Basic Fairing Principles of Fiberglass Pits and Patches

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Abstract

There are many reasons compelling us to automating surface finishing of fiberglass composites. Harmful dusts, repetitive motion injury, and product quality are just a few reasons for automation. We have developed a methodology for robotic surface finishing of fiberglass composite pits and patches. Methods for the filling of pits and patches with a fill material, the subsequent forming of the uncured fill material, and the fairing of the various workpiece features are examined.

An anthropomorphic manipulator is used with “around the arm” force control along with custom developed software called RobSurf. RobSurf provides for the reverse engineering of the samples used, and creation of robot programs based upon the reverse engineered surface. The necessary filling, forming, and fairing process parameters are explored and the subsequent experimentally determined parameters are described. Factory implementation suggestions are provided that utilize commercially available components for workcell development.

1 Introduction and Background

1.1 Automation and Robotics Research Institute

The Automation and Robotics Research Institute (ARRI) is an applied research center in the College of Engineering of the University of Texas at Arlington. Situated in an off-campus industrial park and staffed by permanent staff engineers, faculty and students, ARRI performs sponsored research and development to meet the stated mission of advancing our customers toward World Class

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Manufacturing. ARRI has for many years been using its resources to help advance the field of automated robotic surface finishing. The latest research results from this field are now presented.

1.2 The Need to Automate Surface Finishing of Fiberglass

Surface finishing of fiberglass by hand is often time consuming and fraught with risk to both the worker and the product. Finishing by hand exposes the worker and those around to dusts that can be potentially harmful. Further, the repeated motion of finishing tools across a surface along with the repeated vibrations of the equipment may lead to further health problems with long term use.

The effect personnel fatigue, deleterious health impact and other inconsistencies have on the product is extremely important. People often make mistakes. Further, the grinding results can often be different when done by different people or even by the same person at different times! Inconsistencies in product quality are introduced, which can cause difficulties later on in the manufacturing process. By automating the filling, forming, and fairing of fiberglass surface defects and material interfaces increased product output and quality, plus a safer working environment for the employees, can be achieved.

2 The Automated Surface Finishing Process

ARRI has recently completed a research project on the topic of automating the filling, forming, and fairing of fiberglass patches, pits, and seams. Filling refers to applying or dispensing a paste like material to fill in the gaps between material interfaces, surface voids or pores that are perhaps artifacts of a previous molding process or other manufacturing process artifact. Forming refers to shaping the fill material before it has cured to eliminate air bubbles and voids and conform to the existing surface in order to minimize the amount of material removal that must be accomplished. Finishing then refers to removing any unnecessary fill material after it has cured to produce the desired smooth, contoured surface.

Some difficulties are encountered, which are similar to those of almost any automated surface finishing that is done. These include how to reverse engineer the complex contoured part so it can be operated upon by the robot, how to define the process parameters such as controlling the applied force and generating the proper paths, and how to make the cell flexible enough to handle different shapes and contours of the work pieces.

The use of fiberglass and its filling materials generated an additional set of problems not previously considered:

- No penetration of the outer fiberglass layer
- Smooth blends to aerodynamic surfaces
- Attractive appearance
- No stress risers (scratches)
- Fill material shrinkage compensation

We developed solutions to some of these problems at ARRI. The robot work cell, the tools, mechanical and software, and the processes developed are now discussed.

3 Experimental Setup

3.1 Samples

The experiments were conducted on fiberglass samples that varied in shape from straight to cylindrical. The sample size was approximately 1-½ feet by 4 feet. Pits and patches were simulated by grinding small grooves in the surface of the fiberglass as seen in Figure 1.

The resulting depressions were then filled with either EA-960 or APF-4 paste material. While still wet the filling material was covered with wax paper and was rolled to a desired thickness and shape on the sample. This affected the proper filling of the depressions and aided the fairing process by making the material to be removed a more consistent size and thickness. It is necessary to overfill the depressions due to shrinkage of the filler while drying. An example is seen in Figure 1.

