Development of a New Solder Paste Printer

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ABSTRACT Recent years have seen an explosive dissemination of cellular telephones, personal digital assistants (PDAs) and other types of hand-held information terminals. This has led to increased use of surface mounted components--ball grid arrays (BGAs), chip scale packages (CSPs) and microcomponents like the 0603 chip, which are difficult to inspect or repair once they have been mounted, and this in turn means greater demand for solder paste printers that offer greater accuracy and higher speed. Accordingly the authors have developed a new type of solder paste printer, offering the same high rigidity and higher alignment accuracy as Furukawa Electric's currently used model, together with a new squeegee unit that offers stable printing irrespective of printing speed and an alignment system capable of simultaneous detection of stencil and board.

1. INTRODUCTION

The performance requirements for the solder paste printers used in the surface mounting of electronic components on printed circuit boards are becoming ever more stringent. This is driven by the increased mounting densities that have accompanied the rapid diffusion of cellular telephones, PDAs, and ultrathin notebook computers. The quad flat package (QFP) will also be replaced more and more by BGAs and CSPs, which are difficult to inspect and repair after mounting, and by chips such as the 1005/0603, so that the need for high alignment accuracy and finer printing pitch becomes even more pressing. In addition, a hard look must be taken at printer throughput to drive down costs through improved productivity. This is because unlike the chip mounting process, which can be divided up among a number of mounter units run in parallel, the printing process is indivisible.

The new type of squeegee unit was developed taking account of the the behavior of solder paste on the stencil during printing in order to reduce the number of parameters that must be monitored during printing while assuring printing performance equal to or better than that of the squeegee unit currently in use. The new unit also achieves higher speed through adoption of an alignment system that gives simultaneous detection of stencil and board. The following paper provides a detailed report.

2. DEVELOPING A NEW SQUEEGEE UNIT

2.1 Mechanism of Solder Paste Printing

In solder paste printing, rolling of the paste occurs when it is removed from the stencil using the squeegee. This results in an increase in the internal pressure of the paste, causing it to fill the apertures in the stencil so that it is transferred to the board by detaching the stencil to accomplish printing.

The distribution of the internal pressure of the paste acting on the stencil may be determined from Equation (1)

$$
\begin{aligned}
p_{\mathrm{squeegee}} &= \int dp_{\mathrm{squeegee}} \\
&= [2\alpha \sin\alpha / (\alpha^2 - \sin^2\alpha)]\eta V(1/r) \\
&= f(\alpha)\eta V(1/r) \qquad (1)
\end{aligned}
$$

where:

r is the distance from the point of contact between the squeegee and the stencil,
α is the squeegee angle,
V is the printing speed, and
η is the solder paste viscosity.

An investigation was then made of relationship in Equation (1) between $f(\alpha)$ as a pressure coefficient affecting the pressure distribution on the stencil surface and squeegee angle α. Figure 1 shows the result. It can be seen that the internal pressure of the paste undergoes a major change in accordance with squeegee angle. To maintain constant internal pressure in the paste for stable printing it is necessary to control not only squeegee angle but also printing speed and the physical properties of the solder paste. Figure 2 summarizes the factors giving rise to internal pressure in solder paste.

When solder paste pressure rises in the printing process a force is exerted on the squeegee surface that acts to raise the squeegee unit. This paste reaction force

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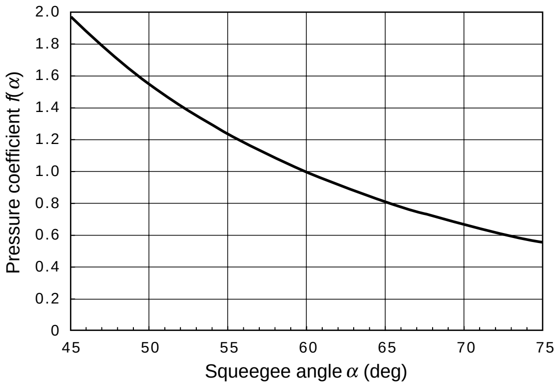


Figure 1 Relationship between squeegee angle α and internal pressure coefficient $f(\alpha)$.

