CASE STUDIES IN CONTINUOUS PROCESS IMPROVEMENT

Atul Mehta
Electronic Packaging & Fabrication
Jet Propulsion Laboratory
California Institute of Technology

Summary

This study focuses on improving the SMT assembly process in a low-volume, high-reliability environment with emphasis on fine pitch and BGA packages. Before a process improvement is carried out, it is important to evaluate where the process stands in terms of process capability. That is, process capability should first be benchmarked prior to conducting any process improvements. This capability is determined by initially measuring the process yield. Once the process yield is established, it serves as a base line for process improvement.

Some of the process steps are divided into two substeps:

a) Initial process parameters set up and
b) Improved process parameters set up.

The eight distinct processes discussed in this paper are:

1. Design for manufacturability (DFM)
2. Printed Wiring Board (PWB) quality assessment
3. Component verification
4. Component processing- lead forming, tinning
5. Screen printing
6. Pick-and-Place
7. Reflow
8. Clean

1. Design for manufacturability

A properly designed board improves the yield of printed wiring board assemblies (PWBA) after reflow.

Some guidelines for proper layout are:

- All polarized components should be laid out with polarity facing in the same direction.
- If the PWBA contains through hole components along with top and bottom side SMT components, only small SMT chip parts should be placed on the bottom side.
- Some high-profile components, such as MELF packages, need special attention for pad design. Standard pad size formulae will yield incorrect footprint dimensions.

- As regards to BGAs (Ball Grid Arrays) with 30 mil diameter, a pad size of 25 to 27 mil is desirable.
- Appropriate test pads must be provided for testability.
- For quad flat pack (QFP) packages with lead pitch of 20 mil or less, the stencil apertures in the X direction must have 85% of the area to those in the Y direction. (See Figure 1).

Note: For high-reliability spacecraft assemblies, it was determined that the following operations must be performed in a clean room environment of Class 10,000 or better.

2. PWB quality assessment

Board quality is subdivided into two groups:

- Integrity of the circuit connections.
- Solderability of the PWB.

Integrity of circuit connections

- An open and short tester is used to ensure that the PWB is free of any interconnection related defects.
- The tester should consist of a high-speed probing mechanism and be capable of using CAD data to program probe locations.
- One sample test PWB from the lot will be sufficient to provide information on the board quality.
- The tester needs the capability of printing a defect report indicating what part of the traces may have a problem and, if so, whether it is an open or a short.

Solderability of the PWB

- A solderability tester operating on the principle of Sequential Electro-chemical Reduction Analysis (SERA) is used.
- The single most important factor causing solderability problems on the PWB surface is the formation of various metal oxides.
- The SERA method involves a chemical reduction of metal oxides by applying an electrolyte on the PWB surface and measuring the voltage level to determine the amount and type of oxide build up.
- Figure 2 shows a series of plateaus corresponding to various types of oxides and their potentials.
- Figure 3 shows the same for a test board.

3. Component verification

For the assembly of high-reliability boards, it is important to verify component values for resistors, capacitors, diodes etc. prior to their placement. A defect detected in the early stage is much less expensive. Verification can be accomplished in two ways:

a) Manually checking the value with a meter.
b) Automatically checking the value by a built-in verifier in the pick-and-place machine.

Every time there is a reel change on the machine or a lot change, it is imperative to verify the component value of the first two parts.

4. Component processing

Lead Forming

For a low-volume operation, the component vendor generally does not supply parts with formed leads. Hence, all flat packs, including QFP type packages, undergo a lead forming operation.
Proper forming die must be used so the formed leads will conform to the pad layout design rules. Although a toe fillet is not an absolute requirement for most commercial type applications, generally pad hangover of 10 to 15 roils beyond the lead edge is sufficient to form a properly wetted **solder joint.**

Pre-tinning (Solder Coating)

For high reliability solder joint formation, it is necessary to pre-tin the component (generally an IC) leads, especially leads that have been gold plated. Pre-tinning will make the leads readily solderable by removing surface compounds formed due to oxidation during handling and storage. in the. case of gold plated leads, the gold is dissolved in the molten solder, thus eliminating the possibility of the formation of gold-tin intermetallics that can cause gold embrittlement.
At JPL, automated robotic tinning equipment is used to pre-tin the leads of all IC components. The system consists of two wave-generating solder pots, a wave fluxer, a preheater and an aqueous cleaner. The components are loaded in a matrix tray for pick up by the robotic head.

The cycle is as follows:

a) Pick up component with suction head.
b) Flux the leads by dipping in organic acid flux wave.
c) Blow off excess flux and preheat using hot air at 180° C.
d) Dip leads in solder pot #1.
e) Dip leads in solder pot #2.
f) Clean with hot water at 45° C.
g) Dry with hot air.

The critical parameters to control are:

- Angle between the component, the component leads and solder wave.
- Dwell time in wave.
- Speed with which the component enters and withdraws from the solder wave.

A schematic representation is shown in Figure 4.
The quality of tinning with robotics equipment is far superior compared to parts tinned using manual methods.

5. Screen Printing

Prior to screen printing, boards are cleaned in an aqueous cleaner using DI water and saponified solution followed by a vacuum bake at 100° C for 8 hours. This is done to ensure that any residue on the board during prior operation and handling is removed from the PWB.

Experiment: 1- The following parameters were set for the screen printing process:

Stencil
Thickness: 7 mil thick stainless steel stencil suspended with polyester mesh.
Aperture: 1:1.

Printer
Stencil-to-Board registration - A manual vision camera is used to register the board pattern with that of the stencil. It is important that the board be flat; i.e. warpage should be under 1 %. For boards with fine pitch and BGA parts, flatness is more critical. Many screen printers, including the one used in this experiment, are fitted with a vacuum source to obtain flatness.

Paste
For space flight application projects, type RMA flux is the only qualified one.

Paste specifications:
Alloy: Sn 63 / Pb 3-7
Viscosity: 800 kcps
Mesh: -200 /+325
Metal Content: 90%

Squeegee Specifications:
Type: 90 durometer polyurethane.
Speed: 15 mm per second,
Pressure: 22 psi.

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After stencil printing, using the above parameters, it was observed that the paste deposition was lessthanoptimum. (See Figure 5).

The following problems were observed:

- There was a paste scooping effect on deposition.
- The paste slumped slightly on the pads.
- The paste was either at the edge of or slightly beyond the edge of fine pitch and BGA pads.

In Experiment 2, the following changes were made in the screen printing process:

- Squeegee material was changed from urethane to metal.
- Squeegee pressure was changed from 22 to 16 psi.
- Paste mesh size was changed from -200 / +325 to -325 / +500.
- Paste viscosity was changed from 800 to 1000 kcps.

The board was printed with solder paste and the resulting deposition was uniform. (See Figure 6). Paste volume was measured using a laser-based 3D measurement system. The height variation among BGA pads was within 2 roils. (See Figure 7 and Figure 8).

