

**IE 605**

**Big Project Progress Report**

By

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12/18/01

## **Detailed Drawings**

The three dimensions used to validate the part are

- 1.
- 2.
- 3.

The three key dimensions are chosen from the point of view of their importance as well as the convenience of measuring them using Co-ordinate Measuring Machine (CMM). There are a few dimensions (like conical surface radii), which are difficult to measure using CMM. Hence, for dimension validations, mainly those dimensions were chosen that could be measured using “2-D features” functionality of CMM.

The detailed drawing is shown in the next page.

## **CAD Model Details**

### ***The Model Selection***

The main purpose of selecting this model was its simplicity and aesthetic appearance. In spite of having simple 2-D surface and one 3-D surface, the model is aesthetically pleasant.

### ***Surfaces used***

#### ***Lofted Surface:***

This surface was used for creating the upper surface of the block on which, the bottom of the main model rested. To create this surface, a rectangle was created first and then two edges of rectangle were selected for conversion into lofted surface.

#### ***Rotational Surface:***

This surface was used for creating the 3-D surface above the 2-D part of the model. To achieve this purpose, a 2-D spline curve was created and then it was given a revolution of 180 degree.

#### ***Composite surface:***

A composite is used for creating a single surface by uniting several different kinds of surfaces. In this case, the lofted surface and rotation surface were united to create the composite surface. Composite surface helps in

### ***Changes in Original Model***

The original model contained a few complex features of very small dimensions, which were not possible to create even with 1/8 inch tool diameter. One of such features was very small leaves with hardly any space between them. This would unnecessary increase the complexity of the model and hence was discarded.

### ***Other types of Surfaces/Curves***

Esprit offers several alternatives to create similar geometry, curves and surfaces. E.g., a rectangle can be created by several methods such as:

- Selecting four points and joining them by straight lines
- Selecting two points on the diagonal and using the “rectangle” option

The selection of a particular option depends on the simplicity of the operation. In some cases all the available options are more or less equally simple or equally complex. In those cases, any of them can be selected to perform the operation.

In this particular model, mainly following curves were used:

*Spline curve:*

Spline curves are useful when many of the dimensions of the model are unknown. In this case, the radii of a few circles as well their center points were unknown. Also, a few distances were missing as well. Hence, the outer boundary of the 2-D geometry was created using spline curve. Circle or arc option cannot be used in these cases as they require center or/and radius of the geometry.

Surfaces used were:

*Lofted surface:*

As explained earlier, lofted surface was selected for creating the upper level of the base block. Another option is to use solid modeler but that would unnecessary take additional memory and also there is no requirement of 3-D modeling as the ultimate goal is to do machining and that can be easily done without using solid modeler.

*Rotational surface:*

This particular surface is the best option when a symmetric surface is required with known axis of symmetry. This can be simply achieved by creating a 2-D geometry and revolving it around that axis. A lofted surface would not be **helpful in this case because it is not a planar surface.**

**A hardcopy of the model is included.**

## Process Details and Plan

### *List of Tools*

| Operation                            | Tool Name         | Tool Dia | Tool Length | Holder Dia | Overall Length | Tool Number |
|--------------------------------------|-------------------|----------|-------------|------------|----------------|-------------|
| <b>Milling (2-D Rough Pocketing)</b> | End-flat          | 0.500    | 1.4         | 1.0        | 1.6            | 1           |
| <b>Milling (Contouring)</b>          | Flat-one-by-eight | 0.125    | 1.1         | 1.0        | 1.2            | 6           |
| <b>3-D Finishing (Planar)</b>        | Ball-one-by-eight | 0.125    | 1.2         | 1.0        | 1.3            | 4           |

All dimensions are in *inch*.

- end-flat: For 2-D pocketing operation on the initial block to obtain the main geometry.
- Flat-one-by-eight: For contouring operation to obtain the final shape of the 2D part of the model.
- Ball-one-by-eight: For 3D planar finishing operation to obtain the final 3D shape of the model.

### **Sequence of Operations**

1. Rough milling of the original block to obtain the rough geometry of the main feature.
2. Contouring of the part obtained from step 1 to obtain the final shape of the 2-D geometry.
3. 3-D finishing operation to obtain the desired shape of the 3-D dome-shaped feature.

### ***Reasons for choosing this sequence***

#### *Roughing:*

There are mainly two types of operation to create any 2-D or 3-D models, namely roughing and finishing. Roughing operation provides a approximate shape of the geometry and finishing operation provides the final desired shape. In terms of time taken, roughing operation is far less time consuming than the finishing one because of the following factors:

- Toll diameter is high in case of roughing operation, resulting in fast removal of material.
- Stepper is around 45% (in face-milling), which substantially reduces the number of movements made by the tool.

