Improved Maintenance and Reliability for Large Volume Underfill Processes

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Abstract
An ever-increasing number of electronics assembly applications are using flip chip packages that require large volume underfill. Large volume underfill is typically defined as being for a die size greater than 12 x 12 millimeters and requiring the underfill volume to be >20 milligram (mg). These types of high volume, high speed, precise underfill processes in High Volume Manufacturing (HVM) are posing significant challenges to meeting higher Units per Hour (UPH) requirements; in some cases these requirements mean up to a 33 percent increase when compared to the previous year's output.

Streaming is gaining favor as a fast and robust non-contact dispense method for underfill; however, when streaming underfill over an extended time, the volume of material passing through the pump may cause problems that impact dot volume repeatability. This is due to the fluid pathway containing dead spaces, which trap the material, complicating flushing and contributing to fluid adhesion over time. Such dot volume fluctuations may lead to undesired fillet size variations, and result in defects. This paper examines proven methods of mitigating dot variations and providing for better maintenance, such that the large volume underfill process can be run without maintenance for more than 3 weeks, an unheard-of zero maintenance interval to date. This paper will also address the challenges faced during dispensing of large volume underfill in HVM, and how control of a number of variables affecting underfill dispensing can achieve up to 3 week zero maintenance intervals for higher throughput and process reliability.

Introduction
To enhance the reliability of many hand-held communication devices, electronics assembly industry has been hunting for materials that can achieve an unprecedented array of complex and demanding requirements like high glass transition temperature (Tg) and high modulus, low temperature fast cure and outstanding processability. Development of underfills has also accelerated due to introduction of epoxy-based laminates for today's Package on Package (PoP), Wafer Level Chip Scale Packages (WLCSP), Chip Scale Packages (CSP) and Ball Grid Array (BGA) devices.

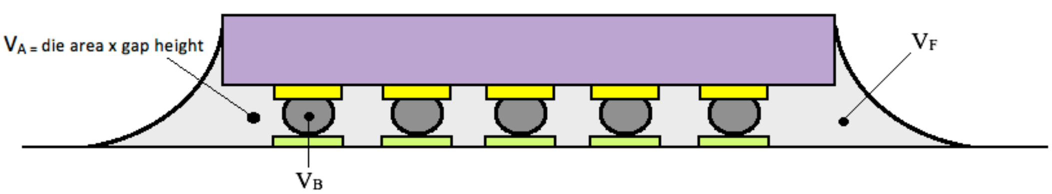
It is necessary for flip chip applications to be able to redistribute stress away from the solder joints to extend thermal aging and product life cycle. Some flip chip underfills are formulated with a high loading of specialty fillers to counter such problems. This also allows for low Coefficient of Thermal Expansion (CTE), which help flip chip encapsulants maintain the ability to flow fast in small gaps, possessing high glass transition temperatures and high modulus.

Underfill BGA
Underfills are generally made of two-part epoxies. These are packaged tightly in syringes, avoiding contaminants as well as eliminating any air from entering into the syringe; it is then stored in a freezer at a temperature of -40˚C. These kinds of underfills have a shelf life of 12 months from the date of manufacture specified on the content label. Materials need to be removed from the freezer to thaw for at least one hour at room temperature to make them workable. In the thawing process, the two part epoxies begin to react slowly and the viscosity can increase in some cases by 25 to 30%. It is advised by the manufacturer to use the underfill syringe completely within the product recommended work life. Many materials have extended work life, in some cases reaching 3 days at room temperature.

The goal of the Underfill process is to dispense the required volume of material to completely underfill the die and form a fillet around the edges without having material extend outside of a predetermined keep out area. The required dispensed volume (V_D) is the volume of total area between the die and the board (V_A) minus the volume of the bumps (V_B) plus the volume of fluid in the fillet around the die (V_F).

If more fluidic volume is dispensed, then the fillet will be outside of its designated keep out area, and if less fluidic volume is dispensed then the die has insufficient volume which leads to air pockets that reduce the reliability of the BGA joint. In both cases either there is fluid on top of the component or variation of volume underneath the die which is unacceptable leading to rework.

$$V_D = V_A - V_B + V_F$$



Paradigm shift in Applying underfill

Applying capillary and no-flow underfill processes can be accomplished through various methods, mainly needle dispense or jetting operations. In high volume assembly operations involving underfill, a series of problems along with some innovative solutions have occurred to achieve a sustainable production process. One of the most common problems is maintaining the dispensed volume of material over the chip and to avoid any contamination over the adjacent parts.

Streaming technology has rapidly evolved for applying underfill, replacing jetting in many high volume applications due to fundamental differences in its method of operation. Jetting technology uses a ball and seat mechanism; to supply the fluid to the ball seat area, air pressure is applied to the syringe which forces the fluid to fill the seat. As the ball moves in the downward direction to strike the seat, it drives the fluid in the form of a drop to dispense on the substrate. Streaming technology fills a cylindrical cavity of a known volume and a piston mechanically displaces the volume of the chamber. The major differentiation from jetting is that the piston streams out material without striking a hard stop, unlike what is done in the ball and seat mechanism of a jet.

Pump Flow Rate

Pump flow rate is defined as the desired mass or volume of underfill dispensed from the pump over time. Accurate flow rate is needed since product quality depends upon the volume of underfill dispensed. Most pump technologies offer automatic weight monitoring through a programmed weight scale measurement that controls pump output. Significant changes in flow rate occur over the pot life of the material as the viscosity increases. Time-pressure and rotary auger dispensing is most susceptible to this issue. Measurement of the flow rate is required periodically, adjusting the dispense volume will ensure that the process is kept close to the target. In many HVM assembly applications, larger flow rates of 30 to 50 milligram per second are becoming more common, but due to the volume of material required for the process they generally suffer from large dispense-edge fillets. Reducing the fillet size by reducing flowrates significantly slows the dispensing process leading to reduced throughput.

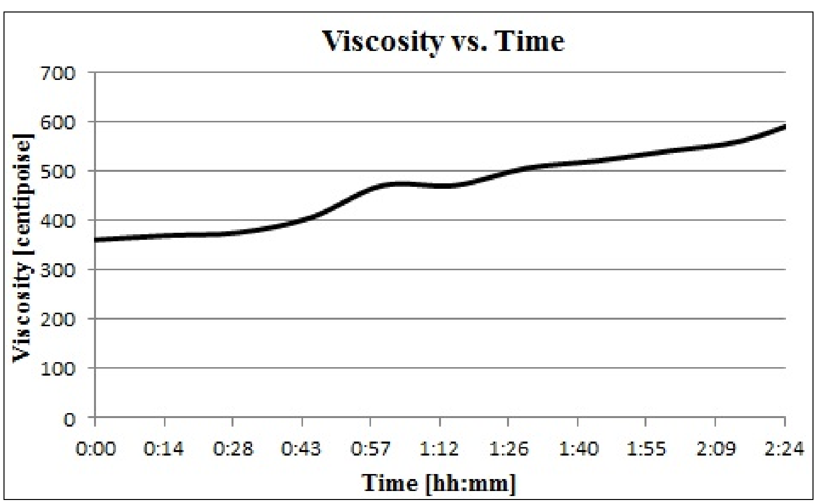


Figure 1- Viscosity versus Time

Figure 1 is a plot of viscosity over time for an underfill fluid during an assembly production run. The viscosity of fluid increases as the fluid starts getting into the path of the moving parts. Automated fluid dispensing equipment have mass flow control systems built into them, which react to the change in volume to accommodate the changes in viscosity. Under normally steady state conditions without any mass flow control the fluid weight tends to reduce over time. To compensate for fluid volume changes, the dispense line speed is reduced to obtain the same weight of fluid on the part with auger dispensing.

With jet dispensing the number of fired dots are adjusted to add more fluid thus increasing the cycle time for the process. Streaming incorporates a continuous stream of fluid of precise volume that is kept consistent by varying piston travel; the number of cycles never changes keeping throughput constant.

Factors Affecting the Dispensing Volume

Dead Volume Spaces

Dead volume spaces are locations inside of a fluid path where the material is stagnant and not constantly being refreshed. The wetted parts inside the fluidic chamber include consumable parts like O-rings or cup-seals for keeping the chamber sealed. A major problem normally seen during production is curing of material inside the dispensing fluidic/pump body. Curing generally occurs due to the dead volume spaces created within the fluidic/pump body. Material gets trapped within the dead spaces and never gets replenished with fresh material flowing through the pump body. This trapped material tends to age due to ongoing slow reaction between the constituents during and after the product's recommended working life which leads to required pump maintenance before the material can damage the pump.

Streaming Theory of Operation

Streaming of epoxies and other materials is changing the way people think of dispensing. For the last twenty years, dispensing has evolved from pushing fluid through a needle using air pressure to a highly automated production process with linear positive dispensing pumps, auger pumps and jets. Controlling fluid deposition, needle position and dispensed volume accuracy has dramatically improved in recent years.

Streaming pump technology refers to volumetrically displacing (streaming) the fluid onto the substrate rather than firing the material as dots such as jetting. Streaming technology functions without the piston striking a hard stop or seat within the fluid chamber to eject material out of the nozzle. The fluid is driven into a cylindrical chamber when the piston is retracted; the reciprocating motion of the piston then pushes material through the chamber during the downward motion delivering the fluid through the nozzle. Streaming eliminates all the wear and tear of the hardware parts found in other technologies (such as piston and seat wear). This helps in maintaining prolonged life of the hardware system since there is no mechanical piston-seat interaction. As a result, streaming operates at lower decibels than jetting thus reducing noise pollution.

