The Influence of Laser Spot Shape on the Stability of the Printing Process

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Abstract: The color obtained by the lithographic printing process is highly sensitive to the size of the dots on the plate. This size must be control as precisely as possible. It must also be as independent as possible against the unavoidable variation in all the processes involved. Variation in the plate characteristic, exposure, processing and changes occurring on the press all may adversely affect the dot size and make the color harder to control. The key for good color stability is a hard dot. We will examine how the laser spot shape and the gamma of the media used influence the dot hardness and therefore the stability of the color on the final printed product.

The only thing that a printer can print is dots. The precise control of the printed dot size is crucial in order to obtain the desired color in the printing process. The size of the dots is first determined by the plate making process. Once on the press, the operator can adjust the amount of ink deposit on the plate. This has two effects. It put a ticker layer of ink on the plate and also makes the dot grow

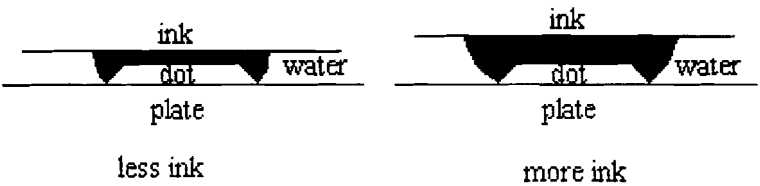

figure 1

(figure 1). Both effects go in the same direction and make the color denser. If the plate is not far off, a good operator can adjust the ink in order to obtain the correct color. However, at the beginning of a press run, this can take some time. During that period, the make ready time, the press produces waste, expensive waste. Also, during the run the dot on the plate can wear, shifting color. The operator must be vigilant and adjust the ink accordingly. Some shift in color may go by unnoticed. Finally, if the plate is way out, no amount of ink adjustment can bring the color to the desired level and the plate must be changed after producing a lot of waste.

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What can be done in the plate making process to minimize these problems? Nowadays, most artworks are produced electronically. There is still a fine art in the color separation process and electronic determination of the dot shape on the plate (the raster image processor or RIP). These processes are extremely important in obtaining the correct color and a lot of thing can go wrong there. However, being digital, it is extremely consistent and repeatable. If you get it wrong, it will always be wrong the same way.

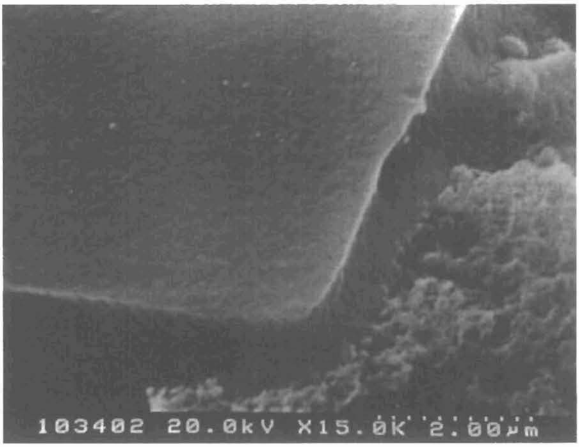

Figure 2 a Hard dot by a CREO trensetter on a thermal plate.

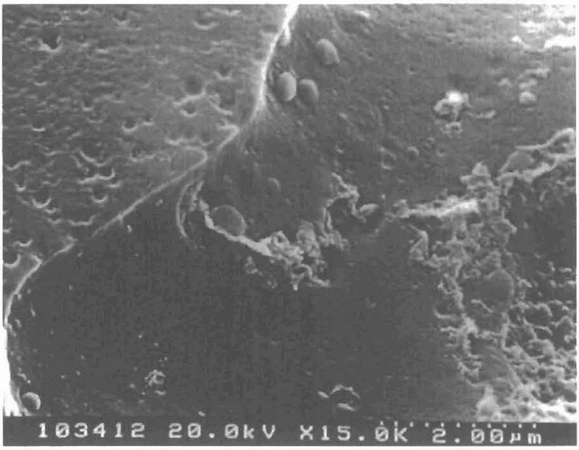

Figure 2 b Softer dot produce by an other thermal machine on the same plate.