Also, in case of flat milling, the roughing operation provides an excellent surface finish at the bottom surface. Taking the above points into consideration, roughing operation was selected for the initial material removal of the block.

#### *Contouring:*

Once the roughing operation is over, we need to obtain the exact dimension of the model. For this, either one can perform pocketing or contouring operations. Pocketing operation is useful when plenty of material needs to be removed as in the case of roughing operation. In this case, since most of the material has already been removed and we need to remove only some material at the contour of the geometry, contouring would be the most appropriate operation.

#### *3-D Planar Finishing:*

To achieve the desired 3-D feature, one can perform the rough cut initially if the amount of material is pretty high. In this case, since not much of the material is to be removed, one can directly go for 3-D finishing. It would save the time for tool change as well as eliminate the need of setting the Program Reference Point again. There are various options for 3-D finishing, namely planar, rotational, translational etc. In case of planar operation, surfaces are automatically selected for milling and at a time tool moves in one plane (in this case YZ plane) only and then moves by the stepper distance in the third direction and repeats the whole cycle. Planar milling provides a good surface finish but not as good as the rotational 3-D finishing does. The problem with 3-D finishing is that it is quite time consuming and is desired only when very high surface finish is required. Translational 3-D finishing provides almost the same degree of surface finish as the planar machining does and hence need not be considered. Keeping all the above-discussed point in view, planar 3-D finishing operation was selected.

### ***Redefining the PRZ***

Program reference zero is the point, which is used as a reference origin for all the coordinate measuring by the controller. This reference is different from the machine zero, which is always fixed. Since, all the co-ordinates heavily depend on PRZ, appropriate selection of PRZ is very important to obtain the desired dimensions of the model. An inappropriate PRZ might create a model of similar shape but the dimensions will never be same.

PRZ of the model needs to be setup with every tool change. One can avoid the need of setting the X and Y coordinate again by initially define the tool change position (in the Esprit Model). Putting X and Y coordinate as (0, 0) brings the tool at the initial position in terms of X and Y coordinate. The main problem is setting the Z coordinate as the different tool lengths of the tool result in different Z coordinates of the tool position. To overcome this difficulty, normally the upper left hand corner of the block is chosen as the PRZ. Then, the following procedure is adopted to redefine the PRZ:

- ❖ The X and Y coordinates of reference position are left unchanged. Only the Z coordinate is redefined.
- ❖ The tool is brought on the top surface of the block (some portion at the top surface of the block must be left unmachined even if that portion is not desired. It can be machined in the last operation) and then a piece of paper is used to redefine the Z coordinate of the upper surface of the block. Then this Z coordinate is defined as the Z coordinate of the program reference zero.

The redefinition of PRZ is not fully accurate because of human error in defining the Z coordinate of the topmost surface. This error continues in further operations.

In this particular case, since the model always had some material on its topmost surface, there was no need to do any extra machining in the last operation.

### ***Cutting Parameters***

There are various cutting parameters, which need to be pre-defined to obtain the desired shape and size of the part. An inappropriate definition of these parameters might result in poor surface finish, gouging or unnecessary high machining time of the part. Following are a few parameters that need to be defined while creating the model in Esprit:

#### *Speed*

The spindle speed should be set at around 3000 rpm to obtain a good surface finish. Also, if the feed rate is high, a higher rpm should be chosen so that the tool can cut the material smoothly.

***Feed rate: 12 feet per minute in X and Y direction, 6 feet per minute in Z direction***

Feed rate along both axes should not be too high as it might cause some damage to tool.

#### *Depth-of-cut*

- 0.50 inch for roughing operation: Since a chunk of material is removed in roughing operation and the tool diameter is also quite high (1/2 inch), a large depth-of-cut is desirable as it would perform the desired task without affecting the tool life.
- 0.10 inch for finishing operation: Tool diameters for finishing operations are normally pretty low as compared to roughing operation, which means a very high

depth-of-cut might cause some damage to the tool. Hence, the depth-of-cut should be kept at such a value that doesn't cause tool wear or tool damage.

#### *Step over*

- 0.30 inch for flat end-mill (Pocketing): Proper selection of step over distance is crucial for good surface finish. For flat end-milling operation, a very small step over (such as 10%) would result in unnecessary high machining time. A step over distance of more than 50% results in poor surface finish because of some material left between the two steps of the tool path.
- 0.10 inch for flat end-mill (Contouring): Ball end-mill doesn't remove the area of the material equal to its cross-sectional area at the bottom of the surface because of point contact with the surface. A high step over distance would result in very poor surface finish because of the unmachined material at the bottom of the surface. Hence, a small step over such as 10% is selected to give the desired surface finish. The disadvantage of this low step over distance is: the machining time increases significantly.

#### *Clearance*

- 0.1 inch: A sufficiently high but not too high value of clearance optimizes the time taken for the machining operation. A very low value might result in collision between tool and machine. A very high value would unnecessarily increase the machining time.