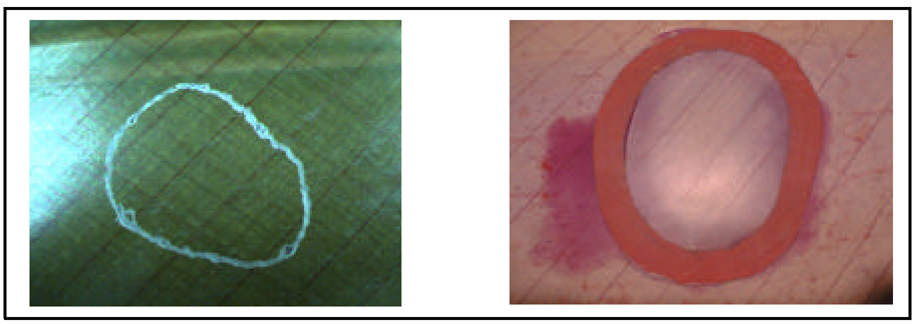

Figure 1: Simulated fiberglass patch

4 Hardware Used and Recommendations for Implementation

There are a number of useful items for proper fairing of fiberglass and other surfaces. Listed below are components used in creating a complete filling, forming, and fairing system. Equipment used for the process development is presented as well as that which would be recommended for implementation, based on our findings.

4.1 Robot

Robot selection for a finishing application such as this needs to take into account several constraints. First the robot needs to have a dexterous workspace large enough so that it can reach all required points on the work piece. If the piece is large or of unusual shape multiple robots or a robot on a track system may be needed. Further, the robot must be able to accurately move the combined weight of the tooling such as the active force device and the grinder and the reaction due to the applied force for finishing purposes. We used a GMF S-400 robot. Since we were only doing relatively small samples in the development process and not implementing the process on a factory floor there was no need to have a track system.

4.2 Active Force Device

The active force device (AFD) is at the heart of a successful fairing system, since robots are very good at controlling position but not in performing force control through the arm. This device provides the proper force control in addition to the needed compliance in the positioning of the grinder and the other equipment. The AFD must be strong enough to hold the attached equipment and be able to accurately control the force through a variety of conditions such as quick update rates and extreme angles. An active rather than a passive force device is recommended since a passive device may not provide reliable force control especially on complex contoured parts. Further, the AFD should be able to interface with the controller or offline programming software that is being used. We used the PushCorp AFD 100 Alpha active force device that met all of our requirements.

4.3 Quick Change End Effector

It may be useful to mount a quick-change device on the end of the AFD. This will allow rapid changing of tools if a single robot is to be used for the filling, forming and finishing operations or if multiple tools of a single type are used. This would avoid the need for multiple robots or tedious manual changing of end effectors. A quick-change end effector was not used for the experimentation, but it would have proven useful.

4.4 Sander

There are many types of sanders that can be used. For this specific application rotational sanders as opposed to belt type sanders were used. The random orbit sanders, also known as dual action (DA) sanders, proved superior to conventional rotary sanders. The orbital action of this sander helps in preventing the deep scratches and direction artifacts that can occur with a spindle type grinder. This is especially noticeable if a grinder is left in contact with the part for even a short time more than the recommended process time.

The sander can be either electric or pneumatic but must be able to accurately maintain its speed under load and not spin too fast when not loaded. A constant velocity is necessary, so that when part contact is first made, the material removal is consistent. For this reason servo speed control is recommended for the grinder motor. Size of the backing pad and hence the grinding disks are chosen for a specific application. The sander could use either hook-and-loop fasteners or pressure sensitive adhesive (PSA) to hold the sanding disks in place.

For our research a Bosch 1370 DEVS random orbit sander was used. It has a six inch diameter pad with dust collection and hook-and-loop fastening.

4.5 Sanding Disks

The main characteristic of sanding disks is their grit size. For our application, we used standard 150 grit hook-and-loop sanding disks with a DA sander. The parts were to be painted afterwards, so a slightly roughened surface was desired. Although we used hook-and-loop fasteners, we recommend one to also experiment with pressure sensitive adhesive (PSA) if many disk changes are needed. For our experimentation, Norton 6 inch, 150 grit, 8 hole, hook-and-loop disks were used.

