How

How to be a great Screen printer

Edited by
Professor Steven Abbott

How to be a great Screen printer

The theory and practice of screen printing

A Macdermid Autotype HowTo eBook
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About this eBook

I'm passionate about screen printing. I get quite angry when I see the industry undermine itself with the myth that it's an art and not a science. And I also get angry when I meet dedicated printers struggling to achieve quality results because they have been trained or misled based on myths and misconceptions.
The industry has helped itself downsize by making life difficult for itself. One of the aims of this eBook is to restore confidence to the industry, to make ourselves proud of the unique capabilities of this fine printing process.

So I'm delighted to be editing a screen printing eBook that is based on science.

Key to this science are my colleagues at Leeds University, Professor Phil Gaskell and Dr Nik Kapur. The pioneering work by Dr Tim Claypole's group in Swansea University is also warmly acknowledged and in particular I need to thank Dr Eiffion Jewell who, I'm happy to say, has proven me wrong on more than one occasion.

The eBook is based on hard-won technical knowledge from MacDermid Autotype's active participation in the screen printing business. The technical group run by Anna Harris, with senior staff Dr Mark Sheldon, Paul Stoddard and Will Shorter have provided lots of hard-won technical data by helping to solve real-world customer problems. Tricia Church carried out some arduous and very important colour-printing and fault-printing trials. From the field, my Sales and Marketing colleagues led by David Parker have often brought back customer challenges. But I believe we found good answers to all of them (so far!) and I urge customers with problems to keep the challenges coming in our direction through David's team.

Finally, two experienced outsiders have provided access to their wealth of practical knowledge. Bill Appleton, arguably one of the UK's top screen printers, provided crucial evidence for and against the ideas in this eBook using the gold standard of proof: real screen prints. And Professor John Davison provided many insights into inks that proved crucial to understanding how to push the limits of resolution to 50μm and below.

For simplicity the book talks in the language of flat-bed screen printing. Those who use cylinder presses can easily translate into their own language as the principles for flat-bed and cylinder presses are essentially identical. Terms such as snap-off (off contact) and peel-off can easily be reinterpreted by cylinder press users. Rotary screen users will have a harder time interpreting the language and images. But although there are many significant process differences, I'm happy to say that extensive conversations with colleagues in the rotary screen world confirm that the scientific principles are unaltered and causes/cures of problems are remarkably similar.

I want to include just one story here. I'd worked with Phil Gaskell for many years on the science of coating but had never asked him about screen printing. Over a cup of tea I outlined the favourite explanations of how screen printing worked and he agreed that they were all worthless. "So, if they're all wrong, what's the right answer?" Remember, Phil had known nothing about screen printing up to about 15 minutes before I asked this question.

He paused for a moment's thought then scribbled a diagram onto a piece of paper. That diagram was the key – it showed the mesh coming out of the ink, and showed how everything else about screen printing simply followed. That was a very productive tea break.

It turns out that Phil was not the first to think of this idea. We later found that the great German screen expert, Prof. Dr. Messerschmitt, had come up with the thought many years earlier. It is unfortunate for the industry that his insight was never fully followed through.

Steven Abbott

Authors

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Tricia Church

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Anna Harris

Table of Contents

The Theory Bit

Steven Abbott

No-one likes theory. We all want to skip straight to the practice. Theory is normally hard work.

But this theory section is very important if you want to be a great screen printer. So it's written in bite-sized chunks, one step at a time, to make it as clear and easy as possible. All the hard theory bits come much later and are clearly marked as optional

And this section is personal. I'm not hiding behind any corporate façade or consultant waffle. I have to do this because this theory section comes with a **guarantee**

Sorry, I can't give you your money back, because we've given you this eBook free of charge.

But what I can guarantee is that if any of the advice in this part of the eBook is wrong, you will have the pleasure of me admitting in public, in the screen trade press, that I was wrong, stupid or both.

I've been making that guarantee for some years now, and so far haven't been caught out.

But I will be *happy* to be proven wrong. That's a great way of learning. And I will make sure that my public apology passes on the new knowledge so great printers can get even better.

After the basic, essential theory there are some optional sections which go deeper into specialist topics. Feel free to dip in and out of them if they are topics relevant to your needs.

Great?

The theory is designed to help you become a great screen printer. What do I mean by "Great"?

There's only one definition of "great" that really matters. A great screen printer is one whose business flourishes. In the short term, "great" could mean someone who spends a lot of precious resource to produce wonderful prints. But if this means that the printer goes out of business, that greatness isn't of much use.

So in this theory section we're going to concentrate on what it takes for you to get the results you want quickly and efficiently. You'll be pushing the boundaries of quality, resolution, customer impact, but you'll be doing it intelligently with a "right first time" approach.

A great Screen printer?

For some people, screen printing is a business. For others it's one step in a bigger production chain. In this eBook we don't care which sort of printer you are – we just care that you get great prints coming off your press.

We *do* care if you're printing graphics or if you're producing technical prints. Although the basic principles for great printing are the same, there are some differences. When something applies just to Graphics and just to Technical printers then this is clearly marked.

As this is a eBook about *printing* we won't touch on pre- or post-press issues except where they directly impact your ability to get the right print coming off your press.

The man with the magic fingers

If your printing relies on the one man who claims to have "magic fingers", who just "knows" how to tweak the process to get it right then you should give up now. You have no hope of being great.

Screen printing is a science, not an art. Those who claim that it is an art (except when they are producing artistic prints) have actively contributed to the downsizing of screen printing.

The advice in this eBook is simple, clear, unambiguous. There is no "magic", no "black art". This stuff really works.

The two golden rules

There are just two rules. Follow these and your printing will be great. Ignore them and life will be hard for you.

A large part of this eBook is taken up with explaining why these rules work so well.

Golden Rule 1

Let the mesh do the metering, let the stencil do the shaping and let the ink do it's thing.

It sounds simple, but this is a revolutionary message that printers continue to resist, at the cost of being worse printers.

The amount of ink going onto your print should be governed almost entirely by your mesh. If you try to control it with the stencil and/or the ink then you immediately cause other problems by compromising what they are doing.

The shape of your print should be controlled only by the shape of your stencil – and the stencil should be doing nothing else. If you are tweaking your stencil to make up for a problem with your ink or your mesh then you're in trouble.

The ink should be formulated for just one thing (1)– to give you the right colour, conductivity, enzymic function or whatever is the prime purpose of the ink. Once you have to formulate it to make up for problems with the mesh or stencil, you get yourself into a cycle of problems that drag you down.

(1) Note: There is one exception to this golden rule. If possible, the ink should be formulated to provide a high-low-high rapid switching of viscosity. If the ink has this optimal characteristic it will give higher speeds, less mesh drag, less slump and be an altogether easier printing experience. This is discussed in detail later in the optional theory section. But for good printers the viscosity has no effect on ink deposit and, other than on slump, should have no effect on the shape of the print.

Golden Rule 2

Set up your press the same way each time, with the minimum pressure, the minimum flood and, especially, with the minimum fuss.

Just insist on getting it right first time.

If you are fiddling with the press after start-up then you are either not following Golden Rule 1 or you haven't followed Golden Rule 2.

Once you get into the habit of minimalist setup you will be amazed at how easy it is to print. And that's what makes a great printer.

This means that you need a good press. It has to be *possible* to set it up the same every time. If you don't know what your pressures are, if your gap settings are a bit too erratic because of mechanical problems, if your bed isn't flat, if your switches and sensors aren't robust then you'll spend all your time fighting the machine rather than screen printing. A great printer will have most of the adjustments to the machine locked off so that no-one can twiddle.

Later on I will be explaining why the squeegee isn't so important. This heresy has been much misunderstood. Of course it's important to have a high-quality squeegee with a nicely-controlled shape. And of course it's important to have a good supplier who gives you the same high quality every time. But if you find that you are spending a lot of time fiddling with your squeegee then you probably think the squeegee is important in a way that it's not. Get into the habit of understanding why the squeegee isn't important, then you'll get yourself a good relationship with a good squeegee supplier and generate mutually profitable business.

Printing 1-2-3

To be a world expert on how screen printing works, you need to be able to understand 1-2-3.

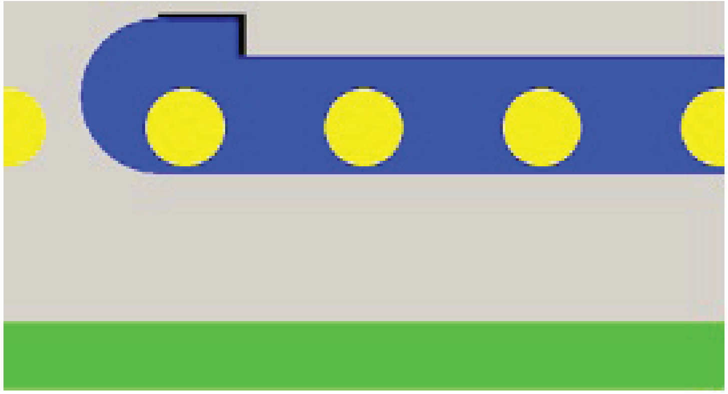
In my time I've heard an extraordinary amount of nonsense about how screen printing works. Hands have been waved, magic has been invoked, the laws of physics have been ignored. And this is all totally unnecessary. Screen printing is as simple as 1-2-3.
So – just 3 steps and you will be a world expert. Trust me!

Step 1 Getting the ink ready to print

What could be simpler? All you're trying to do is get the lightest possible, even covering of ink as close to the top of the mesh as possible.

The right way: a simple, light flood

The wrong way: a strong-deep flood.



I could finish there. It's so easy that really you could go straight on to step 2.

But I've had hour-long arguments with printers who think that flooding should be strong and deep, getting the ink right to the bottom of the stencil so that the squeegee can … Well. They are 100% wrong.

Think about it. If your flooding gets close to the bottom of the stencil, then you're close to going beyond the bottom of the stencil. You're therefore going to have ink sticking out beneath the stencil, and when the stencil contacts the substrate that ink will squash out and give you a messy print.

I'm happy for you to argue with me about the phrase "the lightest possible". I can see your point. If the flood gets you, say, ¾ the way down through the mesh/stencil there's less work for the squeegee to do in step 2.
I have two arguments against you. The first is a bit weak, the second is strong and a bit subtle.

Here's the weak argument. If you really need a strong flood, you probably have something else wrong in the system. For example, your stencil might be so thick that you need large flood and squeegee forces in order to print at all. Why would you want to use a thick stencil? Because you need a thick print. But then you are going against Golden Rule 1. You are using the stencil to control ink thickness, but the rule says that the mesh should be doing that. So, the need for a strong flood can be a symptom of something wrong in your system.

Here's the strong argument. The flood blade is pushing the liquid with relatively low shear. This means that if you have ink that's starting to dry in to the mesh, the push from the flood blade is unlikely to dislodge the drying ink. As we'll see, the squeegee stroke gives a strong shear force that can provide a powerful cleansing action and help keep your mesh open. The first time I thought of this argument I wasn't sure if it was right. But I said it anyway.

And some experienced screen printers said "Funny you should say that, but we often found that with a difficult ink we had to use a light flood – but we could never understand why." Since then this insight has proved to be helpful in many cases. That's why I insist on "the lightest possible" in my description of flooding.

Step 2 Filling the mesh/stencil and cleaning off the surface

The squeegee has nothing to do with screen printing. I can prove this. The squeegee has long since gone past the stencil and mesh when the printing actually happens. Why is this? Because the mesh can't rise from the print till the squeegee has moved on a long way.

So the influence of the squeegee on the actual printing step is precisely zero.

This statement makes a lot of people angry, but it happens to be true. So don't fight it.

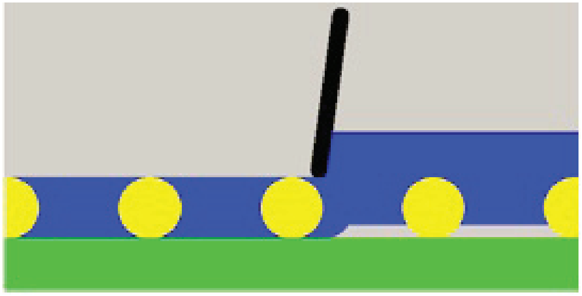
So what is the job of the squeegee?

It has to do three things:

1 The first of these is unfortunate. The squeegee forces the mesh into contact with the substrate. This requires a lot of brute force and is really rather unnecessary. It would be much better if the mesh were brought down by some mechanical force outside the printed area. Some clever press manufacturers have shown that you can remove this task from the squeegee. The less you ask of the squeegee, the better it can do its job, so I urge press manufacturers to continue to explore ways of removing this task. Just ask anyone you can find: "Who in their right mind would give the job of pushing the mesh against the substrate to a precision-sharpened piece of complex rubber?" See the discussion in Anna and David's section on "printable area" in order to avoid the squeegee having to fight even harder to force the mesh onto the substrate.

2 The second is to force the ink through the mesh and stencil when they are in perfect contact with the substrate. Because the ink can't travel any further than the mesh/substrate interface, there's no need to apply a massive force from the squeegee. You need the absolute minimum that does the job. Anything more than this is bad news. You're distorting your mesh, damaging your squeegee, putting extra strain on your press. All for no benefit whatsoever. We'll come back to this point at length. If you are following the Golden Rule, then very light squeegee pressures will do the job. If you aren't, then your squeegee pressures go up and your chances of being a great printer go down.

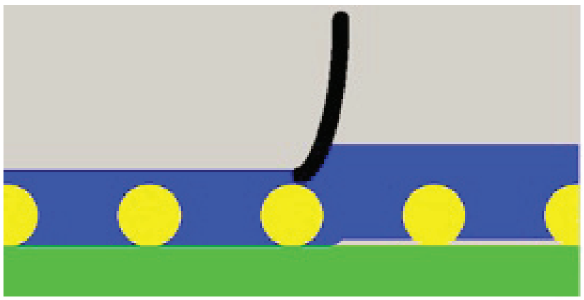
If you do the maths (I've done it for you in the optional ink design section), you find that this filling action involves very high velocities and high shears. This is ideal for shifting the layer of old ink that's sitting on the mesh from the previous print. That's why a light flood is recommended so that the high-speed filling action has the maximum chance of keeping your mesh cleansed.



In control: the squeegee filling the mesh and scraping off the excess ink

3 The third is to scrape off the ink from the top of the mesh, leaving a smooth, even surface. If your pressure is too light then the squeegee hydroplanes along the ink and leaves some ink above the mesh. You get a similar effect with a rounded squeegee. The problem with this is that small changes in press settings will alter the amount you leave behind and your ink deposit is out of control. If your pressure is too high then – well, we've just discussed it – you are putting strain on your mesh, press and squeegee for no good whatsoever – you can't scrape off more than 100% of the excess ink, no matter how hard you try.

This isn't strictly true as the squeegee can dip into the mesh to a certain extent and reduce your ink deposit very slightly, but this turns out to be a small effect and usually not something that's worth the extra squeegee pressure.



Out of control: a soft squeegee leaves a layer of ink above the mesh.

And that's it. A nice, sharp, well-maintained squeegee will do all 3 jobs with the minimum of fuss. And if you can remove the first job, or reduce the need for it by having a very small snap-off, your squeegee will do a great job hour after hour. This may be bad news for squeegee suppliers. But much though I love them, I don't have a duty to keep them in business by increasing their sales through the mistakes of screen printers. My duty is to help you be a great screen printer. And in the long run this helps the squeegee makers because if the screen printers can't make money then they won't be around to buy any more squeegees.

Step 3 Letting the mesh come out of the ink

People have been asking the wrong question for decades. They ask "How does the ink come out of the mesh?" To this wrong question there have been many wrong answers.

The right question is: "How does the mesh come out of the ink?" Now, if I ask you that question you'll say "There's no mystery to that – it's like saying 'How does a spoon come out of a jar of honey?' It just does."

Precisely! The ink doesn't come out of the mesh, the mesh comes out of the ink just like a spoon comes out of a jar of honey. There's no difficult physics. There's no need to think of special surface forces or vacuums or gravitational pulls or any of the myriad of dumb ideas that have been used to explain screen printing.

When you ask the right question, screen printing becomes so simple that a child could do it – which, of course, they can. Which brings us to an important point.

Let me ask you a really simple question. What's the difference between a print done on a handbench by a reasonably skilled operator and the same thing done by a super-sophisticated press? The answer is, basically, none. Of course the print from the press is of higher overall quality, but in terms of ink deposit, edge definition and more or less any other criteria, the prints are about the same.

This is the single most important fact in the whole of screen printing.

There could be many reasons for thinking that a hand print should be totally different from a machine print. And if there were a difference we'd know that screen printing is a subtle science that depends on the precise speeds, pressures, angles etc. of the printing process. But the fact that there is very little difference proves that the process must be very, very simple. It is only our ignorance that makes it such hard work.

I've tried out this question many times. The answer is always the same. And the conclusion is always the same. Screen printing is a simple science and therefore if we find that it's difficult it's because we're doing something wrong.

Now, perhaps, you can understand why I issued the guarantee at the start of the eBook. If screen printing were a subtle science, there's no way I could issue the guarantee. But because I know it's simple, I know that my guarantee is a pretty safe bet.

Let's now look at the details of how the mesh comes out of the ink:

A filled mesh, ready to print

Here we have the nice filled mesh, neatly scraped by the squeegee. Note that we still haven't printed anything, yet the squeegee has already disappeared. So the squeegee has nothing to do with the actual printing.

The mesh starting to come out of the ink

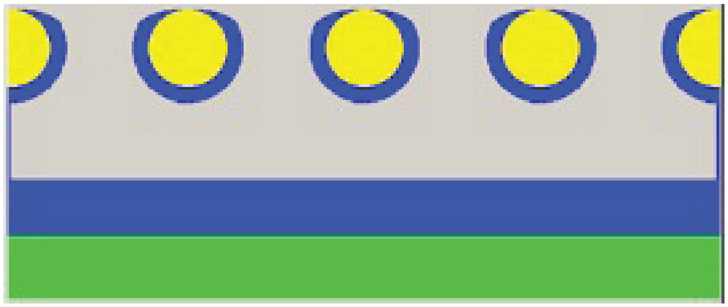
Now the squeegee is far away so the mesh can rise and start to come out of the ink. The ink has no choice but to form those smooth curves around the mesh (positive curvature) and between the mesh (negative curvature).

The formation of the liquid bridge is inevitable

The mesh has risen further. Note that the mesh is almost uniformly covered with a thin layer of ink just as a spoon is covered with a layer of honey, and that there is a "liquid bridge" underneath the mesh.

The bridge has snapped leaving a drop

When the liquid bridge snaps (as it must) it leaves a drop of ink underneath the mesh – i.e. there is more ink under the mesh than between the mesh. This is obvious from the physics but counter-intuitive to most printers.



The drop has disappeared into the print

Hopefully the drops smooth out giving you a nice level print. Note that about 30% of the ink in the mesh at the start remains attached to the mesh – something you can easily measure for yourself if you don't believe the physics.

And that's the 1-2-3 of screen printing.

So let's have some fun and go kill a myth or two

Death to myths

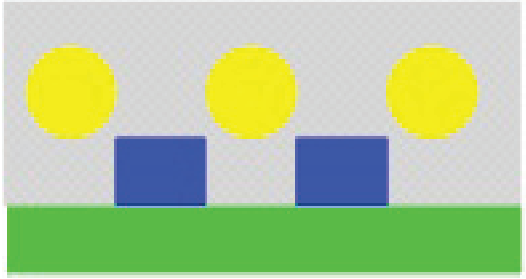
We've already killed a couple of myths on the way.

We know that the flood must not fill the mesh - because if it did then it would probably overflow and blur the print.

We know that the squeegee takes no part in the actual printing process – because it's long gone by before the mesh comes out of the ink. I've proved this in the lab with some special test kit which doesn't use a squeegee. I've changed the speed of this device by a factor of 10 with zero effect on ink deposit. But you can even test it for yourself. Use a tiny snap-off (off-contact) (or switch off your vacuum bed) so your substrate remains stuck to your screen. Now raise your press and peel off the print. Now measure your print. Sure, the print quality won't be quite so nice, but it will be pretty much the same as the one done conventionally. And this reminds us of the most important fact in screen printing: a hand print is almost the same as a machine print, so the process really must be very, very simple.

But let's look at the implications of the diagrams of the mesh coming out of the ink. This helps us kill a very big myth.

9 out of 10 screen printers, when asked, would say that screen printing produces pillars of ink between the mesh and then by some process these pillars level out (more or less). They would confidently predict that the thickest part of a print is therefore between the mesh fibres.



How printers think that screen printing works

As we saw in the diagrams of printing in action, reality is exactly the opposite. The ink is thicker underneath the mesh.

How screen printing actually works

When I first pointed this out to my marketing colleagues they begged me not to say it in public – it would make MacDermid look stupid. Because it's so "obvious" that "ink doesn't go through mesh", the ink deposit "must" be thicker in between the fibres than beneath them. But it takes only a modest effort to prove to yourself that the thicker part of the print is, indeed, under the mesh. Just take some careful microscope images of the mesh near some obvious feature such as a corner, then take images at the same magnification of the print. When you line them up you find that the thicker part of the print is under the mesh fibres. In fact, you find that it is thicker under every other knuckle for reasons (I admit) I haven't really worked out.

Whilst we're here we can explain another common problem in screen printing. When liquid bridges snap they automatically produce a drop or two and these drops can easily fly off in strange directions. This is due to the natural chaotic instability of liquid bridges. If you are doing really wild printing then the flying drops can end up all over your print – classic ink splatter. When I first came up with the theory I had no idea that ink splatter existed so I was gratified that the theory automatically produced an explanation for the effect. Of course when the ink is very stringy then the liquid bridge doesn't snap into drops but produces a classic cobweb.

There's another big myth which we need to kill. It seems rather obvious that a high-viscosity ink should give a different (wet) ink deposit from a low-viscosity ink. You often hear advice that ink viscosity should be carefully controlled in order to preserve a uniform ink deposit. Yet the truth is the opposite. The viscosity of the ink has no effect at all on the thickness of the ink deposit.

How do I know this? Well, first of all a PhD student at Leeds University spent years of careful measurements confirming this fact. But in reality we knew in advance that there would be no effect. Why? Partly because the theory of the ink flow says there will be no effect (for the technically minded, this is because of a plateau in the effect of capillary number on viscous pick-up). Partly because of the basic fact that a hand-print gives essentially the same ink deposit as a machine print – and if viscosity (and viscous drag) were important then there is no way you would get the same deposit. As we will shortly see in the optional theory section, ink doesn't have "a" viscosity it has many viscosities, so if ink deposit depended on viscosity it would vary hugely as different parts of the process changed. The final argument came from work by Dr Eifion Jewell. The very early U. Leeds theory had predicted a strong viscosity dependence. It was only when Eifion produced data showing that there was no dependence did we discover the "capillary number plateau effect" which explained why, in the speed ranges of interest to screen printers, viscosity had no effect. That was one of those times when being proven wrong was a real joy.

There's one final myth that we can easily kill. A fashion arose with mesh makers to sell meshes that gave "better ink release" through "special surface treatments". Don't get me wrong, some of the "special surface treatments" for meshes have been of great help with stencil adhesion. But I can easily prove that no practical surface treatment can have an effect on "ink release". This is a surprising claim, especially to those who've seen wonderful marketing demonstrations of how "special" meshes let drops of water through whilst "ordinary" meshes don't.

To prove it, I can ask a simple question. After the first print, what does the new ink "see" when it arrives on the mesh? Does it "see" the "special surface treatment"? Of course not. All it sees is the layer of ink which is wrapped around the mesh, just as a spoon remains covered as it comes out of a jar of honey. In the optional theory section you will find (and it's easy to prove this for yourself) that ~30% of the ink that we put into the mesh with the squeegee remains on the mesh. But even if you don't believe me about the 30%, you surely know that at the very least there is a slight contamination of the surface with the ink (try putting a clean finger onto the mesh just after a print). So the surface of the mesh is actually just old ink. The new ink never has a chance to see the mesh surface. Therefore the surface can have **no** effect on the ink deposit.

There's one get-out clause. If the mesh surface were like Teflon then the ink remaining on the mesh would tend to roll up into a ball. But try sticking your stencil to a Teflon mesh!

So if the surface treatment can make no difference to the ink deposit, how come so many people say they've seen a difference?

I was challenged on this by one mesh maker, so I challenged them in turn to do careful side-by-side tests under controlled conditions. Remember, these were tests done by the mesh maker, on meshes they thought gave a difference in ink deposit. When they did them under properly controlled conditions, they found absolutely no difference at all.

What had happened is that printers had compared a "new" mesh with an "old" mesh and had assumed that the only difference was the "special surface treatment". But often they were comparing 120/34's with 120/31's or the "34" values differed between different batches depending on weaving, calendaring etc. It was nothing to do with the surface treatment and the demonstration with drops of water.

That myth is well and truly busted.

Why is the 1-2-3 so important?

Because everything else follows from it. Once you start to think 1-2-3 you start to be able to analyse your print problems with precision and clarity. The old way of thinking which confuses the flood, the squeegee and the "ink coming out of the mesh" has proven hopeless at being able to pinpoint the cause of a printing problem. I've read countless articles in the screen press that literally make no sense and leave the reader none the wiser. As soon as you think 1-2-3 all the mystery simply vanishes.

Do you get positive sawtoothing? Easily explained
Do you get negative sawtoothing? Easily explained
Do you get on-off sawtoothing? Easily explained
Do you get puppy paws? Easily explained
Do you find it impossible to balance dot gain with skipping in 4-colour prints? Easily explained
Do you get weird colour shifts in your prints? Easily explained
Do you get moiré that comes and goes? Easily explained
Do you get thick edges to your printed lines and blocks? Easily explained
Do you get mesh patterning in the solid prints? Easily (and surprisingly) explained
Do you get confused about how to specify a perfect ink? Easily explained
Do you get puzzled about ink slump? Easily explained

I'm sorry to bore you with this list. But 1-2-3 makes it easy to identify the root cause of all your problems. It also makes it easy either to find a fix for it, or to explain why no fix is possible.

This isn't about clever theory. This is about solving your screen printing problems.

That's why 1-2-3 is important.

Anna and David use 1-2-3 all the time in their problem solving out in the real world. I leave it to them to show it in action with each of the issues in the list.

That's all the theory you need to know. There are six more optional topics for those who really want to know everything.

The Optional Theory

Steven Abbott

The mesh does the metering

The 1-2-3 stresses that the ink deposit should be controlled by the mesh alone – not print speed, not viscosity, not the squeegee (unless you choose to go out of control with a rounded or light squeegee), not the stencil.

But what controls the amount of ink left behind when the mesh comes out of the ink?

There's an important, but very simple formula:

Ink Deposit = Ink in the Mesh at the Start – Ink on the Mesh at the End

Or

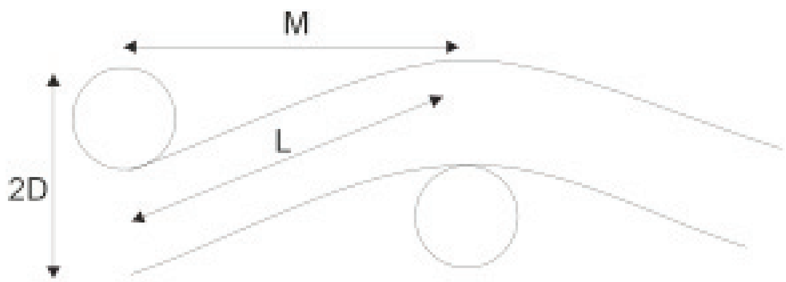
Ink Deposit = IMS – IME

Graphically we find

Ink in the mesh at the start

Ink in the mesh at the end – and on the print

The "Ink in the mesh at the start" is easy to calculate. It's simple geometry.



The total height of this ideal mesh is twice the mesh diameter, 2D and the spacing M is 1/TPM (Threads Per Micron)

The total volume of this cube is:

$$VC = 2DM^2$$

The volume of mesh in this cube is made up of two cylinders (only one shown, the other is at right angles) of length L, diameter D.

$$VM = 2\pi\frac{LD^2}{4}$$

So the (ink in the mesh at the start)

$$IMS = VC - VM = 2DM^2 - 2\pi\frac{LD^2}{4}$$

The ink deposit, in µm =IMS/M2 so

$$ID = 2D - 2\pi\frac{LD^2}{4M^2}$$

This is also considered to be the Theoretical Ink Volume (TIV) as µm is equivalent to cm3/m2.

$$TIV = 2D - 2\pi\frac{LD^2}{4M^2}$$

Simple geometry, followed by rearrangement shows that

$$L = \sqrt{M^2 + D^2} \quad \text{OR} \quad L = M\sqrt{1+\frac{D^2}{M^2}} \quad \text{OR} \quad L = M\sqrt{1+TPM^2D^2}$$

SO

$$TIV = 2D - \pi\frac{D^2\sqrt{1+TPM^2D^2}}{2M} = 2D - \pi\frac{D^2TPM\sqrt{1+TPM^2D^2}}{2}$$

This is the classic TIV formula.

In reality the height of the mesh is not 2D but $2D_{compressed}$ because of the compression of the fibres at the knuckles. And the simple cylinder geometry is no longer valid as the fibres are now elliptical because of the compression. However, the total volume of mesh, VM, has not changed even though the shape has changed so the use of the cylindrical geometry for the cross sectional area of the fibre gives the correct answer. The length of the cylinder depends on the (compressed) height of the fibre, $D_{compressed}$, and the TPM is not the original woven TPM but $TPM_{stretched}$.

This gives us the 'real' TIV formula which has a mixture of D and $D_{compressed}$.

$$TIV = 2D_{compressed} - \pi\frac{D^2 TPM_{stretched}\sqrt{1+TPM_{stretched}^{\ 2}D_{compressed}^{\ 2}}}{2}$$

Although the formula looks a bit ugly, it's very easy to calculate with a spreadsheet. More importantly, all mesh manufacturers could and should use this formula. The fact that they use the simple but totally erroneous "open area" formula is most regrettable. The formula they quote is bad science that often leads to the wrong conclusion. The TIV formula is good science and has always proved to be reliable. It's especially helpful when comparing stainless meshes (D hardly changes) to polyester (D is compressed a little) to liquid crystal (D is compressed a lot).

So far we have IMS. Now we need to know IME.

Whenever I ask printers how much of the ink remains on the mesh after a print I typically get an answer between 1 and 10%. It is unfortunate that very few people have bothered to measure this value because if they had done so a lot of people would have had a big surprise. It is very easy to do this measurement so if you don't believe the answer, try for yourself. Because in general, 30% of the ink in the mesh at the start ends up wrapped around the mesh. When you look at the diagrams earlier in this eBook you can see that this figure makes sense. But for most people it still remains a shock. With every print stroke, 70% remains on the substrate and 30% remains on the mesh.

So if you want a quick estimate of your ink deposit it's

Ink deposit = 0.7 * TIV

It's as easy as that.

It's worth adding that if you use the stencil to increase the ink deposit the rule is very simple. Each 1µm of stencil adds 1µm of ink deposit, simply because the TIV increases by 1µm and all of this (not 70%) stays on the substrate as the mesh knows nothing about it. Of course this 1µm rule only applies over the (short) distance (typically a few mesh openings) where the mesh remains above the substrate thanks to the stencil. When you move a few mesh openings away from the stencil then the mesh touches the substrate and the stencil has no effect, other than creating a (worthless) thick edge.

Designing the perfect ink

Now we're experts on 1-2-3, the specification of a perfect ink becomes easy. I'm not saying that making a perfect ink is easy! I have huge admiration for ink makers and I am all too aware of the difficulty of what they are doing. But those printers who don't follow 1-2-3 make the ink designer's job literally impossible. Out of control printers ask the ink to correct for errors in their mesh and stencil. Good printers follow the 1st Golden Rule and let the mesh do the metering and the stencil do the shaping, so the demands on the ink are greatly reduced.

Before we continue we need to remind ourselves of one myth we killed some pages ago. We now know that viscosity has no effect on the ink deposit. Instead, the deposit is controlled only by the mesh. This is one less thing for the ink designer to worry about.

So let's assume 1-2-3 and design the perfect ink from first principles.

During the print process the ink undergoes 5 steps.