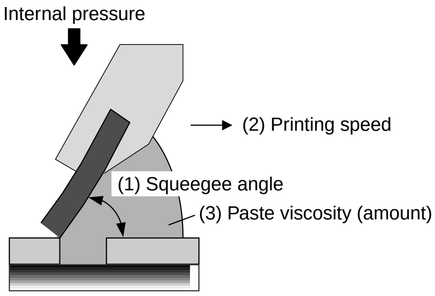


Figure 2 Factors giving rise to internal pressure in solder paste.

F_{lift} may be found by differentiating Equation (1) in the solder paste region as represented by Equation (2)

$$F_{\text{lift}} = \int p_{\text{squeegee}} dr = f(\alpha) f(Q) \eta V \tag{2}$$

where:
Q is the amount of solder paste.

To achieve satisfactory printing it is necessary to wipe the paste on the stencil cleanly away, and with the squeegee currently in use it is necessary to apply printing pressure sufficient to overcome the internal pressure of the solder paste. There is an appropriate value for this printing pressure, which is determined by squeegee angle, printing speed, and the amount and viscosity of the solder paste.

2.2 Problems with the Squeegee Currently in Use

With the squeegee currently in use, the printing pressure is set to the optimum value by a test run prior to the actual printing operation. This not only takes time, but since conditions such as the amount and viscosity of the paste can change as the process goes on, destroying the balance between the internal pressure of the paste and the printing pressure. If printing pressure is either too high or too low, stable printing becomes impossible.

Inadequate printing pressure results in improper wiping of the solder paste leading to improper transfer. Conversely, when printing pressure is excessive, the solder paste will seep to the other surface of the circuit board, causing smudging and bridges. And where stencil apertures are wide, the squeegee may penetrate it, scooping up the solder paste in the apertures so that not enough is available. Furthermore the increase in friction between the stencil and the squeegee will cause the stencil to be shifted in the direction of squeegee movement, with the danger that the printing position may be displaced. In high-speed printing, the printing pressure is particularly high, and problems of excessive pressure occur readily.

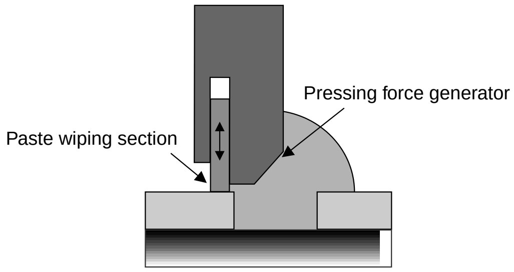
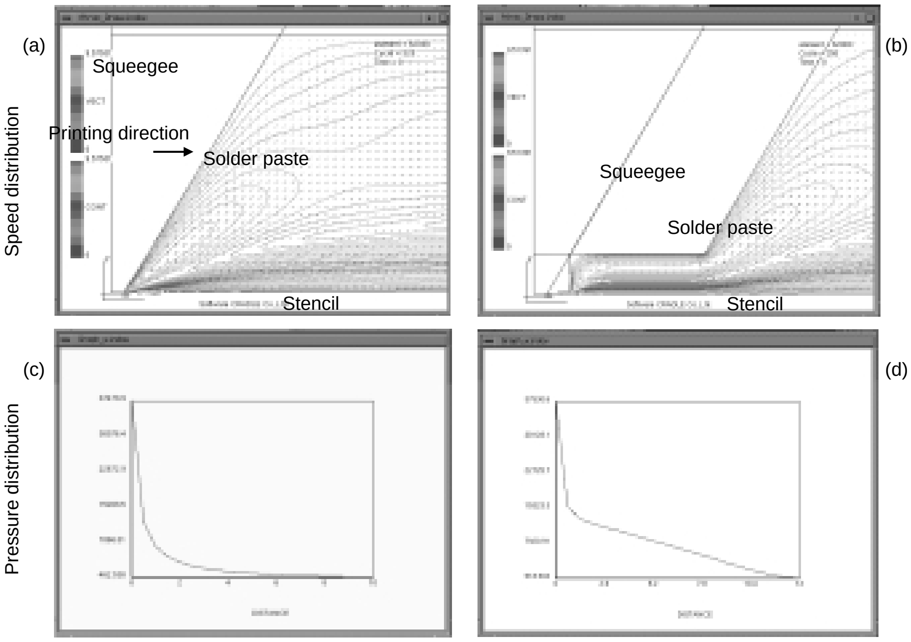