4.6 Weld Shaver

A tool that has proved useful in some applications is the weld shaver. This device was originally developed to remove the weld beads after welding to provide a smoother finish at the joint. It consists of a spinning mill cutter between two guide wheels. The height of the cutter can be adjusted so that the device can shave a bead as low as 0.010 inches. This has proved very useful where a filling medium in a fiberglass joint leaves a bead after drying. This bead could be weld shaved down before grinding thus reducing the amount of material removed on the fiberglass surface, and at the same time provide a consistent bead height for the fairing operation.

4.7 RobSurf

RobSurf is a surface finishing software package developed at ARRI. It automates the reverse engineering of surfaces and generates the needed robot paths according to programmed parameters. It gives the ability to quickly generate code for a variety of test shapes and sizes without the tedious manual reprogramming that would normally be needed through a soft setup capability using a coordinate measuring device. Process parameter interfaces are provided so that some of these parameters may be easily varied along the programmed robot path. This allows the process to be developed in parametric way that can be applied to a variety of situations.

4.8 Final Setup

The current lab implementation of the automated surface finishing cell at ARRI is shown in Figure 2. The actual cell along with various tools is shown in Figure 3.

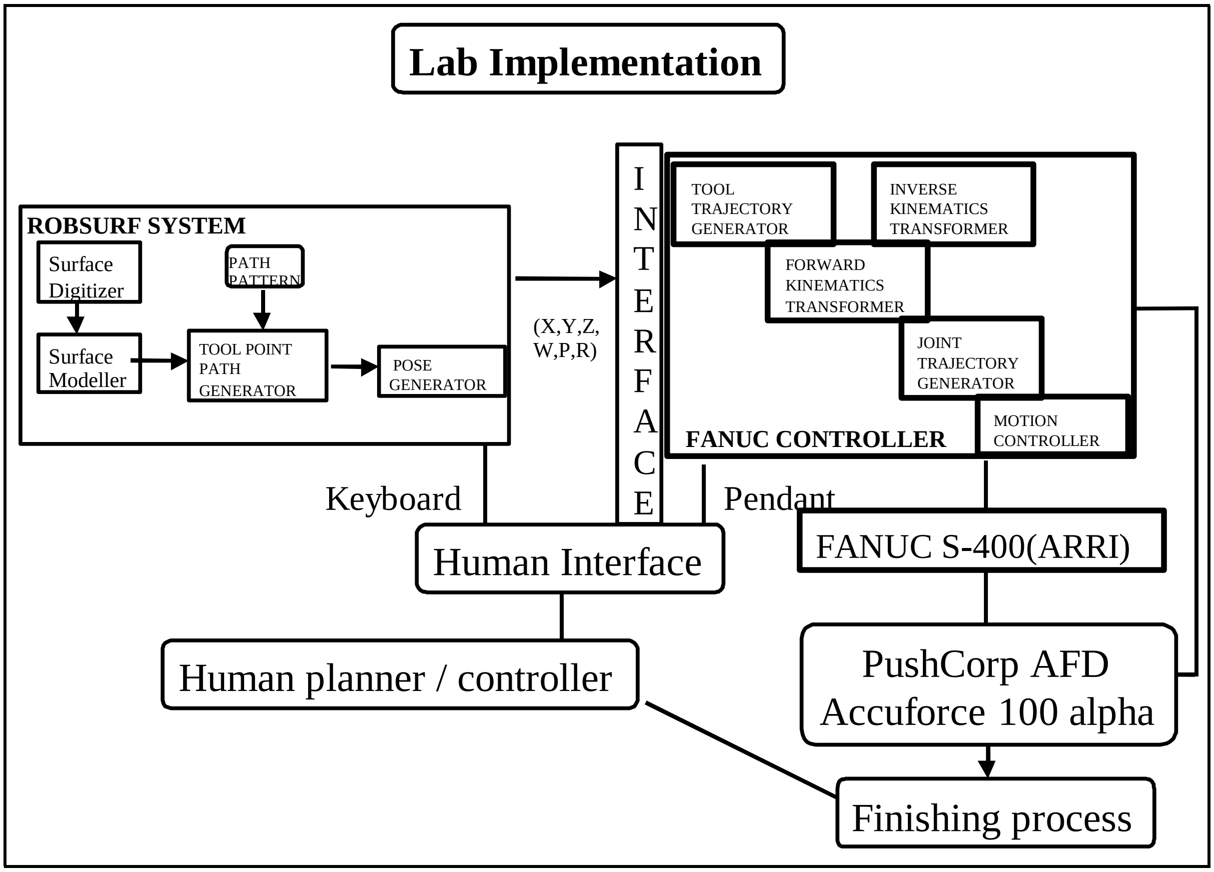

Figure 2: Schematic of current Lab Implementation

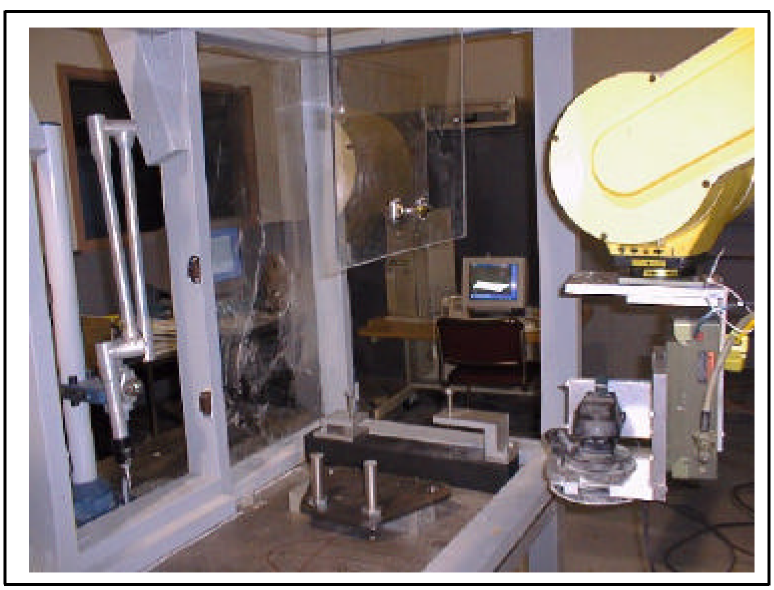

Figure 3: Actual Surface Finishing Cell at ARRI

5 Theory of Experimentation
Grinding Basics and Suggestions for Implementation

5.1 Contact Patch Shape

The contact patch is defined as the area where the grinding disk contacts the work surface. It can vary depending on the angle of attack, force, and contour of the surface being ground. A variety of different contact patch shapes generated on a flat plate, where only the angle and force were changed is shown in Figure 4.

