Process Optimization for Fine Feature Solder Paste Dispensing

Maria Durham, Greg Wade, and Brandon Judd
Indium Corporation
Clinton, NY

John Boggiatto
ITW EAE – Speedline Technologies
Franklin, MA

Abstract
With the rapid trend towards miniaturization in surface mount and MEMs lid-attach technology, it is becoming increasingly challenging to dispense solder paste in ultra-fine dot applications such as those involving chip capacitors or BGA packages, as well as dispensing ultra-fine lines in MEMs lid-attach applications. In order to achieve ultra-fine dots and fine line widths while dispensing solder paste, both the solder material and dispensing equipment need to be optimized. Optimizing the equipment can be very challenging, as there are many input variables that can affect the dispense quality of the solder paste. In this paper we will evaluate the many equipment variables involved in the solder paste dispensing process, and the impact these variables have on the dispense quality of the solder paste.

Introduction
The continuing miniaturization of surface mount technology for personal electronic devices has made it challenging to print ultra-fine solder paste deposits which are acceptable for such applications. Dispensing is becoming an increasingly popular option to utilize in order to produce the ultra-fine solder paste deposits. However, it can still prove challenging to dispense solder paste for applications such as chip capacitors, BGA packages, and MEMs lid attachment. Improperly dispensing fine dots or lines can cause significant problems on the manufacturing line such as equipment down time and rework costs. Due to this, it is extremely important to have an optimized dispensing process for these fine dot and line applications. This paper will discuss results that show which equipment variables can be used to achieve ultra-fine dots and lines with solder paste.

Equipment Parameters
The variables studied covered both equipment hardware and input parameters, including auger dispense versus time pressure dispense, RPM, line width/dot size, dispense height, and supply pressure.

1. Dispensing Hardware Type:
Two types of dispensing mechanisms were used for this testing: auger mechanism (Archimedes valve) and time-pressure (see Figure 1). The auger mechanism (Figure 1a) is a mechanism that consists of an Archimedes screw powered by a servo electric motor. The auger mechanism can be adjusted by varying the speed of the screw and the pitch/depth of its threads. The paste is fed to the screw from a syringe under a constant low pressure. A time pressure mechanism (Figure 1b) is a mechanism that uses pulsed air to push the piston in the solder paste syringe out of a needle.

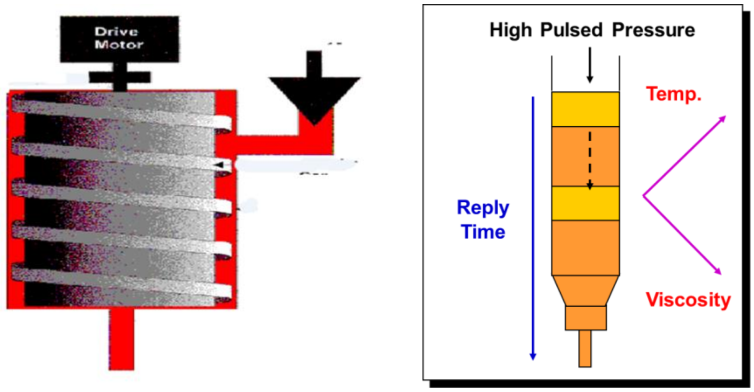

Figure 1. (a) Auger Mechanism, (b) Time Pressure Mechanism

2. RPM:
Revolutions per minute (RPM) would only be applicable to the auger mechanism, and is the rate at which the auger screw turns.

3. Line Width/Dot Size:

- Lines:
  - For the auger mechanism, the line width refers to the number of degrees of rotation of the auger screw per millimeter of needle X/Y travel over the surface of the board. For time pressure dispensing, line width is the number of milliseconds per millimeter of needle X/Y travel over the surface of the board. Entering a large line width in the machine software produces a taller and/or wider line by increasing the solder paste volume.
- Dots:
  - The dot size entered into the machine software is the number of degrees of rotation of the auger screw for the auger mechanism. For the time pressure mechanism; dot size is the number of milliseconds of on time of the supplied pressure.

4. Dispense Height:
The input of dispense height in the machine software is the height at which the needle dispenses the material from in relation to the surface of the board.

5. Supply Pressure:
The supplied pressure is the amount of pressure that pushes on the piston in the syringe.

Design of Experiment (DOE)
The five variables above were the focus for this experiment. Since equipment variables were the focus, the solder paste for all testing remained constant. A no-clean, halogen-free paste with95Sn/5Ag alloy and a Type 6-SG powder mesh size was utilized. Bare copper-OSP FR-4 boards (210 x 155 mm) were used for all of the testing as shown in Figure 2. The dispense needle for all testing also remained constant, and was a 30 gauge ceramic needle as shown in Figure 3. For the auger dispensing, a 1.575mm (0.062”) outer diameter ultra-shallow cut lead screw was used exclusively as shown in Figure 4.

Figure 2. Test Cu-OSP Board

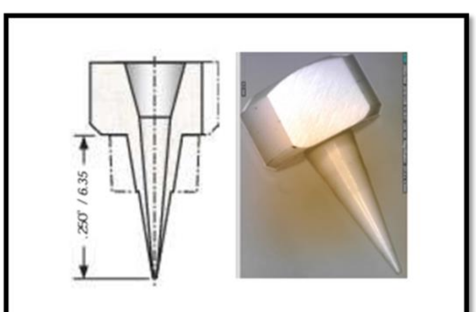

Figure 3. Ceramic Needle **Figure 4. Shallow Cut Auger**

Lines

For line dispensing, 224 25.4mm (1”) lines were used for evaluating consistency from line-to-line. This was the case for both auger and time pressure dispense mechanisms. An example of the testing is shown in Figure 5.

