An Analysis of Archimedes Screw Design Parameters and their Influence on Dispensing Quality for Electronics Assembly Applications.

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ABSTRACT

Dispensing any fluid material onto a mixed technology printed circuit board (PCB) substrate has two basic requirements: applying the material to the exact location required, and dispensing a dot of exact volume. Due to the decreasing pad sizes, and the typical density required in the material pattern, these are major challenges [3]. There are two basic types of dispensing mechanisms that are used for practical production: the Archimedes Metering Valve (AMV) and the Positive Displacement Pump [5]. The performance of the Archimedes Screw in the AMV depends a great deal on screw design and operating conditions. The principle geometric variables of the Archimedes Screw are the channel depths, i.e., the radial distance between the cylinder surface and root diameter of the screw, the pitch of the screw, the type of threads and the number of channels through which the material can flow. The dimensions of the nozzle, such as the nozzle ID and stand off height, and the rheological properties of the material also influence the parameters required for a consistent dot. Dispensing with an AMV is based on the laws of momentum, fluid dynamics, energy, and mass transport. The amount of material dispensed depends upon the pitch of threads, depth of cut, type of thread, length of screw, the number of starts, and angle of rotation of the screw. The quantity of material dispensed increases with an increase in depth of cut, decrease in pitch, increase in encoder counts, and increasing the number of channels. This paper studies the effect of different geometric variables of the screw, and the screw-nozzle combination that optimizes the quantity of material dispensed without affecting dot consistency.

INTRODUCTION

An Archimedes pump utilizes a threaded screw to turn the material down a cylinder. The material is pumped forward by the relative movement of the screw in the cylinder. The transporting mechanism is similar to a nut held in a wrench with the screw rotating in the nut. Normally, the screw advances in the nut, but when the screw is physically prevented from advancing, as in the case of the Archimedes screw, the nut will slide in the wrench. A motor through a gearbox turns the screw, but a circular ring on the head of the screw prevents it from being pushed out of the cylinder. The movement of the screw within the cylinder causes a pressure rise along the length of the screw. When the material reaches the nozzle, it experiences a change in area, and as a result, it undergoes pressure variation. The nozzle offers resistance to the flow of material, termed as ***Back-Pressure***. The force with which the material dispensed is resultant of the pressure difference between the pump and the nozzle. As a result, it is extremely important to understand the screw parameters, the screw-nozzle combination and the operating conditions that maximize production.

SCREW DESIGN PARAMETERS

1. *Pitch of Threads* (t):

This (see Figure 1) is defined as the distance between two consecutive threads [1]. A high value of pitch, i.e., small value of thread/inch,

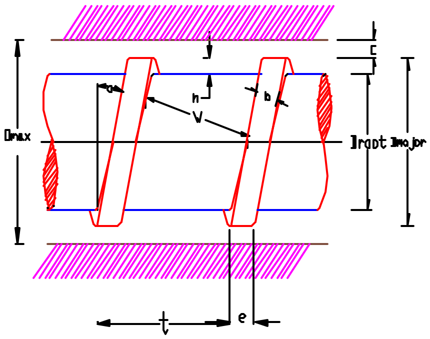

Figure 1 Screw design parameters

reduces the effective surface area of contact. This reduced surface area of contact causes a reduction in pressure build-up as compared to a screw with a greater number of threads/inch. A high pitch causes excessive material to be fed between the threads than the nozzle can handle and, hence, increase the Back-Pressure. This, in turn, reduces the amount of material dispensed as it counteracts the pressure developed to dispense it.

2. $Depth\ of\ Cut\ (h) = \left(D_{major} - D_{root}\right) / 2$:

The amount of material dispensed is directly proportional to the depth of cut, up to a certain point, depending upon the nozzle ID. For a given nozzle ID there is an optimum value for the depth of cut to minimize Back-Pressure. Any increase in the depth of cut beyond this point causes the flux in the solder paste to act as a lubricant, therefore causing slippage between the screw and the solder paste. This reduces the pressure build-up in the cartridge. Hence, to maximize the amount of material dispensed through a nozzle, it is necessary to determine the optimum depth of cut of a screw.

3. *Type of Thread* :

Solder paste is a mixture of solder metal spheres, flux, and additives. The density of the solder metal is about 8 times the density of flux [5]. This density difference between solder metal and flux causes them to separate at high shearing forces. Square threads have sharper edges as compared to angled threads such as the British Standard Whitworth. The square threads can possibly cause excessive shearing of solder paste and, hence, increase separation.

