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Auto-bonding robot for space solar cells

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SUMMARY

An auto-bonding robot (ABR) that consists of the mechanism of adhesive dispensing and auto-bonding, a pneumatic system and a control system, is presented in this paper. It is designed for the bonding operation of cover-glasses and space solar cells using adhesives. An adhesive dispensing method is proposed to control the thickness and position of the adhesive layer on solar cells and to provide a satisfactory bonding accuracy. The bubble-free bonding process is realized by the leaning mechanism of a pneumatic sucker. Experimental comparison of the manual and automatic bonding methods showed that there are no fragment and air bubbles between the cover-glass and the space solar cell, and no outflow adhesive on the surface by the automatic bonding process in a non-vacuum condition. The novel automatic bonding robot greatly improved the lightweight space solar cells bonding quality and production rate.

KEYWORDS: Auto-bonding Robot (ABR); Space solar cell; Dispensing adhesive; Pneumatic system.

1. INTRODUCTION

At present, almost all launched aircrafts around the world employ space solar cell arrays (SSCA) as a power source.[1–9] Because the spacecrafts work in the outer space, the surroundings are very harsh. Radiation levels are up to 13–17 times higher than that on the surface of the globe, the temperature varies greatly and the atmosphere is full of high-energy particles. To assure high reliability of the SSCA in this harsh environment, the process of the solar cell assembly, especially the bonding operation using a cover-glass to protect the solar cell, is an essential step in production.[1,3,10–13]

Due to advantages of its physical properties, one bonding technique for space solar cells is adhesive bonding under non-vacuum conditions.[14,15] The process of adhesive bonding can be described as follows: first, the adhesive is dispensed on the solar cell, then the cover-glass is placed on the solar cell. After that, the adhesive is heated and hardened. Finally, it is tested. The requirements of the treated products are given as follows:

(i) The adhesive layer should be even, and its thickness never to exceed the range of 0.1 mm.
(ii) The bonding rim dislocation should be confined within 0.3 mm.
(iii) During the bonding process, the size and quantity of air bubbles between the cover-glass and solar cell should be strictly controlled.
(iv) The adhesive is not permitted to outflow and stain the cover-glass and solar cell.

Owing to the high costs of space launches, it is the aim to produce lightweight solar cells. Third-generation SSCA's cover-glasses and solar cells become thinner and thinner (cover-glass < 0.08 mm, solar cell < 0.15 mm).[13–14] Inherently, this trend also brings about some difficulties to the operation of adhesive dispensing and bonding. Silk Screen Printing is by far the most widely used in coating with adhesives. If we still manipulate it by means of Silk Screen Printing, it will result in less suitable products and lower production rate. Additionally, some adhesives even do harm to workers' health. To solve these problems, we developed a robot, which realizes the auto-dispensing and auto-bonding operation.

Section 2 describes the general system of the automatic bonding robot. Next, a method of dispensing adhesive is proposed. In Section 4 the adhesive dispensing and auto-bonding mechanism is designed. The configuration of the control system is described in Section 5. Section 6 presents experimental results showing the advantages of automatic bonding methods. Finally, conclusions for our work are given.

2. THE AUTO-BONDING ROBOT (ABR) SYSTEM

Our robot (Fig. 1) consists of the mechanism for adhesive dispensing and auto-bonding, a pneumatic system and a control system. The mechanism of adhesive dispensing and auto-bonding is installed on the Z-axis of the XYZ three DOF auto-moving mechanism. To realize high quality bonds, a reasonable track of adhesive on the surface of the solar cell is needed. To achieve high positioning precision, an adhesive dispensing mechanism is constructed. We adopt the auto-dispensing method through a combination of pneumatic technology with robotics, which can promote high efficiency and precision. After dispensing the adhesive on the solar cell,