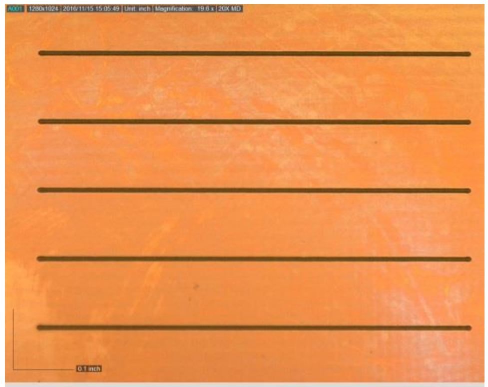

Figure 5. Example of five dispensed 1” lines

- **Auger**
  - For the auger, we varied four different parameters to see their effect on the measured line width. These parameters include: RPM, supply pressure, dispense height, and line width. For this testing, optimal parameters were determined to produce the best line, and these settings were used as a baseline throughout the testing. For auger, the baseline parameters are shown in Table 1.

Table 1. Baseline Auger Line Parameters

RPM	Pressure	Dispense Height	Line Width
40	10 PSI	0.080mm	60

  - For RPM, we varied this parameter from 10 RPM to 50 RPM; for pressure we varied this parameter from 2 PSI to 18 PSI; for dispense height, we varied this parameter from 0.050mm to 0.160mm; and for line width, we varied this parameter from 20 to 100. When each parameter was varied, the remaining parameters were kept constant and the baseline parameters were used.

- **Time Pressure**
  - For time pressure, we varied two different parameters to see their effect on the measured line width. These parameters include dispense height and line width. For this testing, an optimal baseline line was developed based on the final width and consistency of the line. For time pressure, the baseline parameters are shown in Table 2.

Table 2. Baseline Time Pressure Line Parameters

RPM	Pressure	Dispense Height	Line Width
40	4.5 PSI	0.060mm	350

- For dispense height, we varied this parameter from 0.050mm to 0.160mm, and for line width we varied this parameter from 250 to 650.

Dots

For dot dispensing, 1,800 dots were dispensed to evaluate consistency. This was the case for both auger and time pressure dispense mechanisms. An example of the testing is shown in Figure 6.

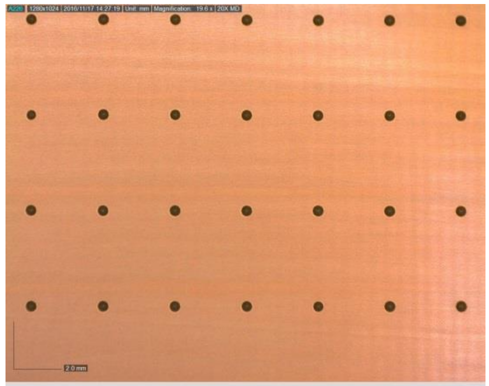

Figure 6. Example of dispensed dots

- **Auger**
  - For auger, we varied four different parameters to see their effect on the measured dot diameter. These parameters include RPM, supply pressure, dispense height, and dot size. For this testing, a baseline dot was developed based on the optimal final dot diameter and consistency. For auger, the baseline parameters are shown in Table 3.

Table 3. Baseline Auger Dot Parameters

RPM	Pressure	Dispense Height	Dot Size
40	10 PSI	0.080mm	50

  - For RPM, we varied this parameter from 10 RPM to 90 RPM; for pressure, we varied this parameter from 2 PSI to 18 PSI; for dispense height, we varied this parameter from 0.050mm to 0.160mm; and for dot size, we varied this parameter from 10 to 90. When each parameter was varied, the remaining parameters were kept constant and the baseline parameters were used.
- **Time Pressure**
  - For time pressure, we varied two different parameters to see their effect on the measured dot diameter. These parameters include dispense height and dot size. For this testing a baseline dot was developed based on the optimal final dot diameter and consistency. For time pressure, the baseline parameters are shown in Table 4.

Table 4. Baseline Time Pressure Dot Parameters

RPM	Pressure	Dispense Height	Line Width
40	4.5 PSI	0.060mm	250

  - For dispense height, we varied this parameter from 0.050mm to 0.160mm, and for dot size we varied this parameter from 175 to 400. When each parameter was varied, the remaining parameters were kept constant and the baseline parameters were used.

Results

After analyzing the measured data from the performed testing the following test results were collected:

Auger

- **Lines**
  - For the auger, results for the dispensed lines with the change in RPM are shown in Figure 7. The measured line width shows that there was only a slight increase in line width when the RPM was increased, but it was not a significant change. This indicates that the RPM does not have a significant change on the final measured line width when all other variables are kept constant.