Figure 3 Conceptual diagram of the new-type squeegee.

2.3 Concept of the New-Type Squeegee Unit

Although printing pressure is not something that has a direct effect on printing performance, stable printing cannot be obtained with the squeegee currently being used without extremely thorough monitoring. The authors therefore proposed to develop a new type of squeegee unit that would maintain printing performance equal to or better than the current type, while eliminating the concept of printing pressure. In the new unit, rolling of the solder paste is retained, while the inclined section that applies the pressing force (solder paste internal pressure) within one unit is separated from the section for the wiping of the solder paste. Figure 3 shows a conceptual diagram.

The wiping section was designed so that it would be difficult for the counterforce from the solder paste to be exerted during printing. To achieve a structure in which the internal pressure in the solder paste would produce rolling and be no less than in the squeegee currently in use, finite element analysis was carried out. Figure 4(a) is a speed distribution diagram representing the results of an analysis of solder paste behavior during printing with the current squeegee; the angle formed by squeegee and stencil was 60°, printing speed was 10 mm/s, and solder paste viscosity was 200 Pa•s. Figure 4(b) is an analogous diagram showing speed distribution during printing with the new squeegee; the values for inclined portion angle, printing speed and solder paste viscosity are similar to those for the current model. In both cases flowing of the solder paste can be observed on the stencil and squeegee surfaces, allowing the mechanism of rolling to be known. Figure 4(c) and (d) show the internal pressure distribution of the solder paste for the current and new-type squeegees respectively. It will be seen that in both cases maximum pressure is exhibited at the point of intersection between squeegee and stencil, and that the pressure diminishes in accordance with the distance from the point of intersection.



Current squeegee New-type squeegee

Figure 4 Simulated speed and pressure distributions in currently used and new-type squeegees.

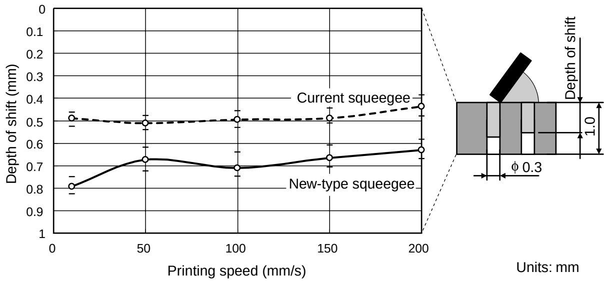


Figure 5 Measurements of effect of depth of shift and internal paste pressure.

To confirm the above results, printing was done at various printing speeds using metal circuit boards 1-mm thick in which through-holes 0.3 mm in diameter had been formed, and the depth of solder paste transfer was investigated. A comparison was then made of the internal pressure of the solder paste using the current and new-type squeegees. Figure 5 shows the results.

It will be seen that at all printing speeds the new-type squeegee gave greater depth of transfer than the currently used type, thereby confirming that the new squeegee structure shown in Figure 3 provides ample solder paste internal pressure.

Since in the new-type squeegee the wiping section is perpendicular to the stencil surface, the force shown in Equation (2) is not exerted on the wiping section, so that resetting of printing pressure at changing model is not required, irrespective of printing speed or solder paste viscosity. That is to say printing can be carried out at low printing pressure, independent of printing speed. Figure 6 shows the results of an investigation of the printing pressure required to remove solder paste cleanly from the stencil at various printing speeds.