3. *Length of Screw* :

The length of screw influences the pressure buildup and distribution. As the solder paste passes along the channels of the screw, it undergoes a pressure variation. Since the cartridge is a constant volume chamber, and as the amount of material fed increases, the pressure of the material within the cartridge rises. A very high-pressure rise within the cartridge could cause separation of flux and solder metal spheres. Hence, there is a limit to the length of the screw that causes sufficient pressure build-up and minimizes separation.

4. *Number of Starts* :

The number of starts determines the number of channels through which the material can flow in the cartridge. With an increase in the number of starts, a greater quantity of material flows into the cartridge. This increases the pressure of the material in the cartridge and consequently increases the volume dispensed. A multi-start thread also provides more channels for the material to leave the screw and also increases the volume dispensed.

OPERATING CONDITIONS

Apart from the screw design parameters, the operating conditions also play an equally important role in the quantity and quality of the dispensed dot. The material parameters, such as viscosity, thixotropic property, metal content and solder powder size, influence the flow behavior. Viscosity is defined as the property of a fluid by virtue of which it offers resistance to the movement of one layer of fluid over an adjacent layer. There is a low and high threshold value for the viscosity of the solder paste. A high value of viscosity (> 400 Kcps) will offer a high resistance to flow affecting the quality of the dispensed dot [6]. Moreover, if the material has a very low viscosity, it will tend to flow freely, thus causing it to drool.

The relationship between the nozzle ID and particle size is also an important aspect for successful dispensing. Too large a particle size through a fine nozzle ID will cause it to clog. A rule of thumb suggests that the nozzle ID should be 8 times larger than the solder paste particle size to avoid clogging [5]. With a decrease in nozzle ID the flow area for the material decreases, increasing the Back-Pressure and thus decreasing the flow rate.

The following is the test plan developed to understand the effect of the above-mentioned parameters on the flow rate of the material.

TEST PLAN

To analyze the effect of the above-mentioned parameters, eight screws with variation in the depth of cut, and number of starts were designed. For the first four screws, the depth of cut is increased keeping the same number of starts (see Table 1). For the next four screws, the number of starts is doubled with the same values of depth of cut. The pitch of the screws is constant.

Table 1 Variation in dimensions of the screws

Code	Number of Starts	Depth of cut (mils)
1	Single	10
2	Single	15
3	Single	20
4	Single	30
5	Double	10
6	Double	15
7	Double	20
8	Double	30

Equipment:

The experiment was conducted on an Archimedes Metering Valve mounted on a XYZ table (Universal Instrument Model GDM 4716A).

Experiment Design:

The motion control is obtained through a servo system using an encoder disc. The encoder counts on the disc control the angle of rotation of the screw. The machine is programmed to dispense from 500 to 5000 encoder counts in steps of 500 encoder counts. A value of 12800 encoder counts corresponds to one complete rotation of the screw. The solder paste was dispensed onto a substrate at each step and weighed. The procedure was repeated 5 times for each step. The experiment was first conducted for unrestricted flow (without any nozzle) and then for restricted flow using a nozzle of 16, 20 and 24 mil ID. The air pressure is kept constant at 15psi to maintain a steady flow of solder paste from the syringe to the cartridge.

Material:

The solder paste used for the study was 63Sn37Pb, Type III with a metal load of 85% (w/w) and viscosity 400Kcps using a Brookfield viscometer at 25^{o}C.

RESULTS

1. *Effect of Depth of Cut:*

For unrestricted flow, (i.e. without a nozzle) the weight of solder paste dispensed increases with an increase in the depth of cut and angle of rotation; Figure 2 validates the conjecture. In performing the same type of experiment with a 16-mil nozzle ID, interesting results are obtained (see Figure 3). While Screw #2 and Screw #3 performed differently under unrestricted flow, Figure 3 indicates that, with this restriction, an increase in depth of cut does not significantly increase the quantity of dispensed solder paste. This trend seems to also be manifested in the comparison of Screws #6 and #7. Another interesting result concerns the comparison between Screws #6, #7, and #8 (the double start screws) in Figure 3. Since Screw #8 has the largest depth of cut, one may expect that it would dispense the largest quantity of solder paste. While this is evidenced for unrestricted flow, it is not the case with a 16-mil nozzle restriction. In fact, Screw #8 at the higher encoder counts dispensed a smaller quantity of solder paste than Screws #6 and #7. Screw #8 has the maximum depth of cut, but dispenses comparatively less than Screw #6 and Screw #7.