6. <u>Pick-and-Place</u>

An automatic pick-and-place machine with the following features, was used to assemble the PWBAS:

- Fiducial vision correction.
- Passive component verification without penalty to placement time.
- Component package verification.
- Fine-pitch lead inspection with co-planarity measurements.
- Z axis force sensor.

It was ascertained that the components were placed uniformly over the pads. This is critical for: a) smaller and lighter chip parts where pads are too large compared to the component (see Figure 9), and b) fine pitch QFPs. Component offsets were maintained under 5 mil in each case.

7. <u>Reflow</u>

A vapor phase reflow process was used for soldering the assemblies.

The reflow cycle was as follows:

. Preheat theassembly with static IR heating.
- Reflow in an inert vapor zone.
- Travel to cool down zone in a nitrogen (N_2) atmosphere.
. Intermediate cool down.
. Final cool down.

Table 1 shows the initial parameter settings for the process.

A temperature profiler was used to monitor the profile of the assembly as it passed through the reflow cycle.
Four thermocouples were placed at various locations on the PWBA. Thermocouples under BGAs, were placed under the device by drilling a hole at the center of each device and threading the thermocouple through from the bottom side of the PWB. This provides an accurate profile at the center of BGA which heats the last. As the assembly came out from reflow, it was inspected.

All the parts, except the BGAs, formed good solder joints. The solder joints under the BGAs, when inspected with X-ray, showed voids and slightly cold solder joints. (See figure 10).
It was concluded that the preheat ramp was somewhat shorter in duration whereas the reflow dwell was not long enough.
The parameters were adjusted per Table 2 and a second temperature profile was run. Figure 11 shows profile of the assy.
Upon reflow and inspection, it was revealed that all the solder joints, including those of BGAs, came out properly wetted. (See Figure 12).

8. <u>Clean PWBA</u>

A two-stage cleaning process is used.
Each stage utilizes a microprocessor controlled batch cleaner.

Stage 1

Use semi-aqueous chemistry with the following cycle:

. Four minute nitrogen purge.
. Eight minute wash with a terpene-based solvent to remove gross flux residue.

Stage 2.

Used aqueous chemistry with the following cycle:

. Wash with DI water and 4% saponified solution.
. Each wash cycle was 5 min. followed by 1 min. rinse at 60° C.
. Minimum number of rinses was set at 5 and maximum number at 10.

. Minimum of 0.5 megohm resistivity was achievable with above settings.
. Final rinse with 75% isopropyl alcohol and 25% DI water solution.
. Final resistivity of a minimum of 2 megohm was achievable.

Table 1 Initial Process Parameter Settings

Parameter	Setting ------	Actual
Preheat Temp	310° c	
Preheat Dwell	150 Seconds	
Entry speed in Vapor zone	150 cm per min	
Exit speed from Vapor zone	150 cm per Min	
Re-flow Dwell	45 Seconds	
Preheat Temp Override	150° c	125°C
Re-flow Temp. Override	213° C	212° C

Table 2 Adjusted Process Parameters Settings

Parameter	Setting	Actual
Preheat Temp	340° C	
Preheat Dwell	180 Seconds	
Entry speed in Vapor zone	50 cm per min	
Exit speed from Vapor zone	50 cm per Min	
Re-flow Dwell	60 Seconds	
Preheat Temp Override	150° c	150° c
Re-flow Temp. Override	215° C	214° C

Conclusions

. Proper design of the pads is extremely critical to obtain high-quality PWAS. Oversize pads can cause the components to shift or tombstone during reflow. Large ground planes unevenly placed around component pads can result in a heating delay around the pads and can cause cold solder joint or component tombstoning.

- The paste parameters must be selected carefully. Paste viscosity of lower than 1000 kcps are not suitable for fine pitch and BGA printing as the paste of viscosity less than 1000 kcps tends to slump.

A metal squeegee produces a more uniform print compared to a polyurethane squeegee.

Reduced stencil aperture will diminish the possibility of paste shifting off the pads during the pick-and-place operation. As aresult, formation of solder balls near the edges of the pads will be eliminatedo rat least greatly reduced.

- Proper component centering is crucial when pads are oversized and designed for avoiding component tombstoning.

- During preheating in the IR zone where the PWBA is stationary during 340° C heating, a slower preheat ramp rate of about 0.75° C per second and a preheat temperature produced the best results. Final reflow in the inert vapor zone, with slightly extended dwell, produced high- quality solder joints in BGAs.

- A nitrogen atmosphere during cooling after reflow and during batch cleaning produced tarnish- free, shiny solder joints.

Acknowledgments

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Bibliography:

Charles Hutchins, *Troubleshooting the SMT/FPT Process,* J.I-i. Lau, Ed. Ball Grid Array Technology, New York McGraw-Hill

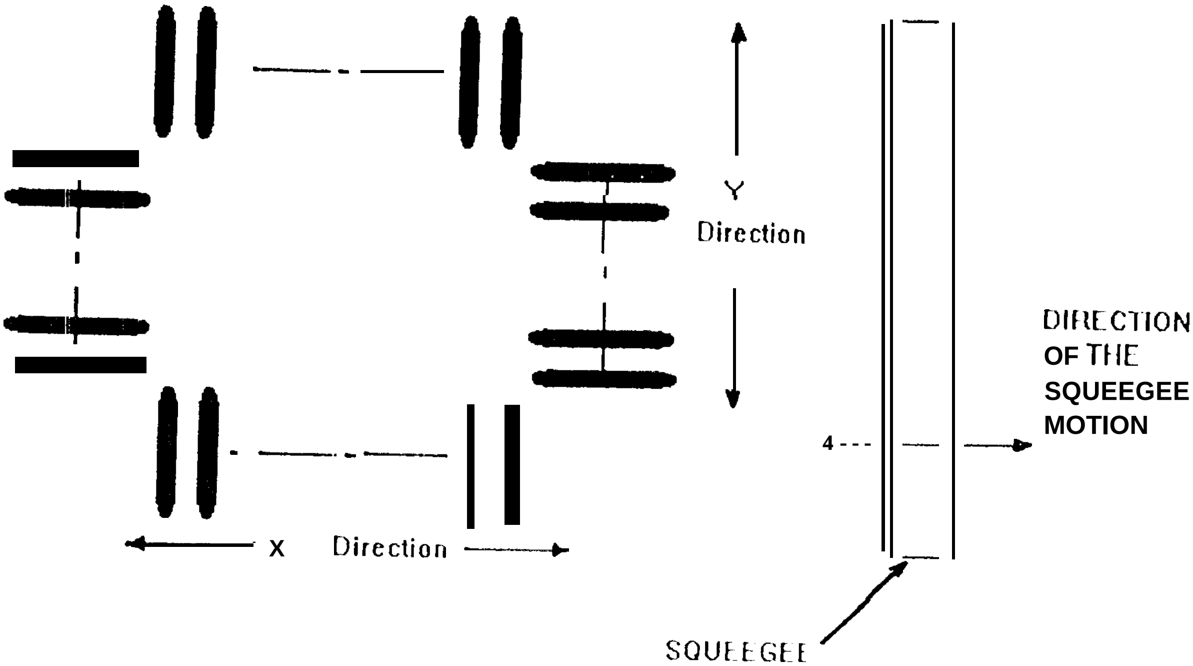

Y
Direction
DIRECTION
OF THE
SQUEEGEE
MOTION
4
X
Direction
SQUEEGEE

Figure 1

SUMMARY OF SERA SIGNALS

VOLTAGE	FEATURE	OXIDE (PROBABLE FORMULA)
-0.35	Flat plateau	Copper (CuO)
-0.5	Flat Plateau	Lead (hydrated PbO)
-0.55 to -0.85	Broad wave/shoulder	Cu-Sn intermetallic
-0.6	Flat plateau	Copper (Cu2O)
-0.6	Flat plateau	Lead (PbO)
-0.85 to -1.0	Flat plateau	Lower tin oxide (Mostly SnO)
-1.0 to -1.3	Plateau	Higher tin oxide (More SnO2)
-1.0 to -1.3	Negative voltage dip	Tin (SnO2 overlayer)

