Recorder spot size and its effect on image quality and halftone reproduction

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Abstract: Many important factors must be considered when designing a digital photographic and/or thermal imaging system. Some of these considerations are: resolving power, contrast ratio, addressability, rise and fall times of the circuitry, pixel time, pulse length, spot size and media characteristics. This paper investigates the effect that spot size has on halftone image quality as well as how it affects exposure latitude, focus latitude, resolving power and image press life. Significant differences between photographic and thermal systems are highlighted.

Introduction

This paper concentrates mainly on the internal drum imaging of plates, but the terms and ideas are similar for film as well as for external drum imaging. Internal drum and external drum both have advantages and disadvantages, and though some of these are mentioned in this paper, this is not a formal comparison between the architectures.

The relevance of spot size has changed over the years. At one time, it was common to find spot sizes that were much larger than the addressability. It was found that by using a larger spot size, the "stair-stepping" or "scalloping" of the digital dots could be reduced, creating smoother dots. This is shown in figures 1 and 2. At that time, most users were only familiar with contact screen dots made on a camera. Those dots were analog, and the digital dots appeared ragged. Eventually, more manufacturers reduced their spot sizes to more closely match the addressability.

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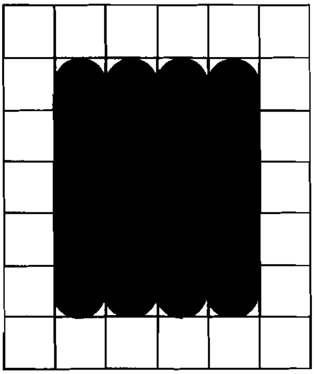


Figure 1. Halftone dot created using matching spot size

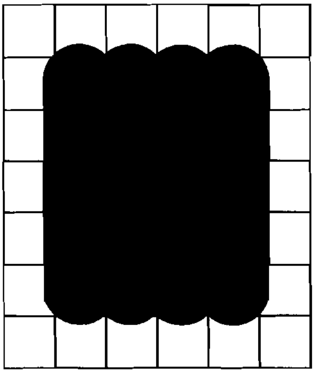


Figure 2. Halftone dot created using 1.4x spot size

When the spot is oversized, as in figure 2, the exposure required to attain the film's recommended Dmax results in non-linear halftone reproduction and poor rendering of small type. The highlight dots are rendered too small, and the shadows too heavy. To overcome this, linearization programs can be used to linearize the gray scale, but this is not necessary if the spot size is optimized for the addressability. Nothing can be done about the loss of small type. The results are similar for platesetters. When imaging positive working CTP plates, such as Agfa's Lithostar Plus or Silverlith, an oversized spot can be compensated for by underexposing, thereby reducing the effective beam size. However, if the spot is too big, the amount of underexposure required to achieve linear output may result in background scumming. When imaging negative working plates, such as some of the photopolymer plates, an oversized spot can lead to excessive dot gain. Underexposing in this case will reduce press life unless the plate is baked. It would seem that the smaller the spot size, the better the output; but this is not necessarily so. Smaller spot sizes generally require larger, more expensive optics, are more sensitive to mis-focus and require more power to image.

This paper discusses some of the effects that spot size has on image quality and recorder behavior, and gives an overview of digital imaging. It would be helpful to start with a short glossary of some of the terms used in this paper and in imagesetting technology.

Ablation: Or "thermal ablation" imaging occurs by vaporizing part of the media with intense heat. Normally, this process is nearly binary, yielding very high resolution images.

Addressability: Usually expressed in dpi, or simply called "resolution." Specifies the number of pixels which can be imaged in 1 linear inch. For example, "2400 dpi."

Astigmatism: The inability of an optical system to focus two perpendicular axes of an image at a common point.

Binary media: Media which has infinite contrast, i.e., only image and non-image areas without any soft edges.

Banding: A general term for an imaging defect or "artifact," normally visible as fine, high-frequency noise in the image. See also Stitching.

Checkerboard: A 50% dot area pattern similar to a checkerboard game board. It is usually expressed numerically as in "1x1 checkerboard" or simply as "1 pixel checkerboard," where the numeral is the side length of the dot in pixels. It is always a 50% dot at a 45-degree angle, regardless of the addressability. It is commonly used as a resolution, exposure and focus target.