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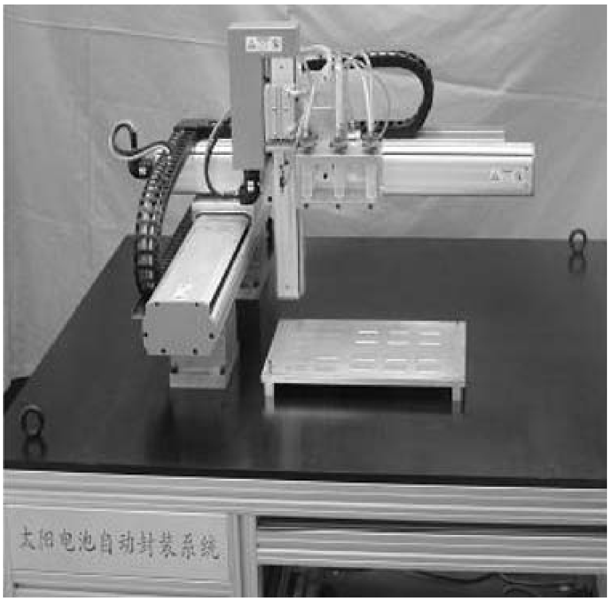

Fig. 1. A photograph of the Automatic Bonding Robot.

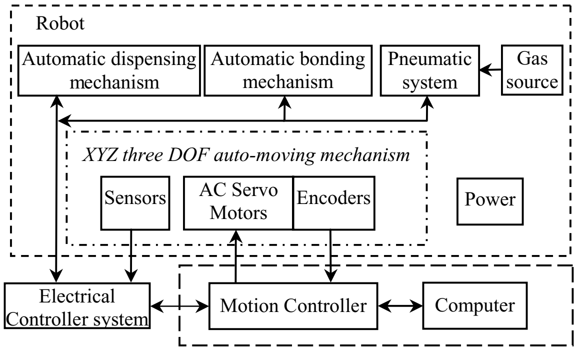

Fig. 2. Block diagram of the Automatic Bonding Robotic system.

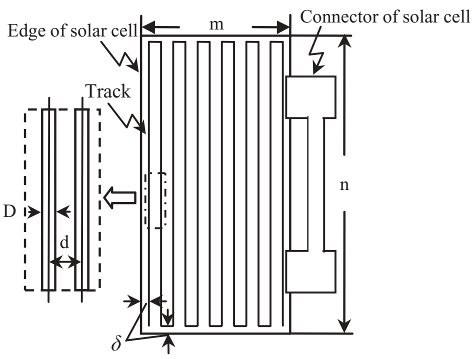

Fig. 3. The track of adhesive dispensing on the surface of the solar cell.

a pneumatic cylinder and a sucker are used to bond the cover-glass and the solar cell together. The block diagram of the Automatic Bonding Robot is illustrated in Fig. 2.

3. METHOD OF ADHESIVE DISPENSING ON SOLAR CELL

Fig. 3 shows the parameters of the solar cell and the adhesive track, such as the length n, the width m, the clearance between tracks d, the diameter of needle D, and the rim δ. In order to satisfy the requirement of the thickness of adhesive layer on the solar cell, we propose a method of dispensing adhesive on solar cell, and analyze the relation between these parameters and the thickness of adhesive layer.

Suppose that the Automatic Bonding Robot (ABR) controls the syringe needle to run back and forth X times at the speed of v_1; the length of track left by a syringe should be:

$$L = X(n - 2\delta + d) - d \tag{1}$$

where $X = [(m-2\delta)/d] + 1$, [.] denotes the result off calculation. Then, it will take the XYZ three DOF auto-moving mechanism $t = L/v_1$ to finish one continuously dispensing cycle. Assume that the adhesive discharging speed $v_2(t)$ is a time-varied function, then during the time t, the approximate volume of adhesive is:

$$V_1 = \pi \left(\frac{D}{2}\right)^2 \cdot \int_0^{L/v_1} v_2(t)\, dt \tag{2}$$

