SPTF

A Guideline to Wet and Dry Ink Deposit Measurement Methods

Part One of Three

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Executive Summary

As the demand for higher quality screen printed products continues to rise, those responsible for manufacturing processes or quality control are increasingly becoming aware of the need for equipment and procedures to monitor the outcome of those items being produced. Equally important is the ability to determine if samples printed today are the same as samples produced last week or last year. True process control and repeatability can become a reality for most companies if proper measurement techniques are implemented. Many types of equipment exist for monitoring various physical changes brought about by the often changing process parameters.

One of those physical changes of importance to the screen printer is the thickness of the ink being deposited on the substrate. A uniform, controlled and repeatable ink deposit is both desirable and essential in most applications.

As a result of the need to measure and control both wet and dry ink deposits a research project has been completed at the Screen Printing Technical Foundation that has provided the information needed to accomplish the following objectives:

- Evaluate tools or instruments, existing in industry, designed to measure wet/dry ink thickness and identify applications that have the best potential benefit to screen printers.
- Develop and recommend specific procedures that will improve the performance of a particular instrument or allow it to be used more successfully in a screen printing application.
- Establish data on the repeatability and level of process control possible for each instrument category in order to provide screen printers with options that fit their particular statistical process control (SPC) requirements.

Experimental Design

The measurement of a wet ink sample presents unusual problems when comparative data from different categories of instruments are desired. If the ideal wet deposit could be created on a perfectly smooth, camberless, nonporous substrate, it would also have to remain in that exact initial condition in order to produce data from different instruments on a sample of known thickness at the same instant in time. In the real world of applied research this perfect comparison is very difficult to achieve, however by taking a slightly different approach, good (not perfect) indications of the relative performance of various measurement devices can be presented.

Before this is developed further, a discussion is in order on the sample preparation methods. Due to the constantly changing conditions produced by the evaporation of solvent based inks, once they are exposed to air it was determined that ultraviolet (UV) curable inks would produce the most stable wet samples for our purposes. Initial data was collected to generate ink settling over time information about the deposits being produced. This was necessary in order to establish the most stable window of time in which data could be col-lected without thickness changes occurring in the inks.

During the planning stages of the project it was hoped that another advantage in selecting “UV” curable

For clarification purposes a glossary has been included with this report. Also, the following symbols are used throughout this report.

Δ % - symbol for percent change

µm - symbol for micrometer

σ - statistical term for one standard deviation (sigma)

$\bar{x}$- symbol for mean

inks would be the ability to determine the initial wet thickness of the sample from its final cured thickness. This would serve as a cross correlation of the wet data being collected on the various instruments. This projection was based on claimed shrink factors of one to three percent after cure. It was quickly determined from experimental data that this belief, although widely held, is far from the truth. As can be seen from the examples represented in Figure 1, five different “UV”

UV Wet and Dry Ink Deposit
390/35 Mesh

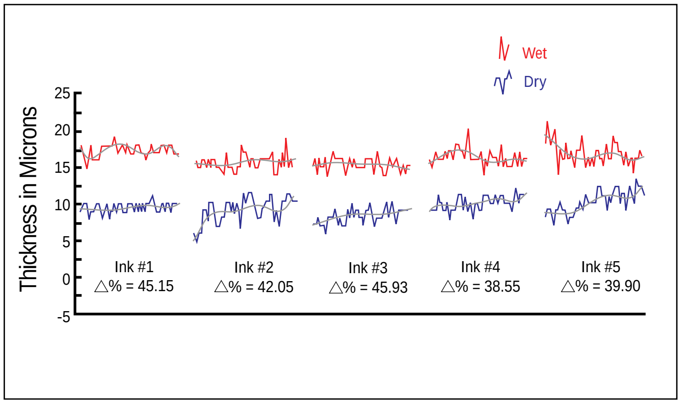


Figure 1. UV ink deposits on glass substates before and after cure.

curable inks were measured on glass substrates before and after cure. All inks tested demonstrated a tendency to shrink far in excess of the claimed values.

The average change for the inks tested in Figure 1 is 42.32 percent using a 390/35 mesh polyester screen. This experiment was repeated on the same five inks with 10 different screen meshes and always exhibited similar results. The overall average shrink factor for all meshes and inks tested was 35.40 percent wet to cured, and ranged from a minimum of 19.3 percent to a maximum of 49.80 percent.

In addition to ink selection and testing, an accurate method of depositing ink at a known and repeatable thickness was needed to establish comparative data on the various measurement procedures being developed.

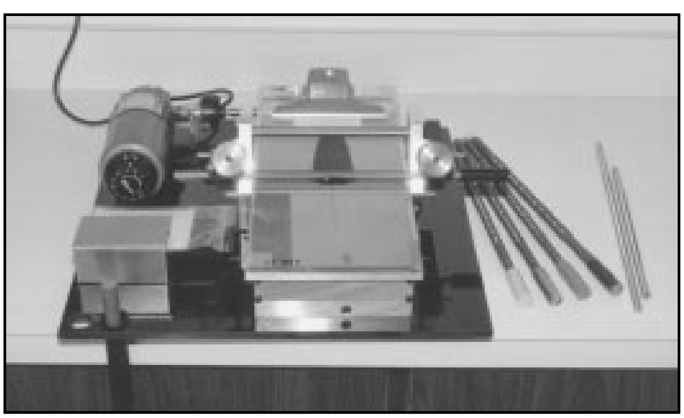


Figure 2. Automated draw down system using wire wound metering bars.