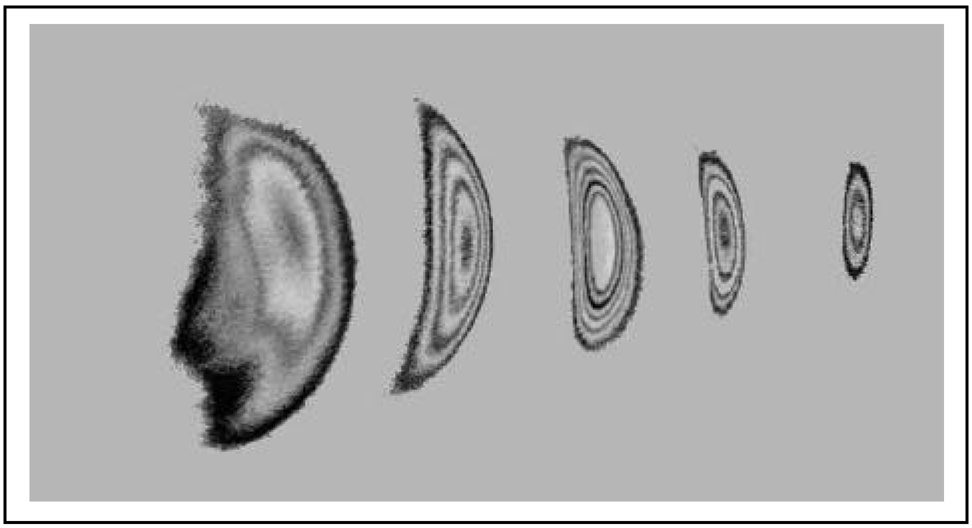

Figure 4: Contact patch shapes

The contact patch can vary from a full circle down to a thin crescent down to a small oval. It is important to find the shape of the available contact patches for successfully grinding the parts. If the surface has complex contours, experimentation to find the available contact patch shapes is necessary.

The control of the direction in which the contact patch moves can be quite useful. The patch can be moved in the direction it is widest or in the direction it is thinnest, depending on the particular finish work present at any time. The former covers wide areas with a lower material removal rate, the latter gives high material removal in a confined area. The first is good for general fairing and smoothing, the second for operating on seams and raised areas of filling material.

Note that the third direction shown in Figure 5 is not recommended for fairing. If the patch is moved in the direction indicated the disk could get caught up on raised areas and edges; sudden changes in shape of the work piece can cause the disk to gouge the part.

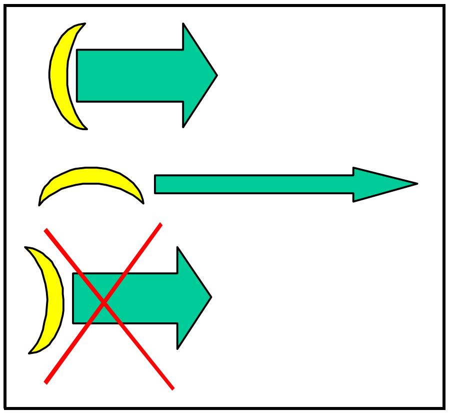

Figure 5: Contact patch motion direction

5.2 Filling Material Properties

Certain materials used to fill pits and seams vary in their desirability for automated surface finishing on fiberglass. Materials with characteristic such as those of APF-4 become soft during the grinding process and load up the grinding disks. This results in frequent changing of the disk before the disk itself is actually worn out. As the disk loads up the effectiveness of the grinding suffers and may actually do more harm than good.

Figure 6: Loading of grinding disks

Filling materials with characteristics such as those of EA-960 do not show this softening characteristic. These type of materials are preferred for automated fairing in that disk life is longer and the wear on the disk is more predictable. Hence, the proper results are more assured.

EA-960 was the settled upon as the recommended material. All paths and process parameters developed for fairing utilized this material.

5.3 Grinding Paths

There are a number of ways that the filling material on the blade can be fired. The basic movements will be discussed. A region can be faired by taking a number of passes with the grinder. Each pass takes on the form shown in Figure 7.

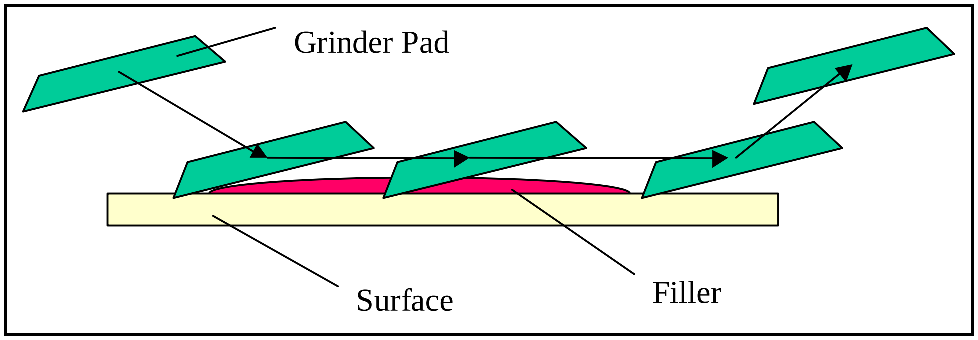

Figure 7: Basic grinding motion

It was deemed useful to declare the tool center point as being in the center of the disk for automated path planning generation as it relates to the tool center point. This makes the center of the contact patch located at approximately ¾ of the radius of the disk as measured from the center depending on the cant angle.

