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ENGINEERING & TECHNOLOGY MANAGEMENT

Title: Defect Reduction for Screen Printing

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Abstract: This Project is to reduce the yield loss realized at In-circuit testing for surface mount solder defects to less tan 1% in Intel Products Group. The team completed: Reviewed the existing surface mount Process, process operating procedures, and process controls; reviewed data from the process measurement system and evaluated the effect of the variation within the measurement system has on the process control system. The conclusion is that the process measurement system presently used to monitor the solder height has too much variation within the measurement process to effectively be used as a process control tool.

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EMGT - 510 TOTAL QUALITY MANAGEMENT II

ENGINEERING MANAGEMENT PROGRAM TERM PROJECT

JUNE 1994

DEFECT REDUCTION FOR SCREEN PRINTING

for

Dr. Deckro

By

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Defect Reduction by Implementing Process Control at Screen Printing

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Executive Summary:

The Intel Products Group manufactures printed circuit boards used in personal computers. The process yield for the circuit boards was reviewed and the causes for defects isolated. Through the use of pareto analysis, the surface mount solder process, or more specifically the solder paste screening process, was determined as the number one cause for defects. The cost to detect and repair a surface mount solder defect at In-circuit testing was determined to be $7.25 per solder defect. It was also determined that the savings for reducing the yield lost due to solder defects from 3% to 1% would be approximately $25,000 per 200,000 circuit boards.

The PSU EMP team assigned to this area of improvement has a goal of reducing the yield loss realized at In-circuit testing for surface mount solder defects to less than 1%. The team completed the following tasks during the second quarter of this year.

- Reviewed the existing surface mount process, process operating procedures, and process controls.
- Reviewed data from the process measurement system and evaluated the effect of the variation within the measurement system has on the process control system.

Conclusion:

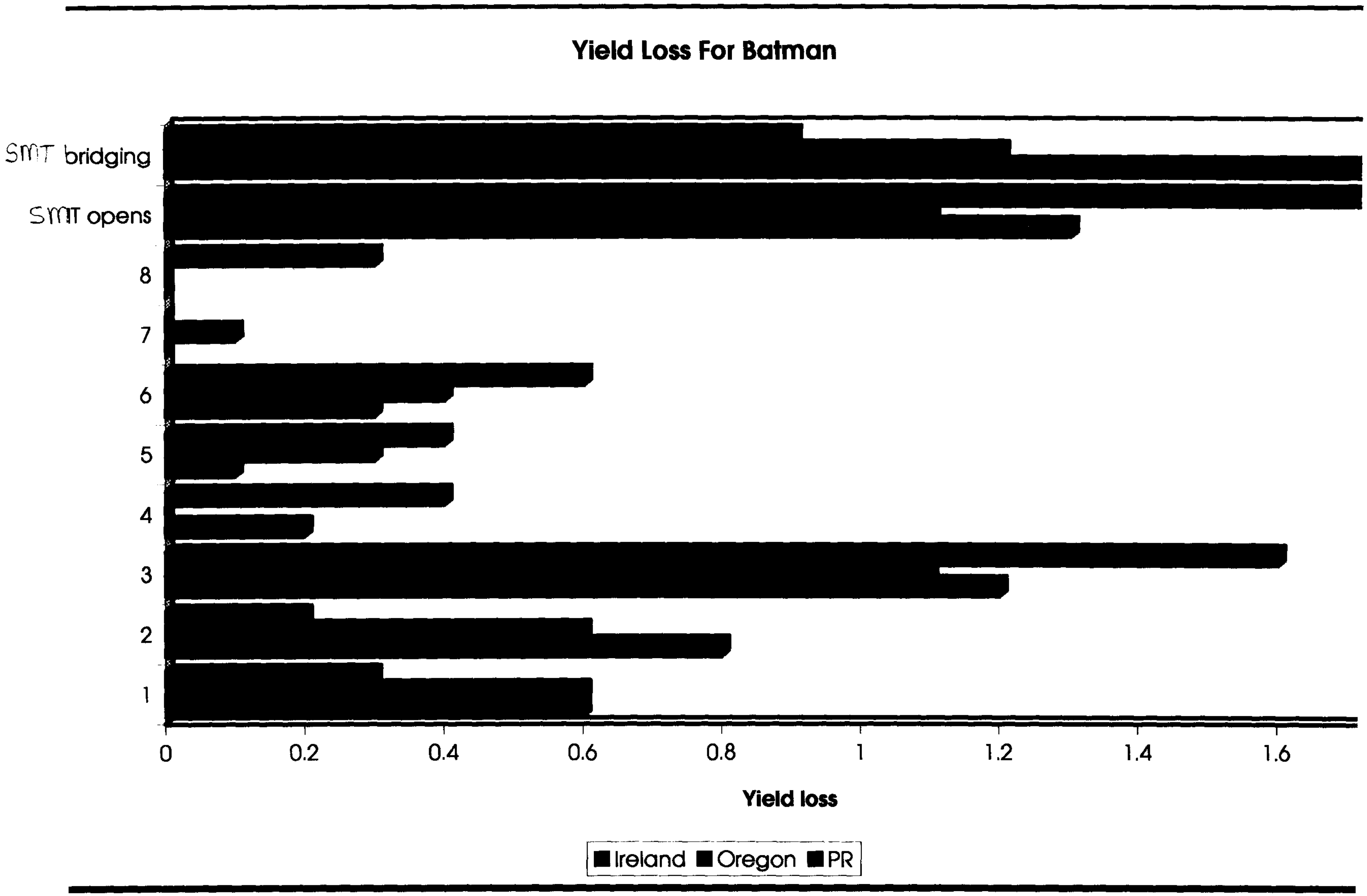
It has been determined that the process measurement system presently used to monitor the solder height has too much variation within the measurement process to effectively be used as a process control tool. It is proposed that a new system to developed which can properly measure the output of the process with minimal variation. After such a tool is developed, then the process can be placed under a process control system and a improvement process can be initiated

Defect Reduction by Implementing Process Control at Screen Printing

Opportunity Assessment:

Surface mount solder defects is one of the top pareto defects seen at process inspection and functional test in the Intel Products Group manufacturing process during the assembly of printed circuit boards used in Personal Computers. The attached pareto analysis, in figure 1, of defects seen over a 6 month period, found at In-Circuit testing shows the yield loss for surface mount technology (SMT) solder defects, being either opens or bridges, ranges from 3.1% in the Ireland factory to 2.3% in the Oregon factory. These two defects are the number 1 factory defects at all Intel sites and alone encompass on average 50% of the total factory defects. The cost to detect and repair a surface mount solder defect at In-circuit test is approximately $7.25. This includes the technician debugging time to locate the defect, the repair time of an operator to fix the defect, and the retest time to validate the repair . This cost also includes possible scrap generated during the repair process. Figure 2 shows the cost of repair based on volume for a SMT yield loss of both 1% and 3% . Depending on the volume of boards built per quarter, the savings for reducing the yield loss at In-circuit testing from the current 3% to 1% defect rate, is $25,000 per quarter assuming a volume of 200,000 boards per quarter or $140,000 for 1,000,000 boards assembled per quarter.

