [5] from STEP AP-214 file. Moreover, the B-rep data contains geometrical and topological attributes of the corresponding 3D modeled part.

Step 2: Identify planes, faces, and edges from B-rep data of 3D model part.

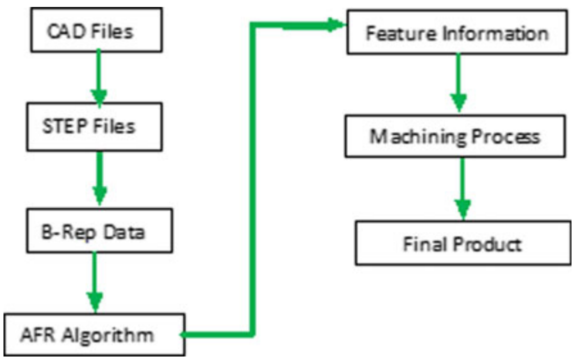

Fig. 1 Flow chart of milling feature extraction process from 3D modeled object

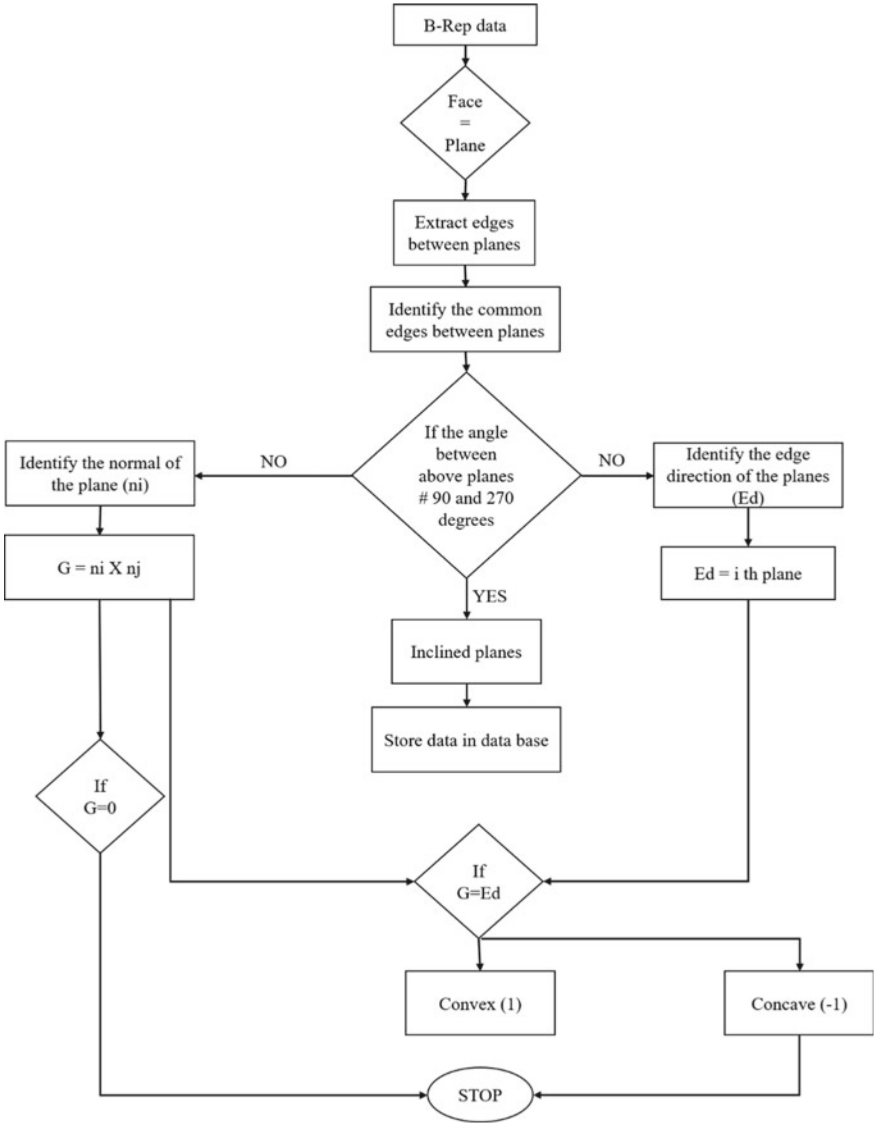

Fig. 2 Milling feature extraction algorithm (MFEA) to extract various milling features

This step collects the information like number of faces, edges, and common edges from the planes.

