PRODUCTION

All Screen Printers

Understanding The Mechanism: The Essence of Process Control

by Dennis Hunt,
Director of Research
Screen Printing
Technical Foundation

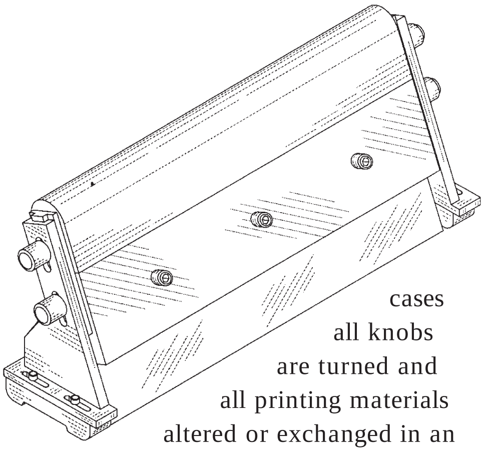
An interesting thing about screen printing is that even when it's "in control" it is still out of control if we don't understand the mechanism. Although skilled artisans continue to improve their craft — while finding better ways of transferring that knowledge to the next generation — if we make the transfer without the benefit of fundamental understanding we are still walking in darkness. The goal of science has always been that of understanding the mechanism. At the heart of every investigation is the goal of unlocking that underlying explanation that helps to make the outcome more predictable. While the Quantum Physicist endeavors to come up with a better theory of how things work in the microcosm, the Astrophysicist attempts to understand the motion of the galaxies. We on the other hand have the distinct advantage of studying something in between.

Some people have suggested that screen printing is by its very nature somewhat mysterious and unpredictable — more than 500 variables that can affect the process have now been identified. At times the complexity of the problem seems overwhelming. The writer Henry David Thoreau suggested that life should be greatly simplified, with only a few major activities with which to deal. I tend to agree, however, Mr. Thoreau was certainly not a scientist and probably never a screen printer — at least not one who depended on the process for his livelihood. Notwithstanding there is an underlying simplicity woven into the fabric of the craft that has delighted its practitioners while mystifying the experts.

FLYING BY THE SEAT OF YOUR PANTS

Persons who print often find they develop an instinct for what works and what doesn't. All things being equal, is this really a bad way to go? Why bother to get instrument rated when you can "fly by the seat of your pants"? Many printers do and have gotten away with little more than this approach for years. The problems come when the "machine stops" and no one understands why. What usually happens next is what is commonly referred to as a "search and destroy mission." In extreme

Why bother with an instrument rating when you can "fly by the seat of your pants"? The problems come when the machine stops and no one understands why.



cases all knobs are turned and all printing materials altered or exchanged in an effort to get the process to produce what it did last week. If the gods are smiling, the problem will disappear and you will look like a hero — or at least get to keep your job. If not, you may just get to spend the rest of your life in the car wash.

Before Louis Pasteur discovered that most infectious diseases are caused by germs many people died needlessly because of what they didn't know. Is the goal of truly understanding the screen printing process dying a slow and needless death because we do not yet fully appreciate the little things that are killing us? A classic example of this is documented in a Screen Printing Technical Foundation (SPTF) study entitled "Bolt-to-Bolt Mesh Variation" by Dawn M. Hohl (SGIA Journal, 1998, Volume Four, Fourth Quarter). In this investigation researchers, at the request of a member company, examined possible causes for an unexplained color shift that was occurring with different lots of polyester fabric. Even though the mesh was supplied from the same source with identical specifications, there was enough lot-to-lot dimensional change at higher tensions (27 Newtons per centimeter and above) to produce visually detectable color shifts in the prints.

Figure 1:

(The Easy Glider: Patented Printing Device) SPTF recently received a patent on an unusual printing apparatus known as the Easy Glider. This device, although creative in its application, represents only one of many possible outcomes from the research that inspired it. It is offered as an example of how seemingly esoteric information will in many cases solve practical problems.

Although skilled artisans continue to improve their craft — while finding better ways of transferring that knowledge to the next generation — if we make the transfer without the benefit of fundamental understanding we are still walking in darkness.

Let me be quick to point out that this does not necessarily reflect poorly on supplier consistency or quality control of extruded polyester thread, or even in the weaving process. In many cases these highly skilled technicians are working at the limits of human understanding with these processes and their Quality Control is second to none. In contrast, the average screen printer is just beginning to have a real incentive to push the edge of the printing envelope as market share diminishes. What it does suggest is that some individuals within this global community of imaging professionals are not satisfied with the status quo when it comes to problem solving. They operate from a self imposed higher standard, never willing to just change something until the problem "goes away" only to have it return later with a vengeance. To find and eliminate problems like this requires more than "Control Charting" and technical assistance from SPTF.
It requires passion!

