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UC-38

FLATPACK
INSTALLATION
BY SINGLE-PROBE
REFLOW SOLDERING

BDX-613-326

May, 1971

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Department 845

PDO 6984701
Final Report

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ABSTRACT

An investigation of several reflow-soldering techniques revealed that use of a single heated probe is superior to the other methods evaluated, including the parallel-probe resistance-soldering method which was in production use at the beginning of this work. The most notable improvements resulting from adoption of the single-probe soldering process were increased production rates, less necessity for reworking the boards to correct for misalignment and imperfect electrical connections, marked improvements in the appearance and quality of the board assemblies, and significant savings in labor and expensive flatpacks. Other supporting processes that were improved during this development included lead forming, lead tinning, and pc-board cleaning processes required to maintain solderability.

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SUMMARY

Problems encountered in the use of parallel-probe resistance soldering in installation of flatpacks on printed wiring boards led to a search for a more suitable reflow soldering method. The principal goals were to increase production rates, to obtain more uniform solder fillets, to reduce rework, and to attain greater process versatility.

The following soldering methods were investigated: a multilead heated probe, for soldering several leads simultaneously; infrared heating, also permitting simultaneous lead soldering; and a single heated probe, whereby leads are soldered individually. Neither the multilead probe nor the infrared heating method provided any appreciable advantage, and both were less satisfactory than the parallel-probe (or parallel-gap) method which was in use at the start of this program. The infrared portion of the investigation was not charged to this project, but to another development order (PDO 6984647) that was planned for that purpose. Results from that work indicated that the process was not satisfactory; therefore, very little time was devoted to consideration of that method. Multilead probes, also, were investigated on another project (PDO-6984374). The work of that project has been reported separately.

Development of the parallel-probe soldering process was completed before this project was begun, and that process was in production use at the beginning of the single-probe development. Because further improvements were needed, the parallel-probe method was used as a basis of comparison to the results obtained from the single-probe process.

The following soldering methods were investigated: a multilead heated probe, for soldering several leads simultaneously; infrared heating, also permitting simultaneous lead soldering; and a single heated probe, whereby leads are soldered individually. Neither the multilead probe nor the infrared heating method provided any appreciable advantage, and both were less satisfactory than the previously used parallel-probe method.

Adaptation of a single probe to the Development Associates Controls (DAC) power supply and control system used with the parallel probes provided most of the desired improvements; production rates were increased significantly, solder-fillet uniformity was improved, and rework was sharply reduced. As a result, the DAC single-probe system was adopted for use in scheduled production of flatpack pc-board assemblies throughout 1970, pending further evaluation of a newly-acquired Browne Auto-Pulse System which controls probe temperature by applying a programmed series of timed pulses.

The single probe used with the Browne equipment is smaller than that used with the DAC single-probe system and is therefore more versatile for both initial soldering and rework on high-component-density boards.

Use of the Browne system resulted in further improvement of solder-fillet uniformity, reduced rework, and increased production rates by a factor of more than three, as compared to those obtainable with the parallel-probe method. Therefore, the Browne single-probe system was adopted for use in scheduled production of all printed wiring board assemblies that contain flatpacks.

Because of increased production rates and reduced rework, significant labor savings are predicted. Because expensive flatpacks are less likely to be damaged by excessive heat and handling with the Browne system, reductions in material costs are expected to add materially to the overall cost savings.

Since lead forming and pretinning are important in installation of flatpacks by reflow soldering, these were also investigated. Leads were successfully formed at angles of 60, 65, and 80 degrees, with both bend angle and lead length within requirements. Leads formed after tinning were not satisfactory because of insufficient solder on the leads.

A special tool was designed to hold the flatpacks and to protect them from excessive heat when they are dipped into molten solder to tin the leads. After trying aluminum and steel tools with Teflon coatings over the head portions without success, a holding tool was machined from solid Teflon. The Teflon was heat-stressed before machining to prevent distortion caused by the heat transfer encountered in normal use. The Teflon reduces heat transfer to the circuitry within the flatpack and lessens the tendency for solder to bridge between the leads when they are dipped. The all-Teflon holding tool proved satisfactory, and was adopted for scheduled production use.

A review of board cleaning procedures resulted in adoption of a simplified method of spray cleaning with trichloroethylene. Tests on oxidized boards revealed that solderability is improved when the boards are cleaned with Surf-Prep (a product of Claude Michael, Inc.). Surf-Prep was found to be very effective in removing oxidation; however, boards cleaned with Surf-Prep could not be stored for extended periods of time under normal storage conditions without additional protection. Kester's Protecto was found satisfactory for use as a protective coating for boards cleaned with Surf-Prep, if applied immediately after cleaning.

DISCUSSION

BACKGROUND

Since flatpack leads are small and closely spaced, the amount of solder to be applied is very critical and must be limited to the amount necessary to produce strong connections and satisfactory fillets, without sufficient flow to short-circuit adjacent leads. Conventional soldering by application of solder to the probe and joint surfaces does not provide sufficient control. Therefore, the proper amount of solder is applied by pretinning the flatpack leads, and the joint areas are heated after the flatpacks are placed in proper position, thereby causing the solder to flow. Such a process is called reflow soldering. The term "plug tip" which was used in the first DAC system is more properly called a single probe; therefore, the term "single-probe" is now used to describe all systems of that type.

SCOPE AND PURPOSE

This investigation of reflow-soldering methods was initiated because of a desire to increase production rates, improve uniformity, and expand the versatility of the soldering process. To improve production, the principal objectives were to reduce the amount of rework and reheating of soldered flatpack leads and to decrease the cleaning time required for parallel-gap soldering. Improvements in the uniformity of solder fillets and solder strength were necessary to improve the overall quality of printed wiring boards and the effectiveness of visual inspection techniques. Greater versatility was desired to increase the capabilities of the equipment for rework and for installation of all types of flatpacks.