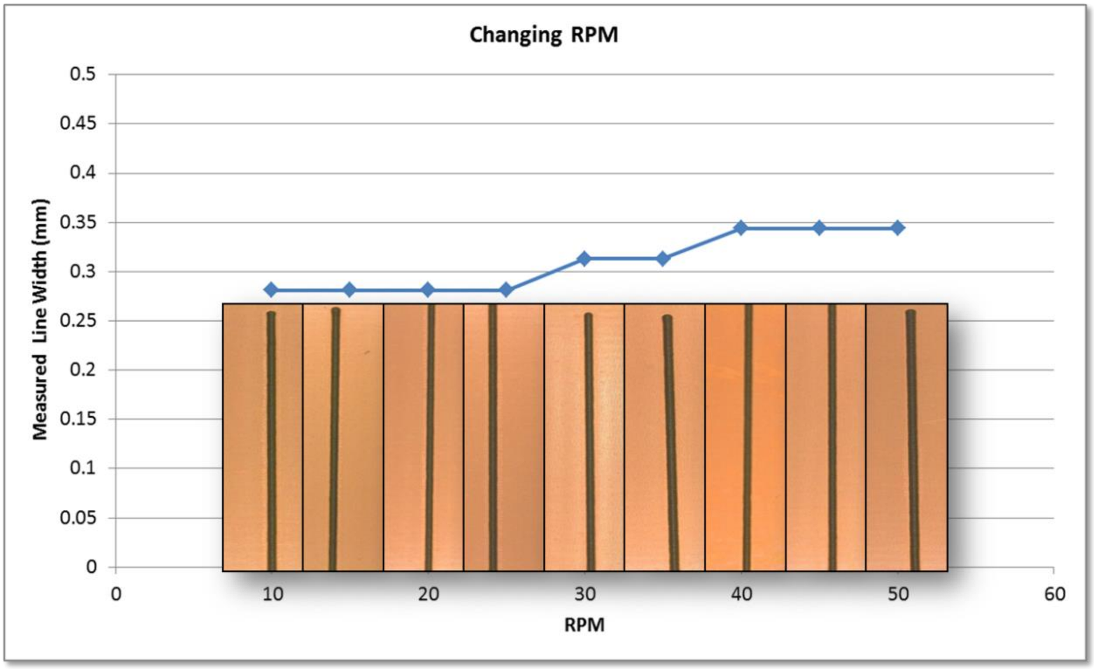

Figure 7. Measured line width versus RPM

- For the auger, results for the dispensed lines with the change in pressure are shown in Figure 8. The measured line width shows there was no significant change when the pressure was increased and all other variables are kept constant. However, if the pressure was increased further, a clog would have occurred because too much paste would be forced into the auger and through the fine gauge needle. A soft clog was already seen at 16 PSI.

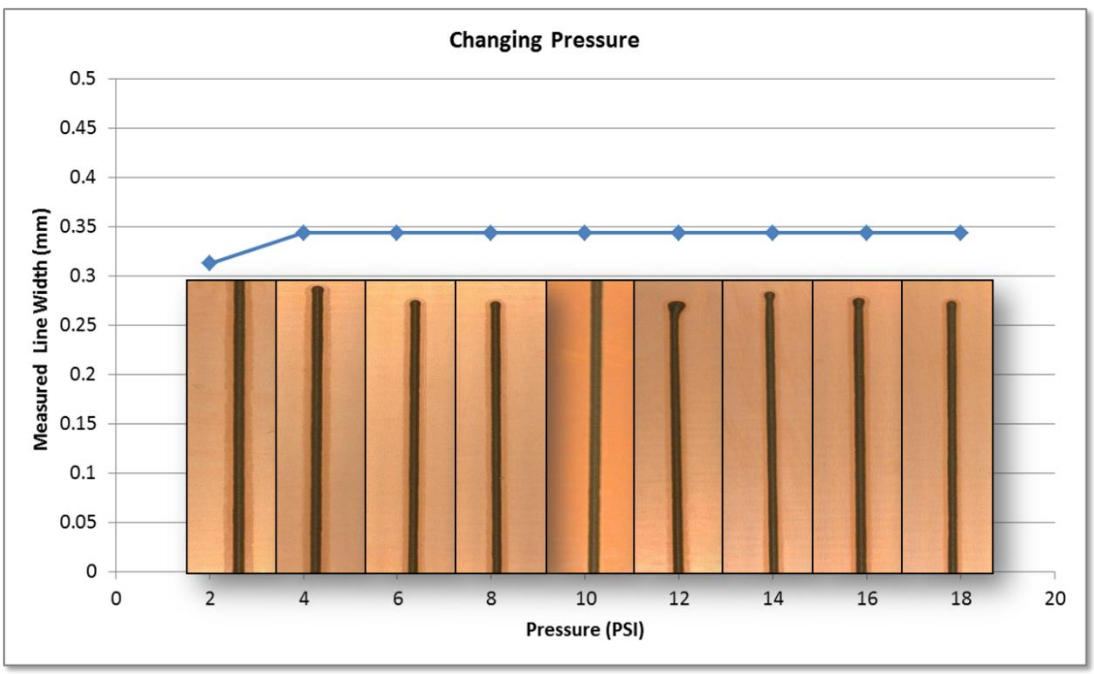

Figure 8. Measured line width versus pressure

- For the auger, results for the dispensed lines with the change in dispense height are shown in Figure 9. The measured line width shows there was no significant change in line width when the dispense height was increased, but there was a significant impact on line quality. As the dispense height increased, the quality of the line decreased because the further away from the surface of the board, the harder it is for the paste to create a constant and consistent line.

