FLUX AMOUNT CONTROL FOR CONSISTENT PROCESS QUALITY.

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ABSTRACT

Flux is one of the most critical parameters in the selective soldering process. Flux deposition on the board needs to be carefully controlled. It should have the right balance between solderability and reliability. Flux has a major impact on barrel filling and defect production in challenging thermal applications. Robust flux design for selective soldering is therefore a critical factor. Partnership between flux and machine designers is a key component for success.

It is important that the right amount of flux is applied on the right spot with a defined spread. Flux must not penetrate into SMD areas. Selective solder flux may not be compatible with solder paste residues. Flux that is not activated may also affect reliability in the long term because of potential electro migration.

The application of flux is done by drop jet systems. Many high-volume applications require a high throughput. Short cycle-times can be achieved with high-frequency drop jets mounted on robots that can accelerate and decelerate quickly. Any clogging of the drop jet may result in solder defects like bridging or open joints. Spraying therefore becomes critical, and the flux supply may also be affected by outer noise such as clogging, flux pollution, pressure, temperature and other changes. Controlling the amount of flux may require a closed-loop system to guarantee a consistent process quality. This study evaluates the flux application process and tries to monitor the impact of drifts and changes. A method is shown where the process can be robust without being sensitive to noise. Statistical tools are used to prove repeatability in a selective soldering process and between different machines.

Key words: flux, selective soldering, control.

INTRODUCTION

The drop jet flux unit contains a vessel, filled with flux. The amount of flux is measured using a balance. The system gives a warning when the flux level reaches a minimum level so the operator is knows to refill when there is a production stop. There is also the option to have a second tank filled with flux that pours flux into the main tank when the minimum flux level is reached. In this case the machine can continue to produce and there is no production stop required for flux refill. The load sensor can be programmed at the levels the user requires and modified for fluxes with different density numbers.

The flux is supplied to the drop jet by pressure. There is a fixed pressure of 400 mbar on the flux supply vessel.

Figure 1. The main flux vessel is refilled by the flux from the replenish tank during production.

In the flux supply line there is a liquid flow meter – a high precision instrument for low flow rates. The sensitivity of this device is defined as less than 1 µl/min with a response time of 40 ms. The meter returns the amount of flux that was sprayed per board. This should be the amount of flux that is applied on the PCB unless there is flux bouncing back, or in case there is too much flux applied, flux is dripping off the assembly.

A small filter is installed in the line to keep the drop jet from clogging. The drop jet is a high-frequency device with an orifice of 180 microns. The amount of flux is controlled by two parameters of this drop jet:

- Open time [ms]
- Frequency [Hz]

The open time defines how much flux is sprayed the when nozzle opens. A longer time gives more flux and wider spreading. The frequency defines how many times the drop jet opens per second. This defines the number of droplets.

The drop jet is mounted on a robot that moves in X and Y directions to the spot on the PCB where the flux has to be applied. In case of a single droplet the wait time is an additional parameter. If a drag line is applied for a component, the robot speed is the other parameter affecting the flux amount.

The amount of flux that should be applied is defined in the product data sheet for the flux. However, this may be modified by the user. In case of poor wettable surfaces, due to oxidation or poor wettable component leads, the amount can be modified accordingly.

PROGRAMMING FLUX RECIPE

The software uses the Gerber data of the assembly to make the flux recipe, together with the flux database and board material data.

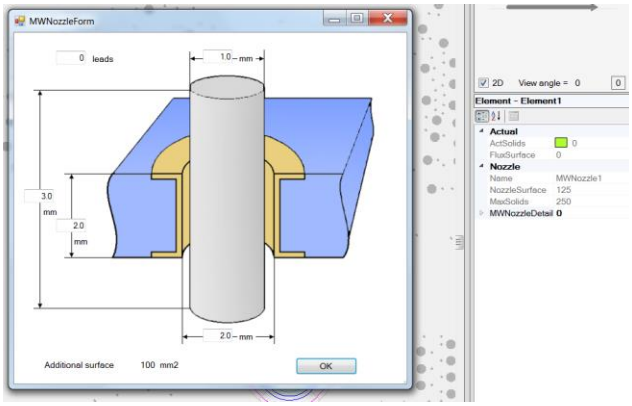

Figure 2. The hole and lead dimensions are used to calculate the metal surface area that requires flux to clean the surface and contribute to wetting.

A library of components and flux data supports the programming. After all flux areas are defined with the required drop jet settings the amounts are verified and the software defines the fastest routing for the robot.

Machine parameters that impact the amount and position of the flux are:

- Robot X and Y position [mm]
- Robot speed [m/s]
- Wait time [ms]
- Open time drop jet [ms]
- Frequency drop jet [Hz]
- Orifice diameter drop jet [µm]
- Pressure on tank [mbar]

To minimize the controls, the pressure on the tank, and the orifice diameter are fixed. The robot X and Y defines the position where all other factors have impact on the amount.

