# Study on Quality Control in the Bonding Processing of Space Solar Cell

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**Abstract**

Solar cell is widely used as space power. The characteristic of anti-irradiation is one of the important differences between ordinary solar cell and space solar cell. In order to ensure space solar cell to work reliably under space environment, it is necessary to bond the anti-irradiation cover-glass to space solar cell active surface through a kind of adhesive, and it is vital to have a reasonable coating thickness. Combining robotics and adhesive-coating technology, the paper gives an automatic bonding system for space solar cell, which can precisely control the coating thickness and realize bonding automation in non-vacuum condition. Moreover, on the basis of the theory about non-Newtonian fluid, the paper presents the model for this system and deduces the formula for coating thickness of space solar cell. Experiments have been performed to validate this model.

**Key words: space solar cell; quality Control; robot; non-Newtonian fluid.**

## 1 Introduction

Space solar cell array is the important part of most spacecraft, and its manufacturing process directly has much to do with the reliability and cost of spacecraft [1-6]. To minimize the permanent electrical degradation and to insure the desirable lifetime, the solar cell has to be protected against the intense damaging ionizing extra-terrestrial environment. The main damaging agents in this case are protons, electrons, and to a lesser extend, gamma-rays and neutrons. The irradiation damage protection consists of bonding to the solar cell active surface a glass slide cover [7-8]. The bonding of anti-irradiation cover-glass is an important point in the manufacturing process of space solar cell array. Silk Screen is by far the most widely used in coating with adhesive. To ensure no air bubble in coating to be visible to the unaided eye, the bonding is usually realized in vacuum. But with development of the third-generation-space solar cell, it becomes the trend that cover-glass and solar cell become more and more thin in order to reduce the cost of corresponding design and launch. So it is more and more important to have precise control on coating thickness for space solar cell. By the means of Silk Screen, the coating thickness can not be controlled very well in this way, and bonding in vacuum requires stricter environment. So, it is necessary to research and develop another automatic bonding system for space solar cell.

Considering that the method by which the desired amount of fluid in syringe is coated to the workpiece has been widely employed in various types of packaging processes in electronics manufacturing [9], and that Cartesian coordinates robot can achieve enough position precision and it is simpler than other robots, we exploit Cartesian coordinates robot as the platform for syringe full of fluid to realize automatic coating for space solar cell. The system mainly consists of robot platform, coating device, bonding device, orientation plate and control subsystem. Robot platform provides the foundation for automatic bonding and it is responsible for three-axis motion. Coating device and bonding device are the executing parts and they are responsible for adhesive flowing and cover-glass-sucking. By means of adjustable leaning mechanism, bonding device can ensure no air bubble in coating to be visible by the unaided eye. Orientation plate provides the precise location where space solar cell and cover-glass are placed. Control subsystem dominates the motion of robot platform and the on-off of coating device and bonding device.

The structure of this paper is as follows: part 2 introduces the fundamental structure of one kind of automatic bonding system for space solar cell which can precisely control the coating thickness and realize bonding automation in non-vacuum condition; part 3 presents the model for coating thickness of space solar cell according to the theory about non-Newtonian fluid; part 4 compares the simulation based on the model to the result from experiment; part 5 is the conclusion of this paper.

## 2 Fundamental structure of automatic bonding system for space solar cell

The system mainly consists of five parts: robot platform, coating device, bonding device, orientation plate and control subsystem.

1) Robot platform

The platform adopts three-axis Cartesian coordinates robot which can meet the needs of position precision. The executing mechanisms of coating device and bonding device are installed on the axis that moves up and down. Thus, the robot, with the executing mechanisms, can realize different motion at different speed according to requirements.

2) Coating device

The device mainly includes executing mechanism (namely syringe), some pneumatic components such as electromagnetic valve, pressure valve and so on. It is responsible for coating space solar cell with some adhesive. In order to improve the efficiency, many syringes are installed in array way. The adhesive viscosity determines the inner diameter of the syringe needle.