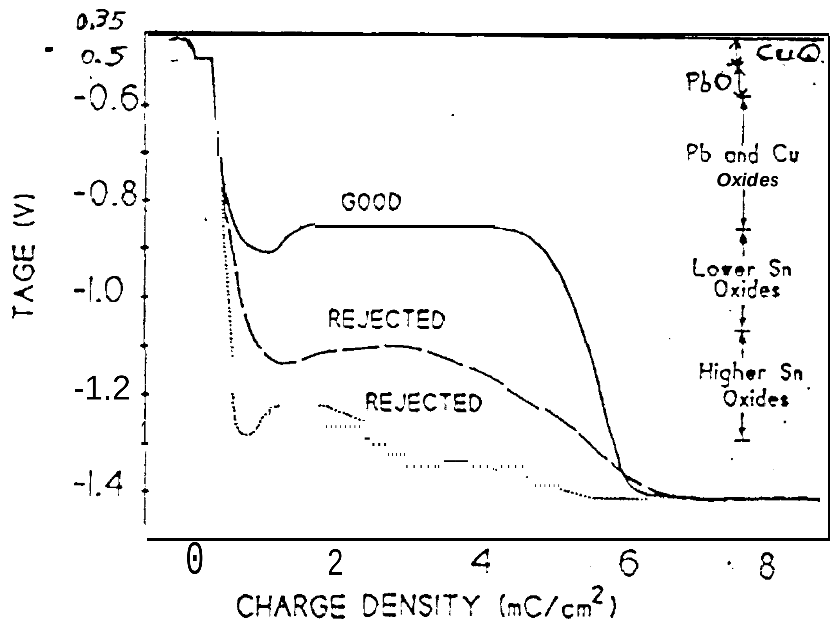
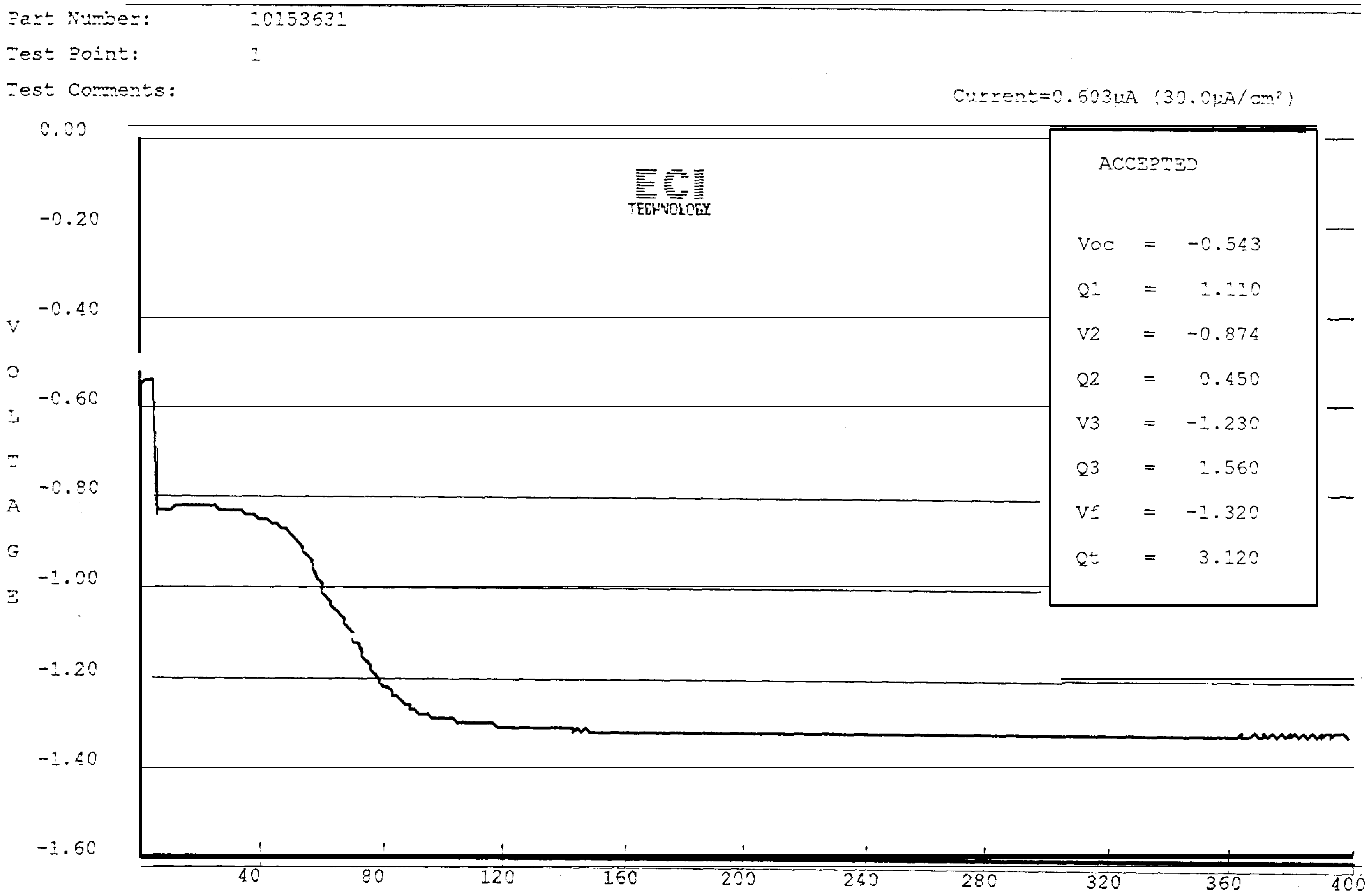


Figure 2



Part Number: 10153631
Test Point: 1
Test Comments:
Current=0.603µA (30.0µA/cm²)
ECI TECHNOLOGY
ACCEPTED
Voc = -0.543
Q1 = 1.110
V2 = -0.874
Q2 = 0.450
V3 = -1.230
Q3 = 1.560
Vf = -1.320
Qt = 3.120
VOLTAGE
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
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-1.40
-1.60
40
80
120
160
200
240
280
320
360
400

