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REAL-TIME THICKNESS MEASUREMENT OF MCC ABLATOR MATERIAL

Preparted By:	R. Bryan Greenway, Jr. Ph.D.
Academic Rank:	Assistant Professor
Institution and Department:	University of Kansas Department of Mechanical Engineering

NASA/MSFC:

Laboratory:	Materials and Processes Laboratory
Division:	Fabrication Services
Branch:	Process Modeling and Automation

MSFC Colleagues:	Maninderpal S. Gill

INTRODUCTION

One of the most favorable characteristics of the Space Shuttle Program is the reusability of two of its primary components: the orbiter itself and the Solid Rocket Boosters (SRB). The SRB's provide the primary source of propulsion for the Space Shuttle during take-off afterwhich they are recovered for refurbishment and reuse. During refurbishment, the SRB's are stripped of all remaining ablative (heat resistant) coating. A new layer is applied to the appropriate sections (nose cone, frustum, forward skirt, and aft skirt). It is the process of applying the ablative coating which provided the impetus for this project. The thickness of this protective layer is considered to be of primary importance to the level of thermal protection provided.

OBJECTIVES

The objectives of this effort are to investigate possible techniques for measuring the thickness of MCC, and if possible to test the specific capabilities of those considered good candidates for implementation. The system should be able to take measurements in real-time as close to the spray gun as possible. This will allow the information to be used in the control of the process without an inordinate time delay between a measurement and its appropriate response. The thickness of the deposited material is to be measured with less than 0.100 inches of uncertainty. This is the defined tolerance window for the ablator thickness. Finally, it must operate within the confines of the chamber which encloses the turntable, robot, and spray system, and therefore is required to be insensitive to, or at least maintainable in, that environment.

PROBLEM DESCRIPTION

Once the SRB's are recovered after a Space Shuttle launch, the individual sections are separated, cleaned and stripped with water blast guns, and inspected for damage. If no critical damage is found, the sections are prepared for reuse. One of the final steps in this process is that of applying the ablative coating to certain sections; the thickness of which depends upon the particular section being sprayed as is indicated in Figure 1.

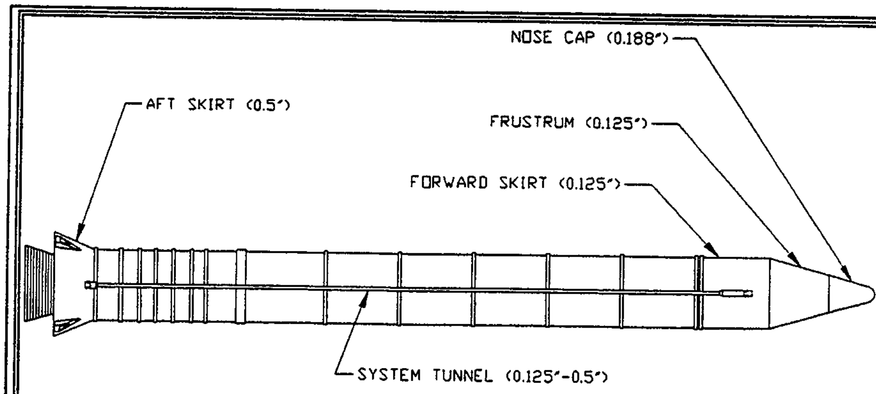

Figure 1 MCC Thickness on Solid Rocket Booster (proposed)

If the ablator thickness is too small, then there will be insufficient thermal protection. If on the other hand, it is too thick, the additional weight reduces the Space Shuttle's payload capacity. It is desirable to monitor the thickness to not only improve process control, but to help alleviate rework. In order to verify the process, thickness measurements are now made after the material is cured. At this point, thicknesses falling outside the permissible tolerances can be very costly.

The material used during this investigation is known as Marshall Convergent Coating (MCC). It is referred to as "convergent" because the components of the material converge and are mixed at the spray gun. MCC is composed primarily of cork and glass and is thus not electrically conductive. It has a fairly high level of surface roughness and moderate porosity. Currently, it is not the material that is "flying", but considered to be the next generation ablator. There are several advantages that MCC has over the previous ablators. There are fewer constituents in MCC, only four versus over ten for some others, which simplifies the management of the process. Previously developed ablators were mixed beforehand in a mixing tank that was used to feed the process. Once the material is mixed, it must be applied within a certain period of time. This added a time constraint to an already complex situation. This also complicated clean-up since the tanks must be cleaned and pumps, valves, and hoses purged. Finally, the absence of environmentally hazardous materials in MCC will comply with governmental regulations to be enforced in the near future.