- The flood stroke
- The squeegee stroke
- 'Mesh coming out of the ink'
- Levelling
- Slumping

What we want to see is:

- Flooding gives a full (but light) coverage of the image area with no dripping beneath the mesh
- The squeegee fills the mesh and the image area with the minimum possible pressure in order to enhance squeegee life and reduce distortion
- The mesh comes out of the ink with the minimum effort so you can print with minimum snap-off (preferably with zero snap-off) to minimise distortion
- Levelling takes place very quickly so no mesh marks are visible
- There is very little slumping so your dots and lines are as close to the original as possible.

Levelling and slumping are somewhat contradictory. You want a high viscosity to reduce slumping but this slows down levelling. Fortunately for us levelling theory shows that we can get away with high viscosities as levelling times should be very short for a well-designed ink.

The reason it is easy to specify the perfect ink is that apart from the issue of levelling v slumping there is no contradiction between any of the desired properties. This is an astounding fact. Many ink makers think that improving one property will make something else worse. If you print with a high-Rz stencil then you really do find such contradictions.

But with the low-Rz, low-EOM stencil there are no contradictions at all. As I never tire of saying, screen printing is intrinsically a

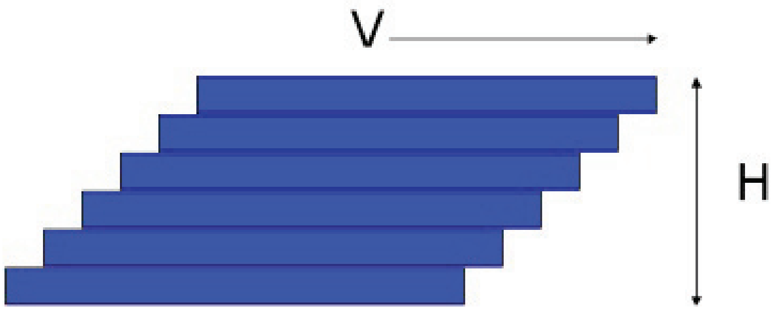
simple, in-control process.
Years of misunderstanding have turned it into a difficult art.

The key to designing the perfect ink is the ability to provide the right viscosity for each step. We can largely ignore surface tension as a variable because in practice we can only tweak it over a modest range (e.g. 25-40 dynes/cm). Of course choosing the right surfactant is important for many aspects of the ink (e.g. pigment dispersion, adequate wetting of the substrate), but the theory shows that it is not of crucial importance for the steps we are discussing here.

If you use a very simple ink then it might be 'Newtonian' which means that its viscosity does not change during the entire process. If you use a Newtonian ink you need only optimise viscosity for one step. If, for example, you aren't worried about printing small dots or lines then go for the minimum viscosity that won't drip through your mesh. If you want precise lines/dots then use a high viscosity ink and accept that you'll need a big squeegee pressure and that you'll need a large snap-off (off-contact) to compensate for the big mesh drag.

For technically challenging prints, such as fine-line conducting tracks printed with good registration then we can't get away with a Newtonian ink. We therefore need a 'non-Newtonian' ink, in particular a pseudoplastic ink, one that shear thins. 'Pseudoplastic' is often confused with 'thixotropic'. Although both shear thin, we don't want a thixotropic ink for reasons we will discuss later.

We all talk about 'shear thinning' and we know that this means that as you work the ink its viscosity gets lower. But what does 'shear' actually mean?



Shear = V/H

Let's suppose our squeegee is moving with velocity V over some ink that is of height H. The ink at the bottom is stationary. The ink at the top is moving with the squeegee. The ink in between is moving as intermediate speed. If we imagine the system to be a stack of playing cards then you see that each card is sliding over the one beneath. This is 'shear'. The formula to calculate shear is very simple:

Shear = V/H

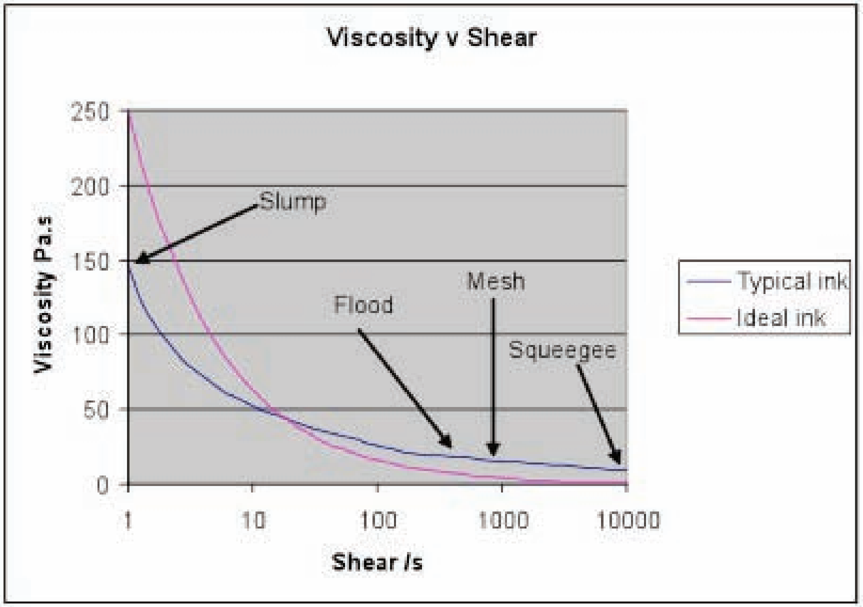
We need to know the shear values of the different steps, so stay with me whilst I calculate them for you.

Suppose our flood bar is moving at V = 50cm/s and the flood gap is H = 1mm. If we put these into units of metres then Shear = 0.5/0.001 = 500/s

For the squeegee stroke the speed might be the same, but the gap is now very small, for example the spacing between two mesh fibres which is 50µm. Now the shear = 0.5/0.00005 = 10000/s

When the mesh is coming out of the ink, the gap is the same 50µm, but the speed is now the vertical speed of the mesh which depends on the squeegee speed and the snap-off angle. If we say that this angle is 5° then the speed = 50*tan(5) ~ 4cm/s so the shear is 800/s

Finally, when the print has to level or to slump it's easy to show that the shear rate is very, very low, <1/s.
If you look at a typical screen ink you will get a graph of viscosity v shear rate that looks something like the Typical ink in this graph.



Viscosity v Shear for a typical ink and an ideal ink

At the shear rates of the flood, squeegee and mesh steps the viscosity is respectably low at around 15Pa.s and at the slump stage in principle it will be 10x higher at 150Pa.s. This is not bad at all. But just think what it would be like with the Ideal ink shown in the same graph. At the typical shear rates, the viscosity is close to 1 Pa.s and at low shear it is 250, a factor of 250x higher. This would give us much less slump and at the same time we would need to apply 15x less pressure on the squeegee and the drag from the mesh (assuming a viscosity at this shear rate of 1.5Pa.s) would be 10x less. Printing with such an ink would be a real joy.

If that's all there were to ink viscosity then life would be very simple. The trouble is that two other effects can cause us problems: time-dependence and viscoelasticity.

Time-dependent phenomena in inks are very common. It's possible, for example, that if you measured the viscosity one second after the mesh step, you would find it to be very similar to its high-shear value, even though the actual shear rate is very low. This would be bad news because you want the viscosity to be very high to limit slumping. If it takes 10s for the ink to recover to its low-shear value you might find that your 75µm line has already expanded to 100µm.

Inks which are 'thixotropic' show this time-dependent behaviour. If you stir a tin of thixotropic paint it gradually becomes thin enough for you to paint with ease. For a few seconds after you've applied the paint it remains thin so that your brush marks can level out. But it's designed to return to its thick state before the ink can 'sag' down your nicely painted door. From the above analysis we can see that thixotropy is, on balance, a nuisance. First, you will get increased ink slump because it takes the ink longer to recover to its low-shear, high viscosity state. Second, you are never printing with the same ink! After each stroke, after each addition of fresh ink, you have an ink of indeterminate history and therefore of different viscosity.

It's quite difficult to get good time-dependent data for screen inks because we are interested in what happens over very short time-scales when we switch from very high to very low shear. You need a high-performance rheometer to get such data. But because quick recovery is so important for high-precision printing, it's worth the effort.

Viscoelasticity shows up as a stringing of the ink when you pull it apart. It can be measured on complex rheometric equipment and if you are lucky you can extract some viscoelastic constants such as a Maxwell relaxation time. Viscoelasticity can give you horrible 'cobwebbing' in your prints, but what concerns us here is that if you have a large Maxwell relaxation time (or equivalent) then the levelling of your print becomes very slow. The reason for this is that such an ink is happy to absorb the forces that are trying to level it, just as an elastic band is happy to absorb the forces you apply to it by stretching itself. Without the elastic component the ink has no choice but to level itself. Furthermore, viscoelasticity fights you in every other step. If your ink is purely viscous then every time you tell it to flow, it will flow. But if it's purely elastic, tell it to flow and all it does is stretch, which is not what you want. A viscoelastic ink will be some combination of good and bad behaviour. Things are even more complicated than that. The proportion of viscous and elastic behaviour depends on the timescale. At sufficiently high speeds, everything is elastic. At sufficiently low speeds everything is viscous. Now we see why our shear rate calculations are valuable. We need our ink to be viscous (as opposed to elastic) even when the shear rate is 1000/s (or our timescale is 1ms). For those familiar with the jargon, this means that we need to find the ratio of G" to G' (loss to storage modulus) at kHz oscillation rates.

So far we've been talking theoretically. Has anyone ever made an ink that is close to my ideal? The answer is 'yes' and I've printed with one myself. The so-called 'cermet' inks (ceramic/metal) are made up of fine particles with a bit of solvent. They have a very high low-shear viscosity, but shear-thin very rapidly to very low viscosities. And they recover very quickly. Those who print with them routinely produce high-quality narrow width prints with low snap-off (off-contact) and modest squeegee pressures. This allows them to print with excellent registration in order, for example, to make multi-layer co-fired ceramic circuits.

As soon as you go to polymer-based inks, (so-called 'PTF', Polymer Thick Film) inks used for membrane touch switches, the story changes dramatically. These inks often start off with a lower viscosity yet don't shear thin so rapidly and they show both thixotropic and viscoelastic behaviour. This is the reason we have so much difficulty printing with them.

I'm not criticising the ink designers. It's probably impossible to produce a PTF ink that could be as good as a cermet ink. But the point of this section is to clarify what properties we are aiming for, to show why we need those properties and what happens if we don't attain them.

One bit of new(ish) science gives some hope that even in the PTF world we can come up with superior inks, closer to the ideal. So-called 'associative thickeners' are popping up in all sorts of places. They thicken by gelation mechanisms that are very different from the polymeric entanglement of normal inks and even modest shear can make these gels fall apart quickly, ready to re-form when the shear stops.

I've come across examples in all sorts of fields that have nothing to do with ink design so I suspect that smart ink formulators have more possibilities than they might suspect.
Of course I'm skipping over issues such as ensuring particles are small enough not to be sieved by the mesh, or solving issues of balancing evaporation to give quick drying without drying in. These are important aspects of the ink designer's art but aren't directly related to the 1-2-3 theory. However, because 1-2-3 makes it easier for the ink designer, there is more freedom to solve these other problems without having to worry about problems caused by bad printers.

In summary, designing the perfect ink is simple. The good printer only asks the ink to be highly shear-thinning with rapid recovery what I call a "High-Low-High" ink and to give the other properties (colour, conductivity, enzymic efficiency…) for which the print is intended. The ink doesn't have to compensate for a high Rz or a thick stencil or an inappropriate mesh and the designer doesn't have to worry about controlling the (wet) ink deposit because it doesn't depend on the ink at all!

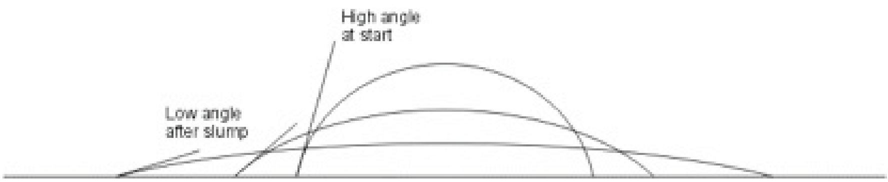
Stopping slump

Slump is the common term used to describe the fact that a drop or line of ink starts off at a certain height/width then "slumps" to give a wider line with less height.

Right at the start we need to kill a common myth about slump. As far as screen printing goes, it has nothing to do with gravity. Our dots and lines are far too small to be affected by gravity and your prints will slump just as much upside down. So if slump is nothing to do with gravity, what is the cause?

It is simply the tendency of your ink to wet the substrate. If you put a drop of water onto the substrate it might do a variety of things. If the substrate is Teflon then the drop will just sit there with no slump. If the substrate is glass then the water spreads out, driven by surface tension, till the drop has become very thin. A typical polymer substrate will be somewhere in between with intermediate slump.

The angle the drop makes to the substrate at any time is the 'contact angle'. You start with an 'initial contact angle' and end up with the 'equilibrium contact angle'. A typical drop on glass might start with a 60° angle then slowly slump down to 0°.



Contact angle decreasing as the ink slumps

The theory of spreading (often called Tanner theory) is so complex that it needs a computer model to work out what happens, but the basic (and approximate) rule is straightforward:

Speed of spreading = K * Surface Tension * ContactAngle^3 / Viscosity

and can be summarised in a table

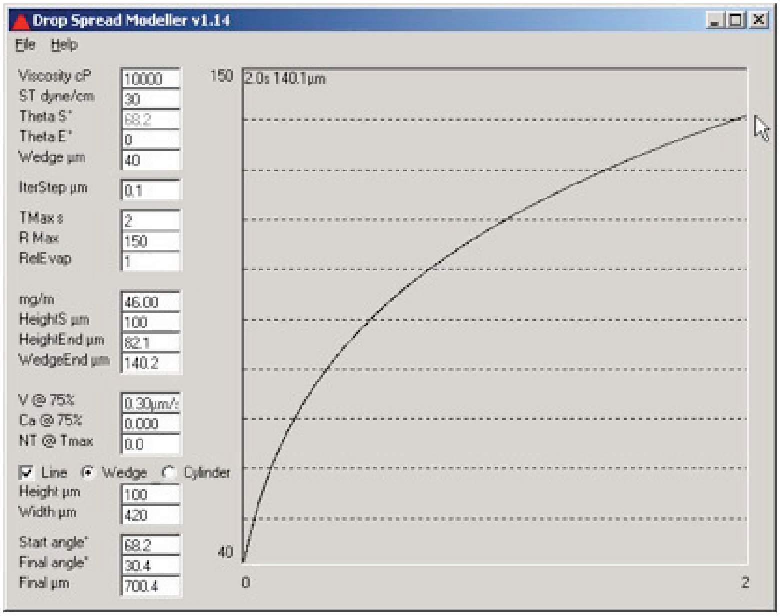
Parameter	**Effect of a High value**
Surface tension	Fast spreading
Initial contact angle or Ink thickness	Fast spreading
Equilibrium contact angle	Slow (or no) spreading
Viscosity	Slow spreading
Viscoelasticity (‘tackiness’)	No effect
Porosity of the substrate	Slow spreading
Evaporation	Slow spreading
Freezing the substrate	Slow spreading

The effect of time is amazing. If it takes 1 second for a drop to grow to a certain diameter, it will take 1024 seconds to grow to twice that diameter! This is because as the drop grows, the contact angle decreases and the spreading speed decreases even faster (as the cube of the angle).

For screen printing, surface tensions are low and viscosities are high. So you would think that slump should not be a significant problem. But as soon as you go to fine lines, ‘significant’ takes on a new meaning. Even with very high viscosities, if the drop has an initial high contact angle then within a few seconds you can easily spread the line by 25µm on each side. So a 50µm line becomes a 100µm line before you’ve had a chance to dry it or UV cure it. By optimising the viscosity behaviour of a silver ink printed onto polyester we were able to print a 50µm line which spread ‘only’ by 12µm each side to give us a 74µm line. If we had been able to cure the material faster we might have produced a sub 70µm line.

Our 50µm line becomes a 75µm line

At the other extreme, slumping can cause a different problem. Some specialist applications require ink deposits which have to achieve a large thickness specification. If, for example, you are trying to print a 100µm thick line, 500µm wide with a reasonably viscous ink (10Pa.s) then within 2 seconds the line is 700µm wide and only 82µm thick. If the specification were 90µm thickness then you'd be in trouble. The computer model shows that you would have to have cured the ink within 0.4 seconds to avoid it slumping below 90µm.



The Drop Spread software models the 100µm high, 500µm wide line

Controlling slump

So what can you do about slump? The table gives you good indications, but there are lots of complications.

Increasing surfactant levels should reduce the surface tension and therefore reduce slump, though this isn't always the case in complex cases. But surfactants can interfere with other aspects of the ink formulation so this isn't always possible. Unfortunately in the example above even if you halve the surface tension you only gain a few extra μm thickness.

The initial contact angle is largely a function of your ink deposit. A thin ink deposit (fine mesh, low-EOM stencil) will give you less slump. Remember that slump speed is proportional to the cube of the initial contact angle, so even modest reductions in ink thickness can give large reductions in slump. In the thick ink example, reducing the starting thickness to 90μm reduces the width of the slumped line by 20μm.

The equilibrium contact angle is often ignored but it can be a vital part of your solution. The ink will stop slumping when the contact angle reaches the equilibrium value. So if you tuned your substrate so the equilibrium angle were equivalent to the initial angle you would get no slump at all. This trick has been used in the world of fine-line inkjet printing where they have very low viscosities and therefore very large slumps.

As we've discovered in the previous section, "viscosity" is not a simple concept so it's important to know which aspect of viscosity is important for slump. It's now obvious that a perfect ink has a low viscosity during the shearing action of the mesh coming out of the ink, followed by a rapid recovery to a high viscosity to avoid slump. In the ceramic conductor industry they can often come close to this ideal as their formulations don't contain polymers. Polymeric inks tend to have less of a reduction in viscosity with shear and strong thixotropic tendencies so they are slow to recover. Hence the battle with slump is much more difficult. Specialist additives exist which can improve the situation and if the ink designer knows what has to be done then there is hope that the slump can be reduced. For example, the computer model says that to attain the 90μm thickness target with a 2 second delay before cure, the low-shear viscosity should be increased from 10 to 50Pa.s.

Ceramic conductive inks are printed onto ceramic substrates. These substrates are often microporous and they rapidly suck the solvent away at the leading edge of the slumping ink. This sends the viscosity skyrocketing and the slump comes to a halt. Crude porous substrates (such as paper) are obviously not a good idea as they destroy edge quality. But micro-porous materials (holes in the μm range) do not have a big effect on edge quality. There are some debates about whether micro-roughness can slow slumping; it probably does but I've not personally seen any convincing evidence either way.

It's obvious that if you have a solvent that flash evaporates your slump will also be reduced. The downside is that the ink will dry in to the mesh.

Finally, if you can cool the substrate relative to the ink on the mesh (either by having a heated ink/mesh or a cooled substrate) then the ink viscosity increases and the slump decreases.

Slumping on the beach

Have you ever noticed a 'beach' effect around your printed line or dot? It's an ultra-thin bit of something that lots of us have seen but never been able to analyze or explain. It turns out that the science of slump offers some insight.

Spreading of a liquid is impossible without a 'precursor film'. This was at first thought of as a mathematical device to do the calculations, but these films, perhaps only 0.1µm thick can be seen under the right conditions. There are hints that the polymers in the ink can have difficulty entering the precursor film; if they can't get in then the ink can't spread. This correlation between beach and precursor film is only speculative, but it might be possible for an ingenious ink designer to take advantage of this effect and produce a low-beach, low-slump ink.

Discouraging and encouraging

This summary of slump might be a bit discouraging. If you have to start with a specific ink thickness onto a specific substrate then the only practical changes you can make are to the ink. Changing the surface tension will have some effect, but it's small. So in general you have to alter the viscous behaviour of your ink. Because there are so many misunderstandings about the effect of the viscosity on the ink deposit, a lot of ink designers are confused about what parameters can be adjusted to reduce slump.

But if you are printing with a good low-EOM, low-Rz stencil, the viscosity has no effect on the ink deposit so you are free to engineer the ink for optimum slump. This is the encouraging aspect of this work.

Acknowledgement

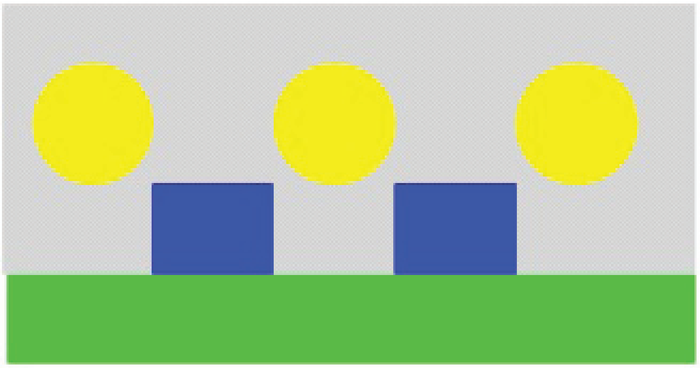
Although there are many papers on the science of slump, the work of Professor Glen McHale at Nottingham Trent University is especially insightful. His papers on spreading of drops and cylinders are the basis for the computational results shown here and his help is gratefully acknowledged. Readers are welcome to a copy of the MacDermid Autotype Drop Spread Modeller based on Prof. McHale's theory.

Mesh marking – causes and cures

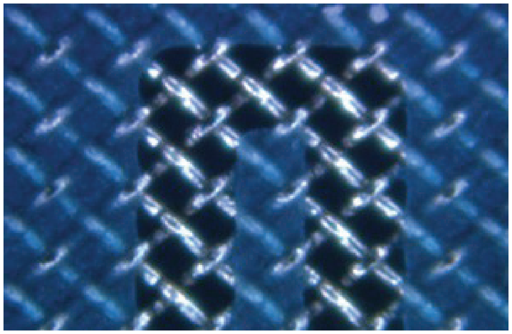
We often see the marks of the mesh left in our printed solids and lines. I would love to offer you a simple insight into the causes and cures, but so far I don't know what they are. What I can do is offer some insights into what they aren't!

We can't solve mesh marking if we start off with a completely wrong idea of where it might be coming from. For those who believe in the myths of screen printing, it seems obvious that the mesh marking is there because you get big pillars of ink printed between the holes in the mesh and that these pillars have to flow together to give you a smooth print.

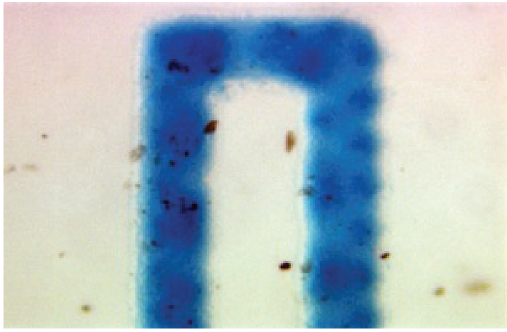
As is so often the case in screen printing a simple experiment can show you that this is completely wrong. Just do a comparison between a printed sample and the original mesh, using a well-defined corner of the image as a reference point, and you will see that the ink is thicker underneath the mesh than between the holes. People think I'm mad when I say this, but you will have no problem confirming the facts for yourself.



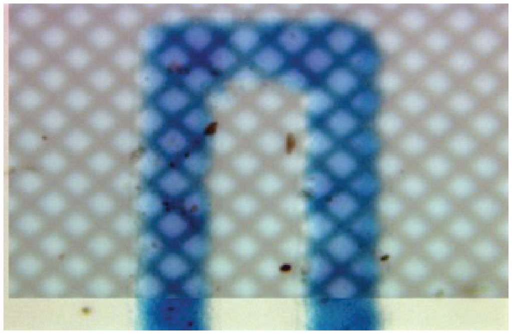
How printers think that screen printing works



The exact part of the stencil used in the print



The mesh marking is the dots of darker blue



A superimposition using Photoshop confirms the theory

Here are 3 images. The first is the stencil. The second is the print with the mesh marking. Under the microscope the marking was very clear, but you can just about make it out in this image. The composite image has made the mesh semi-transparent so it can be superimposed on the image so that stencil edge and print aligned perfectly. You can see (and confirm from the individual images) that the mesh marking indeed coincides with the knuckles.

The 1-2-3 explains this apparently bizarre fact. As the mesh comes out of the ink a meniscus is formed underneath the mesh and this is the source of the extra ink. Printers have often worried about the 'pillars' of ink having a chance to flow together. Instead, the printer has to worry about how the extra ink printed underneath the mesh will be able to level out to a smooth surface.

How screen printing actually works

The basic theory of levelling shows that the levelling should be very fast. In other words, you should never see mesh marking. Obviously the simple theory must be wrong, but it's worth getting to know the theory, even if it only helps you with the chore of painting your house. Levelling theory was developed to help work out how to design paints that wouldn't show brush marks. Here's the formula well-known in the paint industry:

$$LevellingTime = \frac{Constant \times Viscosity \times SpaceBetweenBrushMarks^4}{SurfaceTension \times Thickness^3}$$

The formula basically says that reducing the viscosity or increasing the surface tension is useful, but far more important is to put on a thicker coat of paint (twice the thickness levels in 1/8 the time) or use a brush with finer hairs (brushes that are twice as fine level in 1/16 the time).

For screen printers the important point is that 'Space between brush marks' gets replaced by 'Thread-to-thread spacing' and if you do the calculation you find that this is so small that the levelling time is much less than 1 second, even for very viscous inks (>100Pa.s). It's a very sad fact that even with levelling times of many seconds we still see mesh marking, so this simple model simply doesn't seem to be relevant.

So why do we see mesh marking? It seems that no-one knows, so let's explore one other idea. It seemed a reasonable hypothesis that viscoelasticity ('tackiness', 'stringiness') of the ink was the cause of the problem. Hypotheses are designed to be tested so we printed two inks with the same mesh. Although we could not measure the viscoelastic properties directly, one was definitely tacky/stringy and the other wasn't. We felt there was a good chance that we'd see a difference – and we did. But in the wrong direction. The tacky/stringy ink gave virtually no mesh marking, the other one gave strong marking.

The obvious other place to look for the cause of mesh marking is the mesh. The thinner the mesh fibre, the less ink there is wrapped around it so in principle the less meniscus and the less mesh marking. Yet I've done some printing with a 16µm stainless mesh and could see some very clear marking effects. But there's a clue from the real world. Printers often notice differences in mesh marking between different batches of the 'same' mesh. My favourite hypothesis (though I know of no research on this) is that differences in the shapes of the knuckles will give variations in ink deposit and therefore different levelling times. If, for example, 'warp' knuckles are different from 'weft' knuckles then the mesh marking will be at half the frequency. The eye is much more sensitive to low-frequency visual defects so such a mesh might give the impression of being worse.

Indeed, when I looked at the mesh marking from the 16μm mesh I was alarmed to find that the spacing wasn't what I expected. Then I realised that it repeated with every 2 threads. In other words, one type of knuckle mesh-marked, the other didn't. I then realised that I'd seen this effect on polyester meshes, but because the mesh marking had been less clear I'd not followed up on the observation.

I am grateful for the expert observations of Martin Duda. He has noted that the same ink printed on the same mesh under low and high tension shows totally different mesh-marking properties. The high tension gives prints with much lower mesh marking, even with "tacky" or "thixotropic" inks which, in his experience are the worst for mesh marking. Maybe the extra tension is smoothing out the second knuckle, or maybe the cleaner snap-off gives less tendency for the mesh to hang around in the ink and (somehow) produce worse marking. These observations deserve to be followed up. If higher tension really reduces mesh marking then this deserves to be more widely know - and the explanation for the improvement would surely follow.

Mesh marking is ugly, it makes people feel uncomfortable about screen printing and it degrades technical performance. Because many people have had the wrong model for what it is, very little progress has so far been made in solving it. Now that we've dispelled some myths and now that the 'every other thread' effect seems to offer a clue, let's hope that one of the mesh makers will take up the challenge to determine the cause and the cure. It would be a real money-making opportunity for the mesh maker and a real boost to the screen print industry.

Acknowledgement:
Dr Nik Kapur the University of Leeds has been most helpful in sorting out many of the scientific issues of this complex topic.

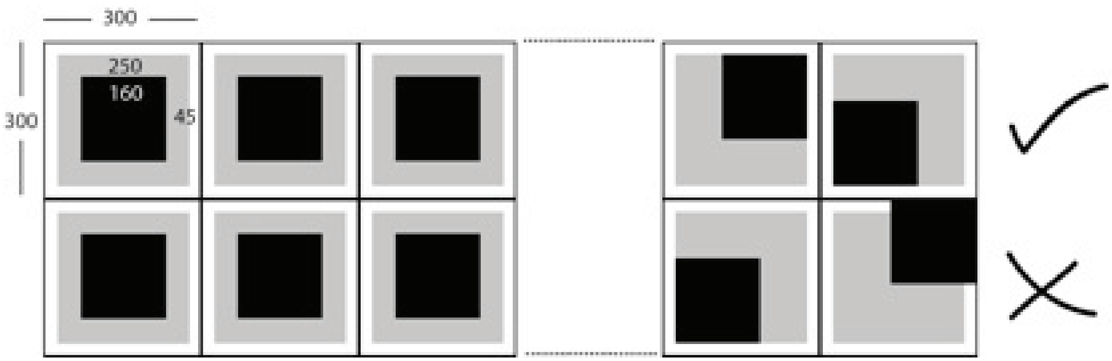
Precision registration

We are all familiar with the problems of registration when the temperature and humidity change during printing on paper. There is less familiarity with the effects on plastics as these are generally quite small. However, as the screen industry heads towards ultra-fine printing for flexible electronics, the registration problems become quite severe.

Let me give a specific example so you can see the scale of the problem. Let's try to screen print a flat-panel display using state-of-the-art plastic transistors and polymer light emitting diodes (PLEDs). Let's assume that the screen printing of each component is not a big problem in itself. With modern stainless meshes, the latest low-EOM, low-Rz stencils and with inks optimized to reduce "slump," we can produce high-quality fine-line work down below 50µm. I'm not claiming that any of this would be easy, but I just want to take this part of the process for granted and concentrate on the real problem of registration.

To simplify even further, let's just concentrate on two elements of the display and assume (wrongly!) that we can print a transistor in one pass and the PLED in the second pass. In other words we need to register 1 million PLED printed dots on top of 1 million transistor dots.

Assuming a display that's 300x300mm with 1000x1000 resolution, each pixel occupies 300µm square. Let's say that the PLED element must be 250µm square, leaving a 25µm border around each pixel. If our transistor dot is smaller, say 160µm square then in perfect registration we have a border of 45µm around the transistor. To make sure that our PLED always fully covers the transistor we have to make sure that we are accurate to 45µm over the whole 300x300mm. The diagram illustrates the idea. The dots on the left are all perfectly arranged with the nice 45µm border. By the time we reach the other end of the image some of the dots are just about OK, but one of them has gone over the 45µ limit.



4 ways misregistration might move the central square

The industry requires accuracies greater than this. For example a typical 'pixel' might be 200μm square, but is made of the 3 colours, RGB, so each becomes a rectangle 200x60μm which leaves only a 10μm border between pixels. But we'll use the 'easy' target of 45μm for the rest of our discussions.

We can readily find single effects that will give us an error of 45μm over 300mm, so the challenge of preserving this accuracy with multiple effects is severe. Here are the first two effects

1.- Suppose our mesh is perfectly stretched and everything is in good registration. Let the screen relax a bit, by a tiny 0.015% (this means, for example, a tension going from 25N to 24.996N!). Over 300mm this is 45μm.

2.- Or let's suppose that we use a large 5mm snap-off (off-contact). Over the 300mm horizontal distance the image becomes ~45μm longer. With extra distortion because of squeegee pressure and drag of the mesh coming out of the ink (especially if the ink is too viscous), this will get significantly longer.

Even if the press itself is perfect, this is still a challenge. We can easily identify three more issues:

3.- Suppose we are using a polyester substrate. It expands by 15μm across 1m for every 1°C of temperature rise. If the temperature changes by 10°C it will expand by 15*0.3*10=45μm.

4.- Another effect, Relative Humidity (RH) comes in to play. Polyester also expands by 15μm/m/%RH. So a 10% change in RH also changes dimensions by 45μm.

5.- If we are printing roll-to-roll then we might want to keep our polyester under tension. If it's 100μm thick then a typical tension of 60N/m will stretch it by 45μm over 300mm.

