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A new rapid prototyping system using universal automated fixturing with feature-based CAD/CAM

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Abstract

Machining is the most commonly used process in the manufacturing of prototypes. This process offers several advantages, such as rigidity of the machine, precision of the operation and an especially quick delivery. The weight and immobility of the machine support and immobilize the part during the operation. However, despite these advantages, machining still presents several limitations. The immobilization, location and support of the parts are referred to as fixturing or workholding and present the biggest challenge for time-efficient machining. Thus, it is important to select and design an appropriate fixturing assembly. This assembly depends on the complexity of the part and the tool path and may require the construction of dedicated fixtures. With traditional techniques, the range of fixturable shapes is limited and the identification of suitable fixtures in a given set-up involves complex reasoning. To solve this limitation and to apply the automation, this paper presents reference- free part encapsulation and the implementation of the encapsulation system. The feature-based modeling and encapsulation systems are explored. A small part for which it is difficult to determine the appropriate fixturing assembly is made by this system.

Keywords: Computer aided design; Computer aided manufacturing; Feature; Fixturing; Encapsulation; Set-up; Rapid prototyping

1. Introduction

1.1. Purpose of research

Machining is the most common process used in developing prototypes. It offers many advantages such as the strength of the machine, precision and fast feed rates. The weight and stability of the machine will hold the part in place during machining. In spite of all these advantages, a few disadvantage must be addressed. Holding the part in place, and determining it's configuration and support, depends on fixturing or workholding, which is a critical component in the machining process. Conventional machining processes required especially trained personnel to properly operate a V-block, vice, or parallel module so that a proper hold can be arranged for the specific geometry of the part. Depending on the geometric complexity of the part and the machine path, a delicate hold should be developed. For example, a typical hold set is limited in different geometric parts it can handle. In reality, this becomes one of the most severe restricting elements in machining a particular geometric configuration. Also the holding device must be assembled manually and this consumes much time as well as requires professional assistance. These characteristics are not suitable for small operations or prototype development. In order to employ more efficient methods in small operations and prototype development, new developments in fixturing methods are underway [1,2]. In the current study, in order to solve the problem of process automation, including problems such as developing an efficient automated system and also the fact that fixturing is limited in standard devices, a new workholding technique named reference-free part encapsulation (RFPE) was introduced and a feature-based modeling system, set-up and actual encapsulation system were developed to generate small prototypes [3–12].

1.2. Research background

Much research is underway to overcome the limitations of fixturing. Among the “universal fixturing techniques” presented, encapsulation methods are the most popular and filling material such as Cerro Alloys and Rigidix have been in use for over 30 years. These low melting point alloys or polymers are used to generate and fix complex shapes.

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Despite advantages such as efficient setting time and easy fixturing, its use is limited to only a few applications in the labs of Pratt & Whitney and Lawrence Berkeley. This is because there are limitations which arise when encapsulation is applied to general use. Encapsulation fulfills only two of the three purposes required by fixturing. These three critical purposes are location, support and hold. Encapsulation, while offering good conditions for hold and support, inevitably shows precision uncertainties and inconvenient factors concerning location. Location pins and die arrays require delicate holding, which may be limited since all location information between set-ups is lost when the filling material is melted. These limitations along with the high cost of low melting point alloys are detrimental in the use of encapsulation techniques. In the recent years, research has been underway to develop all-purpose workholding techniques which may solve the problems of past systems. Phase changing fixturing is a multi-purpose technique which can be used to form a particular geometric shape. As can be seen from the name, the part is immersed into a melted fixturing alloy. After that the alloy is condensed and the part is machined regardless of its geometric shape. As mentioned earlier, fixturing has three important functions which are holding, supporting and part location. Conventional phase change fixturing offered no relief in terms of part location and direction. The configuration of the part in the filler must be transferred to the die. Therefore, for a geometrically unsymmetrical part, a different die must be used in each different set-up. Although it is independent of the specific geometric shape of the part, each time a new set-up is implemented, the location information is lost and must be re-established using probes or a new die. The airline industries have traditionally used this method [1,2]. In comparison, RFPE is a phase changing fixturing which saves the location and direction of the part. RFPE was developed as a fixturing technique applicable to rapid prototyping on milling machines. In the current research, the RFPE technique is discussed and implemented in an actual system.

2. RFPE process and software development

2.1. RFPE process description

An ideal fixturing method is to allow the tool to approach the part from all angles. If the part can be magnetically suspended in air, all sides can be machined without changing the set-up and thus all parts can be formed within one set-up. Unfortunately, this kind of a system does not exist and physical contact is required to hold the part in place. Theoretically, the RFPE process is a mechanism for suspending the part in space. The basic concepts involve filling the space with alternative low melting point matter for holding. This process offers a very easy fixturing method.