Figure 3

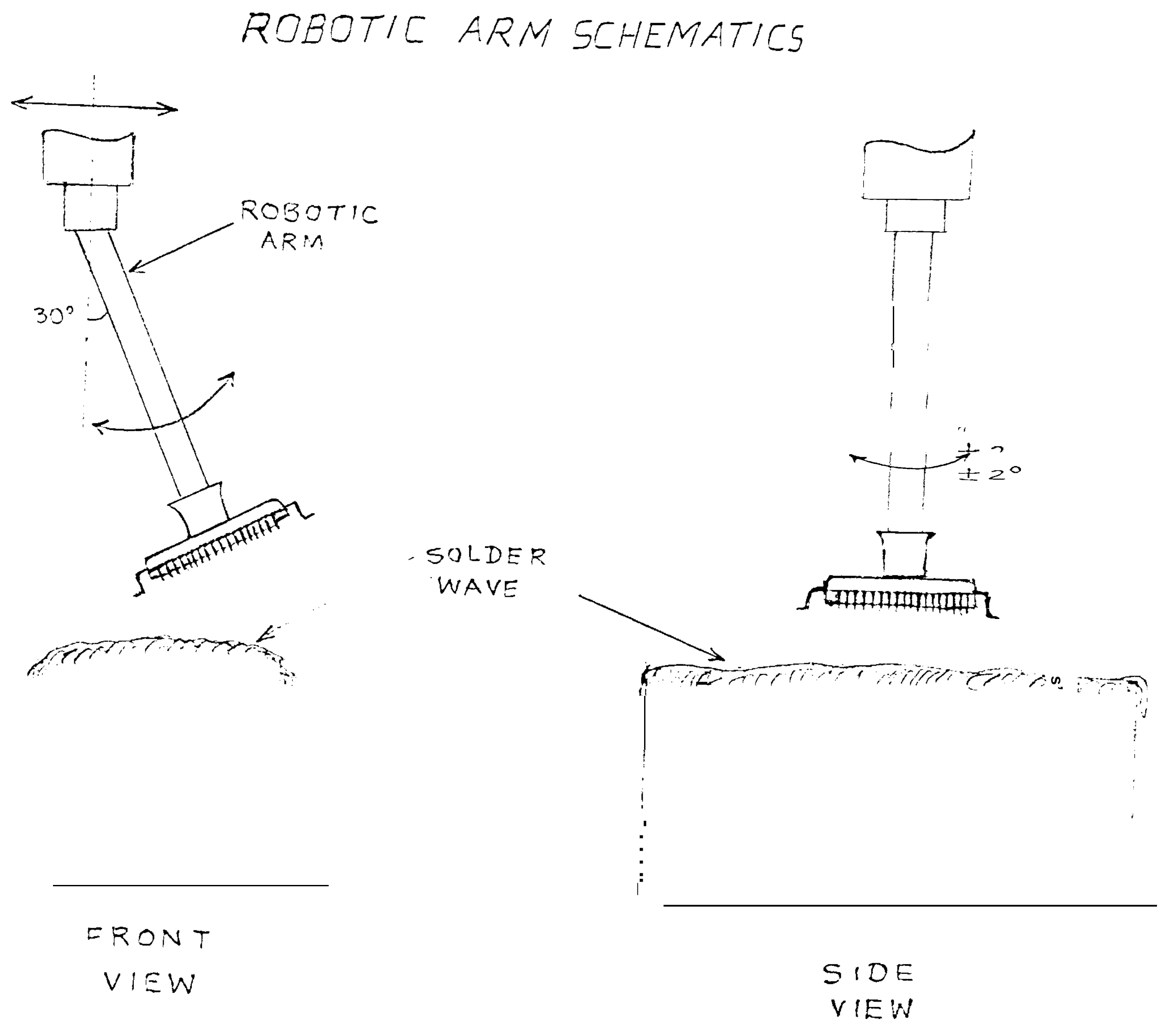

ROBOTIC ARM SCHEMATICS
ROBOTIC ARM
30°
SOLDER WAVE
±2°
FRONT VIEW
SIDE VIEW

Figure 4

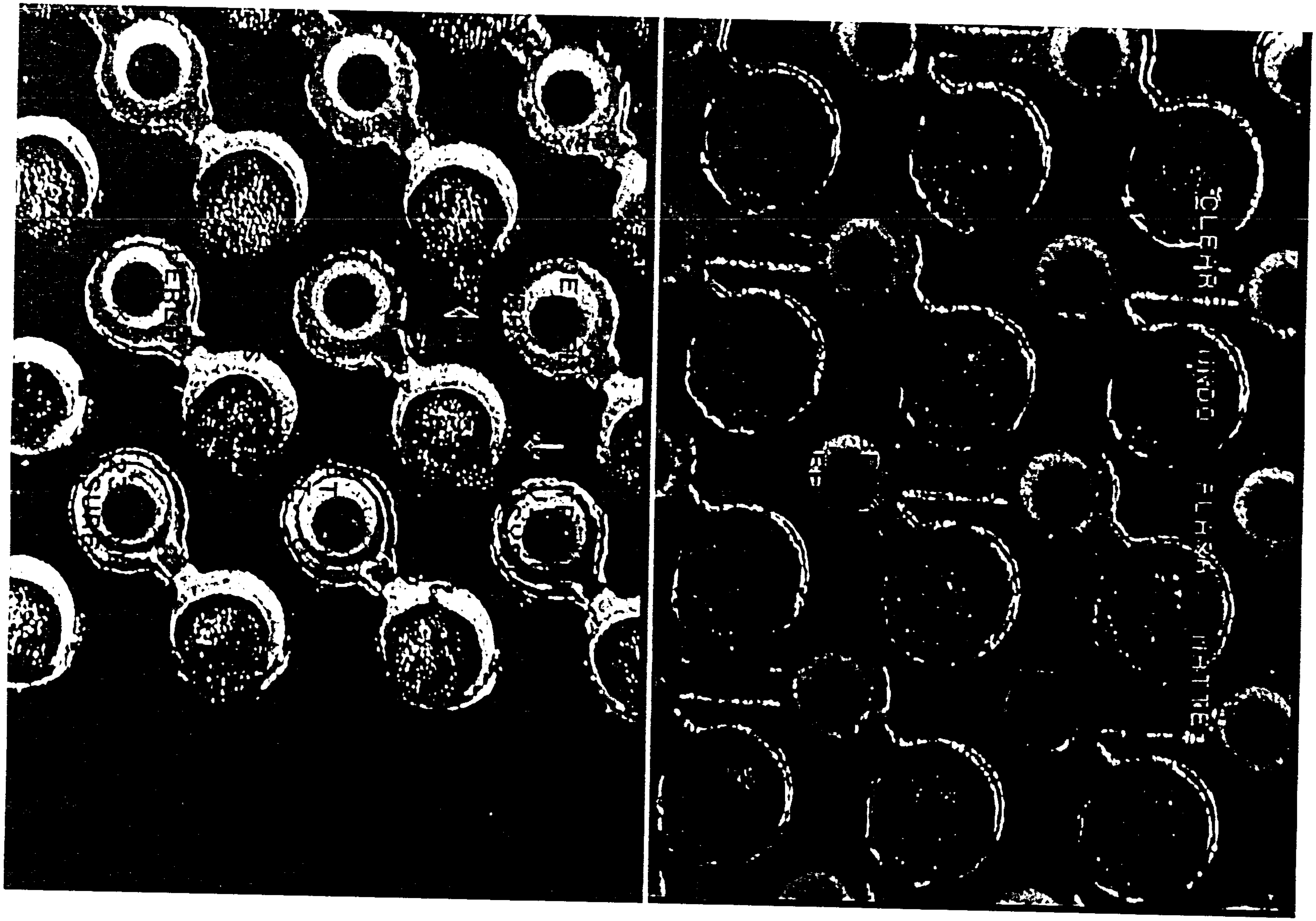


Figure 5

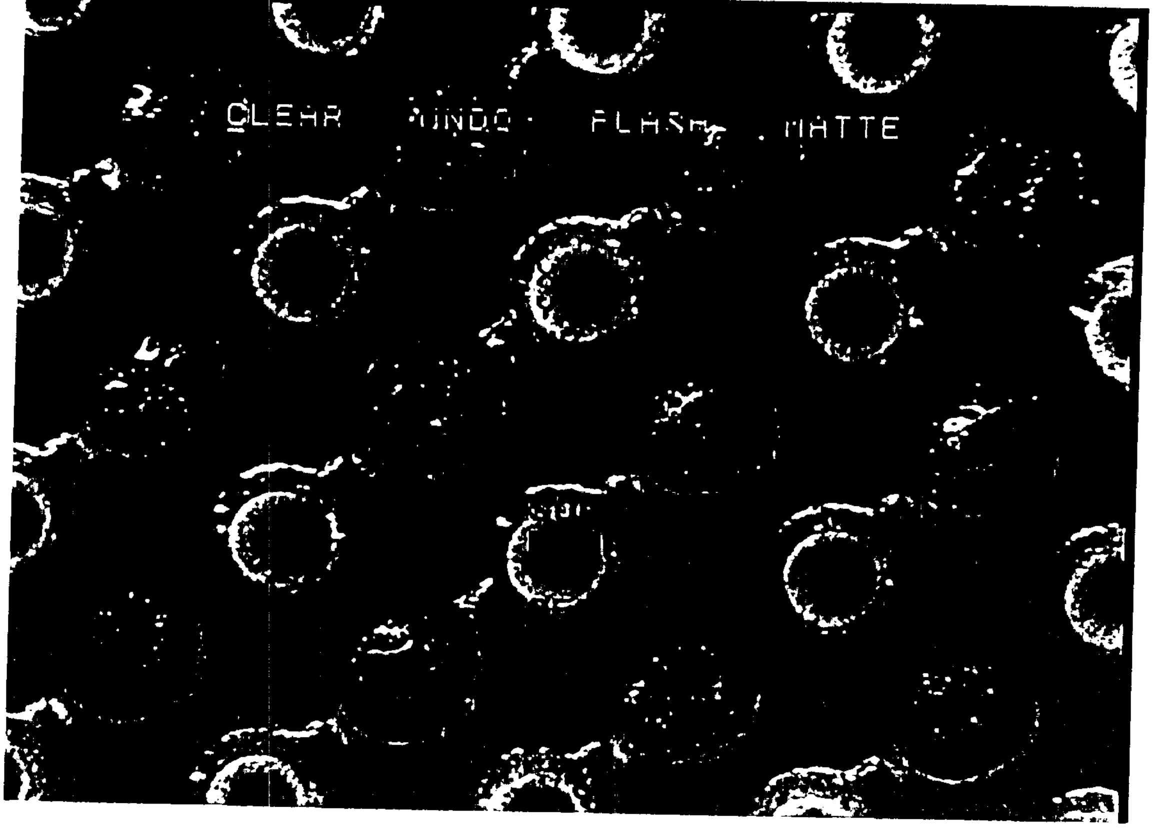


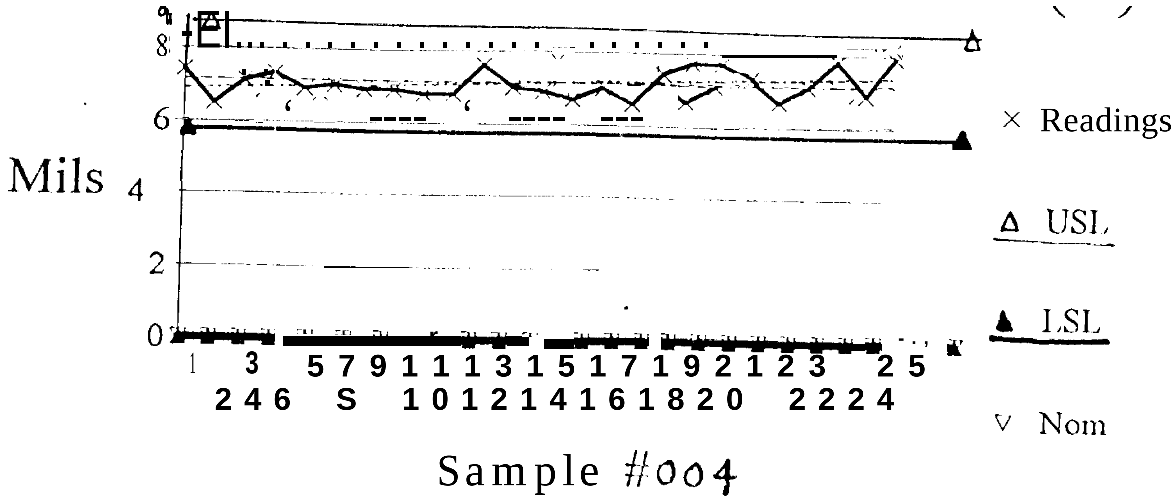
Figure 6

SOLDER, 0.0SO PITCH,.