Streaming technology incorporates two important materials, namely, carbides and sapphires. Both materials are used to design the orifice which is used as a replacement of a nozzle whose inner diameter can be varied depending upon the shot size requirement for a particular application type. While in operation, each cycle can dispense an increased amount of material as compared to a single sphere. The piston is driven by a closed loop linear encoder servo motor that controls the z-axis motion which set up the charge for a particular shot size. Streaming has both combined advantages of a positive piston displacement pump and jetting technology to deliver, in a non-contact fashion, a continuous stream of fluid in a precise amount of volume as shown in Figure 2.

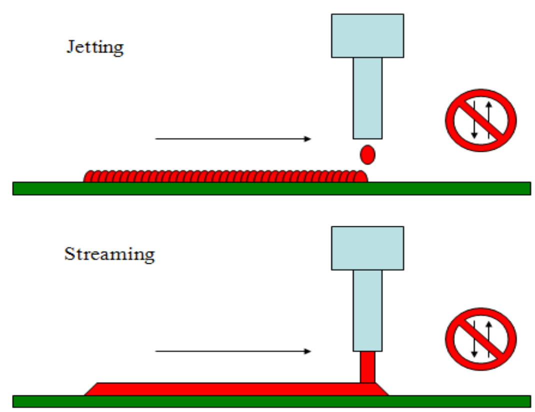


Figure 2 - Jetting versus Streaming technology

Technological Advantages

Streaming technology has similar attributes as jetting technology; it has an edge in terms of application of underfills. Streaming technology works on the positive piston displacement principle, the mechanical piston moves in the downward direction pushing the fluid in the cylinder chamber opening to create a miniature stream of material from the needle or nozzle tip without any wear or abrasion. The inner dimension of the needle whether it is flat or tapered affects the flow rate of the fluid with time which affects the dispensing quality. This technology has undergone extensive testing to provide better results to dispense high volume dots in a consistent manner.

With the miniaturization of portable electronic devices, underfill is a major necessity in the manufacturing of these devices to hold the semiconductor components in place and increase product reliability. In using streaming technology for this application there are some major advantages:

- Throughput improvement: the elimination of Z axis travel and reduction of height sensing steps to locate the distance of the dispense location between the needle and substrate can reduce the cycle time by 25 percent in comparison to legacy needle contact dispensing.
- Reduced wear of mechanical parts compared to jetting: mechanical ball/seat interactions are eliminated in streaming. This increases the life of mechanical parts as well as providing much quieter operation.
- Increased throughput: the volumetric nature of streaming allows for variable shot weight per piston stroke length, a single individual cycle of streamed material can replace several cycles of jetting material, reducing pump cycles and thus increasing throughput.
- Few Consumables: Only 2 low cost seals are required per pump cleaning which lowers cost of ownership in comparison to other pump technologies.
- Lower Maintenance: In field tests running HVM production customers have been able to run 24x7 production with zero (0) pump maintenance for up to 21 days.

Experimental Set-up and Analysis

The main objective of this research is to conduct a detailed study to repeatedly dispense a high volume of fluid, amounting to a deposition size less than or equivalent to 1.000 mg per shot using streaming technology. The study involves the use of a high speed dispensing system with a positive displacement pump installed which can currently dispense 1.000 mg per shot in a repeatable manner without affecting the dot quality.

The study begins at a point of performing the experiment on a positive displacement pump involving different process parameters such as charge, updwell, syringe air pressure, adjustable bumper offset, and nozzle size. The charge value is kept constant, which is the distance travelled by the piston when it is raised from its home position, to the upstroke. Each stroke of the piston expels the fluid contained in the displacement volume of the piston chamber. The displaced volume is the volume between the bottom of the feed slots and bottom stroke of the piston. The vertical chamber feed slots help to avoid any creation of dead volume spaces due to pressure waves generated from incoming fluid into the pump body. An adjustable bumper is used to limit the penetration of the piston into the displacement cylinder. Less penetration of the piston will displace less fluid.

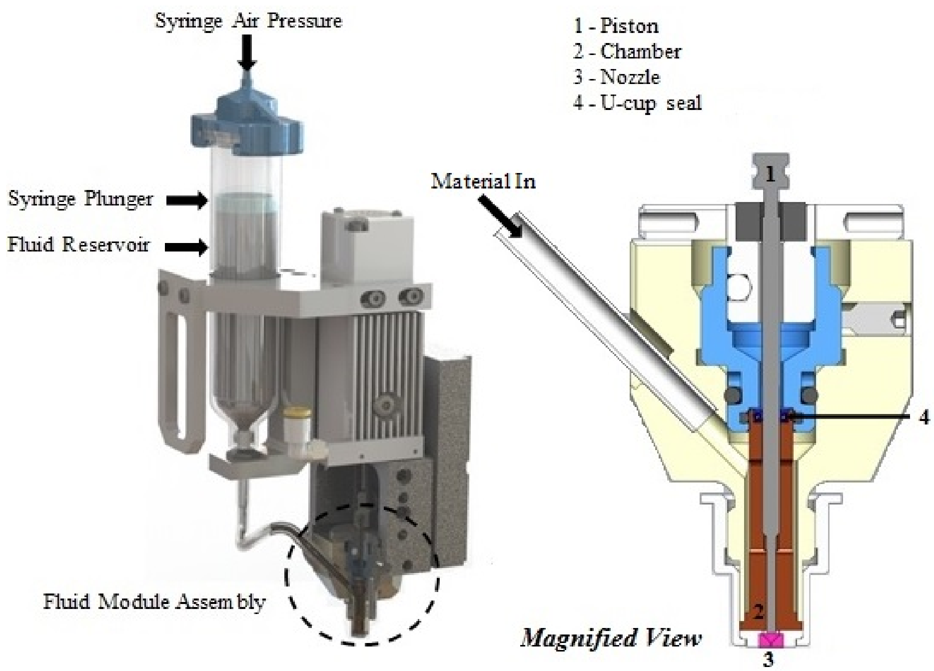


Figure 3 - Schematic diagram of positive displacement dispensing pump

The adjustable bumper offset is set to limit the displacement volume to yield approximately 1.000 mg per dot. High syringe pressures ranging from 10 to 20 psi (pounds per square inch) are used to ensure complete filling and reduced sensitivity in the shot size versus charge relationship. Higher syringe pressures promote smooth movement of the syringe plunger from top to bottom. Less sensitivity to charge improves shot volume repeatability and accuracy. By increasing the bumper offset, the region of stability can be moved to compensate for the different weights. It is desirable to use a relatively small charge value and relatively high syringe pressure. A nozzle heater was used to maintain the fluid temperature equivalent to ambient temperature conditions. The study concludes by running the experimental run in a longevity test to confirm the robustness of the hardware configuration with minimal effect on the dot volume.

The experiment was conducted for a shot size (single pump cycle) equivalent to 1.000 mg with total weight ranging from 5 to 50 milligrams. The experiment is intended to investigate the shot size by dispensing the material into a cup placed on a precision scale. The standard process program involves dispensing of 5 to 50 shots into the weight measuring cup and collecting 25 weight samples.

Figure 4 shows the box plot of variation of shot size versus total dispensed weight. The boxplot provides the graphical distribution of the shot size of 25 samples for total dispensed weight ranging from 5 to 50 milligrams. The median shot size is stable across different total weights while the variability decreases with increase in the total weight. Total weight of 5 milligram exhibits the greatest variability, with an interquartile range of 0.020 mg. The interquartile range box for larger total weights is smaller in comparison to the sample with total weight of 5 milligram. The extreme values are closer to the median for larger total weights. Most of the data points lie within ±2 percent tolerance across the target shot size of 1.000 mg per dot.

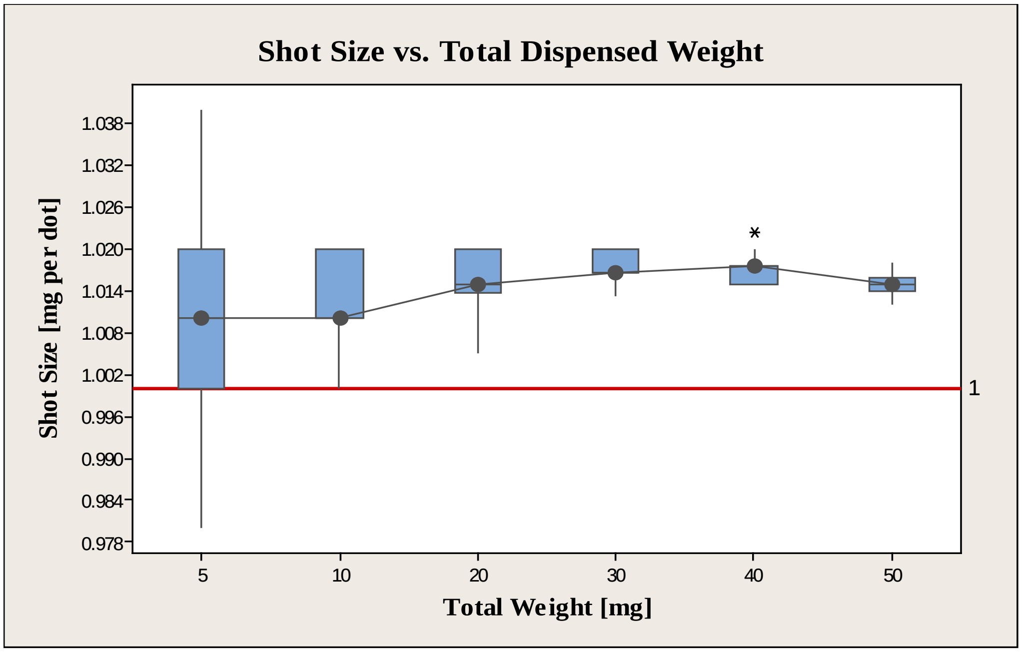


Figure 4 - Box plot of shot size versus total dispensed weight

The shot size versus charge relationship is determined through pump characterization. This utility dispenses and weighs the output of the pump through a desired range of charge. Typically at each charge setting, the pump will purge, clean the nozzle and dispense the number of shots defined by the dot size. The charge for the desired shot size is determined through the interpolation of data points acquired through pump characterization.