Step 3: Extract edges and common edges between the planes and measure angle between planes.

In this step, extract the common edges from the plane's nature and measure the angle between two common edges (i.e., angle is 90° or #90° and # 270°).

Step 4: Calculate normal with respect to planes and corresponding edge directions.

The normal of the two planes and corresponding edge direction is calculated in this step.

Step 5: Determine the cross products between the two planes.

This step involves calculate the normality index via cross-product of two normal of the corresponding planes (i.e., $n_i \times n_j$) and the normal index is denoted by C.

Step 6: Check normal index and direction of the edges.

In this step the normal index and edge direction of the correspond plane is equal then go for next step otherwise repeat the step 3–5.

Step 7: Determine concave and convex between the planes and edges.

The concave and convex relation among the faces is observed based on angle $180° < \theta < 360°$ and $0° < \theta < 180°$, respectively. The convex faces between the planes represent (1) and whereas concave faces between the planes indicate (-1) and the data is stored in the database.

2.2 Cylindrical Feature Extraction Algorithm (CFEA) from B-Rep Data

The cylindrical features like holes, bind holes, taper holes, boss, protrusions, etc. are extracted by using CFEA as shown in Fig. 3, based on logical rule-based approach. The following steps have been adopted to extract above listed cylindrical feature information from 3D modeled object.

Step 1: Extraction of B-rep data from STEP AP-214 file.

In this step, geometrical entities viz., cylinders, circle, radius, Cartesian points, vertex points, staring points, ending points, edge loop, inner bound and outer bound, etc. extracted by using geometrical extraction algorithm (GDE) [5] from STEP AP-214 file. Moreover, the B-rep data contains geometrical and topological attributes of the corresponding part.

Step 2: Identify cylinders and circles from the cylinders from B-rep data of 3D model part.

This step collects the information like number of cylinders and corresponding circles with their attributes of the 3D modeled part.

Step 3: Check the number of edges and vertex of the planes and type of surfaces.

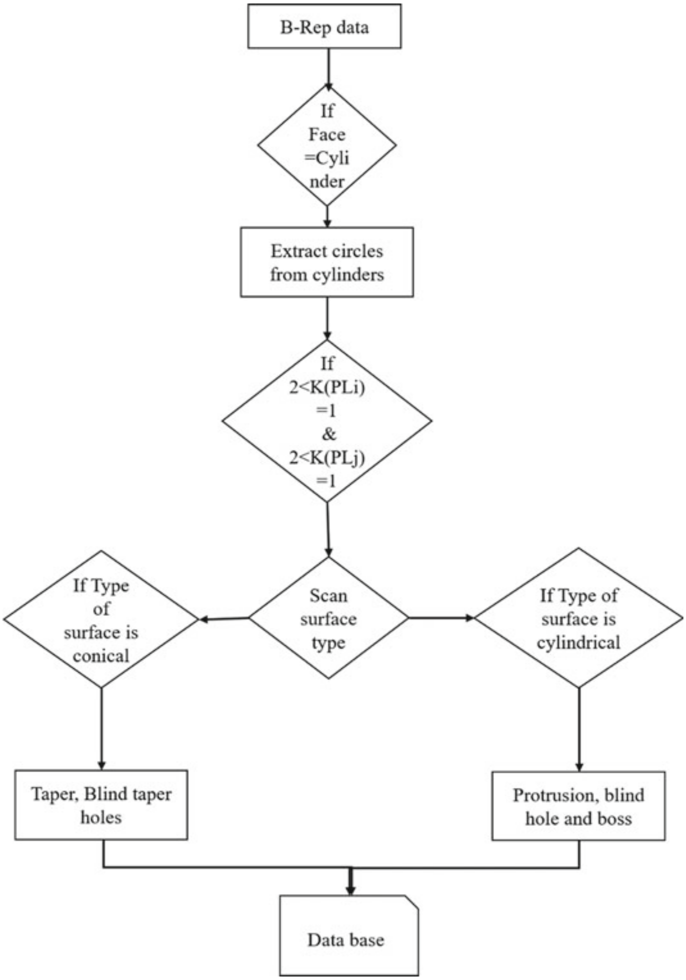

Fig. 3 CFE algorithm to extract cylindrical features

In this step, collect the surface details and check the number of edges and circle details of the corresponding plane. Further the nature information either cylindrical surface, conical surface, and toroidal surface with their geometry and correlate with circles information [6].