Several internal and industry studies have been published reviewing the general causes of surface mount solder defects. The pareto chart in figure 3 shows that about 64% of the solder defects are caused by the screen print process used within the surface mount



Yield Loss For Batman
SMT bridging
SMT opens
8
7
6
5
4
3
2
1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Yield loss
Ireland
Oregon
PR

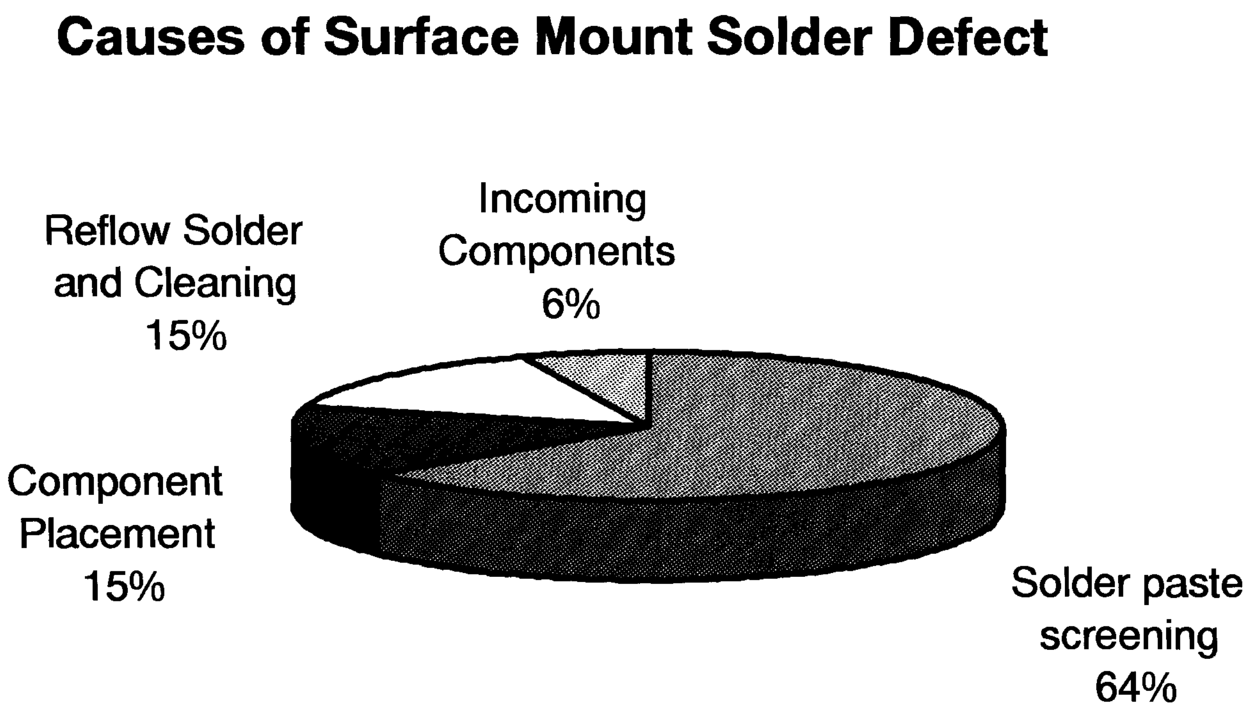
Figure 1

assembly line. Other possible causes listed included the component placement process, the reflow soldering process, and the incoming material quality.

Using the above data, the team analyzed how the surface mount solder defect level could be reduced with the goal of increasing the yield of the products seen at In-Circuit testing. The team's goal is to reduce the yield loss seen at In-circuit testing below 1% for defects caused by the surface mount soldering process. Based on the above data, that the screen print process was the major contributor to the solder defects, the team decided to focus on screen print process improvement. The improvement process used for this project consisted of the following steps:

Step 1: Review and document the existing process used at screen printing and benchmark the process ,against other Intel manufacturing locations and industry quality surveys. This review included looking at how the process was currently being managed , the operating procedures, identification and control of critical variables, and how the critical process variables were being measured.

Step 2: Develop a process measurement system to be used to monitor the stability of the process. The measurement system will be used during the design of experiment phase to measure responses to changes in setup parameters and to define the optimal operational window. A major requirement of this phase of the study is that the measurement system has the accuracy and repeatability required to control the process.



"Understanding where yield is lost is an important part of the quest for higher quality. This chart illustrates that nearly two-thirds of all SMT process-related defects can be attributed to faulty solder paste printing."

-Circuits Assembly, February 1991

Figure 3

Step 3: Complete a passive data collection experiment (run chart). This step will use the measurement system implemented in step 2 . The data collection will be completed over a predetermined period of time of a few weeks. The purpose of this data collection phase is to determine the amount of variability in the system and to measure the effect those variables have on the quality of the solder joint. This data will be used to establish control limits for process run charts. By applying those control limits, the following questions were addressed:

1. Is the process in control or out of control? This will define the steps to be taken in step 4. If the process is out of control efforts need to be taken to understand the origin for the special causes prior to running any designed experiments. Running experiments on a out of control process is worthless since conditions which are not understood are affecting the experiment results. These conditions when they occur will skew the data derived by the design of experiment (DOE).

2. A process capability index can be determined. This will determine the scope of the DOE efforts that will be required. If the process capability index is well above 1, minimal efforts will be required in the following steps. If the process capability index is less than 1, DOE techniques will be required to optimize the process.

steps. If the process capability index is less than 1, DOE techniques will be required to optimize the process.

Step 4: Stabilize process by eliminating special cause situations. As stated in step 3, running DOE type experiments assume the process is stable and in control. To move from step 4 to step 5, special cause situations need to be eliminated.

Step 5: Design experiments to determine variable interactions and a process limits. For the screen print process the critical variables are: squeegee blade hardness, squeegee speed, squeegee pressure, and stencil separation speed. Quality techniques such as fish bone diagrams will be used to identify and prioritize these possible critical variables.

Step 6: Complete a manufacturing capability assessment. This would include running the process and collecting data again. The data collection will validate that the process is operating in control and will be used to establish new control limits. These control limits should be narrower after the DOE is complete. As part of the implementation a new process capability index should be determined. If the capability index is greater than 1 the project is complete. If the capability index is still less than 1, the process goes back to step 5 for additional DOE testing. Step 6 also includes changing the run chart to a control chart and implementing of that system into production.

Note: The above steps are a standard process used at Intel in the development of new processes within manufacturing. The team effort for this quarter was to complete step 1 and most of step 2 in the above process.

Process Overview:

Screen print Process Overview:

In surface mount assembly, the components are soldered to the printed wiring board via a solder reflow process. The assembly process consist of depositing solder paste onto the appropriate locations on the printed wiring board using a printing process. Components are then placed onto the paste which is heated in an oven to melt the solder and bond the parts and form the electrical connection between the board and the components.

The screen printing process consist of using a metal stencil which has been etched such that a hole pattern in the stencil matches the locations on the board where solder paste is required. A board is loaded into the machine via a conveyor and is clamped in place at the print station. A vision system is used to determine the exact x, y, and theta locations of the board. The stencil is then moved via computer control to match the exact same location. The stencil then is lowered into contact with the board and solder paste is squeegeed across the stencil and is deposited into the etched openings.