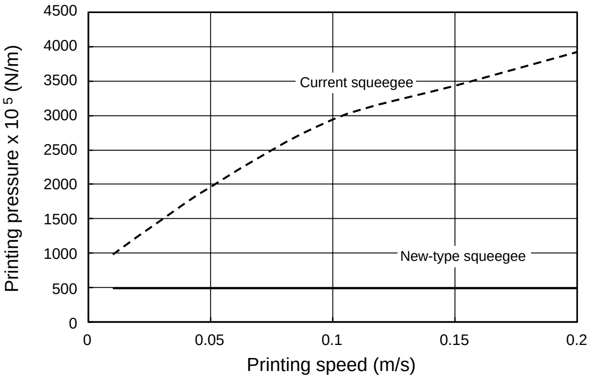
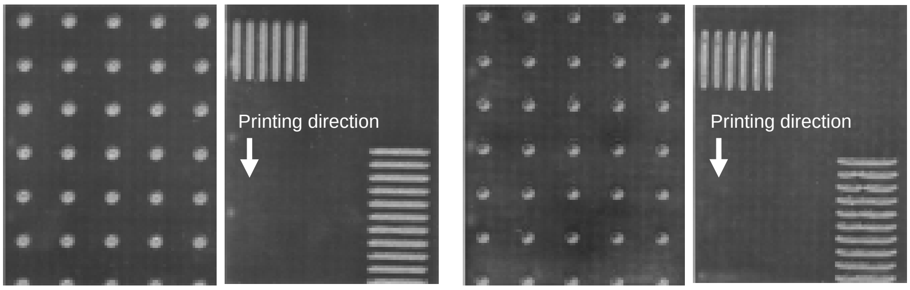


Figure 6 Relationship between printing speed and printing pressure.

With the squeegee currently in use greater printing pressure is required as printing speed increases, whereas it can be seen that with the new-type squeegee the solder paste can be wiped from the stencil at a low level of printing pressure that is independent of printing speed. Accordingly even if the internal pressure of the solder paste is reduced due to changes in the properties or amount of the solder paste, the problems of excessive printing pressure associated with the squeegee now in use are eliminated, and stable printing is possible.

2.4 Print Characteristics of the New-Type Squeegee

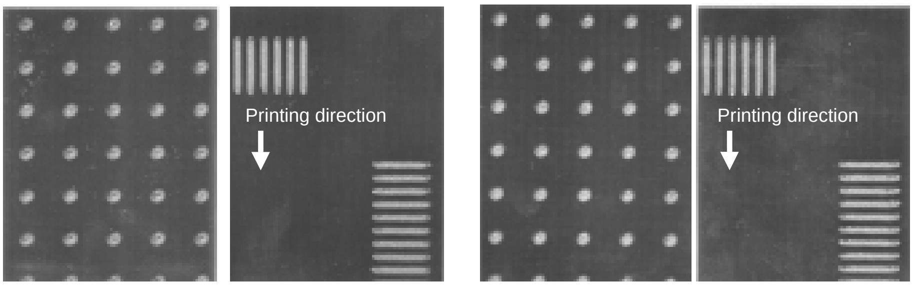
To check the print characteristics of the new-type squeegee both low- and high-speed tests were carried out and comparisons made with the type currently in use. The stencil design used consisted of two patterns: apertures 0.3 mm in diameter in addition to a QFP pattern with a



0.3 mm diameter
0.3-mm pitch; aperture width 0.15 mm
0.3 mm diameter
0.3-mm pitch; aperture width 0.15 mm

a) Printing speed: 50 mm/s
b) Printing speed: 200 mm/s

Photo 1 Results printed with currently used squeegee.



0.3 mm diameter
0.3-mm pitch; aperture width 0.15 mm
0.3 mm diameter
0.3-mm pitch; aperture width 0.15 mm

a) Printing speed: 50 mm/s
b) Printing speed: 200 mm/s

Photo 2 Results printed using new-type squeegee.

lead pitch of 0.3 mm and an aperture width of 0.15 mm. Printing speeds were 50 and 200 mm/s. Printing pressure was set prior to beginning the print run for the currently used squeegee only. Results are shown in Photos 1 and 2.