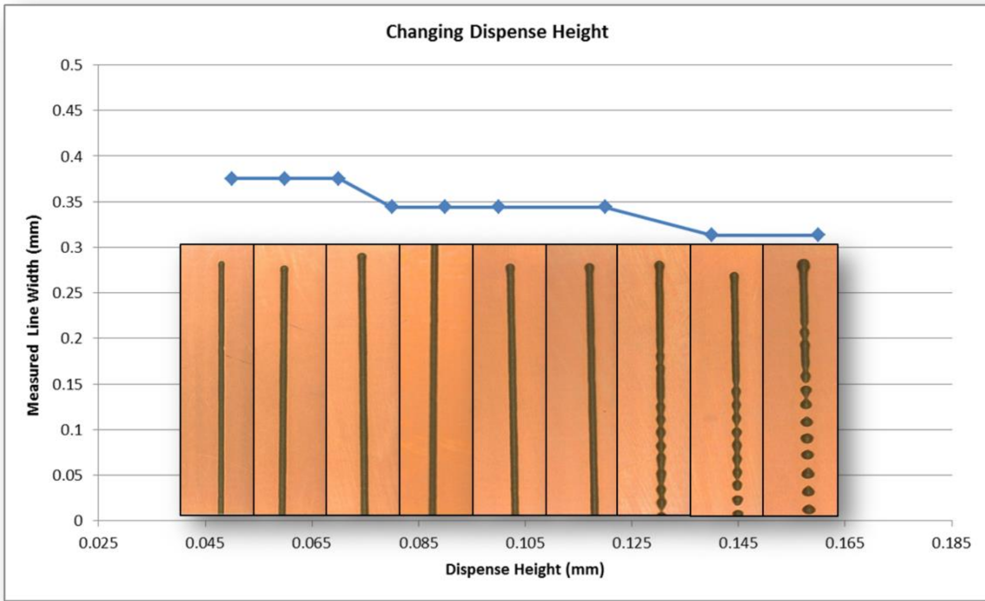

Figure 9. Measured line width versus dispense height

- For the auger, results for the dispensed lines with the change in line width are shown in Figure 10. The change in the line width shows there was a significant impact on measured line width as well as the quality of the line. The lower the line width, the lower the volume of paste that is being dispensed, therefore creating inconsistent lines. Also, a higher dispense width number indicates that a larger measured line width is produced, as more paste is being supplied.

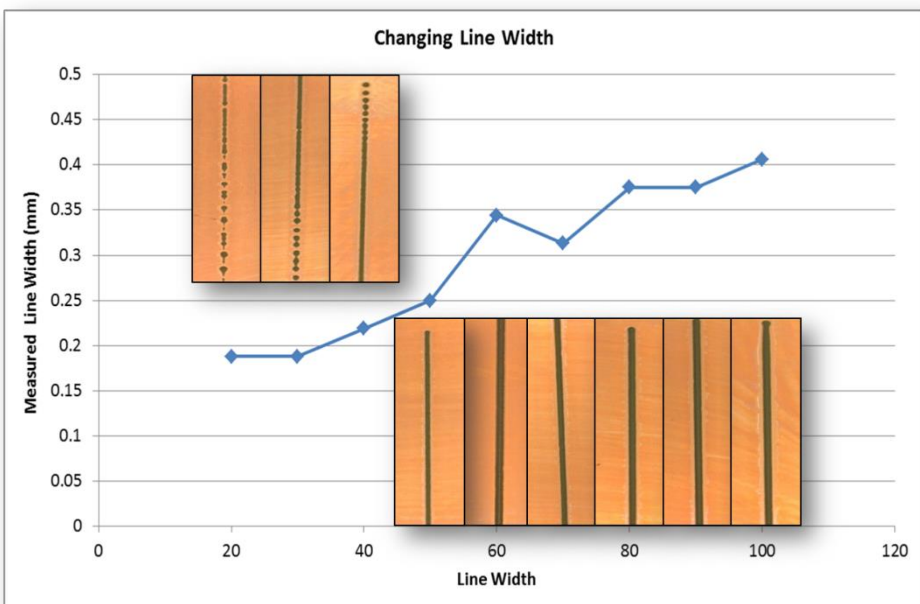

Figure 10. Measured line width versus line width

- **Dots**
  - For the auger, results for the dispensed dots with the change in RPM are shown in Figure 11. The measured dot size was not affected as the RPM was increased. This indicates that the RPM does not have a significant change on the final measured dot size when all other variables are kept constant.