The volume of paste deposited is critical in making a good solder connection. Too much paste will result in a solder bridge being formed between adjacent component pins (the pin to pin spacing between leads in equal to 0.012"). Not enough paste results in no connection or a weak connection between the component pin and the board. These two defects (SMT solder opens and bridges) are as stated above the top two factory defects.

Process Control System Overview:

To ensure the correct volume of paste is being deposited onto the printed board, a off-line laser scanner system is used to randomly measure the solder paste deposit height on certain boards. The laser system has the ability to measure down to 10 microns. The system measures the output for the screen print process with the derived data used as part of the process control system. Figure 4 shows a sample of the process control chart used . The control process system consists of removing a printed board from the line every 30 minutes and measuring five points on the board for paste height. Figure 5 shows a sample of the display the operator checks when measuring the solder paste height. The operator then determines where the transition between board and the solder occurs and the location of the maximum height of the paste. The operator determination of the interface between the board surface and the start of the solder paste is not a exact point which can be marked and requires some judgment. The scanner then determines the height of the paste which is one of the five points used in the sample. Based on these five samples both the mean and the range of the values is plotted on a X(bar), R chart. Data from two of the control charts shown in Figure 4 were put on a single chart which is shown in Figure 6. This data was the basis for all of the analysis done in the data analysis section of this report.

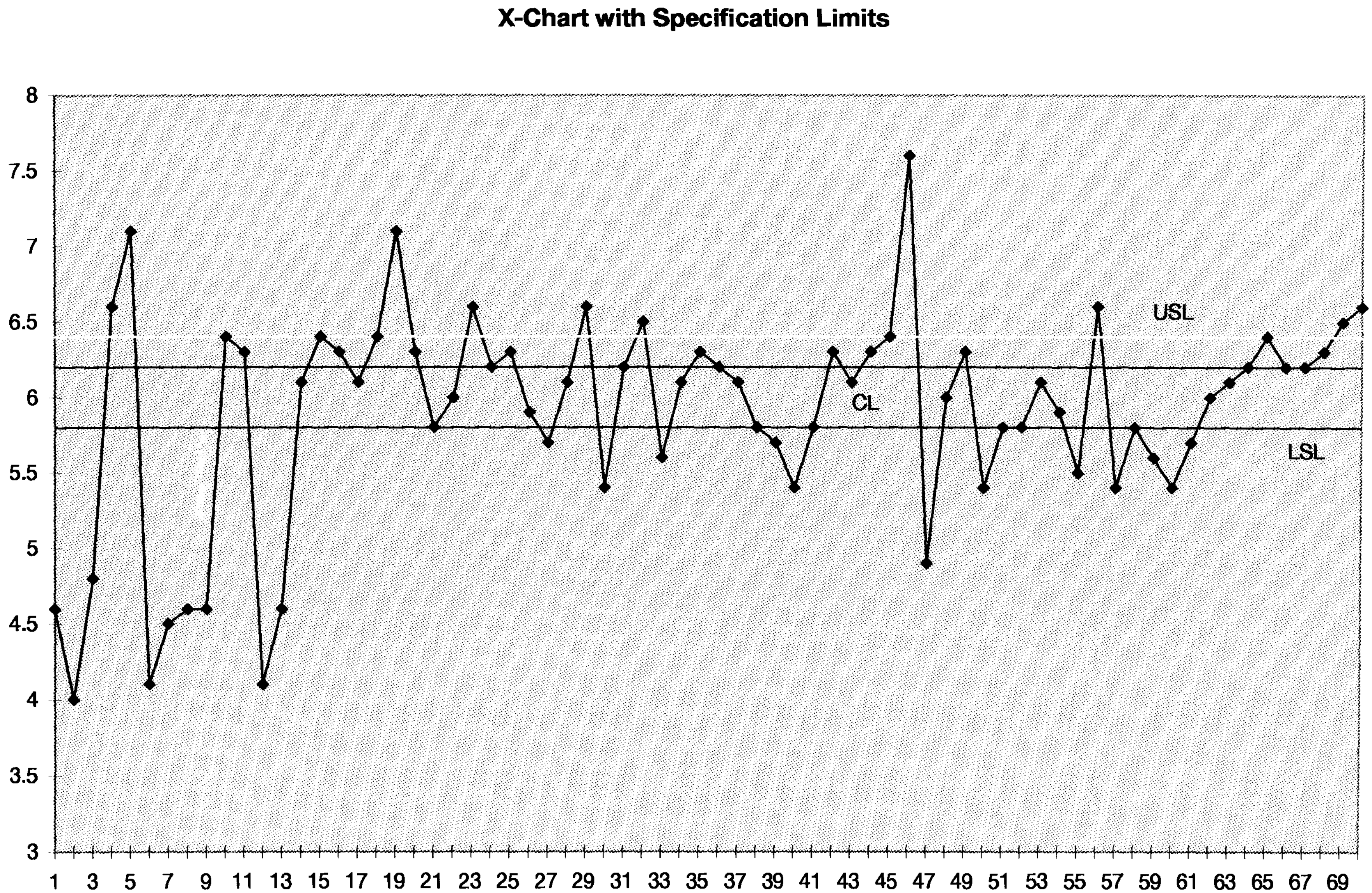
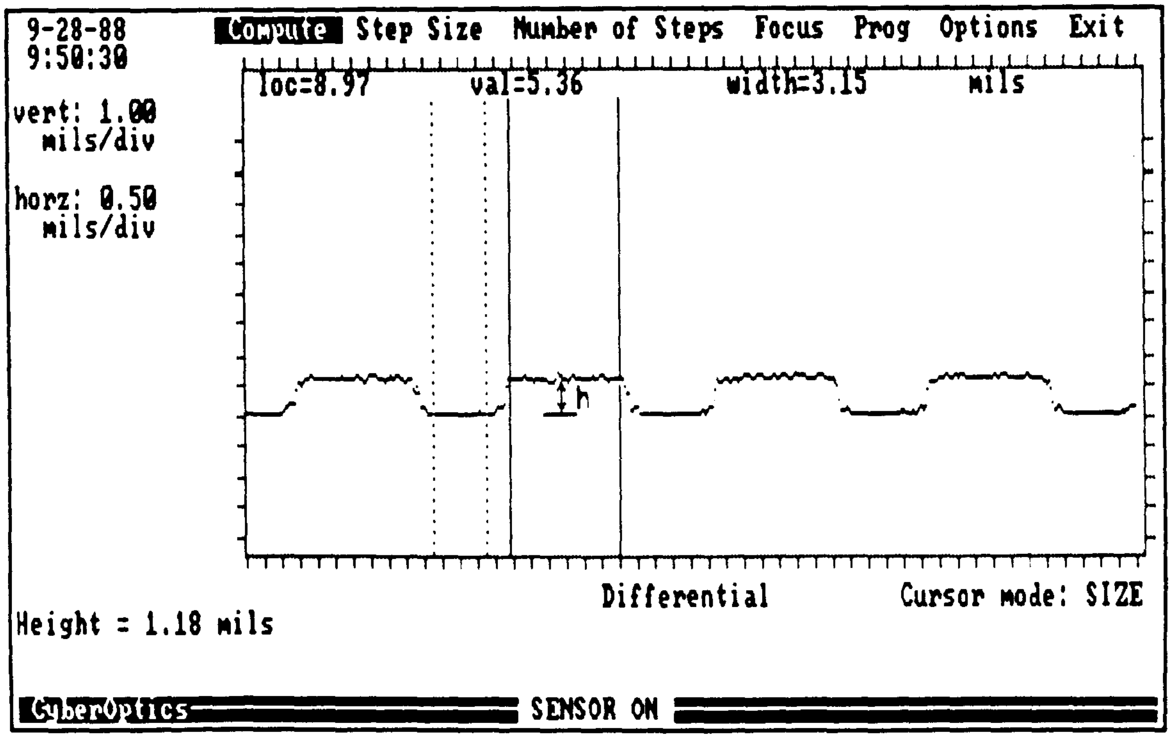