The investigation of reflow-soldering methods included the following areas:

- Parallel-probe and single-probe soldering methods;
- Investigation of other possible methods of reflow soldering;
- Comparing the results obtained by each alternate method investigated to those obtained by the parallel-probe method in use at the beginning of this work;
- Acquisition of knowledge necessary to define operator qualifications and to establish operator training procedures; and
- Development of in-process test methods and procedures to ensure uniform, high-quality soldered connections to flatpack leads.

OBJECTIVES

The major purpose of this project was to evaluate the relative merits of the alternate methods investigated as compared to those of the parallel-probe method and to select the method which would best fulfill the following objectives:

- Increase production rates in flatpack reflow soldering operations;
- Obtain uniform solder fillets, as required to sustain visual inspection reliability and to produce an acceptable board appearance;
- Improve uniformity and repeatability of the soldering process, thereby reducing the necessity for reworking the boards; and
- Establish the greatest possible process versatility, thereby enabling sharp-angle preformed flatpack leads to be soldered on boards that allow little space for soldering-probe access.

PARALLEL-PROBE SOLDERING PROBLEMS

Because of nonuniform soldering of flatpacks to printed wiring boards and the subsequent necessity of reworking an excessively large number of such boards, an investigation was conducted to find an effective means of alleviating that condition. The principal problems encountered with the parallel-probe resistance-soldering process in use at the outset of this program were as follows.

- Cleaning the probes was necessary after approximately seven operations, thus slowing the rate of production.
- The space required for access of the parallel probes to the boards made it difficult to solder multilead flatpacks with 80-degree preformed leads.
- Small discrepancies in lead forming made it difficult to attain the precise alignment required to solder the leads in the correct positions, thereby making it necessary to reheat the solder to align individual leads.
- Nonuniform solder fillets made it difficult to evaluate the strength and condition of the soldered connections by visual inspection methods.
- Occasional arcing because of excessive contact resistance at one or more of the lead, land, or probe-contact points due to highly-resistive flux buildup sometimes caused pits in the contact surfaces.
- Because of the critical nature of the parallel-probe system, down-time for calibration and maintenance was excessive.

PRIOR WORK

Process development work had been done at various times to establish the parallel-probe soldering method which was in production use at the outset of this program. The principal interest in the parallel-probe method in this investigation was to provide a basis for comparison of the results obtained with the single-probe and other methods evaluated. Lead forming techniques, flatpack lead-tinning methods, flux application processes, and cleaning procedures for pc boards and flatpack leads had been developed for parallel-gap soldering; however, it was considered possible that at least some of these might require modifications for other prospective soldering methods.

Operating and calibrating procedures had been established for the Development Associates (DAC) power supply and control system used with the parallel probes; however, new techniques would be required for use of the DAC equipment with a single-probe soldering system.

The DAC parallel-probe system that was developed on PDO 6984374 and was in use at the beginning of this project is shown in Figure 1. Figure 2 illustrates the probe-access problem that is encountered on high-density circuit boards that employ flatpacks with 80-degree preformed leads.

The early work of this program established an interim soldering method which employed a single probe with the DAC equipment, as shown in Figure 3. Soldering procedures were established, and the system was placed in production use pending development of a better system. Results were superior to those obtained with the parallel-probe system, but left something to be desired in the matter of control. The space-saving advantage of the single-probe system in installing closely-spaced flatpacks on printed wiring boards is shown in Figure 4.

Preliminary evaluation of another soldering method, the Browne Auto-Pulse system, indicated that flatpack reflow soldering could be further improved by use of that system. Therefore, work was extended to include a full evaluation of that system. The Browne system is shown in Figure 5.

Although progress has been reported in previous departmental quarterly reports, the work has now progressed to selection and use of a single-probe reflow soldering method which produces satisfactory results in production of flatpack printed wiring board assemblies. The work required to establish that process is related in this report.

Figure 1. The Development Associates Controls Soldering Control System as Used With Parallel Probes

Figure 2. Detail of Parallel Probes in Contact With a Flatpack Lead
(This photograph illustrates the limitations encountered in soldering 80-degree formed flatpack leads with the parallel probes.)

Figure 3. DAC Single-Probe Reflow Soldering Station

Figure 4. Detail of the Single Probe in Soldering Position on a Flatpack Lead

Figure 5. The Browne Auto Pulse Soldering System

APPROACH

Because of the critical nature of flatpack soldering, it was apparent that the capability of the operator and the versatility of the process are equally important. Therefore, operator skills were considered when evaluating each of the processes. Alignment of all leads of multilead flatpacks is difficult and time consuming. If not properly aligned, the leads are not in the proper positions during the initial soldering operation; therefore, at least some of them must be reheated and moved. Such rework is highly critical, and the utmost in both operator skill and process versatility is required to produce correct alignment and uniform solder fillets. Rework operations are usually complicated by space limitations and the close proximity of adjacent flatpack leads and nearby components. Damage to the seal and the internal components of the flatpack due to excessive heat is a potential danger also.

Because of the critical functional and appearance requirements, the plan for the investigation was designed to include the following considerations:

- Evaluation of several reflow soldering methods;
- Establishment of soldering procedures for the preferred method;
- Operator qualification;
- In-process tests; and
- Cleaning methods.

ACTIVITIES

Methods Investigated

Each of the following methods of reflow soldering was investigated, and the results obtained with each were compared to those obtained with the parallel-gap method in use at the outset of this program.