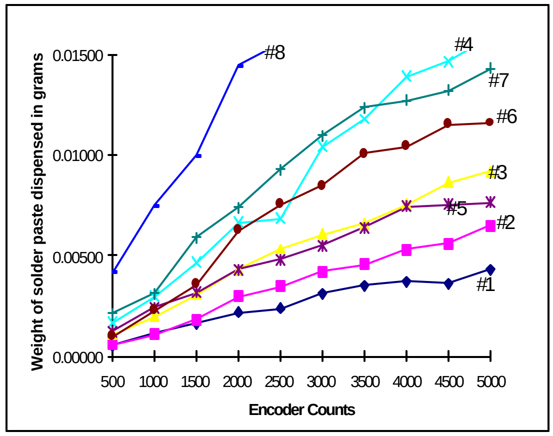

Figure 2 Effect of depth of cut on weight of solder paste dispensed for unrestricted flow

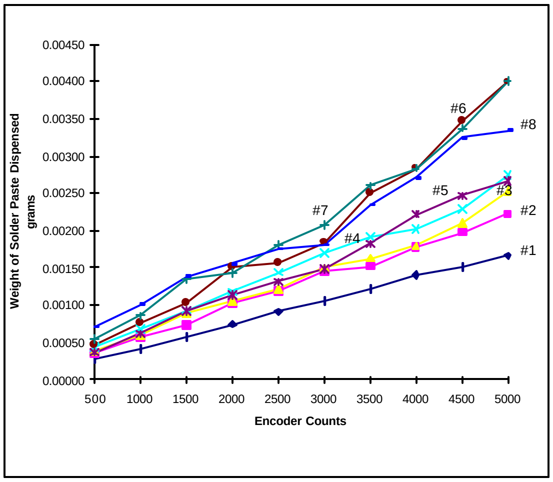

Figure No 3 Effect of depth of cut on weight of solder paste dispensed with a 16-mil ID nozzle.

This inadequate build-up of pressure can be attributed to the slippage between the screw and the material. The above graph indicates the following: increasing the depth of cut need not necessarily increase the dispensed volume. Hence, with reducing nozzle ID it is important to determine the depth of cut that maximizes dispense rate.

2. *Effect of Number of Starts*:
The number of starts determines the distance moved by the material in one rotation of the screw.

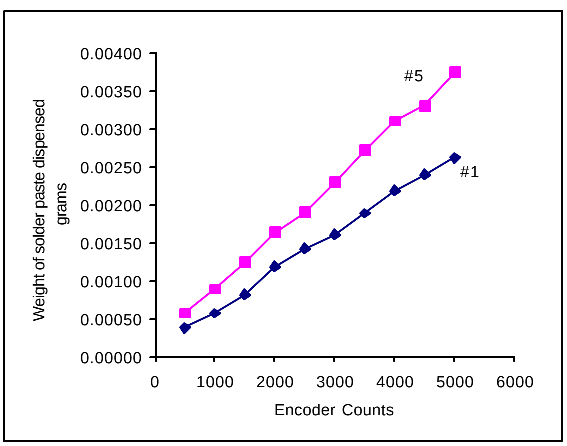

Figure 4 Effect of number of starts on weight of solder paste dispensed for a 20-mil ID nozzle.

For a single threaded screw, the distance moved by the material in one rotation is equal to the pitch of the screw; whereas, for a double threaded screw, the distance moved by the material in one rotation is twice the pitch. Hence, the quantity of material dispensed by a double threaded screw is greater than a single

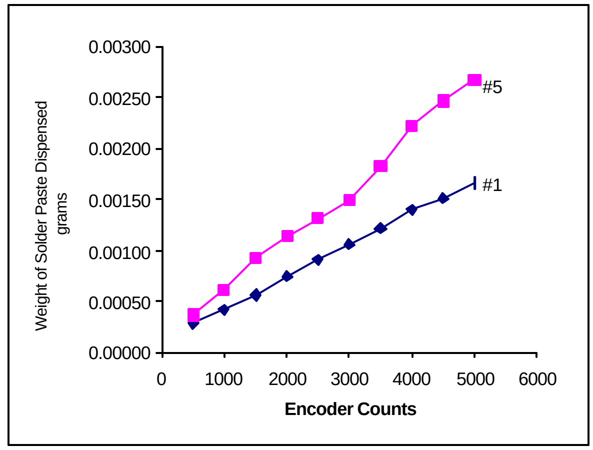

Figure 5 Effect of number of starts on weight of solder paste dispensed for a 16-mil ID nozzle.

threaded screw for the same amount of turn. This is also observed during experimentation. Increasing the number of starts increased the flow rate of the solder paste. For example, Figure 4 and 5 show the increase in the quantity of solder paste dispensed for a 16-mil and a 20-mil ID nozzle using Screw #1 and Screw #5. Similar results are obtained in comparing the other pairs of single vs. double start screw.