These last effects are not so familiar to many printers. If you want to try calculating them for your own system the equations for temperature or humidity expansion are the same, with "Change" either being ºC or %RH:

Expansion = Expansion-Coefficient * Change * Length

You will find large variations in expansion coefficients. For example, PET expands by 15μm/m/ºC, PC expands by 30μm/m/ºC and PP by as much as 100μm/m/ºC. Similarly, PET expands by 15μm/m/%RH, the poly-olefins by ~1μm/m/%RH and PMMA, which absorbs a lot of water, expands by a frightening 100μm/m/%RH.

A good approximate formula for the stretch of a substrate under tension is:

Stretch = Length * Tension / (Modulus * Thickness)

To check out the calculation for PET you need to make sure that everything is in the correct units, so put in 0.3 for Length, 60 for Tension, 4,000,000,000 (4GPa) for the Modulus and 0.0001 for the Thickness. The result, 0.000045, translates to 45μm.

This list of problems (and it's not exhaustive) means that we have to approach the task systematically. Unless we have good temperature, humidity and tension control we can't even begin to tackle the problem. But assuming that all non-screen factors are under control, how do we take care of the screen issues?

We need to know what we're doing when we stretch our screens. Do it badly and the tensions will sag both in storage and during printing. There has been a revolution in understanding how to stretch properly and modern equipment does a far better job.

But however good the mesh is, we can harm it by stressing it too much so we have to get into good habits right from the start:

1.- We need to use a mesh which retains its shape. Polyester is simply not up to the job for this high degree of accuracy. Stainless is, of course, very good. The newer liquid crystal meshes are also remarkably stable.

2.- We need to print with essentially zero snap-off so that there is no need to deform the mesh during the squeegee stroke. The only way we can do this is to minimize the drag on the mesh as it comes out of the ink. A fine stainless mesh will experience less drag than a coarse polyester mesh. Unfortunately, the liquid crystal meshes gain strength in the length-wise direction by sacrificing strength in the cross-thread direction so they tend to be a bit fat and might cause a lot of drag. But ultimately it's down to the ink. It should be strongly shear thinning so that at the shear rates of the mesh coming out of the ink the drag is minimised.

3.- We need to use the minimum squeegee pressure so there is the minimum drag in the direction of the squeegee stroke. Again this means a good shear-thinning ink. It also means the thinnest possible stencil (provided it is low-Rz) so there is the minimum work required to get the ink through to the substrate. An alternative is to get rid of the squeegee altogether and use a pressurised ink delivery system, but this is more speculative.

4.- We should avoid applying the stress in only one direction. So we need a squeegee/flood system that can print in both directions. This is unusual for classic screen printing but is now quite common in high-tech printing.

5.- We need to rely on feedback control. With automatic registration systems it's possible to apply controlled tension to the screen frame itself to compensate for length changes from, e.g. relaxation of the mesh tension.

Such systems will not be cheap. But we're talking about the high-end here. And what's the alternative? If you are using inkjet you have the advantage that you can (in theory at least) place your drops exactly in registration. But this too needs accurate automatic registration systems with feedback to the inkjet positioning systems. This isn't cheap either.

By understanding the individual elements that affect registration, by optimising those elements that are relatively simple to control (shear-thinning ink, thin mesh fibre, low-EOM, low-Rz stencil, near-zero snap-off, alternating squeegee strokes, temperature and humidity control, substrate tension control) then the process is already off to a good start.

Printing tracks on tracks

In most of this eBook we focus on printing onto a flat substrate. Always the optimum combination to get good results is a low-EOM, low-Rz stencil, thin mesh fibre, shear-thinning ink with fast recovery, low snap-off, low squeegee pressure. They all work together in a natural way because the science of screen printing is essentially simple.

So what happens when we try to print one track on top of another?

Broadly there are two problems.

First, printers find 'skipping' in the portion of a track immediately after (as defined by the direction of the squeegee stroke) it crosses over another track.

Second, they find that tracks get much wider when they cross over another track.

It turns out that the answer to both problems is the same – make the previous track as thin as possible. And we already know how to do that, by using a thin mesh and a low-EOM stencil (which has also to be low-Rz to minimise sawtoothing).

Before we start to explain why this helps we need to address an obvious drawback of this solution. If, for example, you are used to printing a track that is 200μm wide and 16μm thick, going down to 8μm (which would greatly help both problems) would immediately halve your conductivity. So you've no choice but to use a more expensive ink which contains more (silver) conductor, more cleverly optimised. If the price/kg is double and you're printing half as much then you're no worse off. But there can be another problem. A more highly-filled conductor might be much higher viscosity so printing might get much more difficult. This is where it's important that you (and your supplier) know how to design the perfect ink for screen printing. The low-shear viscosity is not important (indeed, the higher the better), it's the high-shear viscosity which needs to be low and a good ink manufacturer might still be able to give you this.

Now we can address the skipping issue. If your squeegee is at a nice low pressure that is printing high quality tracks away from crossovers, it's possible that there is not enough pressure to force the ink to travel down the extra 16μm to be in contact with the substrate ready for the print step. No contact = No print. Ahead of the crossover the squeegee is helped by the fact that the ink travels both down and forwards. Just after the crossover, there is no forward-travelling ink so only the downward motion is available. That's why the ink doesn't get a chance to reach the substrate. Increasing the squeegee pressure will help, but there are practical limits as to what you can achieve without introducing distortions to the stencil. Making sure that the ink is highly shear-thinning will also help. And printing slower, giving time for the ink to flow is also an obvious option. Going down to an 8μm thickness makes it much easier to get the ink down to the substrate without excessive squeegee pressure or slowing down the print process. If your mesh is 40μm thick then instead of ink having to travel 56μm it only has to travel 48μm. This requires 48/56 of the pressure, a reduction of 14%.

The broadening issue arises because the stencil is no longer in good contact with the substrate. A high pressure squeegee stroke will force the ink sideways, just as if you had a high Rz stencil. If you do anything with the squeegee, ink or press speed to avoid the skipping you will automatically increase the broadening. So your only choice is to go again to the 8μm track. You automatically reduce the forces that lead to spreading and you gain a wonderful advantage. Suppose that printing over a 16μm track gave you a broadening of 16μm each side of your new track. If you print over an 8μm gap you don't halve the broadening; you reduce it by a factor of 8 to a mere 2μm. This is because flow through a gap (if everything else is constant) goes as gap^3.

As seems to happen very often with the 1-2-3 of screen printing, the laws of physics are very much on our side. Everything you need to do to increase the quality of single-layer prints helps you (and sometimes more than helps you!) print the subsequent tracks with far fewer problems.

Print Faults - Making and fixing them

Tricia Church

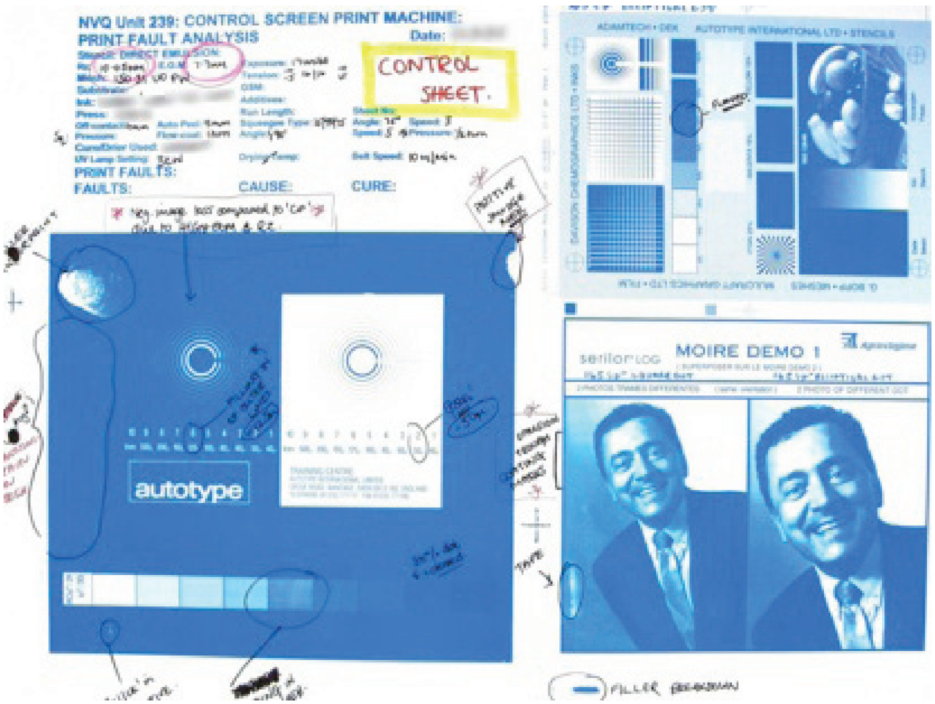
Like everyone, I get faults in my prints. To fix them I need to know the root cause. My favourite resource for finding the root cause is a set of bad prints I made some years ago. These are very special bad prints because, under the wise tuition of Bill Appleton, I had set things up deliberately badly in order to see what happened when things were wrong. I find that it is very easy to spot the deliberate mistake in my set of bad prints and then reset my printing in order to correct for that fault.

I can't give you a copy of my bad prints, but I can give you the next best thing which is pictures of many of those bad prints along with the explanation of what I deliberately did wrong. Hopefully you will find this a useful practical guide for your own problem solving.

It's important to include a range of challenging features in any test printing. The image from the Serilor Log test suite is particularly challenging and insightful and is highly recommended.

A very bad print

Here is the finest ever bad print. Can you spot all the deliberate errors?



A print with many deliberate faults – one of 28 fault-based prints we made.

They include tape marks on the positive, a thumb print in the drying filler, filler breakdown, coating lines in the emulsion from using a (deliberately) bad trough, flooding, filling in, etc. etc. Some of the details of the print settings have been removed from this photograph to ensure that the makers of the ink, press, mesh etc. don't get blamed for our deliberate mistakes.

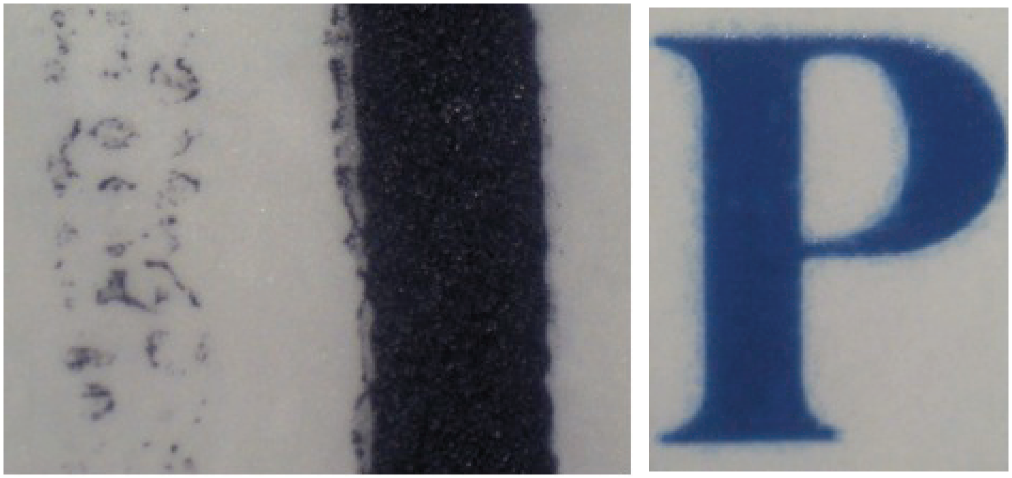
The wrong stencil

Flooding and filling in came mostly because we deliberately used an emulsion with a high Rz (10µm). With a strong squeegee pressure the ink gave massive dot gain. When we re-printed with a low-Rz capillary film using the same press settings, the flooding/filling disappeared.

The wrong mesh

Slur from a slack mesh, or too large a squeegee drag

These two samples show different slurs in different prints but the cause is the same. The squeegee is coming from right to left and because the mesh is too slack and/or the pressure/drag is too large, the squeegee slides the mesh along giving the slur directly connected to the main image. In bad cases shown on the left, the squeegee actually judders up and down, taking the stencil with it and printing a light ghost of the main image when it next judders back into (distorted) contact.

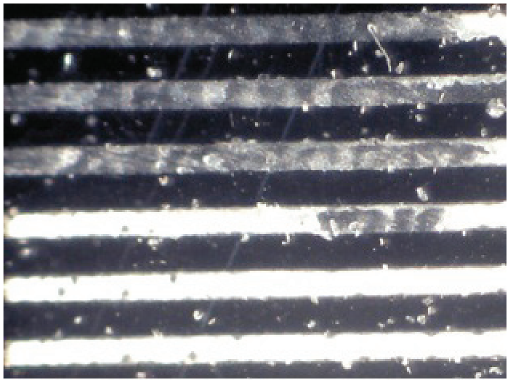


Slur: in both these prints we had a slack mesh and excessive squeegee pressure

All these lines should look like the line along the bottom of the image. But we used a mesh that was too small for the ink particles and we have classic "sieving" where the particles block the mesh holes. You can get something like this if the ink dries in, but this ink was resistant to drying in and we did not get the effect with a coarser mesh. Note that the particles aren't extremely large, but if a hole is <3x the width of the particles then it gets blocked very quickly. In this case there were only 2-3 mesh holes/line width so you can judge that the particles were near the critical 3x limit.

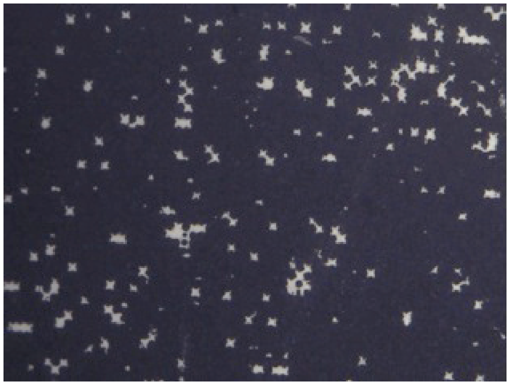
Too fine a mesh

Sieving of large ink particles by too fine a mesh. The printed stripes should look like the silver (white in this image) stripes on the dark substrate. Note the blocking that has started in the 3rd stripe up from the bottom.



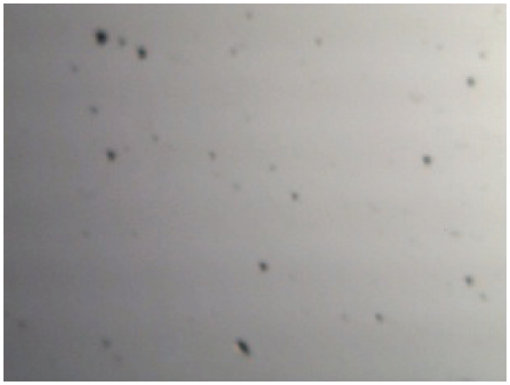
We deliberately waited some time after the flood stroke before printing – and used an ink with no added retarder. Naturally the ink had dried in, blocking some of the holes, giving the classic drying in pattern. We could also achieve drying in only at the image at the start of the print stroke. This is because the ink remaining in the mesh after the print had had longer to dry in before it was re-flooded.

Wrong ink - Drying in



Ink dried into the stencil means missing bits (light areas) in the solid print

Wrong ink - Too much viscous drag (with a large snap-off (off-contact))



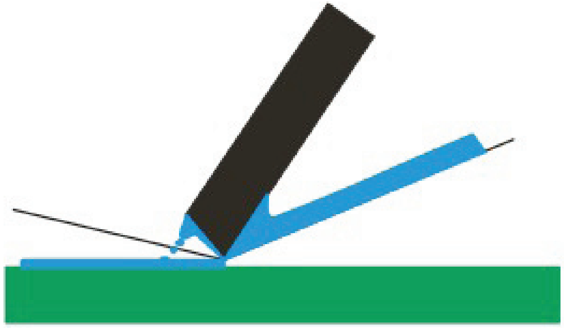
Splatter (dark spots on the white background) from a solid area (off to the left) that flew a long way

We used a very viscous (non-reduced) ink. As the squeegee went along, the drag on the mesh from the ink was too large and the mesh was slow to release. Towards the end of the print, the mesh came out of the ink in a sudden rush. The 1-2-3 shows that there is a "liquid bridge" underneath the mesh. If this breaks in a gentle manner, the drop of ink formed by the break simply goes down onto the print. With a violent release the drop can fly off in all directions. These ink particles were a few mm away from the edge of a solid printed block.

It's easy to imagine that a viscoelastic ("stringy", "tacky") ink would give not individual drops like these but "cobweb" strings.

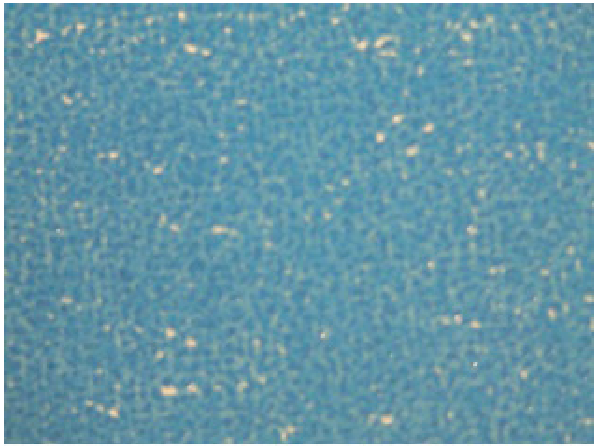
Teardrops

Although these were very easy to see on the print, it was impossible to get a good photo of them. You've probably seen them yourself –blobs of ink (a few mm diameter) often in a straight line, randomly over the print. We made them appear by using a tacky ink and a weak squeegee. The combination meant that during the squeegee stroke, ink built up on the wrong side of the squeegee – partly through hydroplaning, partly because viscoelastic inks naturally "climb" under shear. After a while, there is enough ink built up on the squeegee that it can drop off and fall through the mesh onto the print – giving the characteristic teardrop shape:



How teardrops fall onto your print

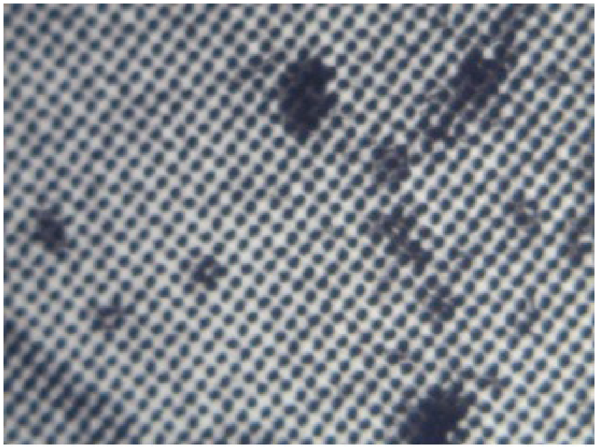
Not clean enough Ghost image



The remains of a ghost. This should be a uniform blue, but the white areas have less ink and are associated with a previous image that had not been properly cleaned.

This screen was deliberately badly cleaned. When we printed it there was a clear ghost image visible. Under the microscope, the ghost is made of patches of unprinted ink. With this mesh and ink, mesh-marking is especially strong and the ghost image seems to magnify the effect.

Dust



Dust can have a devastating effect on a print

We threw some dust onto the press during printing and, not surprisingly, got these "hickies" which would not be appreciated by a customer!

Orange peel

This is hard to image but easy to spot. There are many causes of orange peel, all coming down to the fact that the ink is generally unhappy when it's drying. So printing an incompatible ink on top of another gives one type of orange peel (that's what we did to ensure we saw it). Having the wrong solvent blend, or too much thinner is another way. The cause of this sort of orange peel is interesting and is sometimes called the Marangoni effect. As the more-volatile solvent evaporates it leaves behind a solvent mix with a different surface tension. Ink flows from high to low surface tension so you start to get instabilities. These instabilities work in 3 dimensions and you start to get regular cells where solvent is rising in one point and sinking in another. Under the right (or wrong!) conditions these cells can form perfect hexagons, the classic mark of the extreme Marangoni effect. The cure is either more gentle drying, more compatible solvents (less difference in volatility, less difference in surface tension) or a more effective surface active agent which swamps differences in surface energy.

Belt marks

Again this is a problem that's easily visible on the print but hard to show in a photograph. You see a broad regular pattern on the print that coincides with the pattern of the belt that conveys your prints through the oven. We got the pattern to appear when the oven was too hot. Anna and David have an explanation in their section on Drying problems.

Registration problems

We don't need to show you the images because you know what they look like, but it was a useful exercise deliberately to dry or to humidify a print before printing the same image on top of it. The dried print shrank by 2mm over a 400mm print (0.5%) and the humidified print expanded by 1mm (0.25%). Such gross mis-registrations are easy to spot, but doing this test was a reminder that for precision printing, exact equilibration of the substrate between prints is of great importance. For paper, the effect of water is well-known. But the effects on plastic substrates are less well-known. See Steve's "Registration" section for a discussion of thermal and hygroscopic effects in ultra-high-precision printing onto plastics.

Colour Shifts

Tricia Church

What's the best order to print your four colours? This is a question that has been around for years and there's been no definitive answer. As a practical project we decided to revisit the question to see if a clearer answer would emerge. What we found is that subjective opinion left the question open, but that science allowed us to come up with a better answer.

Background

The printing literature is full of contradictory reports on the best sequence for printing CMYK (Cyan, Magenta, Yellow and Black). Many of them are said to be scientific reports, but the fact that they so often contradict each other makes it hard for real printers to know what is best for them and their customers. Even more confusingly, ISO Standards for colour printing refer to them as "CMYK standards" which might imply that CMYK is the standard order, even though no standard order is mandated.

We all know that the key issue is one of "dot-on-dot" gain which can readily be understood with the following diagrams.

With a small dot, just after the squeegee has passed, there is a modest amount of ink ready to be printed.

With a larger dot, there is much more ink ready to be printed

When the stencil is nicely in contact with the substrate, a certain amount of ink is printed. When the stencil is held above the substrate by the presence of a preceding dot then more ink must be printed.

The definitive study of this effect was carried out in 1999-2001 by Eifion Jewell's team at Swansea University and Autotype reported on the implications of that work in the 2001 SGIA magazine. Their study showed that the amount of gain depended on the amount of dot underneath.
A small dot gave a small dot gain, a large dot (i.e. something approaching a solid) also gives a small gain, and intermediate dots give the largest gain. This means that there is no simple correction process that can be provided to a print to compensate for the effect. So we can guarantee that we will have dot-on-dot problems and that no print sequence can be perfect.
Now we know we aren't looking for perfection, can we at least find a good compromise? That was the function of our study.

Basic rules

There is no point in doing such a study if you don't have the basics in place. These aspects of printing 4-colour jobs are entirely under your rational control. If you don't do these then your nightmare with the dot-on-dot effects will simply be worse.

1.- Use a low EOM, low Rz stencil

It's now widely appreciated that a low EOM gives you the smallest dots and therefore the minimum dot-on-dot gain. High EOM regularly gives "skipping" in addition to terrible dot-on-dot gain. As "skipping" often gets confused with moiré a printer with a high-EOM stencil can get very confused in trying to sort out the various problems. The rule is simple – never do 4-colour work with a high-EOM stencil! It is also appreciated that a low Rz (stencil roughness) is needed to stop squeegee-induced gain. This gives the second rule – never do 4-colour work with a high Rz stencil! If you have a stencil with both low EOM and low Rz then your mono-colour prints are under excellent control (dot gains typically < 10% and with a total immunity to squeegee settings, print speeds etc.) and your dot-on-dot problems are minimized. We used Capillex CP with a 3µm EOM and a high-frequency (non-flooding) Rz of 4µm as this has consistently proved to be an excellent balance of stencil properties for high-quality printing. We found no skipping, our mono dot gain was under good control and the job was easy to print. The stencil also has a proven high fidelity from film to print so we were reducing stencil-induced colour shifts to a minimum.

2.- Use a "thin" mesh

In addition to choosing a thin stencil, you need to use the thinnest practical mesh which holds, and therefore prints, the least amount of ink.

3.- Choose an ink with a thin deposit

Obviously solvent-based inks can give you a thinner ink deposit. With UV inks the only relevant "solvent" is water and we all know that water-based UV gives less dot-on-dot gain than standard UV. However, water-based UV has its own challenges. We deliberately chose a standard UV ink as this would maximise the print sequence effects in which we were interested.

4.- Make sure you have the right CMYK intensities from your inks

We have to admit to making an error here that is all too common. We printed our solid inks onto our chosen substrate (a matt coated paper) then "based" the inks till they reached the required ISO density standards for 4-colour screen. What was our error? We forgot that the paper absorbed a small amount of the ink so the intensity of the first ink down is higher than that of subsequent prints. With hindsight we should have based the inks to a compromise value based on, e.g. densities obtained by printing onto a non-absorbent plastic substrate. However, we found that we are not alone. Many printers make this error and ascribe the reduced colour of subsequent inks to some mythical "trapping" effect. Simple experiments on non-absorbent substrates show that such "trapping" is a myth. We've learned from our mistake, we hope you will learn from it too.

5.- Choose a mesh/lpi combination which will give zero mesh moiré

As we are not expert printers and were using a single-colour press we didn't want to be too ambitious so we chose to print at 80lpi. Using the MacDermid Autotype Mesh Moiré Calculator we were able to determine that our C,Y and M screens at 37.5, 82.5 and 7.5° would be free of mesh moiré on a 150/31 mesh but that there would be a strong moiré with the K at 67.5°. We therefore printed the K on a 180/27 mesh which the Calculator showed to be moiré free. See Steve's moiré section for an explanation.

6.- Make sure you have good registration and fit

As this was a complex job done over many weeks it was not realistic for us to have substrates all stabilized perfectly to the same extent. So registration and fit were not perfect. However, careful inspection showed that this in no way affected the conclusions about the print sequence.

7.- Always have a definition of "truth"

We used a high quality colour proof as our definition of truth. The definition of good colour, good shadows, grey balance etc. was taken to be the proof.

The test images

It was important to have a good range of test images as the different print sequences will show different effects on different images. We therefore chose (a) a child's face with lots of difficult skin tone, (b) a beautiful lily for aesthetic reasons [but this choice turned out to be important as we will see later on], (c) a fiendishly difficult grey image, (d) some pretty tulips including a duotone for educational purposes. In addition we printed standard test strips from Linotype-Hell including the all-important grey-balance test area.

The Caza sequences

We are very grateful for Michel Caza's active intervention in our work. Caza has strong views, based on his years of printing and teaching, that his "Yellow-last" sequences are highly effective so we were keen to see how they compared to more conventional sequences.

The test sequences

There are 24 possible CMYK print sequences. Our mentors narrowed the choice down to 6 plus the two Caza sequences. This gave us

1	CYMK
2	KCMY (Caza b)
3	YMCK
4	MCYK
5	MYCK
6	YCMK
7	CMYK
8	CMKY (Caza a)

The results

Needless to say, we found large differences between the various sequences, and some of the prints were appallingly bad. Dot-on-dot gain is not a pretty thing to see! You can get some idea of the variations from this view of four of the eight sequences.

We formed our own (subjective) opinions of the various sequences but were then fortunate that FESPA Slovakia were holding a meeting at which Bill Appleton was speaking. The experienced Slovakian printers gave their own opinions. There was, of course, no agreement about which sequence was best, though sequence 5 and one of the Caza sequences had their supporters. Preferences depended, not surprisingly, on what people were looking for. As we will see, the 15° moiré effect strongly biased many of the judgements. As this effect can be taken into account by a very simple process we will ignore this aspect of the prints till we come to the section devoted specifically to the effect.

This portion of one of the Linotype-Hell test images shows the wide colour variation from four of the eight test sequences. Clockwise from the top left, 4:MCYK, 5:MYCK, 6:YCMK, 8:CMKY

Rather than rely on subjectivity, we decided to create an objective measure which we call the Colour Fidelity Index, CFI. This captures 3 independent factors, all of which have to be right:

- Good greys –shifts in greys are a good indication of a print generally out of control
- Good 3-colour tones – this captures the fact that a lot of the subjective colour judgement was based on the more complex tones which often looked far too dark.
- Good shadows – we want to lose as little shadow detail as possible.

We had anticipated (because of other work done at Swansea) using a fourth criterion – the colour gamut. But careful Lab measurements and plots on the CIE chart showed that there was no significant difference in gamut in any of the sequences. We have no explanation for why our results differed from Swansea's and others might like to include gamut in their own CFI.

The idea was to obtain objective measures for each of these factors, scale each of them from 0→100 then divide the total by 3 to give us a 0→100 CFI, where 100 is the perfect print.

Getting the objective measure for the greys was easy. For a 20%, 50% and 90%

grey, the Lab values of the printed and reference greys were measured (you need a spectrophotometer or spectrodensitometer for this, but all serious colour printers should have these) and the colour difference (DeltaE) calculated. The DeltaE's for the three greys were then summed and put on a 0→100% scale with the average value ~50 and defined so that perfect greys (i.e. a DeltaE sum of 0) gave 100%.

For the 3-colour tones the most satisfactory method turned out to be a simple measure of the %K along a 0→100% 3-colour tone strip followed by adding together the difference between the measured %K and the specified value. Again the results were put on a 0→100% scale with the average set at 50 and perfection defined as 100%.

Because the shadows are so important for a good print, and because the Caza b sequence showed a clear advantage over the other prints (there is no dot-on-dot shadow gain when the K is printed first) we wanted to do the same sort of measure as with the 3-colour tones. Unfortunately our printed 4-colour strip was a pure theoretical strip with no GCR/UCA. It showed enormous dot-gain, making the measurement technique unsatisfactory. We reluctantly resorted to an expert relative assessment of the degree of shadow clarity (using the proof as a reference standard) and to be consistent with the other measures gave the prints a score either side of 50 with a scatter similar to the other measures.

So we were able to provide numbers for three values. To calculate the CFI we added the three values then divided by three to get their average. For example, Seq 1 had values of 31, 60, 48 which gave a total of 139. Divide that by 3, gives 46.

15° moiré

Our subjective judgements of the print quality was greatly affected by the fact that prints 1, 3 and 7 had terrible moiré visible in the pretty lily. The reason quickly became clear. In each case we were printing a light M tint on top of a relatively solid Y. This isn't entirely obvious because sequence 3 is YCMK; but the lily has almost no C so the M was going directly on top of the Y. The next fact to check was the screen angles. The Y and M are indeed 15° apart. You would not expect any moiré from Y and C as they are 45° apart, and there isn't much K on Y printing. Why were we seeing moiré **only** in M on Y? The important answer is that we weren't! In the 4 image prints, it happened that only the lily was set up to show the moiré. In the 2-colour test strips there was very strong moiré of both M on Y and Y on M in the middle tones.

As explained in Steve's moiré section of the eBook, moiré depends on three factors. The first is the maths, the second is the human eye, the third is amplification of the mathematical effect. Mathematically 15° moiré is always present. But generally the human eye accepts it if its amplitude is below a certain level. What happens when you print a set of M dots on top of a set of Y dots (or vice versa) is that the dot-on-dot effect fades in and out on a regular basis as some dots (say every 3rd dot) are printed directly on top of a yellow dot (no dot gain) some are printed mostly in the space between yellow dots (no dot gain) and some are printed on the shoulders of yellow dots and give gain. So the dot-on-dot gain rises and falls in a regular manner, giving a more easily visible moiré. If the second colour is mostly above midtone then the larger dots will, on average spread out fairly regularly so the amplitude diminishes That's why the lily print was so important. The M on Y showed up strongly, but Y on M had no moiré. However, on the test strips the M on Y and Y on M show equal degrees of moiré (albeit with different colour shifts!) because the dot-on-dot effects are the same.

This leads to a simple rule. If you know in advance that the colour that is 15° away from Y (some choose M, others choose C) will have significant areas of midtones on top of relatively solid Y (and it seems that Y's tend to be rather more solid than other colours) then make sure you print the Y after that colour. If you don't have such issues then you can decide your Y print order based on the pure colour criteria of the previous section.

And the winner is...

Seq	Order	Grey	3-Colour	Shadow	CFI
1	CYMK	31	60	48	46
2	KCMY (Caza b)	40	63	60	54
3	YMCK	56	54	52	54
4	MCYK	33	65	56	51
5	MYCK	56	65	50	57
6	YCMK	48	56	46	50
7	CMYK	25	67	58	50
8	CMKY (Caza a)	27	62	54	48

The overall winner is Seq 5, MYCK. This has good general performance with the best colour balance. It was often a favourite of experienced judges. Seq 3, YMCK, is also quite good but was always disliked because of its strong moiré in the lily. If the angles for the M and the C were reversed then this would have been rated up there with Seq 5 by expert judges.