Infrared Heating

Infrared heating was generally unsatisfactory because it was not possible to confine the heat to the desired areas; consequently, heat-sensitive components were subjected to excessive heat. The method was not suitable for rework applications because the heat could not be restricted to individual leads.

Simultaneous alignment and soldering of leads was extremely difficult, and the leads could not be held in position until the solder cooled.

Less cleaning was required, as compared to the parallel-gap method, and flatpack installation required less time; however, the necessary additional rework resulted in an overall decrease in the production rate, and the solder fillets were irregular.

Heated Multilead Probe

Results obtained with the multilead probe were similar to those obtained with the infrared heating method. It was difficult to align and hold the leads; therefore, much rework was required after the initial flatpack installation.

Since heat could not be restricted to a single flatpack lead, the multilead probe was not suitable for use in reworking the boards. The initial installation was faster than with the parallel-probe method, and 80-degree formed leads could be soldered; however the additional rework reduced the overall production rate.

Heated Single Probe

Single-tip soldering probes were used in conjunction with the existing DAC soldering control equipment and the Browne Auto-Pulse system to evaluate the single-probe reflow soldering process. A thermocouple was mounted on the probe used with the DAC equipment to provide the temperature-sensing function necessary to monitor and control the process. See Figures 3, 4, and 5.

Advantages of Single-Probe Soldering

Comparisons of the results of the single-probe soldering process to those obtained with the other methods investigated proved the single-probe method superior in the following respects.

- Reduced Probe Cleaning. The necessity for cleaning the probe was reduced by a factor of nearly 10, as compared to the parallel-probe method. Single-probe cleaning was required only after 50 to 75 joints, whereas the parallel probes required cleaning after approximately 7 operations.
- Improved Heating Uniformity. Heating was more uniform and predictable; thereby enabling the process to be controlled more closely. Reliance on the contact resistance of the parallel probes was eliminated; therefore, the heat applied to the joints was dependent only upon the constant resistance of the single probe and the controlled current applied thereto.

- Less Damage to Lead and Board Surfaces. Elimination of the flux buildup problem, which caused arcing, occasional circuit board damage, and pitted surfaces on the parallel probes, resulted in less damage to lead and board surfaces. Consequently, the single-probe method was more reliable and repeatability was improved.
- Improved Fillet Uniformity. More-uniform solder fillets were produced by use of the single probe, thus reducing the necessity for reheating connections after initial soldering, improving the appearance and dependability of the board assemblies, and avoiding damage to components and boards which sometimes results from repeated heating.
- Reduced Rework. Improvements resulting from use of the single probe allowed easier alignment during initial soldering. Therefore, less rework was necessary.
- Suitability for use in Rework. Because of the small access space required and the ability of the single probe to concentrate heat on small areas, the single-probe soldering method is ideally suited for rework operations. Therefore, use of the single-probe method for initial soldering eliminates the need for an alternate reworking process.
- Reduced Heat Conduction. Concentration of the heat upon one lead at a time reduces the transfer of heat to adjacent connections and components. Adjacent soldered joints therefore exhibit less tendency to loosen, and heat-sensitive components are less likely to be damaged by excessive heat.
- Greater Versatility. Because of the small size of the single probe, as compared to those of the probes used with the parallel-gap and multilead-probe methods, the single probe is more suitable for dense-packaging applications. Because of a smaller probe which permits satisfactory soldering on a 0.025-inch foot length, the Browne system is even more versatile than the DAC
- Increased Production and Improved Quality. Because of the superiority of the single-probe method over the other reflow-soldering techniques investigated, production rates have increased significantly, and the quality of printed wiring board subassemblies that contain multilead flatpacks is now superior to those produced by previous methods.
- Operating Simplicity. After initial adjustment for a specific board, no further adjustment of either the DAC or the Browne single-probe systems is normally required. When changing to a different type of board, only the temperature control need be adjusted. Since the parallel-probe method required frequent adjustment of current and temperature and because much reheating was necessary to redress the leads and fillets, the operating simplicity of the single-probe systems is a distinct advantage.

- DAC Maintenance and Calibration. Initial calibration of the DAC system is performed with the probe thermocouple attached, rather than by use of a resistance standard such as that used in most other systems. For that reason, calibration can be accomplished at the production station, thus eliminating the need to transport the equipment to a maintenance section. Subsequent recalibrations require only a verification of settings, rather than a complete realignment. The DAC power supply need not be turned off between periods of use, thereby eliminating the 4-hour warmup required to stabilize the control limitec contained in the power supply.
- Browne Maintenance and Calibration. Calibration of the Browne equipment is not required. Tip replacement on the Browne can be performed by the operator in about one minute, without calibration or verification. For those reasons, the Browne equipment is not subject to down time for calibration or tip replacement. In addition, no warmup period is required.
- Improved Appearance. The appearance of boards soldered by either of the single-probe processes was much improved over that of the boards soldered by the parallel-probe, infrared, and multilead-probe methods. Connection surfaces were more smooth and shiny, solder fillets were more uniform, lead dress was improved, and blistering or measling on the board surfaces was significantly reduced. For that reason, and because of the results obtained from the investigative procedures reported in the following section, the single-probe soldering method was adopted for use in current production of printed wiring board assemblies that contain multilead flatpacks.

Diluted Soldering Flux

Solder-fillet uniformity was further improved by use of a diluted liquid flux which dries before soldering. The dry flux does not conduct heat away from the joint area as readily as the wet flux which was used with the parallel probes. The diluted flux can be applied more uniformly and without excess. The dry flux has less tendency to run or splatter when heat is applied, thus reducing cleanup requirements. The dry boards can be handled more conveniently, also. Since the single probe can be used in any position, fixed board-positioning fixtures are not required and precise adjustment of height, angle, and rotation such as that required with the parallel-probe method is no longer necessary. The resultant time saving is a definite aid to production.