	Time & Date	VOLUME(W)	VOLUME(H)
1	5/16/96 12:47:14 PM	37.9	7.4
2	5/16/96 12:47:36 PM	37.9	6.5
3	5/16/96 12:47:48 PM	37.9	7.1
4	5/16/96 12:48:02 PM	37.9	7.3
5	5/16/96 12:48:15 PM	37.9	6.9
6	5/16/96 12:48:30 PM	37.9	7
7	5/16/96 12:48:47 PM	37.9	6.9
8	5/16/96 12:48:55 PM	37.9	6.9
9	5/16/96 12:49:08 PM	37.9	6.8
10	5/16/96 12:49:20 PM	37.9	6.S
11	5/16/96 12:49:34 PM	37.9	7.6
12	5/16/96 12:49:45 PM	37.9	7
13	5/16/96 12:50:00 PM	37.9	6.9
14	5/16/96 12:50:20 PM	37.9	6.7
15	5/16/96 12:50:31 PM	37.9	7
16	5/16/96 12:50:47 PM	37.9	6.6
17	5/16/96 12:51:00 PM	37.9	7.4
18	5/16/96 12:51:10 PM	37,9	7.7
19	5/16/96 12:51:19 PM	37.9	7.7
20	5/16/96 12:51:30 PM	37.9	7.3
21	5/16/96 12:51:42 PM	37.9	6.7
22	5/16/96 12:51:55 PM	37.9	7.1
23	5/16/96 12:52:12 PM	37.9	7.8
24	5/16/96 12:52:26 PM	37.9	6.9
25	5/16/96 12:52:43 PM	37.9	7.9

Figure 7

SOLDER 0.050 PITCH VOLUME(H)