X-Chart with Specification Limits
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69
USL
CL
LSL

Figure 6



Sample plot from Laser Scanner

Figure 5

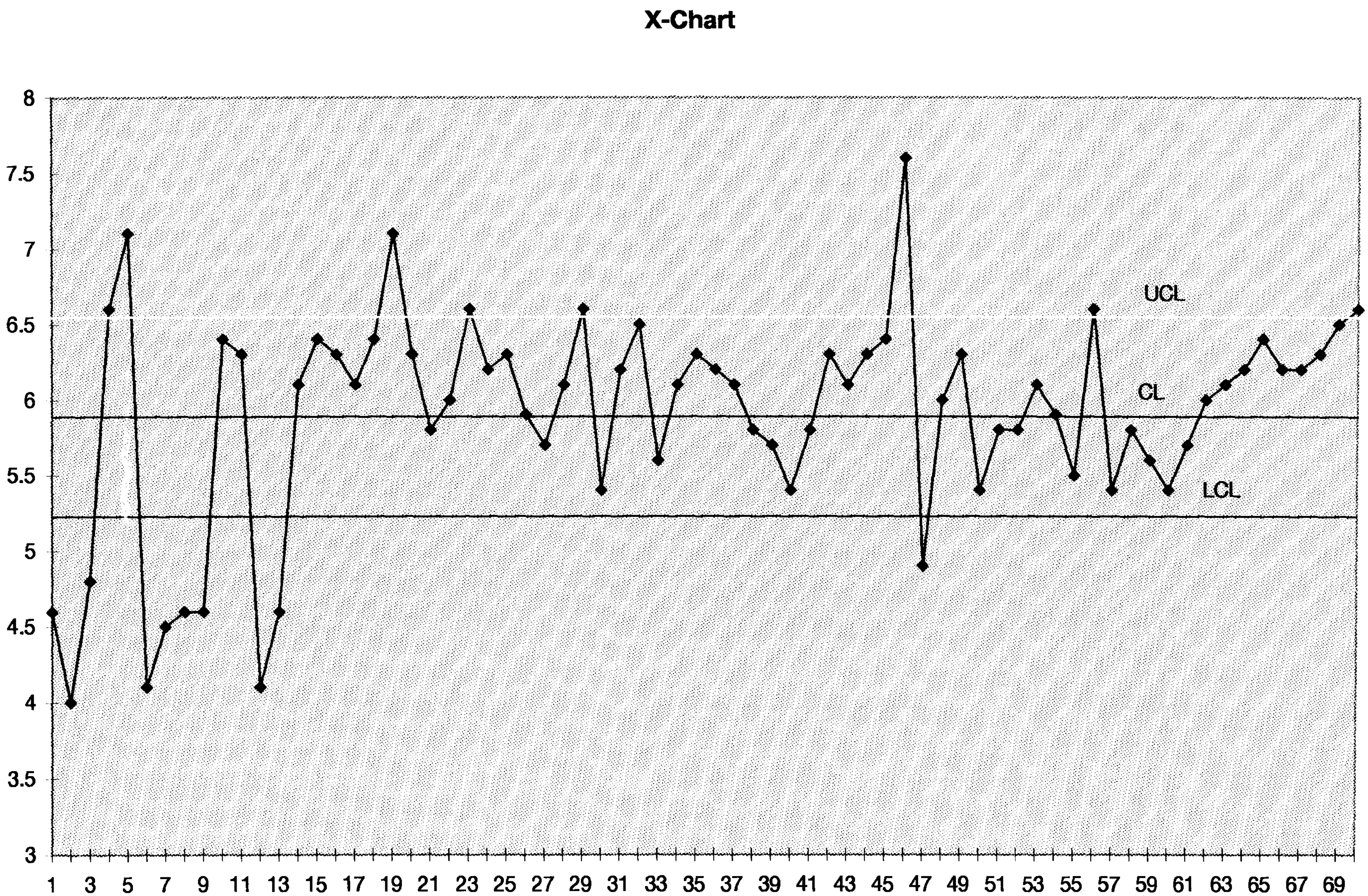
Step 1: Review and Document the current process and the control system

The screen print system is currently operating under the guidelines of a process control system (sample chart in figure 4). During system review the following issues were identified:

1. What is marked as control limits in figure 4 are really process specification limits for acceptable solder paste heights. If the solder paste is higher than the upper specification limit of 0.0064", the chance of getting a solder bridge is greater and therefore the process is adjusted to reduce paste height. If the paste is less than 0.0058", the process is adjusted to increase the amount of paste being deposited, to reduce the chance of getting an open solder . Using the data given in figure 4, a new control chart was developed with control limits calculated based on three standard deviations. The x(bar) chart is shown in Figure 7 and the range chart is shown in Figure 8. Three major points are noted on the charts:

    1. From the x (bar) chart, the variability indicates that the process is out of control. Over 25% of the samples points are outside (either above or below) the control limits of the process. In addition, there are several type 2 and 3 statistical process control (SPC) rule violations.

    2. The mean range on the control chart is very large compared to the process limits. The mean range from Figure 8 is 0.0015", compared to a process bandwidth of 0.0006" (the upper specification limit minus the lower specification limit). The range in the measurement system is over two times the process specification bandwidth.


X-Chart
8
7.5
7
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6
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5
4.5
4
3.5
3
UCL
CL
LCL
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69