Investigation Procedures

The results of tests and studies conducted to determine the relative merits of single-probe soldering method as compared to the parallel-probe method are given in this section. Experiments and tests, such as forming flatpack leads, tinning the leads prior to soldering, cleaning techniques, and other considerations that influence the quality of the finished product are also discussed.

Pull Strength Tests

The comparative pull strengths of leads soldered by the single-probe and parallel-probe methods were determined by testing fifty 60-degree-formed specimens prepared by each method.

Of the 50 leads soldered by the Browne single-probe method (Figure 5), 40 leads broke before reaching the ultimate pull strength of the joints. Of the remaining 10 leads that pulled loose, the lowest pull strength was 5 lb, 7 oz.

Of the 50 leads soldered by the parallel-probe method (Figure 6), only 23 broke before reaching the joint pull strength, and the remaining 27 pulled loose. The pull strength of the weakest of the parallel-probe soldered joints was 2 lb, 3 oz--less than half that of the weakest joints soldered with the single probe.

Plots of the data from the pull strength tests are shown in Figures 6 through 9. Those graphs show the pull strengths of the leads that broke before reaching the ultimate pull strengths of the joints as being equal to the break strength of the leads. Therefore, there was no way of measuring the joint strength of the broken leads.

Process capability studies of the test results from the two methods were performed on an IBM 360 computer. The printouts from those studies are shown in Figures 10 through 13. The mean ($\bar{X}$) was increased from 89.1 to 97.9 oz, and the standard deviation was reduced from 14.9 to 6.39 oz on a sample size of 50. The reduction of the standard deviation illustrates the improvement in process uniformity and substantiates the superiority of the single-probe soldering technique.

Lead Forming

Uniformity of length and bending angle of the leads is highly important when flatpacks are to be soldered to wiring boards. The leads must be of proper length after bending, and the lower surfaces of the terminal ends of the leads must rest flatly upon the land surfaces. Therefore, it is necessary to consider the spring-back of the leads when calculating the desired length and clearance between the bottom of the flatpack and the board surface.

Figure 6. Pull Strengths of Parallel-Probe Soldered Samples

Figure 7. Pull Strengths of DAC Single-Probe Soldered Samples

Figure 8. Pull Strengths of 0.050-Inch-Foot-Dimension Samples Soldered With the Browne System

Figure 9. Pull Strengths of 0.025-Inch-Foot-Dimension Samples Soldered With the Browne System

Parallel-Gap Process Capability Study

(Weights are stated in ounces)

Lower Specification Limit: 35.00000 Upper Specification Limit: 105.00000

Part No: Parallel-Gap Characteristic No: Foot (F) = 0.050 inch

Date: 4300

Sample Size: 50 Mean: 89.16000 Standard Deviation: 14.8535156 Range: 69.00000

Percent Defective Statements:

Number of standard deviations between the mean and the upper specification limit	1.066	QU
Number of standard deviations between the mean and the lower specification limit	3.646	QL
Estimate of the percent defective above the upper specification limit	14.335	PU
Estimate of the percent defective below the lower specification limit	0.025	PL
Estimate of the total percent defective (PU + PL)	14.360	

Normality Statement:

The process is significantly non-normal because the distribution is skewed to the smaller values.
 The distribution is peaked. Skewness -1.49 Kurtosis 2.72

Tolerance Limit Statement:

With 95 percent confidence 99 percent of the population is between 42.72558 and 135.59442

Control Statement:

The process is assumed to be in control.

95 percent Confidence Statements:

The true population mean is between 84.93989 and 93.38001

The true population standard deviation is between 12.4026852 and 18.5074615

The true population percent defective is between 7.89 and 23.69

Figure 10. Computer Printout From Parallel-Gap Process Capability Study Program

Single-Probe Process Capability Study

(Weights are stated in ounces)

Lower Specification Limit: 85.00000 Upper Specification Limit: 120.00000

Part No: Single-Probe Characteristic No: Foot (F) = 0.050 inch

Date: 4300

Sample Size: 50 Mean: 101.06000 Standard Deviation: 6.3129597 Range: 29.00000

Percent Defective Statements:

Number of standard deviations between the mean and the upper specification limit	3.000	QU
Number of standard deviations between the mean and the lower specification limit	2.544	QL
Estimate of the percent defective above the upper specification limit	0.158	PU
Estimate of the percent defective below the lower specification limit	0.563	PL
Estimate of the total percent defective (PU + PL)	0.721	

Normality Statement:

The process is normal.

Skewness. -0.38 Kurtosis -0.03

Tolerance Limit Statement:

With 95 percent confidence 99 percent of the population is between 81.32470 and 120.79530

Control Statement:

The process is assumed to be in control.

95 percent Confidence Statements:

The true population mean is between 99.26639 and 120.85361

The true population standard deviation is between 5.2713203 and 7.8659430

The true population percent defective is between 0.16 and 2.92

Figure 11. Computer Printout From DAC Single-Probe Process Capability Study Program

Browne Single-Probe Process Capability Study

(Weights are stated in ounces)

Part No: Single Probe Characteristic No: Foot (F) = 0.050 inch Lower Spec: 68.00000 Upper Spec: 108.00000

Sample Size 50 Mean 97.90000 Standard Deviation 6.3927565 Range 20.00000 Date 62470

Percent Defective Statements:

Number of standard deviations between the mean and the upper specification limit	1.580	QL
Number of standard deviations between the mean and the lower specification limit	1.861	QL
Estimate of the percent defective above the upper specification limit	5.692	PU
Estimate of the percent defective below the lower specification limit	3.111	PL
Estimate of the total percent defective (PU + PL)	8.803	