SOLDER 0.050 PITCH

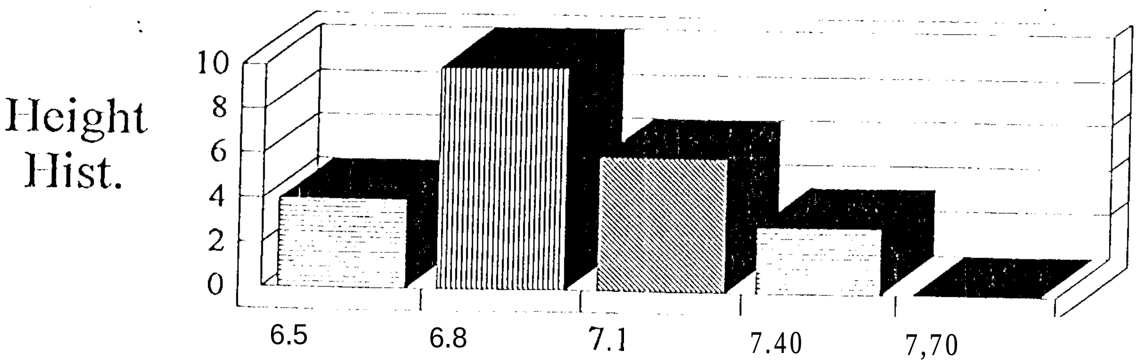


Figure 8

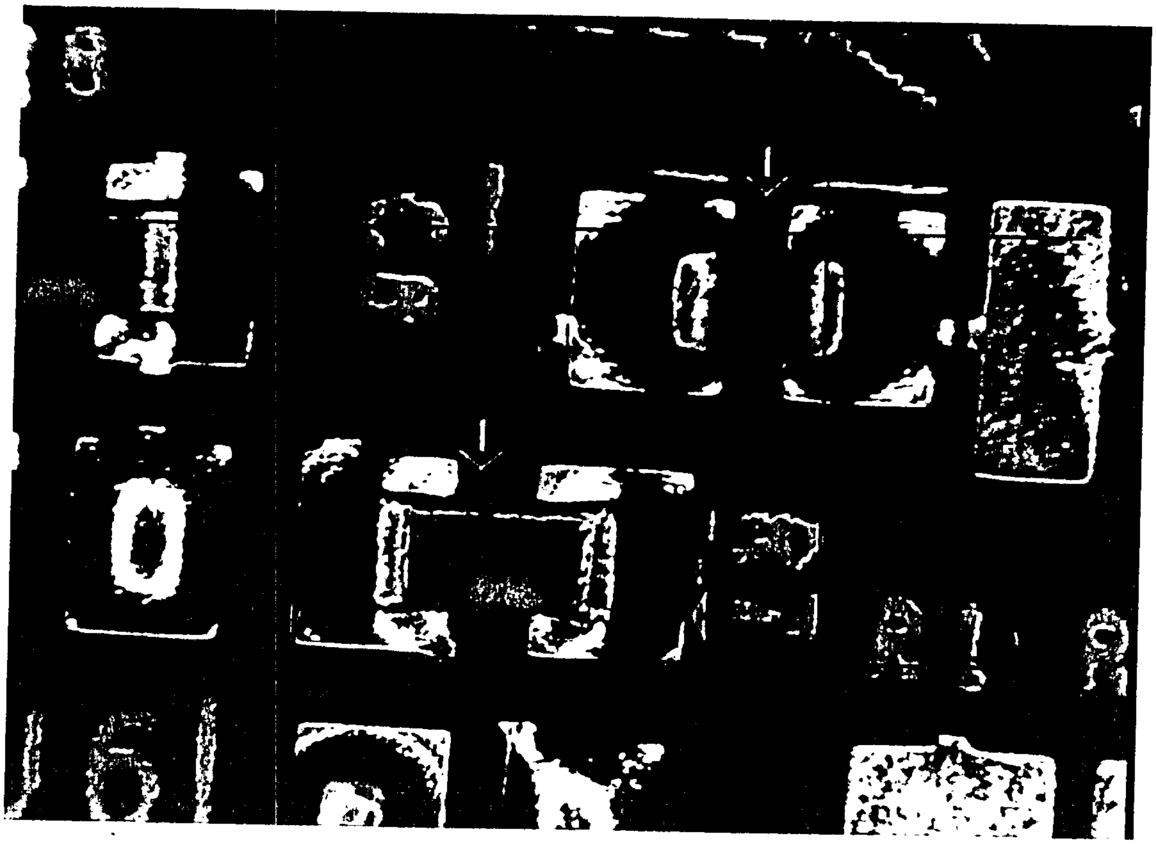