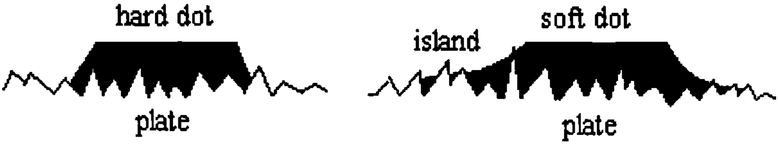

Figure 3

Once all the computers have finish their work, it is time to put the digital information on the plate. This must be done accurately and the dots produce on the plate must have sharp, well-defined edge. Something called hard dot. Why is it important to have hard dot? Consider a dot on a typical plate. The discussion is also valid for other plate system. The plate is grained anodized aluminum that carries the water in the lithographic process and the dot is a polymer that carries the ink (figure 2 and 3). The dot on figure a is harder then the dot on figure b. Where will the water-ink boundary sit on these dots? On the hard dot, the boundary will sit nicely at the edge of the dot. On the soft dot, there is some island of anodized aluminum sticking out of the thin tail of the polymer. Water will stick to the aluminum and ink on the polymer. Because of the surface tension of the ink-water interface the very small geometry from these island will not be resolved and the interface will sit at some average position. Lets now consider the stability of the position of the water-ink interface in the presence of some variation in the many process involved.

Most plate are prepared by exposing the uniform polymer coating with some light (UV, visible, or infrared) then processing the plate with some chemical that selectively remove the coating where the light exposed it, or where the light did not exposed it (positive and negative plate). Some thermal processless plates also exist. For these, the processor part of the variability is out of the equation. There can be variation in the coating thickness, coating sensitivity to the exposure and exposure level. The plate processor can have variation in the processing time, temperature of chemicals and strength of chemicals. Also, many plates need some sort of heat treatment (often called pre-heat) in the processing. That can also vary. These variations can happen between two plates or even within one plate at different location on the plate. Finally, on the press, the plate will sustain mechanical and chemical attack that can wear off the polymer. All these variable will affect how much polymer is being etched off the plate.

Lets now see how hard and soft dots respond to more or less polymer being removed (figure 4). The ink-water interface on the hard dot is not affected significantly by the change. However, on the soft dot, the ink-water interface recedes when small amount of polymer is removed.

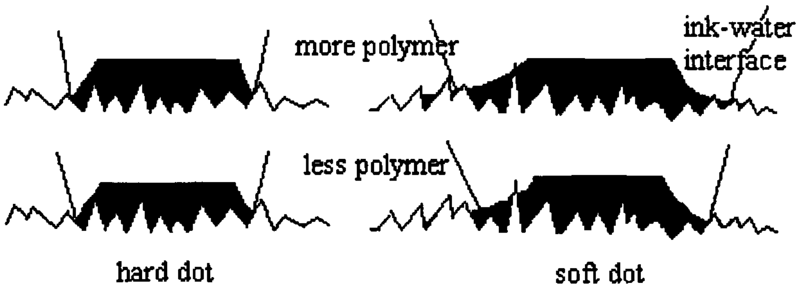

Figure 4

This mean that with a plate with soft dots, the colors you get on the final printed product will vary from plate batch to plate batch, how long your plate have been sitting around, in witch condition of temperature and humidity, the state of your exposure system and processing line, etc, etc. This does not mean that the plate is useless, although is some extreme case it could. It means that you will generate more waste during the make ready time, some color shift will happen during the press run and the total run-length that can be achieved while retaining the correct color will be reduced. A hard dot greatly reduces these problems.

We are now convinced that we need hard dots (well maybe). The digital data coming out of the computer is intrinsically infinitely hard. It is the job of the imagesetter or, recently, the platesetter to produce the hard dots. The imagesetter produce a film that is then use as a mask for a contact print on a printing plate. The platesetter directly image on the plate. For the imagesetter we need to consider both process, imaging and contacting, to establish the dot hardness. For the platesetter only imaging need to be considered.

Let's first examine the imaging process. Two factors influence the dot hardness of an imaging device: the gamma of the media and the laser spot shape or image sharpness (in the case of a non-laser imager). The gamma of the media is the slope of the response of the media as a function of exposure (figure 5 a). The response can be optical density, for a silver halide film for example, or maybe solubility in the processing chemistry for a printing plate, or % of coating ablated in the case of a thermal ablative media. High gamma produces hard dot. Ideally you want the media to do nothing until a certain threshold exposure is attain and then very suddenly react completely above this threshold. Such a perfect media is called binary. Off course no such thing exist. But certain media approximate this behavior better then other. Over the last few years, a completely new class of media called thermal media have appeared made commercially possible by recent advance in low cost high power laser diode, Thermal media react to heat, not to the light itself. Chemical and physical process rate are typical exponential with respect to temperature and linear with respect to light exposure. An exponential is a much faster function then linear giving intrinsically high gamma to thermal media. The exponential is a non-linear function therefore these media do not obey the reciprocity law (1/2 exposure for 2X the time does not give the same result on thermal media). Low level exposure (to heat in this case) does not affect the media at all. No special precautions are needed in the handling of the material (like low light level). These materials have such a high gamma that they earn the label of binary media.