Contrast ratio: The ratio of exposure "on" power to the "off" power.

Collimated: Light rays that travel parallel to each other, as if in a column.

DLogE curve: A very useful graph describing the relationship between relative log exposure and image density.

Dmax: Short for Maximum Density. On negative working films and plates, a certain Dmax is often recommended for acceptable output.

Dots: Halftone dots, comprised of a number of pixels, or spots.

Duty cycle: The percentage of imaged pixels to total pixels when referring to test targets, or the percentage of pulse time to total time when referring to modulation. For example, a duty cycle of 50 % means the time the laser is "on" is equal to the time it is "off".

Exposure latitude: The change in exposure necessary to cause a given change in image density or other image quality parameter such as banding.

Focus latitude: The change in focus necessary to cause a given change in image density or other image quality parameter such as banding.

Horizontal line: A line which is imaged along the imaging axis. It is imaged as a continuous line and is not modulated.

Image density: Measured with a transmission or reflection densitometer, it usually refers to the density of a solid tone area (Dmax). It can also refer to the density of a checkerboard image, or to halftone dot area on film, plate or print.

Matching spot size: The width of the focused laser spot at the 50% intensity point is equal to the addressability.

Matching microlines: The exposure required to render positive and negative lines of equal width.

Modulate: Turning the laser on and off. In some recorders, the laser itself is modulated. In others, the laser remains on while a device, called a modulator, blocks or transmits the laser energy.

N.A.: Numerical Aperture. Equal to the sine of ½ the cone angle of the laser beam converging at the image plane or diverging from the source.

Off power: During modulation, the power that the film or plate receives when the pixel is "off." Different amounts can have a beneficial effect or a detrimental effect on image quality.

Pixel: The smallest unit of information.

Pixel time: The amount of time it takes to image a single pixel, measured in nanoseconds or microseconds. A resolution dependent value determined by dividing the spot velocity by the addressability.

Photographic: A process which uses the reduction of silver ions to create an image. It normally uses visible light, but not necessarily.

Power density: Amount of energy per unit area. Ex.: millijoules/cm^2

Pulse time: Related to pixel time, it is the amount of time during which the laser beam is "on." See also duty cycle.

Resolving power: The ability to distinguish between two or more small image elements. It is determined by the sum of all of the variables that are included in the imaging process, regardless of the medium.

Rise/fall time: The speed with which the optical power can be modulated. Usually measured in nanoseconds or microseconds, the amount of time it takes to change power between the 10% and 90% power points.

Source: The origin of the laser energy. This could be, but is not necessarily the laser. In systems that use external modulators, the "source" is the beam diverging from the modulator, not the laser itself.

Spot: A recorder pixel, a number of which construct a dot.

Spot to pitch ratio: The ratio of the spot size to the addressability.

Spot size: The width of the spot, usually measured in microns. It is completely independent of addressability.

Spot overlap: The amount of overlap that occurs when spots are exposed adjacent to each other. Different amounts can have a beneficial effect or a detrimental effect on image quality.

Stitching: A pixel placement error characterized by an incongruous line, marking the point where one laser beam stops imaging and the next one begins.

Thermal: A process that uses heat to expose the image. Normally these are very high contrast materials.

Vertical line: A line that is imaged perpendicular to the imaging axis.

The following section describes the effects that spot size has on exposure latitude, focus latitude, resolving power and press life. When possible, the data was gathered empirically. When this was not possible, computer simulations were made using a model developed at Agfa.

Resolving power

Spot size and spot to pitch ratio have a direct effect on resolving power. Figures 3 and 4 show the intensity profiles of different size gaussian spots at a single addressability. It follows that the smaller the beam, the better the resolution. Is there a limit to this? Note in figure 3 how the width of the laser beam varies with exposure. If the spot size is made too large or too small, then the exposure required to reach a particular Dmax, to clear the background of the plate or to match microlines will result in poor image quality. The critical exposure will be too close to the tip or to the base of the beam, and there will not be any exposure latitude. Spot overlap will also become a problem, causing artifacts in the image. At this point, the addressability must be changed.