Figure 7

R-Chart

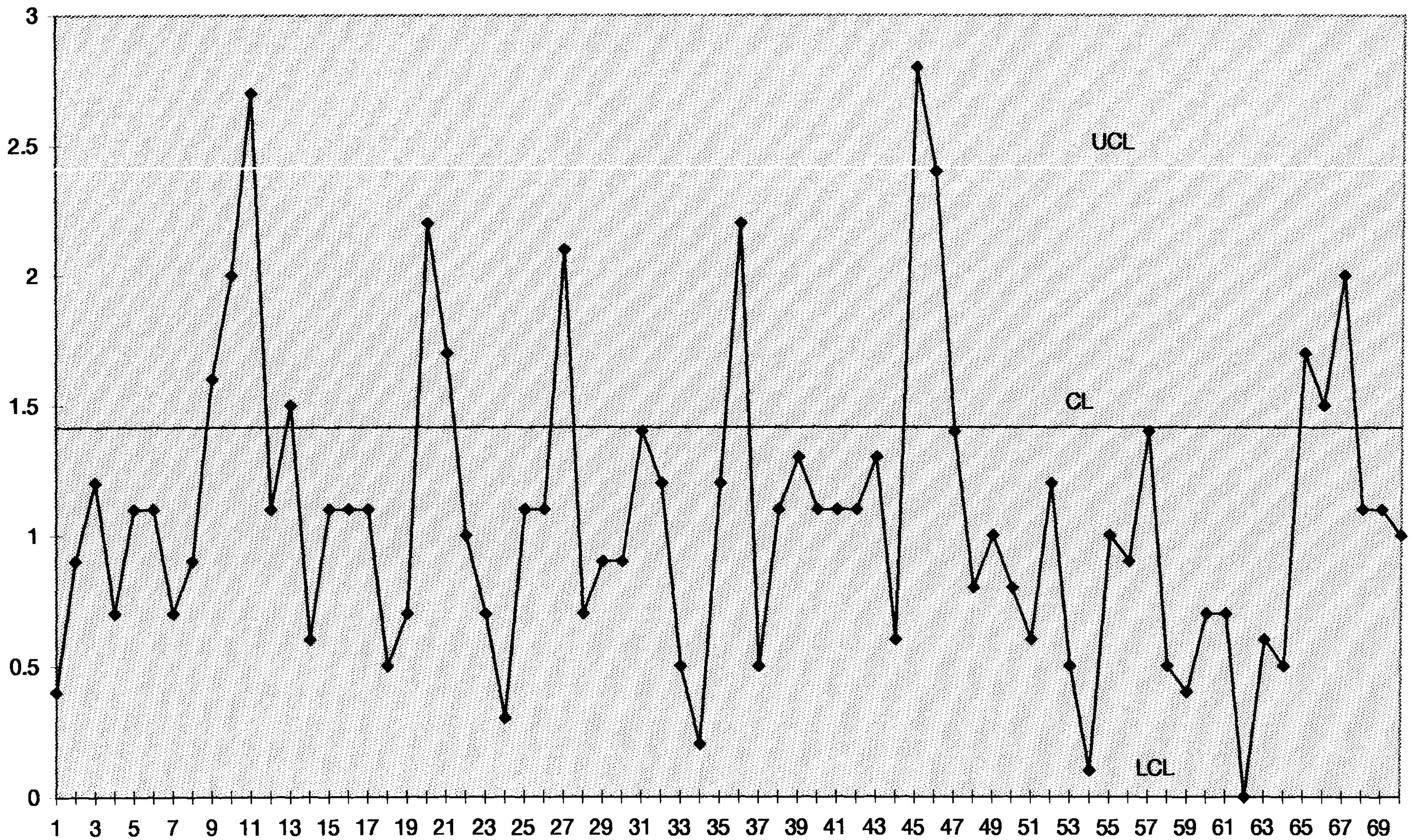


Figure 8

3. The control limits of the process are much greater than the process specification limits. The process capability index is equal to 0.14. Figure 9 shows a modified x (bar) chart from Figure 7 with the control process index (CPK) overlaying the process specification limits.

Under the current control system the operator can intuitively adjust or tweak the process . By allowing the operator to tweak the process when it falls either above or below the process specification limits, the operator is technically changing the process which is running within control limits. This practice goes against the idea of using control charts. Allowing the operator to continually tweak a process which is under control is introducing a major source of process variation. The current process as used , allows for process tweaking which is a major source of process variation.

Step 2: Measurement system development and gauge study

A gauge study was completed on the process measurement system in its current operating mode to determine its accuracy and repeatability. One study consisted of having 4 operators plus the process engineer and technician determine the sample mean x(bar) 20 times on a control board. The same board was used for all of the readings by each person and for every test. The data from the test is shown in Table 1. This data shows that the process variation of the measurement system (including the operator) has a range of 0.00072" (at -+ 3 sigma) which is greater than the operating band the process is trying to be controlled within. If the variability caused by using different operators is removed the process still has a large range. For example, operator 1 (in table 1) using the current

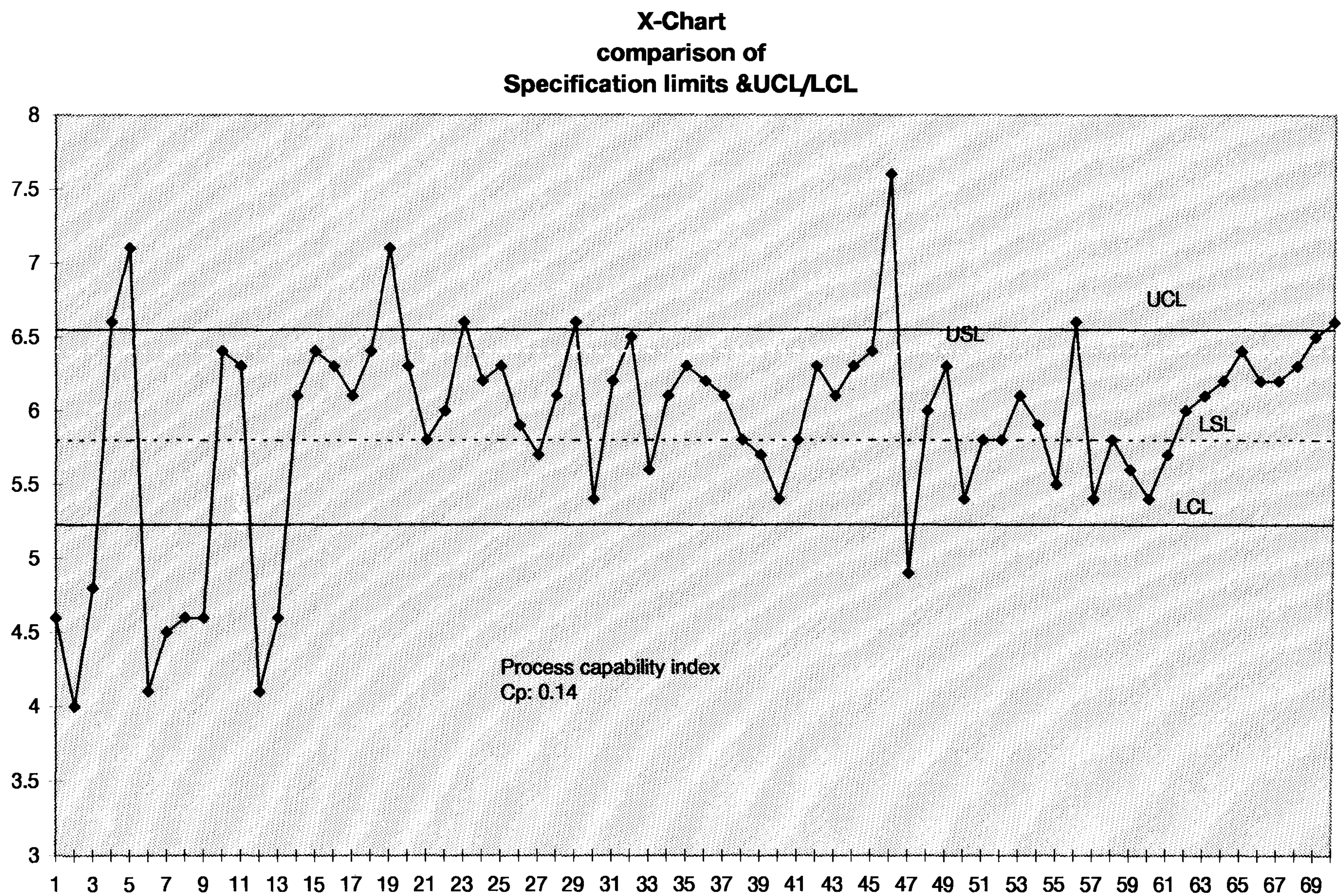

X-Chart
comparison of
Specification limits &UCL/LCL
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
UCL
USL
LSL
LCL
Process capability index
Cp: 0.14
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69