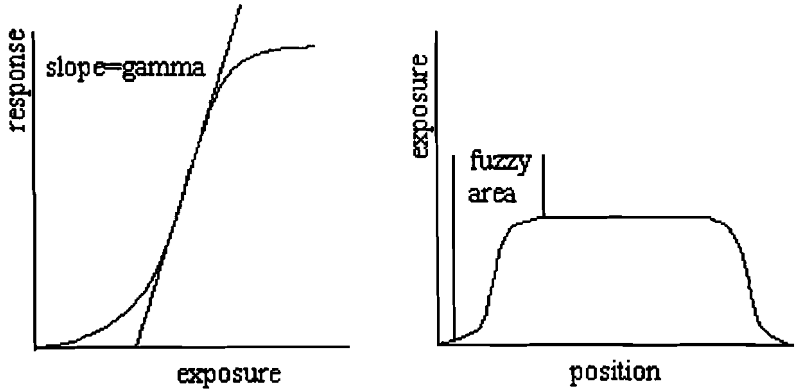

Figure 5 a　　Figure 5 b

The second factor that determine dot hardness is how fast the exposure goes from zero in the non imaged area to maximum in the image area (figure 5 b). The edge of the dot is a convolution of the exposure profile and the gamma of the media. Notice that a very high gamma can produce hard dot even with poor exposure profile. However, the size of this dot would be very sensitive to the exact exposure and media threshold. Although this plate would be stable against variation on the press or in the plate processing, it would be difficult to repeatably image the same dot size du to plate threshold and exposure variation. An infinitely sharp exposure would give hard dot with stable size even on low gamma material. Unfortunately some nasty little law of physics prevent this from being achievable. So in practice, the hardess dot with good size stability will be obtained with the highest available gamma material exposed with the sharpest imaging system.

How can we make a sharp imaging system? First a note of caution: most people think that the dpi (dot per inch) is a measure of imaging sharpness. This is

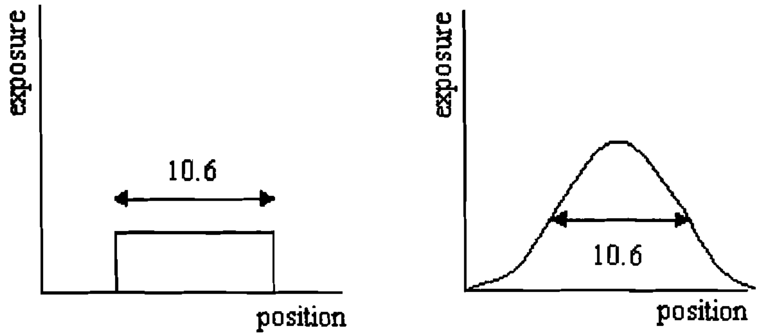

Figure 6

wrong! The dpi is just that, dot per inch. It is a measure of the resolution of where you can put a spot on the plate regardless of the size or edge sharpness of this spot. A machine could be able to center it's spot on a 10.6 μm grid and be called 2400 dpi even if the spots are 1 mm in diameter with soft edge. This is particularly abused in the ink-jet market where 1200 dpi are advertised even if the smallest ink drop is many time bigger then 21 μm (1200 dpi). Even a machine that claims 2400 dpi and 10.6 μm spot diameter does not tell the entire story. When the spot profile is not square, a typical way of measuring the size is the FWHM (full width at half maximum). Consider the two profiles on figure 6. They both have 10.6 μm size but obviously, from our previous discussion, the one on the left will produce a more stable plate. Also, when the spot is not square, its size is not well defined and many parameters can be used. So if somebody state a 10 μm size, ask what that mean. For example many laser and imager produce a so-called gaussien beam. The intensity of this beam correspond to the function:

$$I(r) = I_o e^{-2r^2/\omega^2}$$

I = intensity of the laser
r = radius at witch the intensity is measured

The parameter ω is the radius where the intensity drops to $1/e^2$ of the intensity in the middle. It is often use as size. 2ω is the diameter at $1/e^2$ intensity. Also often use as a size. Finally FWHM is the diameter at ½ intensity and HWHM (half width at half maximum) is the radius at ½ intensity. For a gaussien beam FWHM=1.2 ω. So you can see that just talking about the size of a laser spot can be somewhat confusing.