The Caza b, KCMY has a very strong grey balance shift so loses a lot of points for general purpose printing. However, there is a less pronounced 3-colour density shift than Seq 5, so gives quite satisfactory complex shades and the K-first strategy gives optimal shadow performance which justifies Caza's endorsement of this sequence. It will also tend to be less prone to 15° moiré because the Y is printed on top of a jumble of other dots, making it less likely for the moiré to appear, another advantage.

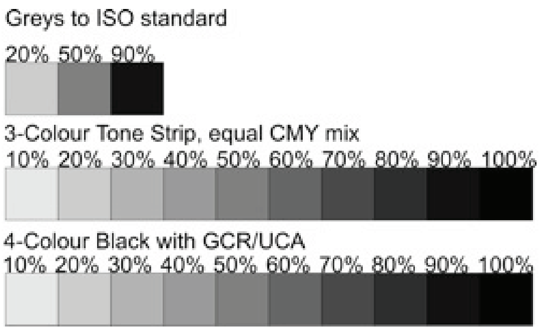
So, do we have an objective choice? Yes and no. We found the CFI incredibly helpful in debating the various merits of the different prints. By having numbers instead of opinions we found that we could debate the opinions much more sensibly. If we were real printers then we would probably choose to restrict ourselves to just two sequences, MYCK and KCMY. For any particular job we would be able to make a quick decision; if there's a lot of subtle grey then MYCK would be used, if a lot of darker complex tones and shadows then we'd use Caza b.

Do it yourself CFI

How applicable are our results to your printing? The sequence that was best for us will not necessarily be best for you. The dot-on-dot gain effects will be different for each stencil/mesh/ink/basing/lpi combination so your results might differ.

Caza finds, for example, that for his very high lpi printing that Caza a, which happened to have a low CFI for us, works very well. It would be interesting to see the CFI data at these high linecounts.

What is applicable is our methodology. First, the principles of dot-on-dot gain need to be grasped by your organisation. Next you need to make sure you are printing with low-EOM and low-Rz to ensure you have the minimum dot-on-dot and squeegee-based gain. You need to choose a thin mesh and, if possible, a "thinnable" ink such as water-based UV. Then you need to decide which colour should be 15° from the yellow to minimise the moiré effect. Then you can make up a simple test strip with 3 grey balance patches, a 3-colour tone curve and a 4-colour black (with your own GCR/UCA settings) and quickly print a few different sequences using your four stencils.



A simple test strip that would let you measure the CFI of any set of print sequences.

With a spectrophotometer (or spectrodensitometer) you can measure the grey scale changes and with an ordinary % Dot densitometer you can measure the 3-colour tone densities and the 4-colour black densities. A simple spreadsheet will then let you work out your own CFI. In a shop with a 4-colour press the whole process would be very quick and very insightful.

Conclusion

As so often with screen printing, when you strip away unnecessary confusions by getting the basic preparation right it becomes much easier to make sensible decisions that affect you and your customers. Choosing the right stencil, the right choice of mesh to remove mesh moiré, the right ink density, agreeing on a standard of "truth" made our task much simpler. With a relatively few objective measurements, and with the simple understanding of moiré we were able to come up with a couple of print sequences which we would use on a routine basis for colour printing. We hope that you will be able to reach a similar conclusion by carrying out a few objective tests on your own prints.

Acknowledgments

Thanks to Bill Appleton, Prof John Davison, Michel Caza, Prof Long Lin for advice and practical help.

Getting the right exposure

Anna Harris

You can have the best ink, the best mesh, the best press and the best film/emulsion, but if you don't get the exposure right, you can get poor image quality on your stencil and/or poor print-life on the press. This chapter starts with a review of exposure science and ends with a set of tips and tricks for getting the right exposure.

Exposure

Definition : *'On exposure to UV, light the sensitizer within the photostencil materials reacts to crosslink the molecules in the stencil to produce a layer insoluble in water'.*

The practical mechanics of exposure are fairly simple. The photostencil material is held in intimate contact with a film positive and exposed to an ultraviolet light source for a pre-determined time.

Photo-stencil sensitivity

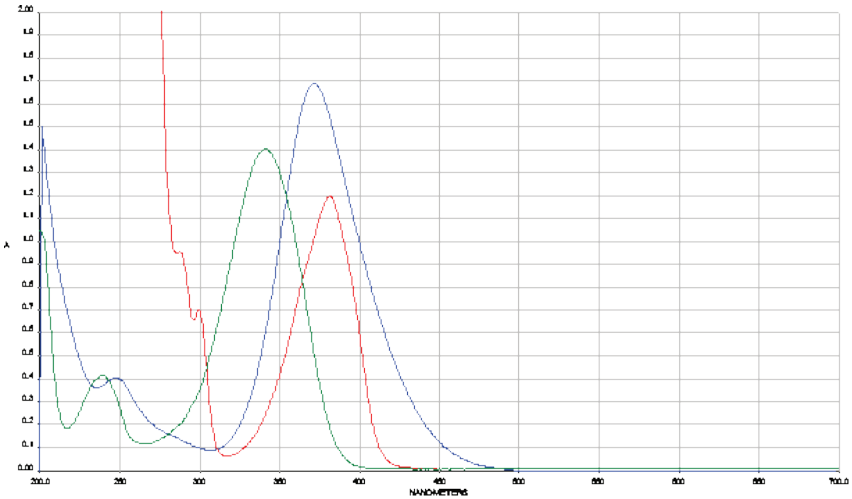
The emulsions used to produce a photostencil (liquid or film) use light energy to activate the sensitizer which initiates the crosslinking reaction that in turn cures the stencil.

The wavelength of light that the sensitizer absorbs will depend upon it's chemical nature. Typically emulsion sensitizers absorb light between 300 and 450nm, common absorption curves are:

Diazo – alone in single-cure emulsions.

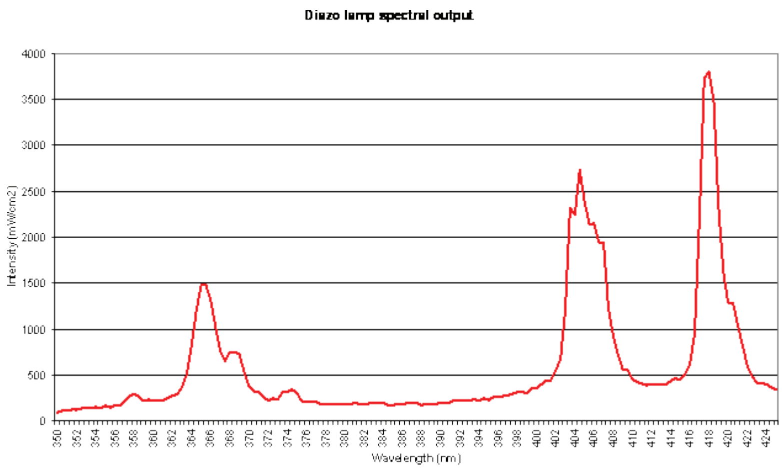
Acrylate sensitiser – present with diazo in dual-cure emulsions.

Photopolymer – used in 'One Pot' emulsions.

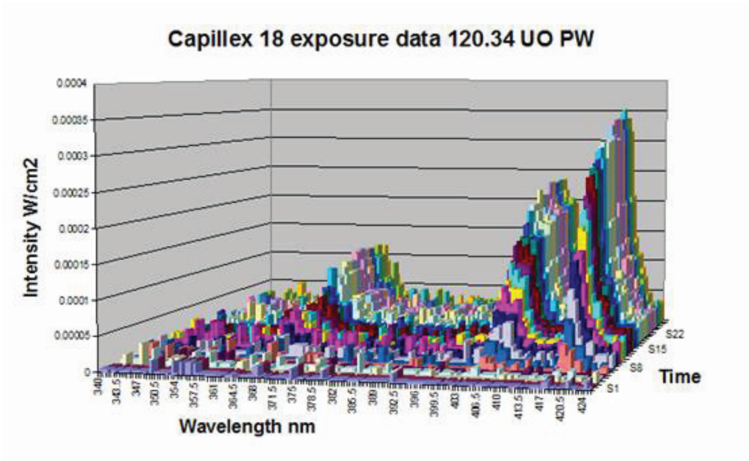


The light source for exposure needs to emit light of a suitable wavelength for the sensitizer to absorb. The screen printer mainly uses metal halide lamps, mercury vapour lamps or UV fluorescent tubes.
Neither the photo flood nor the quartz-halogen lamp has an output sufficiently high in ultraviolet to be worth considering for photostencil applications.

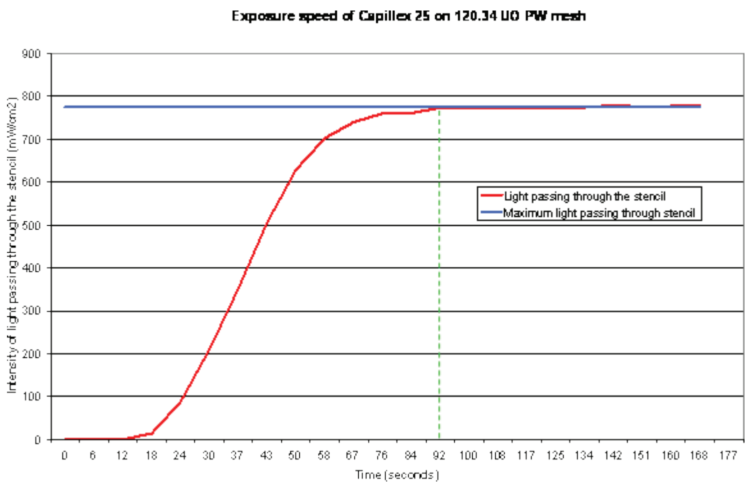
Here is a typical plot of lamp output.



If the spectral output of the lamp and the adsorption of the sensitizer match, then the light energy will be used by the sensitizer for reaction. Once the reaction is complete then light which is not absorbed by the pigments in the emulsion and dye of the mesh will pass through the stencil. This light can be detected and measured with a radiometer and then plotted as illustrated:



As exposure time increases more of the light emitted by the lamp passes through the stencil as less is used in the crosslinking reaction. If only 418nm light is considered then the reaction can be seen to be complete when the light reaches it's maximum:

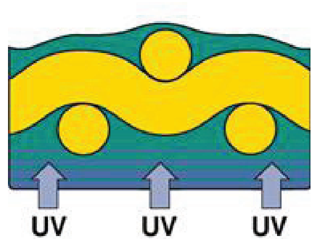


In this example the light reaches a maximum at 92 seconds and so this is full exposure.

If exposure is insufficient and the whole layer is not penetrated by UV light, the stencil may wash completely off the mesh during developing, or the stencil may be intact after washout but break down, or become tacky during the print run.
The resolution and definition of the image are compromised by over exposure as excess light is scattered under the positive. Resolution is taken to be the finest limit of reproduction achievable.

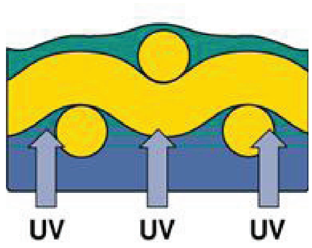
Definition is the reproductive quality as regards, for example, the straightness of edges of print. There are no real gains in stencil durability from over exposure.
The following diagrams outline the effects of under-exposure at 1/4, 1/2 and 3/4 of the full exposure for a direct stencil.

1/4 full exposure



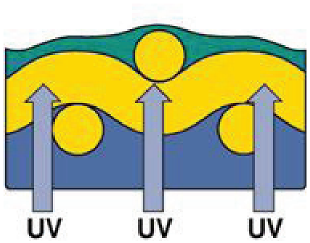
EFFECTS: During washout the image would appear and the stencil would probably start to come away during washout.

1/2 full exposure



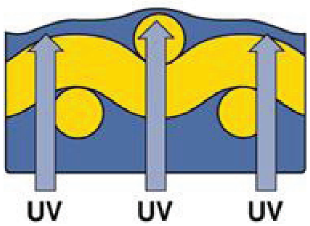
EFFECTS: The stencil would probably be damaged by a strong washout spray. The emulsion appears soft on the squeegee side.

3/4 full exposure



EFFECTS: Emulsion appears slightly soft on squeegee side. Stencil will scum if not washed out properly. Durability is compromised. Stencil is harder to de-coat.

Full exposure



EFFECTS: All the emulsion is fully hardened and the stencil will provide the optimum resistance and durability.

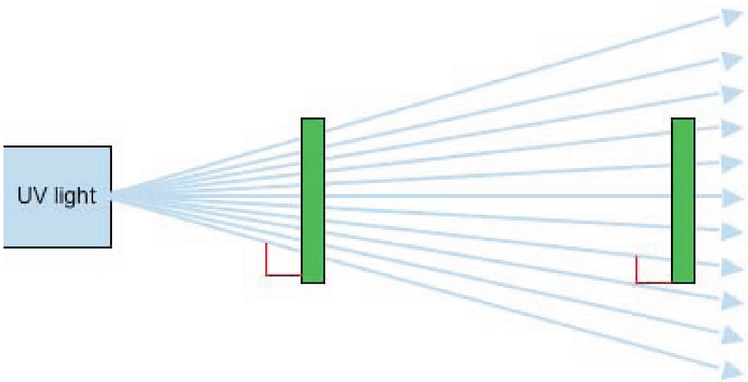
Exposure time depends on many factors:

- Mesh
- Stencil (type, thickness)
- Lamp (type, distance, age of bulb, reflector design…)

Comparing exposure times at different distances from the lamp

As a general rule the minimum distance between the exposure lamp and the vacuum frame should be equal to the diagonal of the area to be exposed. This will ensure fairly even illumination over the exposure area.

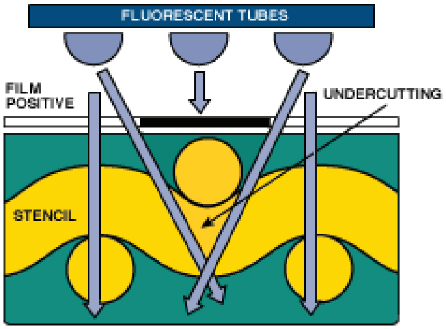
Depending upon the exposure area and the size/power of the lamp, the light intensity will fall off at the edges of the exposed area because of the increase in distance between the lamp at the centre and the edges of the vacuum frame. This becomes more critical the nearer the lamp is to the vacuum frame. A test stencil using an Autotype Exposure Calculator will show the maximum area that can be effectively exposed by a given light source.



As the distance between the light source and the vacuum frame increases so less light hits the stencil. This means that the time to achieve full exposure will increase. The formula for calculating this is:
X = Y x (a)2/(b)2

Where:
X = New exposure time
Y= Original exposure time
a = New distance
b = Old distance

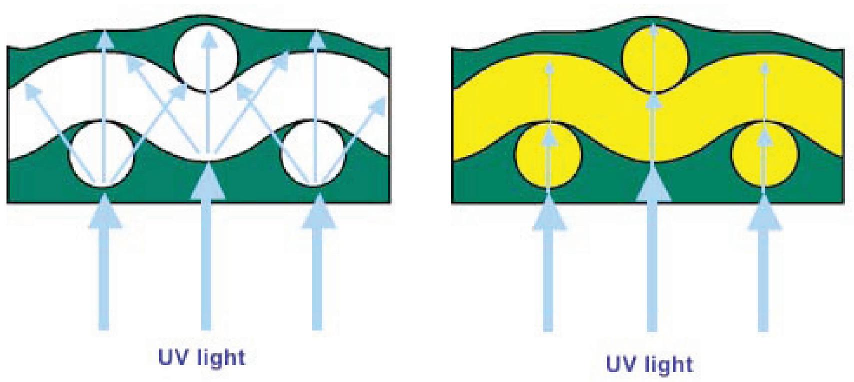
At the same time, the light hitting the stencil becomes closer to 90°. This will result in less undercutting and improved resolution. This is because light rays that are not parallel can expose bits of stencil that should have been masked by the film. This is often referred to as light undercutting.



From a practical point of view poor light geometry effects do not present a problem when processing general work, i.e. lettering down to about 6 point and halftones of 65 lines (25 cm) or coarser.

It is only when trying to accurately reproduce very fine line halftones or images that attention must be paid to light geometry. Very high quality work uses a lens system on the exposure unit which collimates the light, ensuring that it all arrives at 90º.

There is always a compromise between exposure time and achievable resolution because there is always some scatter within the system. As you increase exposure to create a harder stencil you automatically start to reduce the resolution.
Comparing exposure times with white and anti-halation dyed mesh



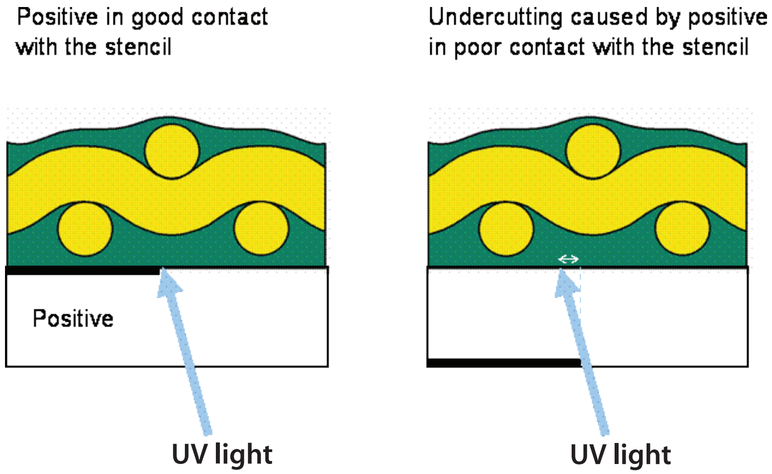
White mesh transmits and scatters light, yellow and orange mesh absorb the wavelengths needed for the crosslinking reaction, but scatter far less of the light.

This means that dyed meshes require longer exposures (up to 4x for some yellow meshes) but give better resolution and definition. Light scatter increases with mesh count and exposure time.

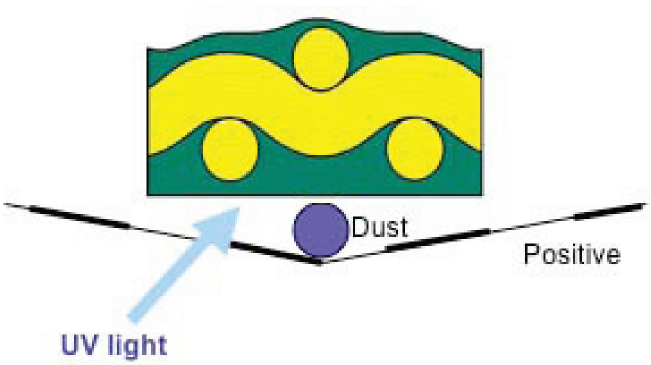
This makes using dyed mesh particularly important for fine detail resolution on fine meshes.

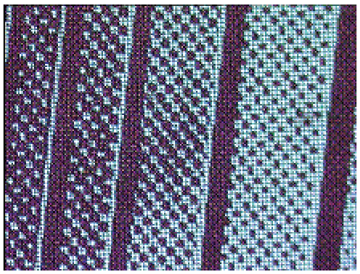
Poor contact with positive
The contact between positive and stencil should be as perfect as possible, inadequate contact results in light undercutting, more so when combined with poor light geometry.

Here's what can happen if the positive is placed the wrong way up. Light undercutting has resulted in loss of resolution.



Similarly, poor contact caused by dust can cause noticeable blemishes in half tones.

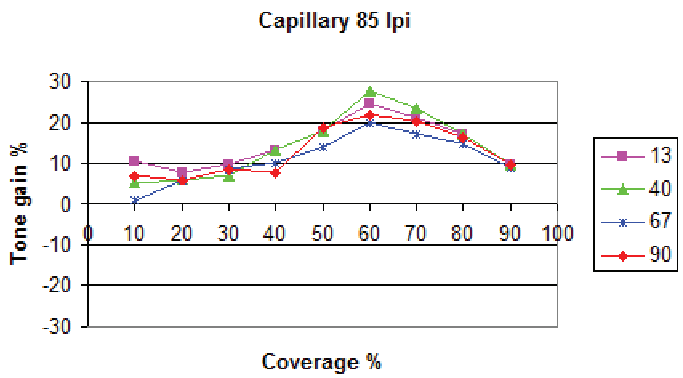




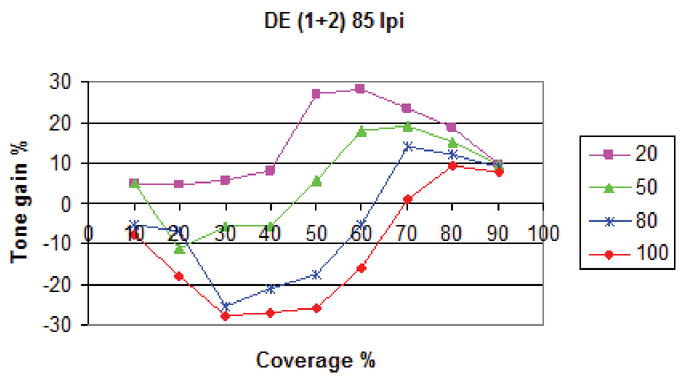
Microscope picture showing blemish in what should have been an even tone in the centre

Undercutting from a rough stencil

Some brilliant detective work by Dr Eifion Jewell showed that high Rz stencils suffer serious problems during exposure. He used sophisticated equipment to measure "tone gain" (i.e. size of exposed dot compared to expected dot size) in the dots on the stencil itself. The scattering from the high Rz stencil made dots smaller and smaller as exposure was increased. Here is a comparison between a capillary film and a typical emulsion:



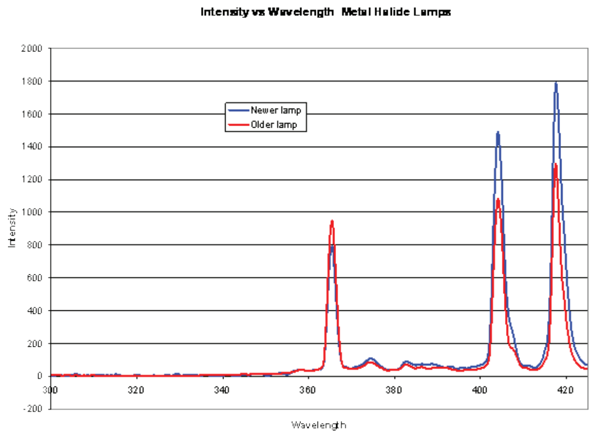
Effect of exposure time on tone gain for an 85lpi test positive in a capillary stencil. There is very little change from increased exposure times because there is very little scattering from the smooth stencil surface.



The same experiment using a 1+2 Direct Emulsion (high Rz). With increased exposure time, the scatter from the Rz caused dramatic filling-in of the dots, i.e. severe undercutting.

Comparing lamp age

As lamps get older the light integrator will ensure that the same amount of light hits the stencil so maintaining the level of cure by increasing the exposure time. As lamps get older, however, the wavelength emitted also shifts. The intensity of the longer wavelength light decreases relative to the shorter wavelength. The longer wavelength light penetrates better than shorter wavelength light. So the lamp can deteriorate enough to give poor through-cure whilst still seeming to be bright. Regular lamp changes are essential to prevent this problem.



Practical issues

Although it may seem obvious, we have to point out some practical issues which have caused many print-shop problems.

- Dirty glass increases exposure times and the scattering causes loss of resolution.
- A poor vacuum gives poor contact between film positive and stencil and therefore a loss of resolution.
- A change of mesh-count has a complicated effect on exposure time. There is no good way to calculate the various trade-offs, so if you change your mesh, you must re-optimize your exposure.

Autotype Exposure Calculator

Exposure is extremely important to the finished stencil and the most frequent cause of stencil failure. The Autotype Exposure Calculator provides quick, accurate determination of exposure times with all photostencil systems. It can also be used as a printing aid to optimise print quality, or as a means of process control.

To use the calculator for diazo and dual-cure emulsions.

1. Estimate the correct exposure time using the guidelines available for all Autotype photostencil materials then DOUBLE it.
2. Expose the photostencil to the Exposure Calculator in the normal way, washout and dry thoroughly.
3. Examine the stencil in white light and determine the correct exposure time by colour change.

The stencil will show variations in colour from one factor to the next. Follow the colour change through shades of yellow until it stops. The factor where the colour change stops is the column that represents optimum exposure.

Once the correct factor has been chosen, multiply the factor by the test exposure time. This gives the correct exposure time (or number of units) for that particular stencil/mesh/light source combination.

Example: 0.7 x 10 minutes = 7 minutes

Correct factor x test exposure = Correct Exposure

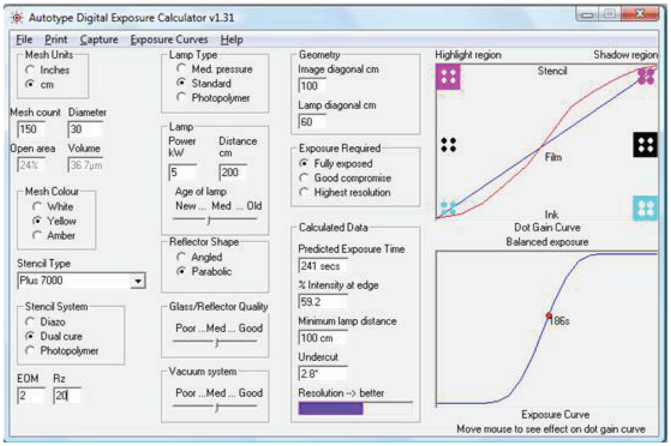
If there is still a colour change between Factor 0.7 and Factor 1, this indicates an under-exposed stencil, DOUBLE the original test exposure, and repeat the test.
The Exposure Calculator can also be used to assess printed edge definition (straightness/ clarity of the printed edge) and print resolution (fineness of detail achievable). The target is designed to allow the user to select the best angle to position the film positive stencils in order to avoid "saw tooth" and mesh interference. Resolution is checked by assessing the degree of "filling in" at the centre of the target.

As part of the Autotype Digital Screen Printer software suite, the Digital Exposure Calculator lets you explore many of the effects discussed in this chapter. Although it cannot be a precise guide, the general trends shown in the software can be helpful for thinking through exposure issues. The graphs on the right are particularly helpful in understanding what happens to the dots in the high-light and shadow regions – as you try to improve the situation for one, you tend to make things worse for the other. The screen shot shows what happens if the Rz is set to a very high value – producing a very large change in the dot-gain curve from the exposure.

Exposure tips and tricks

- Get the right distance between lamp and stencil. Too close and you have insufficient exposure at the edges and also strong undercutting.

Autotype Digital Exposure Calculator



Too far and your exposure times are unnecessarily long.

• Use a light integrator to ensure you have the same exposure each time.

• Change out old bulbs as these can give poor exposure.

• Use an exposure calculator to get the right balance between full exposure (full colour change) and resolution.

• If you have to seriously under-expose your stencil to get the right resolution then there's something wrong with your lamp (too close?), your mesh (white mesh?, too coarse?) or your stencil material (too low-tech?, too thick?, high Rz?)

• High Rz stencils give poor contact with your film positive and therefore give large variations in resolution according to UV dose. So go for low Rz stencils, without going too thick. For emulsions this can only be done via multiple wet-on-dry coats; for capillary films it comes naturally.

• Make sure your glass is clean and not scratched or hazy.

• Use a good vacuum. A loss in vacuum gives a loss in resolution.

• Re-calibrate exposures if you change your mesh.

• Work in a clean environment to minimize the chances of trapping dust between film positive and stencil.

• Do not use Perspex/Plexiglass instead of glass in the exposure unit as they absorb a large amount of UV light when compared to glass.

• Do not let the exposure glass get too hot as this can harden the stencil.

• Underexposed stencils breakdown quickly and are harder to decoat.

• Underexposure is the single biggest cause of problems in screen printing!

Solving problems in the real world

Anna Harris & David Parker

Over the years we've built up a large number of case studies of problems found in the real world. Here we share our experience of the things that have caused screen printers real problems – and the solutions we have found for those problems.

Dirt

Dirt obviously can mess up your print in many ways. Dirt on the mesh during coating can cause streaks. Dirt on film positive or on the stencil during exposure can cause pinholes. Dirt during printing gives pinholes and streaks.

The highest quality screen printers do their work in cleanrooms. It's amazing how much easier life is when you don't have to fight with dirt. If you don't have the luxury of a cleanroom then here are tips we've found make a real difference.

1.- Install a simple filter in the water supply used for your stencils and meshes – and remember to change it regularly. It costs a few cents yet can save large amounts of money in avoidable rework.

2.- Clean all surfaces and floor. Use a damp cloth or vacuum with a HEPA filtered exhaust.

3.- Close doors and use tack mats to minimise dust and dirt entering the screen printing area. Also minimise the number of people moving around in the area. People are the biggest source of dust. If adding additional enclosure take care that air movement into the area is from a clean source. For instance shutting the door will be a waste of time if the air is then going to be pulled from a dirty air space above ceiling tiles.

4.- Use lint free wipes

5.- Avoid fibrous packaging, sheets should be removed from the transit box prior to use. Card and paper should be kept away from the printing area if possible.

6.- Raise humidity (this reduces static). If you damp down the floors, take care to avoid slip hazards

7.- Wear clean room overalls

8.- Filter air conditioning. If you turn off air conditioning on days that it is not necessary, make sure that the alternative source of air is not dust laden.

9.- Use an ionising air-gun to clean your mesh. An ordinary air-gun can create static (yes, we've measured the effect) and attract dirt back onto the mesh. The ionising air gives a really clean result.

Static control

Static causes dust to be attracted to surfaces. It is produced in 3 ways

1. Separation
2. Friction
3. Induction

The simple act of removing a sheet of film from a stack, or passing a film through a rubber roller nip produces static by separation and friction.

Static is hard to eliminate once it has been produced so the best thing to do is to reduce the chances of creating it. An environment with a relative humidity greater than 50% helps. Reduce handling and rubber-roller nips to a minimum.

Then make sure you have anti-static devices at critical positions. An ionising air-gun is useful for spot work (especially for the final cleaning of a screen). An ionising air-system installed on a press keeps critical areas static free. And although "Christmas tinsel" does a reasonable job of removing static, it doesn't look too professional and is easily broken; modern anti-static bungee-cords are a better alternative.

The wrong mesh

We're astonished at how often printers choose the wrong mesh. The most common error is to use white mesh, then complain about lack of resolution. Next is an inappropriate choice of mesh-count and diameter. What is puzzling about this is that the choice should be very simple. If the print contains large blocks of open image then desired ink deposit can only come from a relatively small number of meshes – too coarse and the deposit is too large, too fine and the deposit is too thin. If the print contains lots of fine detail then the rule-of-thumb "2.5x the thread diameter is the minimum size of printable feature" gets you fairly close to the right answer. For fine-line printing there is no alternative to the finest stainless mesh you can handle. And if you are after accurate registration then a stainless or liquid-crystal mesh are your most likely choices as polyester simply does not have sufficient long-term stability.

The other aspect of mesh choice is more subtle. You must avoid mesh moiré. Fortunately, the Mesh Moiré Calculator (see the section on moiré) helps you find the right mesh-count for your 4-colour settings.

As most high-resolution screen printers are moving to stainless, there's one more tip we've learned from our most advanced customers. Get hold of blackened stainless mesh as this has a dramatic effect on improving resolution. It's currently hard to get hold of, but the more customers who demand it, the more the stainless mesh manufacturers will start to supply it.

Image too close to the frame

If you have a few mm snap-off (off-contact), the pressure from the squeegee needed to force the mesh into contact with the substrate might be modest in the middle of the mesh, but will be higher when the squeegee gets close to the edge of the frame. This comes from simple geometry.

Middle of the mesh, relatively low pressure required, medium distortion

Edge of the mesh, relatively high pressure required, large distortion

It's therefore important to make sure your image area is not too close to the frame, both in the lengthwise and crosswise direction.

What happens if you get too close to the frame? First you get large image distortion. Second, you are forced to use a larger squeegee pressure which can damage the squeegee and can also cause judder and extra dot gain (graphics) or positive saw-toothing (technical).

There is also evidence that the squeegee gets distorted near the edge and cannot do a good job of scraping off the excess ink, thereby giving a higher ink deposit in the areas near the frame.