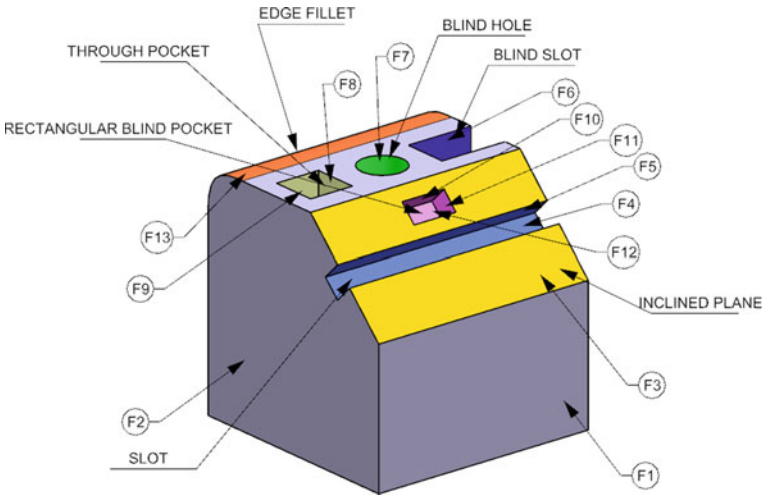

Fig. 4 Milling feature part model

3 Implementation of HAFRA Via Case Study

3.1 3D Modeling Using CATIA Software

In this study, 3D solid model is developed by using Catia software version 5. The features embedded in the model such as blind hole, blind slot, through pocket, and also features like blind pocket and through slot on inclined plane as shown in Fig. 4.

3.2 B-rep Data from GDE Algorithm

The boundary representation data (B-rep data) as shown in Fig. 5, contains geometrical information, as well as topological information of 3D model, is extracted by using GDE algorithm [5].

3.3 Results and Discussion of HAFRA

The obtained B-rep data from GDE algorithm given as an input to developed HAFRA for extraction of features from inclined plane and edge fillet by using logical rule-based theory and concavity relation. The HAFRA mechanism is the combination of both MFEA and CFEA mechanisms.

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0||1||35.5||40.||60.||44.5||40.||60.||LINE||1.||1.||0.||0.||null||null||null||PLANE||null||50.||60.|
|60.||0.||0.||1.||1.||0.||0.||
0||2||35.5||40.||60.||35.5||60.||60.||LINE||1.||0.||1.||0.||null||null||null||PLANE||null||50.||60.|
|60.||0.||0.||1.||1.||0.||0.||
0||3||35.5||60.||60.||21.||60.||60.||LINE||1.||-
1.||0.||0.||null||null||null||PLANE||null||50.||60.||60.||0.||0.||1.||1.||0.||0.||
0||4||21.||60.||60.||21.||0.||60.||LINE||1.||0.||-
1.||0.||null||null||null||PLANE||null||50.||60.||60.||0.||0.||1.||1.||0.||0.||
.
.
1.||0.||null||null||null||PLANE||null||60.||41.||25.||0.||0.||1.||1.||0.||0.||
24||2||60.||41.||25.||85.||41.||25.||LINE||1.||1.||0.||0.||null||null||null||PLANE||null||60.||41.||
25.||0.||0.||1.||1.||0.||0.||
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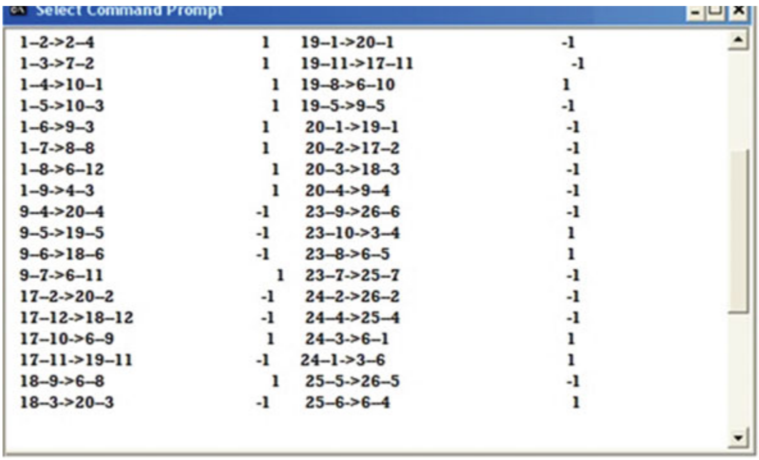
Fig. 5 B-rep data from GDE algorithm