Usually, imager have one or many laser spot that move on the surface of the media and are turned on and off to produce the image. We must consider separately the direction in witch the spot move (scan direction) and the direction perpendicular to the spot motion (cross scan). In the cross scan direction the exposure is the cross scan profile of the laser spot shape. In the scan direction the exposure is the convolution of the scan profile of the laser spot shape and the time dependence of the laser intensity.

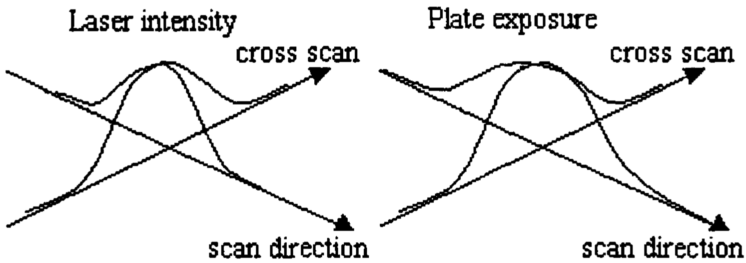

Figure 7

For example: A symmetric gaussien beam of intensity $I(r)=I_0\ e^{-2r^2/w^2}$; w=10 μm is scanned on the surface of the media at 1 m/s. I am trying to do a 10 μm spot so I turn the laser on with negligible rise time for 10 μm/ 1 m/s=10 μs, then turn it off with negligible decay time. I got the exposure shown on figure 7. Notices that the exposure is sharper in the cross scan direction then the scan direction. In practice one most also include the turn on and turn-off time which may or may not be negligible dependant on the imager design. These will make the scan direction even less sharp. How can we do better? First we must make the cross scan profile as square as possible. However even a square scan profile will not produce a sharp exposure in the scan direction (figure 8). To fix that, the laser could be pulsed with a duration so that the spot does not move significantly during the pulsed exposure. This pulse is repeated after the spot have moved by one pixel on the media. We can also use a step and repeat approach. The spot is moved to a location, then stop, expose this area, move to the next location, stop, and expose again. A simpler approach is to use an asymmetric laser spot shape where the scan profile is much smaller then the cross scan profile (figure 9). The ultimate shape being a thin line with very fast rise and decay time.

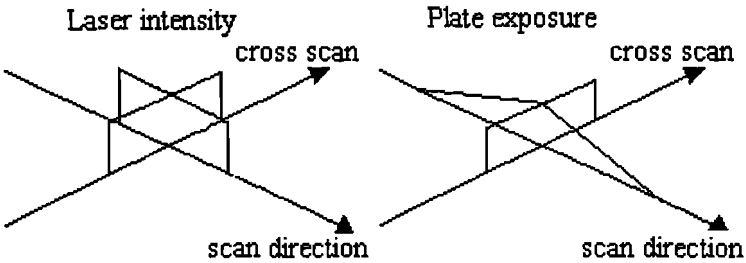

Figure 8

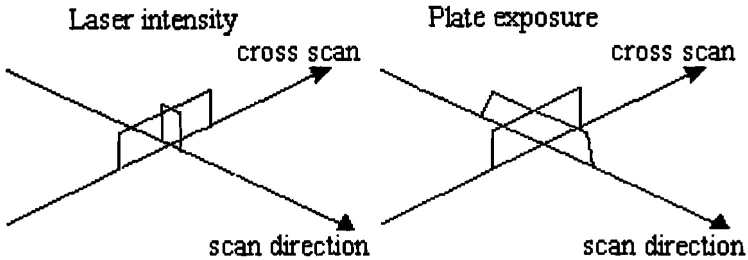

Figure 9

The nasty little physic law that prevents us from having a perfectly square exposure or very thin line is called diffraction. It states that the smallest spot or smallest size of the fuzzy area around a square that you can do at the focus of a lens is given by:

Size $\cong \lambda / NA \cong \lambda F\#$
λ: wavelength of the light use
NA: numerical aperture of the lens
F#: F number of the lens. Focal length/diameter

This say that smaller wavelength will produce sharp dot. At a given NA, infrared at 0.8 μm will be 60% less sharp then visible at 0.5 μm. Focussing very tight with the cone form by the light coming to the focal point having a large apex angle also reduce the fuzzy area. Unfortunately, focusing tightly mean that the depth of field, the distance in and out of focus where the spot stays sharp is also very small.