3) Bonding device

The device mainly consists of executing mechanism, some pneumatic components such as electromagnetic valve, pressure valve, etc. It is in charge of bonding to space solar cell active surface the anti-irradiation cover-glass. The executing mechanism includes suction plate, leaning mechanism and cylinder. The suction plate is installed on the cylinder through the leaning mechanism. The cylinder is fixed on the axis of the robot, which moves up and down, and its task is to realize the height difference about position of suction plate and syringe. By adjusting the leaning mechanism, the angle between the surface of the suction plate and the horizontal surface varies from zero to some tiny degrees. The reasonable degree will be obtained by experiments. Thus, while bonding in non-vacuum condition, the cover-glass sucked by suction plate will contact the coated solar cell by one edge at first. Once the suction disappears, the cover-glass will gradually contact the coated solar cell from one edge to the whole face due to the surface tension of adhesive. So, air will be driven out and no air bubble will exist in coating of space solar cell.

4) Orientation plate

The plate is oriented on the robot platform and provides the location where space solar cells and cover-glasses are placed. Many grooves are made on the plate to realize the orientation of space solar cell and cover-glass. The number of orientation grooves for space solar cell is the same as that of syringes. So is the number of orientation grooves for cover-glass.

5) Control subsystem

The control subsystem is responsible for the motion control of robot platform and the on-off control of coating device and bonding device.

**3 Modeling for coating thickness of space solar cell**

In order to have precise control on coating thickness for space solar cell, the model of coating process should be established. Fig.1 is a model resembling the syringe part of coating. The balance of forces transferred by friction (viscosity) to the fluid layer and that of forces caused by the pressure gradients in the syringe determine the movement of the fluid. Since the radius of the tube segment of the syringe $R_t$ is far larger than that of the needle segment of the syringe $R_n$ and very little amount of fluid flows in the coating process, the main motion part of fluid is concentrated on the needle segment of the syringe.

To describe the flow in the needle segment, the cylindrical coordinates are adopted, ($r, \theta, z$), of which the origin is at the axis of the needle, r is oriented along the radius of the needle, and z is along the direction of the flow, which is symmetrical with regard to $\theta$.

Generally, the velocity field of the fluid is described as the following forms:

$$u_r = u_r(r,z,t) \quad u_z = u_z(r,z,t) \quad u_\theta = 0$$

Thus, the equation of continuity can be described to

$$\frac{\partial \rho}{\partial t} + \frac{1}{r}\frac{\partial(\rho u_r r)}{\partial r} + \frac{\partial(\rho u_z)}{\partial z} = 0 \tag{1}$$

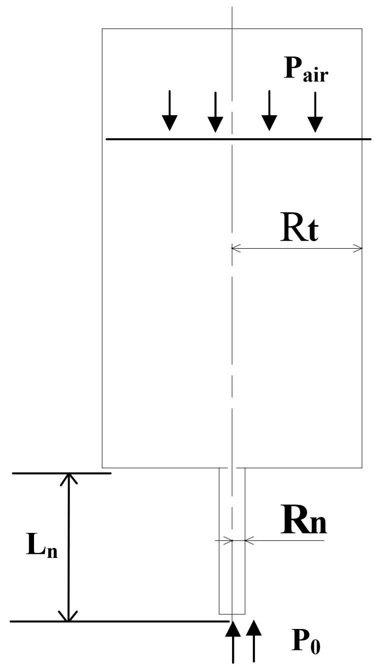


Fig. 1 Diagram of the syringe part of coating

And the equations of momentum can be described as [2]

$$\rho\left(\frac{\partial u_r}{\partial t} + u_r\frac{\partial u_r}{\partial r} + u_z\frac{\partial u_r}{\partial z}\right) = -\frac{\partial p}{\partial r} + \frac{\partial \tau_{rr}}{\partial r} + \frac{\partial \tau_{rz}}{\partial z} + \frac{\tau_{rr} - \tau_{\theta\theta}}{r} \tag{2}$$

$$\rho\left(\frac{\partial u_z}{\partial t} + u_r\frac{\partial u_z}{\partial r} + u_z\frac{\partial u_z}{\partial z}\right) = -\frac{\partial p}{\partial z} + \frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rz}) + \frac{\partial \tau_{zz}}{\partial z} + F_z \tag{3}$$

where $\rho$ is the fluid density, p is the thermal pressure, $\tau$ is the partial stress component, $F_z$ is the gravitation.

The boundary condition of the flow is defined to

$$u_r\,|_{r=R_n} = 0 \quad u_z\,|_{r=R_n} = 0$$

For the purpose of the analysis, the following assumptions are made: the adhesive is incompressible, which indicates that $\rho$ is a constant; the flow is steady, laminar, isothermal and axis symmetrical; gravitational effect, motion in radial direction and non-linear convective acceleration terms are negligible.