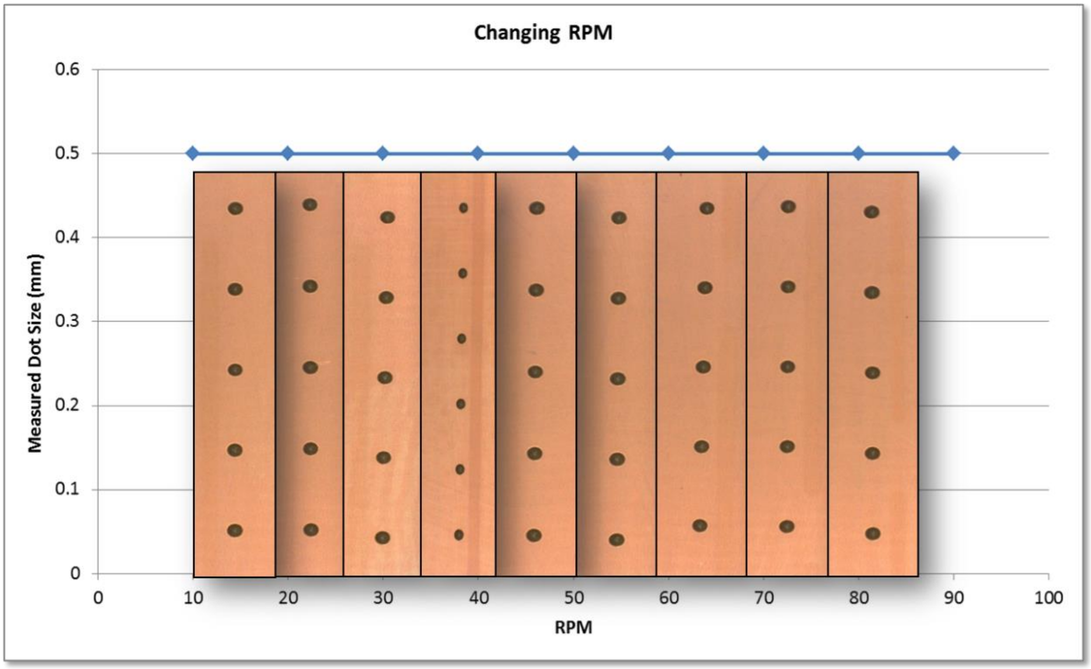

Figure 11. Measured dot size versus RPM

- For the auger, results for the dispensed dots with the change in pressure are shown in Figure 12. The measured dot size shows that there was no significant change as the pressure was increased when all other variables are kept constant. However, if the pressure was increased further, a clog would have occurred because too much paste would be forced into the auger and through the fine gauge needle.

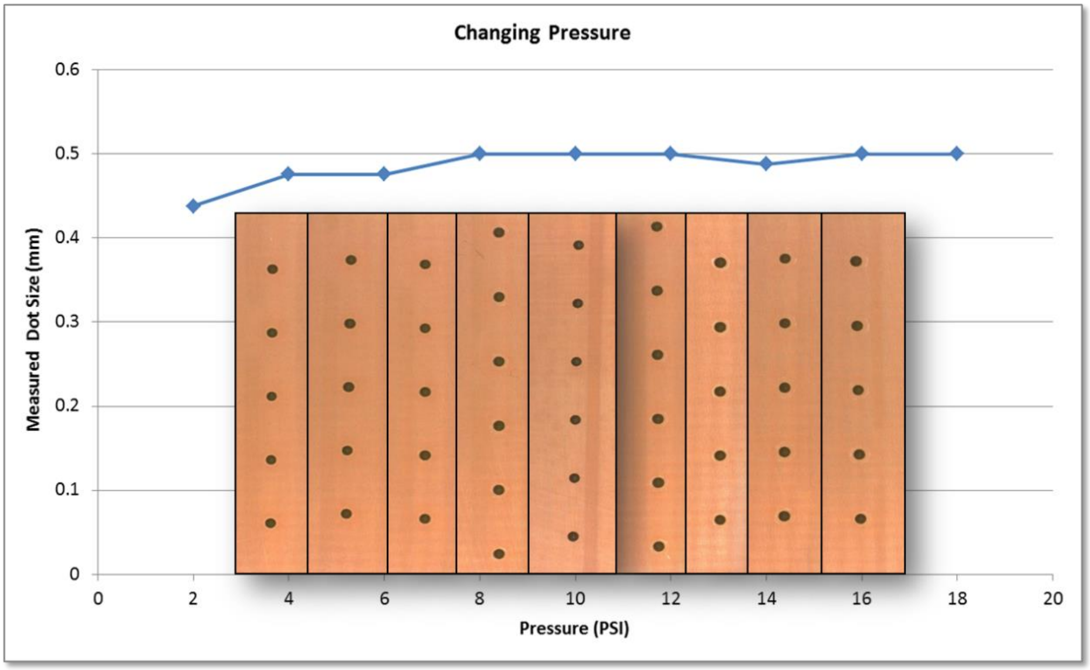

Figure 12. Measured dot size versus pressure

- For the auger, results for the dispensed dots with the change in dispense height are shown in Figure 13. The measured dot size shows there was not a significant change in dot size as the dispense height was increased, but there was a significant impact on the consistent dot quality. As the dispense height increased, the quality of the consistent dot quality decreased because the further away from the surface of the board, the harder it is for the paste to create a consistent dot-to-dot.