Normality Statement:

The process is significantly non-normal because the distribution is flat

Skewness -0.34 Kurtosis -1.33

Tolerance Limit Statement:

With 95 percent confidence 99 percent of the population is between 77.91524 and 117.88476

Control Statements:

The process is not in statistical control according to control charts

There are 1 range and 4 mean subgroups of size 2 out of control

95 Percent Confidence Statements:

The true population mean is between 96.08372 and 99.71628

The true population standard deviation is between 5.3379507 and 7.9653702

The true population percent defective is between 4.08 and 16.68

Figure 12. Computer Printout From Browne Single-Probe Process Capability Study Where F = 0.050

Browne Single-Probe Process Capability Study

(Weights are stated in ounces)

Part No: Single-Probe Characteristic No: Foot (F) = 0.025inch Lower Spec: 70.00000 Upper Spec: 110.00000

Sample Size 50 Mean 86.80000 Standard Deviation 10.5733585 Range 44.00000 Date 62470

Percent Defective Statements:

Number of standard deviations between the mean and the upper specification limit	2.194	QL
Number of standard deviations between the mean and the lower specification limit	1.589	QL
Estimate of the percent defective above the upper specification limit	1.404	PU
Estimate of the percent defective below the lower specification limit	5.589	PL
Estimate of the total percent defective (PU = PL)	6.993	

Normality Statement:

The process is normal. Skewness -0.32 Kurtosis -0.32

Tolerance Limit Statement:

With 95 percent confidence 99 percent of the population is between 53.74602 and 119.85398

Control Statements:

The process is not in statistical control according to control charts.
There are 0 range and 1 mean subgroups of size 2 out of control.

95 Percent Confidence Statements:

The true population mean is between 83.79595 and 89.80405
The true population standard deviation is between 8.8287535 and 13.1743975
The true population percent defective is between 2.99 and 14.17

Figure 13. Computer Printout From Browne Single-Probe Process Capability Study Where $F = 0.025$

Lead samples were formed at angles of 60, 65, and 80 degrees by use of two different bending tools (FA228124-400 and K2604), with appropriate dies. Five samples from each of the three groups were encapsulated as shown in Figure 14 and sectioned as shown in Figure 15. The lines superimposed on the photograph in Figure 15 define the angle of measurement. The length and the bending-angle measurements of the 15 samples are shown in Table 1.

Although results with both bending tools and at all three bending angles were within requirements, those with the FA228124-400 adjustable tool with the 65-degree and 80-degree dies were closer to the tooling dimensions than those with the K2604 tool and 60-degree die. Therefore, the former tool is preferred.

Regardless of the tooling used, it is important that the ends of the leads be sheared upward, thereby ensuring flat contact with the board and avoiding contact of the sharp edges of the leads upon the land surfaces.

Tinning the leads before forming was tried; however, bending could not be accomplished satisfactorily after an adequate amount of solder had been deposited on the leads, and solder flow over the sheared lead ends during reflow soldering was not adequate. Therefore, the final process requires that the leads be formed before tinning.

Flatpack Lead Tinning

Application of solder to flatpack leads for reflow soldering is accomplished by dipping the lead ends in liquidus solder. Solder temperature, dipping time and depth, and the number of dips must be controlled for the required amount of solder to be deposited on the leads.

A flatpack holding tool is used to control the depth of the dip and to prevent excessive transfer of heat to temperature-sensitive elements in the flatpack. The original flatpack holding tool was made of aluminum, with a Teflon coated head where the tool comes into contact with the molten solder. That tool was initially satisfactory; however, the Teflon coating deteriorated after approximately a week of continued production use. The result was an increased tendency for the solder to bridge between the leads. A similar tool made of steel with a high-temperature Teflon-S coating over the head area lasted about two weeks. A third tool made of solid Teflon lasted about two months. The Teflon used to make the solid Teflon tinning tool was heat stressed before machining to reduce the tendency of the Teflon to lose shape and rigidity during use. The latest tinning tool, shown in Figure 16, is in current production use.

Tempilac, a temperature-indicating paint, was used during the tinning experiments to determine the amount of heat conducted to the flatpack seals. Tempilac melts at ± 1 percent of the temperature at which it is rated, thus providing a comparatively accurate method of measuring the temperature rise at a specific surface location.

Figure 14. Encapsulation for Sectioning

Figure 15. Encapsulated Flatpack Sectioned for Lead-Forming Check

Table 1. Flatpack Lead-Forming Test Measurements

FA228124-400 Tool - 65° Die (A, C, and S Adjustable)					
Specimen	θ_L (°-')	θ_R (°-')	F_L (in.)	F_R (in.)	C (in.)
1	66° 25'	64° 36'	0.0529	0.0519	0.4599
2	68° 28'	64° 56'	0.0521	0.0608	0.4573
3	68° 10'	68° 15'	0.0516	0.0490	0.4567
4	65° 0'	65° 10'	0.0511	0.0512	0.4613
5	66° 30'	70° 32'	0.0500	0.0530	0.4608
Deviation	3° 10'	5° 56'	0.0029	0.0118	0.0046
FA228124-400 Tool - 80° Die (A, C, and S Adjustable)					
Specimen	θ_L (°-')	θ_R (°-')	F_L (in.)	F_R (in.)	C (in.)
1	78° 38'	79° 0'	0.0580	0.0685	0.4288
2	83° 11'	78° 42'	0.0589	0.0630	0.4355
3	76° 45'	76° 44'	0.0593	0.0633	0.4408
4	76° 51'	79° 9'	0.0602	0.0585	0.4394
5	78° 5'	78° 57'	0.0592	0.0702	0.4339
Deviation	6° 26'	2° 25'	0.0022	0.0117	0.0120
K2604 Tool - K2708 60° Die					
Specimen	θ_L (°-')	θ_R (°-')	F_L (in.)	F_R (in.)	C (in.)
1	56° 2'	54° 58'	0.0538	0.0525	0.4888
2	57° 12'	52° 54'	0.0529	0.0521	0.4889
3	53° 21'	56° 59'	0.0611	0.0534	0.4963
4	60° 15'	57° 41'	0.0502	0.0519	0.4848
5	62° 9'	59° 12'	0.0515	0.0495	0.4832
Deviation	8° 48'	6° 18'	0.0109	0.0039	0.0131