In order to minimize the number of variables that had to be controlled and produce predictable samples, an automated draw down system was chosen for further evaluation and initial testing.

Theory of Operation

This automated draw down system meters ink onto the substrate by means of a precision wire wound rod. The rod is drawn through the ink sample at a pre-selected uniform speed and held in contact with the substrate at a constant pressure by over hanging weights. Ink at a constant rate of shear flows through the openings created by the wire diameter between the rod and the substrate. Various wire diameters and rod types can be selected for different deposit thickness.

Experimental work was performed to establish the accuracy and precision of this system before comparative results could be obtained on the different wet measurement devices and procedures being evaluated.

Accuracy and Precision versus Speed

Basic flow characteristics obtained from various inks are the result of the rheological design of the product at the manufacturer, and any intentional or unintentional alterations created by the end user. The amount of force applied and the method of application chosen can result in varying shear rates for the ink being transferred. Ink flow can vary considerably with changing rates of shear and must be controlled for repeatable deposits. In order to establish the best operating conditions for the inks used in this work, tests were performed to determine the accuracy and precision produced at various speeds with this method of sample preparation.

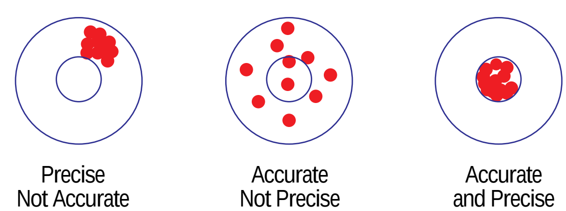


Figure 3

The velocities tested were from 1.5 cm/sec to 17.5 cm/sec and represented the full practical speed range of the automated draw down instrument. As can be seen in Figure 4, only two speed settings produced results that averaged close to the predicted thickness of 24 microns expected from the 24 micron wire wound bar. Of those two positions on the velocity curve one represented a better choice for producing the best combination of accuracy and precision. From the data in Figure 5, we can see that the speed setting of 10.3

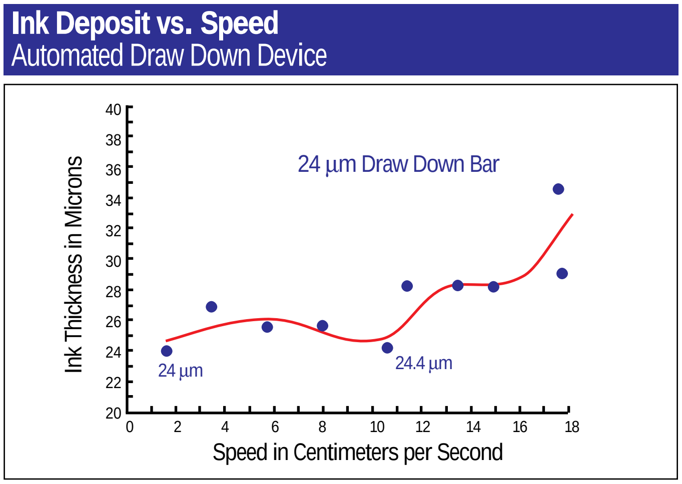


Figure 4. Only two speed settings produced an average thickness of 24 microns wet.

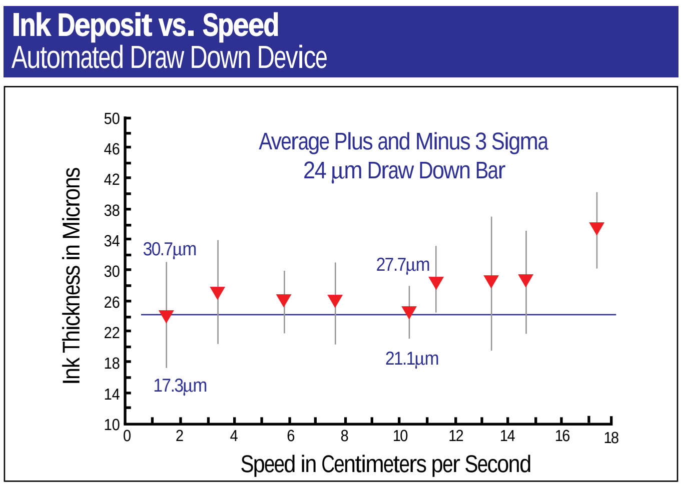


Figure 5. A speed setting of 10.3 cm/sec produced the best combination of accuracy and precision.