The order of concepts in this process is as follows:

Step 1. The stock is inserted into a cubed frame and filled with filler material.
Step 2. The cubed frame is secured onto the table using the vice of a securing device.
Step 3. Machining is applied on the cubed frame and the stock.
Step 4. All the machining that can be done with the current setting is completed and the filling is recharged.
Step 5. The set-up is changed.
Step 6. The routine from step 2 to step 5 is repeated until all the machining process is completed for all the set-up.
Step 7. After all the machining is completed, the filling material is melted and the final product is retrieved. The filling material can be recycled for later use.
Step 8. The machined part can also be recycled for later use.

Fig. 1 shows the encapsulation process routine visually. The key to this process is that a block of constant shape is used so that the fixturing process is kept constant in nature. Therefore, complex geometric shapes can be formed.

2.2. Feature-based software for RFPE process

In this study, a program was developed to generate set-up and machining sequences using feature-based modeling and feature-based model data. Fig. 2 shows the entire structure of the software. The software is comprised of two main modules. One module is for feature-based modeling. The other is for using the modeling data to retrieve information regarding machining. Additional modules utilize tool databases to select the correct tool for the feature-based model. In further

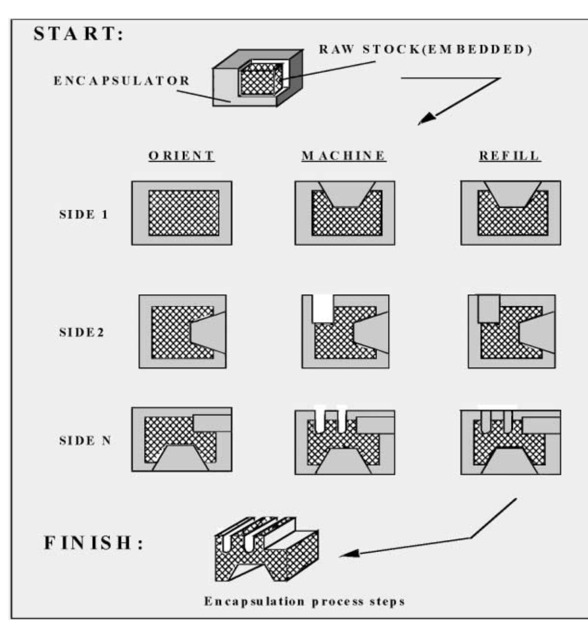


Fig. 1. The encapsulation-process routine.

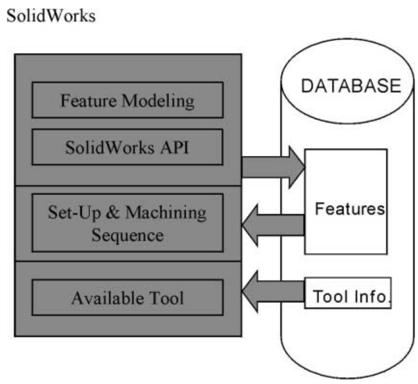


Fig. 2. The diagram of the software system.

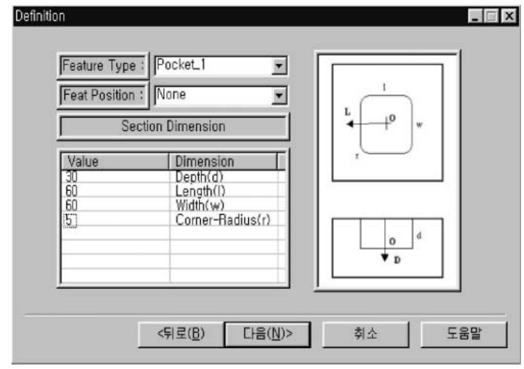


Fig. 3. The input of the feature dimensions.

detail, a feature-based library is constructed first. After this the machining information is stored based on the 3D models created by SolidWorks, a 3D modeling software and Visual C++ [13–15].