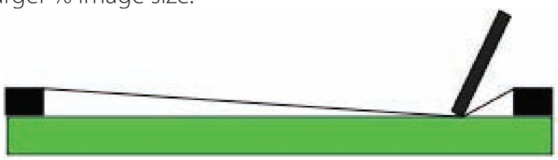
Of course, as you go to lower and lower snap-off, the problems get less and less so you can go to a larger % image size.

Poor cleaning

Failure to properly clean and reclaim a mesh gives you ghost images. For many years the effect puzzled us. Often we couldn't see any residue on the mesh, yet the ghost was still there. Where was it coming from?

The answer was that the knuckles of the mesh are where most of the ghosts hide out. Why is this important? Because the amount of ink held in the mesh, and the amount of ink remaining on the mesh when it comes out of the ink both depend strongly on the knuckles.

A small amount of ghost hiding in the corner of a knuckle is enough to change the printed ink volume. See Steve's mesh marking section for his hypothesis about mesh marking.



Lower snap-off (off contact) and relatively lower pressure/distortion

Emulsion coating

The advice about cleanliness is really important for emulsion coating. When we developed ultra-clean emulsions for the high-end electronics printers we were not able to properly test our own product till our QC department moved into a full clean-room environment. Only then could we be sure that our emulsions were as clean as they had to be – before that we could never tell if a defect was in the emulsion or from the test laboratory.

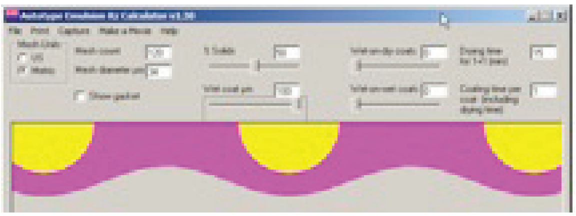
We're not going to say much about coating troughs. Our preference is for a simple, sharp-edged trough and we take good care of them because any defect in the trough ends up as a defect on the stencil.

Not everyone knows that controlling the level of emulsion in the trough is important. The amount that flows out as you coat is highly dependent on the level. A full trough gives a higher EOM. So if you don't control this level, every stencil will turn out to be different.

Everyone knows about producing 1+1 or 3+2 emulsion coatings, but we are surprised that there are still printers who don't understand why, for example, the simultaneous coating on both sides from an automatic machine must give different results from individual coatings. The reason is simple, only the individual squeegee side coating can push through enough emulsion to the print side to give a significant EOM – when you have two troughs opposite each other, they don't allow any excess on either side.

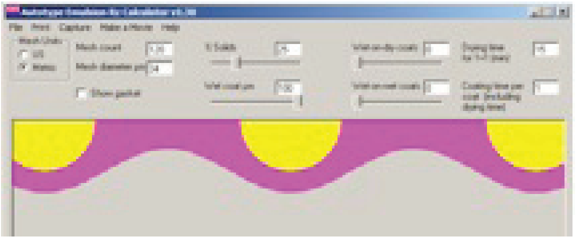
The high Rz of a simple emulsion coating gives lots of problems during printing. We often have to remind printers where the Rz comes from. You start with a uniform coating and the water evaporates. Let's suppose (for simplicity) you have a 100µm total wet coating on a mesh that is 50µm thick. And suppose it's an advanced 50% solids emulsion.

Then the 100µm of emulsion in the open areas of the mesh dries to 50µm, so is just level with the surface of the mesh. But the 50µm of emulsion sitting above 50µm of solid mesh also halves in thickness to 25µm. So above the solid mesh you have 25µm, and in the mesh holes you have 0µm. This means you have an Rz of 25µm.



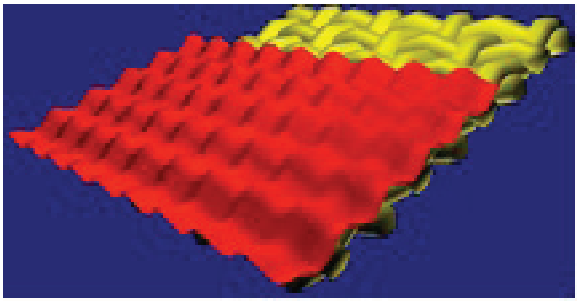
A high solid emulsion gives a medium Rz

The lower the solids, the higher the Rz. If we had a 25% solids emulsion in the example above then in the holes it would shrink to 25µm below the mesh surface and in the solid areas it would shrink to 12.5µm, giving an Rz of 37.5µm.



A low-solids emulsion gives a high Rz

Here's a 3D view of how Rz is caused by shrinkage above the holes in the mesh:



A 3D view of high Rz

The advantage of wet-on-wet coating is that it is quick and easy. The disadvantage is that it doesn't do all that much. As you put on subsequent coats you drag away plenty of the previous coats. The benefits to both Rz and EOM are modest.

Wet-on-dry coating involves much more work. Each drying stage takes up precious time. But the results speak for themselves. You can get much closer to the ideal of a low-Rz and low-EOM if you are prepared to take the time to do multiple wet-on-dry coats.

Our own experience is that by far the best way to achieve a low-Rz, low-EOM stencil is to use a capillary film especially designed to give that balance of properties. It's much faster and more reproducible than all those wet-on-dry coatings!

Drying

It's amazing how many printers don't understand that you can't dry a stencil without some warmth and some flow of air that isn't already saturated with water vapour. The theory of drying says that air flow is usually more important than mere temperature. Just think of the difference of drying your hair with a cool hair dryer (plenty of air flow but little heat) and with an electric heater (plenty of heat but little air flow). The hair dryer wins every time. And remember that overheating the stencil will cause it to fuse and give poor reclaim.

A quick tip to help with a poor drying setup is to install a de-humidifier in the system. There's a different sort of drying issue we see from time to time. If your print is being dried on a belt going through the oven, the pattern on the belt sometimes shows through on the print.

The higher thermal conductivity of the belt means that that part of the print dries faster, so ink flows from the less dried part to fill in, and the net effect is more ink corresponding to the areas in contact with the belt.

Exposure control

Everyone's in a hurry and likes to under-expose. It obviously helps with resolution too. But it's very easy for the current level of under-exposure to be regarded as being full-exposure, so someone under-exposes a bit more … till you get a soft stencil with poor edge definition and a poor print life. Drifts downwards in levels of under-exposure, coupled with the drift downwards in output from the lamps is the single biggest source of problems we've found in the whole screen-print business!

Static

We've already mentioned static in terms of dirt. It can also cause cobwebbing and dendrites (patterns like a bolt of lightning!). Good earthing of the press, preserving a moderately high relative humidity and adding an ionised air flow will all help reduce the static. In addition we've found that for prints onto smooth substrates there can be a lot of static generated when the stencil and substrate separate. A fix for this is to use a rough stencil with lower stencil/substrate contact. But generally this reduces print quality. A stencil with a high-frequency micro-roughness (such as Capillex CP and CX) gives the reduced static but without the reduction in print quality.

Thick edges

It's amazing how many printers try to use a thick stencil to get a thick print. This can work for narrow features, but then you get other problems such as negative sawtoothing described below. But in general, a thick stencil merely gives you a thick edge, simply because the stencil has no influence on the amount of ink that's printed a few mesh holes away. As we'll see in a moment "no influence" hides another problem caused by thick stencils.

This thick stencil will give negative sawtoothing

With low squeegee pressure and this very thick stencil, the ink doesn't properly reach the substrate so you get skipping or negative sawtoothing:

The ugly effect of a thick stencil and inadequate squeegee pressure

The same thick stencil…

With a high squeegee pressure the ink fills the stencil and you get a thick edge to the print:

… this time with higher squeegee pressure and now an ugly thick edge to the print

Thick edges are evil in many ways. First, they can look ugly. Second, they will cause increased slump (see below). Third, they give you non-uniform properties over the printed part. Fourth, they help mess-up anything you print on top of them as their uneven topography guarantees to give uneven printing. (We knew one printer who was so bothered by thick edges that they were ground down in a special process. Another printer filled the gaps between tracks to somehow compensate for the thick edge.) Fifth, we've even found examples where the thick edges destroy inter-layer ink adhesion!

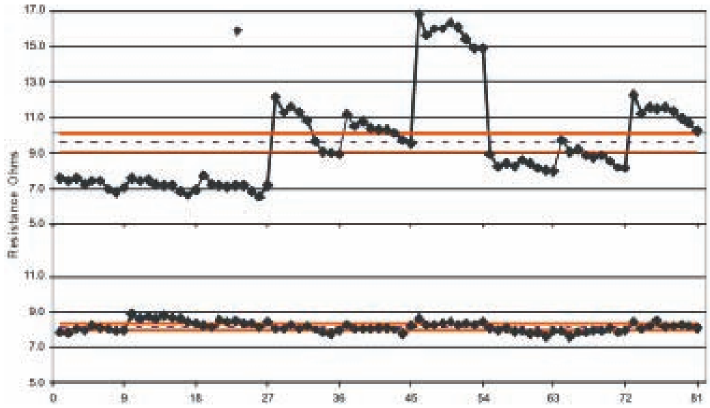
And sixth. This is a much more subtle effect. We found it during our Print Quantification Project. We were printing a silver conductive ink and saw some alarming variations in conductivity that depended both on the orientation of the printed track with respect to the squeegee (horizontal gave higher resistivity than vertical) and on the squeegee pressure/angle. At high pressures the resistivity went up.

At first we tried to explain this via the "scoop out" effect (discussed in Steve's section on theoretical ink volume) but data from a low-EOM, low-Rz stencil during the same run showed this effect to be very small. Higher resistivity for lines with generally good edge quality can only come if the ink deposit is thinner. But how could high pressure give thinner deposit? We realised that the diagram of how a thick stencil causes a thick edge needed modification.

If you have a really strong squeegee pressure (relative to mesh tension) then instead of the 3rd bit of mesh being in contact with the substrate (as in the picture above) maybe the 1st is in contact – so the thick edge extends only a small way. With really weak squeegee pressure then the mesh won't be in contact with the substrate at all, so the whole track is "thick". What constitutes high or low pressure also (for subtle reasons) depends on the orientation of the line with respect to the squeegee, so we end up with a nightmare of uncontrolled ink deposit. This is not some theoretical worry. In our experiments, over a reasonable range of squeegee pressures, angles and line orientations (captured in 81 different prints) here's how a high EOM and low EOM stencil (both low-Rz) compared:

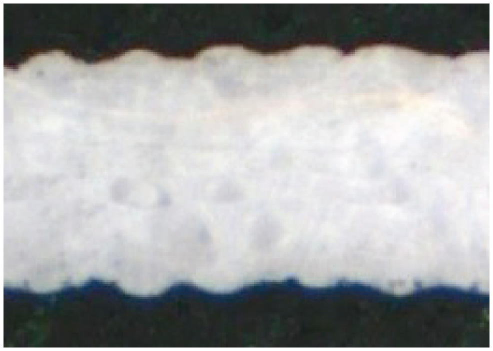
With the high-EOM stencil in the top graph, track resistances varied from ~7 to more than 15 ohms. With the low-EOM stencil, resistance was amazingly constant. See the next section for another example of why the low-EOM, low-Rz stencil also performs much better compared to its high-Rz alternative.

The high-EOM stencil (top) gives large thickness/resistivity changes with squeegee pressure/angle/orientation. The low-EOM, low-Rz stencil (below) is in better control



The rule is to use a thin (low EOM) stencil with a low roughness (Rz) to give you uniform thickness and accurate edges.

Positive sawtoothing (Technical printing)



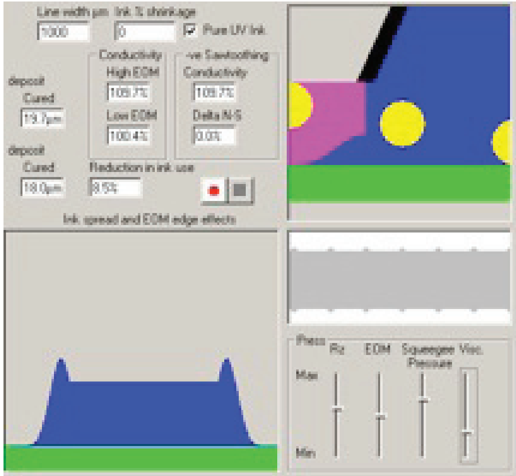
The classic result of a high Rz stencil – positive sawtoothing

This is classic sawtoothing – the ink spreads outside the line in a regular wavy pattern. We've seen it a million times and it always comes from thin stencils with a high Rz. Usually we are shocked that when we ask "What's the Rz of your stencil?" the printer doesn't know because "Our screen supplier told us it would be fine." We generally carry an Rz meter with us and we use the DSP on our laptops to explain why high Rz naturally leads to positive sawtoothing.

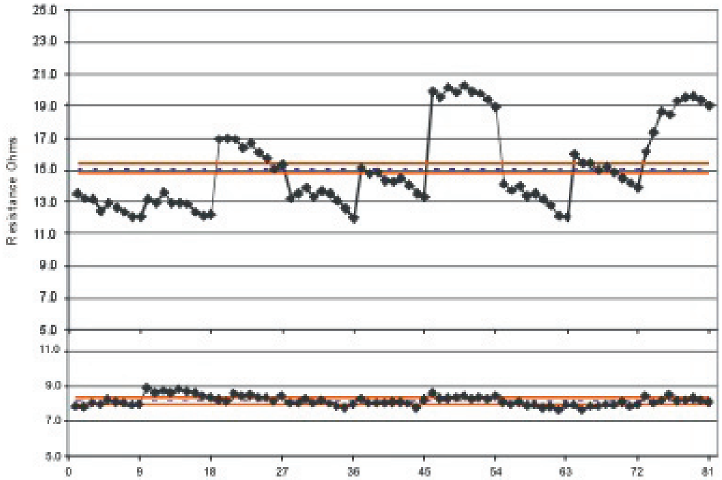
This screen-shot from the Line Edge Demonstrator from the DSP shows a high EOM and high Rz leading to positive sawtoothing, thick edges and increased line-width from slump!

A low Rz automatically gives you low positive sawtoothing.

The sawtoothing gives large variations of resistivity for a printed conducting track. We found this during our Print Quantification Project as shown in the diagram where the print from a 1+1 emulsion (low-EOM, high-Rz) is compared to a low-EOM, low-Rz capillary film. Note that superficially the variations are the same as those found for the high-EOM, low-Rz stencil discussed under Thick Edges above. In fact the root cause is totally different! Had we not carefully compared the 3 cases (low-EOM + high-Rz; high-EOM + low-Rz; low-EOM + low-Rz) we would not have been able to disentangle the different effects.



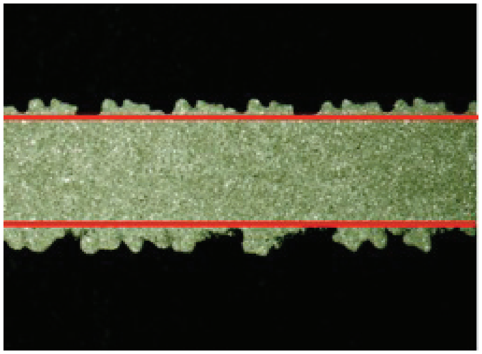
Where positive sawtoothing comes from



The high-Rz, low-EOM emulsion stencil (top) gives large variations in resistance over the 81 variants of squeegee pressure/angle/orientation compared to the low-Rz, low-EOM capillary film (below).

The reason the high-Rz gives such a large variation is subtle. There are two competing effects. A high pressure can give more total ink printed and therefore a lower resistance. But much of that extra ink is along a sawtoothed edge which gives a higher resistance because there is no continuous path. If the total volume printed is the same (compared to a perfect stencil) but more of it spreads out into the sawtoothed edges then the overall resistance is higher, which is what we measure.

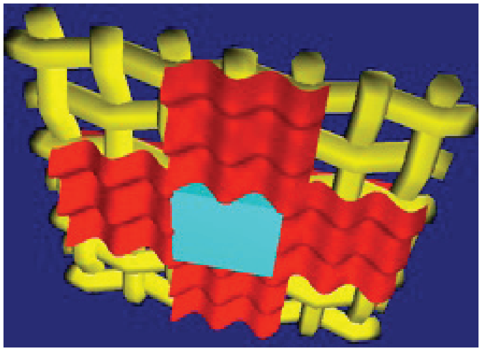
The extra width gained by the Rz spreading provides very poor conductivity so the effective conductive width is likely to be that shown between the red lines



Dot-gain (spreading) (Graphics printing)

A high Rz stencil automatically causes the ink to spread. The amount of spread is under poor control as it depends strongly on squeegee pressure and ink viscosity. To stop such dot-gain you have no choice but to go to a low-Rz stencil.

That blue ink is going to spread along the Rz channels and the amount of spread is going to depend on viscosity and squeegee pressure so is going to be out of control.

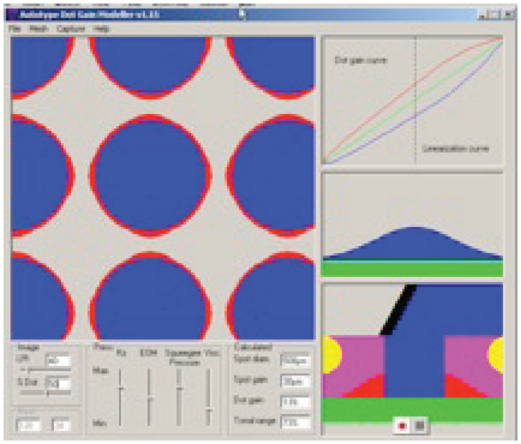


However, a typical low-Rz stencil is high EOM and a high EOM gives you a bigger ink deposit which also spreads (slumps) more to give you dot gain.

Worse even than that is that the thick dots from a high-EOM stencil give you a rough substrate when you print subsequent dots, so you get even more dot gain that is mostly out of control because the % of previous dots varies across the print.

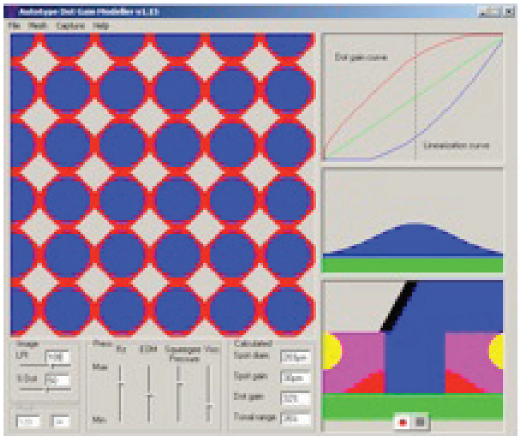
We've seen this situation time and time again. The only cure is a low-Rz, low-EOM stencil that reduces dot gain on the first print (no spreading via the Rz) and, by giving dots that aren't so high, reduces the effective roughness of the stencil for subsequent colours.

Remember that a small absolute increase in dot size will give you a small dot-gain on a low lpi image and a large dot-gain on a high lpi image. This is shown in the Dot Gain Modeller from the DSP:



A modest Rz gives a modest absolute spot gain and modest 13% dot gain…

Because of the high Rz we have dot gain (shown in red). This happens to be 30µm of absolute dot gain, giving a 13% dot gain for a 50% dot.

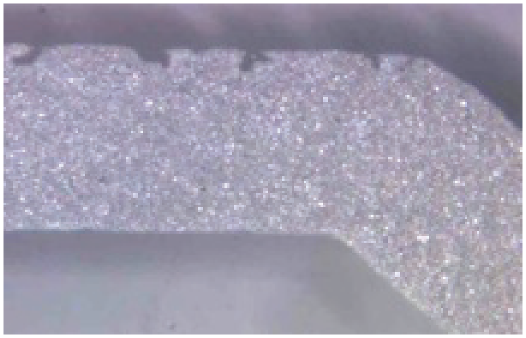


… but for a high lpi print the same spot gain gives disastrous dot gain

At 100lpi we have exactly the same absolute dot gain (30µm) but because the spot is only 203µm compared to 508µm there is 32% dot gain for a 50% dot.

This is the key reason why printers have so much trouble when they go to higher lpi in response to demands from their customers. If they keep their same high Rz stencils, their dot gain becomes enormous.

Negative sawtoothing (Technical printing)

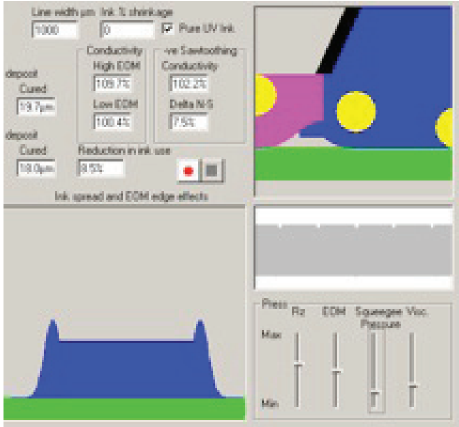


Negative sawtoothing visible only on the leading edge of horizontal lines

This is the opposite effect to positive sawtoothing. The printed line has chunks eaten out of it. And mysteriously (to the printer) the negative sawtoothing only takes place on the leading edge of the line.

The cause is a high EOM stencil. The squeegee cannot get enough ink into the stencil at this point, and if the ink doesn't touch the substrate then it doesn't get printed, so you get the chunk eaten out of your printed line.

Very often we ask "What's the EOM of your stencil?" and the printer doesn't know " Because our screen supplier told us it would be fine". We generally carry an EOM meter around with us, and on our laptop we have the Line Edge Demonstrator software that explains why the high EOM leads to the negative sawtoothing.



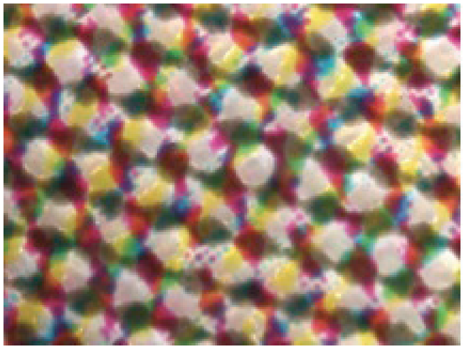
The root cause of negative sawtoothing

The image is exactly the same setup as for the one shown in positive sawtoothing, but the squeegee pressure has been reduced so the ink cannot reach the substrate right next to the stencil edge.

The cure is simple – go to a low EOM stencil. But if the low EOM stencil is also high Rz (which is usually the case) you swap one defect for another. You have to have both low EOM and low Rz for a great print.

Skipping (Graphics printing)

A high EOM makes it hard to get the ink through to the substrate and you print only a little "puppy paw" in the middle of the dot.

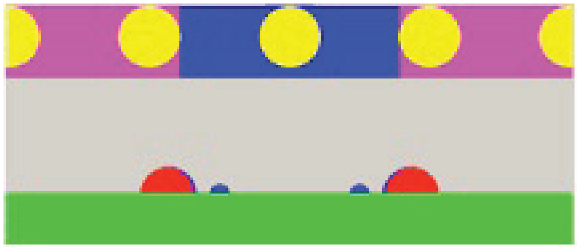


Skipping – the graphics equivalent to negative sawtoothing

This is basic skipping. Generally you have to be completely out of control to get this in a single colour. The real problem comes when you print the 2nd or 3rd colour in the set. Now your stencil is often sitting on top of a big dot and the ink has even further to travel before it can reach the substrate – so again it only prints a "puppy paw" in the middle of the dot. This is classic skipping. As so often is the case, the Screen Print Animator shows what's going on:

The large previous dot makes skipping inevitable at this squeegee pressure

The squeegee pressure isn't high enough to force the ink down the extra distance caused by the previous dots. So when the stencil rises, it only leaves little dots where the ink touched the surface of the substrate.



It's skipped!

Because the skipping fades in and out depending on where your new dot is with respect to previous dots, the skipping isn't uniform. To the uneducated eye it can look like moiré and the printer then wastes a lot of time trying to fix the non-existent moiré! In fact, after classic mesh moiré, skipping is the single largest source of "moiré" that we've seen. It's entirely unnecessary and can easily be cured. The most obvious cure is to increase the squeegee pressure, but then you get lots more spreading and lose quality and resolution.

A higher squeegee pressure add lots more ink . . .

Now the ink fully fills the extra space caused by the dots, but look how much more ink is deposited compared to the places where the stencil is in perfect contact with the substrate!

… so you get massive dot gain, "spreading"

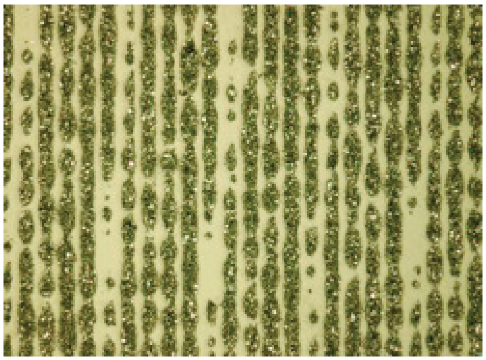
So the only root-cause cure is to ensure that your previously printed dots are as small as possible. To do this you must either use low-solids solvent-based (or water-based) inks or use a very thin stencil which gives the minimum deposit. However, a thin stencil often has a high Rz so you get lots of dot-gain. You can only fix skipping and avoid spreading by using a specialist low-EOM, low-Rz stencil, either as a film such as Capillex CP/CX or as a multi-coat wet-on-dry emulsion process.

Colour shifts (Graphics printing)

Everything we know about colour shifts is best described in Tricia's colour-shift section of this eBook.

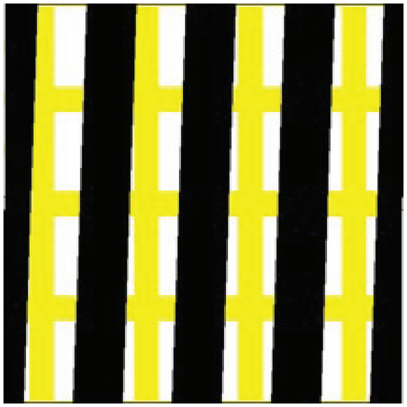
On-off sawtoothing (Technical printing)

We see this problem more and more as printers push to finer lines. At finer lines you really can't afford to have a high Rz or a high EOM so printers generally have good stencils when they see this problem. What's so puzzling is that some of the edges are nice and straight and others are very sawtoothed. Closer examination shows that the quality fades in and out along the line. Here's an extreme example of a silver ink being printed with too coarse a mesh for the 50μm line/spacing:



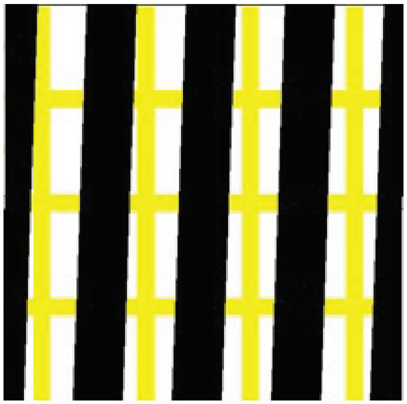
An extreme case of on-off sawtoothing

The explanation is simple. The printer has pushed the boundaries of the ink and the stencil but has failed to push the boundaries of the mesh. You can't print fine lines with a coarse mesh! The on-off sawtoothing comes about when the edge of the line starts getting trapped between a mesh fibre and the edge of the stencil.
Here's an idealised image of an inappropriate mesh (a 120/20 mesh trying to print 40µm lines/spaces)



Trying to print with too large a mesh diameter

The mesh simply gets in the way and stops ink flowing properly to the substrate. Higher squeegee pressure can help a little, but fundamentally there's only one thing you can do, which is go to the finest stainless mesh you can find. Here's a simulation using a 120/13 mesh:



Thinner mesh gives a much higher probability of success

Stencil X gives better dots than Stencil Y

Over the years we've learned to be careful not to rush to judgement when someone shows us prints where Stencil X is better than Stencil Y. The key reason for caution is that printers rarely have the chance to carry out properly controlled scientific comparisons. For example, one time we were given prints where Stencil X was very much better than Stencil Y. We were asked to explain why Y was so much worse. The golden rule is to get out the digital microscope we carry with us and compare images of the prints on our laptops. With the digital images it is very easy to use the MacDermid Autotype ImageAnalyzer software (you are welcome to a free copy) to measure the distance between dots. In this example we were able to show that the dot-to-dot differences were completely different. In other words X was printed at one lpi and Y was printed at a very different lpi. Although the printer thought he was comparing two different stencils, he'd actually been comparing two different lpis!

Poor quality lines

For years we've had similar problems with judging the relative qualities of printed lines. Someone would show us that Stencil X gave smooth lines and Stencil Y gave rough lines. Of course, many times this is for genuine reason (e.g. Y had a high Rz) but sometimes we couldn't make sense of the differences. That all changed when we started using our ImageAnalyzer software with our digital microscopes. It then became easy to measure two different aspects of the lines.

The first aspect was how wide they were compared to what they were supposed to be. That's when we discovered that many "good" lines were only "good" because they were twice the width of the film positive and almost twice the width of the rougher "bad" line. Anyone can print a big, fat smooth line, but if the customer wants a thin line, then fat is not good enough.

The second aspect was how rough the line was compared to the original. There is an objective measure of roughness which ImageAnalyzer can calculate.

We could then calculate the overall acuity (fidelity to the original) of the printed line using the Acuity Index (AI). A perfect line has, by definition, an AI of 100, with a perfect 50 points for being the correct width (not too wide, not too narrow) and a perfect 50 points for being smooth. If a line was perfectly smooth (50points) but twice the width (~10points) it would score an AI of ~60. A line that was somewhat rough (40 points) but close to the right width (40points) would score a total of 80 for being a better balance of right and wrong. And, of course, a line that was very rough (~10 points) but the pefect width (50 points) would have the same AI (60) as the smooth/wide print but would equally be inferior to the middle example.

We've found the AI has been of great benefit to us, our customers and their customers. We no longer have fruitless debates based on visual impressions of microscope images, but hard numbers we can all agree on. Our work on AI was particularly useful in confirming that a low-EOM, low-Rz stencil was by far the best for printing lines. Not only was the AI high, it was almost independent of press settings and angle of the line with respect to the squeegee. High-EOM or high-Rz stencils showed worse and highly variable AIs.

Moiré

We come across this all the time. Our digital microscopes help us diagnose the problems by following the ideas described in the Moiré section of this eBook. All we can say here from our experience in the field is that the techniques described in the moiré section really work!

Printing very fine lines

As many printers are struggling with the challenge of going down to 50µm and lower it's worth summarizing here our recipe for success. Well, not quite. It's a recipe for giving you the best chance of success. What's important is that those who don't follow this recipe are guaranteed failure. We are very happy to offer this advice, and very sad that each time it has been ignored failure is inevitable. We learned all the mistakes the hard way when we first embarked on our "50µm project" adventure. That's how we became so confident in the recipe.

• Use the finest stainless mesh possible. We've loved using 16µm and have heard of lucky printers who have access to 13µm.

• Use blackened stainless to ensure optimum print exposure without losing resolution from scattering. It's hard to get hold of, but worth it.

• Use a specialist low-Rz, low-EOM stencil – either Capillex CX or a multi-coat wet-on-dry emulsion (if you have the time and patience).

• Use a clean-room environment.

• Find a reliable source of beautifully sharpened medium-to-hard sharp-profile squeegees.

• Set up your press with minimum snap-off (off-contact), minimum squeegee pressure (you've got a delicate mesh and an exquisite squeegee!).

• Insist that your ink supplier gives you a high-low-high, rapid recovery ink – as close as possible to the printing behaviour of the cermet inks that are routinely used in ceramic-based electronic printing. (See Steve's ink design optional theory section for an explanation).

• Control slump through (a) the rapid-recovery ink, (b) a controlled (relatively high) static contact angle of the ink with the substrate and (c) as rapid a "cure" (UV, solvent evaporation, solvent absorption) as possible. If you can control/understand the beach effect you are in even better shape. (Again, see Steve's ink section).

• When you can't reduce the slump any further, reduce the width of the line in the film positive by the amount of the slump.

Moiré, causes and cures

Steven Abbott

In 2003 we published a handbook explaining the causes and cures for moiré. The original print run was very modest, but it soon proved so popular that we had to print and send out many more copies. It has been translated into a number of languages and has hopefully helped many printers solve their moiré problems.

The original version of the handbook came with a personal guarantee. Since then we've been challenged many times with moiré samples and each time the diagnostic techniques in the handbook have proven capable of correctly determining the root cause. So the guarantee remains:

"I have strong opinions backed up by lots of good data. I am happy when I'm shown to be right, but even happier when I'm shown to be wrong – because from error comes greater understanding. As with all my screen publications, I am happy to offer a public admission of error in the light of good data, and will upgrade the Handbook accordingly. If you are the one to correct me, I will be happy to acknowledge your input."