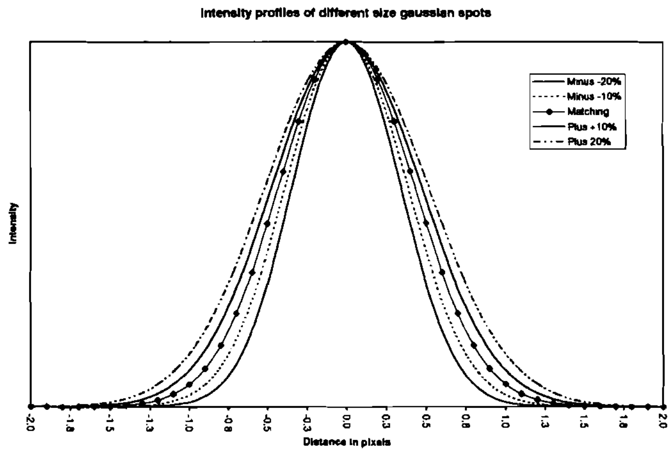


Figure 3. Intensity profiles of different size gaussian spots

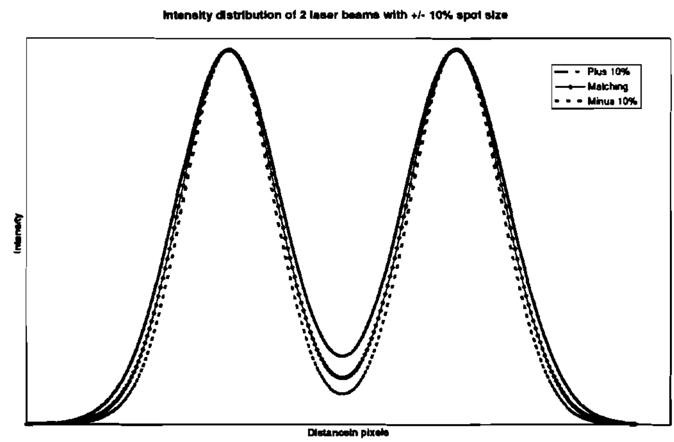


Figure 4. Intensity profiles of 1 on 1 off horizontal lines using different spot to pitch ratios: -10%, matching and +10%.

Although the intensity profiles in figure 4 appear to be quite different, there is actually very little change in edge sharpness on the plate or recorded line width. This is shown in figure 5. However, smaller spots require more laser power. A benefit of this is an increased under-exposure latitude. This is shown in figure 6.

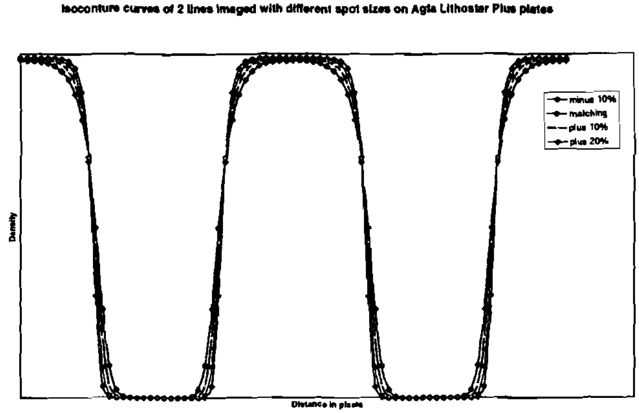


Figure 5. Changes in spot size of 10% to 20% have a minimal influence on edge sharpness.