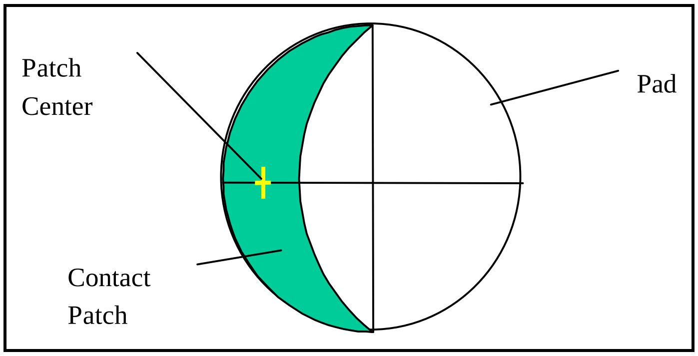

Figure 8: Location of patch center

When programming the paths, care must be taken to include the offset distance between the pad center and the contact patch center in the calculations so that the proper area is fully faired. One may wonder why not just have the contact patch center point coincide with the tool center point. This can be done only if the same direction and orientation of the tool is always being used. However, it is more useful to be able to change the orientation of the grinder, and thus adjust the contact patch position on the grinding disk. This enables complex paths to be easily followed, makes rastering across a surface easier and it allows fairing in both directions, thus reducing cycle time.

An offset angle measured from the normal of the surface is used to generate the contact patch. The greater the angle the smaller the contact patch. A smaller contact patch is useful for grinding off high spots or when greater material removal rates are needed in confined areas such as along a seam or an edge. For most grinding purposes an offset angle of 5 degrees makes a good starting point for experimentation.

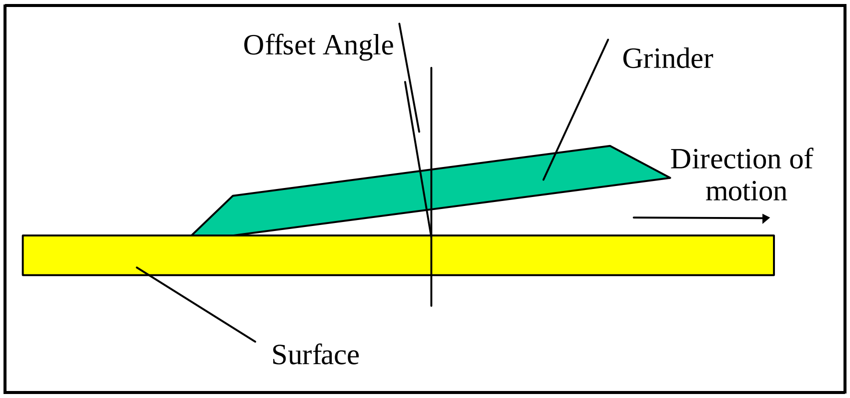

Figure 9: Offset angle definition

The speed at which the grinder traverses the fiberglass is important since slower speeds result in much greater material removal. We recommend to make numerous quick passes at lower force rather than fewer slower passes at greater force. The exact speed and applied force should be determined experimentally for each application.

5.4 Grinding Paths for Patches and Pits

The paths were generated using RobSurf. RobSurf is an automated surface finishing package created at ARRI to aid in reverse engineering a surface in AutoCAD, and then generate the necessary robot code to fair the part. The soft setup capabilities of RobSurf gave the freedom to generate basic path motions and then be able to quickly apply them to different samples that varied in size, curvature, and position for experimentation.

The active force device was found to provide satisfactory results on a setting of 15 pounds with an offset angle of approximately 5 degrees for fiberglass finishing. The seam and patch paths are shown in Figures 9 and 10.