We've found that we didn't have to make many changes to what follows, so if you have a copy of the original handbook, you don't have to read this part of the eBook.

Over the years the Mesh Moiré Calculator has proven particularly effective at solving the most frequent source of moiré. At one time it was used to solve a problem at a printer's in India whilst I was in America. The software comes with a video-recording capability and the video explaining why he got moiré with a particular mesh/angle combination was sent to the printer who was able to understand the cause and cure in record time.

Introduction

Moiré drives us all mad. Screen printing without moiré would be a much easier way of earning a living. There is no way to eliminate moiré from our lives, but at least we can reduce it to an acceptable level.

This section of the eBook has only one aim – to allow the practical screenprinter to get control over moiré and make more money. The first part gives you proven recipes for success. The second part (for those who like such things) explains why these recipes work.

The recipes have been thoroughly tested in the real world and checked against a huge number of moiréd prints. They are backed up by a sophisticated computer model which examines moiré at a fundamental level.

A lot of bright people have helped produce the ideas in this article. A prime source of inspiration is Mark Coudray's influential article from ScreenPrinting 1991. From MacDermid Autotype, Joe Raymond and Bill Appleton and David Parker have been exceedingly helpful in all sorts of ways. Finally, Mike Ware of Wasatch Inc. is to be warmly thanked for his insights into moiré coming from his expertise in the field of RIPs.

Terminology can be tricky in screen printing, so remember to refer to the glossary to help make it clear what I mean by the various terms.

The majority of the readers of this eBook work in lpi and dpi so the examples are defined in those terms. The conversions into metric equivalents (lpc, dpc) are rounded for convenience.

Angora goats

Not a lot of people know that the word moiré comes from Angora goats! Here's an explanation from the 1911 Encyclopaedia: "MOHAIR, the hair of a variety of goat originally inhabiting the regions of Asiatic Turkey of which Angora is the centre, whence the animal is known as the Angora goat.

The Arabic *mukhayyar* or *muhayyar* ر-ي-خم from which the word came into English probably through the Ital. *moccacaro* or Fr. *inocayart*, meant literally, 'choice' or 'select', and was applied to cloth made of goats' hair. In the 17th century the word, which before appears in such forms as *mocayare* or *mokaire*, became corrupted to the English "mohair" from which the French adapted moiré, a watered silk fabric."

It then became the general word for the effect we are all familiar with when we see railings on bridges, shimmering clothes on TV presenters and ugly patterns in our screen prints. There was, alas, never a Professor Moiré who discovered the maths of the effect.

Moiré maths

You don't need to know any maths to understand this section. But moiré is a mathematical phenomenon and can only be analysed properly using some powerful mathematical techniques.

The results have all been produced from powerful computer models. The good news is that there is an exact match between the outputs of the models and the facts of real life.

One of the models, the Moiré Mesh Calculator is part of the MacDermid Autotype DSP which can be downloaded from this eBooks' website.

Where does moiré come from?

The human eye has evolved to be sensitive to patterns. It's rather important to know that a set of stripes is heading in your direction if you want to avoid being eaten by a tiger. Moiré is seen when two regular patterns combine to form a third pattern. A typical example is seen when you pass beneath a bridge. To your eyes, the railings at the front of the bridge are at a slightly different spacing from those at the back and you get a pattern such as:

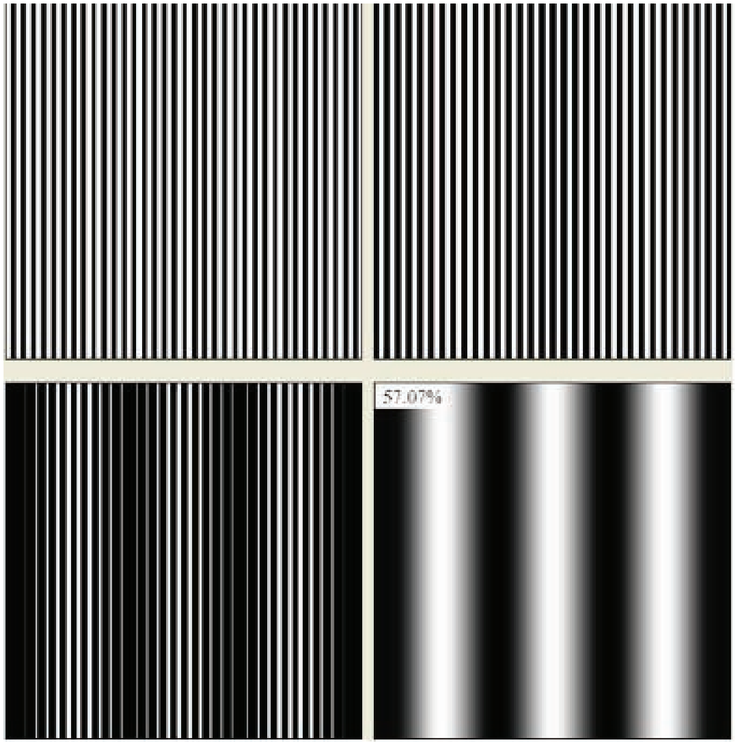


Figure i. Moiré when two similar line patterns are overlayed.

The top two squares are the same pattern of vertical lines, the one on the right is spaced slightly further apart. When you combine the two as in the bottom left, sometimes the lines are on top of each other, making the line the same as the original, and sometimes the line of one falls in the spacing of the other, making the whole thing much darker. The image in the bottom right is the calculated moiré, showing a good match between theory and the human eye. If I show you the combined image in colour, you see where the problem comes from.

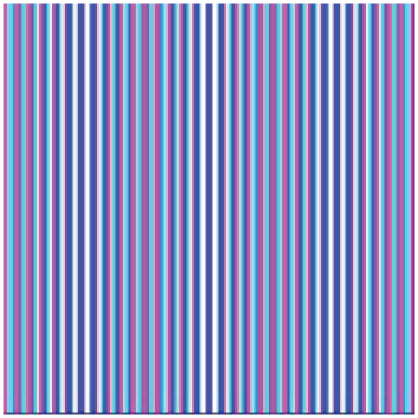
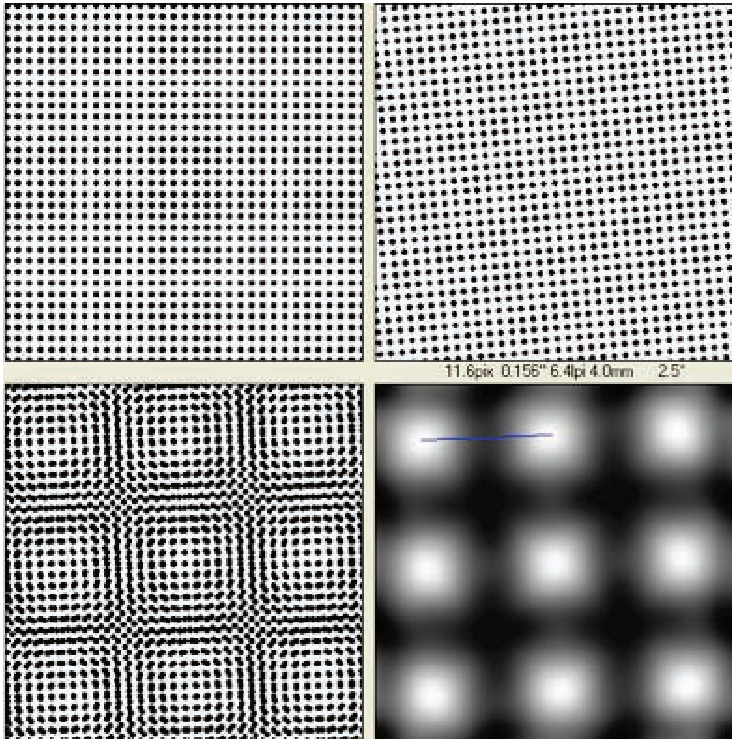


Figure ii. The overlayed pattern from Figure i, but shown in colour.

Figure iii. Moiré when the same two patterns are overlayed at different angles, in this case 5°.

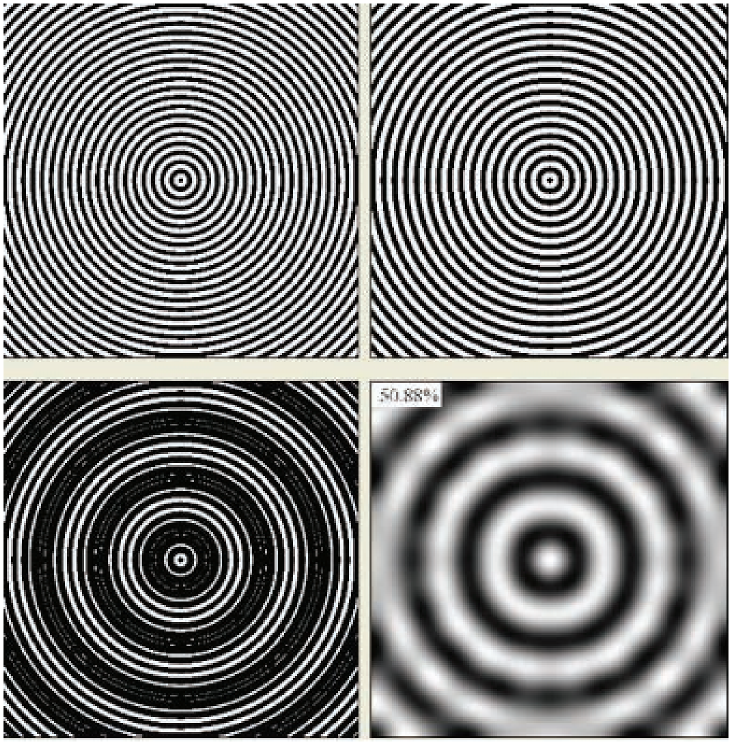


The two originals are Cyan and Magenta. You see Blue lines where they fall on top of each other and stripes of C & M where they fall in between each other. If the moiré comes from the railings of a bridge as you drive underneath you see a moving moiré because the front and rear railings shift in relative position. The moiré pattern stays the same, but the dark and light areas move along in sequence.

To get a moiré you need regular patterns which differ in some way. For the railings example the difference was in the spacing. In the next example the difference is in the angle:

The spots of the top left are combined with the spots of the top right into the resultant pattern bottom left. The moiré calculated by the computer model is shown bottom right and closely matches the observed pattern, with a regular repeated pattern of 6.4 lpi (2.5 lpc) and an angle of 2.5° produced by combining a 0° and 5° screen.
You can get moirés from just about any regular patterns. Here's what happens when you mix circles of different spacing:

Fig iv. Moiré from two circular patterns of slightly different spacing.



These gross moirés are fun to play with, but they aren't the things that cause us so much pain in our screen printing. What we are faced with is much more subtle. But the basic cause of our subtle moiré problems is the same – regular, but different, patterns on top of each other, and the human eye evolved to pick out any regularities in the result.

Causes and cures of moiré – recipes for success

Note. These recipes assume that you have checked that you are not printing onto a regularly corrugated surface, and that you've checked that there's no moiré in your film positives.

1 Mesh moiré

Symptoms

We all know that the regular pattern of the mesh may clash with the regular pattern of the print and give us moiré. We all know that a coarse mesh and high lpi have a high chance of giving a very strong moiré. So we choose fine meshes for our high lpi prints. Yet still we get moiré. Sometimes the moiré occurs only in particular tints. Sometimes it's wavy. Sometimes it occurs only on one colour, sometimes on more than one. It comes and goes.

Cause

The Moiré Mesh Calculator (MMC) quickly shows you that when you are at a reasonably high ratio of mesh count to halftone ruling (e.g. using a 150 tpc mesh with a 39 lpi halftone [380 tpi / 100 lpi] so you have a ratio of 3.8:1), you are very likely to find that at three of your screen angles you get no visible moiré. But at a fourth angle you might be unlucky. For some of these unlucky angles, small changes in the mesh (tension, angle) make no big difference, for others, the maths shows that small changes can give big differences and you get wavy moiré. Finally, the maths shows that certain dot shapes and sizes will make the unlucky moiré more or less visible. In short, the maths of the MMC explains all the mysteries we see when we have mesh moiré.

Identification

Mesh moiré appears when you print a single colour on a flat substrate. It will generally fade in and out at different densities of tint. If you use a thin, low Rz (flat) stencil the moiré is reduced significantly and thinning the ink reduces it further. If you have a thick stencil or a high Rz stencil then there's not much you can do to change things.

Cross-check

Make sure the moiré isn't in the film positive for this particular colour!

Cure

Ideal. Use the MMC to find a mesh/lpi combination that gives no moiré.
Example: 63 lpi print with a 355 mesh. No mesh moiré for the standard 7.5°, 22.5°, 37.5°, 67.5° set.

Good. If just one colour is bad, keep the original mesh count for the other three colours and find a nearby mesh count for which the MMC predicts no moiré.
Example: 63 lpi print with a 305 mesh. No mesh moiré except for the 37.5°. Change this to a 355 mesh and all is fine.
OK. Print your least noticeable colour (usually yellow) at the angle which gives the mesh moiré.

OK. Use the smallest possible thread diameter to reduce the visibility of the moiré. Example: Going from a 34µm thread to a 27µm thread can make a big difference.

OK. If the MMC says you have strong moiré with a set of film positives at 0°,15°,30°,60°, change them to 7.5°,22.5°,37.5°,67.5° - or vice versa. But beware of the simple moiré between your 0° colour and the mesh. Problem solved/reduced.

OK. If the mesh moiré is seen as lines rather than dots, make your printed dot-shape rounder. This will make the lines weaker and hopefully the dots won't be so visible.

OK. If the mesh moiré is seen as lines rather than dots the other possibility is that the squeegee is amplifying the problem in the direction of the squeegee stroke. Reduce squeegee pressure and/or stencil Rz.

OK. Switch to MacDermid Autotype's Capillex CP or CX, the ultra-low EOM, low, controlled Rz. This reduces the intensity of the moiré. This is not just Marketing hype. It really helps at the fundamental level.

OK. If you have a low Rz stencil, use a thinner ink.

OK. If you have a high Rz stencil, try to reduce the Rz without going too thick with the stencil, then use a thinner ink.

OK. Hope that the presence of the other 3 colours will mask the moiré.

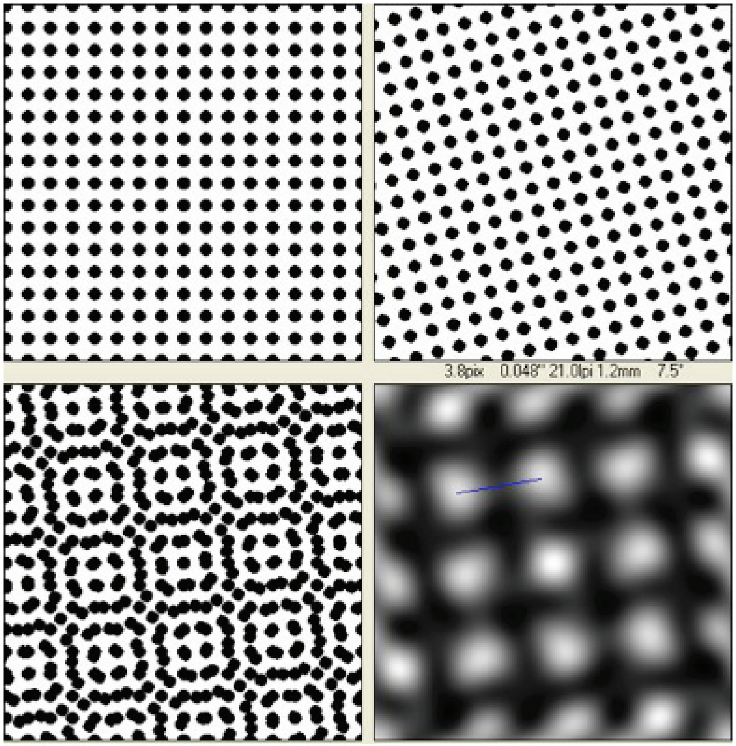
OK. If you really, really can't change any of the above, and if you have an ugly wavy moiré, then get your screen stretched properly. You'll have a moiré, but it won't be quite so ugly.

Myths

There's a myth that if only you had a 'perfect' mesh then moiré would go away. This is false. Imperfections in the mesh may make some moirés more visible by making them wavy, but if the mesh were perfect, the moiré would still be there. Don't bother looking for the perfect mesh to fix your moiré. Just use the MMC to find a mesh that doesn't clash with your lpi/angle combination. Small imperfections in the mesh won't alter the fact that it doesn't clash, so you'll get no moiré.

2 15° moiré

It's an unfortunate fact of life that in any screen set we have to have one of the colours at 15° to the others. This is guaranteed to give a moiré as the computer simulation shows:



It's characterised by a pattern that's at an angle of 7.5° (i.e. halfway) with a repeat every 3.8 dots. *You will see the 15° moiré very clearly in your film positives when you superimpose them. This is completely normal. You see the moiré because (a) in black and white the contrast is very high so the eye can see the pattern very clearly and (b) you are usually looking very closely at your positives. If you step back to a more normal viewing distance, the moiré will seem less awful.*

You'll have to read the long explanation later on to understand why you often don't see it. But here's the recipe for keeping it as invisible as possible.

Symptoms

Only seen when you print the 15° colour.

Cause

The clash between dots at 15° to each other.

Identification

If you don't have a 4-colour print, then it's not 15° moiré (though if you are printing a duotone, make sure the separations are at 30°) With a loupe or microscope look at the moiré area of your print. If you see regular repeats every 3.8 (i.e., roughly 4) dots, then it's 15° moiré. Sometimes you see it as a pattern of dots, sometimes as lines. Its intensity will vary across the print.

Cure

Ideal. Replace the 15° component with a different frequency (dangerous unless you know what you are doing) or, as some modern RIPs do, replace it with some sort of stochastic equivalent.

OK. Reduce its visibility by switching the 15° component to a less visible colour (usually yellow).

OK. Reduce its visibility by printing the 15° component last. With luck it will find a more random surface because of the variety of dots underneath and the moiré won't be so intense.

OK. If the moiré is seen as lines rather than dots, make your printed dot-shape rounder. This will make the lines weaker and hopefully the dots won't be so visible.

OK. If the moiré is seen as lines rather than dots the other possibility is that the squeegee is amplifying the problem in the direction of the squeegee stroke. Reduce squeegee pressure and/or use a low-EOM, low, controlled Rz film. This reduces the intensity of the moiré. This is not just Marketing hype. It really helps at the fundamental level.

OK. If you have a low Rz stencil, use a thinner ink.

OK. If you have a high Rz stencil, try to reduce the Rz without going too thick with the stencil, then use a thinner ink.

3 Moiré look-alikes

Anything which looks like an unwanted regular pattern in parts of a print gets labelled as moiré. But there are plenty of 'moirés' that aren't. But you still need to solve them, so here they are.

3a. Skipping

Symptoms

An unpleasant 'dotty' area, usually in darker regions of the print. Often found when you back off squeegee pressure to avoid flooding in darker areas.

Cause

Insufficient squeegee pressure (or, equivalently, ink too thick) when printing one dot on top of another region of dots. Skipping has been discussed at length in Anna and David's section of this eBook.

Identification

Under a loupe or microscope you see that the halftone dots are broken up into several smaller dots or the dots are much smaller than expected. These small dots are generally found in the valleys between previously printed dots.

Cure

Good. For a given ink, there is only one way to reduce skipping without increasing spreading (or flooding). You most switch to a low EOM, low Rz stencil. As this is very difficult and expensive to attain with an emulsion, you need to switch to MacDermid Autotype's Capillex CP or CX which are designed specifically to reduce skipping and spreading.

Good. Switch to solvent or water-based UV, both of which give you a lower build which automatically reduces skipping and spreading.

3b. Spreading transfer

Symptoms

Tricky! It looks like a normal moiré, but it comes and goes from print to print. Very hard to pin down unless you know what you are looking for.

Cause

When you get spreading (excess ink going underneath the stencil because you are printing on top of previous dots), your stencil is going to 'print' that excess ink on to the next print. If you have perfect registration between prints, this will not cause a problem. But minor changes in registration mean that you get extra dots where you don't want them and they appear as a moiré.

Identification

Look at the regular pattern of your real dots. If you have extra dots in between them then this is spreading transfer. It seems odd to look for dots that shouldn't be there, but once you get into the mindset, you find it very easy to track down this type of pseudo-moiré.

Cure

Good. For a given ink, there is only one way to reduce spreading without increasing skipping. You most switch to a low EOM, low Rz stencil. As this is very difficult and expensive to attain with an emulsion, you need to switch to MacDermid Autotype's Capillex CP or CX which were designed specifically to reduce skipping and spreading.

Good. Switch to solvent or water-based UV, both of which give you a lower build which automatically reduces skipping and spreading.

3c. PostScript banding

Symptoms

Bands in regular tonal gradients (vignettes)

Cause

If you ask for a high lpi screen from a low dpi imagesetter, the basic PostScript can only deliver a limited number of different grey levels. So instead of a smooth vignette you see distinct bands.

Identification

Found in PostScript vignettes.

Cure

Ideal. Use a higher dpi imagesetter that gives you more grey levels

Ideal. Use a smarter RIP that knows how to get more effective grey levels from a given lpi/dpi combination.

Good. Reduce your lpi (hoping that your customer won't notice).

3d. Mesh patterning in solids

Hopefully it doesn't need me to say that this is not a moiré. But it can certainly look ugly. Mesh patterning in solids is discussed in the optional theory section. The obvious things to try are a thinner thread diameter and a lower viscosity ink, though neither is guaranteed to work. If you use a lower viscosity ink you will need a lower Rz stencil. And as you always need low EOM for high quality printing, once again you need to use Capillex CP which combines low EOM with low Rz.

Myths

The term 'topographic moiré' is often used. But there's no such thing. Moiré is the interference of regular patterns and the moiré will be there whether those patterns are topographic or perfectly flat. However, as we've noted above, surfaces with rough topographies may show a more visible moiré than their smoother counterparts, assuming that there is an underlying moiré pattern in the first place. If you want to talk about topographic effects, talk about 'topographically amplified moiré'.

The closest thing to 'topographic moiré' is the spreading pseudo-moiré discussed above.

4 Unstable rosettes

Symptoms

Your 4-colour prints look very unhappy, but you can't put your finger on why.

Cause

Your registration between colours is rather poor, so what should be nice classical rosettes are ugly, unhappy ones. Moiré maths show that it takes very little to go from a nice rosette to an unstable one.

Identification

Under the loupe, your rosettes are highly variable.

Cure

Ideal. Better registration.

Ideal. Find a RIP with an option for 'stable rosettes' that are mathematically more resistant to mis-registration but which, in my opinion, do not look so good in the first place.
Good. Any of the things above that reduce the visibility of a moiré, in particular, print thinner, high quality dots using a low EOM, low Rz film.

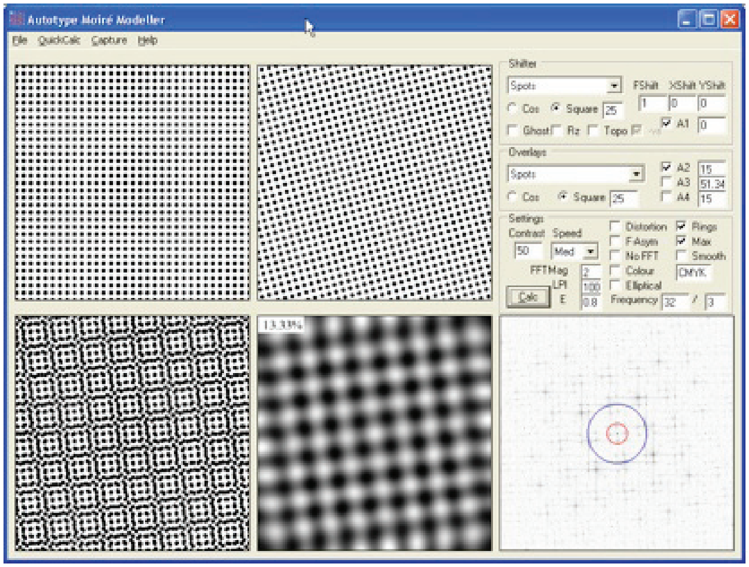
Summary

The only tricky thing you need is the MacDermid Autotype Moiré Mesh Calculator to make sure you have the right screen sets. After that, get yourself a decent stencil system with low EOM and low Rz. You get an extra benefit from this. You can use much lower squeegee pressures, lower viscosity inks and lower snap-off (off-contact). This means you are much gentler to your mesh. So you can go to a finer mesh diameter which reduces the intensity of any mesh moiré and gives you a larger dynamic print range. It is rather surprising that this virtuous cycle exists; but that's what the maths says, that's what we've found in real life, and I'm confident that you will find it too. This is the real recipe for success.

The science of moiré – the reasons for the recipes

Moiré science

It's only since the publication in 2000 of *The Theory of Moiré Phenomenon* by Isaac Amidror that it's become possible to fully understand and model what's going on. The maths of the MacDermid Autotype Moiré Mesh Calculator and the Fourier Transforms used in MacDermid Autotype's own Moiré Modeller are all inspired by Amidror's beautiful book. The screen shot from the Modeller gives some idea of the complexity of the problem. The bottom right-hand section, for example is the Fourier Transform of the combined image on the bottom left. The bottom-middle image is the filtered inverse Fourier Transform that accurately models the perceived moiré.



Moiré characteristics

There are three things that characterise any moiré: its **frequency**, **angle**, and **amplitude** (or intensity). A lot of the confusion about moiré comes from not understanding the relative importance of these characteristics. There is a fourth component which is often forgotten, and that is the **human eye**. It is the human eye that dictates the relative importance of the three moiré characteristics.

1 - Frequency

We are all used to specifying frequencies in screen printing. When we talk about an 80 lpi (32tpc) halftone we are describing its frequency. Sometimes when we talk about moirés we say that they repeat every 0.5" (1.3cm). This half inch is the period and is the inverse of the frequency. So the frequency of a 0.5" moiré is 1/0.5=2 lpi (1/1.3=0.8 lpc)

This talk about frequencies is very important. It's very easy to do theoretical calculations and prove that you have a moiré with a frequency of, say, 40 lpi (16tpc). You then have to ask whether this frequency would show up in the print. In one way, the answer must always be 'yes' it will show up. Try hard and you will be able to find it. But as printers we are only interested in one question: *will the customer see it?* In principle, the customer might try hard to find it. But let's assume that the customer has some intelligence. The customer wants the print to look good for its purpose. So examining a large poster with a high-powered microscope is not relevant. On the other hand, viewing a printed DVD from too far way is also not relevant.

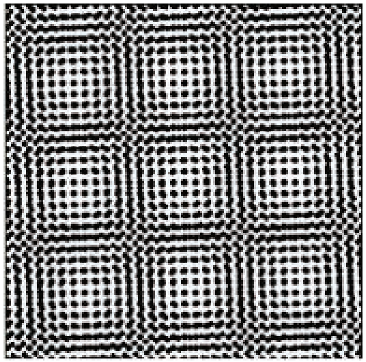
It turns out that there is a useful rule of thumb – the MRN Rule of 4. Divide the frequency of your print by the frequency of your moiré. This is your Moiré Ratio Number (MRN). In this case, Big is Bad. A high MRN means a high visibility moiré. If the MRN is less than 4 then you're probably OK. So for your 80 lpi (32tpc) print, a moiré of more than 20 lpi (8tpc) will not be a problem. I recently had a startling reminder of the validity of this rule. I was shown some truly ugly prints with a really vicious moiré. I was amazed that any customer had paid for these prints. But they were prints with a very low lpi (32 lpi, 12tpc), designed for viewing from a reasonable distance. Sure enough, when you put them at their viewing distance, not only did the moiré disappear, but the prints looked stunningly good. Whoever had designed them had a great artistic sense, and the faith to ignore the strong moiré visible at close distances. The particular moiré had a frequency of 8.4 lpi (3.3tpc) so its MRN was 32/8.4=3.8, just below the Rule of 4 limit, and great for the viewing distance of a 32 lpi image. An 8.4 lpi moiré on an 80 lpi print (MRN=9.5) would be a catastrophe!

Why does the rule apply? Surely a moiré is a moiré? But remember the fourth factor – the human eye. It only has so much resolution and below that resolution it can't pick out any detail. Your customer will have specified an lpi that's significantly higher than the resolution of their customers' eyes at the normal viewing distance, hence there is a reasonable margin of resolution to protect against moiré.

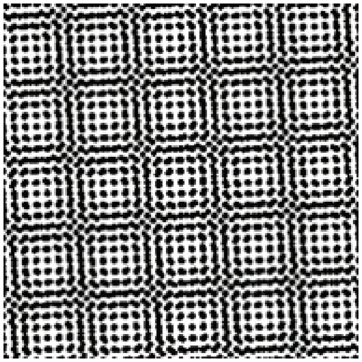
The following series of images gives you an idea of the phenomenon. Each image has a strong moiré, but the frequency is increasing.

It's debatable where the cutoff is between ugly moiré and pleasant half-tone pattern, but 4 is a good approximation.

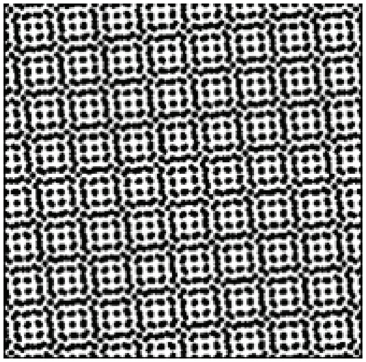
Note that the example with a MRN=2 is the pattern between two colours at 30°.



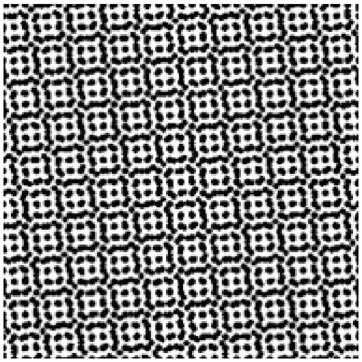
MRN=10



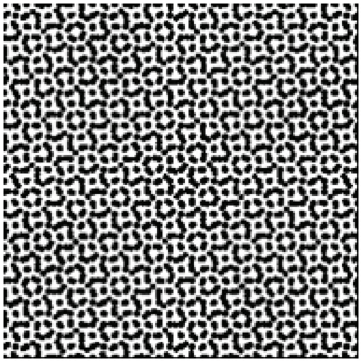
MRN=6



MRN=4



MRN=3



MRN=2

This Rule of 4 has some important exceptions which I'll discuss later.

2 - Angle

The angle of a moiré has some small effect on the visibility of the moiré. The human eye is more sensitive to vertical and horizontal moirés. But in general, the angle is a useful ally for the printer. It offers a clue as to which parts of the system are producing the moiré. As a simple rule, the angle of the moiré is 90° + the angle between the two patterns. So a screen at 15° and one at 30° will have a moiré at 90+22.5°=112.5°. If you have a simple dot screen then you will also see a moiré at right angles to this (i.e. 22.5°) but if you have an elliptical dot, one of the angles will be stronger than the other. If you use a geometric screen then your moiré will be a line rather than a grid.

Using this simple rule, you can often pinpoint which things are interacting. For example, a 3.7° (or 93.7°) moiré is a symptom of a mesh (0°) clashing with your 7.5° colour.

3 - Amplitude

We'll soon be discussing one type of moiré that's always with us, but which we seldom see. Its frequency is close to our Rule of 4 cutoff so it's a marginal call whether we see it or not. If you look closely at any print (or if you overlay the original film positives) you'll be able to pick it out. Yet most of the time it's not a problem. However, this same moiré can sometimes leap out and hit you in the face. Why? Because some other effects are increasing the amplitude of the moiré.

The word amplitude is the scientifically correct word for discussing these optical effects, but it also provides a familiar analogy with sound. A quiet sound has a low amplitude, a loud sound has a high amplitude. A low amplitude optical effect is hardly visible (subtle changes in tint), a high amplitude optical effect (black and white stripes) is highly visible. In general we hear loud sounds but don't hear quiet sounds. Yet if everything else is very quiet, then a quiet sound can appear loud ("You could hear a pin drop"). So a moiré of low amplitude is generally not visible; but if it's in an area (e.g. a light, even tint) of low general amplitude (i.e. absence of strong image contrasts) then it can become visible. Similarly a reasonably loud sound gets drowned in a noisy room, so a reasonably high amplitude moiré can disappear in 'busy' areas of a print.