TANGIBLE BENEFITS

Although this kind of effort may not always provide immediate tangible benefits, in the long haul these are the people who will find themselves gaining market share instead of losing it. The reasons are simple: they can do it faster, they can do it better, and they can do it cheaper, because they have taken the time to understand the mechanism. This basic understanding will sometimes let you do things others cannot, but more importantly it will always allow the same outcome to be achieved with less effort. Less effort translates into lower cost for the same quality, which means more business or more importantly, more new business. This is where the Screen Printing Technical Foundation comes into the

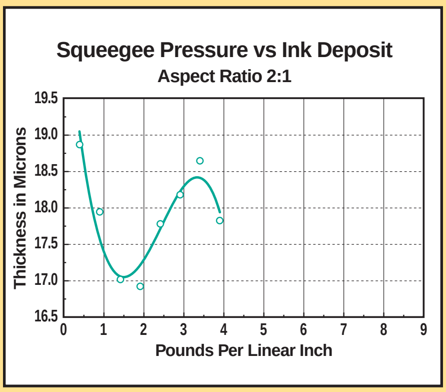


Figure 2:

(Squeegee Pressure vs Ink Deposit, Aspect Ratio 2:1) Using an aspect ratio of 2:1 (a 12-inch squeegee inside of a 24-inch screen frame) we find that as squeegee pressure increases the average wet ink deposit decreases, but only through a specific range of adjustment (from approximately 0.5 to 1.5 lb./linear inch). If we continue, however, to increase squeegee pressure beyond this clearly defined bottom on the chart, the exact opposite will occur (ink deposit actually increases from the additional squeegee pressure of 1.5 through 3.5 lb./linear inch).

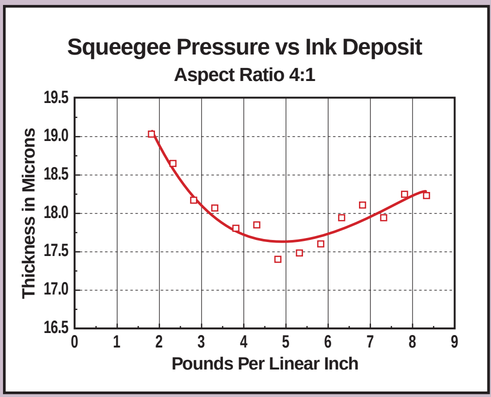


Figure 3:

(Squeegee Pressure vs Ink Deposit, Aspect Ratio 4:1)
In this figure, we can see the result of the same test with a squeegee exactly one half as long as the one in Figure 2 (a 6-inch squeegee inside of a 24-inch screen frame). In this experiment it took nearly 5.0 lb./linear inch of squeegee pressure to reach the low point on the curve and the change was less pronounced (only a 1.4 micrometer decrease in ink film thickness compared to a 2.0 micrometer change in Figure 2). Our process was becoming more robust in its response to squeegee pressure.

equation, at the most fundamental level we can provide a better understanding of how the process works. Unfortunately what we can't do is make people use that information to their best advantage. It takes desire, diligence and some degree of intolerance to mediocrity to make it happen.

Perhaps some of the opportunities are less visible to the average consumer because they are not presented as predigested knowledge. This approach is both necessary and beneficial due to the nature of the subject matter. Fundamental research produces the seed; it's the consumer who will ultimately decide how that information will be used. Pre-assigning the information to a single specific application could actually limit its usefulness. People tend to think more creatively when the door is left open to all possibilities.

FROM "INTERESTING" TO PRACTICAL

This brings me back to the sum and substance of authentic process control, understanding the mechanism. SPTF recently received a patent on an unusual printing apparatus known as the Easy Glider (Figure 1). This device, although creative in its application, represents only one of many possible outcomes from the research that inspired it. The Easy Glider is offered as an example of how seemingly esoteric information will in many cases solve practical problems.

The study that inspired the Easy Glider was an investigation into the relationship of squeegee pressure and the aspect ratio (ratio of the screen frame size to the squeegee length) on wet ink film thickness. The conditions of the investigation were these: Printing was conducted on an AMI computer controlled press with an 80 durometer diamond profile squeegee and a 24 x 24 inch inside diameter screen frame. The Sefar America Inc 305/34 LE mesh was tensioned to 20 Newtons per centimeter using a Harlacher mechanical stretching system. The substrate was a super flat ceramic platen selected to avoid introducing variation into the experiment due to substrate camber. A 4 x 4 and 1 x 4 inch rectangular pattern was printed in order to isolate the stencil effect from the wet film thickness.