The application process involves placing a clean skirt, frustum, or nose cone onto a large turn table as shown in Figure 2. The MCC spray gun is mounted to a robot which controls the standoff distance from the material and the angle between the spray gun axis and the surface normal. As the turn table rotates, the robot pans upward. The turn table spins at a rate of 0.5 to 6 rpm depending on the particular section being sprayed. The target substrate speed is approximately 40 feet per minute or 8 inches per second. In other words, the surface of the section being sprayed passes beneath the nozzle at a rate of approximately 8 ips. The rate of robot movement is set such that it moves about one inch vertically per full revolution of the turn table. The resulting pattern of material is that of an overlapping, helical strip with a lead (the amount of vertical travel per revolution) of one inch. Since the substrate and the spray gun are moving relative to one another, it is necessary to perform any thickness measurements on a non-contact basis. The ideal place to mount such a sensing system would be on the end-effector of the robot.

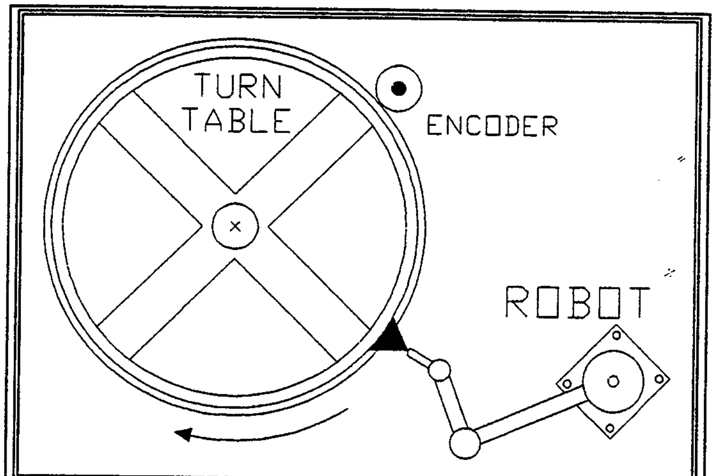

Figure 2 MCC Spray Cell Schematic

The spray gun emits MCC which fills a conic volume with a cone angle of approximately 31 degrees. The standoff distance (i.e. distance from spray gun tip to the substrate) is approximately 8 inches. This results in a near circular spray pattern with a diameter of 4.5 inches. This can be seen in the Figure 3. It can now be determined from the size of the spray pattern and the amount of lead, that each point on the surface of the substrate will pass through the spray pattern at least four times.

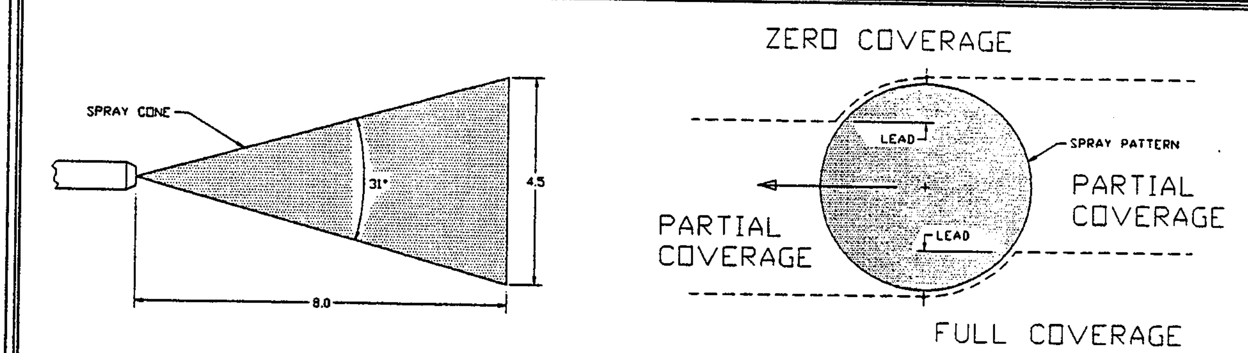

Figure 3 MCC Spray Pattern

APPROACH

With this process understood, different techniques for taking thickness measurements can now be considered. The ideal time to take the measurement is as soon after the application as possible. This will allow for appropriate responses to be undertaken before large areas are created with out of tolerance thicknesses.