Figure 5 shows the pump characterization showcasing shot size versus charge relationship. Each of the charge value constitute of 21 data points collected through pump characterization ran over 3 weeks equivalent to 21 days of continuous testing. The upper and lower specification limits are calculated around the desired shot size of 1.000 mg per dot with tolerance level of ±5 percent. The upper and lower specification limits are defined as 0.950 and 1.050 mg per dot respectively on the figure shown below.

Pump characterization is repeatable within those 21 individual data points for each charge value. Shot size versus charge relationship is stable due to the offset on the adjustable bumper restricting the displacement volume. A complete stroke of the cylinder will dispense close to 0.835 microliters of volume. Generally CSP/BGA underfills have specific gravity around 1.1 to 1.2 which amounts to 1 milligram of total weight during one complete stroke of the piston. During each stroke the displacement volume gets replenished with fresh material through the vertical chamber feed slots thus avoiding any creation of dead volume spaces within the fluidic assembly. This prevents material from getting cured around the piston seal avoiding malfunctioning of the valve that leads to failure during long hours of operation.

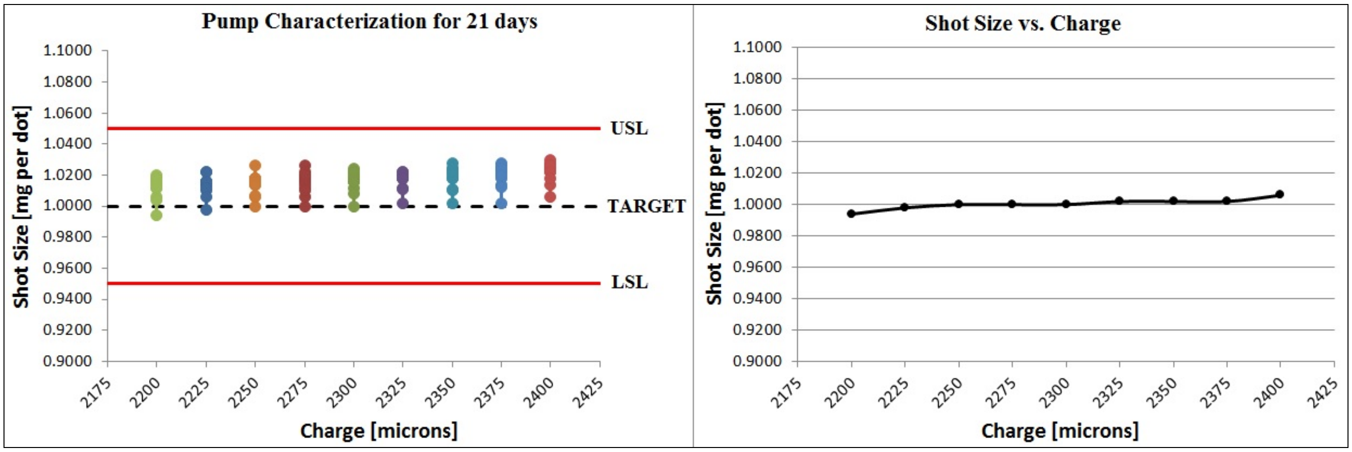


Figure 5 - Pump Characterization demonstrating shot size versus charge relationship

Figure 6 shows the process capability chart for different total weights ranging from 5 to 50 milligrams. The upper and lower specification limits are calculated around the target shot size of 1.000 milligram per dot with ±5 percent tolerance. Process capability is determined by comparing the width of process variation with the width of the specification limits. The process mean for all different total weights is close to the target (1.000) as shown in table 1. For 5 milligram total weight, Pp = 1.414 indicate that the specification interval is 1.414 times greater than the process range. The specification interval increases with the increase in the total weight. PPM < LSL (0.02) indicates that the 0.02 out of 1 million parts are less than the lower specification limit of 0.950 milligram per dot. PPM > LSL (0.90) indicates that the 0.90 out of 1 million parts exceed the upper specification limit of 1.050 milligram per dot. A total of 1 part out of 1 million parts will have the total dispense volume out of specification for 5 milligram total weight. There will be no part defects due to dispense volume for total weights greater than 5 milligrams.

Table 1 - Process Capability and Process Performance Data for last day interval

Process Data

Variable	LSL	Target	USL	Sample Mean	Sample N	StDev(Within)	StDev(Overall)
5 MG	0.95	1.00	1.05	1.00344	25	0.0097518	0.0088416
10 MG	0.95	1.00	1.05	1.00656	25	0.0075355	0.0073148
20 MG	0.95	1.00	1.05	1.00866	25	0.0038601	0.0039257
30 MG	0.95	1.00	1.05	1.00877	25	0.0027458	0.0028686
40 MG	0.95	1.00	1.05	1.00892	25	0.0020409	0.0024777
50 MG	0.95	1.00	1.05	1.00454	25	0.0019577	0.0020418

	Overall Capability					Potential (Within) Capability			
Variable	Pp	PPL	PPU	Ppk	Cpm	Cp	CPL	CPU	Cpk
5 MG	1.414	1.511	1.317	1.317	1.314	1.282	1.370	1.194	1.194
10 MG	1.709	1.933	1.485	1.485	1.261	1.659	1.876	1.441	1.441
20 MG	3.184	3.736	2.633	2.633	1.293	3.238	3.799	2.677	2.677
30 MG	4.358	5.122	3.593	3.593	1.329	4.552	5.351	3.754	3.754
40 MG	5.045	5.945	4.145	4.145	1.325	6.125	7.218	5.032	5.032
50 MG	6.122	6.677	5.567	5.567	2.470	6.385	6.964	5.806	5.806

Observed Performance

Variable	PPM < LSL	PPM > USL	PPM Total
5 MG	0.00	0.00	0.00
10 MG	0.00	0.00	0.00
20 MG	0.00	0.00	0.00
30 MG	0.00	0.00	0.00
40 MG	0.00	0.00	0.00
50 MG	0.00	0.00	0.00

	Exp. Within Performance			Exp. Overall Performance		
Variable	PPM < LSL	PPM > USL	PPM Total	PPM < LSL	PPM > USL	PPM Total
5 MG	0.02	0.90	0.92	0.00	0.07	0.07
10 MG	0.00	0.00	0.00	0.00	0.00	0.00
20 MG	0.00	0.00	0.00	0.00	0.00	0.00
30 MG	0.00	0.00	0.00	0.00	0.00	0.00
40 MG	0.00	0.00	0.00	0.00	0.00	0.00
50 MG	0.00	0.00	0.00	0.00	0.00	0.00

For the interpretation of process capability statistics, the data should approximately follow a normal distribution. The Process performance index, *Ppk* indicates whether the process will produce units within the tolerance limits. *Ppk* is an estimate of overall process capability determining variation within subgroups and between subgroups. *Pp*, on the other hand, ignores subgroups and considers the overall variation of the entire process. This overall variation accounts for the shift and drift that can occur between subgroups; therefore, it is useful in measuring capability over time. If the *Pp* value differs greatly from the *Cp* value, you conclude that there is significant variation from one subgroup to another.

Cp indices recognize the fact that the samples represent rational subgroups, which indicate how the process would perform if the shift and drift between subgroups could be eliminated. Therefore, it calculates process spread using within-subgroup variation. Process capability index, *Cpk* measures how close the process is to the target and how consistent the process is around its average performance. An operator may be performing with minimum variation, but he/she can be away from his/her target towards one of the specification limit, which indicates lower *Cpk*, whereas *Cp* will be high. For both the shifts, high value of *Cp* and low value of *Cpk* indicate that the process has a centering problem. A generally accepted minimum value for the indices is 1.33 according to industry guidelines to determine whether the process is capable. Figure 6 shows that the both tails for all of the six distributions at different total weights fall inside the specification limits.Greater *Ppk* values indicate that the process is capable during long run for different total weights for tolerance level of ±5 percent at ±4 sigma capability.