NOISE IN THE FLUX PROCESS

Apart from the machine parameters there are several unwanted noise factors that also have impact on the flux amount and makes the applied flux volume less consistent. These noise factors need to be monitored and quantified in order to make the flux process more robust and less sensitive to noise. Customers make recipes that they want to apply on all selective machines. It should not be necessary to modify a flux recipe if the boards are produced on another line or even on a selective solder machine anywhere else in the world.

The process window should be big enough to handle unwanted variations in the quality of the materials to be soldered. Although the process window is defined mostly by the flux capability, the noise factors should be reduced as much as possible.

Some noise factors are due to machine parts such as variation in the nozzles and flowmeter, pressure on the tank, clogging of the drop jet, air bubbles in hoses, and bending of the hoses. Other noise factors are material related, like solid content variations in flux, solder mask surface energy, different batches, flux contamination, and component surface.

Other noise factors are disturbances during production. This can be an E-stop, opening the flux tank for manual refill, lunch break, maintenance, etc.

In this report we attempted to measure the influence of this noise and tools were made to make the process robust.

DROP JET TO DROP JET VARIATION

The drop jet can be compared with an ink jet device. The difference is that this device is mounted upside down compared to a printer. The distance to the PCB is also much larger (bottom side components) so the spraying of the flux by the drop jet becomes more critical. The drop jet selected is used often in other industries like pharmaceutical applications where fine amounts have to be added precisely. The drop jet can work with very high frequencies, this allows fast movements under the PCB in order to reduce cycle times. For boards with many through-hole components, the fluxing might be the bottleneck in cycle time. Dual robot axis and multiple drop jets are options to minimize fluxing time.

When multiple nozzles are applied it becomes even more important that all spray the same flux amount at identical set points. The first experiment is to identify variation between the drop jets. Three different nozzles were used to flux ten different settings three times on two different machines to compare repeatability and nozzle to nozzle variation. The flux amount was measured with the flow meters, and for verification, 130 runs were also measured using a balance.

The drop jets were not used to eliminate variation due to contamination.

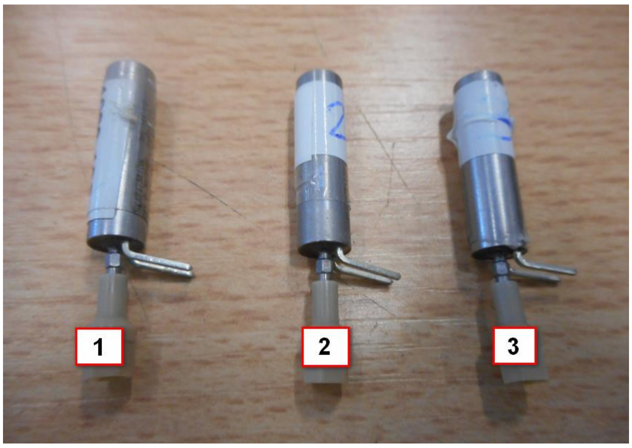

Figure 3. The three drop jets with a small filter unit on the bottom to prevent clogging.

This test only focus on variation between the drop jets. For this reason the flux program was very simple and didn't include movement of the robot. The drop jet was parked at its spray position and the flux was sprayed for 10 seconds onto the PCB. The amount was defined in two ways:

- Flow meter measuring the flow during the 10 seconds
- The flux was collected in a tissue and a balance was used to measure the amount

For the drop jet, the open time and frequency was varied. More data of the experiments can be found in the appendix. As shown in the next graphs there is quite a difference between the drop jets.

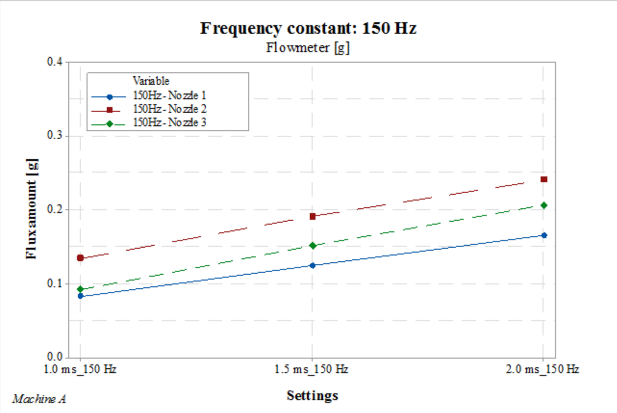

Figure 4. The measured flux amount [g] with the flow meter for different settings at 150 Hz for all three drop jets.

The variation is up to 40%. Most likely the tolerances on the orifice diameter and plunger stroke length of the drop jets are the cause of this. To overcome this variation there is a correction factor built into the software with a calibration procedure. The correction factor modifies the open time to a setting that make the flux volume equal to a reference value. Due to this calibration the amount of flux out of the drop jet is the same and so is the spreading.

FLOWMETER VERSUS BALANCE

The next graph shows the impact on the flux amount due to different factors. Changing open time and frequency is the way to control the amount in the software program. The drop jets (nozzle 1-3) show the variation as discussed. The flowmeter 1 and the balance were measuring the same flow. Flowmeter 2 was on a different machine. Variation between the flowmeters was low, but this will be investigated in a separate experiment later.