Figure 16. The Teflon Flatpack Lead-Tinning Holder

As measured by the Tempilac method, the temperature at the flatpack seals was well below 300°F when the leads were tinned in the Teflon holder. After dipping the leads three times in molten solder, 250°F Tempilac melted on the leads, but little melting was apparent at the seals. (Almost identical conditions were later encountered when the flatpack was reflow soldered to the board.) After the first dip, the 250°F Tempilac melted to the top edge of the Teflon jaws of the holder, and 200°F Tempilac melted to the seals.

The aluminum and steel holders required longer dipping times to acquire smooth, shiny surfaces; therefore, the temperature at the flatpack seals often exceeded 300°F.

Because of lower seal temperatures, increased tool life, and more convenient operation, the Teflon holder offered distinct advantages over those of aluminum and steel, while maintaining equal or better tinning quality.

Single dipping proved insufficient to remove the gold plating and to deposit an adequate amount of solder for reflow soldering. The coating deposit was dull, as shown in Figure 17. A sweeping lateral movement is to be avoided in dipping the leads because the forward edges of the leads tend to pick up oxidation from the molten solder, even when the solder has been skimmed a short time before dipping. The result is a rough surface and spurs on the leads, as shown in Figure 18.

Experiments with various numbers of dips, dipping and cooling times, fluxing and cleaning procedures, and related process variations, resulted in adoption of the following procedure.

Tinning Procedure

- Form and cut leads.
- Spray clean with solvent (as specified on Production Traveler).
- Apply diluted flux (50/50 ratio, MS4705011 flux/MS4601030 alcohol) with small camel-hair brush to one-half to three-quarters of the lead length.
- Dip three times, vertically, in molten solder, using the Teflon holder and submerging the leads to the holder. (Each dip can vary between one and three seconds in duration, with an equal cooling time between dips.)

Application of flux before each dip produced no improvement in tinning quality; therefore, flux is applied only once --before the first dip.

Figure 17. Single Dipping Produces Dull Finish on Leads and Insufficient Solder Deposit

Figure 18. Lateral Movement in Dipping Produces Spurs on Leads

The solder buildup ranged from 0.004 to 0.012 inch thick on each side of the flat portion of the flatpack leads, and the desired uniformity and shiny surface finish were obtained. (See Figure 19.) The angle formed between the foot and the slope of the leads contained an additional solder buildup which assisted in forming satisfactory fillets when the leads were reflow soldered to the board. That additional buildup is shown in the magnified view of a cross-sectioned encapsulated joint in Figure 20.

Surface Preparation

Adequate cleaning of printed wiring board surfaces is a vital consideration in preparing the boards for soldering. Principally because of the use of reflow soldering methods, board cleaning requirements are even more stringent on leads of flatpacks which are to be installed by soldering. Both the leads and the board lands are very small, and the close spacing of adjacent leads requires precise flatpack alignment, critical lead dress, and close control of solder fillets. To ensure free solder flow, it is necessary to remove all oil and chemical residue from the board surfaces. Cleaning operations should be performed immediately before soldering to prevent further collection of foreign matter.

Three methods of cleaning the boards were compared: The first employed Surf-Prep, a product of Claude Michael, Inc., as the cleaning agent; the second was a simplified procedure using trichloroethylene; and the third was a scrubber-drier method. A Marco machine was used in this test.

The Surf-Prep Cleaning procedure was as follows:

- Solvent clean or vapor degrease in trichloroethylene or perchloroethylene for one to two minutes to remove grease and soil-type contaminants;
- Dry with nitrogen or clean air;
- Immerse in Surf-Prep solder cleaner for one to three minutes at approximately 70°F to remove oxides;
- Rinse in running water;
- Ultrasonic clean in distilled water for one to two minutes to ensure complete removal of Surf-Prep;
- Rinse in running water;
- Oven dry for 10 minutes at 125°F;
- Dip in Kester Protecto for 10 seconds;

Figure 19. Deposit Uniformity and Good Surface Finish Obtained by Multiple Dipping

Figure 20. Magnified Cross-Section of Soldered Flatpack Lead
Showing Details of Acceptable Solder Fillets

- Blow dry;
- Oven bake at 130°F for 15 minutes; and
- Pack individually in clean plastic bags.

The trichloroethylene cleaning procedure follows:

- Spray both sides of boards thoroughly with trichloroethylene at a pressure of 45 to 50 psig;
- Dry with nitrogen; and
- Package individually in clean plastic bags.

The scrubber-dryer operating procedure is as follows:

- Set height of brushes to provide correct pressure on the boards to be cleaned;
- Turn the machine power on;
- Feed pc boards onto the rollers at the front of the machine;
- Remove the boards from the rear of the machine; and
- Package individually in clean plastic bags.

Evaluation of Cleaning Methods

Sixteen printed wiring boards were selected from various types produced at Bendix during the preceding two years. Because of oxidation and surface contamination the finish on most of the boards was dull, thus providing very poor surfaces for reflow soldering. Each board was halved and labeled, one half to be cleaned by the Surf-Prep method, the other by the trichloroethylene procedure. There was no visible difference in the appearance of the boards when soldered immediately after cleaning. (Compare Figures 21 and 22.)