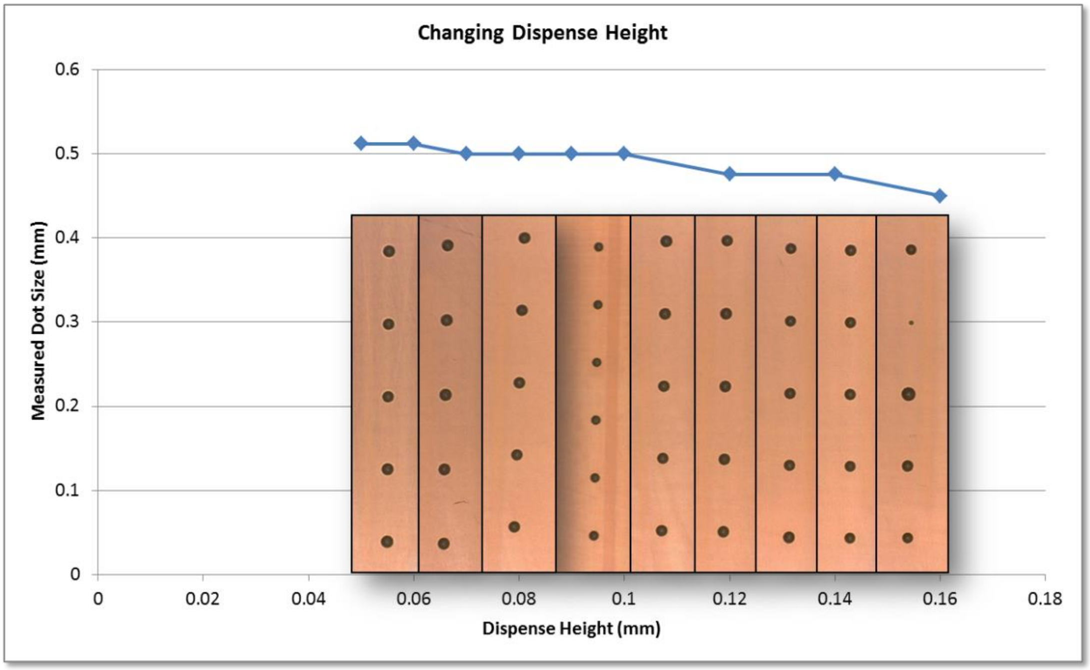

Figure 13. Measured dot size versus dispense height

- For the auger, results for the dispensed dots with the change in dot size are shown in Figure 14. The measured dot size shows there was a significant impact on measured dot size as well as the consistent dot quality. The lower the dot size, the lower the volume of paste that is being put out, therefore creating inconsistent dot-to-dot. Also, the higher the dot size number the larger measured line width is produced as more paste is being supplied.

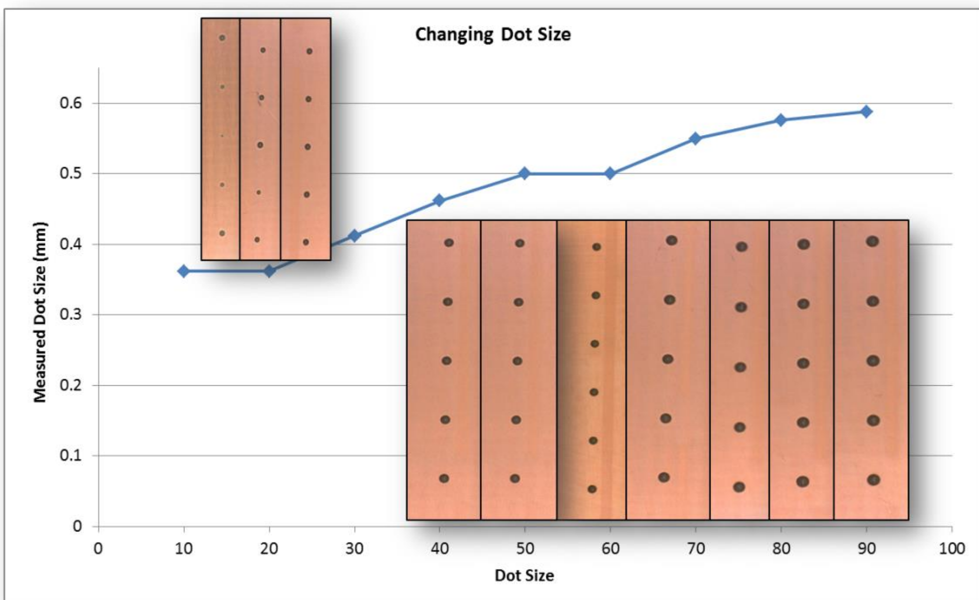

Figure 14. Measured dot size versus dot size

Time Pressure

The optimal settings for one type of mechanism are not necessarily the same for another**.** Figure 15 shows an example of this, comparing an auger mechanism to a time pressure mechanism dispensing lines using the same input parameters. For time pressure, the settings had to be adjusted to get the same quality line or dot that we were able to achieve by the auger mechanism. To obtain the same quality, the dispense height had to be lowered, the pressure had to be lowered, and the line width had to be increased.

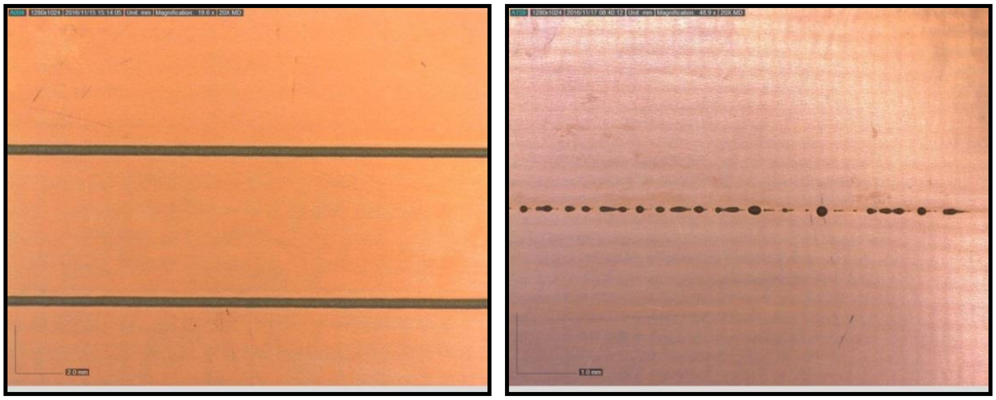

Figure 15. (a) Auger Dispense, (b) Time Pressure Dispense

- **Lines**
  - For the time pressure dispensed, results change in dispense height are shown in Figure 16. There was not a significant change in line width as the dispense height increased, but there was a significant impact on line quality. As the dispense height increased, the quality of the line decreased because the further away from the surface of the board, the harder it is for the paste to create a consistent line. The quality of the line was so bad at the dispense height of 0.160mm that the line width was not able to be measured.