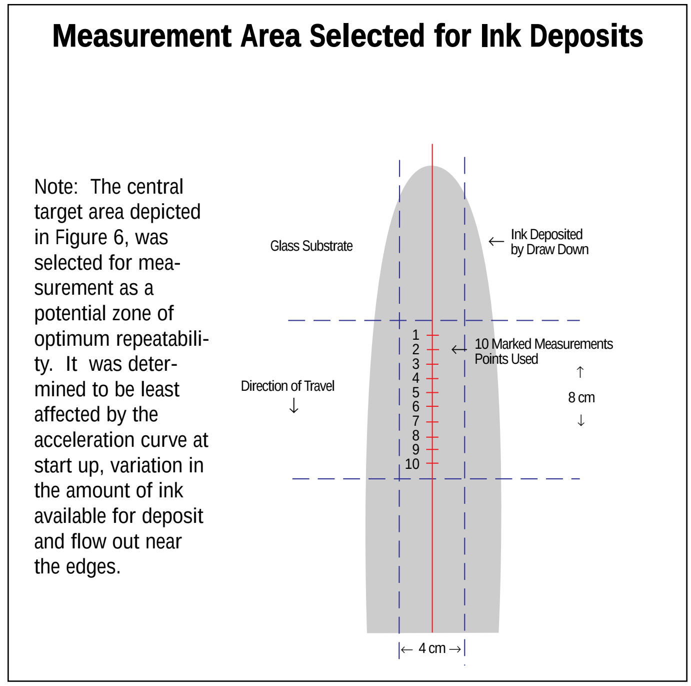


Figure 6. A 4 cm. by 8 cm. central section was selected for comparative data collection.

cm/sec produced a statistical range of 21.1 to 27.7 microns of wet deposit thickness.

The second choice occurring at a speed setting of approximately 1.5 cm/sec, although producing an average deposit thickness of exactly 24 microns, ranged from 17.3 microns to 30.7 microns statistically and was not acceptable for our work.

In addition to the improvements gained by fine tuning the system for a specific ink and wire wound bar combination, further refinements are possible by proper substrate selection. In many applications cast glass is used as a support surface for a more flexible substrate when inks are drawn down for comparison. It may also serve as the primary substrate depending on the application for which inks are being evaluated. Our data of ink deposited on cast glass substrates demonstrated an overall system error of plus or minus 20.4 microns (fixed speed, fixed weights, 50 micron wire wound bar, UV curable ink). See Figure 6 and Figure 7.

However, when the same experiment is repeated using a low cost ground glass substrate, the total system error is reduced to plus or minus 9.54 microns and is more evenly distributed about the target ink deposit thickness, which in this case was 24 microns. (Figure 8)

Even with these refinements a more predictable and repeatable method of ink deposit for sample preparation was desired. Investigations into various aspects of the screen printing process yielded results that were somewhat surprising in the light of conventional thought concerning process control and predictability. Traditionally it has been assumed that the great number of variables and the complexity of developing methods of controlling those variables had effectively reduced screen printing to an art form rather than a science. We found this to be untrue even in the most basic approach. When using a hand proofing press, normal process controls such as the angle, pressure and speed of the squeegee are somewhat free to float within a large operational window depending on the skill of the operator. As can be seen from the results obtained in Figure 9 a high quality, properly tensioned polyester screen demonstrated the ability to effectively meter ink deposited onto a ground glass substrate at a repeatability level that was superior to the best results we had been able to obtain using the automated draw down approach to sample preparation.

These results were amazing given the great number of variables that were only loosely controlled by this very simplistic printing mechanism. Other investigations included producing samples on a computer controlled press typically used in electronic printed circuit board prototyping and production. (Figure 11) This represented the upper extreme in the area of sophistication and process control as can be seen from the data depicted in Figure 10.

Automated Draw Down Device
50 µm Rod on Cast Glass Substrate

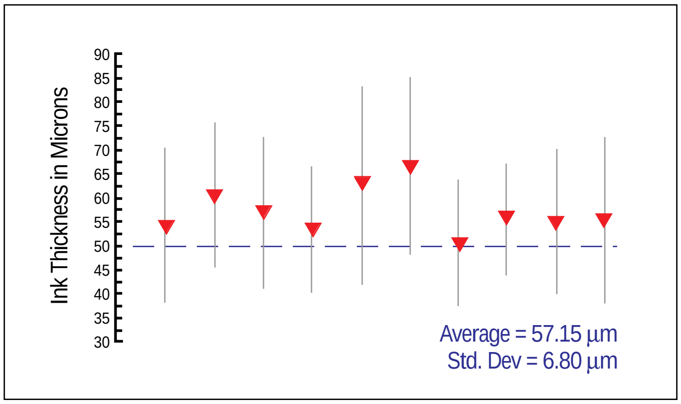


Figure 7. Ink thickness variation on cast glass substrates.