Depth of field = $\lambda/(NA)^2$

Example: With infrared at λ= 0.8 μm focusing at NA = 0.1 (a relatively weak focus), the fuzzy area are about 8 μm compare to a pixel size of 10 μm for 2400 dpi. This is quite large. The depth of field is about 80 μm, not too demanding.

With the same light at NA =0.3, the fuzzy area goes to 2.4 μm. That would make a 10 μm spot look quite square. But the depth of field goes down to 9 μm. Keeping the distance between the imaging system and the plate within 9 μm is very difficult. Mechanical tolerances of 9 μm in a large machine exposing big film or plate are too difficult to meet economically. The best way out is to use an autofocus system that constantly measure the distance between the lens and the media and adjust the lens position to stay at focus. Increasing NA is also very demanding on the quality of the lens and going much beyond NA =0.3 becomes impractical.

This describes the physical limit on the size of the fuzzy area. However in practice, many light sources emit light that has characteristic way worst then the diffraction limit. Also, even if a good laser emit at near the diffraction limit, the optical system that the laser beam go through from the laser source to the plate may not conserve that quality. It is the job of the imager designer to choose a light source and optical system that get as close to the diffraction limit as possible. Otherwise for a given NA the laser spot will be less sharp. Compensating by increasing NA is expensive and the depth of field reduced. At the maximum practical NA, the closer you get to the diffraction limit, the sharper the spot.

Imager architecture comes in many varieties. There is internal drum and flat bed that use a rotating prism or mirror to scan the beam on a fixed media. A fast one channel modulator turn the beam on an off. Because of the high rotation speed needed for good throughput, the rotating element must be small to limit centrifuge forces. The beam is projected a relatively long way to cover big film or plates. This creates a low NA system that even with the use of nice laser beam with near diffraction limit characteristic can only generate laser spot with lower sharpness.

External drum or flat bed with a head that moves close to the material allows the use of higher NA optic. Most manufacturers unfortunately use round beam without pulsing the laser. This generates blurred dots. Some machine uses a step and repeat flat bed approach imaging a 2 dimensional light valve array on the media. The light valve can be turned from transparent to opaque electrically forming an image on the media. With sufficient NA this could generate sharp spots although the throughput is reduced because of the mechanical move and wait limitation. Thermal machine use infrared laser. Even if they are at a small disadvantage because of the longer wavelength, the very high gamma of thermal media more then compensates for it. These machines often use fiber coupled high power laser diode. The laser light is send in an optical fiber, the other end of the fiber is imaged on the media. The laser is turn on and off according to the data. This approach degrades the already less then diffraction limit characteristic of the laser diode. These lasers emit light in a small line of 1 μm X 100 μm or so. Coupling that to a round optical fiber degrades the nice 1 μm width of the laser. A better idea is to image that nice small line on a 1 dimensional fast light valve and imaging this light valve on the media with a large NA This system produces the scanning line approach described above and can generate the sharpest possible spot at high throughput. Coupled with the high gamma of thermal media, this approach lead to the hardest dots on the market today.

Any of these imaging devices can be used as an imagesetter or as a platesetter. Even thermal machine can be use in both roles as many thermal films are commercially available.

However, the contact print process is a second copy on top of the original creation and quality is reduced. Most films have a bumpy surface finish of a few um in order for the vacuum frame to take all the air out between the film and the plate. This plus area of poor contact produces a small gap between the film and plate. The UV light in an exposure frame is diffuse so the shadow of the film is not very sharp. Therefore the exposure of the plate is less sharp then the original film. Also, UV plates typically have a smaller gamma then a thermal media further reducing dot hardness. This is one of the reason that CTP platesetter are increasingly chosen over the standard imagesetter and contact process.

Conclusion

Hard dot on the printing plate limit color variation du to variability in the plate making process and printing process. The hardest dot can be produce using a thermal media and a CTP platesetter. Scanning a line laser spot on the media with fast on-off transition or a square spot with pulse illumination produce the sharpest exposure. Alternatively a step and repeat approach can also attain good exposure but at a lower throughput. High NA focusing optic must be used. This reduced the depth of field to the point were an auto-focus system must be used. The advantage to the printer is faster make-ready, better color stability during the run and longer run-length. The reduced waste goes straight to the printer bottom line.