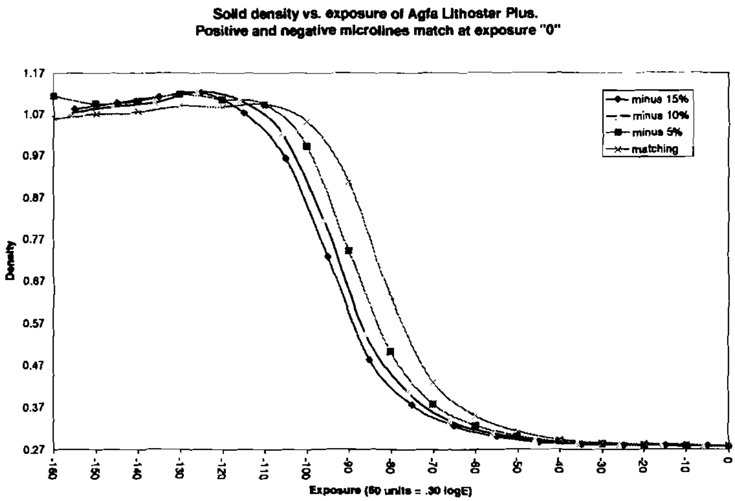
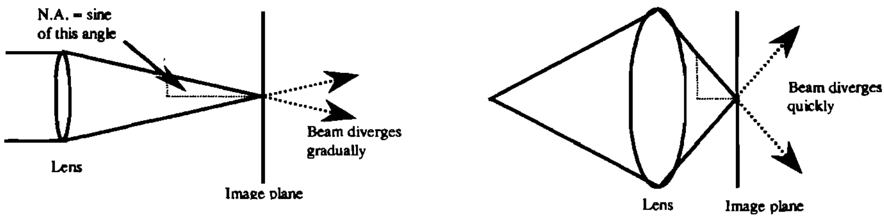


Figure 6. Smaller spots require more exposure to match microlines on positive working plates. The extra exposure is useful in preventing background scumming due to normal process variations, provided that the extra power is available.

Depth of focus

When the issue of spot size arises during the design phase of recorder development, one of the first concerns is depth of focus. The smaller the beam is at the image plane, the more sensitive it is to focus variations. This is due to the increased Numerical Aperture, or N.A., of the optics needed to create a smaller spot. Depth of focus decreases by the square of the N.A.. If the N.A. is doubled, there will be ¼ as much depth of focus. As a rule, internal drum architectures have low N.A.'s, providing much more depth of focus than external drum architectures which have very high N.A.'s. Because external drum architectures have virtually no depth of focus, focus has to be monitored and adjusted during imaging. Compact disc players also have this challenge. Conversely, internal drum systems cannot adjust the focus while imaging because the spinner speed is too high, but they don't need to because of the greater depth of focus. Figures 7 and 8 demonstrate the concept of numerical aperture.



Figures 7 and 8. Low and High Numerical Apertures.

Astigmatism is another factor that must be considered when measuring depth of focus. All optical systems have some degree of astigmatism. Astigmatism is characterized by the inability to focus two axes of the laser spot at the same focal point. It differs from field curvature in that all points along an axis will be in focus with astigmatism, while all points at a radius "n" will be in focus with field curvature. See figure 9.

Focus affects photographic and thermal systems significantly differently. Take the case of the horizontal lines that are illustrated in figure 5. On a thermal plate, the edge profiles of the lines would be nearly vertical, because the exposure caused by overlapping fringes does not count for thermal plates. This is because thermal plate exposure only occurs upon reaching a threshold temperature. By the time the next line is imaged, two revolutions later, the plate surface has fully cooled and partially exposed areas will not be imaged. See figure 10.

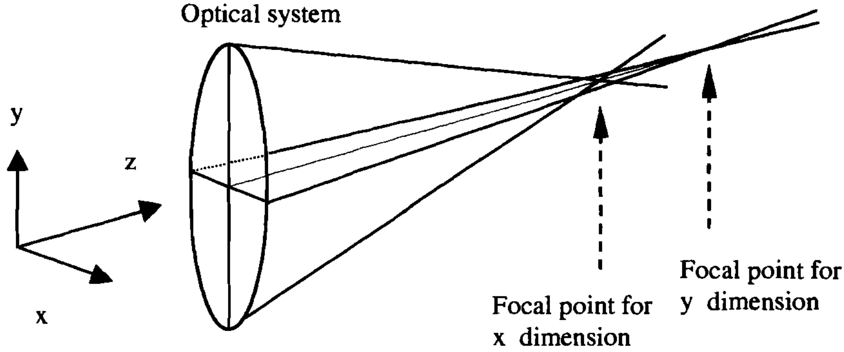


Figure 9. An astigmatic spot has a different focal point for each axis.