With the currently used squeegee, printing failures occurred at the 200 mm/s speed with the pad perpendicular to the printing direction, whereas the new-type squeegee printed at lower printing pressure, producing satisfactory conditions irrespective of direction at both 50 and 200 mm/s.

Thus it was possible to realize a new-type squeegee that provided print characteristics equal to or better than those of the currently used type, without the pre-setting of printing pressure that was heretofore needed to obtain stable printing.

3. FUNCTIONS AND FEATURES OF NEW TYPE FPX-46A PRINTER

The newly developed printer, to be known as the FPX-46A is shown in Photo 3. It has the following functions and characteristics.

3.1 Basic Specifications

Photo 3 FPX-46A solder paste printer.

Table 1 shows the basic specifications of the FPX-46A solder paste printer. It is capable of handling large circuit boards measuring up to 510 mm in the length or transport direction and 460 mm in the width or transverse direction. Both the transport direction and transport reference can be freely selected at manufacture. Printing stencils can measure up to 800 mm in the transport direction and 750 mm transverse.

3.2 Reduced Cycle Times

To achieve more rapid cycling a change was made in the method for aligning the positions of the print stencil and the circuit board, from the currently used two-camera system consisting of a movable stencil camera unit mounted

Table 1 Basic specifications of the FPX-46A printer.

Depth	1600 mm
Height	1625 mm
Weight (approx.)	1400 kg
Line accommodation	Freely accommodates to transport direction
Processing stand	
Printing stencil	Center-registered (max. 800(l) x 750 (w) mm)
Max. dimensions	510(L)x750(W) mm
Min. dimensions	50(L)x50(W) mm
Thickness	0.5-3.0 mm (below 1.0 mm by option)
Printing method	Contact printing with stencil detaching speed control
Printing functions	
Print direction	Perpendicular to direction of circuit board transport
Squeegee control	Bi-directional printing with double squeegee
Squeegee speed	Variable from 5 to 200 mm/s
Cycle time	Approx. 8 s (not including printing time)
Board support	By magnetic pin and insertion pin method (standard)
Power supply	200 V AC, 3-ph, 5 kVA

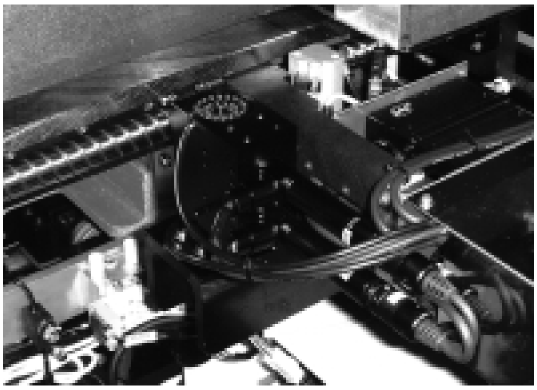


Photo 4 Single camera unit.

on the print table and a fixed circuit board camera unit to system in which an XY camera shaft is mounted between the stencil and the print table so that the stencil camera and circuit board camera are accommodated in a single camera unit (see Photo 4).

Table 2 shows a comparison of the alignment axis specifications of the currently used and new units. In the currently used type the printing table moves in the X and Y directions relative to the circuit board camera, requiring that the travel distance is large. In the new type, on the other hand the only travel is that required for fine adjustments. This eliminates movement of the printing table, which has high inertia, and by moving the lightweight camera unit at high speed making it possible to significantly shortening the cycle when not printing.

As a result it was possible to achieve a non-printing cycle time of some 8 s for the new type, versus 22 s for the type currently in use (see Figure 7).

Table 2 Comparison of alignment axis specifications between new and currently used designs.