#### *Full Clearance*

- 0.5 inch: A relatively high value of full clearance avoids any machine-tool collision during the process of change in operation, tool change etc.

## **Tool Paths**

Tool path generation is very critical from the machining point of view. Following methods were used to generate the tool path of the features in the model:

- ❖ Concentric-in machining for pocketing
- ❖ Planar finishing for 3-D finishing
- ❖ The tool was brought to full clearance level after each operation
- ❖ Over then down method was used for entering the tool (for contouring)
- ❖ Over then up method was used for exiting the tool (for contouring)
- ❖ Full clearance (0.75 inch) for return and retract plane
- ❖ Concentric-In tool motion pattern
- ❖ Climb cutting strategy for pocket milling

## **The Machining**

After creating the CAD model, the second part of the project included CAM, I.e. Computer Added Manufacturing. Various operations with different tools were selected for this purpose and then after selecting the required parameters, NC code was generated that could be used on Dynamite Milling Machine. After generating the NC code, following steps were adopted for machining the part:

1. *Downloading the NC code on Dyna computer:* First of all, the computer was restarted in MS Dos mode to clear off any memory left by the earlier use of

machine. The clearing of memory is important as any leftover memory tremendously increases the loading and transmitting time for the data. Once the computer was restarted, the code (stored in a floppy) was downloaded to the computer.

2. *Simulation on the computer:* Once the code was downloaded, it was checked for simulation. Simulation is necessary to make sure that the code is error free and the machining is performed as desired.
3. *Bringing Dyna controller into receiving mode:* Before the data can be transmitted from the computer to Dyna controller, the Dyna controller must be in the receiving mode. To achieve this purpose, after switching on the Dyna machine, first the memory of the controller is cleared and then download option is used to set the controller in receiving mode.
4. *Transferring data from the computer to controller:* After setting the Dyna controller into receiving mode, the data transfer process is started. Because of the restriction on Dyna controller, at a time only 900 blocks of NC code can be stored in the controller. Next set of data can be transferred only after the previous commands are executed.
5. *Fixturing the model:* The model needs to be put into a fixture before it can be machined. A hand vice is used for this purpose. The hand vice doesn't allow the model to move while machining is taking place.
6. *Setting up the tool:* The first tool used for the machining operation is mounted on the tool holder. The spindle is set in the off position.
7. *Setting PRZ:* Once the first set of data is transferred to the controller, the next step is to set the Program Reference Zero, also called PRZ. The PRZ is the left hand corner at the top of the block. All three references are set using eye approximation by making sure that the center of the tool coincides with that point. The Z coordinate is fixed by bringing the tool near the topmost surface and then using a piece of paper to make sure that the tool is at the desired height. Small increments are used towards the end of the Z coordinate movement of the tool. After removing the paper, 3 more downward increments are provided in order to take care of the thickness of the paper.
8. *Start machining:* After setting up the PRZ, the spindle is turned on and once the speed reaches to about 3000 rpm, "next" button is pressed on the controller. This starts the machining process and then the commands on NC blocks are followed by machine. After every 900 lines, the machining stops and next 900 lines of codes are automatically transferred to the controller and the process goes on.
9. *Tool change:* Once all the operation (s) supposed to be performed by the first tool are done, the tool moves to the tool change position, which is 10 inch above the PRZ. The existing tool is removed and the new tool is loaded. Now, the PRZ again needs to be defined. Since the X and Y coordinate of the tool is still the same as those of PRZ, only Z coordinate needs to be redefined. This is done by bringing the tool on the top surface of the block and performing the same sequence of methods as were used to define the PRZ. Once the PRZ is redefined, the "next" button is pressed to start the machining again from the place where it was left.

10. *Unclamping the model:* Once the machining is over, the spindle is turned off and then the part is unclamped & taken out of the table.

***Difference between expected and actual machining***

Actual machining was more or less similar to the expected machining as predicted by Esprit except the amount of time taken, which will be discussed in the next section. A few deviations that were observed are as follows:

- The fillet between the 2-D and 3-D surfaces was not machined properly because of very small radius of the fillet. This was due to the fact that the radius of fillet was smaller than the tool radius.
- There were a few dots on the fillet described above. This again might be because of large tool diameter.
- There was a very thin layer of material left at one side of lower 0.5 inch of the 2-D portion of the model. This was due to the discontinuation in the data transmission during the machining of that portion. This discontinuation required the PRZ to be redefined, which might have led to this error.
- The spindle RPM was set up at 2900 RPM in the Esprit but was taken at 3040 RPM instead by the controller.