Figure 9

Screen Print Solder Paste Inspection

Solder paste height in 0.001"

Freq.	1	2	3	4	5	6
1	6.4	6.3	6.4	6.4	6.3	6.1
2	6.4	6.4	6.3	6.5	6.4	6.3
3	6.5	6.4	6.4	6.4	6.4	6.3
4	6.3	6.3	6.2	6.5	6.4	6.2
5	6.2	6.3	6.2	6.4	6.4	6.3
6	6.4	6.2	6.2	6.6	6.5	6.3
7	6.5	6.3	6.3	6.6	6.5	6.2
8	6.6	6.4	6.3	6.5	6.6	6.1
9	6.4	6.5	6.3	6.7	6.6	6
10	6.4	6.2	6.4	6.4	6.5	6.2
11	6.4	6.3	6.3	6.4	6.7	6.2
12	6.5	6.3	6.5	6.3	6.5	6.3
13	6.7	6.4	6.3	6.4	6.5	6.4
14	6.3	6.2	6.2	6.5	6.6	6.2
15	6.5	6.5	6.2	6.6	6.5	6.3
16	6.5	6.4	6.3	6.5	6.5	6.2
17	6.6	6.4	6.3	6.7	6.6	6.2
18	6.5	6.4	6.2	6.5	6.2	6.1
19	6.6	6.3	6.1	6.6	6.1	6.1
20	6.5	6.3	6.4	6.6	6.5	6

Analysis

Std. Dev	0.118766	0.088258	0.096791	0.109904	0.142441	0.107606
Mean	6.46	6.34	6.29	6.505	6.465	6.2
Median	6.5	6.3	6.3	6.5	6.5	6.2
Max	6.7	6.5	6.5	6.7	6.7	6.4
Min	6.2	6.2	6.1	6.3	6.1	6

Person to person variation

Mean	6.38
Std. Dev	0.119401
+ 3 sigma	6.734871
- 3 sigma	6.018463

System variation with random points
Table 1

operating system (upper specification limit of 0.0064") would have marked this board out of control for 11 of the 20 samples and in control for the remaining nine. This can be compared to operator six, who would have determined the process is in control all 20 times. This means that if the operator measures a point which is in control, there is a 50% chance that the solder paste height is actually out of specification. The opposite can also be said for a out of control condition being actually within the control limits.

Figure 10 shows the variability introduced by the measurement system plotted against the control chart used in the process. There are several locations on the chart where the variability of the measurement system could cause a data points to exceed the control limits of the process when the point was actually plotted within control. The range of each measurement outside the control limits shows the amount of uncertainty created by the measurement system.

In the next phase of the gauge study, the measurement process was re-evaluated . Instead of measuring random locations on the board , five fixed locations on the board were checked. Using fixed locations removes variation caused by choosing random location on the board . This required a procedure to be written so that the same pads were measured by each operator . This increased the board measurement time but assured the same pads were always evaluated. A summary of this data can be seen in table 2.

When compared to figure 10, the measurement process variability was reduced from 0.00072" to 0.00047". While this is an improvement it still leaves open issues on the

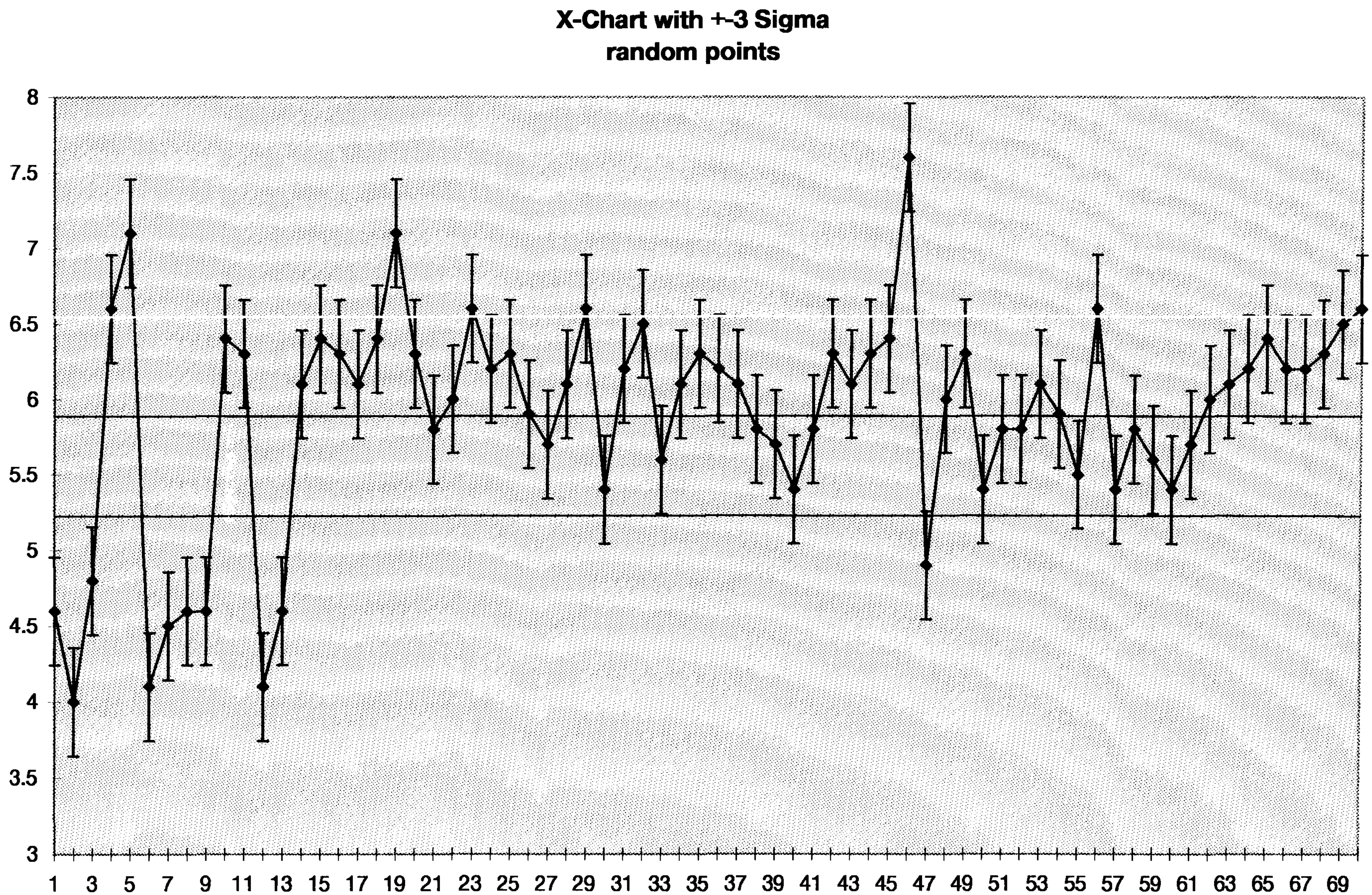

X-Chart with +-3 Sigma
random points
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69