3. *Effect of Nozzle ID:*
A nozzle is specified in terms of its standoff and inner diameter (ID). The nozzle ID determines the size of the dispensed dot. As the solder paste flows from the cartridge into the nozzle, it undergoes a change in flow area, resulting in pressure change. A high-pressure variation could result in separation of the flux and the solder balls. With a decrease in nozzle ID, the resistance to flow also increases, thus increasing the Back-Pressure. If the screw feeds more material than the nozzle can handle, excessive build-up of Back-Pressure occurs, causing slippage between the screw and the material. This slippage results in inadequate pressure build-up for dispensing. This is possibly due to the separation between the flux and the solder balls, where the flux acts as a lubricant, preventing surface contact of the solder metal spheres with the screw surface.

For given dimensions of the screw and material properties, the Back-Pressure increases with a decrease in nozzle ID. Due to this increase in

Back-Pressure, the quantity of solder paste dispensed decreases.

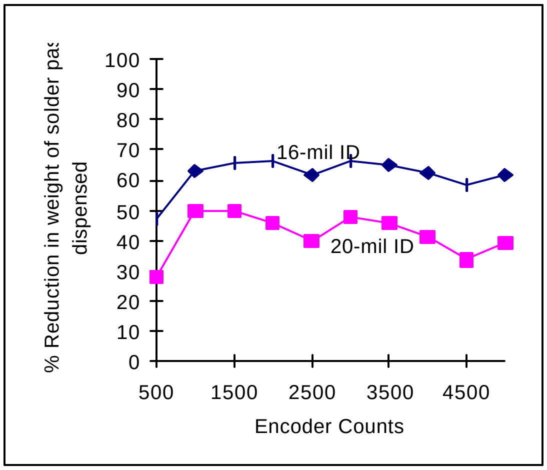

Figure 6 Effect of nozzle ID on the quantity of the solder paste dispensed using Screw #1.

Experimentation with a 16-mil and 20-mil ID nozzle (see Figure 6) indicates that the percentage reduction is constant for different amounts of rotation of the screw. The percentage reduction is a relative difference calculation[1]. A similar effect is observed with the remaining seven screws indicating that the Back-Pressure increases with a decrease in nozzle ID and an increase in encoder counts to keep the percentage reduction constant.

CONCLUSION

The effect of different geometric variables of the Archimedes Screw and nozzle ID on the quantity of material dispensed were studied. In order to achieve the maximum flow rate, it is necessary to determine the depth of cut, the number of starts, and the screw-nozzle combination. It was noted that the quantity of dispensed material increases with an increase in encoder counts, but after a certain point for a high depth of cut, the quantity of material dispensed decreases for a reduced nozzle ID. This indicates that there is an optimal screw-nozzle combination that maximizes production rate. In general, increasing the number of starts or the channels for the material to flow increased the quantity of material dispensed. The nozzle ID sets the limit to the depth of cut. For a 16-mil ID nozzle, Screw #6 and Screw #7 dispensed more than Screw #8. Also, increasing the depth of cut from 16-mils to 20-mils did not result in an increase in the quantity of dispensed material.

It is also concluded that the Back-Pressure increases with a decrease in nozzle ID and increase in encoder counts. Hence, for a given nozzle ID, it is necessary to determine the amount of rotation of a screw so that the pressure developed to dispense is greater than the Back-Pressure. Any further increase in rotation could result in a marginally reduced quantity of solder paste dispensed and increased separation.

FUTURE WORK

Apart from studying the effect of different nozzle ID size, the number of starts, and the depth of cut on the volume dispensed, it would also be interesting to see the effect of different pitch values, the different types of threads and variation in the length of screw. The experiment was studied using a solder paste with 85% metal loading. A variation in the metal loading of the solder paste could significantly result in the change of volume dispensed and hence the Screw-Nozzle combination that optimizes dispensing.

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[1] Percentage Reduction = $(W_g - W_r) / W_r$
Where
W_g = Weight of solder paste with unrestricted flow.
W_r = Weight of solder paste with restricted flow.