***Difference in machining times***

|                           | <b>Operation 1<br/>(min)</b> | <b>Operation 2<br/>(min)</b> | <b>Operation 3<br/>(min)</b> | <b>Total Time<br/>(min)</b> |
|---------------------------|------------------------------|------------------------------|------------------------------|-----------------------------|
| <b>Esprit (Predicted)</b> | 11:15:89                     |                              |                              |                             |
| <b>Actual (Approx.)</b>   | 30                           | 15                           | 75                           | 120                         |

As we can see, the actual machining time is more than that predicted by Esprit. Following are the possible reasons for this difference:

- *Delay in data transfer:* Data transmission from computer to Dyna takes significant amount of time because of the limited 900 lines capacity of Dyna controller. After every 900 of code, the machine has to wait for data to get downloaded to the controller. There are some 25-30 such transmissions during the whole machining process.
- *Tool change time:* Each tool change requires a considerable amount of time. Tool change requires redefinition of PRZ as well, which further increases the machining time. This time is not taken care of by the Esprit.

***Gouging***

Prevention of gouging is very important to achieve the part as desired. Gouging is a machining defect that occurs because of intricacies in design. Gouging normally occurs when the model has some features, which cannot be machined because of the limited movement of tool. For example, a feature, which requires the tool to go inside the model, cannot be machined. If the part program for machining this feature is run, the tool will gouge into the model and damage the part. Gouging also takes place because of any undesired movement of tool into the model. Gouging damages both the model as well as the tool. To prevent gouging, following steps were taken:

- No intricate features were introduced in the CAD model. It was made sure that the tool didn't have to go inside the model to perform the machining.

- The full clearance and clearance was kept at a relatively high value to avoid any accidental gouging of tool into the model.
- For contouring operation over then down entry and up then over exit mode was selected, again to avoid collision between tool and the part.
- After every operation, the tool was moved back to full clearance to make sure that for next operation tool doesn't have to pass through the model.
- The tool change position was kept at a high Z value.

### *Comparison of three dimensions*

|  | <b>Dim 1</b> | <b>Dim 2</b> | <b>Dim 3</b> |
|--|--------------|--------------|--------------|
| <b>Dimension as given by Esprit (inch)</b> |              |              |              |
| <b>Dimension as measured on CMM (inch)</b> |              |              |              |

Reasons for difference in the dimensions:

- ❖ Definition of PRZ: Since the PRZ is defined using eye approximation, the center of tool might not perfectly match with X or/and Y axis. This would cause some error in dimensions involving X and Y coordinate. Also, Z coordinate reference is set up using a piece of paper that might result in a few extra or less small increments along the Z axis while setting up the PRZ. This might cause some errors in the dimensions involving Z coordinates.
- ❖ Redefinition of PRZ: Since after every tool change (and in this particular case also because of interruption in data transfer) the PRZ has to be redefined, errors along the Z direction might be introduced. No error in X and Y directions will be introduced because of the PRZ redefinition as reference coordinates in these two directions are unchanged.
- ❖ Manual handling of CMM: Coordinate measuring machine is manually operated to measure the various dimensions. This might cause some errors as in many cases the center of the measuring sphere might not exactly coincide with the edge of the model.

## **Critique of Esprit and DYNA**

### *Esprit: Strong Points*

- User friendly software
- Provides versatile tools such as curves, surfaces etc. to create a CAD model
- Various machining operations (2D milling, 3D milling, drilling etc.) are available along with different sets of tools.
- Easy interface for directly generating NC code for Dynamite machine

### *Esprit: Weak Points*

- No keyboard control unlike many other CAD softwares (like Mechanical Desk Top etc.)
- No "Redo" facility

- Cannot work on more than one Esprit files at a time as it doesn't allow to open more than one windows at a time.

*Dyna: Strong Points*

- User friendly
- Facilitates offline programming i.e. NC blocks can be directly transferred from the computer to the controller that eliminates the need to type them online.
- Provides a variety of tools to perform different types of operations.
- Provides almost accurate part that means presence of excellent feedback system.

*Dyna: Weak Points*

- Cannot store more than 900 lines of program.
- Doesn't support simultaneous machining and data transfer. The machine waits for data to get transferred and then it starts executing those commands.
- Has to redefine PRZ after every tool change.
- Needs to delete any program stored in its memory before it can execute and other program of length exceeding 900 lines.

*Contouring*

*3-D Finishing (Contouring)*

*Assessment of the meeting with the schedule as in phase 1*

| Steps  | Proposed   | Status     |
|--|------------|------------|
| Generate CAD Model & Identify Key dimensions for part validation                               | Week 1     | Done       |
| Generate the process plan, Identify the sequence of operations, Define the tool specifications | Week 2,3,4 | Done       |
| Define fixtures and jigs requirements,   | Week 5     | To be done |
| Generate the tool path,  | Week 6     | To be done |
| Generate NC code,  | Week 6     | To be done |
| Perform machining,   | Week 7     | To be done |
| Validate the model on CMM  | Week 7     | To be done |