Figure 10

Screen Print Solder Paste Inspection

Solder paste height in 0.001"

Freq.	1	2	3	4	5	6
1	6.4	6.3	6.2	6.4	6.3	6.2
2	6.4	6.3	6.2	6.4	6.4	6.3
3	6.5	6.3	6.3	6.4	6.4	6.3
4	6.4	6.3	6.2	6.4	6.4	6.4
5	6.3	6.3	6.3	6.4	6.4	6.3
6	6.5	6.3	6.3	6.5	6.4	6.3
7	6.5	6.4	6.4	6.5	6.5	6.4
8	6.6	6.3	6.3	6.5	6.4	6.3
9	6.4	6.2	6.3	6.3	6.5	6.3
10	6.4	6.3	6.2	6.4	6.3	6.4
11	6.4	6.2	6.2	6.4	6.4	6.4
12	6.5	6.1	6.2	6.3	6.5	6.3
13	6.3	6.3	6.3	6.4	6.5	6.4
14	6.4	6.3	6.3	6.5	6.6	6.5
15	6.5	6.4	6.3	6.4	6.5	6.3
16	6.5	6.3	6.3	6.5	6.5	6.4
17	6.6	6.3	6.3	6.4	6.4	6.3
18	6.5	6.4	6.2	6.4	6.3	6.4
19	6.5	6.3	6.1	6.4	6.3	6.3
20	6.5	6.3	6.3	6.5	6.5	6.5

Analysis

Std. Dev	0.082558	0.068633	0.068056	0.061559	0.08507	0.076089
Mean	6.455	6.295	6.26	6.42	6.425	6.35
Median	6.5	6.3	6.3	6.4	6.4	6.3
Max	6.6	6.4	6.4	6.5	6.6	6.5
Min	6.3	6.1	6.1	6.3	6.3	6.2

Person to person variation

Mean	6.37
Std. Dev	0.078533
+ 3 sigma	6.6031
- 3 sigma	6.1319

System variation with non-random points
Table 2

control chart ,which can be seen in Figure 11. To further prove this point of the variation in the measurement system causing incorrect decision about process control to be made, a Z-test on the data from figure 11 was developed. Table 3 shows that a paste height measurement below 0.0049 has a 100% chance of being out of control at the low end while a reading above 0.0069" as a 100% chance of being out of control at the upper end. But readings such as 0.0065", 0.0066", 0.0053", and 0.0052 have a very good probability of a false call being made. These false calls will introduce variation into the process which making managing the process more difficult.

To remove the variation of the measurement system from the process control system, a inline system which automatically measures the paste height was investigated. The system was selected and while it has not be delivered yet some acceptance testing was completed on the system prior to shipment. Table 4 shows summary data from a test which consisted of having the machine read a board 80 times to check for repeatability. The variation from this system was 0.00035". This variation was plotted onto the x bar chart which can be seen in figure 12. The variation in the measurement process has been reduced by 50% when compared to figure 10.

Conclusion:

The conclusion of the gauge study is that the current system is not capable of accurately and repeatedly measuring the output of the screen print process and therefore should not be used as part of the control system. The variability in the measurement system drives the operator to tweak a process that can be under control and not alter a process which

X-Chart with +- 3 Sigma
(specific points)

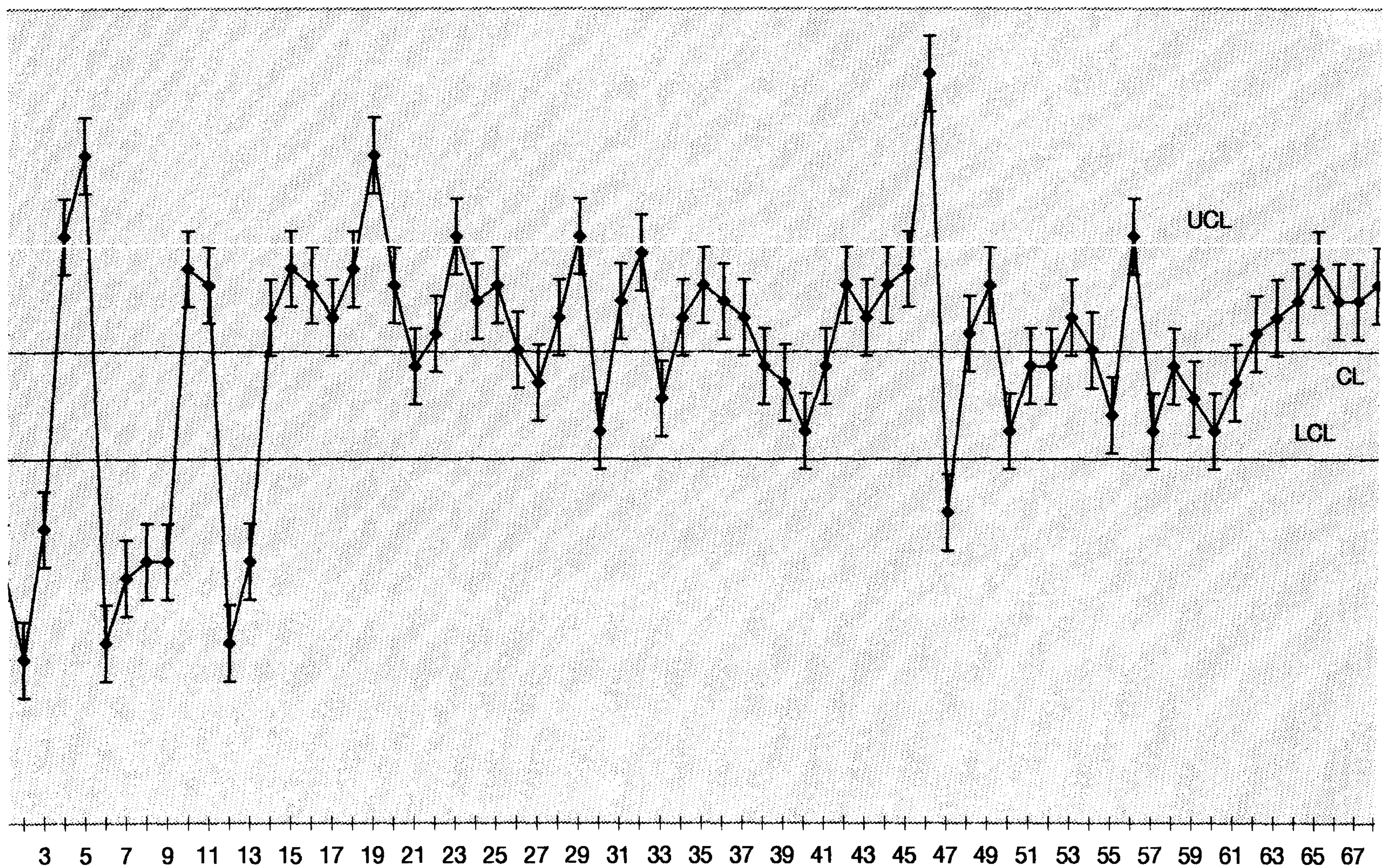


Figure 11

PROBABILITY THAT A GIVEN MEASUREMENT IS IN CONTROL

VALUE	PROBABILITY	
	IN	OUT
4.9	0.00%	100.00%
5.0	0.25%	99.75%
5.1	6.25%	93.75%
5.2	39.75%	60.25%
5.3	84.47%	15.53%
5.4	98.89%	1.11%
5.5	99.98%	0.02%
5.6	100.00%	0.00%
5.7	100.00%	0.00%
5.8	100.00%	0.00%
5.9	100.00%	0.00%
6.0	100.00%	0.00%
6.1	100.00%	0.00%
6.2	100.00%	0.00%
6.3	99.95%	0.05%
6.4	97.71%	2.29%
6.5	76.53%	23.47%
6.6	29.11%	70.89%
6.7	3.41%	96.59%
6.8	0.10%	99.90%
6.9	0.00%	100.00%