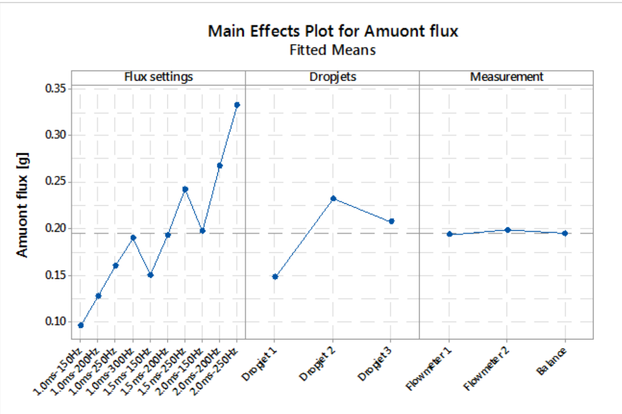

Figure 5. The control parameters of the machine (open time and frequency) versus the noise factors (different drop jets and flowmeters)

The data from flowmeter 1 and the measured weight on the balance are compared in a two-sample t-test. The hypotheses is "the mean of flowmeter 1 is different from the mean of the balance".

The results are listed in the summary in the next figure. The data concludes that there is not enough evidence that the mean of both methods differs. In other words, the amount of flux sprayed on the PCB (tissue) is equal to the flow measured with the flow meter.

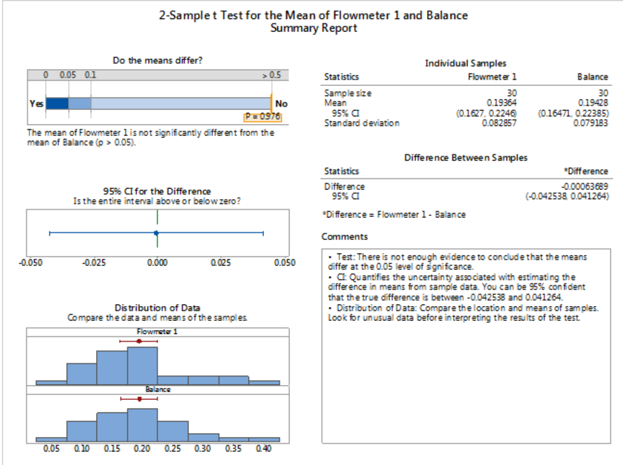

Figure 5. The results of the 2-sample t-test for measuring the flux amount with the balance versus the flowmeter.

GAGE R&R STUDY FLOWMETERS

This study defines the performance of the flowmeter. The Gage R&R experiment determines whether the flowmeter variability is small compared to the process variability. Three flowmeters are tested with the ten different settings that were also used in the previous experiment.

Table 1. Overview Gage R&R study

Run	Drop jet	Flowmeter	Parts (settings)
1	Nozzle 1	Flowmeter 1	1.0ms - 150Hz
2		Flowmeter 2	2.0ms - 150Hz
3		Flowmeter 3	2.0ms - 200Hz
4			1.0ms - 200Hz
5			1.0ms - 250Hz
6			2.0ms - 250Hz
7			1.5ms - 150Hz
8			1.5ms - 200Hz
9			1.5ms - 250Hz
10			1.0ms - 300Hz

All the three flowmeters where placed in serial so the data measured should be identical. The test was repeated three times.

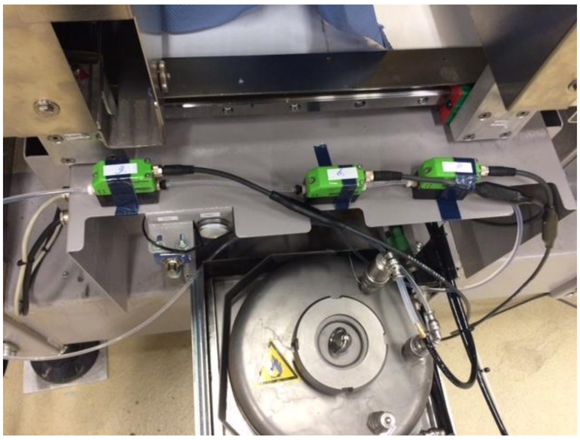

Figure 6. The flowmeters installed in one supply tube.

Gage R&R

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                                   %Contribution
Source               VarComp        (of VarComp)
Total Gage R&R           438                0.27
  Repeatability          438                0.27
  Reproducibility          0                0.00
    Operators              0                0.00
Part-To-Part          160958               99.73
Total Variation       161396              100.00


                                       Study Var   %Study Var
Source                 StdDev (SD)      (6 * SD)         (%SV)
Total Gage R&R              20.936        125.62          5.21
  Repeatability             20.936        125.62          5.21
  Reproducibility            0.000          0.00          0.00
    Operators                0.000          0.00          0.00
Part-To-Part               401.196       2407.17         99.86
Total Variation            401.742       2410.45        100.00


Number of Distinct Categories = 27
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Conclusions from the Gage R&R study are:
Total Gage R&R variation is 5.21% which is acceptable for a measurement in an application like this. A measurement is acceptable when the Gage R&R contribution is less than 10%. In the previous two-sample t-test it proved that the flowmeters return equal data compared to how much flux is applied on the PCB. In the Gage R&R study it proved that the flowmeters are repeatable and reproducible in measuring flux amount in an adequate way.