Figure 9

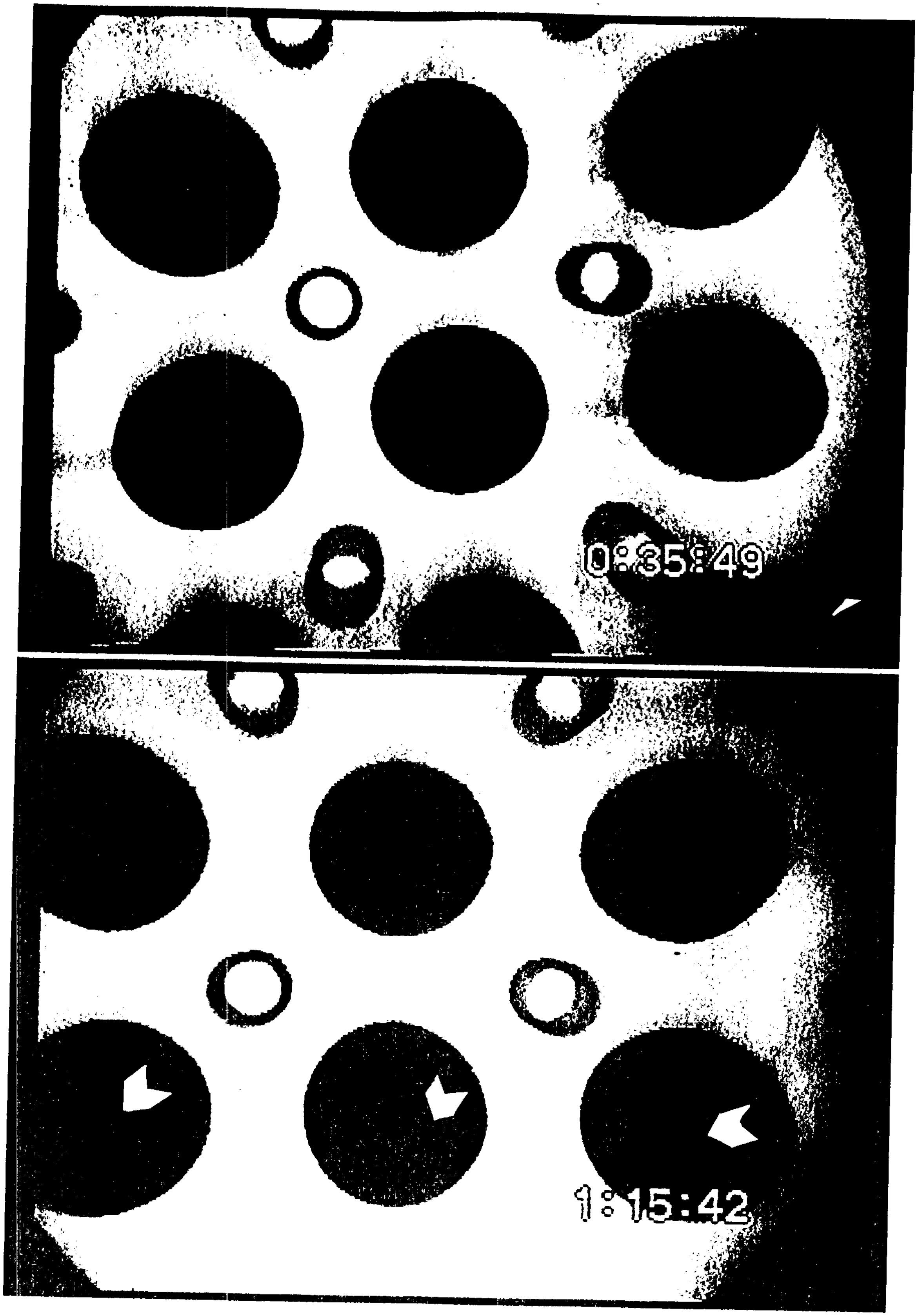


Figure 10

REFLOW PROFILE

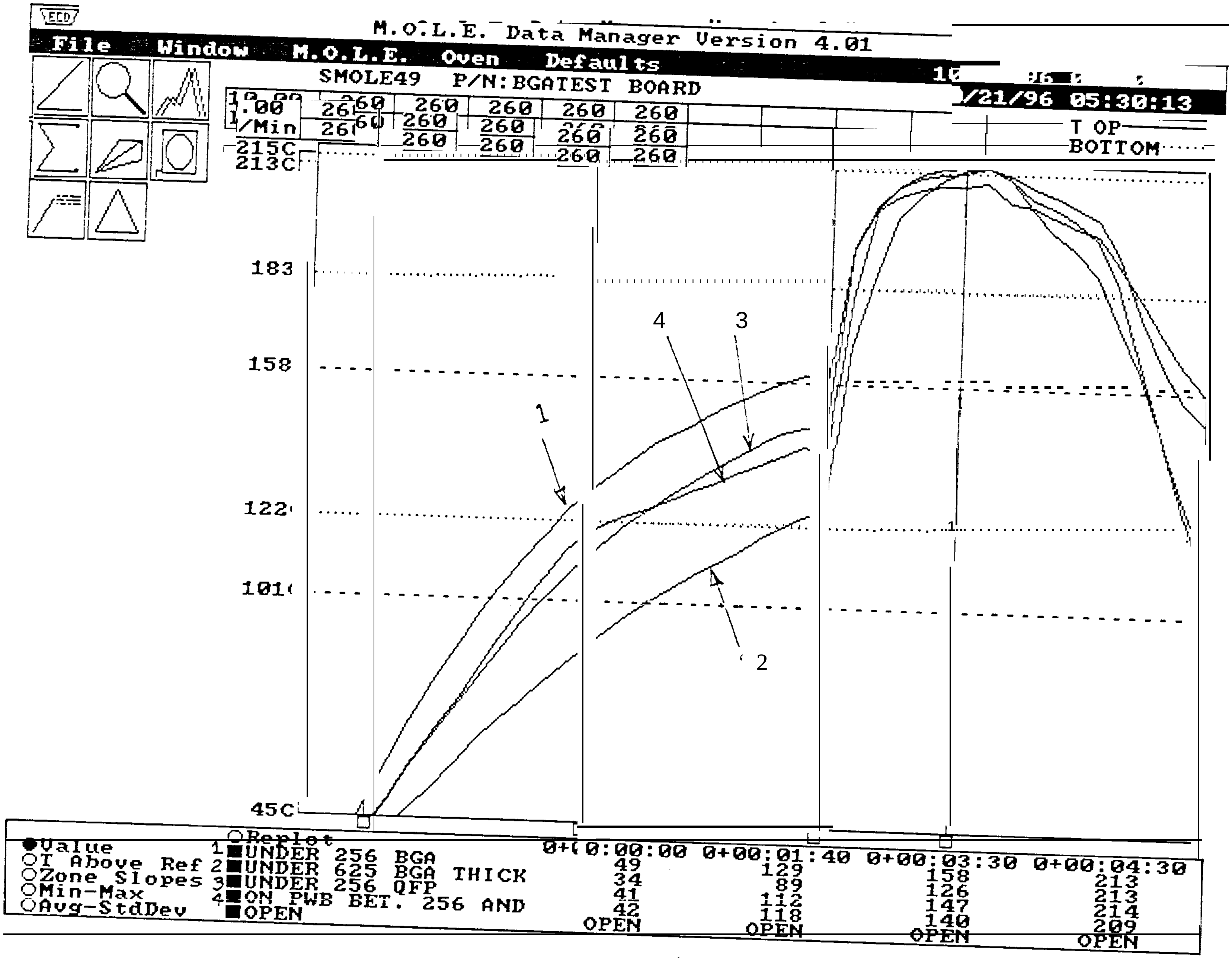