The feature-based objects defined in this study are machining feature-based objects and have been subdivided into five categories which are pocket, slot, step, hole and groove. Pockets have been further divided into nine types, slots, steps and holes into six types and one type of groove. In all, 28 types have been defined. A feature-based data structure has been generated through classes and the common data in all feature-based objects have been made into one abstract class, where each abstract class is formed from the data transferred from the previous abstract class. To initiate feature-based modeling, the location, direction and dimensional information of the feature-based object is required. Based on this information, 3D solid modeling is done. In this modeling procedure, machining information used for the set-up and determining the machining sequence is stored. In this study, SolidWorks API was used for 3D solid modeling. First, the feature-based object was chosen and related geometric information was entered. Using this information the feature-based object profile was sketched on a selected surface. The object profile was then removed from the surface using normal and opposite direction depth information. This modeling procedure was made into a wizard format like that used in the installing programs. The user needs only to enter the required values in each stage. In this simple modeling process, the set-up and machining sequences are determined or entered and stored. Fig. 3 shows a modeling wizard in the process of entering dimensions. Using the combo box at the top of the screen, the specific type of feature-based object can be chosen, the picture on the right shows the picture of the part.

Using the modeled data, set-up and machining sequences can be determined. In this study, the main purpose of a set-up change is to allow the tool to approach the object. Therefore, when determining a set-up, the direction of tool approach was considered foremost. The tool approach path is determined from the information given by the object profile on the flat surface. The opposite of the normal direction on the profile surface becomes the tool approach path. Depending on the type of feature-based object involved, one to three additional tool approach may be added. Using the tool approach data for each feature-based object obtained from the above, the set-up sequence is determined so that only a minimum number of set-up changes is needed. First, the set-up information is added and the set-up direction which occurs most frequently is selected. Machining that can be achieved from this set-up is checked out. If the parent feature cannot be processed in this set-up, then the offspring set-up cannot be processed also. When the checking is complete for one set-up, the remaining set-up directions are added again. This process is repeated until all the features are checked. When a set-up direction is decided for each feature-based part, the features that have the same set-up can be grouped and the categorization can be completed. Then, for each set-up, machining sequences are determined so that the final sequence of the entire process is mapped. For each feature-based part, a list of available tools is shown so that the user may decide which one to use. Fig. 4 shows the generated feature-based parts in a tree structure while Fig. 5 shows the set-up direction for each feature-based part. Thus the directions of tool approach are divided into groups. Fig. 6 shows the relations between set-up directions and set-up sequence as well as machining directions determined from the set-up

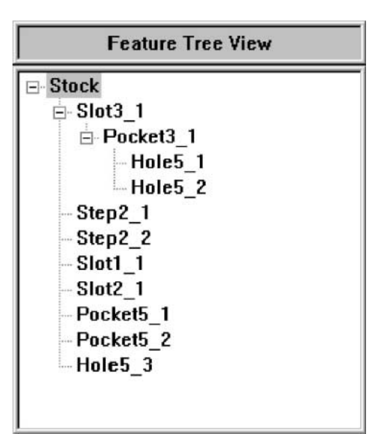


Fig. 4. The feature tree view.

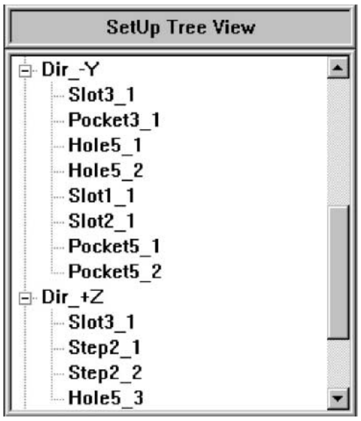
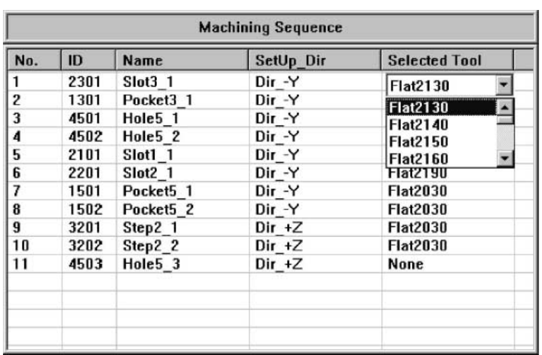


Fig. 5. The set-up tree view.



Machining Sequence

No.	ID	Name	SetUp_Dir	Selected Tool
1	2301	Slot3_1	Dir_-Y	Flat2130
2	1301	Pocket3_1	Dir_-Y	Flat2130
3	4501	Hole5_1	Dir_-Y	Flat2140
4	4502	Hole5_2	Dir_-Y	Flat2150
5	2101	Slot1_1	Dir_-Y	Flat2160
6	2201	Slot2_1	Dir_-Y	Flat2190
7	1501	Pocket5_1	Dir_-Y	Flat2030
8	1502	Pocket5_2	Dir_-Y	Flat2030
9	3201	Step2_1	Dir_+Z	Flat2030
10	3202	Step2_2	Dir_+Z	Flat2030
11	4503	Hole5_3	Dir_+Z	None

Fig. 6. The set-up and machining sequence.

directions. In this picture, an appropriate tool for the operation is being selected.