One obvious method would be to take a measurement at a point before any ablator (pre-spray) is applied and then again after it is applied (post-spray). Subtracting the two measurements will thus give the thickness of the deposited layer. The pre-spray measurement(s) could be taken completely before the process is started. This would in a sense create a topological map of the bare surface of the substrate. Following this, the ablator is applied during which time post-spray measurements are taken at positions that are coincident with those taken pre-spray. Thereby, thickness measurements are made. This technique would require only one sensor, but the process of taking the pre-spray measurements could significantly lengthen the process.

Another approach would be to mount two sensors to the robot and take all measurements while spraying. If this method is used, however, sensor placement is critical. The pre-spray measurement should find the distance from the sensor to the substrate (i.e. no ablator yet applied). The post-spray measurement should find the distance from the sensor to the outer surface of the MCC after it has been completely applied. From Figure 3 above, it can be seen which areas that the sensors should be aimed to take correct measurements. The pre-spray measurement should fall into the area defined by zero coverage, while the post-spray should fall into the area of full coverage. A pre-spray value will have to be "remembered" for several revolutions before a coincident post-spray value is taken and a thickness calculation made.

In order to accomplish either one of the previously described techniques, a sensor must be obtained which will measure the distance from its mounted position on the robot end-effector to the nearest surface crossing its line of sight. There are many types of transducers that will perform this function of which ultrasonic and laser were considered. This was done not so much as to prove the transducer performance, but to investigate the approach to finding the thickness.

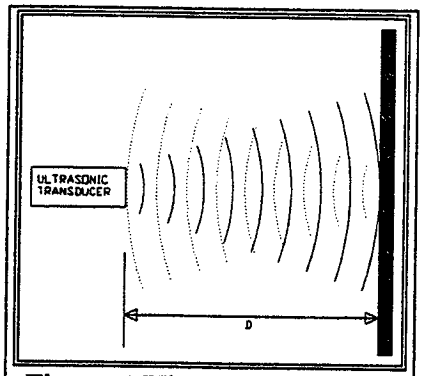

Figure 4 Ultrasonic Ranging

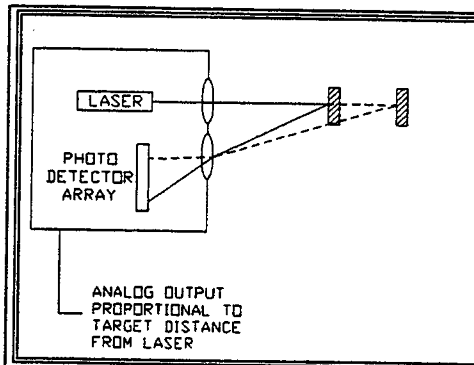

Figure 5 Laser Ranging

These two transducing methods are shown schematically in Figures 4 and 5. With ultrasonic ranging, sound wave fanout acts as both a help and a hindrance. It helps by averaging out the surface roughness. The disadvantage is that it may miss smaller flaws and undulations of the surface. On the other hand, the laser ranging method takes a measurement at a point. This gives the advantage of finding small flaws, but requires that several readings be taken and averaged to get a good measurement (because of the surface roughness of MCC). Another problem with the laser approach is that of keeping the laser optics clean. This could probably be taken care by using some type of air purge system.

Both of the previously described approaches seem feasible if using some sort of pre- and post-spray measurement, but ideally the best method would be to use a single system that could take a direct thickness measurement. In order to do this, the location of the substrate surface must be found by somehow "seeing through" the MCC. The outer surface of the MCC can easily be found by using either ultrasonic or laser ranging. One way to locate the substrate through the MCC would be to use an eddy current (EC) sensor. An EC sensor will find the surface of the nearest electrically conductive material.