Automated Draw Down Device
24 µm Rod on Ground Glass Substrate

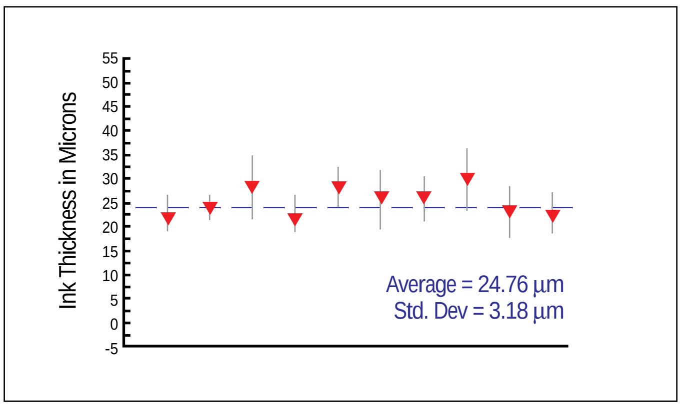


Figure 8. Ink thickness variations on ground glass substrates.

A quick review of the statistical information reveals a process in Figure 10 that will remain within a 7.8 micron window (six times the standard deviation) when all variables are controlled. This represents an improvement of 47.13 percent over the repeatability possible when these variables are loosely controlled as in Figure 9.

Hand Screen Printing
305/40 Mesh

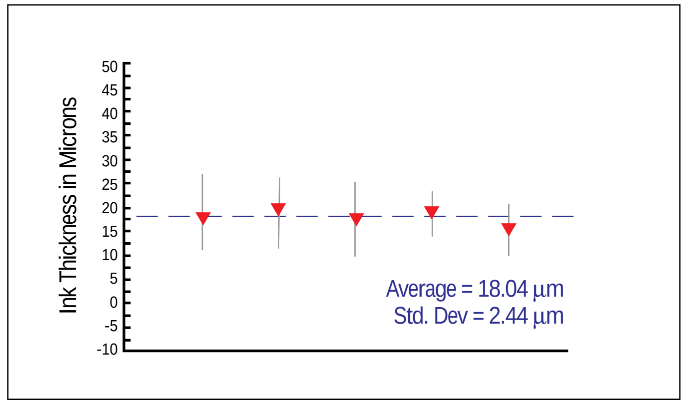


Figure 9. Ink thickness variations on hand operated proofing press.

Computer Controlled Press
305/40 Mesh

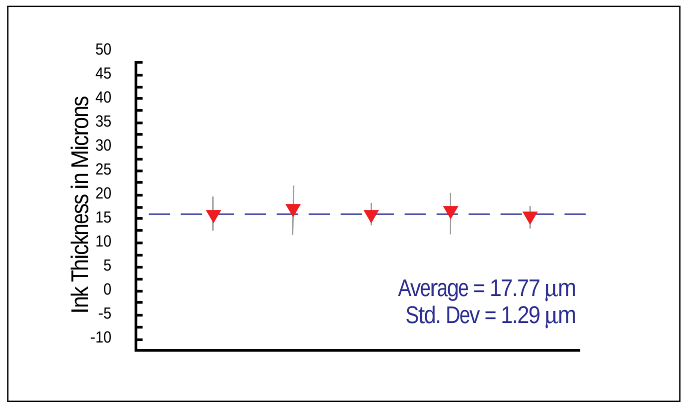


Figure 10. Ink thickness variations on computer controlled precision press.

This level of sample preparation was considered acceptable for our purposes due to the predictability of the expected wet ink thickness within a fairly narrow operating window.

Establishing a Reference Instrument

Although the procedure for sample preparation just described represents a good attempt at reproducing perfect wet samples in an imperfect world. There is still enough process drift to defy direct comparisons when a precision of greater than 3-4 microns is desired. For this reason comparisons were made against readings taken on a known reference instrument. The instrument of choice for this project work was the Electronic Micro Gauge (Figure 12).

The Electronic Micro Gauge ("EMG") combines optical and mechanical precision with electronic readouts to provide information useful to the screen printer. It can be used to measure wet laydowns, dry laydowns, screen tensions, squeegee durometer, emulsion thickness, substrate thickness and warpage. A printer option allows statistical processing of the minimum value, maximum value, mean value, standard

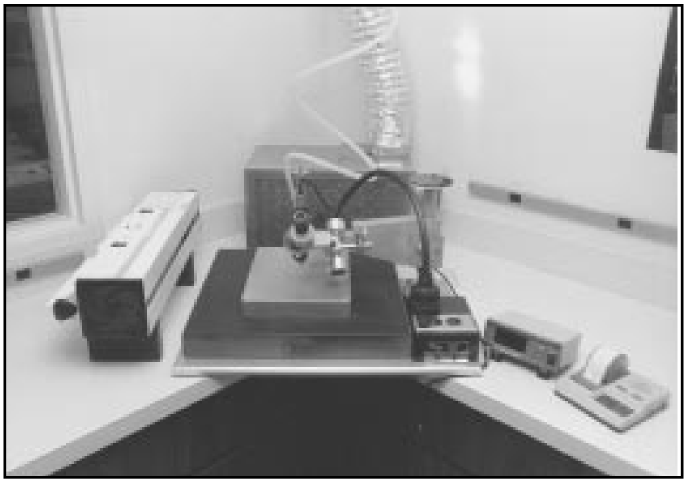


Figure 12. Electronic micro gauge shown with SPTF modifications.

deviation, histogram plotting and tolerance setting.