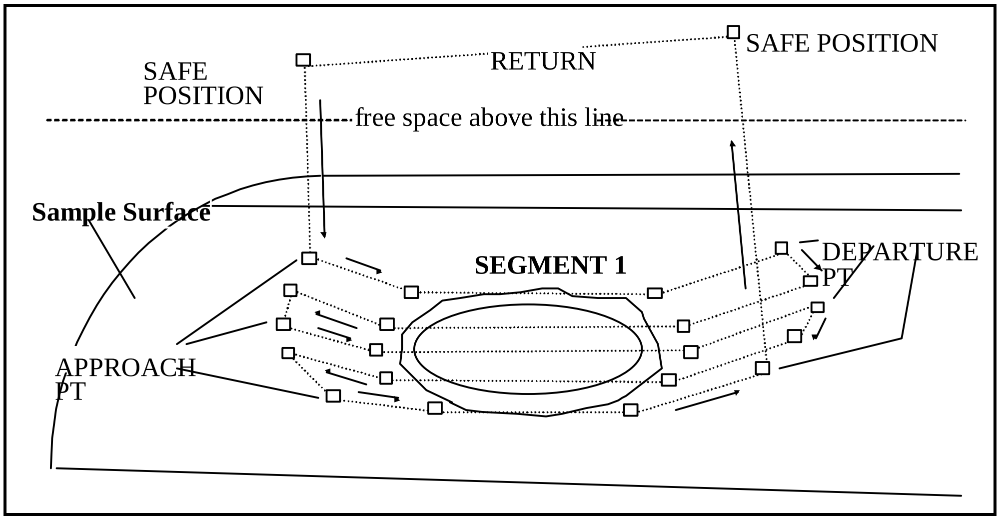

Figure 10: Patch Feature Routine

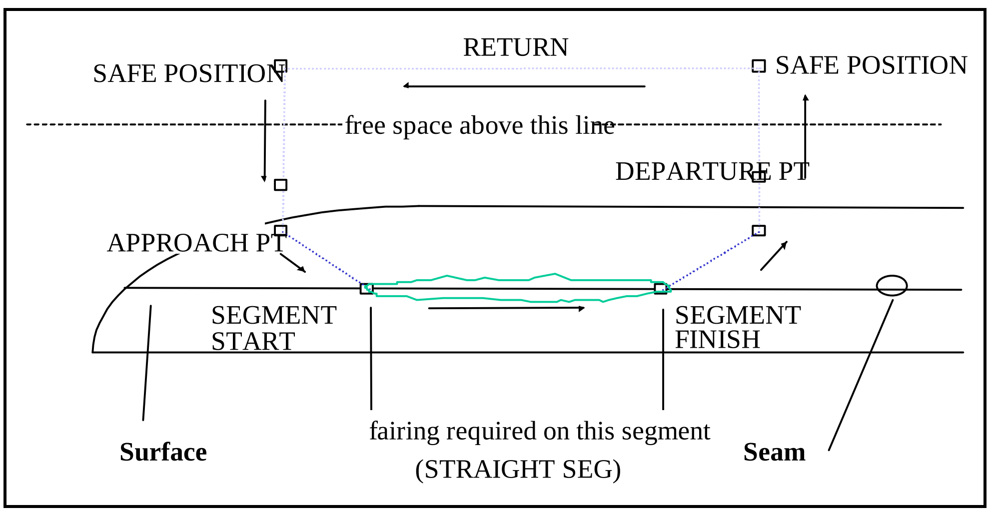

Figure 11: Seam Feature Routine

It is important to make sure the motion is continuous and consistent. Pausing when the grinder is in contact with the surface can result in gouges being cut into the surface. If the offset angle is too large a tip cut can result when first contact is made which could damage the surface.

As stated earlier, the grinding process was greatly aided by the forming method. By rolling the material thin before drying only a few passes were required to fair the surface. If the pits and depressions are not to deep the material can be rolled extremely thin. Care must be taken so the filler material does not shrink below the surface of the part after drying. It was our finding that the shrinkage of EA-960 was approximately 10%. If the pits are deep and variable in depth, more filling material may be needed to assure proper filling. This could lead to much more material than can be ground off easily.