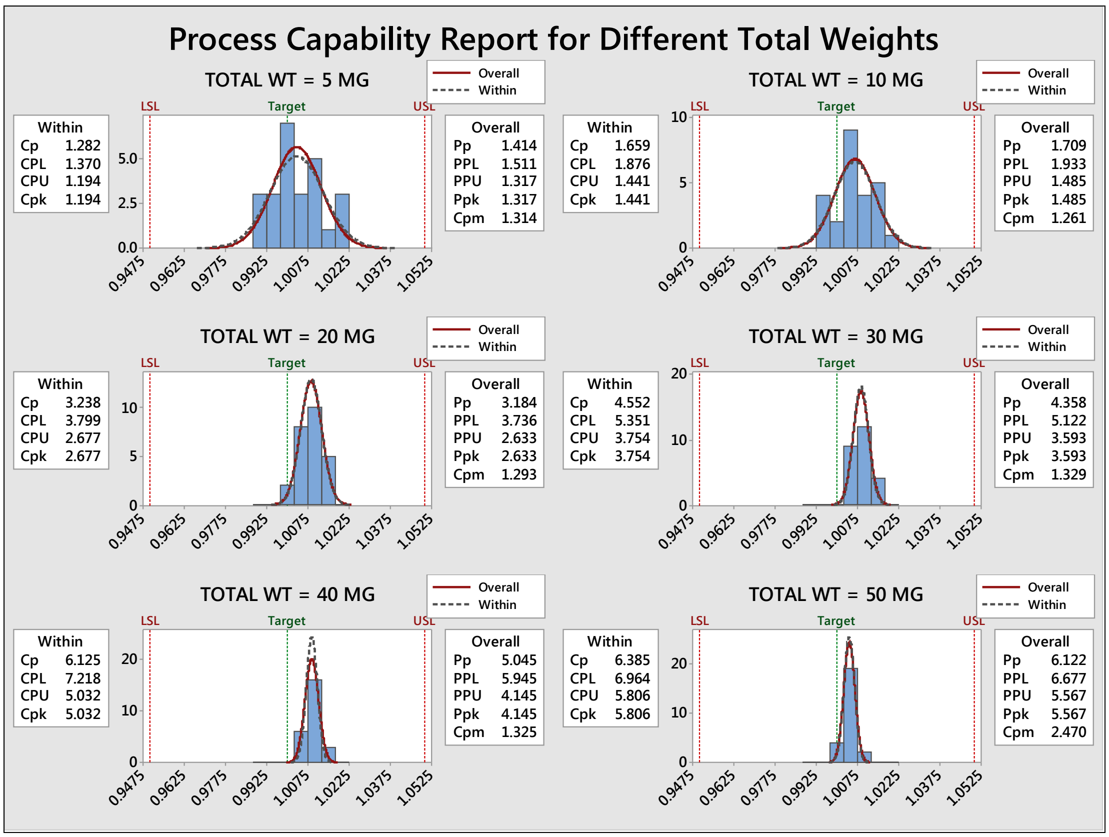


Figure 6 Process Capability Report for Different Total Weights

Improved Maintenance and Pump Reliability

Streaming provides increased process capability and repeatability with stable throughput as presented with the results above. The elimination of dead space in the pump enables consistent material replenishment that further reduces the need for preventive maintenance. Pumps were placed into a 24x7 HVM production site with the goal to operate the pump for at least 14 days without maintenance in a real manufacturing environment.

The low maintenance cycle target has been achieved and surpassed, thanks to two main factors. Firstly, presence of non-reactive U shaped cup seal providing excellent resistance to solvents and epoxies preventing piston sticking to avoid pump failure. Secondly, the material within the displacement volume in the chamber gets replenished with fresh material through the vertical feed slots during each piston stroke. Pressure waves are created as the piston moves from the upstroke to the down stroke position eliminating any creation of dead volume space within the fluidic/pump body. With these advancements to the fluidic body, the pumps havebeen able to run underfill process with no issues i.e. zero pump maintenance for more than 21 days in a 24x7 production line.

Summary

Streaming technology has brought a new level of robustness to the high volume underfill process. With no z-axis motion required, streaming has mitigated all the effects from needles required in auger dispensing.

The parts wear and tear problem associated with jetting technology is not associated with the non-contact streaming technology thus providing lower cost of ownership. Streaming also delivers fluid to the substrate through a non-breakable fluid stream leading to higher mass transfer in comparison to small spherical dots with the jetting technology. Jetting underfill requires multiple cycles to put down the same volume of material in comparison to streaming, therefore requiring more time yielding lower throughput during the production run. The U shaped cup seal has played an important role to avoid any piston sticking because of its non-reactive nature. The vertical feed slots help with proper flushing during each piston stroke with fresh material within the chamber walls and movable piston to overcome friction due to movable parts. All these design enhancements have helped to achieve prolonged life of the fluidic/pump body leading to 21 days of production with no maintenance.

With *Cpk* numbers greater than 2.0 for high volume underfill applications, total weights ranging from 30 to 50 milligrams, denotes zero nonconforming parts per million at ±6 sigma capability during an average underfill production run. The streaming process widens the process window in such a manner that even if the process mean shifts by as much as ±1.5 sigma the process will produce no more than 3.4 non-conforming parts per million. An era of streaming has arrived offering greater degree of process control with zero maintenance required for 21 days or more providing good product reliability during the production run.

References

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Introduction

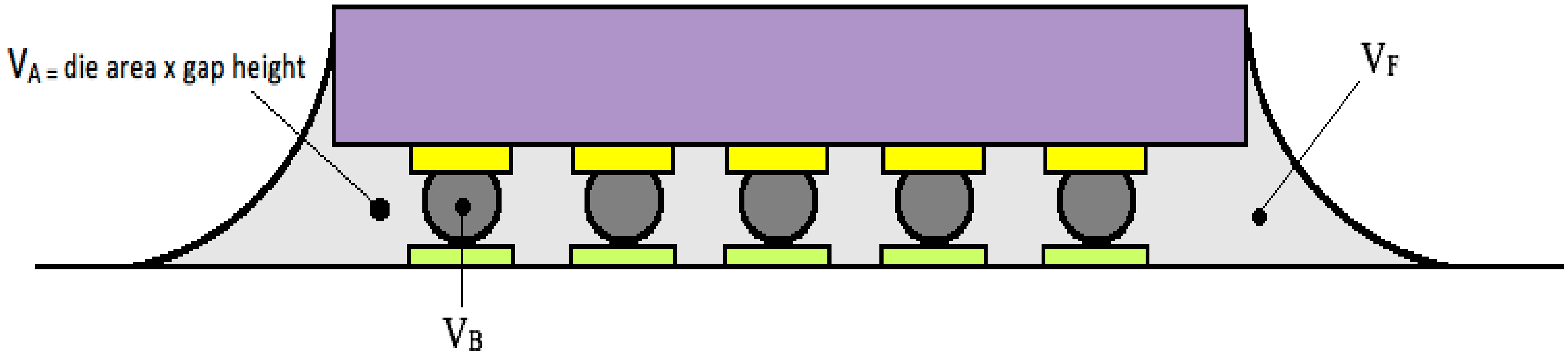
- Underfill is a widely used application in electronics manufacturing.
- Requirements reduce keep out zones, smaller process window.
- Production targets demand higher throughput:
  - ✓ Faster cycle time
  - ✓ *Reduced Maintenance*

Reduced Maintenance is key to enable higher throughput

Underfill BGA

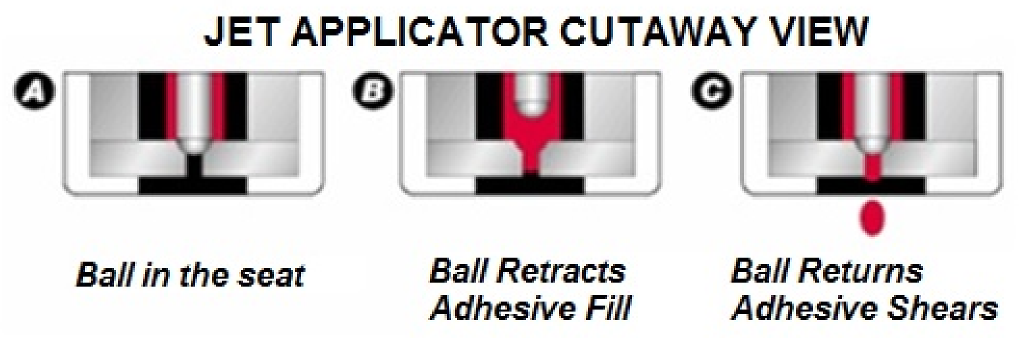
- Goal – Dispense material to completely underfill die and form a fillet with no material contacting keep out area