Thickness measurements are accomplished on this instrument through a photoelectric linear encoder and microscrew probe-height adjustment mechanism. For wet measurements a 2.54 micron radius-tipped Tungsten needle is lowered toward the surface of the ink while being monitored through an attached 15x to 60x microscope and high-intensity illuminator*. The probe is easily observed as it approaches the ink and can be slowed at this point to descend in steps of less than one micron each (Figure 15a). The position of the wet surface is easily determined by a condition called hydrostatic upthrust (Figure 15b) occurring at the point of contact between the Tungsten needle and the surface of the ink. Plainly stated the liquid being probed has a tendency to jump up the needle once the surface tension is broken, making the decision of when to zero the digital read out very easy. Most operators will be able to find the surface of the ink to within plus or minus 2 microns with 30 minutes of instruction. At this point the digital read out is zeroed and the needle allowed to continue its controlled descent until resting on the surface of the substrate (Figure 15c).

With the touch of a button the data can be entered and processed by the statistical printer if that option has been chosen. Care must be taken when measuring ink deposits that have irregular surfaces as needle placement can effect the thickness of readings obtained by this method. (Figure 16 a, b, c) When surface conditions are known to be irregular, multiple probe positions and measurements must be recorded for accurate average results. Other conditions that often occur in the real world are substrate camber and thickness variations. Fortunately, with the Tungsten needle dropping vertically through the column of ink the effects of substrate camber and thickness are virtually eliminated. (Figure 17 a, b, c) An addition that will allow the verification of the calibration of this instrument is the Tensioned Ring Gauge. (Figure 18)

Figure 18. Tensioned ring gauges.

This consists of a tensioned diaphragm of known thickness made of polymide that is supported and stabilized with a ring of suitable diameter and height. The ring maintains the tension of the diaphragm by possessing a lower coefficient of thermal expansion than the polymide.

The thickness of the gauges used for our purposes are certified by "NBS" to within 0.254 microns and are

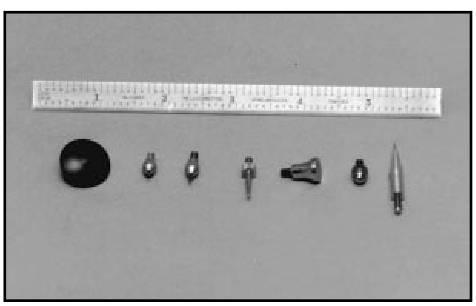


Figure 13. Many probe options make it possible to measure different materials accurately on the "EMG."

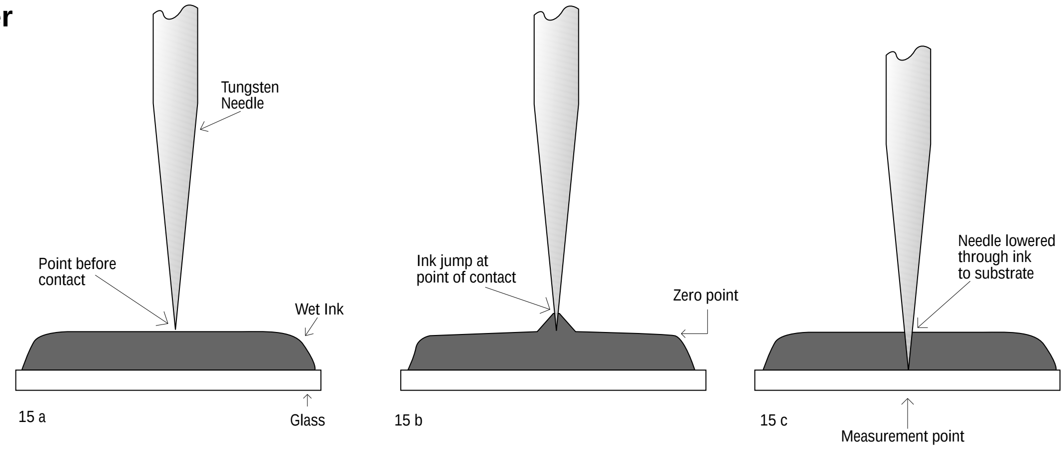
Figure 14. A statistical processing printer and electronic read outs provide quick process information for statistical process control (SPC.)

**A yellow filter was added to the high intensity illuminator to prevent curing of the UV inks while measurements were taken.*