In that case the bead of material left after rolling can be weld shaved off. This will result in a fully filled yet extremely thin strip of filling material that can be ground off in one or two passes with the grinder.

5.5 Experimental Process Results

Once the basic procedure was developed consistent results were achieved with good repeatability. The before and after fairing pictures on different samples is shown in Figure 11. Note that the filling material has been formed with a roller and the wax paper used in the forming has been removed.

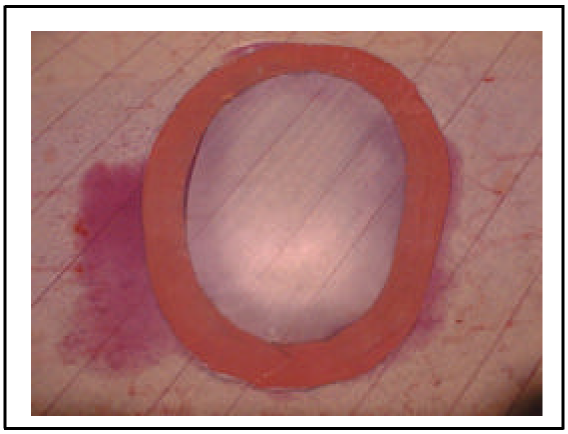

Figure 12: Sample ready to be faired

After the fairing process is completed according to the steps previously listed, the results for two different samples are shown in Figure 13. We observe that there is no penetration of the thin film covering of the sample. The pits have been fully filled and faired smooth. The part is now ready for painting or other processing.

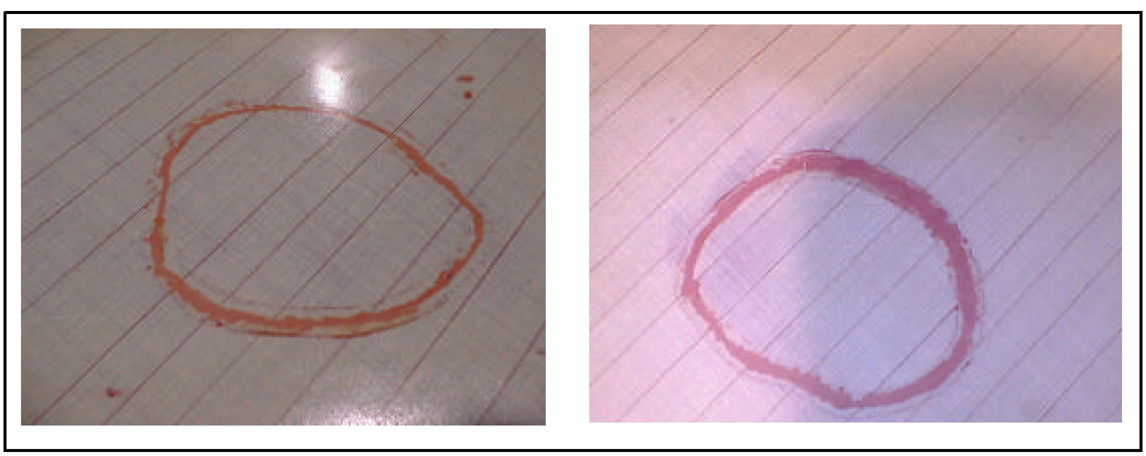

Figure 13: Finished samples

6 Conclusions

An experimental development program has been completed to allow the robotic automation of surface finishing of fiberglass parts and components with contoured surfaces. Recommendations for work cell and process components have been made. Sufficient information is now available to allow the release of a detailed specification suitable for a robot integrator contractor to develop a practicable industrial work cell for this type of application.

Although automated surface finishing of fiberglass skins is difficult, it can be achieved if consistency in all levels from filling, forming, to fairing is maintained. If properly performed cycle time can be decreased, quality improved and health risks lowered.

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