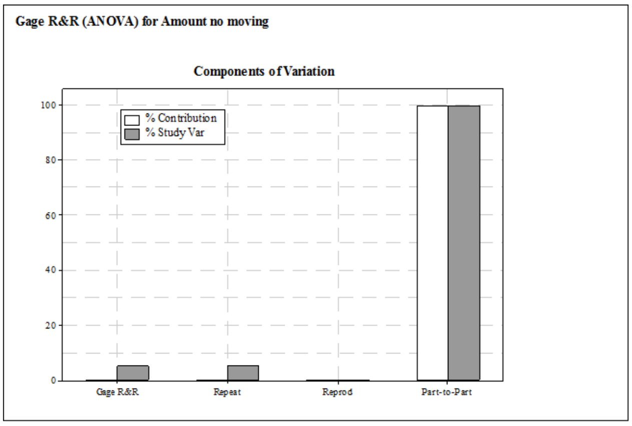

Figure 7. Showing the variation of the flowmeter versus the overall variation in the flux process.

The reproducibility of the flowmeters represents only 0.29% of the total process variation. In other words the differences between the flowmeters are small.

IMPACT OF SWITCHING DROP JET

During production the user may want to take out the drop jet and re-install it. Disconnecting the drop jet may introduce disturbances like air in the tubing, pressure drop or other noise. This test studies the different volumes of the drop jets, the effect of the drop jet direction (spray in X or Y direction) and the effect of purge time of the drop jet. The sequence during the runs is:

1. Machine in manual mode
2. Move to park position
3. Switch off pressure
4. Disconnect mounting strip of drop jet
5. Disconnect electrical wire drop jet
6. Remove drop jet
7. Install next drop jet
8. Connect electrical wire new drop jet
9. Mount unit back into the robot
10. Pressure back on to the system
11. Purge flux according to the set-point
12. Load next program

After a drop jet is installed the flux is purged through the drop jet to enable air bubbles to escape. The purge time is varied from 0.5 to 5 minutes to see if a longer purge results in a more consistent flow.

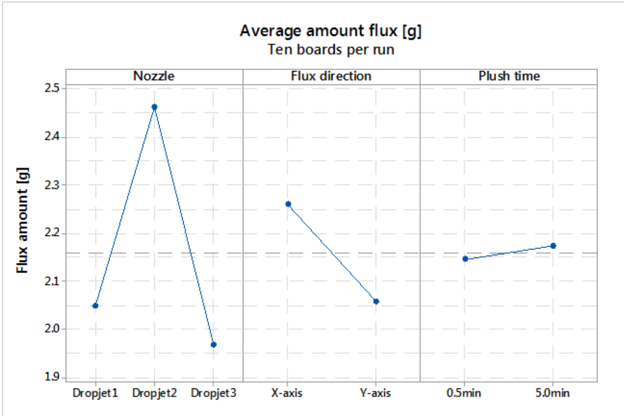

Figure 8. Most variation is between the drop jets.

Although the spray time and length is equal for the X and Y direction there is almost 10% variation. The routing of the supply hose and the friction as a result of that is the cause for the difference between both directions. The longer purge did not have a significant impact on the flux amount. The nozzle variation is less significant, as in the previous test, but still around 20%.

EFFECT OF EVENTS

So far the test showed variation in flux amount due to control and noise factors. However, once a process is running and there are no disturbances, the flux flow is very consistent. A machine capability analysis is done for each machine before shipping to the customer. This test is a run of at least 100 boards at the same settings to define the variation in the process. The next figure shows a probability plot of the flux amount for a drop jet set at 1.5ms – 100 Hz and fluxing in X and Y-direction for two strokes (one forward and one backwards) of 90 mm.

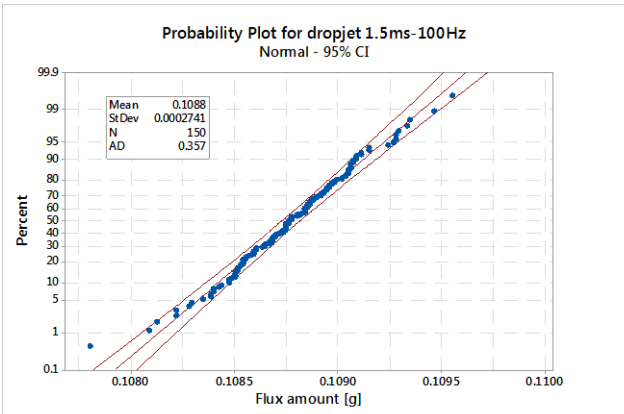

Figure 9. Showing a consistent flux amount for 150 boards.