3. Experiments

3.1. Selection of the material

Choosing the right filler material, the material used in encapsulation is critical. To ensure firm and precise fixturing, the material was selected based on the experimental results. Since the material had to have a lower melting point than the stock and have little change caused by heat, materials with similar or lower thermal expansion factors than the stock were selected. It also had to be environmentally friendly. These characteristics were determined through experimentation, Bi/Sn (58/42) alloy finally being selected. The melting point of the chosen alloy was 135°C with a thermal expansion coefficient of $15 \times 10^{-6}/^{\circ}C$ [16].

3.2. Introduction of small and large scale encapsulation devices

In order to apply machining to the stock and filling block and then refill the block with filler material, an encapsulation system was required. The encapsulation system must completely refill the block and maintain low porosity, smooth surface finishing and precise dimensions. If the mold is incompletely filled, the stock may not be firmly held. Porosity reduces the strength and toughness of the mold causing imprecise surface finishing. Since the orientation is determined in relation to the surface, finishing is of critical importance. Also in soluble alloys, it is important to maintain dimensional stability and precision which may be affected by contraction and expansion of the alloy and also surface corrosion. The injection system as well as the mold temperature and injection temperature parameters should be designed with these facts in mind. If the injection temperature is increased, filling the internal area of the stock will be easier. However, vapor holes may be formed along with a reduced quality in surface finishing. Mold temperatures over 110°C are suitable to fill the block completely while a temperature over 120°C will result in excellent surface finishing. However, high temperature will requires a longer cooling time and cause drastic changes due to thermal expansion factors. Higher injection temperature is good for filling the block and dimensional stability. However, due to the longer cooling time required, the entire cycle time will be increased.

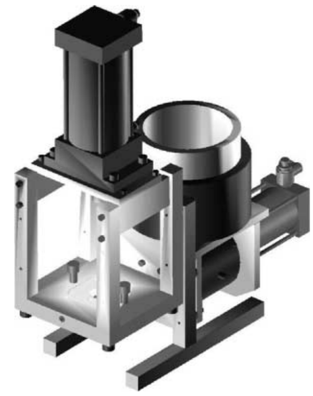


Fig. 7. The small encapsulation system.

Fig. 7 shows a small scale encapsulation system. The stock size of the small encapsulation system is 25.4 mm × 25.4 mm × 33.0 mm. Small systems are used to produce smaller items and was developed in the stages previous to that of a large scale system. Fig. 8 shows a large scale

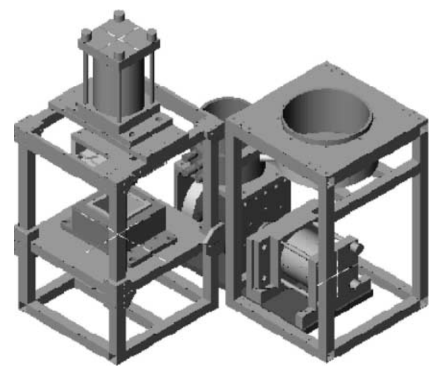


Fig. 8. The large encapsulation system.

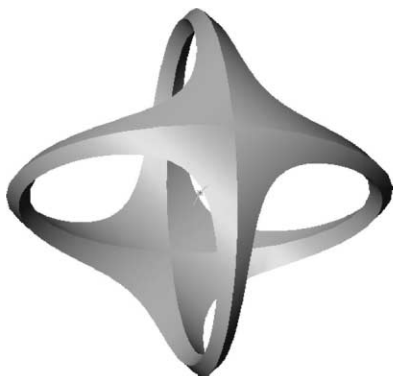
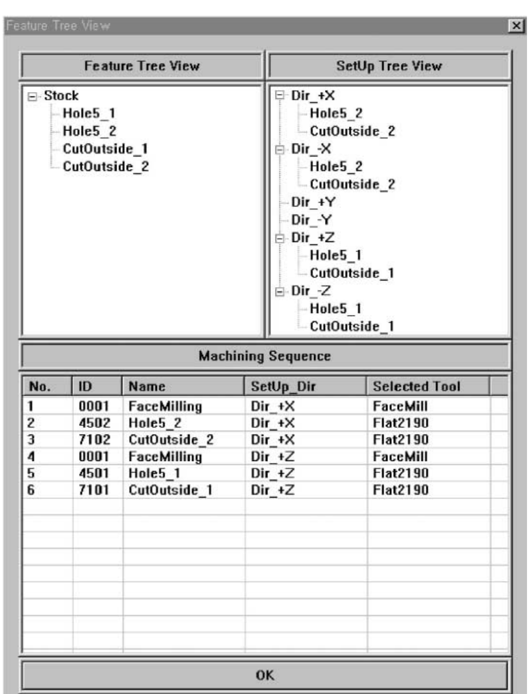