During normal imaging, thermal energy is not additive. Only when modulating extremely fast, as when imaging the finest checkerboard patterns, can this cooling not have time to occur. With photographic systems, the light energy is always additive.

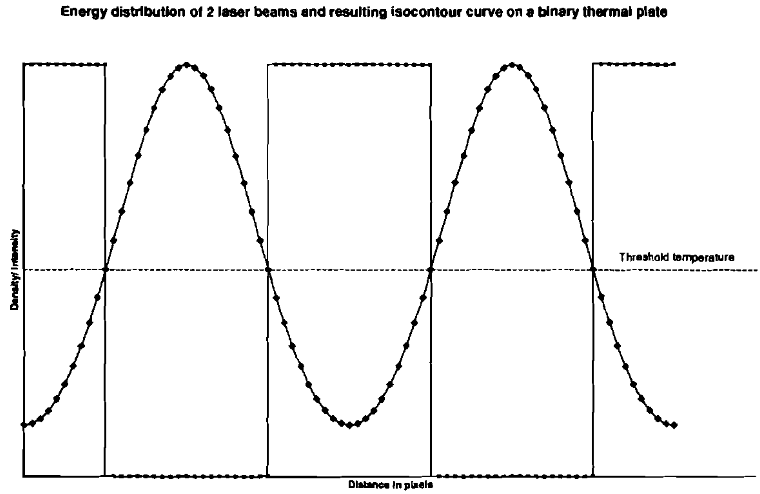


Figure 10. Thermal plates are exposed only at threshold temperature, and any exposure level below this doesn't affect the plate. In photographic plates, all energy is used by the plate.

What relevance does this have to focus? With photographic plates, an out of focus beam spreads the light energy out, widening the exposed area. Although the light is less concentrated, there is more overlap between pixels and the result is wider lines. With thermal plates, the lines simply become thinner because the power density has dropped. The energy, which has been spread out, is lost. The threshold temperature is now found at a thinner portion of the beam. This translates into a change in dot area. In a positive working thermal system, this causes dot gain. In a positive working photographic system, it causes dot sharpening. See figures 11 and 12.

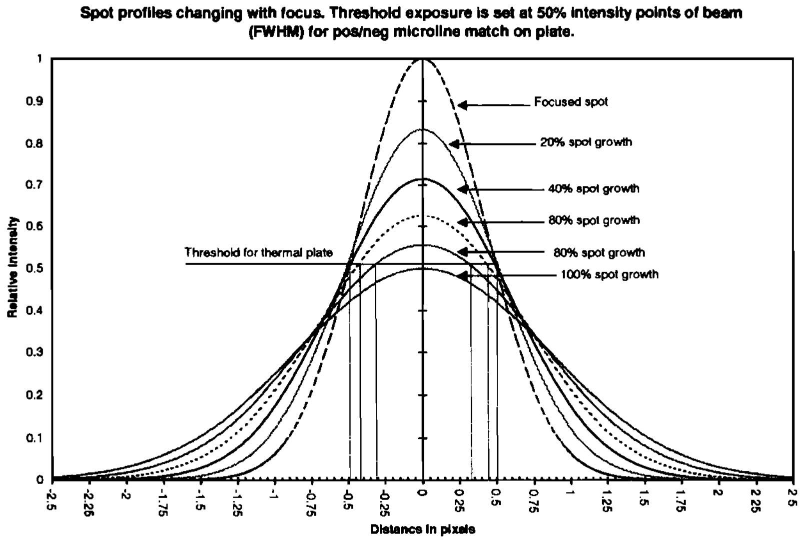


Figure 11. As the laser spot is defocused, the total energy remains the same, but the power density is reduced. This affects thermal plates differently than photographic plates.