Solderability tests were conducted both immediately after cleaning and after exposure to high-humidity/high-temperature storage conditions. Initial solderability was equally good on boards cleaned by either of the two methods. The DAC single-probe soldering process was used in the tests, with the same control settings and the same type of flatpack used in all of the tests.

After the initial solderability tests, 10 of the worst-appearing boards were placed in a controlled humidity chamber at 90-percent rh and cycled from 77 to 149°F twice during each 24-hour period for 15 days. A similar dull

Figure 21. Appearance of Flatpack Leads on Boards Cleaned With Surf-Prep and Soldered Before Storage

Figure 22. Appearance of Flatpack Leads on Boards Cleaned With Trichloroethylene and Soldered Before Storage

appearance was evident on all of the boards at the end of that time. The two boards shown in Figure 23 are typical of the monochromatic differences in the appearances of boards cleaned by the two different methods after exposure to temperature and humidity.

Solderability tests on the boards that had been subjected to humidity revealed that the Surf-Prep cleaned boards could not be soldered satisfactorily, whereas those cleaned with trichloroethylene were unaffected by humidity. for that reason, Surf-Prep was not included in the current cleaning procedure. However, application of a protective coating such as diluted flux or Kester Protecto to the board immediately after Surf-Prep cleaning will preserve the solderability of the boards during expended exposure to normal storage conditions.

Flux Application

Usual production procedures require that MS4705011 flux be applied to the board lands and flatpack leads with a small camel-hair or sable brush immediately before soldering. Soldering normally follows before the flux dries on the surfaces; hence, the term wet-flux soldering. MS4705011 flux is relatively heavy-bodied and rather tacky; therefore, it is difficult to maintain uniform application--frequently resulting in deposition of a greater amount of flux than is necessary to perform the required function. When heated, the excess flux flows, leaving an unnecessarily large amount of flux residue on the board surface. The excess flux conducts heat away from the joint, thus requiring use of higher probe temperature to obtain satisfactory solder fillets. The additional heat transfer tends to produce delaminations, blisters, or measling on the board surfaces.

A series of single-probe reflow soldering tests was conducted to compare the relative merits of the conventional wet flux to those of the same flux diluted 50/50 with alcohol and allowed to dry before soldering. For convenience, the diluted flux is called 50/50 flux to distinguish it from the undiluted tacky flux.

Typical flatpack connections soldered with each of the flux systems are shown in Figure 24. Although detail in the photographs is somewhat limited, it was easily apparent by visual observation that the boards soldered with 50/50 diluted flux were less measled than those upon which undiluted flux was used. Because of the more uniform application of 50/50 flux, excess flux was avoided; therefore, less cleaning was required after soldering.

DAC Single-Probe Calibration

The soldering experiments revealed that the most uniform solder fillets and best joint strengths were obtained with probe temperatures ranging

Cleaned With
Surf-Prep

Cleaned With
Trichloroethylene

Figure 23. Appearance of Boards After Exposure to Humidity

Soldered With 50/50 Diluted Flux
(Clean, bright joints, and no measling)

Soldered With Undiluted Flux
(Measling apparent)

Figure 24. Soldering Quality With Diluted Flux Compared to That With Undiluted Flux

between 600°F and 650°F. Therefore, all of the DAC Limitecs were calibrated for a probe temperature of 625°F with the control set at Position 1. Heat sinks were not used in the initial calibration. Average printed wiring board paths (acting as heat sinks) drop the probe-tip temperature about 100°F at the end of a normal soldering operation; however, the tip returns to the calibration temperature very quickly when removed from contact with the joint.

Although a second calibration point at about midscale on the Limitec control would have provided more convenient control of varied soldering operations, such calibration was not possible because of variations of the controls at the many soldering stations. The simple single-point calibration, however, provides a uniform starting point from which settings for a specific soldering operation can be readily determined.

Browne Calibration and Maintenance

Evaluation of the Browne soldering system confirmed that only a very simple calibration is required to ensure reliability and uniformity of operation. Therefore, only annual preventive maintenance is recommended for that system.

Flatpack Soldering Procedure

The experimental work produced a single-probe reflow soldering technique which improved the quality and appearance of flatpack printed wiring boards to a significant degree and is capable of yielding repeatable results in production soldering operations.

The Browne Auto Pulse, Model 950 Soldering System, which employs a timed 0.20 to 3.5 second pulse method of probe heating (rather than the cutoff principle of the DAC system) was evaluated and adopted for production use. The Browne equipment does not require a thermocouple in the probe; it permits the application of heat to be programmed for a specific soldering requirement, thus eliminating the need for a temperature-sensing device. When properly programmed, the probe temperature remains essentially constant throughout the soldering operation.

The experiments with the Browne system proved that use of that equipment will increase production rates, maintain equal or better joint strength and fillet uniformity, reduce rework, and reduce equipment maintenance. The probe used with the Browne system is smaller than that used with the DAC single-probe system; therefore, it is more suitable for both initial soldering and rework operations on closely-spaced flatpack leads and dense circuit boards.

The single-probe soldering procedure which was developed during this investigation is controlled by Flatpack Soldering Specification 9913008 and has been adopted for current production use. The procedure is listed below.

- Form the flatpack leads on a forming fixture.
- Clean the flatpack leads with solvent spray.
- Tin the flatpack leads; use the special Teflon holder.
- Clean all leads and board surfaces with solvent spray.
- Apply diluted flux to flatpack leads and board lands (avoid excess).
- Solder the flatpack to the printed wiring board.
- Clean the entire assembly with solvent spray.