Suppose that the solar cell has a flat surface and the adhesive is well dispensed, the volume of adhesive should be:

$$V_2 = (m - 2\delta + d)(n - 2\delta + d)h \tag{3}$$

where, h denotes the average thickness of adhesive layer. If the $v_2(t)$ is a constant, according to the assumption that the whole volume of adhesive dispensed remains constant, namely $V_1 = V_2$, the thickness should be:

$$h = \frac{\pi D^2(([(m - 2\delta)/d] + 1)(n - 2\delta + d) - d)v_2}{4(m - 2\delta + d)(n - 2\delta + d)v_1} \tag{4}$$

To ensure an uninterrupted adhesive line, the moving speed of Z-axis mechanism v_1 with the adhesive discharging speed v_2 has to be adjusted. If the adhesive dispensing mechanism moves at a low speed, the thickness h will increase. To avoid an adhesive outflow, the rim δ and the clearance d must be increased. The optimization of parameters should be determined by simulation and experiments. For a solar cell size of $m = 40$ mm, $n = 20$ mm and assuming $v_1 = v_2$, the simulation result is shown in Fig. 4.

Fig. 4 shows that the thickness of adhesive layer can be controlled within 0.1 mm when the path clearance d and the needle diameter D are in a reasonable range. Therefore, the method of adhesive dispensing satisfies the thickness requirement of the adhesive layer on the suitable space solar cells. Based on formula (4), if the needle diameter D is 0.25 mm, the relation between thickness h and path clearance d is listed in Table I. We can realize the control of the adhesive layer thickness by synchronizing the speed of adhesive dispensing mechanisms' movement (v_1) and the velocity of adhesive discharging from the syringe needle (v_2) with a reasonable diameter D (see Fig. 3).

Table I. Relation between the thickness h and the path clearance d.

Path clearance d (mm)	0.5	0.6	0.7	0.8	0.9	1.0
Thickness h (mm)	0.098	0.080	0.069	0.060	0.055	0.049

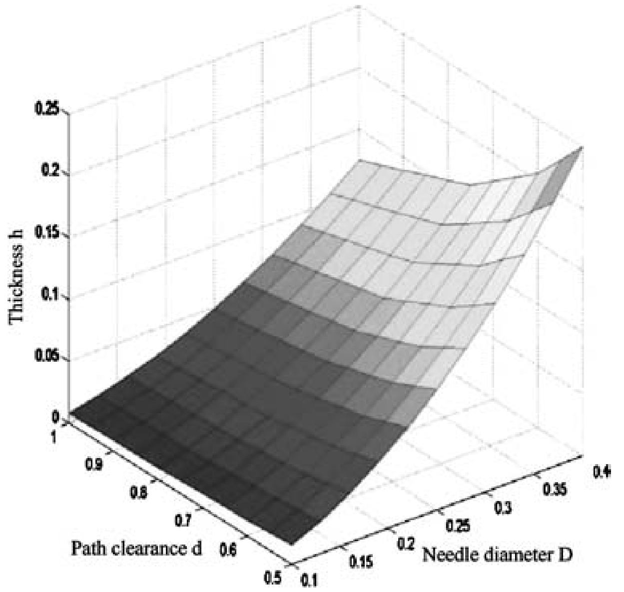

Fig. 4. The relation of the thickness of the adhesive layer, the path clearance and the needle diameter.

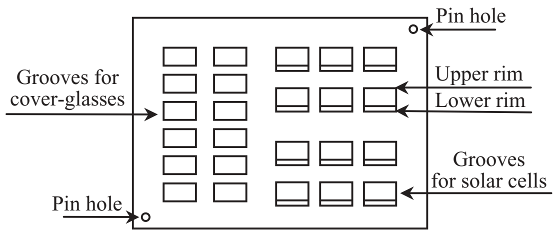

Fig. 5. The orientation plate.