**For demonstration purposes, this graph shows greatly exaggerated amounts of focus change. For an internal drum recorder with a low N.A., a focus change of as much as 8-10 mils may be required to cause only 10% spot growth, less than half of the smallest amount shown here. Typical focus variations cause only a few percent spot growth. (an undetectable change in dot area) For external drum recorders, it may require far less than 1 mil for 10% spot growth (about 1% dot area).*

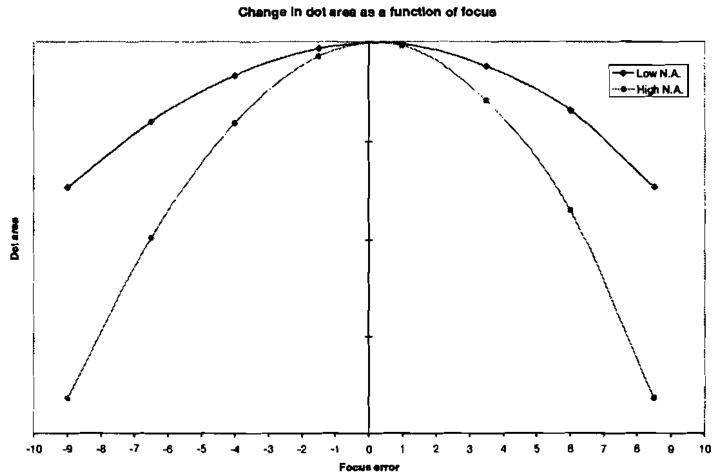


Figure 12. Dot area changes slowly as a function of focus for a system with a low N.A and faster for a system with a high N.A.

Dot hardness and press life

A final measure of dot quality is found in the printed matter. With all the talk about spot integrity, spot shape and spot hardness, it is difficult to distinguish what level of each is required for reliable imaging. The press sheet will reveal what is truly on the plate, because what does not print, does not exist. This can be determined from a single press sheet. Microdensitometers are normally used to measure dot hardness on film, but they will not work on plates. Instead, press life is a good indicator of dot hardness on the plate. Halftone dots grow and shrink from their edges. It can be presumed that harder edges will be less affected by wear over the course of a press run, much the same as they are affected less by exposure. A press run was made using plates imaged with different spot sizes and focus positions. The plates were imaged in an Agfa Galileo platesetter on Agfa Lithostar Plus plates at 3600 dpi, using spot sizes ranging from 7.6 microns (8% oversized) to 10.6 microns (50% oversized) at both correct focus and at 4 mils out of focus. The plates were run black only for 100,000 impressions. The screen ruling that was used for this experiment was 318 lpi and the press sheets were measured with an X-Rite 418 non-polarized densitometer.

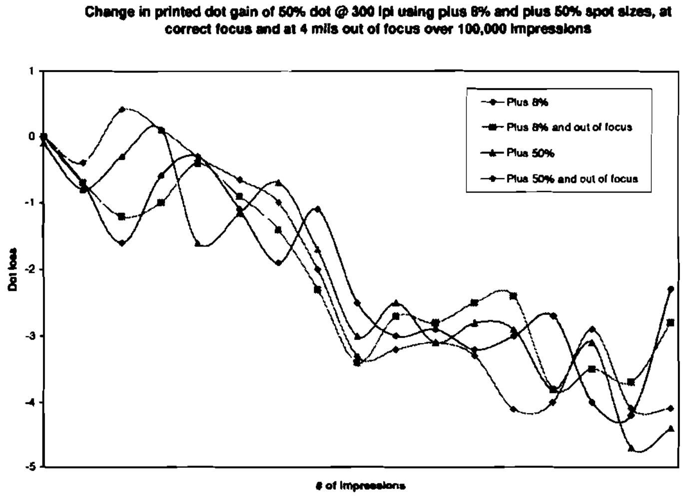


Figure 13. Press life is a good indicator of dot hardness on the plate. Although the data is somewhat noisy, figure 13 shows that there is virtually no difference in dot hardness between a spot which is oversized by 8% and one which is oversized by 50%, even when 4 mils out of focus. Also, this data is for a 300 lpi halftone. Typical work at lower screen rulings are even less affected by spot size and focus variations.