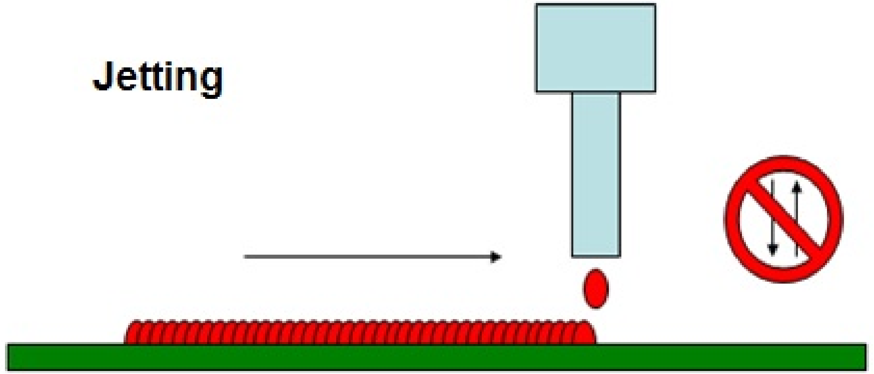
$$V_D = V_A - V_B + V_F$$

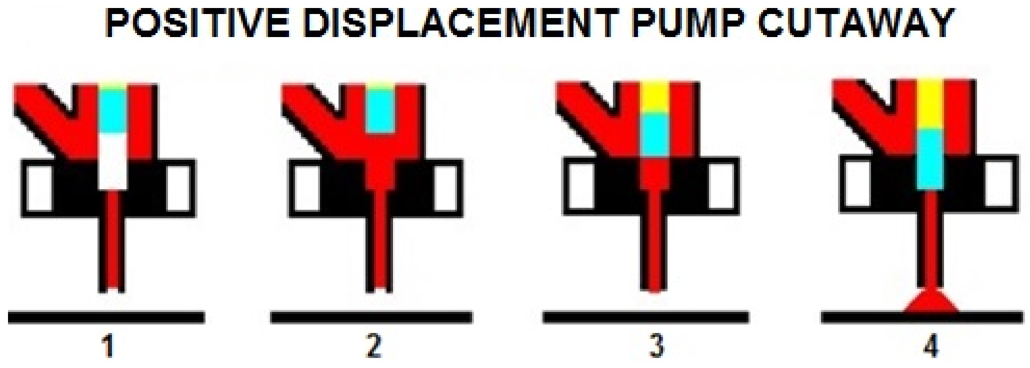


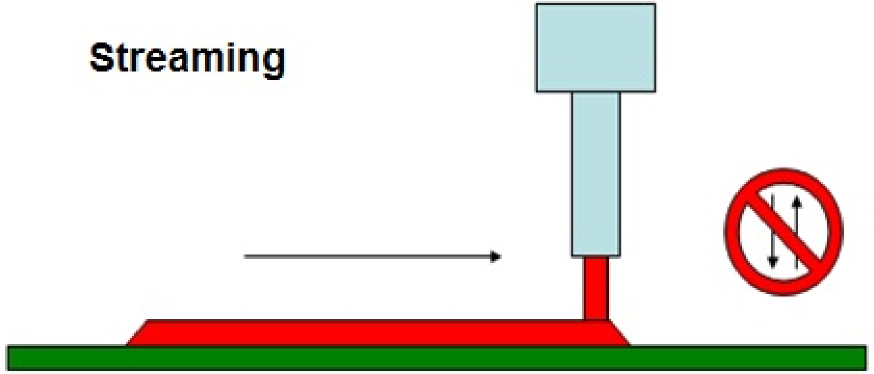
Paradigm Shift in Applying Underfill

- Jetting fires droplets through ball and seat mechanism
- Streaming streams out material with piston mechanically displacing the volume of the cylinder without striking a hard stop



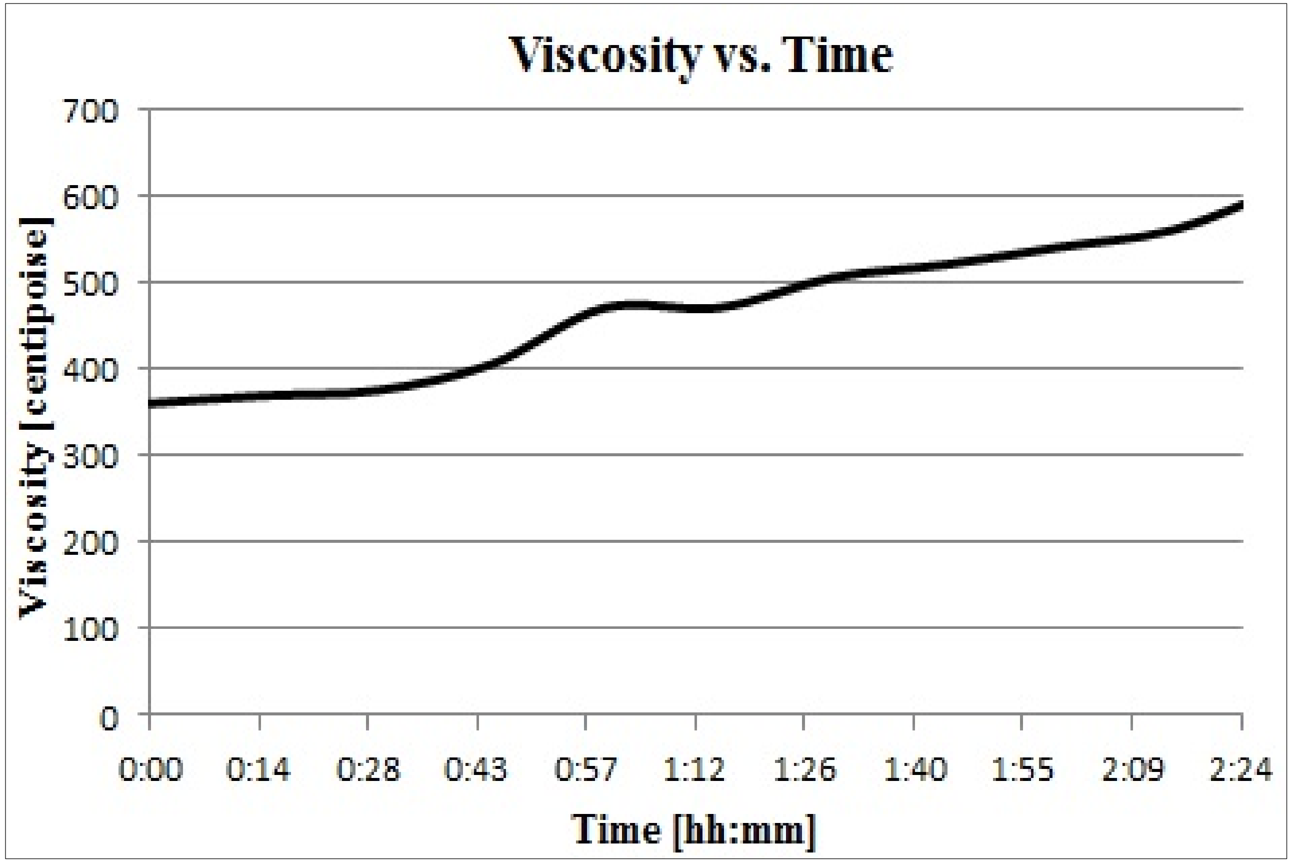






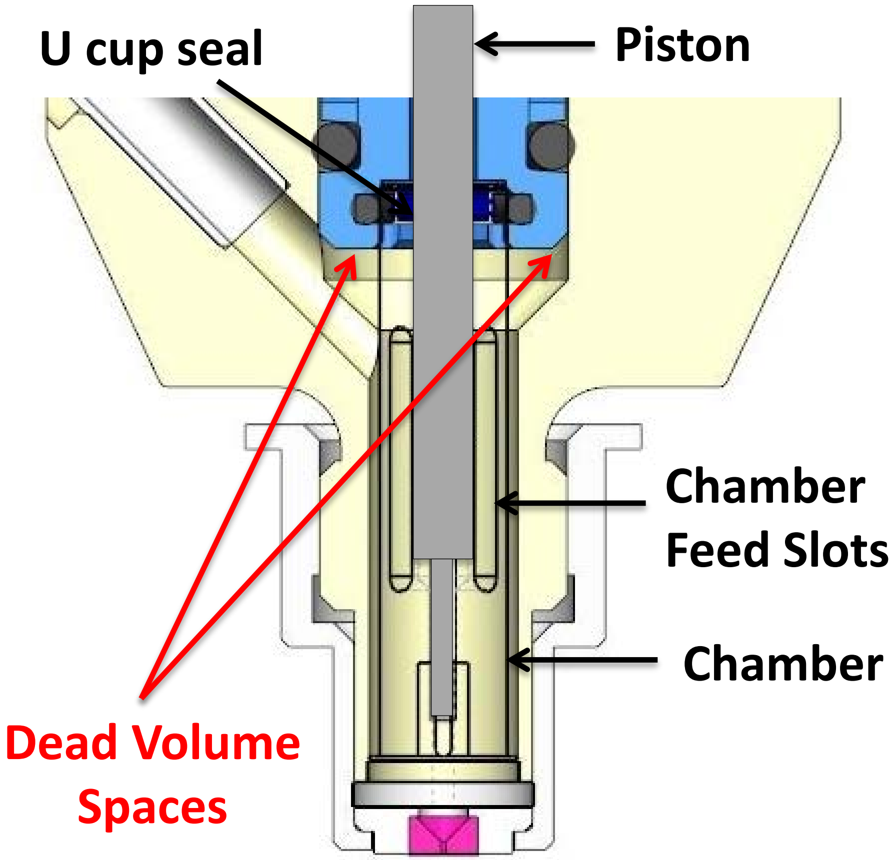
Pump Flow Rate

- Desired mass or volume of underfill dispensed from the pump over time
- Product quality is dependent on accurate flow rate
- Viscosity of fluid increases over time



Dead Volume Spaces

- Material is stagnant and not constantly being refreshed
- Trapped material tends to cure due to slow ongoing reaction
- Damage to pump body and consumable parts (i.e.: O-rings)
- Lead to more pump maintenance