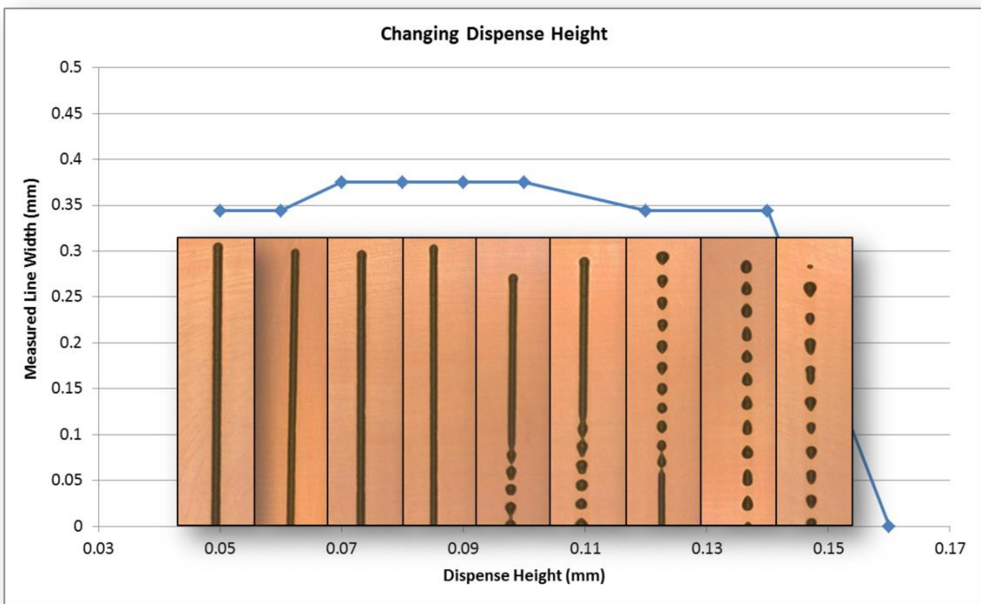

Figure 16. Measured line width versus dispense height

  - For the time pressure dispensed, results for the change in line width are shown in Figure 17. There was a significant impact on the measured line width and no impact of the quality of the line. Also, a higher dispense width number indicates that a larger measured line width is produced, as more paste is being supplied.

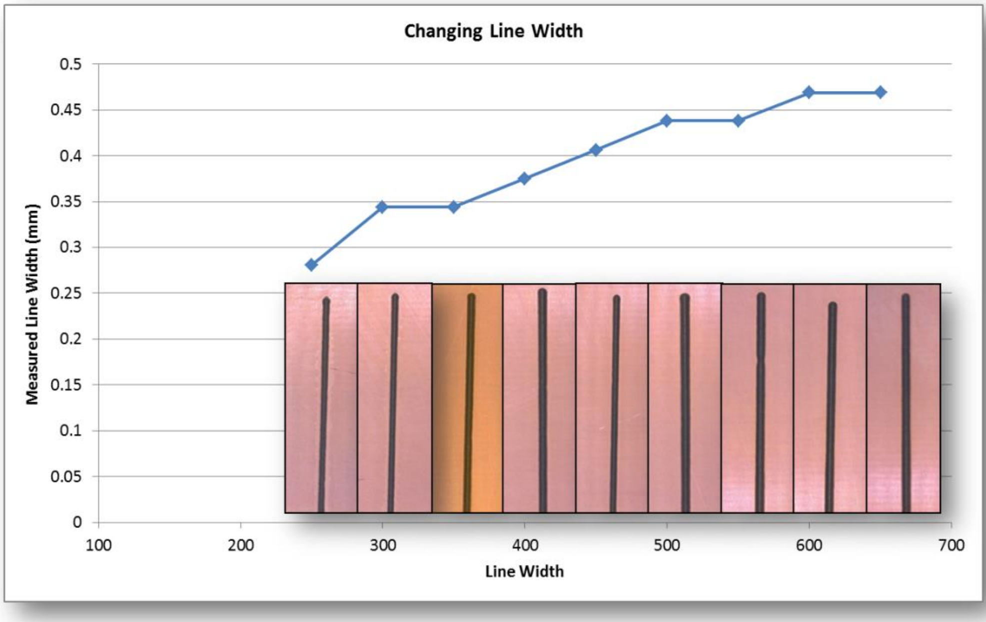

Figure 17. Measured line width versus line width

- **Dots**
  - For the time pressure dispense, results for the dots with the change in dispense height are shown in Figure 18. There was not a significant change in dot size as the dispense height was increased. However, there was a significant impact on the consistent quality of the dots. As the dispense height increased, the quality of the dot-to-dot consistency decreased because the further away from the surface of the board, the harder it is for the paste to create consistent dots repeatedly.