A series of printing tests were performed while varying the squeegee pressure from approximately 0.5 lb./linear inch to 8.5 lb./linear inch. This was the typical range of "reasonable results" (the point where printing first occurs to the point where excessive distortion occurs). The graph in Figure 2 illustrates this effect quite well. Using an aspect ratio of 2:1 (a 12-inch squeegee inside of a 24-inch screen frame) we find that as squeegee pressure increases the average wet ink deposit decreases, but only through a specific range of adjustment (from approximately 0.5 to 1.5 lb./linear inch). However if we continue to increase squeegee pressure beyond this clearly defined bottom on the chart, the exact opposite will occur (ink deposit actually increases from the additional squeegee pressure of 1.5 through 3.5 lb./linear inch). The curve is typical but will vary greatly depending on the materials used and various printing conditions. This effect is well known in the electronic screen printing industry and is thought to be caused by distortion of the squeegee at the screen/squeegee interface.

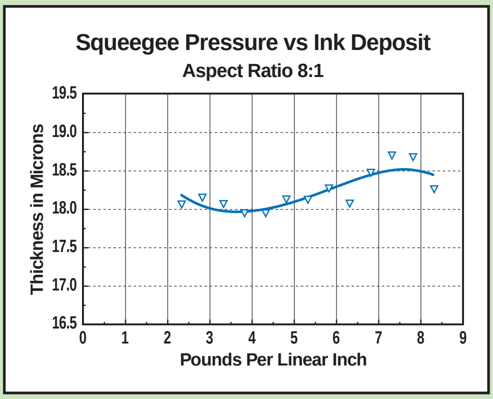


Figure 4:

(Squeegee Pressure vs Ink Deposit, Aspect Ratio 8:1)
Once again the squeegee was reduced by one half. We are now printing with a 3-inch squeegee inside of our original 24-inch screen frame. Our characteristic curve, so distinct in Figure 2, has all but disappeared. Through the full range of squeegee pressure (approximately 2 to 8 lb./linear inch) the change in wet film thickness was less than 0.75 micrometers.

TROUBLING DATA

As our database grew, however, this general belief became more troubling. In Figure 3 we can see the result of the same test with a squeegee exactly one half as long as the one in Figure 2 (a 6-inch squeegee inside of a 24-inch screen frame). In this experiment it took nearly 5.0 lb./linear inch of

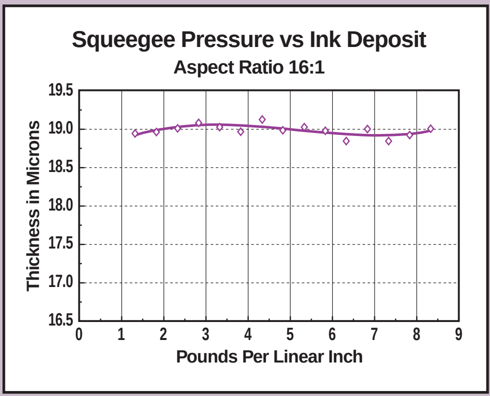


Figure 5:

(Squeegee Pressure vs Ink Deposit, Aspect Ratio 16:1) Again the squeegee was cut in half (1.5-inch squeegee, 24-inch frame, 16:1 aspect ratio) with unusual results. Though the squeegee pressure was increased by a factor of over 8:1 the wet film thickness remained almost perfectly uniform. The average variation of the wet film thickness remained at the sub-micrometer level.

squeegee pressure to reach the low point on the curve and the change was less pronounced (only a 1.4 micrometer decrease in ink film thickness compared to a 2.0 micrometer change in Figure 2). Our process was becoming more robust in its response to squeegee pressure.

Once again the squeegee was reduced by one half (Figure 4), and we are now printing with a 3-inch squeegee inside of our original 24-inch screen frame. (This may be a good time to point out that the purpose of this study was to investigate fundamental relationships. As such it often becomes necessary to look at things in the extreme in order to better understand the underlying operating principles. Hence the ridiculously short squeegee). Our characteristic curve, so distinct in Figure 2, has all but disappeared. Through the full range of squeegee pressure (approximately 2 to 8 lb./linear inch) the change in wet film thickness was less than 0.75 micrometers. But before we discuss the implications, let's look at another example.

Again the squeegee was cut in half (1.5-inch squeegee, 24-inch frame, 16:1 aspect ratio) with unusual results (Figure 5). Though the squeegee pressure was increased by a factor of over 8:1 the wet film thickness remained almost perfectly uniform (the average variation of the wet film thickness remained at the sub-micrometer level throughout the testing). Let's pause for a moment and think about what has just taken place. Through the manipulation of one variable (the aspect ratio) and the control of others, I have been able to produce wet ink deposits with consistent sub-micrometer variations in thickness. Look at the summary graph in Figure 6, as the aspect ratio increases, the effect of squeegee pressure rapidly diminishes to where it becomes of no consequence. In my opinion that also diminishes the possibility of squeegee bending being the sole cause of the pronounced curve depicted in Figure 2; especially in the data using a 16:1 aspect ratio. At both ends of this example (top line of figure 6) the average wet film thickness is exactly the same (19 micrometers) and yet no one would argue that a squeegee pressure of 8.4 lb./linear inch will produce a decidedly different bend on the squeegee when compared to its beginning pressure of only 1.4 lb./linear inch.