Operator Qualification

Knowledge acquired from this investigation resulted in development of audio-visual aids and a training program to insure a sufficient number of qualified operators to man the flatpack reflow soldering stations. During the initial phases of training the prospective operators are taught the fundamentals of flatpack reflow soldering: precautions necessary to avoid heat damage to heat-sensitive components and boards tinning and soldering; handling to avoid surface contamination; equipment adjustment and use; and correct reflow soldering techniques. Later phases of the training program include lead forming; tinning; flatpack lead and printed wiring board cleaning; and correct procedures for initial flatpack installation, reheating, and replacement. The training in equipment operation includes control settings, probe maintenance, and verification of joint quality.

Satisfactory completion of the training program requires that each operator demonstrate proficiency in all phases of flatpack reflow soldering and re-working procedures to the requirements of Flatpack Soldering Specification 9913008 and Visual Aid to Inspection SS230039.

After completion of the training program, operator skills are maintained by supervisory surveillance and access to an audio-visual station in the production area. Audio-visual programs are promptly up-dated to reflect any change in the reflow soldering process.

Destructive Testing

Flatpack lead forming and soldering are the two principal functions that must be monitored for repeatable results. Neither can be checked satisfactorily by nondestructive methods. The forming fixtures and dies must be monitored at intervals to ensure that proper lead dimensions and correct bend angles are maintained without damage to the flatpack cases, leads, or seals. Results from each soldering station must be checked at frequent intervals to ensure high-quality soldered joints and uniformity of soldering for all stations.

Destructive tests are normally conducted at 3-month intervals to verify the performance of the lead-forming tools and dies used in continuous production. Such tests are required each time lead length or bend angle is changed. New fixtures and dies are checked in the same manner before they are placed in production use.

Lead-forming destructive tests require two representative flatpacks formed with each fixture. Defective flatpacks or dummy cases are frequently used for this purpose when they are available. After the leads are formed, each flatpack is encapsulated and sectioned as previously shown in Figures 14 and 15. A photomicrograph at 20-times magnification of a lead on each side of the flatpack is carefully examined for lead dimensions, bend angle, and strain marks in the leads, case, and seals.

Tests to determine soldering uniformity at the various stations require visual inspection of ten 60-degree formed leads soldered at each station. Each set of leads is then encapsulated and sectioned. The sectioned leads are examined for desired solder fillets and freedom from visible flaws. Routine tests are performed at intervals of approximately three months during continuous production. Additional tests are required each time the soldering equipment is altered and when the probe and thermocouple in the DAC single-probe are replaced.

ACCOMPLISHMENTS

The work that has been performed and the present status of the single-probe reflow soldering process which is now in scheduled production use substantiate the following conclusions.

- The single-probe soldering process, either DAC or Browne, is superior to the previously used parallel-probe method in these respects:
 - Production rates are increased;
 - Solder fillets are more uniform;
 - Cleaning is reduced;
 - Flatpacks and boards are less subject to heat damage; and
 - Rework is significantly reduced.
- The Browne timed-pulse heating system is superior to all of the other methods investigated, including the DAC/single-probe system. The Browne hand probe also facilitates rework on stacked printed wiring board assemblies.
- Diluted flux (MS 4705011 flux diluted 50:50 with alcohol and allowed to dry before soldering) is superior to the same flux in undiluted form.
- Kester Protecto surface coating is recommended for protecting and maintaining solderable surfaces. It should be applied immediately after pc-board fabrication or just after cleaning with Surf-Prep.
- The success of the operator qualification program resulted in increased production rates, improved product quality, reduced rework, and availability of a sufficient number of qualified operators to man the reflow soldering stations.

The Browne single-probe soldering technique is now producing high-quality flatpack printed wiring board assemblies at rates appreciably higher than was possible with the DAC single-probe system. An example of the soldering quality obtained by use of the DAC single-probe system during the interim period while awaiting evaluation of the Browne system and procurement of equipment for the soldering stations is shown in Figure 25. Soldering quality now obtained with the Browne equipment is equal or superior to that shown in Figure 25, with the advantages of increased production rates, reduced maintenance requirements, and greater versatility in the less-frequent rework operations that are now required.

Figure 25. Example of Present Soldering Quality

Good solder joints appear very much alike, regardless of the method used to solder them. However, joints produced by either of the single-probe systems are consistently better than those soldered with the parallel probes or any of the other methods investigated. Although the quality of joints soldered by the DAC single-probe method and those soldered with the Browne system is approximately the same for best-case conditions, the Browne system is more consistent and is better suited for rework applications.

In addition to the cost savings brought about by increased production rates and reduced rework, expensive flatpacks are less likely to be damaged in either initial soldering or rework operations with the Browne equipment. Improved appearance and higher quality are plus factors that are not frequently accompanied by cost savings.

Multilayer boards of satisfactory quality for present applications were not available for experimentation at the time of this work; however, it was apparent from the controllability and consistent results of the process that the Browne system would be suitable for use on multilayer boards. Use of the Browne equipment on multilayer boards that became available after the close of this project substantiated that conclusion.

FUTURE WORK

Since completion of the work planned for PDO 6984701 resulted in a superior reflow soldering process for installation of flatpacks, the success attained in that work indicates that additional effort should be expended toward expansion of the Browne single-probe reflow soldering process to installation of other types of components on printed wiring boards. Such a program should include lead forming on components other than flatpacks, redesign of pc-board terminals, use of solder preforms, and possible other factors which might facilitate the process.

No further work on single-probe reflow soldering development is planned at this time; however, future work may be necessary to meet the requirements of new designs that are not foreseen.

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