4. THE MECHANISM OF ADHESIVE DISPENSING AND AUTO-BONDING

In order to accurately control the thickness of adhesive layer, a mechanism of dispensing adhesive is designed. To allow a high precision placement of the cover-glass in respect to the solar cell, a mechanism of auto-bonding and an orientation plate are proposed. To simplify the system and reduce position error, the AC servo motor and the ball screw of the XYZ three DOF auto-moving mechanism both adopt a direct linkage style.

4.1. Orientation plate

The Automatic Bonding Robot (ABR) needs to precisely dispense the adhesive in each work cycle before executing the bonding operation. To make sure that the positions of the solar cell and cover-glass are accurate, we designed an orientation plate (Fig. 5).

Before operating, we place the cells and cover-glasses on the plate by tweezers, and then put the plate on the work platform. There are two pins on the table of the robot positioning the orientation plate. Twelve grooves on the left side of the plate are used for placing cover-glasses; correspondingly, there are twelve grooves on the right side arranging solar cells. The lower rim of the groove is deeper than the upper one. We must put the cover-glasses and space solar cells at the upper rim of the grooves. This makes sure that the cell's connectors never turn upward after the cells' placing and keep the whole plane of the solar cell level with the work platform.

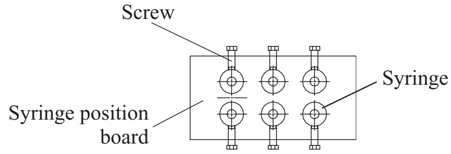

Fig. 6. The fastening plate for fixing and adjusting Syringes.

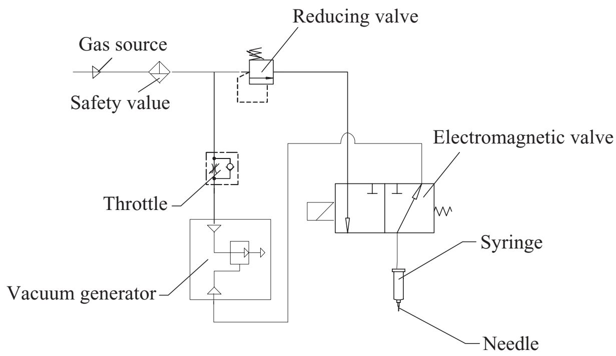

Fig. 7. The pneumatic system for adhesive dispensing.

4.2. Fastening plate for syringes

The mechanism mainly includes the component for fixing and adjusting syringes, some pneumatic parts such as an electromagnetic valve and a vacuum generator. It is responsible for coating space solar cell with the adhesive. To adjust the position of the syringes, we designed a fastening plate for fixing and adjusting syringes (shown in Fig. 6). During the dispensing process, the distance between the needle tip and solar cell has to be consistent. The adjustment procedure consists of the following steps: first, put the empty plate on the platform, then control the robot to keep every syringe above its groove on the orientation plate. Next, lower the height of syringes to make the needles vertically reach the groove. Finally, locate the syringes with the positioning board and tighten the screw. In this way, we can control the robot to maintain a given distance (0.1–0.3 mm) between the needle tips and the grooves on the orientation plate. In order to improve the efficiency, six syringes are installed in an array way. The mechanism can be equipped with up to six syringes each time, so it only needs to work twice to finish dispensing adhesive on twelve solar cells.

The pneumatic parts (Fig. 7) play an important role in the dispensing operation. If the electromagnetic valve is open, the compressed air will discharge from the gas source, pass the safety and the reducing valve. The syringe is compressed, thus the adhesive starts to flow from the needle. At the same time, the XY axes auto-moving mechanism starts to move along the given path (shown in Fig. 3). The computer can control the moving track and the speed of the XYZ three DOF auto-moving mechanism in a given way. At the end of the dispensing process the syringes are moved upwards. Meanwhile, the electromagnetic valve is closed, and the compressed air will go through the throttle to the vacuum

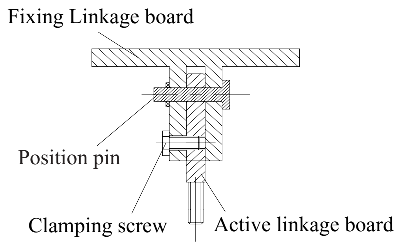

Fig. 8. The leaning mechanism of a sucker.