Control axis	New	Current
Print table		
X Stroke	±5 mm	540 mm
Resolution	0.49 µm/pulse	0.98 µm/pulse
Max. speed	50 mm/s	533 mm/s
Y Stroke	±5 mm	808 mm
Resolution	0.49 µm/pulse	0.98 µm/pulse
Max. speed	50 mm/s	533 mm/s
θ Stroke deg	±1.0 deg(±5.41 mm)	±1.5 deg(±8.1 mm)
Resolution	2.26x10^{-5} deg/pulse	4.52x10^{-5} deg/pulse
Max. speed	4.8 deg/s	9.6 deg/s
Z Stroke	155 mm	46 mm
Resolution	0.407 µm/pulse	0.098 µm/pulse
Max. speed	222 mm/s	40 mm/s
T Stroke	36 mm±2 mm	34 mm±2 mm
Resolution	0.407 µm/pulse	0.12 µm/pulse
Max. speed	222 mm/s	50 mm/s
Camera T Stroke	540 mm	
Resolution	2.44 µm/pulse	
Max. speed	1000 mm/s	
Camera Y Stroke	850 mm	
Resolution	2.44 µm/pulse	
Max. speed	1000 mm/s	
Cycle time not including printing time (s)	8	22

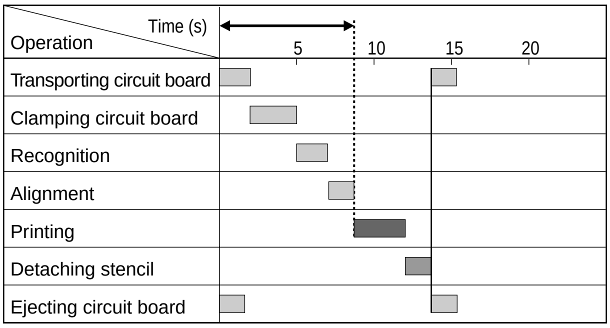


Figure 7 Cycle time.

3.3 High-Accuracy Alignment

The use of a single camera unit makes possible the simultaneous detection of the alignment marks of both the printing stencil and the circuit board. Figure 8 shows the method used.

The stencil camera and the circuit board camera are independent, superimposed on a vertical shaft. Images are transmitted through the respective lenses, and directed by the pentaprism to the CCD cameras. The vertical offset between the two cameras is adjusted automatically during printing by a calibration jig provided at the escape position of the camera unit. This design makes it possible to recognize the stencil and circuit board automatically each time, rendering it unnecessary for test runs to detect and compensate for offset errors.

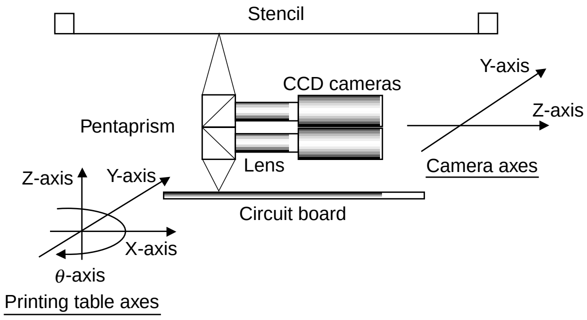


Figure 8 Alignment method using single camera unit.

4. SUMMARY

The new squeegee unit used in the printer developed in this work achieves printing performance equal to or better than that obtained from the currently used squeegee unit, while eliminating the need to set printing pressure. And the use of an alignment system that provides simultaneous detection of stencil and circuit board makes it possible to achieve both increases alignment accuracy and higher speed.

This has made it possible to market a printer offering the high levels of performance envisaged in the original development targets.

5. CONCLUSION

Solder paste printers are of increasing importance in surface mounting technology. The new printer developed in this work may be distinguished from competitors' products in that it accepts LL circuit boards, while providing high-speed printing and, despite its compact dimensions, enables major options to be built-in. It is expected that by identifying target users and conducting a systematic marketing campaign, it will be possible to equal the market share of reflow furnace systems.

ACKNOWLEDGMENTS

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REFERENCE

1) D. E. Riemer; "The theoretical fundamentals of the screen printing process", Hybrid Circuits, No. 18, pp. 8-15, 1989.

Manuscript received on June 21, 2001.