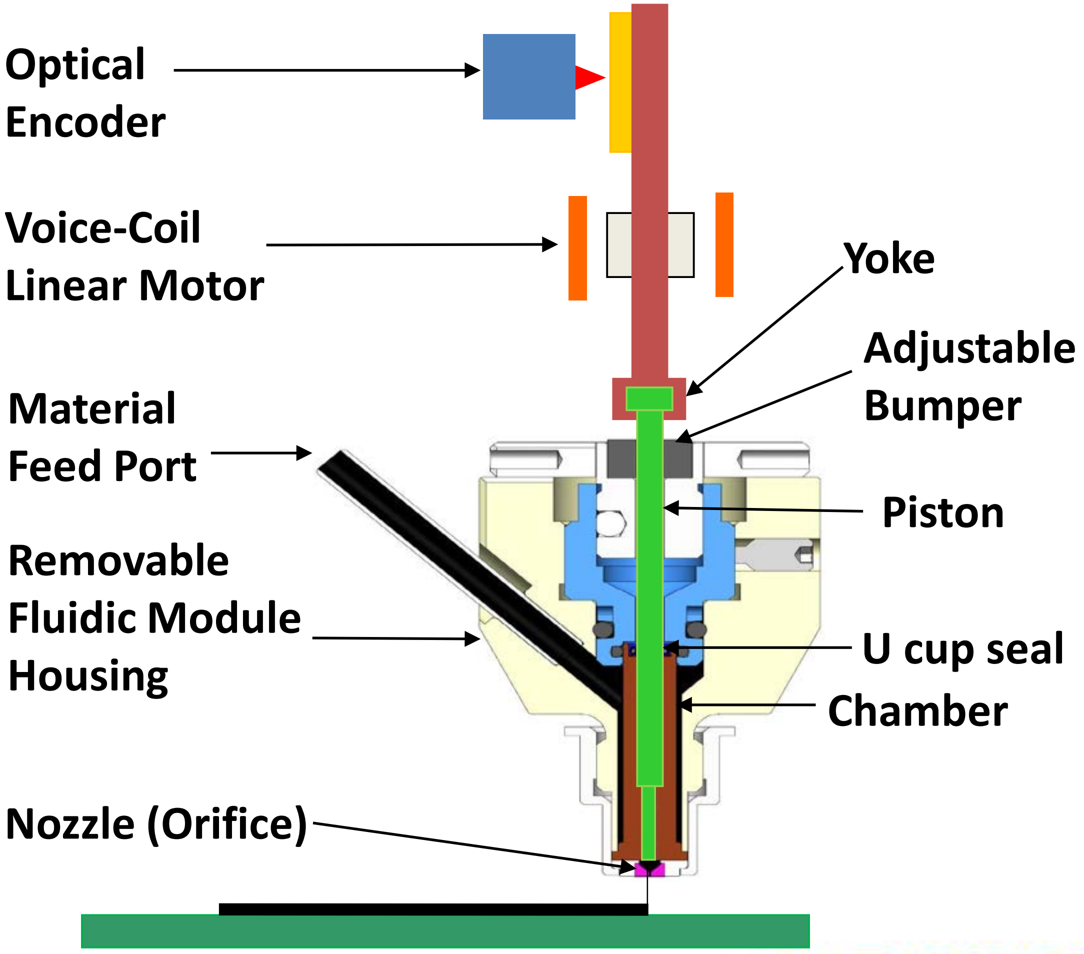


Fluidic Magnified View

Streaming: Theory of Operation

- Material fills the chamber as the piston is raised, and is displaced as the piston is lowered

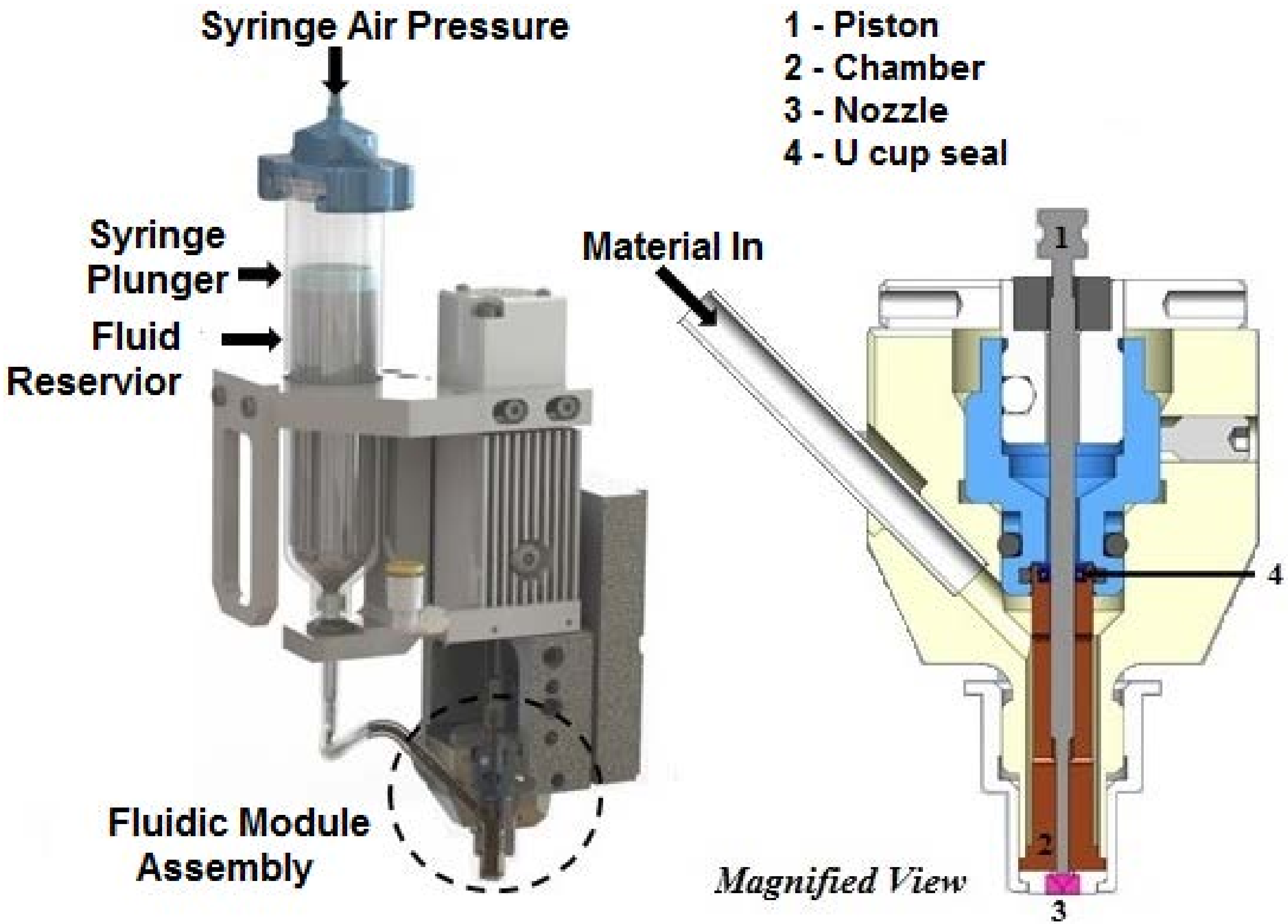
  (Positive Displacement)
- Dispenses a column of material with each piston stroke
- A controlled stream of material is produced when the piston is cycled at high frequency



Technological Advantages

- Lower Maintenance: 24x7 production with zero (0) pump maintenance for up to 21 days
- Increased throughput
- Few Consumables
- Reduced wear of mechanical parts compared to jetting
- Quieter in comparison to noisier jetting operation