3.3.1 Mechanism Involved to Extract Milling Features in MFEA

The milling features like through pocket, rectangular blind pocket, slot and blind slot, respectively. The mechanism involved in MFEA to extract above listed features based on con cavity relations among faces between the planes. The concave and convex relation among the faces is observed based on angle 180° < θ < 360° and 0° < θ < 180°, respectively. The validation of developed MFEA is done via in house developed JAVA program and the corresponding results as depicted in Fig. 6. The following key points have been noted for extraction of milling features mechanism.

- The B-rep data as shown in Fig. 5, given as input to the MFEA and the corresponding output results of MFEA as shown in Fig. 6.



1–2->2–4	1	19–1->20–1	-1
1–3->7–2	1	19–11->17–11	-1
1–4->10–1	1	19–8->6–10	1
1–5->10–3	1	19–5->9–5	-1
1–6->9–3	1	20–1->19–1	-1
1–7->8–8	1	20–2->17–2	-1
1–8->6–12	1	20–3->18–3	-1
1–9->4–3	1	20–4->9–4	-1
9–4->20–4	-1	23–9->26–6	-1
9–5->19–5	-1	23–10->3–4	1
9–6->18–6	-1	23–8->6–5	1
9–7->6–11	1	23–7->25–7	-1
17–2->20–2	-1	24–2->26–2	-1
17–12->18–12	-1	24–4->25–4	-1
17–10->6–9	1	24–3->6–1	1
17–11->19–11	-1	24–1->3–6	1
18–9->6–8	1	25–5->26–5	-1
18–3->20–3	-1	25–6->6–4	1

Fig. 6 Concavity relation of milling features

Table 1 Attribute relation among the faces

	0
No relation bsetween the Faces	2
Convex faces	1
Concave faces	−1

Table 2 Attributes relation between the faces based on relation matrix

FN	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21
F4	0	-1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	-1
F5	-1	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
F6	2	2	0	2	2	2	2	2	2	1	2	2	2	2	-1	2	-1	2
F7	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2
F8	2	2	2	2	0	-1	2	2	2	1	2	-1	2	2	2	2	2	2
F9	2	2	2	2	-1	0	2	2	2	2	-1	2	2	2	2	2	2	2
F10	2	2	2	2	2	2	0	-1	2	2	2	2	-1	-1	2	2	2	2
F11	2	2	2	2	2	2	-1	0	-1	2	2	2	2	-1	2	2	2	2
F12	2	2	2	2	2	2	2	-1	0	2	2	2	-1	-1	2	2	2	2
F13	2	2	1	2	1	1	2	2	2	0	1	1	2	2	1	1	1	2
F14	2	2	2	2	-1	-1	2	2	2	1	0	2	2	2	2	2	2	2
F15	2	2	2	2	-1	-1	2	2	2	1	2	0	2	2	2	2	2	2
F16	2	2	2	2	2	-1	2	-1	2	2	2	2	0	-1	2	2	2	2
F17	2	2	2	2	2	2	-1	-1	-1	2	2	2	-1	0	2	2	2	2
F18	2	2	-1	2	2	2	2	2	2	1	2	2	2	2	0	-1	-1	2
F19	2	1	2	2	2	2	2	2	2	1	2	2	2	2	-1	0	-1	2
F20	2	2	-1	2	2	2	2	2	2	2	2	2	2	2	-1	-1	0	2
F21	-1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0

- The face relation and corresponding attributes are depicted in Table 1.
- The attribute relationship among the faces between the planes and feature formation based on relation matrix information is mentioned in Table 2.
- From the relationship matrix concave (−1) data applied to production rules, result in corresponding milling features like through pocket, rectangular blind pocket, blind slot and slot are formed as shown in the Table 3a–d, respectively.