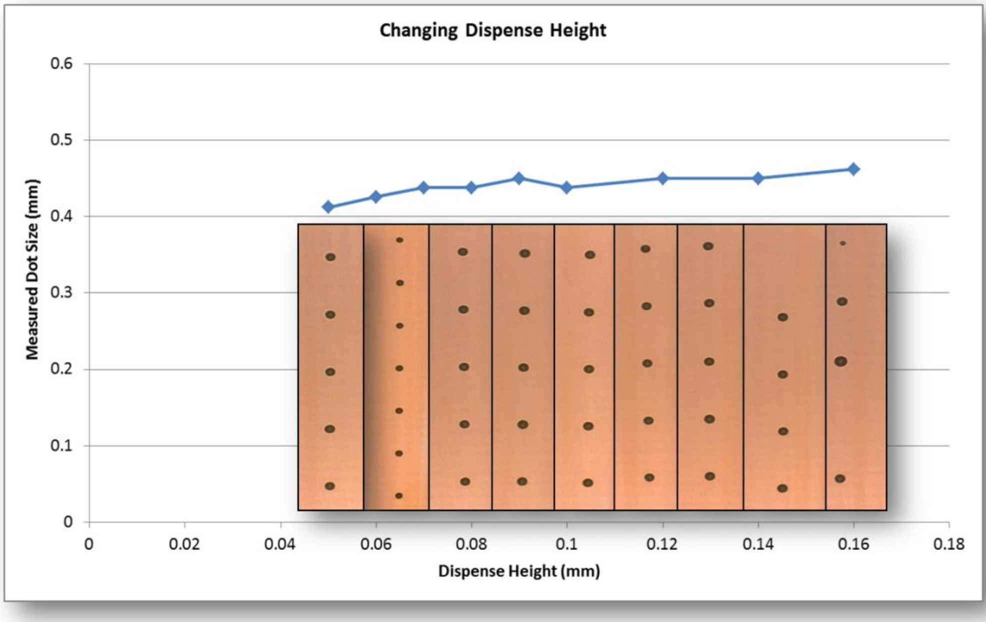

Figure 18. Measured dot size width versus dispense height

  - For the time pressure dispense, results for the dots with the change in dot size are shown in Figure 19. There was a significant impact on measured line width and the quality from dot-to-dot. The higher the dot size number is, indicates that the larger the measured dot size was produced, as more paste is being supplied.

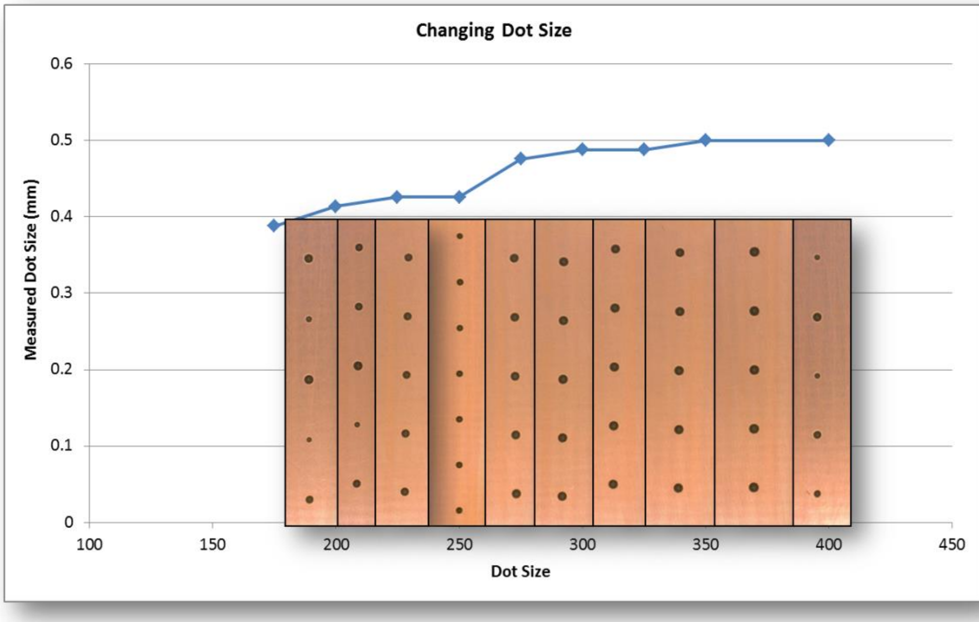

Figure19. Measured dot size width versus dot size

Conclusion

While the changes exhibited in the graphs show a definite trend, the changes are relatively small in many cases. In this testing, we intentionally changed only one parameter at a time. Had multiple settings been changed, the effect on line width and dot size would have potentially been greater. In this test, only one board of each parameter was tested. More extensive testing would involve significantly more samples to be produced to ensure the process is repeatable and consistent. The RPM parameter did not have a significant change on the final measured line width or dot diameter when all other variables are kept constant. This parameter would have had a more significant impact if line width/dot size was changed in conjunction with it. The supplied pressure also did not have a significant impact on the final measured line width or dot diameter when all other variables are kept constant. If the pressure was increased further, a clog would have occurred as too much paste would be forced into the auger and through the fine gauge needle. This had been seen in other testing. Dispense height had more of an effect on the fine measured line or dot diameter. As the dispense height increased, the dot quality/repeatability or line quality decreased because the further away from the surface of the board the needle is, the harder it is for the paste to create a repeatable dot or line. The dot size or line width input parameter had the greatest impact on the final measured line width or dot diameter, but if too small a number or too large a number is used without changing any other parameters, there will not be a consistent dot or line. The other aspect of this paper shows that with hardware technology, the optimal settings for one type of mechanism are not necessarily the same for another. The results for this testing show that having the correct combination of parameters such as the hardware technology, the RPM, the supplied pressure, the dispense height, and the line width or dot size is critical in producing an ultra-fine and consistent line or dot in applications such as those involving chip capacitors or BGA packages, or MEMs lid-attach applications.

Reference

[1] Achieving Ultra-Fine Dot Solder Paste Dispensing – Dr. Richard Ludwig and Dr. Ning-Cheng Lee (Indium Corporation), Steven Rocco Marongelli, Sergio Porcari and Sumil Chhabra (Universal Instrument Corporation)