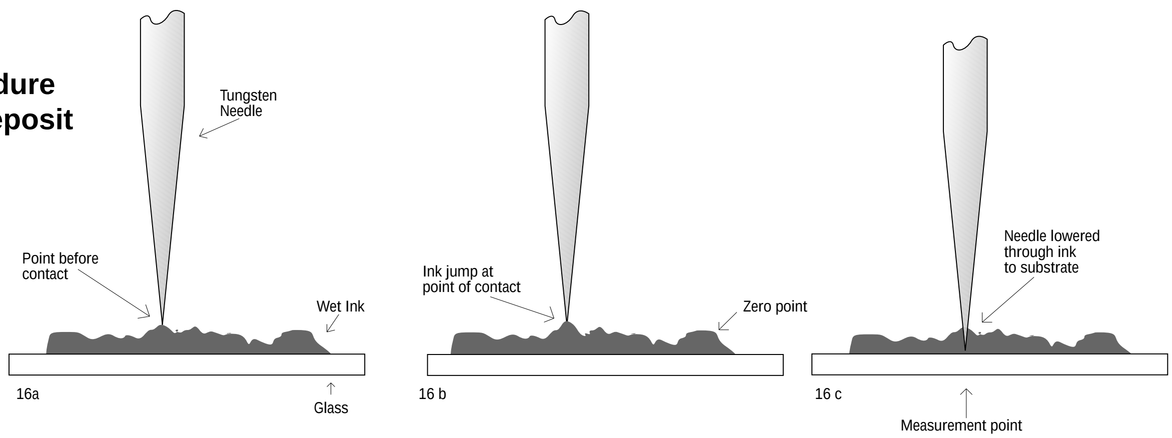
Figure 19. Endstat static eliminator

Electronic Micro Gauge Measurement Procedure

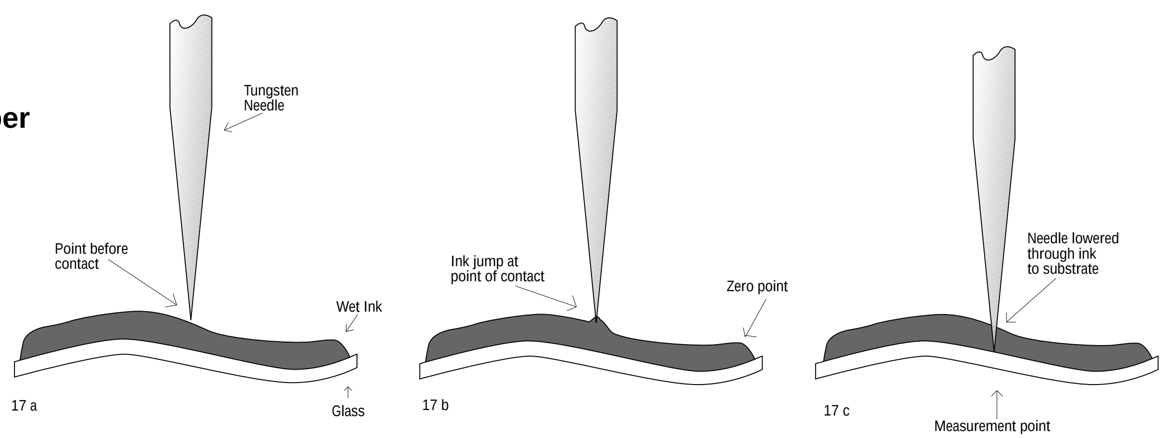
Measurements under Ideal Conditions Not Affected by Tip Placement



Measurements Affected by Placement Procedure on Uneven Ink Deposit



Measurements Not Affected by Substrate Camber



used to reference thickness measuring devices. Other additions that increased the ability to measure wet deposits accurately were a static eliminator (Figure 19), a vacuum block to secure the ground glass substrates (Figure 20), and a larger format granite surface plate (Figure 21).

A proper diameter tip must be selected for more yielding materials and substrates. In the picture in Figure 22, a large flat probe was selected for larger format measuring of the dry deposit thickness on a material that could be imprinted by smaller surface area probes. For wet measurement on soft substrates small cylindrical probes are recommended to replace the sharp Tungsten needle. A diameter must be selected that allows no more than 2 microns of drift into the substrate after 30 seconds at 1.76 Newtons of measuring force (weight of the down force on the probe). In this way a reasonable zero point will be established.

By following these simple procedures, printers will be able to achieve maximum capability from this and other instruments that have been evaluated by SPTF.

Summary

It is essential that in any attempt at controlling the process, printers establish some ability to measure things. Wet and dry film thickness are at the heart of these measurements. Without solid information on ink laydown, adjustments become, at best, a hit and miss exercise in futility. The bottom line is why guess when you can measure?

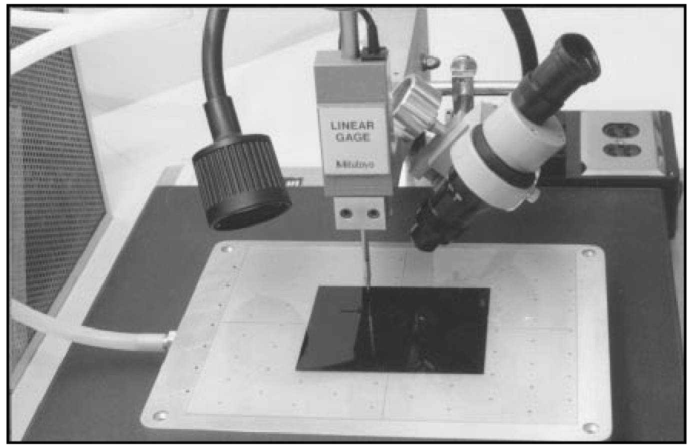


Figure 20. Vacuum block to secure glass substrate.