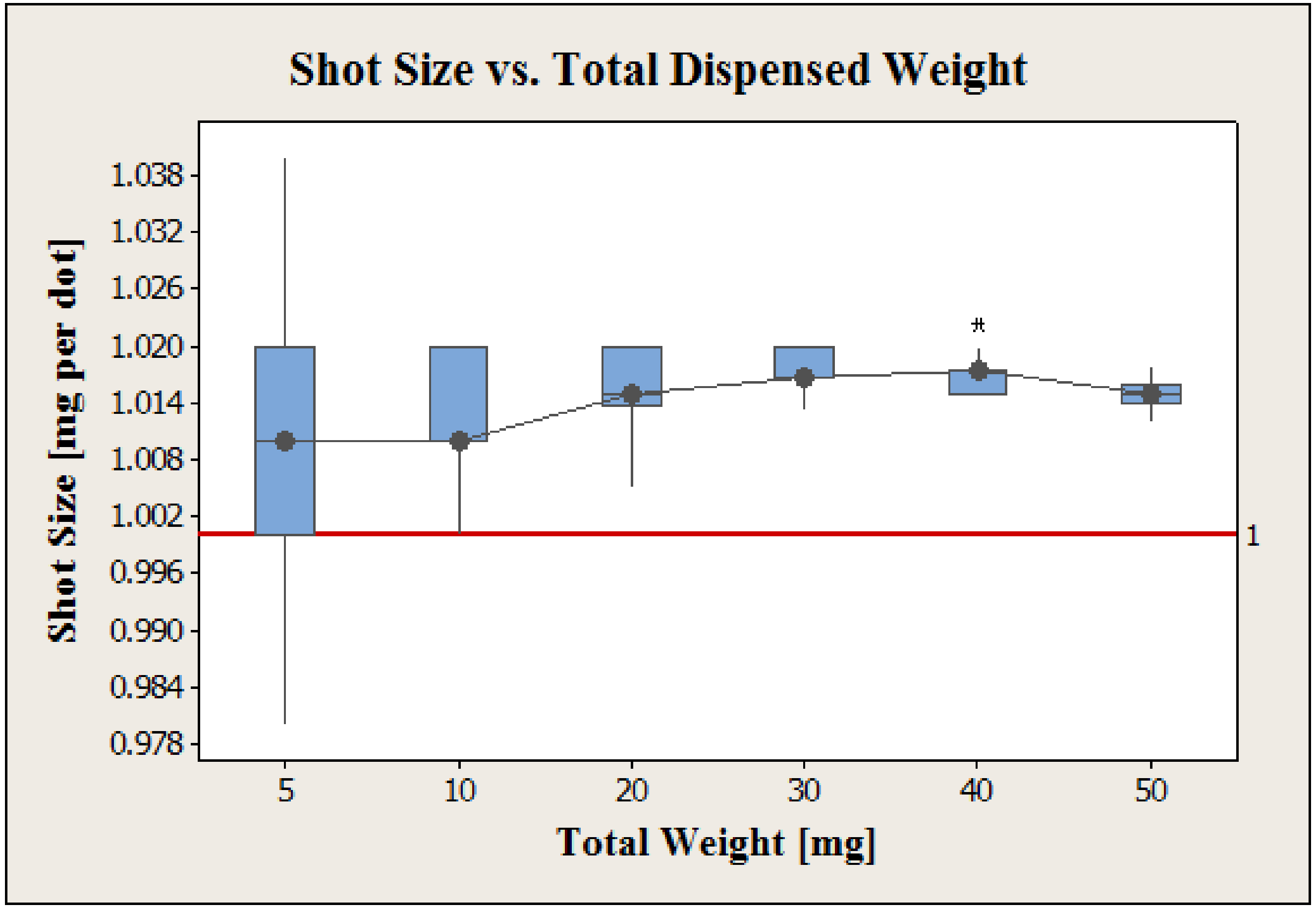
Experimental Set-up



- Unique process parameters:
  - ✓ Charge
  - ✓ Updwell
  - ✓ Syringe air pressure
  - ✓ Adjustable bumper offset
  - ✓ Nozzle size
- Shot Size = 1.000 mg/dot
- Total weights = 5 to 50 mg
- No. of weight samples = 25

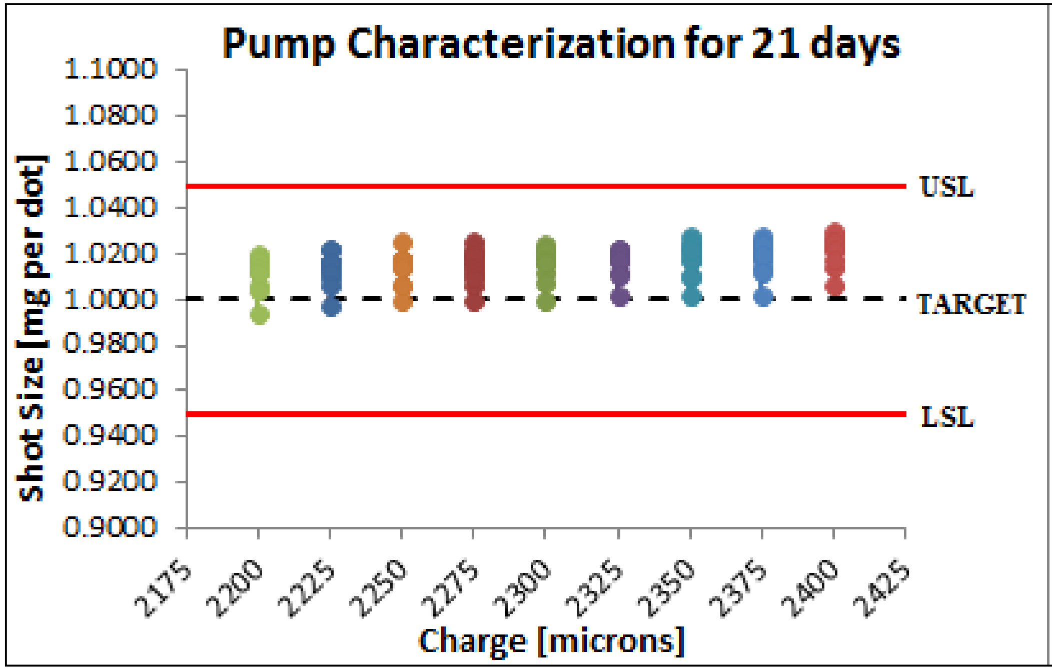
Analysis

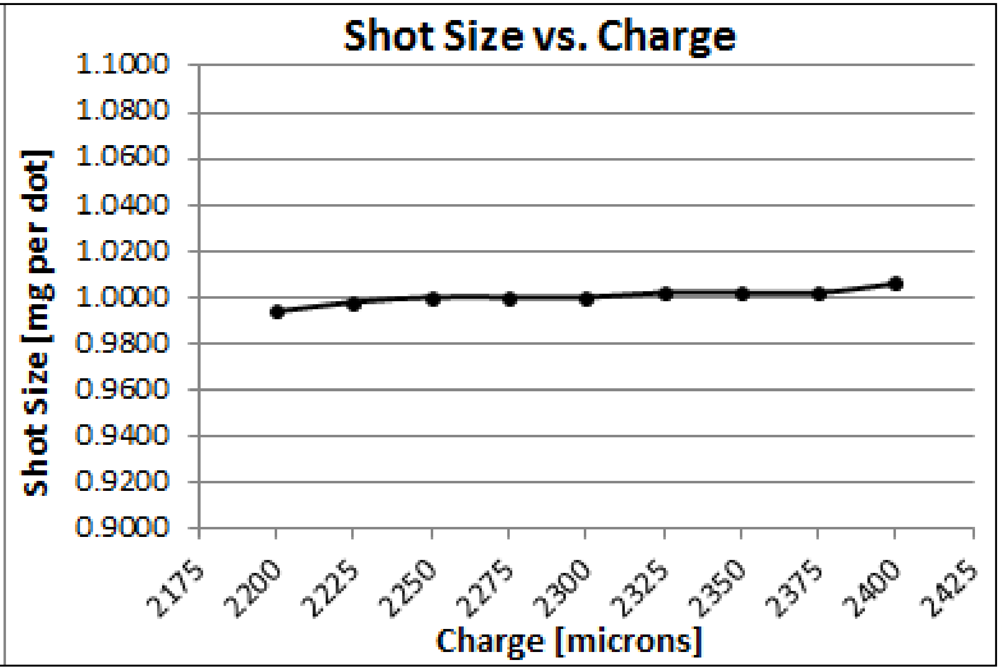
- Most of data points lie within ±2 percent tolerance
- Median shot size is stable across different total weights
- Variability decreases with increase in the total weight
- Greatest variability for total weight of 5 mg with an interquartile range of 0.020 mg



Analysis - Pump Characterization

- Pump characterization determines shot size versus charge relationship
- Pump characterization is stable
- Displacement volume gets replenished with fresh material through the vertical chamber feed slots, avoiding creation of dead volume spaces





Process Capability

Process Data

Variable	LSL	Target	USL	Sample Mean	Sample N	StDev(Within)	StDev(Overall)
5 MG	0.95	1.00	1.05	1.00344	25	0.0097518	0.0088416
10 MG	0.95	1.00	1.05	1.00656	25	0.0075355	0.0073148
20 MG	0.95	1.00	1.05	1.00866	25	0.0038601	0.0039257
30 MG	0.95	1.00	1.05	1.00877	25	0.0027458	0.0028686
40 MG	0.95	1.00	1.05	1.00892	25	0.0020409	0.0024777
50 MG	0.95	1.00	1.05	1.00454	25	0.0019577	0.0020418

	Overall Capability					Potential (Within) Capability			
Variable	Pp	PPL	PPU	Ppk	Cpm	Cp	CPL	CPU	Cpk
5 MG	1.414	1.511	1.317	1.317	1.314	1.282	1.370	1.194	1.194
10 MG	1.709	1.933	1.485	1.485	1.261	1.659	1.876	1.441	1.441
20 MG	3.184	3.736	2.633	2.633	1.293	3.238	3.799	2.677	2.677
30 MG	4.358	5.122	3.593	3.593	1.329	4.552	5.351	3.754	3.754
40 MG	5.045	5.945	4.145	4.145	1.325	6.125	7.218	5.032	5.032
50 MG	6.122	6.677	5.567	5.567	2.470	6.385	6.964	5.806	5.806