Conclusions

This has been a review of some of the main issues concerning spot size. Spot size and spot to pitch ratio have a direct influence on image resolution, depth of focus and exposure latitude. The press run for this paper did not show that spot size has a measurable effect on press life. Generally speaking though, smaller spot sizes are better than larger ones for CTP imaging. The final optical design is chosen only after careful consideration of cost, marketability, image quality, manufacturability, etc. Internal drum systems offer the ability to optimize the spot size for each addressability in a way that considers all imaging variables, some of which were reviewed in this paper. The author hopes that this brief review has been helpful in understanding some of the little known facts about spot size and imagesetting.

Appendix

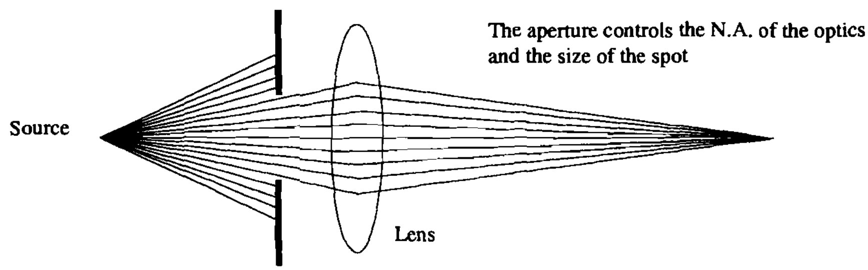
A closer look at optics

Numerical Aperture = the sine of the divergence (or convergence) angle

Internal drum

Internal drum recorders are capable of producing small spot sizes with low N.A.'s and great depth of focus primarily because they use a single, well controlled, laser. Spot size in internal drum recorders is determined primarily by the diffraction limit of the optical system. Diffraction is always present in an optical system and occurs when light waves pass by an opaque edge, such as an aperture. The edge of the aperture alters the wave form from its normal path. By making the aperture larger, the relative amount of diffraction is reduced and the spot can be focused to a smaller point.

Another way of looking at this is to think of the aperture as a frequency filter rather than a spatial filter. In order to resolve high frequency components of an image, such as sharp edges or small points, the N.A. of the optical system must be high. A larger aperture will allow more of the light waves at higher divergence angles pass through and a smaller aperture will clip these high frequency components. The smaller the aperture is made, the more high frequency component is lost, and the lower the N.A. becomes. When this happens, the focused image, or spot, will be larger. When the aperture is large, the spot size will be small.

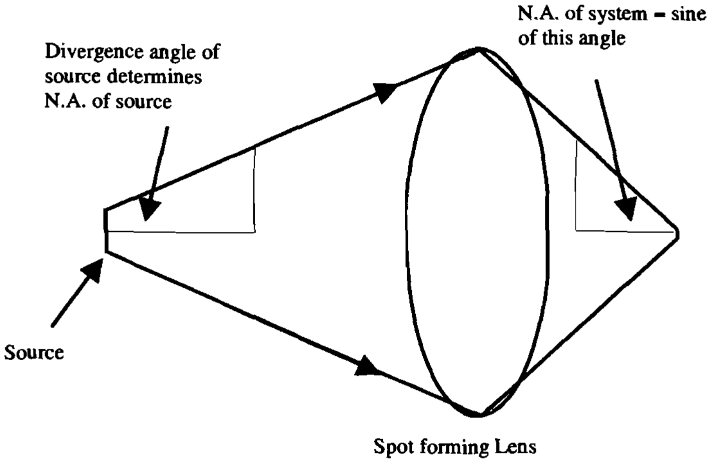


Spot size = Source size x Magnification

Magnification = N.A. of source/ N.A. at image plane

External drum

External drum recorders typically use laser diode bars. These are essentially a row of laser diodes placed next to each other, contained in a single unit. The multiplicity of diodes, combined with their extreme asymmetry (aspect ratio ≈ 150:1) results in a high source N.A. and a large source size. The product of these two specifications is one measure of the quality of the laser. This "quality" of the beam at the point of origin can be matched at the image plane, but not improved. Since the source size is much larger than the desired spot size, it must be de-magnified. This may be on the order of 10:1. In order to do this, the N.A of the beam at the image plane must be that many times greater than the N.A. of the source. Having established this, it is easy to realize that in order to achieve small spot sizes in external drum recorders using diode bars, the N.A. at the image plane must be very high.



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