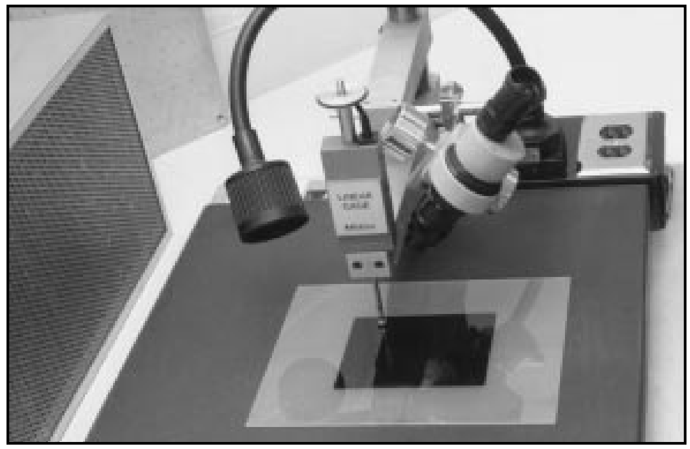


Figure 21. Large format granite surface plate.

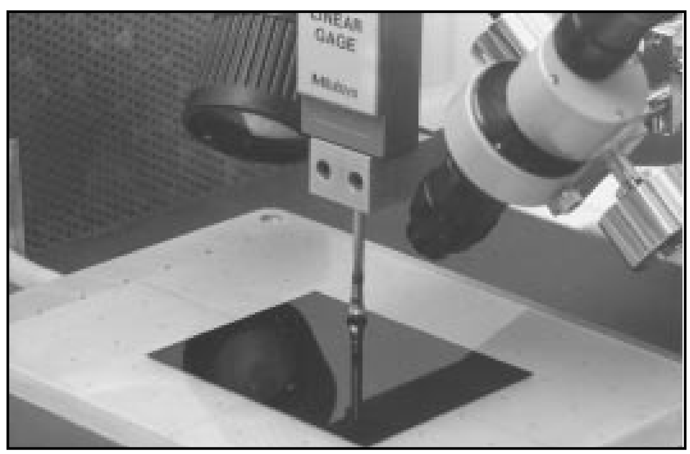


Figure 22. Larger diameter probe used on irregular or soft materials.

Practical Applications

In the course of preparing procedures for sample preparation documented earlier in this report, we found this instrument very useful in the following areas:

Wet Ink Deposit Averages
Measured with Electronic Micro Gauge

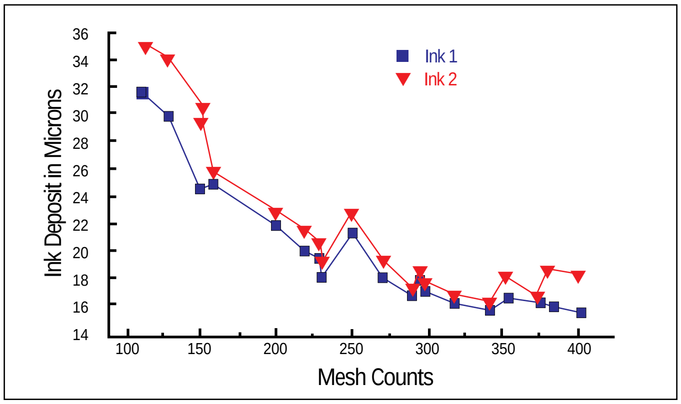


Figure 23. Wet and cured UV ink deposit thicknesses for various screen mesh selections. Data was taken from 27 different mesh counts using both a thick and thin UV ink. Notice the affect of ink rheology at both ends of the graph.

Statistical Process Control
Polycarbonate Substrates

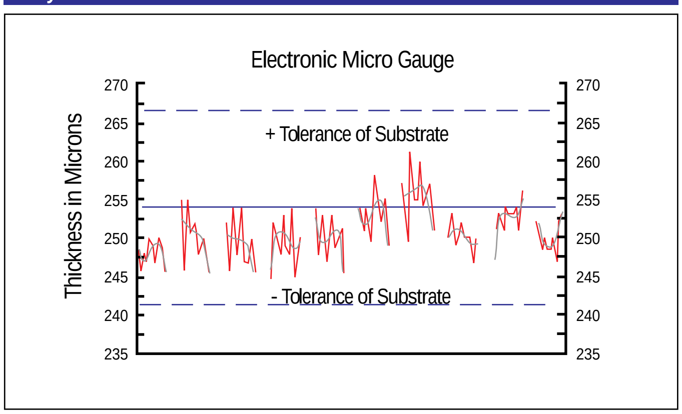


Figure 24. Statistical process control on polycarbonate substrates. Why guess when you can measure? Don't take anybody's word for it, establish your own QC lab and the tolerances you can live with.

