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Rotating Diffraction Grating Laser Beam Scanner

J. C. Wyant

Optical Sciences Center, University of Arizona, Tucson, Arizona 85721.
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The resolution, bandwidth, and duty cycle of a laser beam scanner make it useful as an image recorder. Laser image recorders can have either a flatfield or a cylindrical recording surface, the flatfield being preferable in applications where dimensional stability is extremely important .[1] A problem with flat field recording systems is the difficulty in obtaining a constant scan rate. This difficulty is a result of the image position for a distortion-free lens being proportional to the tangent of the field angle, rather than the field angle itself. Hence, if the field angle changes at a constant rate (such as the case for rotating mirror scanners), the scan rate is not a constant. One method of eliminating this problem is to use a so-called f-0 lens, which produces a distorted image by the conventional definition, so the image height is proportional to the field angle.[2]

This Letter describes a second method of obtaining a linear scan rate for a flat field recorder. It is shown that by using two counterrotating diffraction gratings a constant angular mechanical motion can be used to give a nonuniform angular scan of a light beam. Under appropriate conditions, the angular scan is sufficiently nonlinear that when used with a distortion-free focusing lens a substantially linear scan rate results. The counterrotating diffraction grating scan system has been described previously by Brameley in U.S. Patent 3,721,486[3]; however, it was not pointed out that for appropriate grating parameters a substantially linear scan rate is obtained over a reasonable scan angle. Also, this paper demonstrates that similar results can be obtained using a single rotating diffraction grating folded back onto itself. The rotating diffraction grating scanner is capable of scanning more than one line at a time without line curvature. A 100% duty cycle can be obtained.

The rotating diffraction grating scanner is illustrated in Fig. 1. If two identical blazed diffraction gratings are illuminated with a quasi-monochromatic plane wavefront, as illustrated in the figure, and the gratings are counterrotated, the focus of the principal diffraction order will scan a vertical straight line in the focal plane of the focusing lens. If in the zero angle position the lines in the two gratings are parallel, when one grating rotates an angle α in the clockwise direction and the other grating rotates an angle α in the counterclockwise direction, the beam resulting from the +1 diffraction order of the first grating and the -1 diffracted order of this beam produced by the second grating is deviated by an angle θ, given by the equation

$$\theta = \sin^{-1}\left(\frac{2\lambda}{d}\sin\alpha\right), \qquad (1)$$

where d is the spacing of the grating lines and l is the wavelength. If the lens is distortion-free and has focal length f, the focused spot will move a distance l, given by the equation

$$l = f\tan\left[\sin^{-1}\left(\frac{2\lambda}{d}\sin\alpha\right)\right]. \qquad (2)$$

The interesting fact is that for certain values of d, l is nearly equal to $f(2\lambda/d)\alpha$, i.e.. the scan velocity is nearly proportional to the angular velocity of the gratings. The percent distortion, defined as

$$\left[\tan\theta - \left(\frac{2\lambda}{d}\right)\alpha\right] \Big/ \left(\frac{2\lambda}{d}\alpha\right),$$

vs scan position is illustrated in Fig. 2(a) for two different grating line spacings. The graphs show that the distortion increases slightly from zero up to a maximum positive value back down to zero distortion, after which the distortion increases rapidly. α_m, the value of α for which the distortion passes through zero and begins to increase rapidly in the negative direction can be obtained from Eq. (2) by writing the equality

$$\tan\left[\sin^{-1}\left(\frac{2\lambda}{d}\sin\alpha_m\right)\right] = \frac{2\lambda}{d}\alpha_m. \qquad (3)$$

α_m is thus given by the equation

$$\alpha_m = \pm\left[\csc^2\alpha_m - \left(\frac{2\lambda}{d}\right)^2\right]^{-1/2}. \qquad (4)$$

As illustrated in Fig. 2(a), increasing the grating line spacing from 1.69 µm to 1.74 µm reduced both the distortion for small scan angles and the value of a_m, for which the distortion begins to increase negatively at a rapid rate. It is obvious that in selecting the grating line spacing a compromise must be made between the maximum amount of distortion and the maximum scan position.