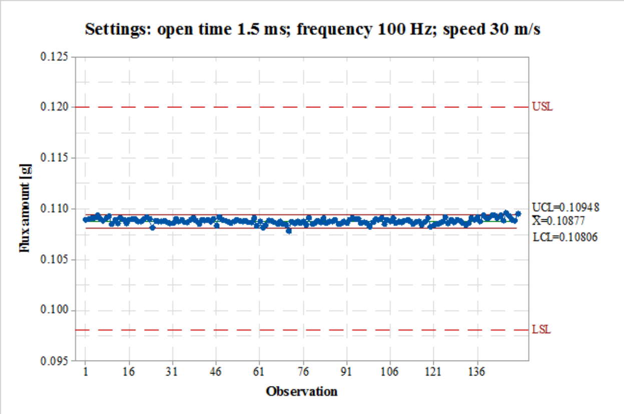

Figure 10. The data is consistent and has a Cp > 2.

The drop jet settings were changed to 1.5 ms open time and 300 Hz frequency. The machine was set to automatic mode and over 500 boards were fluxed with these conditions. The following events were applied to investigate their impact on the flux amount:

1. Load a new recipe
2. Start up the next day (machine off during the night)
3. E-stop
4. High power mode
5. One hour break
6. Open flux tank (pressure off)
7. Refill tank with flux (different flux level in tank)

During the production run, the total flux amount sprayed onto the board is recorded for every single board. This allows customers to trace issues since each board has a unique barcode number. Later, defects and flux amount can be compared. In this study the consistency of the flux amount sprayed, the effect of events on the average, and spreading of the flux are determined.

The experiment started with loading the new program and over 150 boards were run. The runs started immediately after selecting the program without cleaning the drop jet. This resulted in the lower amount for the first boards. After five boards the amount more or less stabilized. The machine was powered off and the experiment was continued the next day. Although the first boards showed flux volume similar to the previous runs, there was a significant drop in flux amount for some unclear reasons.

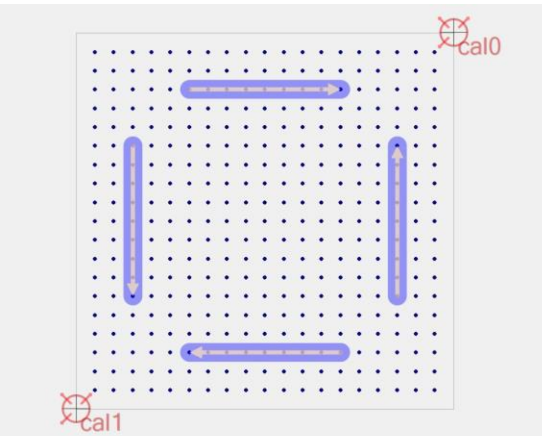

Figure 11. The flux program. Drags in all directions.

The following events: machine in high power mode, E-stop, production stop for one hour and opening the flux tank did not have an impact on the amount or on the spreading. Only when the flux tank was opened and 400 ml flux was added was the increase significant. But the amount dropped again after approximately 20 boards for some unclear reason.

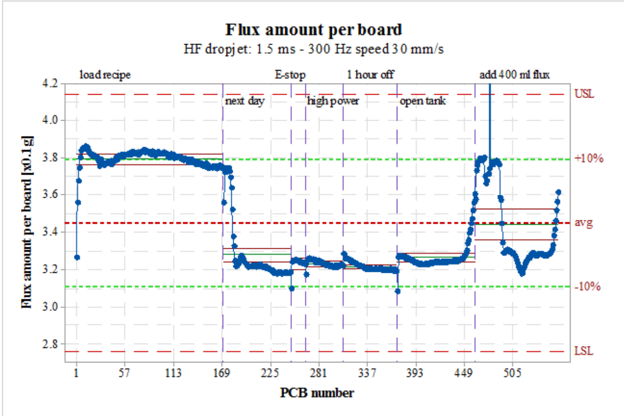

Figure 12. All events with their effect on the flux amount.

The data show different averages due to the events. However, of all 500 + data points, there is only one outlier. This board has to be inspected since from this data it is not clear if there is such a huge amount of flux on the board. Most likely there was a small air bubble in the tube due to the manual adding of the 400 ml flux. Inspection of the board clarified that there was no excessive flux.

FEASIBILITY FLUX CONTROL

The flux amount sprayed is quite consistent as long as there are no disturbances. The software has upper and lower alarm levels to make sure that flux amount does not exceed predefined limits (datasheet flux supplier).

The flux amount is influence by four factors:

1. Open time [ms]
2. Frequency [Hz]
3. Robot speed [mm/s] or wait time [ms]
4. Pressure on flux tank [mbar]

Open time is used for calibration of the drop jets, the frequency defines the number of droplets (change not preferred), and the robot speed also defines the cycle time (keep it fixed). This leaves the pressure on the flux tank as a parameter that can be used for control.

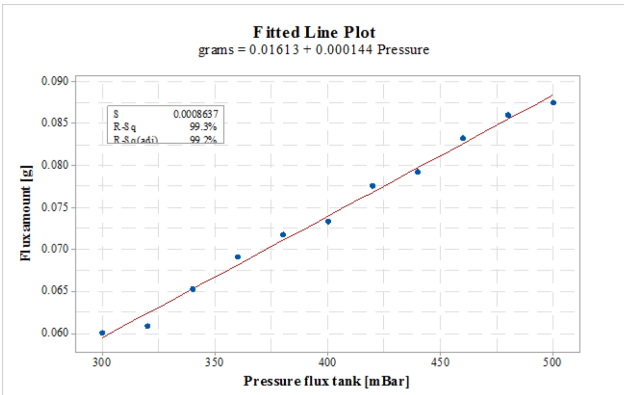

Figure 13. Shows that the flux amount is linear with the tank pressure.