If there were a simple way of predicting amplitude, we'd have resolved all moiré issues a long time ago. But it turns out that you need a sophisticated theoretical model to calculate the amplitude of most practical moirés and that's not something you'd have next to your press! The MacDermid Autotype Moiré Modeller provides helpful insights (and the images) for this Chapter. One thing that emerges from such a model is that moirés with higher frequency tend to have a lower amplitude. This helps justify the Rule of 4 rule (high frequency means low MRN). At this frequency the moiré is likely to be of lower amplitude than one with an MRN of 8. So although you might think that something at the Rule of 4 frequency should be visible at a reasonable viewing distance, if the amplitude is low you won't spot it.

This amplitude effect is what makes moiré such a will-o-the-wisp. You might print a moiré-free job yesterday with a careful set of press parameters, then get a horrible moiré today with the same set. This is because the amplitude of some marginal moiré happens to have increased to above the visibility limit. I'll give you some helpful insights into this effect so you can go some way to bringing it under control.

4 - The human eye

Even with the sophisticated model I can't predict some moiré effects. The model says that they should be insignificant, but there they are staring me in the face. It turns out that the majority of these prediction failures are due to the fact that the eye is incredibly sensitive to patches of white within a dark area. Even a tiny change in the number or size of little white areas within (say) rosettes, is sufficient to produce a visible moiré. At this point, even the most devout theoretician has to admit that the human eye is smarter than a sophisticated computer model.

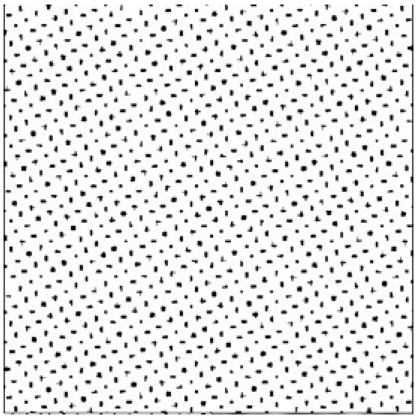
The causes of moiré

That's enough generalities. Let's get stuck in to the real issues. I'm now convinced that there are only three types of moiré that cause us real problems in screen printing. In theory, there are many more causes. By narrowing the field down to three, it gets much easier to come up with ways of making things better and we can stop chasing alternative causes that are usually not important. The other types of 'moiré' that cause us problems aren't moiré at all. I'll discuss them later because you need cures for these pseudo-moirés as much as for the real ones.

In the good old days there was a reliable fourth source of moiré – your film positives could arrive with all sorts of scanning and imaging artefacts. I'm assuming that you have a reputable supplier who has these sources under control. If you haven't, then you are making life far too hard for yourself - and there are plenty of good sources of good positives that will solve your problems for you.

Figure 2 A typical mesh blocking between a 380 mesh and a 150 lpi screen at 20% dot at 30° to the mesh. Although this is a calculated image, it looks very close to the real thing.

1 - Mesh moiré



It's been obvious to us all that the pattern of the mesh interferes with the pattern of the print, so is guaranteed to give us moiré.

The mesh causes three types of interference.

First, as shown in Figure 2, the mesh can block fine details of some dots making them smaller than they should be. This effect is well-known and the moiré from it can be quite distinctive.

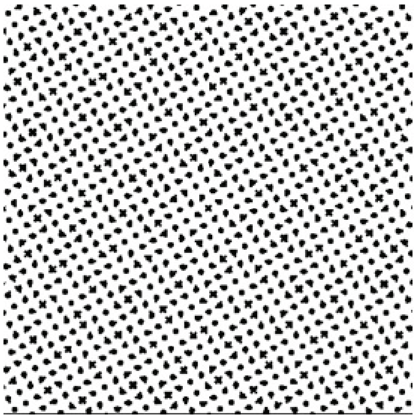


Figure 3 The same mesh and screen as Figure 2 but this time a high Rz stencil leads to the classic starry dot created by leaks through the poor gasket.

Second, as shown in Figure 3, we can get precisely the opposite! If you have a high Rz stencil you will get the classic leaking of the ink where the Rz causes a poor gasket. As the Rz comes mostly from the mesh, this leakage must follow the pattern of the mesh, so you can get a strong interaction that makes dots bigger than they should be.

Third, there's 'negative sawtoothing'. This effect is often seen as a rough leading edge of straight lines when a printer uses a thick ink and a thick stencil. The same combination means that dots get off to a bad start when they coincide with the mesh.

For the discussions that follow it doesn't really matter which type you have (you might even have a mixture). The fact that you have a strong interaction between mesh and stencil means that you might have a moiré. The question we all want to know is whether you will see it in your print.

We can quickly agree with some well-known rules of thumb.
Everyone agrees that the smaller the mesh diameter the better. If you can change from a 34 mesh to a 31 mesh, you will reduce the visibility of any moiré.

And everyone agrees that in general, as Mark Coudray correctly pointed out, the higher the ratio of mesh count to lpi, the weaker (in general) the moiré. With modern pressures to go to high lpi prints it's getting more and more difficult to find a mesh with a sufficiently high ratio, but in general it's worth the trouble.

It's often said that if the mesh and the image are in an exact integer ratio (i.e. the mesh frequency is exactly divisible by the image, such as 150/50=3) then you are likely to get strong moiré. This, unfortunately, is a half-truth. Given that most of us use angles such as 7.5°, 22.5° etc. the real ratio between mesh and image is no longer a simple calculation (you need trigonometry!) so you can get perfectly reasonable results from an integer ratio, as an example below will show.

But even if you follow such rules, you can still find yourself in big trouble. Not only can the resulting moiré be ugly, but it can also be ugly and wavy – making it doubly unacceptable to you and your customer. And sometimes it affects just one colour, sometimes more. And sometimes it affects one tint but not another. It can be very frustrating.
There are two sets of explanations for all these problems. The first are mathematical. The second are physical. Let's get the maths out of the way first.

Simple formulae for calculating moiré are useless when it comes to finding out moiré between very different patterns. The standard formula 'proves' that you can have no moiré between a 305 mesh and a 63 lpi image (120/25), yet do a print and there it is. The MacDermid Autotype Mesh Moiré Calculator carries out the very complex maths required for the more sophisticated formula and a typical screen shot is shown in Figure 4.
The columns for Moiré K values and Visibility, the choice of dot shape and K Max are for advanced users and are explained in the Help file for the MMC.

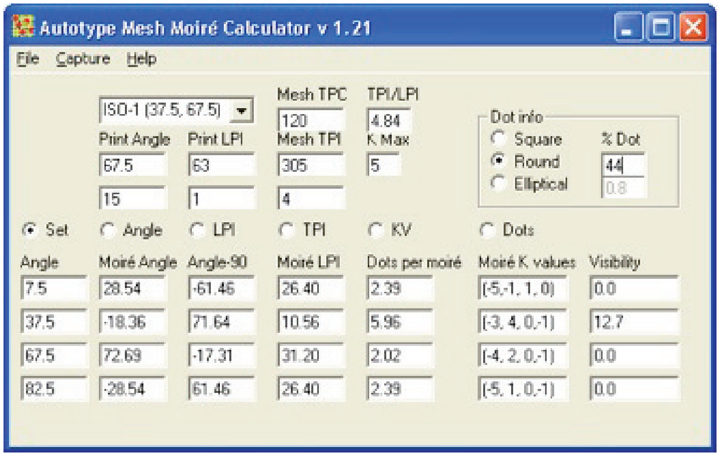


Figure 4 Calculating the mesh moiré possibilities for a 63 lpi print with a 305 mesh (25/120)

There's a lot going on, but just look at the column marked Moiré LPI. For most angles the LPI of the moiré is rather high and you won't be able to see it. But at 37.5° you have a moiré that is low frequency, giving a high MRN=63/10.56=5.96 (look in the Dots per moiré column), and at the other angles there is only high frequency moiré with MRNs all below 4.

Now let's look more closely at that 37.5° moiré and see what happens when, as shown in the TPI column (the left-hand column), the TPI (the actual mesh count, not the manufacturer's theoretical number) of the mesh changes a little bit (e.g. because of tension variations over the mesh).

Figure 5 shows that the lpi and angle of the moiré changes by modest amounts. In this case, then, you will get a non-wavy moiré.

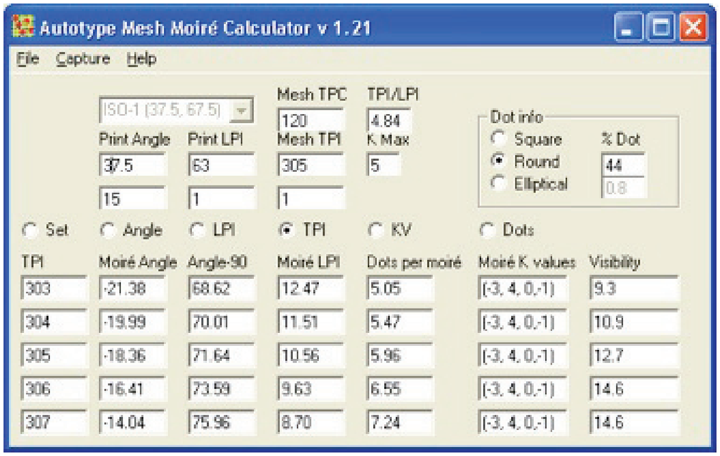


Figure 5 The moiré does not change all that much (e.g. the angle changes from –21.38 to –14.04°) when the thread count changes by a modest amount.

Now let's look at what would happen if you printed at 71 lpi with a 355 mesh (28/140). Figure 6 shows that small changes in the mesh count will give huge changes in the moiré angle. This will look very ugly indeed.

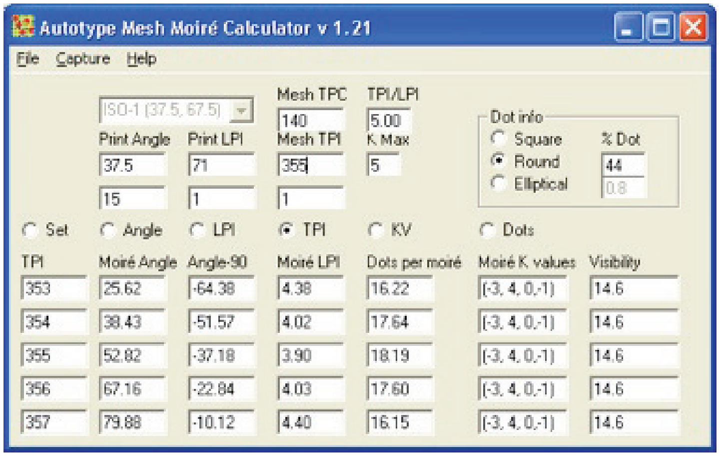


Figure 6 The moiré now changes by a large amount (e.g. the angle changes from 25.62 to 79.88°!) for the same small change in mesh count.

Incidentally, note that the ratio of TPI/LPI (355/71) is exactly 5, yet the modeller shows that at the other angles there is no significant moiré – so an integer ratio is not what's important.

There has in the past been much puzzling about how accurate the mesh needs to be to avoid mesh moiré. We now see where the confusion has arisen. Exactly the same process can give huge differences in sensitivity to the mesh. When you add on the other factors (thread diameter, ink colour, Rz/EOM of the stencil, type of ink) no wonder the situation has seemed so unclear.

By using such a moiré calculator it's possible to have a good idea which, if any, colours are going to give you problems. What are you going to do about it?

Sticking with the maths, there's one simple thing you can do (and many printers are already doing it). If (as in the case above) you have a bad moiré just for one colour, use this mesh/lpi combination for the other three colours and change your mesh for this colour.

A quick test on the modeller shows that a change to a 380 (150) mesh solves the problem for the 37.5° colour (but don't change them all over as the 67.5° colour now has a strong moiré).

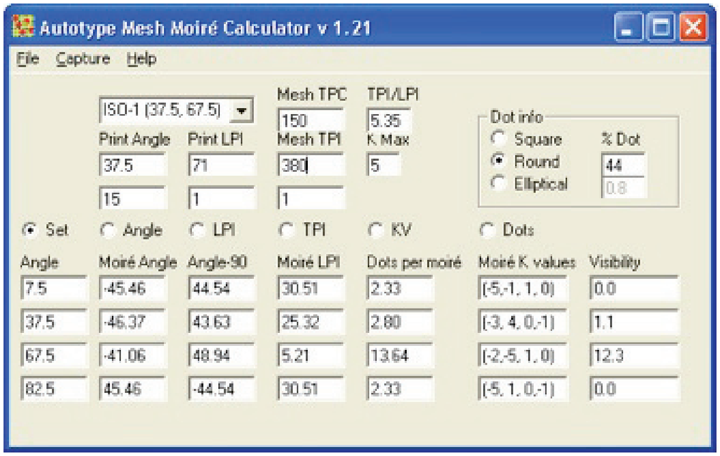


Figure 6a. A change to a 380 (150) mesh lets you print the 37.5° with no problem, but the 67.5° would be a disaster.

If you don't want to fight the maths then you have to work with the physics.

The maths only says if you might get a moiré. The visibility of it partly depends on what you do about it. If you use a thin thread, if you have a low Rz and low EOM stencil, if you use a relatively free-flowing ink, if you print the yellow at the worst angle for moiré then you will probably get away with it. You might see the moiré on the single coloured print, but it might disappear with the other three colours. Oh, and of course don't use a twill weave which effectively reduces the frequency of the mesh by a factor of two and almost certainly will land you in big trouble.

The list above is uncontroversial (or should be!) except, perhaps, for the low EOM. The reason for that (especially when you have thread eclipsure) needs to be discussed.

The usual diagram explaining thread eclipsure and therefore this aspect of mesh moiré is rather misleading. If you took it literally, then you'd always get horrible mesh effects. The old adage that 'ink is dumb' so it can't flow through a mesh fibre is true but misleading. In reality, as long as the ink can wet the substrate beneath an obstruction such as a fibre, it will have a chance to print. Otherwise a print of plain mesh would be impossible! Figure 7 helps make this clear. In open areas it is easy to flow around the thread so you get no eclipsure. As holes get smaller, and the thread gets closer to the edge of the hole, it gets harder to flow. You can improve the chances of flowing by increasing the squeegee pressure or decreasing ink viscosity (these will reduce mesh moiré) but this usually comes at the cost of higher dot gain. You can also improve the chances of flowing by decreasing the stencil EOM. If you do this with a simple 1+1 emulsion you'll reduce the mesh moiré in one way, but give yourself horrible Rz problems, including the Rz-induced moiré. Only if you use a low EOM film with a low controlled Rz can you benefit from this approach, in which case you can also use a lower viscosity ink without fear of excess dot gain. However, if you reduce the EOM to 0 then the thread will be in perfect contact with the substrate and no ink will be able to print in the area between the thread and the stencil. Increasing the EOM to, say, 2µm, lets a small amount of ink through to the edge of the stencil and the standard ink transfer mechanism (discussed in the 1-2-3 of this eBook) ensures that you get a reasonable amount of ink printed in this area.

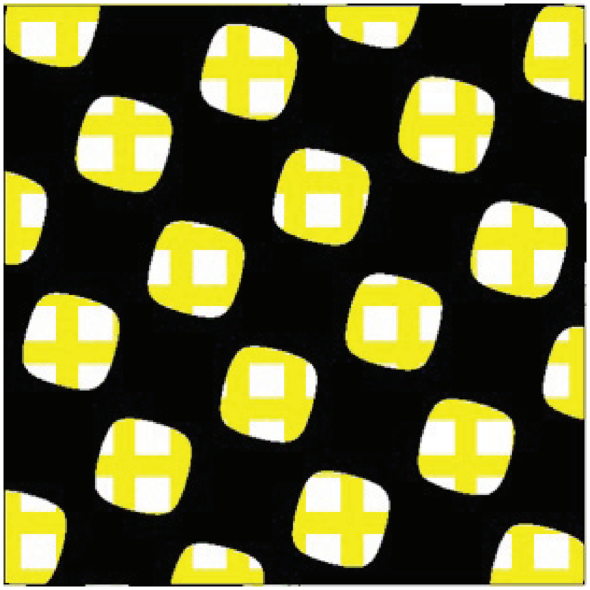


Figure 7. You might think that the threads in the middle of the hole in the stencil will block the flow of ink, giving very serious thread eclipsure. But given adequate squeegee pressure, a low viscosity ink and a thin stencil, ink can flow around the thread and print a full dot. When the thread is at the edge of a hole, it would block half the thread diameter, unless you have the right stencil/ink combination. This is the same 2.54 mesh to stencil ratio as used in calculating the mesh moiré in Figure 2.

So, surprisingly, we've suddenly found that you can greatly reduce mesh moiré effects by changing to the right stencil system. Careful printing and examination of moiré from real-world print jobs has confirmed all these effects.

Note that twice in this discussion we've emphasised the amplitude effect in thinking about moiré. First, the size of the eclipsure relative to the size of the dot affects the moiré amplitude. Second, high Rz amplifies the effects of the mesh and amplifies the moiré. There's a third amplification factor. The amount of ink that squeezes along the Rz channels depends strongly on your squeegee pressure. If you increase the squeegee pressure (or thin the ink) then you increase the moiré. But if you have negative sawtoothing, increasing the squeegee pressure (or thinning the ink) will reduce the sawtoothing and reduce the moiré.

Now you can start to see why mesh moiré can be so confusing. It partly depends on pure maths (angles, dots sizes, thread diameters). But it partly depends on subtle interactions on the press if you are using a high Rz and/or high EOM stencil. By going to a low Rz, low EOM stencil, you get much closer to the 'pure' case and the moiré is much more under your control.

So, if you want to reduce mesh moiré you must go to a low EOM, low Rz stencil system on the finest mesh with the thinnest mesh diameter. A lower viscosity ink also helps, but only if you have a low Rz to avoid high dot gain. If you know in advance which angles will give the worst moiré, you can choose to print that with the yellow. The closer you get to this ideal, the happier you will be. Guaranteed!

2 - 15° moiré

In perfect world we would only need three colours for tri-chromatic printing, but we don't live in such a world and in creating our 4-colour prints we have to make a compromise. Having three of our colours 30° apart at 0°, 30° and 60° (or 7.5, 37.5, 67.5 in order to reduce mesh moiré) gives us a beautiful rosette with no moiré. Yet we can't go to 90° because that's the same as 0° and any small change in press parameters will lead to a horrible moiré. So we have to put the fourth colour in at a 15° separation. Very often this works splendidly. But all too often it gives us pain. The insights above can start to help us understand why 15° moiré comes and goes.

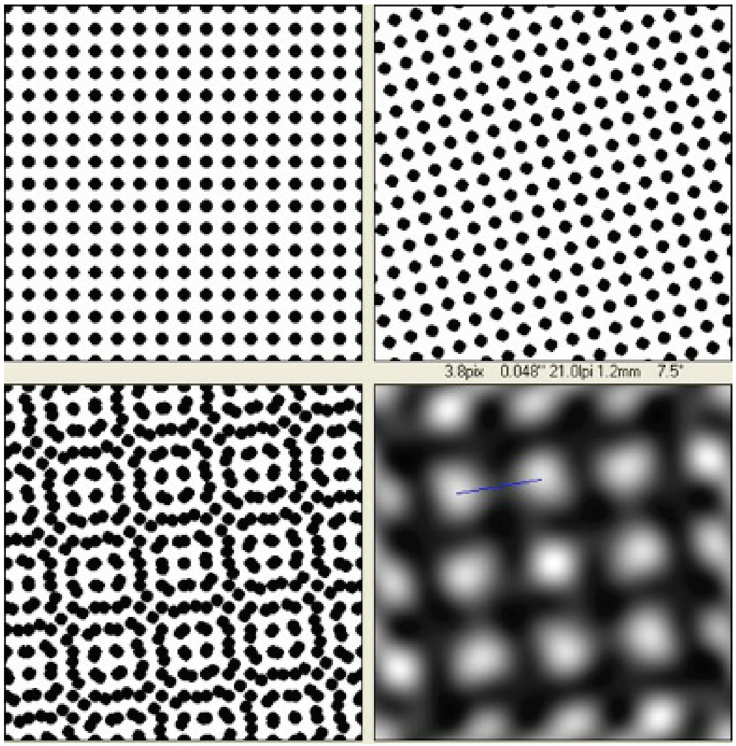


Figure 8 The 15° moiré. Note the characteristic 3.8 pixel repeat and the 7.5° angle.

If you do the calculations, you find that 15° moiré comes in at close to the Rule of 4 frequency limit (the MRN=3.8 in this case). It's an obvious moiré when you look at it closely, but when you go to a normal viewing distance it disappears. That's why we can usually live with it (and, incidentally, the justification for the Rule of 4). Yet there are times that it seems to stand out from the print and look positively ugly. Why?

The answer, as hinted above, is to do with amplitude. Anything which increases the amplitude of the 15° moiré can bring it out so it becomes unacceptable.

Let me explain. Suppose that every other dot in the 15° moiré became a little bigger because of interactions between printed dots. If you calculate the moiré from that, you don't see anything very different. It's still a 15° moiré. But the amplitude of that moiré must be bigger – you are superimposing an extra effect. Or suppose that every 3rd interacting dot got a little smaller. Again you'll have the same 15° moiré but its amplitude is bigger. This makes intuitive sense and is confirmed by theoretical calculations. The important thing is that these extra effects don't introduce a new type of moiré, they just make the current one more visible. This is a fundamental law of moiré and every time I've forgotten it, I've landed myself in big trouble!

Elsewhere in this eBook Anna and David discuss 'skipping' and 'spreading'. These describe dot-on-dot printing effects. In the first, the presence of a previous dot can cause the new dot to 'skip', i.e. to print a tiny fragment of a dot. In the second, the previous dot causes the new dot to print bigger than it would have been, i.e. you get dot-on-dot gain. In any 4 colour print you are guaranteed to get skipping or spreading (in some prints I've seen both!). All you can do is try to minimize the effects. As skipping is usually very ugly, most of us end up with the extra dot gain from spreading.

Now you can see how 15° moiré can become amplified. Each time a second dot happens to be on top of a first dot, the size of the second dot will change from what it would have been. The *frequency* and *angle* of moiré do not change, but the *amplitude* does.

There's a quick method for identifying 15° moiré. Count how often a dot goes in and out of phase with another dot in your moiré pattern. If it's around once every 3.8 times then you have 15° moiré. This is close to once every 4 dots, i.e. close to the Rule of 4 limit, which is why it's usually acceptable. You can also measure its angle. It should be half way between whichever components are separated by 15° (or, more precisely, 90° to the half angle). I've seen a very distinctive 15° moiré as a set of clear lines within print using "geometric" Postscript dots. It was easy to relate the angle to the angles of the geometric screens used in this case. But I was puzzled to see lines (rather than a grid) in a conventional set that was printed on the same sheet. How could dots give a lined moiré? They should give a grid pattern. Close examination showed that the dots were elliptical. This provided sufficient asymmetry to bring out the moiré in one particular direction. In both cases, the moiré was amplified by skipping.

Other aspects of the 3D nature of screen printing can introduce asymmetries that can also amplify the moiré. Once again it is these subtleties that can make moiré such a frustrating will-o'-the-wisp.

In my opinion, backed up by looking at countless moirés on a wide variety of prints, 15° moiré becomes a significant problem only when you have skipping or spreading. So the only way to reduce it is to reduce skipping or spreading. And, as we've shown in recent articles, the only effective way to reduce them (other than using expensive planarising layers) is to print a smaller dot. And the only ways to print a smaller dot are:

1.- use solvent-based inks or water-based UV

2.- use a thinner mesh

3.- go to a low EOM stencil with a low Rz, which means in turn that you have to go to a modern film stencil material.

Note that 2 and 3 above also help reduce mesh moiré. Thinner mesh and a better stencil reduce two types of moiré. It's nice that the laws of physics are on our side.

Recognition of this dot-on-dot effect is, of course, not new. Coudray pointed it out in his article. The crucial new point is that the mechanism behind it is better understood as is the understanding of the only way (smaller dots) to reduce it.

Is that really the only way? At the systematic level, yes. But if you are willing to play various games you might reduce it via other means. First, you can swap around the 15° colour in the hope that in your particular print it won't be too visible – the human eye is less sensitive to some colours than to others. Second, you can try printing the 15° colour as the 4th colour on top of the previous rosettes. With luck those rosettes will have sufficiently planarised the substrate that the dot-on-dot effects will be minimised. Good luck if you try these. And sometimes this is the only thing you can do. But what we're trying to do in this industry is stop the constant messing around from job to job. So do whatever you can to print smaller dots in the first place and the amplification of the 15° moiré will be reduced at a fundamental level.

There's one other factor that can affect the visibility of the 15° moiré. If you use a round dot then the amplitude of the moiré is equal in two directions. If you use a highly elliptical, rhomboid (diamond) or geometrical halftone then, as mentioned above, the amplitude is concentrated in one direction and you see a line rather than a grid pattern. By concentrating the amplitude of the effect in a single direction, the moiré becomes more visible (the computer model confirms this). So if you choose an asymmetric dot shape (to avoid the tone-jump problems with symmetric dots) it's a good idea to use the minimum asymmetry that will solve your tone-jump problems.

Out of interest I show a moiré that seemed to be hard to explain. The printer was so fed up with 15° moiré that he decided to print CMK at 72 lpi and Y at 55 lpi. This indeed removed the 15° moiré. But it introduced an even uglier, low frequency moiré. It was a pleasant confirmation of the power of the computer model that the calculated moiré exactly matched what was seen in the print.

Finally, some advanced RIP suppliers offer a choice of a 15° with a certain degree of stochastic content. As you go higher in stochastic content the moiré disappears, but to some eyes the print starts to look uglier. With a good RIP you can get the balance right, just bringing down the visibility of the moiré without destroying that comforting halftone look in your print.

3 – Unstable Rosette Moiré

Our beloved rosettes are a form of high frequency moiré. Because they are high frequency, we don't really notice them, indeed we instinctively have a nice warm feeling about a nice rosette. But there's an ugly side to the rosette. In general, it is an unstable configuration. I'd have to go into some hairy maths to describe all this, but

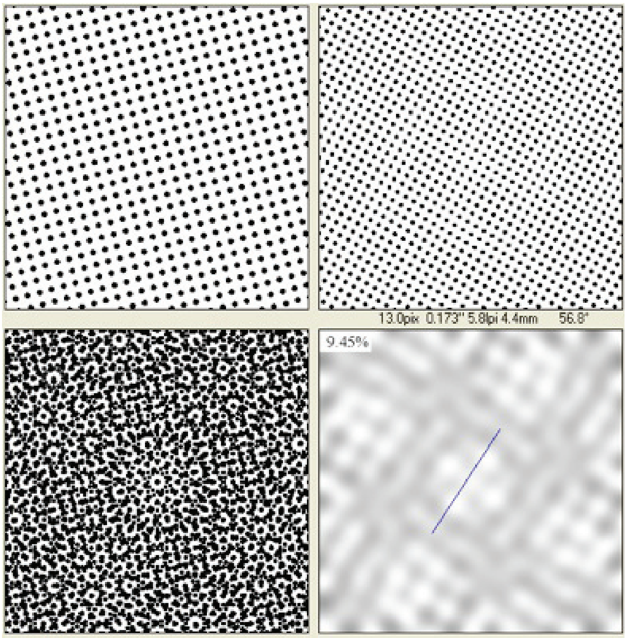


Figure 9. A moiré as a result of trying to be too clever.

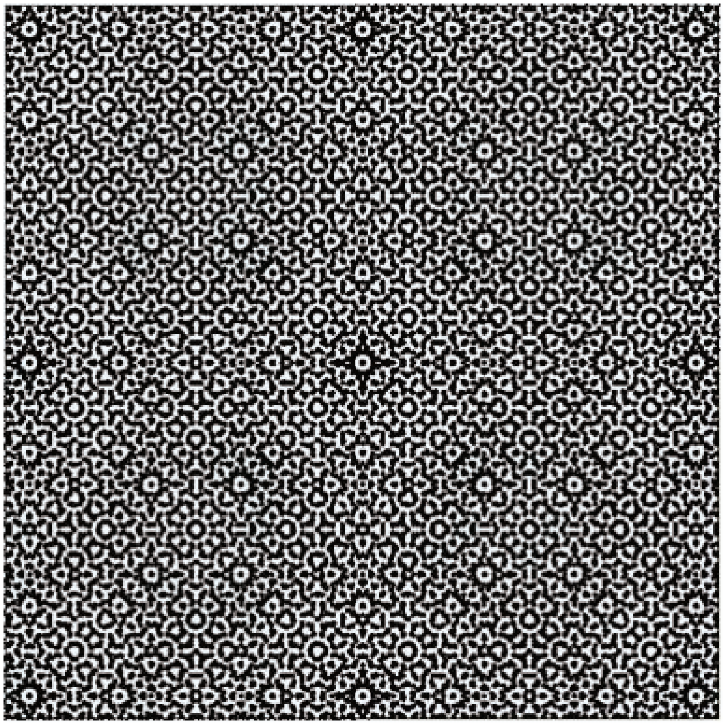
what this means is that as soon as you go even slightly away from the perfect rosette configuration, you end up with some lower frequency sub-patterns in your rosette. And the human eye can pick these out. If you try to simulate them, the amplitude is found to be relatively small. But the human eye can spot even low amplitude variations provided they are at low frequencies, which is where you find yourself as soon as you deviate from the perfect rosette.

And the sad fact is that we are almost guaranteed to be away from that perfect rosette. If you ask your imagesetter at 1200dpi to produce 100 lpi screens at 0, 30 and 60° the one thing you *don't* get is what you asked for. Instead (if the imagesetter is using standard PostScript® settings) you get 0°/100 lpi, 30.964°/102.9 lpi, 59.036°/102.899 lpi. So before you've even started, you have settings that are away from the perfect rosette. Now introduce some errors in placing your positives on your screen (or in the registration of your printed sheets), and add some changes in mesh tension and you are even further from the perfect rosette.

So you are effectively guaranteed to have this sort of moiré. In a way, this is good news. Most of the time, most printers don't have severe unstable rosette moiré, so what we normally do is normally good enough. Remember, the amplitude of this moiré is relatively small and you can often get away with it.

But you can't get away with it if you are too sloppy in your choice of screen sets (and the error from the imperfections gets worse the higher you go in line ruling) or if you don't register your prints accurately or if you are sloppy in controlling mesh tensions.

Figure 10 This rosette is definitely unstable. Your customers probably wouldn't like it.



If you are seeing this moiré on a regular basis, you need simply to attend to the fine details. Get a better set of screens from your RIP (you might have to change your supplier or your RIP as there have been a steady stream of improvements to screen sets over recent years). Some theoretical analyses suggest that you can create rosettes that are intrinsically stable to small changes. If your RIP offers such a choice, it's worth a try.
Invest in improved registration control (or better staff). And there's no excuse for not keeping your meshes under good tension control. Modern stretching machines (combined with modern mesh fabrics) can give you great uniformity over large areas and over large time scales. If you're not getting this, then change your supplier of stretched screens.

Once again I'm in disagreement with those who worry about the fine details of meshes in relation to this type of moiré. Of course a very low tension mesh and a high snap-off (off-contact) will give large distortions which will make unstable rosette moiré worse. But if you are this bad a printer, you will have many worse things to worry about. As long as you have reasonably good control over your mesh any wavy moiré you see will most likely be due to spreading transfer (see below). This is affected by bad control of your mesh, snap-off and squeegee pressure so my disagreement is about the cause of such moiré, not its cure!

Although I have no direct evidence to support this assertion, I am also confident that the amplitude of unstable rosette moiré can be reduced by reducing dot-on-dot effects. So for a third time, the virtuous combination of fine mesh and low EOM low Rz stencil will help you reduce moiré.

Other causes and pseudo-moirés

Mark Coudray helpfully pointed out that corrugated substrates can cause moiré. If your substrate has a regular frequency close to that of your screens, you will see some horrible effects. Because it's so easily diagnosed by printing onto a sheet of known smoothness, I'll not discuss it further.

The mesh will leave regular patterns on your 100% solids and can look quite ugly with coarse meshes and viscous inks. This isn't a moiré, nor should it be a problem if your mesh frequency is significantly higher than your lpi. Thinner thread diameters and lower viscosity inks can help reduce mesh marking. See the optional theory section on mesh marking for a fuller discussion.