Fig. 9. The test model.

encapsulation system. The stock size of the large encapsulation system is 80.0 mm × 80.0 mm × 98.0 mm and it has two filler material reservoirs

3.3. Examples of software application

Using the following feature-based software, items were modeled and modeling data was then utilized to determine the set-up and machining sequences. Fig. 9 shows the model to which this system was applied. First, features such as the hole and cut outside were modeled as in Fig. 9 after which set-up and machining sequences were determined as in Fig. 10. In addition, the correct tool was selected using the tool database. With these factors determined, codes for machining could be generated. Before generating the actual codes, CL data was generated using the software so that smooth code generation could be checked. Fig. 11 shows the CL data display for the hole feature, while Fig. 12 shows CL data display for the cutoutside feature.



No.	ID	Name	SetUp_Dir	Selected Tool
1	0001	FaceMilling	Dir_+X	FaceMill
2	4502	Hole5_2	Dir_+X	Flat2190
3	7102	CutOutside_2	Dir_+X	Flat2190
4	0001	FaceMilling	Dir_+Z	FaceMill
5	4501	Hole5_1	Dir_+Z	Flat2190
6	7101	CutOutside_1	Dir_+Z	Flat2190

Fig. 10. The set-up and machining sequence result.

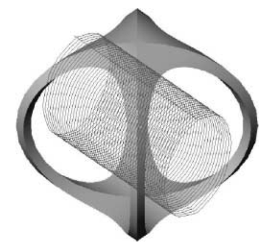


Fig. 11. The CL data of the hole.

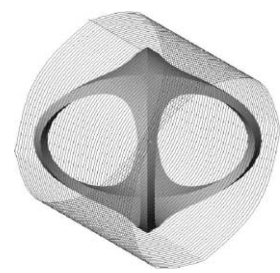


Fig. 12. The CL data of the cutoutside.

3.4. Machining experiments

In the previous section, CL data and machining codes were generated based on the information concerning the selected set-up, machining sequence and tools. Using this machining code, actual machining operations were carried out on a small scale encapsulation device. The machining operation utilized a 3R chuck system so that the set-up could be changed easily by simply rotating the entire block. Fig. 13 shows an encapsulated block being machined on a 3R chuck system. The stock and filling material will be processed simultaneously. Fig. 14 shows the part after the feature-based cutoutside processing has been applied. This is then refilled within the encapsulation device to form a full block for further processing. During the encapsulation and machining processes, the block is continuously secured to a 3R chuck system so that the information regarding location coordinates is not lost. After further processing, the block is refilled in the encapsulation device as in Fig. 15. After all the

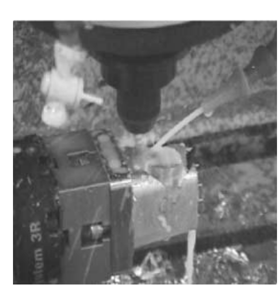


Fig. 13. Machining.

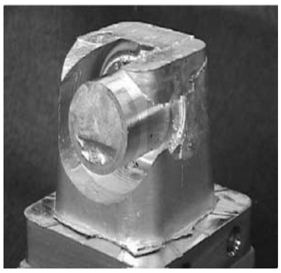


Fig. 14. Part after machining.

Fig. 15. Part after remolding.

Fig. 16. Final parts.

machining has been applied and the filler material has been melted away, the final product is achieved as in Fig. 16. Using this process, fixturing problems that arise when the set-up is changed can be eliminated. Also material failure that occurs in producing very slim parts can be avoided by the presence of the filler material and produced safely. A disadvantage is that a larger stock would require more filler material and would need a longer cooling time.

4. Results and future research

From this study, the following conclusion regarding the feature-based RFPE system can be drawn:

1. Feature-based modeling system software for generating set-up and machining sequences was developed.
2. An RFPE system which can fixture arbitrary geometric shapes easily was developed.
3. This system is expected to be very effective in automated machining systems.
4. A small scale encapsulation device for smaller objects along with a larger size system for larger objects was developed and actually tested. Results indicate that complex geometric objects can be produced easily through the fixturing method.

Future studies are needed to address integrating the encapsulating system and machining system into one automated system.

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