The target is to apply 0.072 gram of flux on the PCB. The linear relation between flux tank pressure and flux amount is used to make a kind of closed loop system. After a board is fluxed the measured value corresponds to a pressure in the linear graph. This pressure is compared to the target pressure and the next run will have a modified tank pressure. The response time of the tank pressure (proportional valve) is fast enough to be ready before the next board enters the flux station. The board is fluxed and the data is recorded with different events to simulate disturbances.

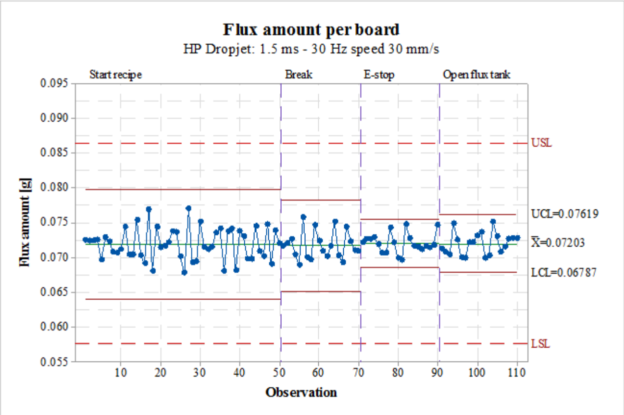

Figure 14. Showing the results of fluxing 110 boards.

The data shows slightly more spreading, but isn't sensitive to events anymore. Different from the previous data set with no control, there are no trends observed.

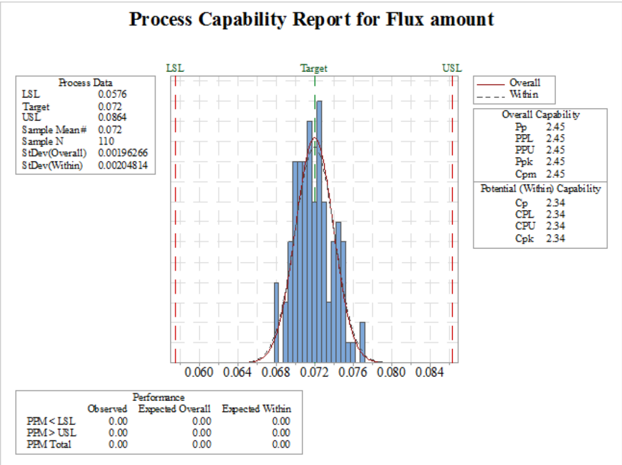

Figure 15. The gauss curve shows a Cp and Cpk > 2 which is acceptable for this application.

SPRAY DIRECTION

Due to the component clearance on the bottom side of the PCB, the distance from the drop jet to the board is approximately 30 mm. For this reason it is very hard to check the direction of the flux bundle. A fork sensor mounted on top of the drop jet is able to detect the presence of flux but not accurate enough to verify its direction. The spray bundle is shown in the next picture.

Figure 16. The spray bundle of the drop jet.

Although the drop jet sprays small droplets it is not possible to count droplets or define spray direction with a sensor or camera.

Figure 17. Test setup with drop jet spraying on paper and camera measuring the position and shape of the droplet.

In order to determine the center of the droplet and the shape the flux, a dedicated test setup was made. With additional light and self-made software it was possible to measure the offset from the target as well as the area with a special camera.

The data was automatically written in a text file so analysis could be done on position accuracy and droplet shape.

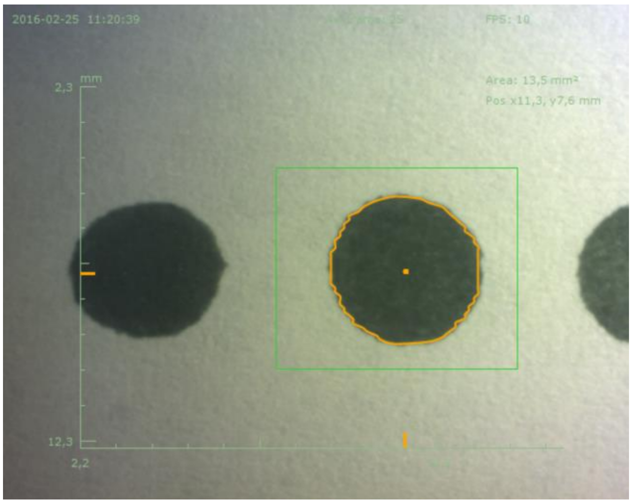

Figure 18. The X, and Y position of the center and the area are determined with the software.

The drop jet sprayed 150 times and that data is used to do statistical analysis. The probability plot shows a normal distribution of the measured area.