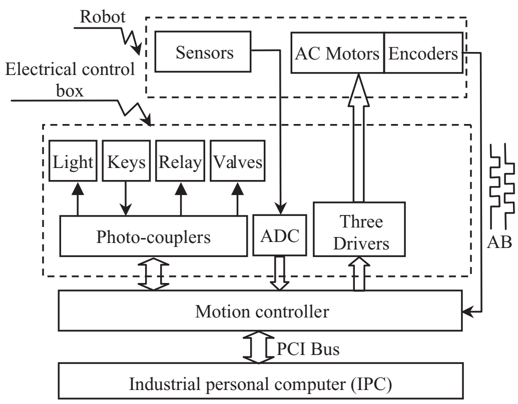

Fig. 9. The configuration of the robotic control system.

generator. The negative pressure is applied to the syringes to avoid the leakage of the adhesive from the needle.

4.3. Mechanism for auto-bonding

When the adhesive is well distributed on the solar cells, the robot begins to bond the cover-glass. The automatic bonding robot is equipped with a cylinder and a sucker. Through the active linkage board of the leaning mechanism the sucker is installed on the cylinder. It is mounted on the slide block of the Z-axis auto-moving mechanism, which moves up and down and realizes the position control of the sucker and syringes (see Fig. 8).

If the bonding angle of the cover-glass is not suitable, it will result in air bubbles. By adjusting two screws and tilting the active linkage board, we can obtain a reasonable small angle between the vacuum sucker and the horizontal plane. Thus, in a non-vacuum condition the cover-glass will contact the surface of solar cell at one edge at first. Once the sucker is switched off, the cover-glass will gradually contact the surface of solar cell from one edge to whole surface due to the gravity and viscosity. As a result, there are no air bubbles between cover-glass and solar cell after bonding.

5. CONTROL SYSTEM

The configuration of the robotic control system is illustrated in Fig. 9.

The system consists of a 32-bit IPC computer with Intel® Pentium® 4 processor and a control box. It is responsible for the motion control of the robot and other I/O controls. The Windows 2000 OS and control software are installed on the IPC. The computer can send signals to the electrical control box through the motion controller. At the same time, the encoders will feedback the position of the motor axes to the motion controller, which performs a close position control. The control software can harmonize the action of pneumatic system with the moving position of the robot according to the different processes, such as dispensing adhesives and bonding.

6. EXPERIMENT

If we adopt a manual-bonding operation, we cannot accurately control neither the volume of adhesive nor the position of bonding. After bonding, the phenomenon of outflow of adhesive frequently takes place, which will contaminate solar cells. Therefore, the wiping operation is imperative in the manual operation. But this procedure will cause the following problems:

(i) The shape of the connector-integrated cell will be changed and even damaged.
(ii) The solar cells or the cover-glasses can be fragmented.
(iii) The quality of wiping process will influence the welding of the connector of the space solar cell.

In addition, the manual-bonding will produce air bubbles in the adhesive layer. The automatic bonding robot can essentially settle these problems. Because this article adopts the method of auto-dispensing and auto-bonding in non-vacuum condition, no outflow occurs, and the adhesive layer will bubble-free. As the wiping is not necessary, there is no danger to fragment the solar cells or the cover-glasses. One person cannot bond more than 200 solar cells by manual operation in eight hours. If we adopt the automatic bonding robot to perform auto-bonding, the efficiency will be greatly increased. When the robot works at a low speed, it will take six minutes to bond six solar cells. If it works eight hours a day, the efficiency of the robotic system is up to 480 slices. The test parameters for one solar cell are given as follows:

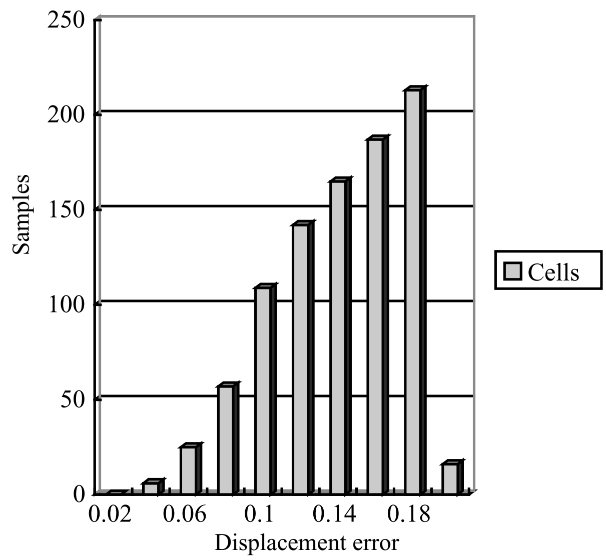

Fig. 10. The experimental result of the manual-bonding method.

Table II. Auto-bonding test parameters for one solar cell.

No.	Test parameters	Values
1	Path clearance d (mm)	0.9
2	Margin δ (mm)	1.45
3	Diameter of Syringe Needle D (Guage)	25
4	Speed for XY axes' movement v_1(mm/s)	1.5
5	Speed for bonding cover-glass (mm/s)	30

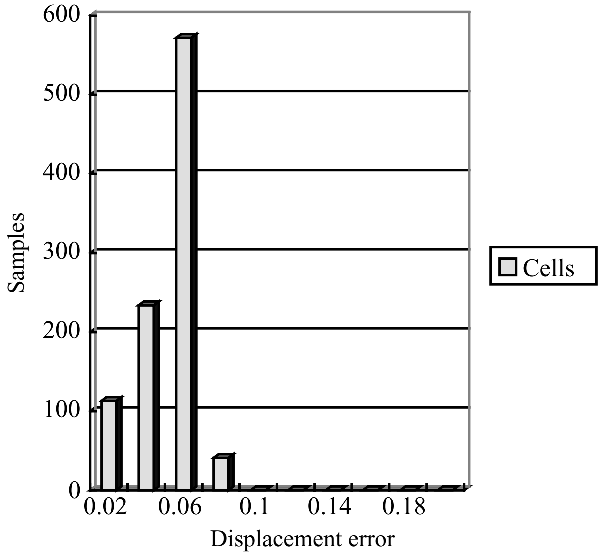

Fig. 11. The experimental result of the auto-bonding method.

If we take 960 solar cells as a sample, the experimental comparison of the manual and automatic methods is demonstrated in Fig. 10 and Fig. 11. From experiments we obtain the result that the fragment rate of manual bonding comes up to 4% and the misplacement will exist in the range of 0.04 to 0.2 mm. Comparatively, the fragment rate of auto-bonding is zero, and the bonding error emerges in the domain of 0 to 0.1 mm.

7. CONCLUSION

The Auto-bonding Robot (ABR) enhances the bonding quality and efficiency of the space solar cell in a non-vacuum condition and shelters workers from the poisonous chemicals. It entirely satisfies the following technical requirements of the space solar cell production:

(i) Bonding efficiency is up to 60 cells per hour;
(ii) The adhesive layer of solar cell is well dispensed, and the thickness is under the control of the ABR and within the range of 0.1 mm;
(iii) There are no air bubbles between the cover-glass and solar cell after bonding;
(iv) The adhesive no longer outflows and stains the cover-glass and solar cell;
(v) The bonding rim dislocation is confined within the range of 0.1 mm.

The space solar cell bonding performed in our project was limited to a special size of solar cell and cover-glass (20 × 40 mm). A progression of the bonding process would be to extend to sizes of the solar cells, ranging from 5 × 5 mm to 100 × 250 mm or more. The automatic bonding technique has potential applications in the subsequent processes of the space solar cell array (SSCA) assembly in future.

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