Having now arrived at this obvious conclusion through the deductive reasoning process, it should be mentioned that the addition of the stencil effect into this conversation will undoubtedly open a whole new can of worms. Also this experiment was only designed to measure one outcome variable: wet film thickness. Nevertheless, the result has given us some valuable insight into the fundamental mechanisms that are responsible for process variation and control. We now know that we have to eliminate as much direct (or should I say detrimental) screen/squeegee interaction as possible. And we also need to accomplish this in a way that makes it possible to apply the solution to real world printing applications.

THE EASY GLIDER: ONE POSSIBLE APPLICATION

In Figure 7 you will see one application of the information produced in this study and one possible solution to the problem. The Easy Glider is basically a modified squeegee holder that "glides" on Teflon runners at the outermost ends of the squeegee. In this way the squeegee itself is relieved from becoming a "rubber bumper" on the screen during the print stroke. Most of the back force resulting from mesh deflection is absorbed by the Teflon runners. This allows the squeegee to perform its function without also being required to deflect the screen. We believe this will offer the printer several advantages: a) the squeegee will not be required to engage the screen at elevated pressures, thus reducing detrimental interference patterns; b) actual pressures along the squeegee should become more uniform; c) squeegee wear will be reduced; and d) when printing by hand for color checks, the print-to-print uniformity should be improved due to the Easy Glider's ability to fix the angle and pressure applied to the squeegee.

FAVORABLE RESULTS AND AVAILABILITY

Off-site testing has generally been quite favorable with some expressing no small amount of enthusiasm for our only prototype. The applications range from printed circuits to greeting cards. Most would like to purchase one immediately from SPTF. Unfortunately at this time that is not a possibility. However, the plans and instructions for building you very own Easy Glider Experimenter's Kit are available free to SPTF investors and at a

Remember, it's not what you know that counts, but what you do with what you know. Small insights properly applied will always win over great insights that are never applied.

nominal cost to SGIA members. Qualified SPTF investor companies may also manufacture their own version of the device for resale.

Figure 7: *(The Easy Glider: One Possible Application)*
The Easy Glider is basically a modified squeegee holder that "glides" on Teflon runners at the outermost ends of the squeegee. In this way the squeegee itself is relieved from becoming a "rubber bumper" on the screen during the print stroke. Most of the back force resulting from mesh deflection is absorbed by the Teflon runners. This allows the squeegee to perform its function without also being required to deflect the screen.

SUMMARY

We have discussed the importance of understanding the underlying causes of why things work or don't work in the screen printing process. The squeegee pressure study performed at SPTF is one of many fundamental investigations seeking to expand our knowledge in this area. As you can see from the result, in many ways the study produced as many questions as it answered. This is often the nature of research: like reaching the top of a mountain only to find it is part of a series of mountains ranging as far as the eye can see. Nevertheless, just reaching that peak will help us to think differently about that part of the picture we do see and understand. After reviewing the data from this project I will never think of the squeegee in exactly the same way again. Hopefully neither will you.

My interpretation of the particulars and the resulting application of the information presented here is only one of many possibilities. Hopefully others will build and expand on this knowledge base, find new insight into the data or apply the knowledge in new and better ways. Remember, it's not what you know that counts, but what you do with what you know. Small insights properly applied will always win over great insights that are never applied. I wish you great success in your investigation of the screen printing process. May we all "Boldly Go Where No One Has Gone Before." ■

For more information on the "Easy Glider" or other topics discussed in this article please contact the author at 703-359-1321 or dennis@sgia.org.

Figure 6:
(Squeegee Pressure vs Ink Deposit, Various Aspect Ratios)
As the aspect ratio increases the effect of squeegee pressure rapidly diminishes to where it becomes of no consequence. This also diminishes the possibility of squeegee bending being the sole cause of the pronounced curve depicted in the 2:1 aspect ratio. Especially when compared to the data using a 16:1 aspect ratio. At both ends of this example (16:1) the average wet film thickness is exactly the same (19 micrometers) and yet no one would argue that a squeegee pressure of 8.4 lb./linear inch will produce a decidedly different bend on the squeegee when compared to its beginning pressure of only 1.4 lb./linear inch.