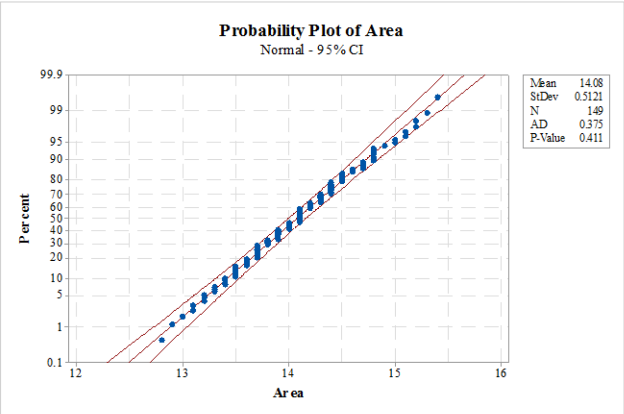

Figure 19. The area of the droplets in a normal plot.

One would like to keep the center of the droplet within ± 0.5 mm. All the scores are within this specification, however, it is unclear what the impact of the paper is on the spreading of the flux.

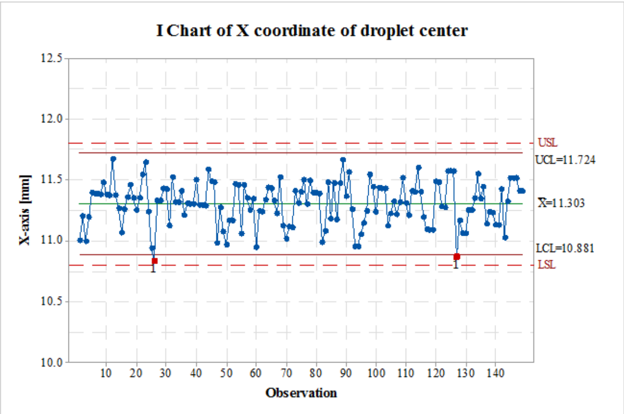

Figure 20. Center of the flux area X-coordinate

The same graph for the Y-axis shows identical variation. Also for this coordinate we have the same specification within ± 0.5 mm.

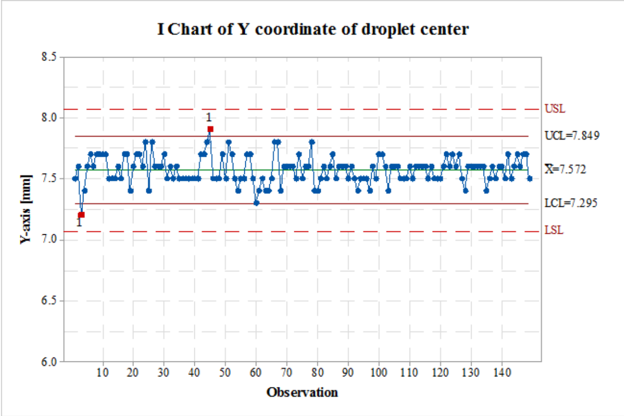

Figure 21. Center of the flux area Y-coordinate

Also in this test setup the impact of air bubbles in the flux tube can be visualized.

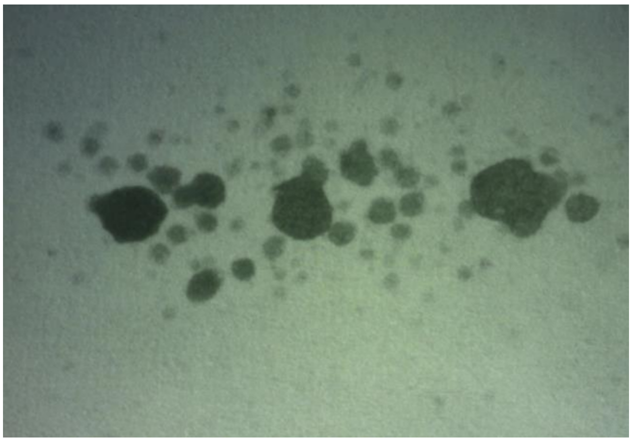

Figure 22. Three droplets influenced by air in the flux hose.

As shown in this picture the flux is spattered around the area where it was intended to be. This is a critical situation not only for the solderability, but also for reliability of the product afterwards. This kind of excessive air bubbles are identified by the flow meter and generates an alarm.

SUMMARY

In order to apply an accurate and consistent amount of flux there are several actions required to make the flux process more robust.

- Drop jets show deviations from each other. A calibration tool in the software equals better performances.
- The Gage R&R showed that the flowmeters are capable of measuring these small flux amounts and the data is repeatable.
- The flux system is consistent and capable when there are no disturbances. Events like E-stop or opening the flux tank may result in an offset of flux amount.
- To refill the flux the use of a replenishment tank is recommended.
- The feasibility study showed that the tank pressure might be used for correction of the flux amount.

- Small filters should avoid clogging of the drop jet.
- Replenish tank should be used for refilling of the flux. This not only to avoid production intervention but also to make sure no air is able to enter the flux supply.