Then the velocity field could be simplified as

$$u_z = u_z(r) \quad u_r = u_\theta = 0 .$$

The equation of continuity (1) is satisfied automatically, the equation of momentum (2) is ignored and the equation (3) is simplified to

$$\frac{\partial p}{\partial z} = \frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rz}) \tag{4}$$

For p is a function of z only, by integration, (4) becomes

$$\tau_{rz} = \frac{r}{2}\frac{dp}{dz} + C' \tag{5}$$

The non-Newtonian characteristics of the adhesive can be best described by the Power Law Model, a constitute equation proposed by Ostwald and Waele [3]

$$\tau_{rz} = m\left|\frac{\partial u_z}{\partial r}\right|^{n-1}\frac{\partial u_z}{\partial r} \tag{6}$$

where m is the consistency, n is the power law index.

Combine (5) and (6), then integrate it, using the boundary condition $u_z \mid_{r=R_n} = 0$, we can obtain that

$$u_z = \frac{n}{n+1}\left(\frac{1}{2m}\frac{dp}{dz}\right)^{\frac{1}{n}}(R_n^{\frac{n+1}{n}} - r^{\frac{n+1}{n}}) \tag{7}$$

Thus, according to the following formula

$$Q = \iint_S u_z dS = \int_0^{R_n} u_z \cdot 2\pi r \cdot dr \tag{8}$$

where Q is the flow rate, take formula (7) into formula (8) and then we can obtain that

$$Q = \pi\left(\frac{1}{2m}\frac{dp}{dz}\right)^{\frac{1}{n}}\frac{n}{1+3n}R_n^{\frac{1+3n}{n}} \tag{9}$$

Since $dp/dz$ is constant, (9) can be written as

$$Q = \pi\left(\frac{1}{2m}\frac{\Delta P}{L_n}\right)^{\frac{1}{n}}\frac{n}{1+3n}R_n^{\frac{1+3n}{n}}$$

where $L_n$ is the length of the needle, $\triangle P=P_L-P_0$, $P_L$ is the applied pressure and $P_0$ is the atmospheric pressure.

With the robot, every needle moves on the corresponding solar cell in a zigzag, see Fig. 2. So, the length of the coating track is

$$L_t = (\frac{w-2\delta_2}{s}+1)(l-2\delta_1) + \frac{w-2\delta_2}{s}s \tag{10}$$

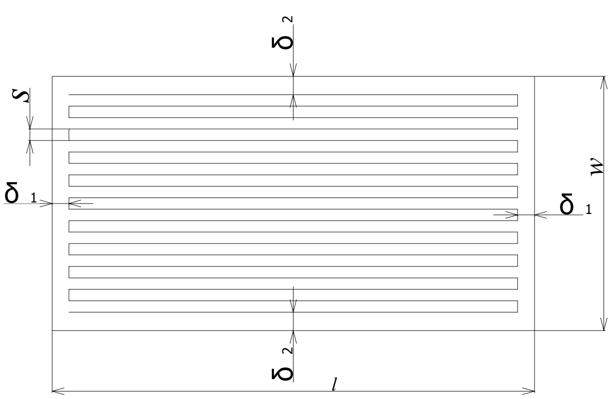


Fig. 2 Diagram of coating tracks

where $L_t$ is the length of the coating track, *l* and w are respectively the length and the width of space solar cell, s is the interval between two tracks, $\delta_1$ and $\delta_2$ are respectively the margin in the direction of *l* and w. Let

$$k = \frac{(w-2\delta_2)}{s}+1, \tag{11}$$

then

$$L_t = k(l-2\delta_1)+(k-1)s = kl - 2k\delta_1 + ks - s \tag{12}$$

Hence, the coating thickness is as followings

$$h = \frac{QL_t}{lwv_n} \tag{13}$$

where $v_n$ is the motion speed of the needle, namely the motion speed of the robot.

Take formula (12) into formula (13), so

$$h = \frac{\pi\left(\frac{1}{2m}\frac{\Delta P}{L_n}\right)^{\frac{1}{n}}\frac{n}{1+3n}R_n^{\frac{1+3n}{n}}\left(kl - 2k\delta_1 + ks - s\right)}{lwv_n} \tag{14}$$

where k is the times of needle motion in the direction of *l*.