UCL = 6.5568
LCL = 5.2204
SIGMA = 0.0785

Table 3

Screen Print Solder Paste Inspection

Solder paste height in 0.001"

Sample #		Sample #		Sample #		Sample #	
1	6.2	21	6.2	41	6.3	61	6.2
2	6.2	22	6.2	42	6.2	62	6.2
3	6.3	23	6.3	43	6.1	63	6.2
4	6.2	24	6.2	44	6.1	64	6.3
5	6.1	25	6.2	45	6.2	65	6.3
6	6.3	26	6.2	46	6.2	66	6.2
7	6.2	27	6.2	47	6.3	67	6.3
8	6.2	28	6.3	48	6.2	68	6.2
9	6.2	29	6.2	49	6.2	69	6.2
10	6.3	30	6.2	50	6.3	70	6.2
11	6.2	31	6.2	51	6.2	71	6.3
12	6.3	32	6.3	52	6.2	72	6.3
13	6.2	33	6.3	53	6.2	73	6.2
14	6.4	34	6.2	54	6.3	74	6.3
15	6.2	35	6.2	55	6.2	75	6.2
16	6.3	36	6.2	56	6.3	76	6.3
17	6.3	37	6.2	57	6.2	77	6.2
18	6.3	38	6.2	58	6.3	78	6.3
19	6.2	39	6.2	59	6.2	79	6.2
20	6.2	40	6.2	60	6.2	80	6.2

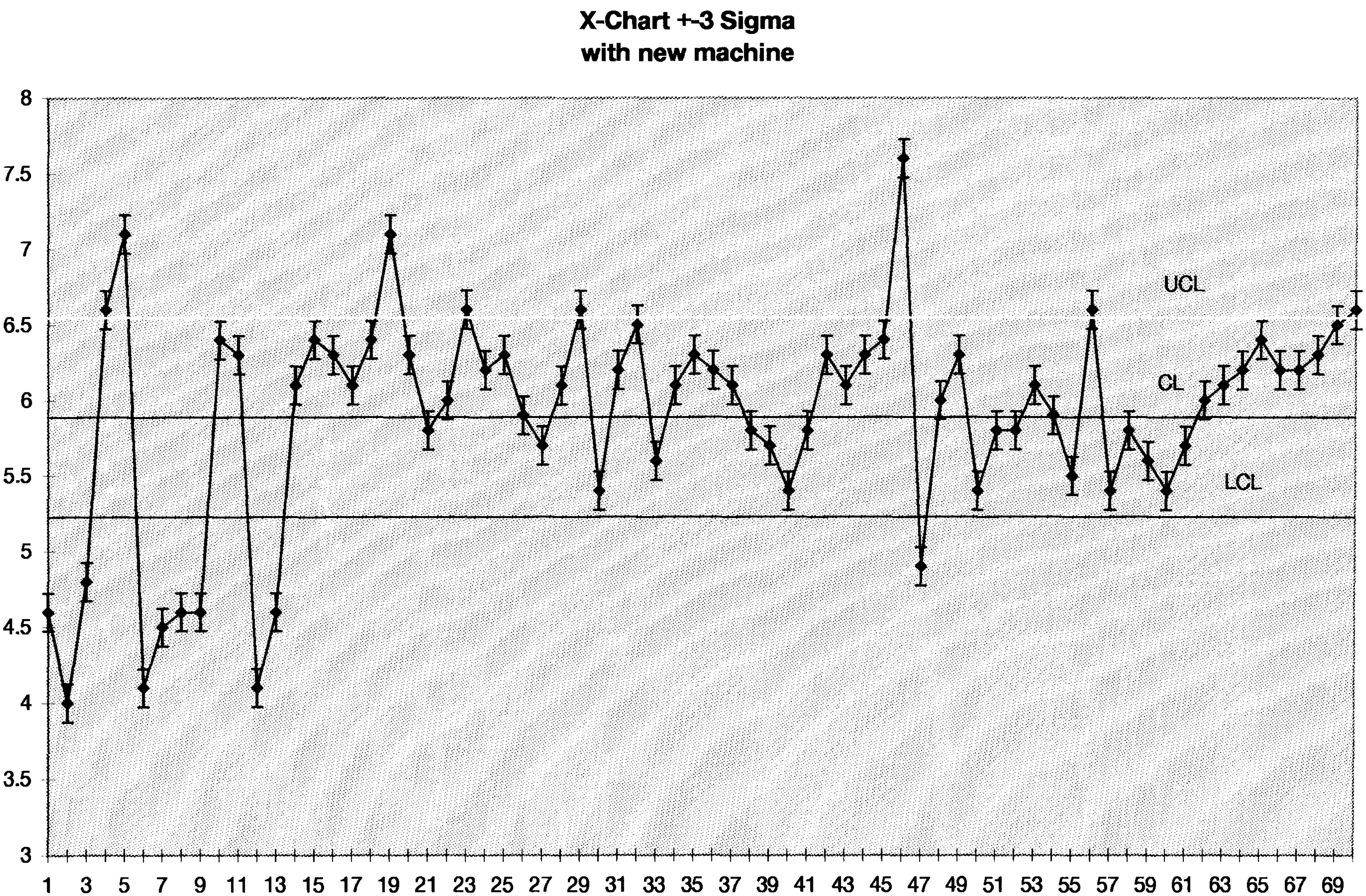
Analysis

Std. Dev	0.057063
Mean	6.23
Median	6.2
Max	6.4
Min	6.1

Std. Dev	0.057063
+ 3 sigma	6.401188
- 3 sigma	6.058812

Proposed system variation

Table 4



X-Chart +-3 Sigma
with new machine
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
UCL
CL
LCL
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69

Figure 12

is actually out of control. With the new proposed system, the chance of this happening has been reduced by 50%. The advantages of the new system are as follows:

1. An on-line system can measure 100% of the boards coming off the machine.
2. An on-line system can measure the exact same locations of every board identifying the x,y coordinates using a scan program. This eliminates the error created by random measured pads.
3. An on-line system would have a software routine for determining where the solder paste starts and the board pad ends. This would eliminate the most significant source of variation in the current measuring system.
4. An on-line system constructs control chart automatically and plots the measured points. This would allow keeping track of different products by plotting individualized charts.

Plan For Continuous Improvement:

Assuming the proposed system discussed above passes all of the criteria for acceptance testing, step 2 in the process development cycled would be completed. The next process step would be to go to step 3 which would be a passive data collection system to determine if the process is in control or not.