3.3.2 Mechanism Involved to Extract Cylindrical Features in CFEA

The cylindrical feature like blind hole, through hole, taper hole, boss and protrusion fillets, etc. The cylindrical features are extracted by using CFEA based on rule-based approach. The validation of developed CFEA is done via in house developed JAVA program and the corresponding results as shown in Fig. 7. The following mechanism points have been noted to while extracting the cylindrical features as well as edge fillet from the developed 3D model part.

Table 3 **a–d** Feature formation from relation matrix based on production rules

(a) Through Pocket

FN	F8	F9	F14	F15
F8	0	-1	2	-1
F9	-1	0	-1	2
F14	-1	-1	0	2
F15	-1	-1	2	0

(b) Rectangular Blind Pocket

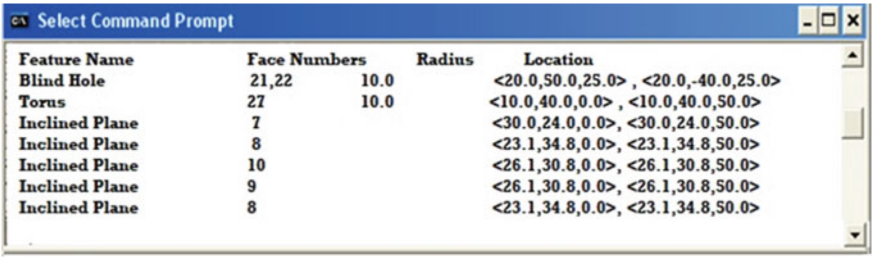
FN	F10	F11	F12	F16	F17
F10	0	-1	2	-1	-1
F11	-1	0	-1	2	-1
F12	2	-1	0	-1	-1
F16	2	-1	2	0	-1
F17	-1	-1	-1	-1	0

(c) Blind Slot

FN	F6	F18	F19	F20
F6	0	-1	2	-1
F18	-1	0	-1	-1
F19	2	-1	0	-1
F20	-1	-1	-1	0

(d) Slot

FN	F4	F5	F21
F4	0	-1	-1
F5	-1	0	2
F21	-1	2	0


Select Command Prompt

Feature Name	Face Numbers	Radius	Location
Blind Hole	21,22	10.0	<20.0,50.0,25.0> , <20.0,-40.0,25.0>
Torus	27	10.0	<10.0,40.0,0.0> , <10.0,40.0,50.0>
Inclined Plane	7		<30.0,24.0,0.0>, <30.0,24.0,50.0>
Inclined Plane	8		<23.1,34.8,0.0>, <23.1,34.8,50.0>
Inclined Plane	10		<26.1,30.8,0.0>, <26.1,30.8,50.0>
Inclined Plane	9		<26.1,30.8,0.0>, <26.1,30.8,50.0>
Inclined Plane	8		<23.1,34.8,0.0>, <23.1,34.8,50.0>

Fig. 7 Output results of CFEA of 3D modeled part

- The two cylindrical faces 21 and 22 having same geometrical information (radius) and having same center point. Moreover, if the number of edges of the cylinder one side having more than two and other side is equal to two, the obtained feature is blind hole and the information is stored in database.
- The cylindrical face 27 having same radius and tangent to, and join two surfaces of the corresponding planes, then the obtained plane is toroidal edge fillet and the corresponding data is stored in database for further applications.
- The inclined plane is Identified based on the cross-product of two planes not equal to 90° and not equal to 270°. The inclined plane details and the corresponding features on inclined plane information is stored in the database.

- The type of surface either cylindrical surface, conical surface, and toroidal surface and the corresponding direction (negative or positive) of the axis information with their geometry obtained the cylindrical features in the 3D modeled part.

4 Conclusions

This work developed a new HAFR algorithm to recognize milling and cylindrical features like pocket, blind slot, through slot, blind hole, edge fillet by using combination of MFEA and CFEA based on logical rules and concavity relation with relation matrix. The 3D solid model is developed by Catia version 5 software and corresponding data exchange standard STEP AP-214 is to be considered. The new HAFR algorithm is implemented through java program and the embedded features on the solid model are successfully extracted and the corresponding information is stored in the database for further downstream applications like process planning, CNC, and CAM.

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