Figure 11

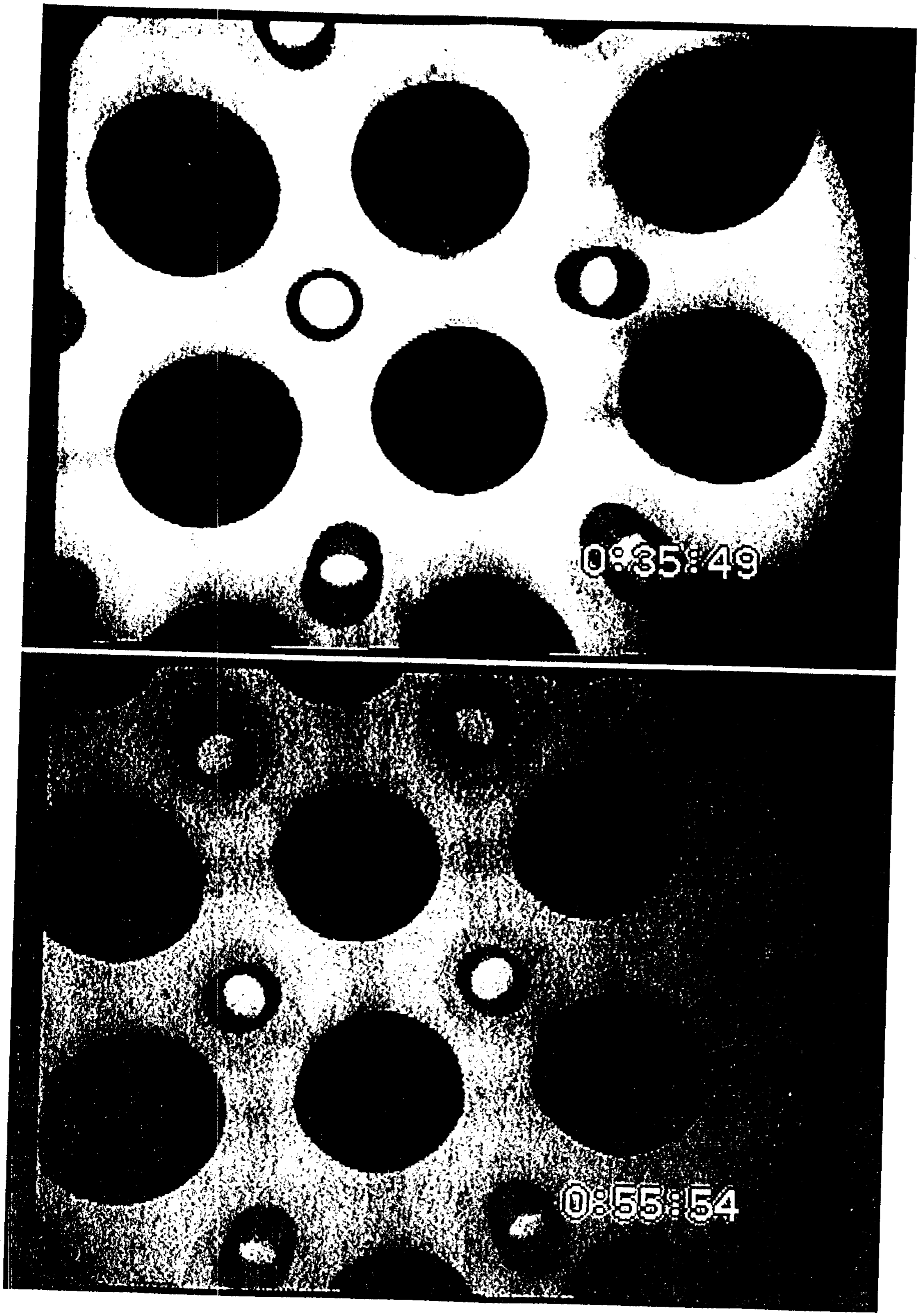


Figure 12

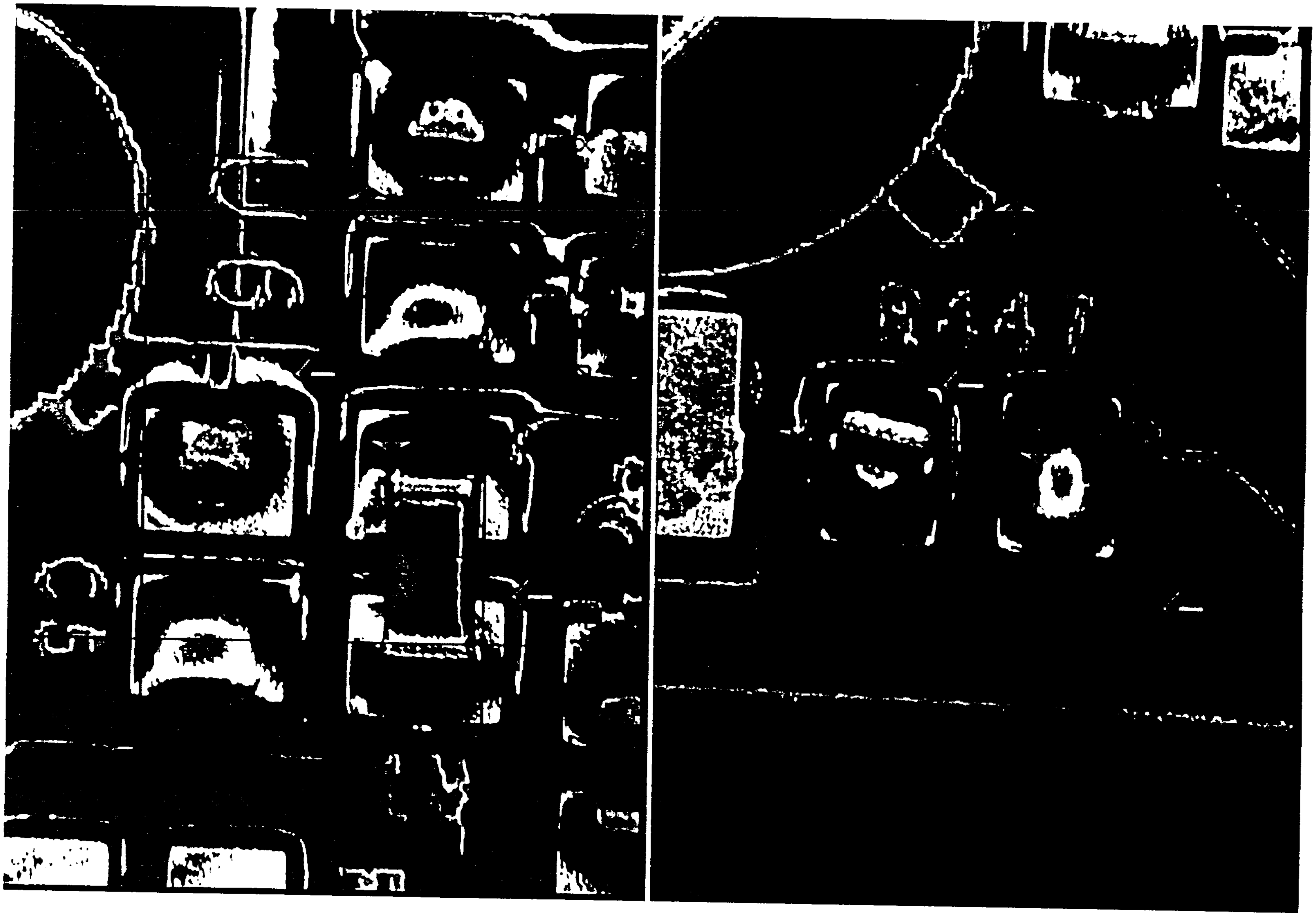


Figure 13