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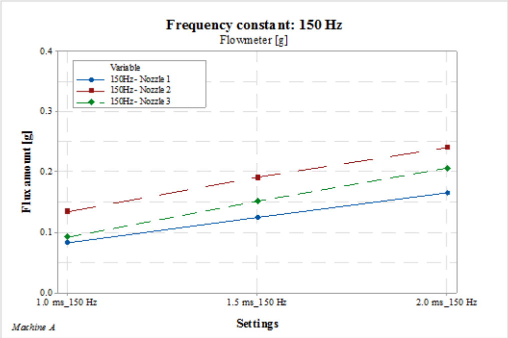
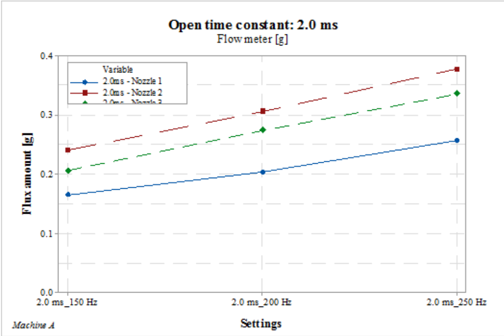
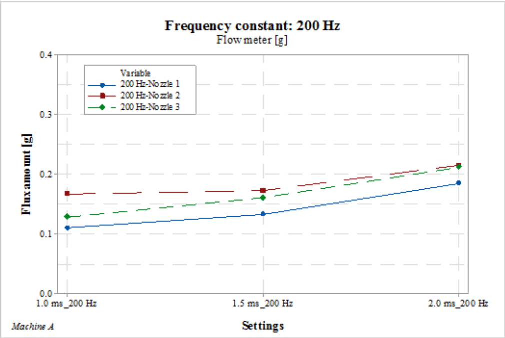
APPENDIX 1



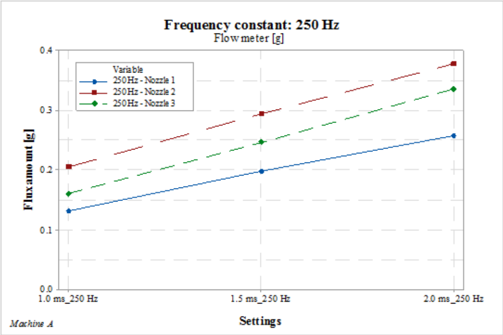
Frequency constant: 150 Hz
Flowmeter [g]
Variable
150Hz - Nozzle 1
150Hz - Nozzle 2
150Hz - Nozzle 3
Flux amount [g]
Settings
1.0 ms_150 Hz
1.5 ms_150 Hz
2.0 ms_150 Hz
Machine A



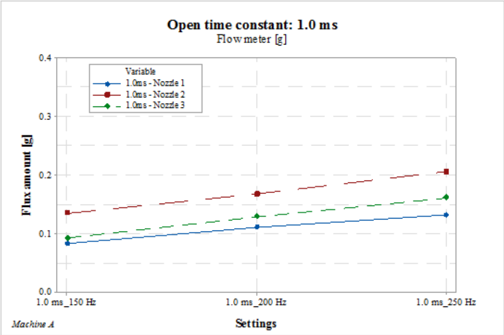
Open time constant: 2.0 ms
Flowmeter [g]
Variable
2.0ms - Nozzle 1
2.0ms - Nozzle 2
Flux amount [g]
Settings
2.0 ms_150 Hz
2.0 ms_200 Hz
2.0 ms_250 Hz
Machine A



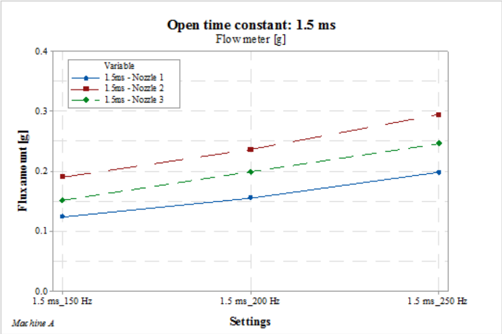
Frequency constant: 200 Hz
Flowmeter [g]
Variable
200 Hz-Nozzle 1
200 Hz-Nozzle 2
200 Hz-Nozzle 3
Flux amount [g]
Settings
1.0 ms_200 Hz
1.5 ms_200 Hz
2.0 ms_200 Hz
Machine A



Frequency constant: 250 Hz
Flowmeter [g]
Variable
250 Hz - Nozzle 1
250 Hz - Nozzle 2
250 Hz - Nozzle 3
Flux amount [g]
Settings
1.0 ms_250 Hz
1.5 ms_250 Hz
2.0 ms_250 Hz
Machine A



Open time constant: 1.0 ms
Flowmeter [g]
Variable
1.0ms - Nozzle 1
1.0ms - Nozzle 2
1.0ms - Nozzle 3
Flux amount [g]
Settings
1.0 ms_150 Hz
1.0 ms_200 Hz
1.0 ms_250 Hz
Machine A



Open time constant: 1.5 ms
Flowmeter [g]
Variable
1.5ms - Nozzle 1
1.5ms - Nozzle 2
1.5ms - Nozzle 3
Flux amount [g]
Settings
1.5 ms_150 Hz
1.5 ms_200 Hz
1.5 ms_250 Hz
Machine A