Skipping (puppy paws) – the effect that has sometimes been erroneously described as thread eclipsure – is always very ugly. When looking for moiré in various prints I've seen 'ugly' effects that haven't been a typical moiré but most people would describe it as a moiré. In each case, an inspection with a microscope shows that there's skipping.

Arguably the skipping takes place preferentially in holes surrounded by mountains of other dots, and these holes form some sort of pattern. But the frequency of these skipping dots are too high to be a real moiré. Instead, the eye just picks them out as being plain old ugly.

Spreading, gives another 'moiré' effect that has sometimes puzzled us. This particular effect drifted in and out during the print run and defied all rational moiré analyses. It also gave a peculiar wavy pattern that looked as if it might be a mesh moiré, but we had the data to rule out this particular cause. Then we realised that the effect was due to extra dots of ink appearing where they shouldn't. How can dots appear from nowhere? They are remnants of spreading dots underneath the stencil. If each subsequent print is exactly in register with the previous print, then this extra amount of ink will print as classic spreading dot gain. But slight mis-registration means that these dots can appear between other dots and give rise to moiré-like effects. The waviness came from the fact that the spreading dots were rather widely spaced on the bottom of the previous print (because they are long-range interactions with the underlying rosette) and only show up as a 'moiré' when, by chance, they span a pair of newly printed dots – and the positions of these interactions are not regular. It was a good example of how important it is to combine both pure science and hands-on analysis. The pure computer model couldn't possibly anticipate such an effect as it assumes perfect registration every time!

If you have very low frequency variations in your process, e.g. if you use banks of UV fluorescent tubes for exposure instead of a UV lamp, you will be able to see variations in your print. But because the frequency of the effect is exactly that of your variation, it's not really a moiré. Theoretically you can get additional moiré effects, but in practice you would have to be very unlucky. Moiré tends to be most severe when angles and frequencies are very similar.

Printers often complain of a type of moiré in their vignettes – those gentle fading tints that designers love and printers hate. This 'moiré' appears as regular bands. But this isn't moiré. It's tonal banding resulting from the limitations of PostScript screens. If you try to print at 120 lpi with a 1200dpi imagesetter you will only get 100 different levels of grey. So instead of a gentle gradation you will see 100 individual steps. The fix for this is a lower lpi, a higher dpi imagesetter or a more sophisticated RIP that can extend the tonal range.

You can also get different types of tonal jumps depending on your dot shapes. Round dots give one big tonal jump, elliptical dots give two smaller jumps.

One way to reduce moiré is to introduce noise to confuse the eye. I once tried to do this and found that it needed a surprising, and unacceptable amount of noise to do a good job. However, there is some evidence that poor-quality screens (high Rz, poor edge definition) can mask moiré. This is not a recommended method.

Classification

We've found that terminology can lead to a lot of confusion. For example, the term 'topographical moiré' means different things to different people and can cause lots of confusion. Creating terminology for its own sake is a waste of time, but we have found that our own discussions have been greatly helped by having a common accepted classification. We offer it here for discussion purposes among the screen community:

- Simple moiré (e.g. two screens ac cidentally at the same angle but one stretched a little com pared to the other)
- Pure moiré from bad screen com binations (e.g. the example of a 55 lpi yellow used with a 72 lpi CMK)
- Pure 15deg moiré
- Asymmetric dot amplified 15deg moiré
- Squeegee asymmetry amplified 15deg moiré
- Warp/weft asymmetry amplified 15deg moiré
- Dot-on-dot amplified 15deg moiré
- Spreading dot-on-dot amplified 15deg moiré
- Skipping dot-on-dot amplified 15deg moiré
- Eclipsure mesh moiré (including dot loss in the highlights and dot gain in the shadows)
- Rz enhanced mesh moiré
- Negative sawtoothing enhanced mesh moiré.
- Unstable rosette moiré (angles and frequencies are imperfect from your RIP or through bad on-press alignment)
- Dot-on-dot amplified unstable rosette moiré
- Spreading transfer patterning (from the spreading dots of the previous print). The pattern itself may or may not be considered as a moiré and may or may not create a new moiré when trans ferred.
- Scanner-induced moiré
- Imagesetter-induced moiré

Summary

As Mark Coudray said back in 1991, you need to look carefully at your moirés with both a loupe and a microscope. I'm pretty certain that when you do so you will see some moiré on your lighter mono-tones which are due to mesh moiré. You will also start to pick out the 3.8 dot characteristic of the 15° moiré. And you will certainly, when you stand back a little, see some unstable rosette moiré.

The best way to combat them is also the best way (as discussed elsewhere in this eBook) to control your colour balance and avoid skipping and spreading: use the thinnest possible mesh at the highest thread count, use a low EOM, low Rz film stencil. In addition, a lower viscosity ink will help reduce mesh moiré – though you can only use it if you have a low Rz stencil, otherwise you get unacceptable dot gain. If you use low EOM, low Rz you can print with lower viscosity inks. You can therefore use lower snap-off (off-contact). You can also use lower squeegee pressures. The net result is that in every way you are being kinder to your mesh. You can therefore use a lower thread diameter without fear of breaking the mesh. You then get lower mesh moiré. This is a wonderful virtuous circle, but the only convenient way to enter it is by using MacDermid Autotype's Capillex CP or CX which have all these properties by deliberate design.

Although I've not discussed film positives in any detail, you must ensure that you have a state-of-the-art set that are free of intrinsic moirés and bandings and which, if possible, ensure you are nicely close to the perfect rosette settings and don't have any tonal banding that will confuse you.

The spreading transfer patterning is obvious once you know what to look for and is not really a genuine moiré, but it's certainly a significant concern and is best addressed by reducing the extent of spreading (once again with low-EOM, low-Rz stencils) and by keeping good dot-on-dot registration between prints. It's at this point that good control over mesh tension, snap-off and squeegee pays dividends in reducing 'moiré'.

After that, just be your professional self attending to the other details of your trade. Moiré won't disappear completely. But I guarantee that you will spend far less time fighting it, giving you more time to provide your customers with prints to the quality they require.

Problem solving Guide

Moiré

Description

An unexpected pattern in the print which was not in the artwork. It is always associated with regularly repeating patterns in the print, either dots in 4-colur process or lines. In 4 colour process it is generally not present over the whole print area but related to areas of particular density.

Cause

Moiré is caused by the interference of regularly repeating patterns. They can be dot to dot, dot to mesh or line to line or line to mesh.

This is an example of classic 15° moiré

Technical reference

See ***'Moiré causes and cures'*** chapter.

Solution

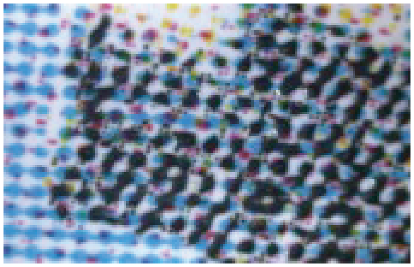
Use the MMC to find a mesh/LPI combination which will not cause moiré.
Change the screen angles.
Use the problematic angle for yellow to make the moiré less noticable.
Change the mesh count slightly for the screen causing the moiré.

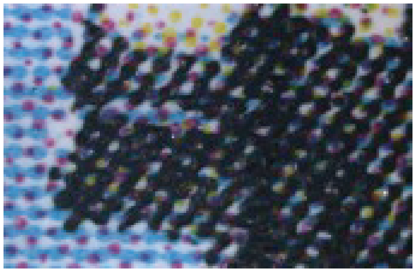
Skipping

Description

Dotty pattern in the 4-colour UV ink print, usually in mid tones.

Under magnification the dots have not printed cleanly and look like 'puppy paws'.





Cause
Dots are not printed cleanly because the mesh is being held away from the substrate surface by previously printed dots.

Technical reference
See ***'Problem solving in the real world'*** chapter.

Solution
Reduce the height of the printed dots by using a low EOM stencil, 3µm profile is ideal.

Mesh marks

Description
The ink has a textured surface.

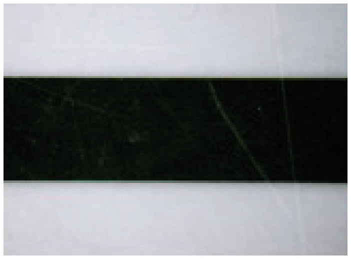
Cause
The ink is not flowing out well after the mesh and ink have separated.

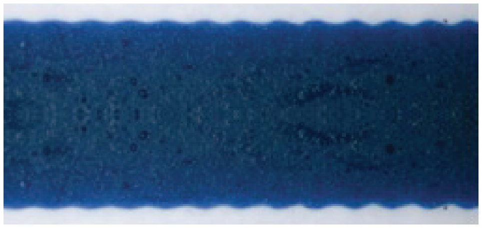
Technical reference
See ***'Optional theory'*** chapter.

Solution
Increase time between printing and curing to allow flow.
Change to a mesh with smaller diameter.
Change the ink to one with better flow characteristics.

Saw toothed lines or dots

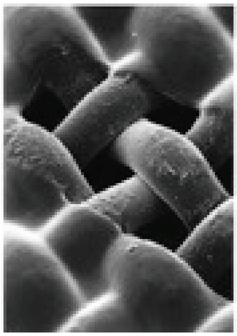
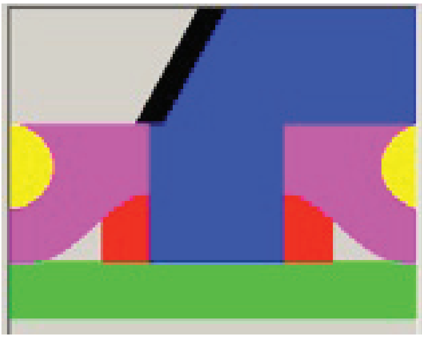
Description
The printed edge of the image is more ragged than the positive.



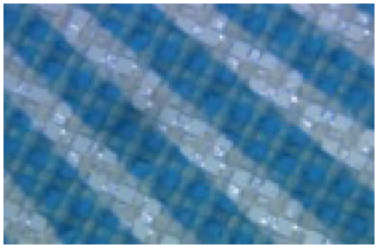


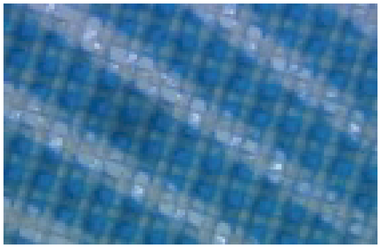
Cause

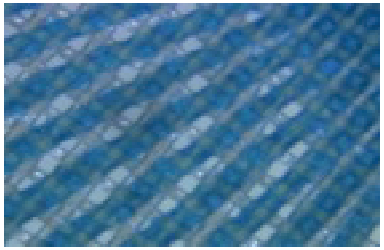
1. The most common cause of this is that the Rz of the stencil is too high.

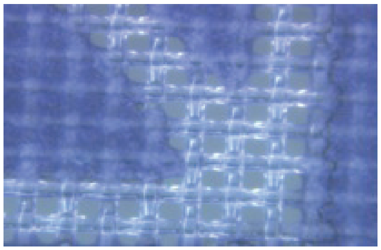
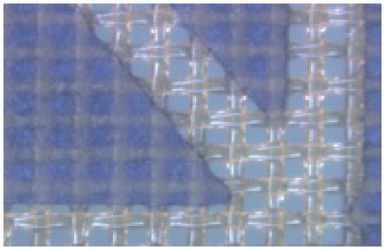
2. It also could be under or over exposure of the stencil.


Ideal exposure


Over-exposure


Under-exposure

3. Use of a white mesh.

4. Stepping caused by image angle to the mesh

Technical reference

1. See ***'Problem solving in the real world'*** chapter.

2. See ***'Getting the right exposure'*** chapter.

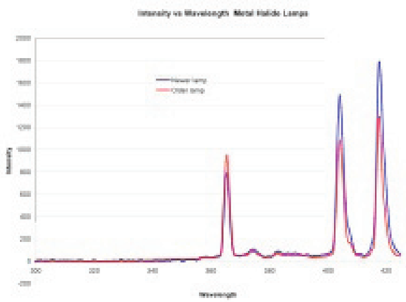
3. See ***'Getting the right exposure'*** chapter.

4. See ***'Problem solving in the real world'*** chapter.

Solution

1. Reduce the Rz of the stencil, Capillary and Indirect film give very low Rz stencils. Using high solids emulsion or multicoating emulsions, wet on dry, will reduce the stencil Rz, but be warned this will also increase the EOM.

2. Find the correct exposure time by using a MacDermid Autotype Exposure Calculator. This should be done regularly because as lamps age so their output changes. This means that the lamp may look bright and register on the integrator but the light may have changed sufficiently to not expose the screen properly.



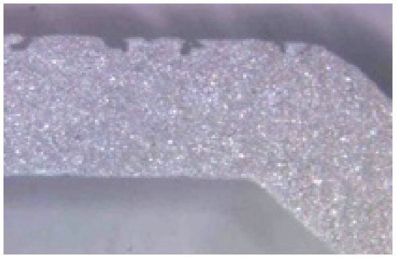
3. Use dyed mesh instead of white or blackened stainless instead of stainless mesh.

4. Reduce the thread diameter.

Negative sawtoothing

Description

More ragged edge on one the leading edge of an image parallel to the squeegee.



Cause

Ink is not filling the stencil.

Technical reference

See ***'Problem solving in the real world'*** chapter.

Solution

Use low EOM stencil.

Increase squeegee pressure but be warned this could lead to flooding.

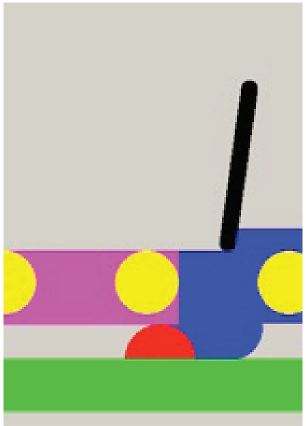
Dark spots / Hickies

Description

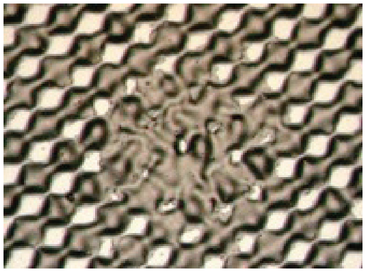
Dark spots in the half tone area usually 0.5-2mm in diameter.

Cause

The cause is dust or debris on the substrate lifting the stencil away from it. This allows the ink to flood under the stencil causing a dark spot. The dust may stay attached to the substrate or it may then stick to the stencil causing the same blemish over many prints.



Under magnification it can be seen that the ink is severely undercutting the stencil.



There is still evidence of the intended image within the blemish which means that it is not a pin hole in the stencil.

Solution

The immediate solution is to wash up the stencil and clean subsequent sheets of substrate using antistatic wipes or tacky rollers.

In the long term antistatic and clean room measures can be taken.

Static

Presence of static will cause more dust to be attracted to surfaces. Static is produced in 3 ways.

1. Separation
2. Friction
3. Induction

The simple act of removing a sheet of film from a stack produces static by separation and friction.
Antistatic wipes, static eliminator bars and antistatic air knives can be used to reduce the problem.

Basic clean up measures

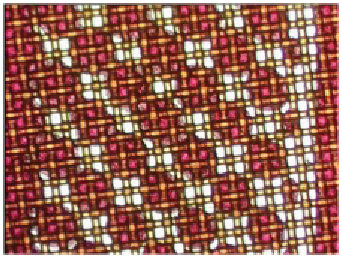
Contamination is present on surfaces and in the air. Clean up measures can be employed to minimise dust.

1. Clean all surfaces and floor.
Use a damp cloth or vacuum with a HEPA filtered exhaust.
2. Close doors and use tack mats to minimise dust and dirt entering the screen printing area. Also minimise the number of people moving around in the area. People are the biggest source of dust. If adding additional enclosure take care that air movement into the area is from a clean source. For instance shutting the door will be a waste of time if the air is then going to be pulled from filthy air space above ceiling tiles.
3. Use lint free wipes.
4. Avoid fibrous packaging, sheets should be removed from the transit box prior to use. Card and paper should be kept away from the printing area if possible.
5. Raise humidity, care should be taken if damping down the floor to avoid slip hazards.
6. Wear clean room overalls.
7. Filter air conditioning. Care should be taken if turning off air conditioning that the new source of air is not more dust laden.

Light spots

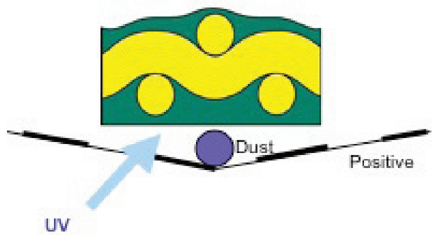
Description

Light spots in the print caused by gain in the stencil.



Cause

Undercutting caused by a dust particle between the stencil and positive during exposure.



Technical reference

See ***'Getting the right exposure'*** chapter.

Solution

Positive and stencil surface must be clean before exposure. Use a clean room wipe or Teknek roller.

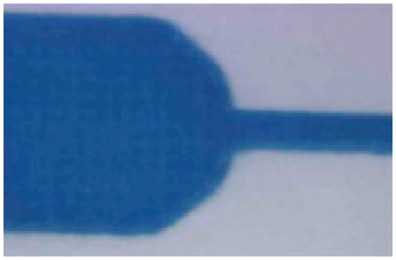
Printed line/dot larger than positive

Description

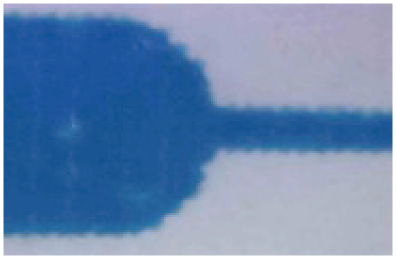
Printed line/dot wider than positive.

Cause

1. Ink slump.
2. Sawtooth.



Rz 4.5



Rz 22.5

Technical reference

1. See ***'Optional theory'*** chapter.
2. See ***'Problem solving in the real world'*** chapter.

Solution

1. Change the ink.
2. See Sawtooth problem in this guide.

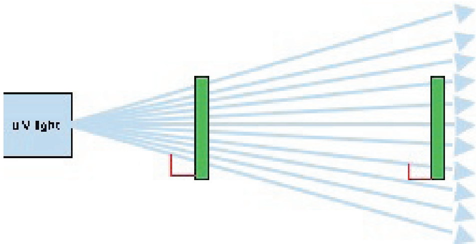
Printed line/dot smaller than positive

Description

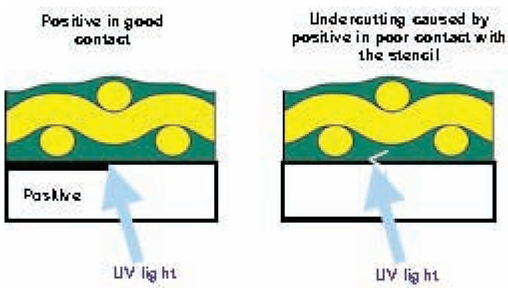
Printed line/dot smaller than positive.

Cause

Undercutting causing reduced image size on the stencil.



2. Poor vaccum.
3. Positive upside down.
4. Backing sheet not removed.



5. Over exposure.

Poor washout of the stencil causing reduced image size of the stencil.

1. Low washout pressure.
2. Stencil fogged by heat or light.
3. Low density positive.

Technical reference

See ***'Getting the right exposure'*** chapter.

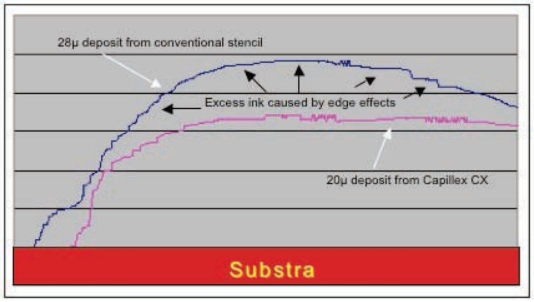
Solution

1. Optimise exposure conditions.
2. Optimise washout conditions, most stencils will benefit from washing out with a high pressure gun from 1m distance.

Thick edges to print

Description

Thick image edge.



Cause

Stencil EOM too high.

Technical reference

See **'Problem solving in the real world'** chapter.

Solution

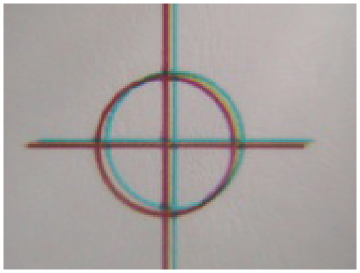
Reduce the EOM of the stencil. Capillex CX and Capillex CP give controlled low EOM stencils designed to resolve this problem.

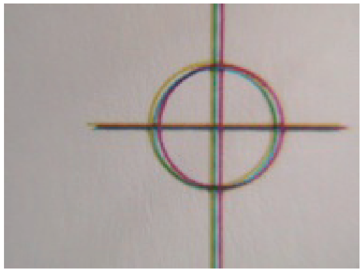
Image distortion

Description

Unable to register multicolour prints or change in the size of the print across the stencil.

Cause





1. Off contact too high.
2. Squeegee pressure too high.
3. Image too close to the screen edge.
4. Screens of different tension.
5. Too flexible mesh choice for the job.

6. Substrate unstable.
7. Changes in temperature during stencil processing.
8. Changes in humidity during stencil processing.

Technical reference
See **'Optional theory'** chapter and **'Problem solving in the real world'** chapter.

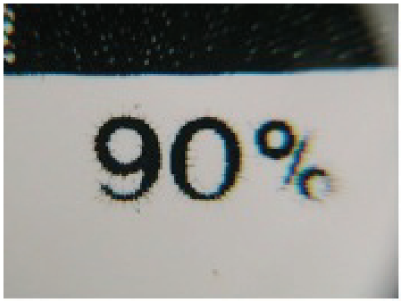
Solution
1. Reduce off contact
2. Reduce squeegee pressure, using a low EOM stencil minimises the need for high squeegee pressure.
3. Use a larger screen for the job
4. Screen should be less than 1N/cm difference in mesh tension.
5. Stainless steel mesh gives minimum stretch.
6. Condition the substrate before use
7. Always expose and print the stencil at a constant temperature and humidity.

Ink Sieving
Description
Stencil open but ink not passing through.

Cause
Mesh too fine to allow all the ink particles to pass through.

Technical reference
See 'Print faults and fixing them' chapter.
Solution
Use coarser mesh. Capillex CX will allow a coarse mesh to be used whilst giving a low profile, fine resolution stencil.

Cobwebbing
Description



Random trails of ink spreading from the image.

Cause
Static.

Technical reference
See ***'Problem solving in the real world'*** chapter.

Solution

1. Earth the press.

2. Raise the print room humidity.

3. Use deionised air reduce static on the substrate.

Poor cure of UV ink

Description

Poor cure of UV ink generally results in poor adhesion. Ink not adhering well to the substrate can be seen as reticulation or wrinkled surface. Adhesion can be tested by 'finger nail scratch and tape test' 'cross hatch and tape test' or 'thumb twist'.

Cause

1. UV curing unit not working correctly.

2. UV ink layer too high.

3. Substrate and ink combination are not compatible.

Solution

1. Check lamp, power setting, lamp assembly cleanliness, bulbs and belt speed.

2. Check that the ink layer is not too high, check the mesh count and use a low EOM stencil.

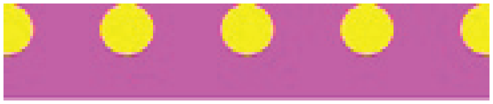
3. Ensure that the ink and substrate are recommended for use with one another.

4. Ensure that the substrate is not porous to the ink.

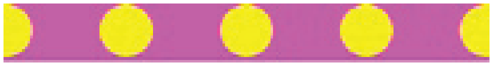
Glossary of terms used in this eBook

EOM

Emulsion Over Mesh (sometimes called Profile) – the extra thickness provided by the stencil material, i.e.
Thickness of the screen with stencil – Thickness of the screen without stencil.
One of the themes of this eBook is that in general High EOM is a bad thing.

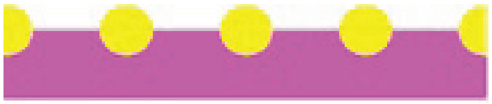


High EOM

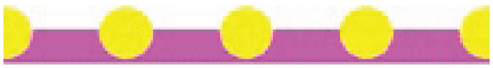


Low EOM

For capillary films, the stencil usually penetrates ~50% into the mesh so the two images look like:



High EOM capillary film

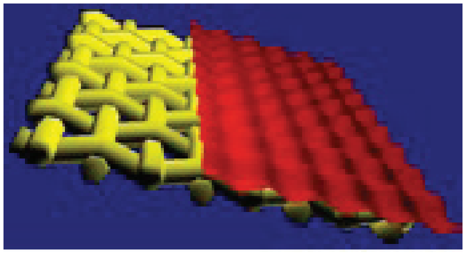


Low EOM capillary film

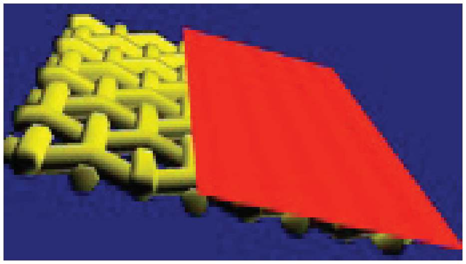
with, of course, the stencil being on the print side of the mesh.

Rz

A measurement of the roughness of the stencil. A stencil profilometer can give different measures of the roughness, such as Ra or RMS. But Rz is the most useful as there is a very strong correlation between high Rz and bad edge definition. The pictures illustrate where Rz comes from (the stencil follows the ups and downs of the mesh) and the difference between high (bad) and low (good) Rz.



High Rz



Low Rz

MacDermid Autotype DSP
The MacDermid Autotype Digital Screen Printer is a suite of PC programs that let you explore many aspects of screen printing science. You can download the suite from the same website as this eBook.

MMC
Moiré Mesh Calculator – one member of the DSP which lets you calculate moiré clashes between your halftone pattern and your mesh.

Mesh ruling
Meshes are specified as so many threads per inch or threads per cm. The finer the mesh the higher the ruling.
You have to be aware that some stainless meshes are measured in threads per French inch, which is 0.9384 of an American inch.

Thread diameter
The thickness of the mesh thread (or fibre) is important as it influences the ink deposit and the amount the mesh interferes with the image. The diameter is specified in microns, µm.

Halftone ruling
Halftone images are made up of dots spaced at regular intervals specified as lpi (lines per inch) or lpc (lines per cm). Higher quality usually implies higher halftone ruling.

Dot shape
The printer can choose the shape of the halftone dots. They can be circular, elliptical, rhomboid etc. Shapes such as elliptical are different in each direction (thinner in one direction, thicker in another) and are called asymmetric because they are no longer symmetric. This asymmetry can affect the visibility of a moiré pattern.

Rosette pattern
When you print a 3-colour or 4-colour halftone the dots overlay to produce the classic rosette pattern that printers and customers seem to like.

Dot build
The thickness of the printed dots of ink. A high build will give you stronger colours but also gives you a rough surface (and plenty of problems) if you print another colour on top

Dot gain
Increase in size of the printed dot over the size in the positive and/or the stencil. Negative dot gain is a decrease in the size. Sawtoothing is one form of dot gain.

Positive sawtoothing (or simply Sawtoothing)
When you print with a high Rz stencil, the ink leaks underneath the stencil and converts a smooth dot or a line into a sawtoothed version.
The sawtooth makes the dot or line bigger, so it's called positive sawtoothing.

Negative sawtoothing
Here the dot or line is sawtoothed, but the dot or line is smaller than it should be. This is negative sawtoothing and is usually caused by stencils with a high EOM.

Moiré frequency
A frequency is simply the number of times something repeats itself. So a moiré frequency is how many moiré spots or lines you find per inch or cm.

Moiré amplitude

The amplitude of a sound is how loud it is – you can easily hear a loud (high amplitude) sound and can't hear a soft (low amplitude) sound. The amplitude of a moiré is a measure of how visible it is – a high amplitude moiré is easily visible.

MRN

This is the Moiré Ratio Number, the ratio of the frequency of your print (in other words, the halftone ruling) to the moiré frequency. An MRN of 4 or more means that you are likely to see the moiré.

Loupe & Microscope

Most printers have a hand-held magnifier, commonly called a loupe. If you need greater magnification you normally have to use a microscope.

Viscosity

This is measure of how easily a liquid flows, with a runny liquid being a low viscosity. It is scientifically measured in Pas (Pascal-seconds) or in cP (centiPoise) or Poise. However as a rough guide, "low" viscosity is water (0.001Pas), "medium" viscosity is honey (3Pas) and "high" viscosity starts at molasses (or treacle depending your linguistic tradition) (10Pas) through peanut butter (200Pas) up to window putty (100,000Pas)

Non-Newtonian Viscosity

Simple viscous liquids don't change their viscosity when you stir, mix, squeeze or in any other way "shear" them. They are said to be "Newtonian." Typical screen printing inks tend to reduce their viscosity when sheared and are said to be Non-Newtonian. Is non-Newtonian behaviour desirable? In general it's what you want, but if the non-Newtonian behaviour is time-dependent (i.e. the change in viscosity depends on how long ago you sheared it) then that's probably undesirable.

Viscoelasticity

A simple liquid is viscous. A simple rubber is elastic. But many liquids have a stretchy component to them and many rubbers flow when stretched. This mixture of viscosity and stretchiness is called Viscoelasticity and in general is undesirable for screen printing. It's rather difficult to measure viscoelasticity, but most printers are used to a more homely descriptive term: "tackiness" or "stringiness."

Surface Tension

We all know that water tends to form spherical drops, and that by adding a surfactant this tendency greatly reduces. The force which causes the water to bead up is called Surface Tension. Surfactants greatly reduce this force. Pure water has a surface tension of 72 dynes/cm. Adding typical surfactants will bring that down to a level typical of simple alcohols, 30-40 dynes/cm. It is hard to get a liquid with a surface tension below 20-dynes/cm. Note that viscosity covers a huge range (the samples quoted above cover a range of 100,000,000), but surface tension usually varies only by a factor of 2-3.

Surface Energy

A drop of water on glass or metal tends to spread out. The "surface energy" of the surface tends to overcome the surface tension of the water. On a typical plastic, a drop of water will form a drop with an angle of ~60º to the surface. On Teflon the angle is close to 90º. Clearly Teflon has a low surface energy, the plastic an intermediate one and glass or metal a high surface energy. The relationship between surface tension and surface energy is important for drop spreading and for tendency towards pinholing. Contrary to popular mythology the surface energy has nothing much to do with adhesion. This is easily proven as PVC and PET have identical surface energies and most inks stick well to PVC and few stick to PET. Adhesion is all about mingling of polymer chains. Some surface treatments which increase surface energy happen to increase mingling of chains so increase adhesion. But once again PET is a good counter-example. Some high surface energy PETs can still have very poor adhesion.

Snap-off (off-contact) and Peel-off

Snap-off also called off-contact is simply the distance of the mesh above the substrate. Many printers use a high snap-off (5mm). It takes a lot of pressure from the squeegee to push the mesh down into contact with the substrate to print, and there are large geometrical distortions caused by such large snap-offs. Many electronics printers print with essentially zero snap-off – the mesh is in close contact with the substrate during the squeegee stroke. The print is separated from the mesh when the platen drops. This requires the minimum pressure from the squeegee (allowing a more delicate blade to be used under modest pressure) and produces minimum geometric distortion.

Peel-off is a separate motion of the frame relative to the substrate; the end away from the squeegee rises during the print, giving extra force to pull the mesh out of the ink.

For cylinder presses it is the rotation of the cylinder which provides the effects of snap-off. If you do the geometrical calculations you find

- The vertical separation speed for a flat-bed varies across the squeegee stroke (it's obviously faster near the beginning and end of the stroke) but is unvarying for a cylinder press

- At any point during the squeegee stroke, the vertical speed is constant for the flat-bed but rapidly accelerating for the cylinder press

- The first few µm of vertical separation (corresponding to ~0.5mm horizontal travel) are slower for the cylinder press but in the 10-20µm (>1mm horizontal) range the cylinder is significantly faster

- Science shows that these vertical speeds are not too significant for the print process so the differences are probably not significant – especially if the flat-bed is using a well-tensioned mesh with a relatively small snap-off, the sign of a good printer.

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