## 4 Simulation and experiment

The experimental setup is shown as Fig. 3. The following experimental parameter is used: the pressure produced by air pump is reduced to 0.4MPa via pressure valve; the length of the needle is 20mm; the length and the width of space solar cell are respectively 40mm and 20mm; the interval between two tracks is 0.9mm; the margin in the direction of length and width of space solar cell are respectively 1.4mm and 1.45mm; the motion speed of the robot, namely the motion speed of the needle is 2.8mm/s.

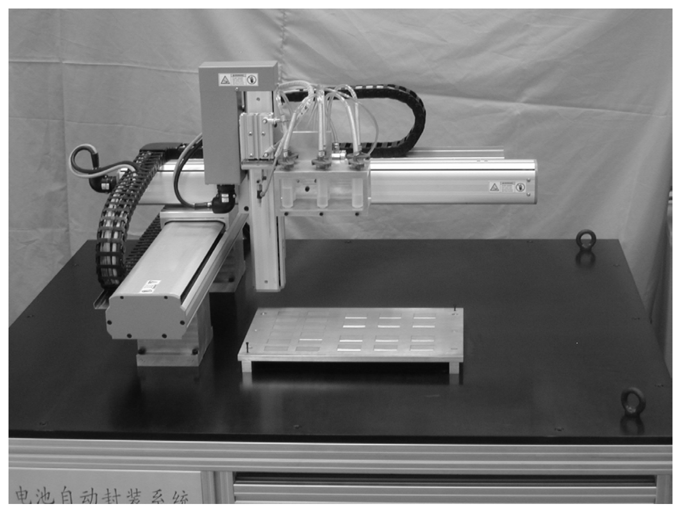

Fig. 3 Experimental system setup

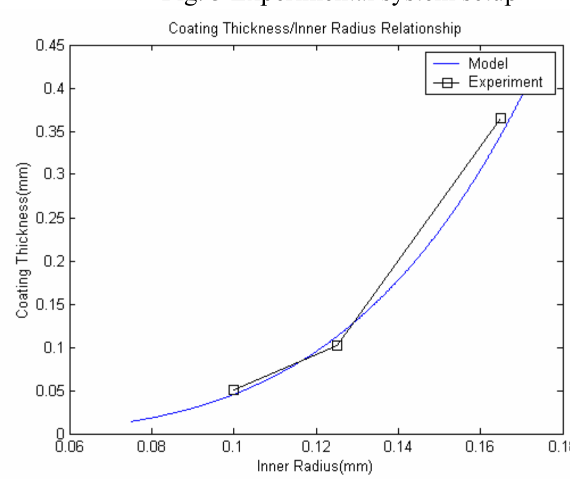


Fig. 4 Comparison of simulation and experiment results under different needles

The first experiment is to compare the model prediction under the conditions of needles with various inner diameters. Fig. 4 shows the comparison of simulation and experiment results under different needles.

The second experiment is to compare the model prediction under different kinds of adhesive. The comparison of simulation and experiment results is shown as Fig. 5.

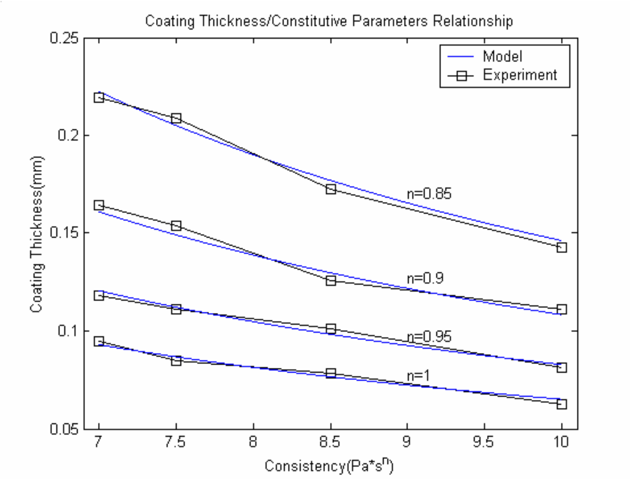


Fig. 5 Comparison of simulation and experiment results under different kinds of adhesive

## 5 Conclusions

From what has been discussed above, the mathematical model for coating thickness of space solar cell is in close agreement with the experiments. So, according to the model, we can have a precise control of the coating thickness by the automatic bonding system for space solar cell. In addition, the system can realize air-bubble-free bonding in non-vacuum condition by means of using leaning mechanism. Owing to its characteristics such as the simple structure, convenient control, low cost, the exploitation of the kind of bonding system has broad prospects.

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## Biography

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