Ink Thickness Variations on 3 Substrates
Electronic Micro Gauge

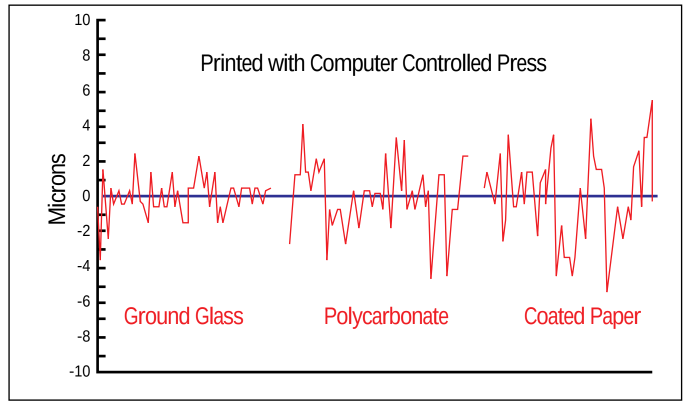


Figure 25. Surface profile of wet ink on various substrate materials. The substrate affect is a strong influence on the finished product.

Transfer Factor
Computer Controlled Press

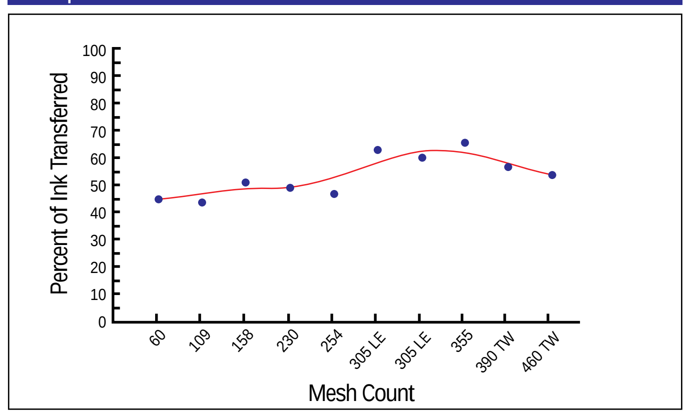


Figure 26. Percent of ink transferred to substrate from ink available in one square centimeter of tensioned polyester fabric This information is essential in being able to establish accurate ink consumption tables. To date SPTF has the only reliable information on estimating wet/dry film thicknesses. This is only possible by establishing good ink transfer data.

Additional reports from this project will continue to provide useful information and comparative data on measurement procedures used with eight other wet and dry measurement devices.

Definition of Terms

Accuracy - a generic concept of exactness related to the closeness of agreement between the average of one or more test results and accepted reference value.

Cast Glass Substrate - a glass substrate where the characteristics of the casting mold used to form it dictates the flatness and uniformity of the surface.

Deviation - the difference between the value of the controlled variables and the value at which it is being controlled.

Ground Glass Substrate - a cast glass substrate where one side has been finely ground to improve flatness and uniformity.

Hydrostatic Upthrust - the fluid jump seen when the tip of a tungsten needle makes contact with a wet film deposit on the electronic micro gauge. This phenomena is caused from the back pressure of the surface tension of a liquid.

Mean - ($\bar{x}$) a measure of central tendency equal to the sum of the observations divided by the number of observations. Also known as a statistical average.

Micron - (µm) a metric unit representing one millionth (1/1,000,000) of a meter or 0.000039 of an inch.

Mil - an English unit representing one thousandth of an inch or 25.4 microns.

NBS - acronym for the National Bureau of Standards.

Percent Change (∆%) - indicates percentage increase or percentage decrease between two numbers.

Precision - a generic concept related to the closeness of agreement between test results obtained under prescribed like conditions from the measurement process being evaluated.

Repeatability - the closeness of agreement between test results obtained under repeatable conditions.

Rheology - the science of flow and deformation of fluid matter under pressure. Rheological characteristics of liquids include viscosity, plasticity, elasticity and rigidity.

Shear - the relative movement of adjacent layers in a liquid or plastic during flow.

Shrink Factor - a factor determined from the average percentage decrease in wet to dry ink deposit thickness for UV curable screen printing inks.

Sigma (σ) - the Greek symbol for standard deviation.

± 3 Sigma (± 3 σ) - defines 99.73% of the area under a normal curve where only 3 of 1000 samples fall outside of that curve. These values are often the basis for control charts.

SPC - acronym for statistical process control defined as the use of statistical techniques, such as control charts to analyze a process or its outputs to realize and maintain statistical control.

Standard Deviation - a numerical value that measures the spreading tendency or dispersion of the data. A large standard deviation represents a greater variability than a small standard deviation.

Surface Tension - a property brought about by intermolecular attraction within a liquid that causes the surface of that liquid to contract to reduce the volume into a form having the least area.

Tensioned Ring Gauges - a tensioned diaphragm of known thickness made of polymide that is supported and stabilized with a ring of suitable diameter and height. The ring maintains the tension of the diaphragm by possessing a lower coefficient of thermal expansion than the polymide. Thickness is accurate to 2.54 microns and can be certified to 0.254 microns.

∆ % - symbol for percent change (also called delta percent)

µm - symbol for micrometer

σ - symbol for sigma, the statistical term for one "standard deviation"

$\bar{x}$ - symbol for the mean or average