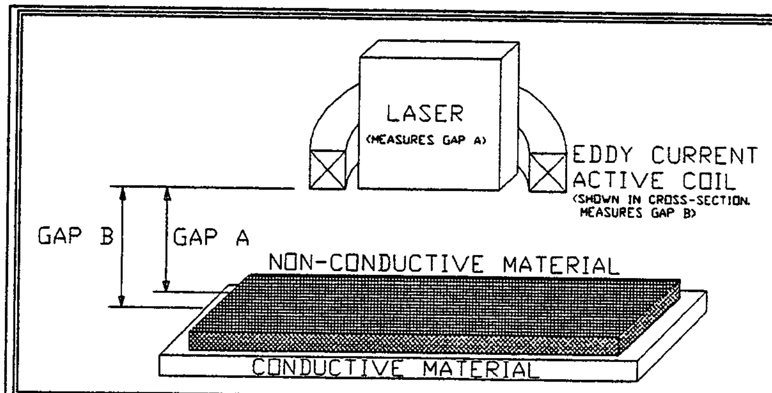

Figure 6 Combined EC/Laser Thickness Sensing

Used in combination with a laser sensor, a system such as that shown in Figure 6 could be used. The EC sensor would measure Gap B (distance to substrate surface) and the laser would measure Gap A (distance to MCC surface). The difference between the two measurements would give the MCC thickness. The down side to this approach is that caused by the maximum standoff distance of the EC sensor. They typically have ranges of 0.1 inch for small diameter sensors to 1.5 inches for those with larger diameters. This could be a problem since the MCC spray gun operates with a stand off distance of 8 inches.

EXPERIMENTAL RESULTS

Both the pre/post spray and the combined EC/Laser techniques were tested by acquiring temporary equipment loans from sensor manufacturers. Two Senix Ultra-S ultrasonic transducers were used for the pre/post spray technique, and a Kaman CTS 8500 EC/Laser system was also tested. Both systems were tested for accuracy and sensitivity to possible alignment errors (i.e. not being perfectly normal to the surface being measured). Figure 7 shows a the output resulting from a linear scan of an MCC test panel. It can be noted from this diagram that even though the distance from the substrate changes (i.e. the robot is not maintaining the standoff distance) that a correct measurement is still obtained.

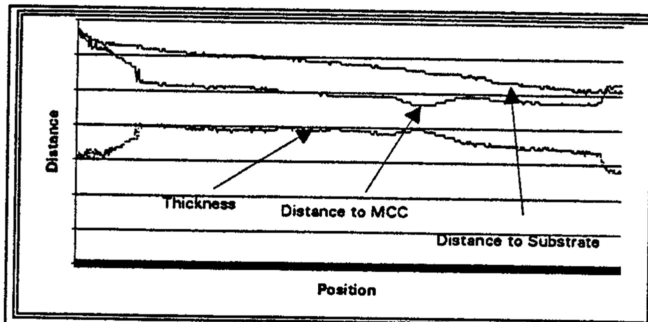

Figure 7 EC/Laser Scan, normal to surface

CONCLUSIONS

The pre/post measurement technique is feasible, but requires time-shifting the data by keeping track of pre-spray measurements for approximately revolutions. These types of measurements were successfully made by both ultrasonic and laser systems with the required accuracy. However, the required mounting for this type of measurement makes the system sensitive to variations from the surface normal.

The EC/Laser system allowed direct measurement of MCC thickness with exceptional accuracy; however, the maximum standoff distance was approximately 1 inch. EC calibration was also somewhat difficult, but should only be required once at installation. The laser optics may need to be protected from airborne particles through the use of an air purge. The approach is must less sensitive to variations from the surface normal.

RECOMMENDATIONS

1. Pursue testing of the EC/Laser system in actual use.

2. Investigate ways to eliminate the problem caused by standoff distance allowed by the EC sensor. This may be done by increasing the EC's active coil diameter, mounting the EC on a retracting mechanism, or by using a different "MCC penetrating" sensing technique (possibly microwave ranging).

3. Investigate the possibility of using only a post spray measurement. Since the hardware being sprayed is of a specified geometry, the robot should be able to hold a fixed distance from the surface while it is spraying. Hence, a pre-spray measurement can be assumed. It should be noted that axial and radial runout can cause errors using this approach.