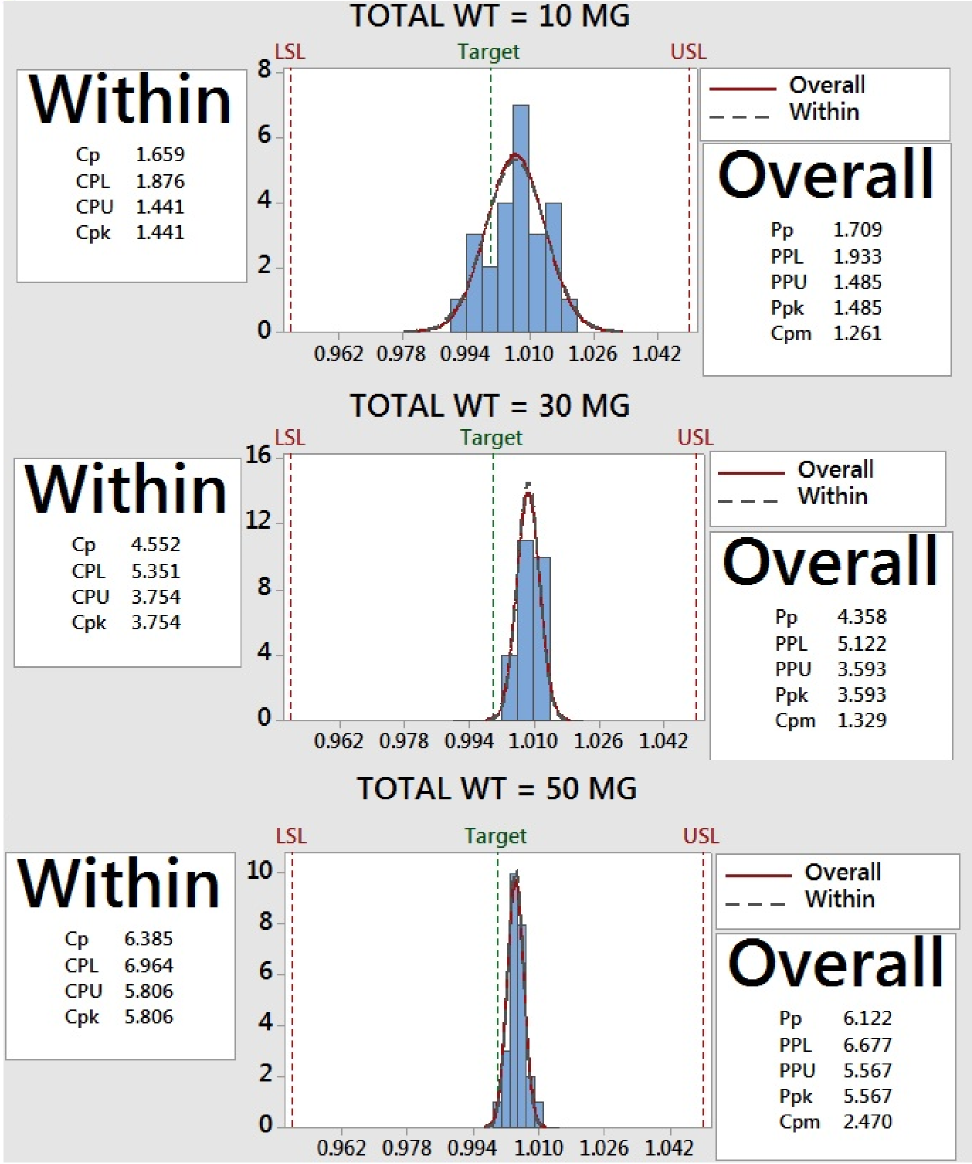
Observed Performance

Variable	PPM < LSL	PPM > USL	PPM Total
5 MG	0.00	0.00	0.00
10 MG	0.00	0.00	0.00
20 MG	0.00	0.00	0.00
30 MG	0.00	0.00	0.00
40 MG	0.00	0.00	0.00
50 MG	0.00	0.00	0.00

	Exp. Within Performance			Exp. Overall Performance		
Variable	PPM < LSL	PPM > USL	PPM Total	PPM < LSL	PPM > USL	PPM Total
5 MG	0.02	0.90	0.92	0.00	0.07	0.07
10 MG	0.00	0.00	0.00	0.00	0.00	0.00
20 MG	0.00	0.00	0.00	0.00	0.00	0.00
30 MG	0.00	0.00	0.00	0.00	0.00	0.00
40 MG	0.00	0.00	0.00	0.00	0.00	0.00
50 MG	0.00	0.00	0.00	0.00	0.00	0.00

- Tolerance = ±5 percent
- Target shot size = 1.000 mg/dot
- USL = 1.050 mg/dot, LSL = 0.950 mg/dot
- Process level = ±4 sigma capability
- Total weight = 5 milligram
  - ✓ Pp = 1.414 indicate that the specification interval is 1.414 times greater than the process range
  - ✓ PPM < LSL (0.02)
  - ✓ PPM > USL (0.90)
  - ✓ PPM Total = 0.92
- Total weight > 5 milligram
  - ✓ No part defects due to dispense volume

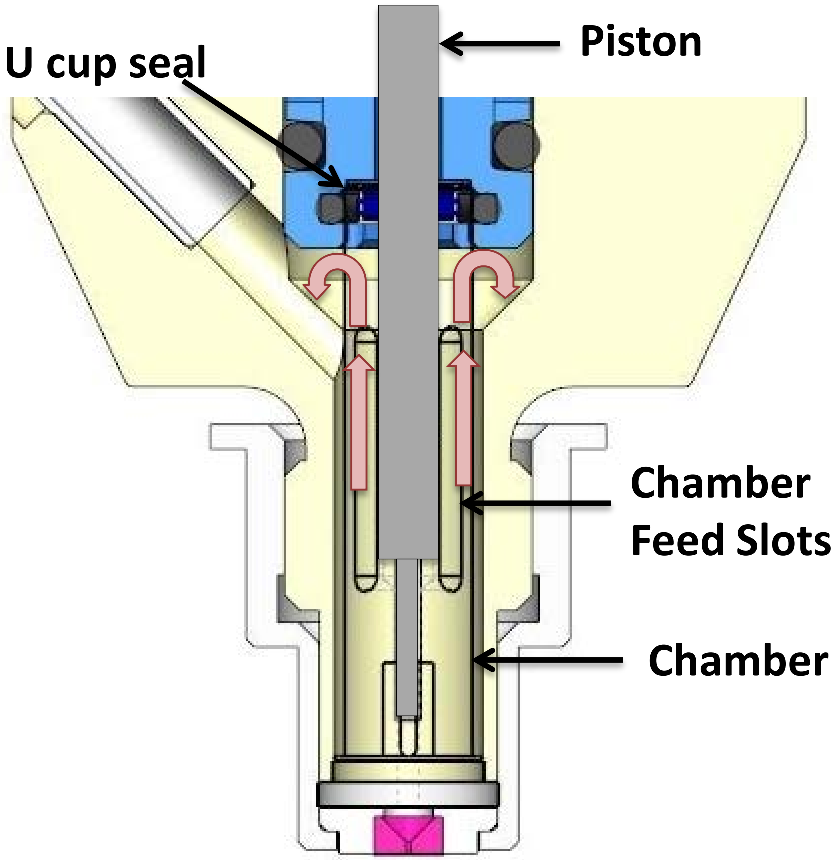
Process Capability



- Data follows a normal distribution
- Tolerance = ±5 percent
- *Cpk* > 1.33 for total weights ranging from 10 to 50 mg at ±4 sigma capability
- Greater *Ppk* values indicate that the process is capable during long run

Improved Maintenance and Pump Reliability

- Elimination of dead spaces with material replenishment
- Non-reactive U cup seal avoids piston sticking
- Zero pump maintenance for more than <u>21 days</u> in a 24x7 production line



Fluidic Magnified View

Consumables

- Low cost of ownership
- Easy to install and maintain
- U cup-seal non reactive to most cleaning solvents
- U cup seal does not need to be removed from the piston cylinder unlike most of the O-ring seal
- Consumable parts
  - ✓ 1 x O-Ring seal replaced every 21 days
  - ✓ 1 x U cup seal replaced every 21 days
  - ✓ 1 x Material feed tube replaced after 21 days i.e. 3 weeks

- Cleaning time < 10 minutes
- Changeover time < 5 minutes (applicable with spare fluidic assembly only)

Pump Maintenance

With 1 set of fluidic module assembly

Pump Maintenance Cycle	No of pump maintenance cycles in 21 days	Time consumed during Pump Maintenance + Set-up, *minutes*	Total Machine Downtime, *minutes*	Hours lost during 21 days of production, *hours*
8 hours	41	15	615	**10.25**
12 hours	27	15	405	**6.75**
24 hours	13	15	195	**3.25**
3 days i.e. 48 hours	6	15	90	**1.50**
1 week i.e. 96 hours	3	15	45	**0.75**
21 days i.e. 336 hours	0	15	0	**0.00**

- *Machine uptime can be increased with other spare fluidic with quick changeover*
- *Time consumed during **Fluidic Changeover + Set-up** < 7 minutes*

Note: 1 day running comprises of two shifts (day/night) of 8 hours each

Summary

- Lower cost of ownership with non-contact streaming technology
- Higher mass transfer in comparison to small spherical dots with jetting
- Maximum throughput during 24x7 production run
- *Cpk* > 1.33 for total weights from 10 to 50 mg at ±4 sigma capability
- *Cpk* > 2.00 for total weights from 30 to 50 mg at ±6 sigma capability
- Zero defects per 1 million parts due to dispense volume *(10 – 50 mg)*
- Less operation intervention, maximum equipment utilization and uptime
- Good product reliability with zero maintenance for <u>21 days</u> or more

References

- Agarwal, S., “Low Volume Dispensing with High Speed Dispensers,” Master’s Thesis, State University of New York at Binghamton, December 2012
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Thank You!