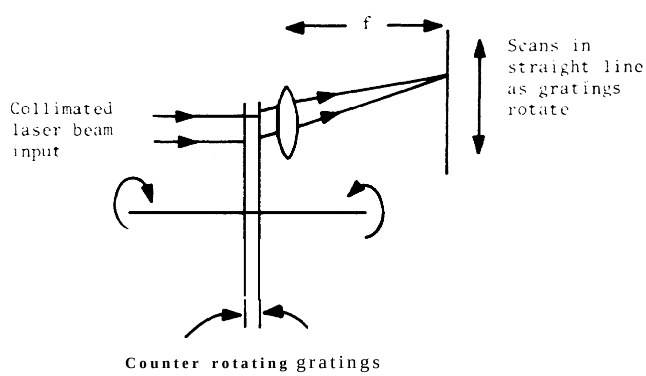
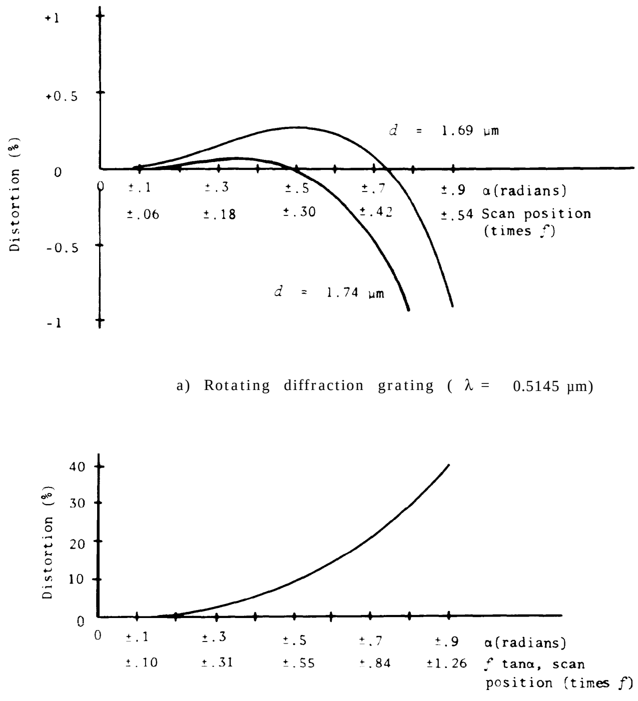


Fig. 1. Rotating diffraction grating laser beam scanner.



a) Rotating diffraction grating (λ = 0.5145 μm)

b) Rotating mirror scanner

Fig. 2. Percent distortion vs scan position. (a) Rotating diffraction grating (λ = 0.5145 μm). (b) Rotating mirror scanner.

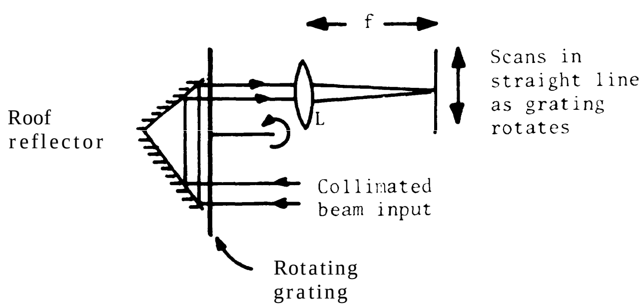


Fig. 3. Rotating grating scanner using single grating.

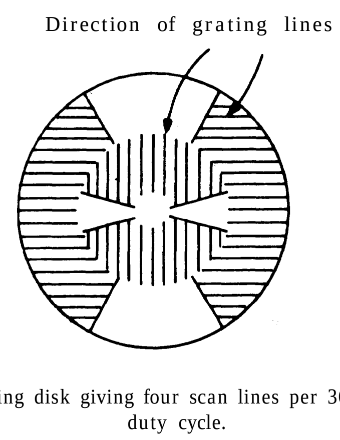


Fig. 4. Grating disk giving four scan lines per 360° and a 100% duty cycle.

Figure 2(b) shows the distortion (or nonlinearity) that would be obtained if the scan were achieved by using a rotating mirror and a distortion-free lens over a flat format. In this case the distortion is given by $(\tan\alpha - \alpha)/\alpha$ The rotating diffraction grating is seen to give a much more linear scan than a rotating mirror.

Problems associated with having two gratings rotating at the same speed but in opposite directions can be eliminated by using a single grating in a setup where the optical system is folded back onto itself as shown in Fig. 3.[4]

Figure 4 illustrates what a grating might look like to give four scan lines per 360° rotation. As the beam produced by the grating on the outer portion of the disk scans out of the format, the beam produced by the grating on the inner portion of the disk scans into the format, and vice versa. By choosing the proper format size, only one scan line is present at a given time; and a 100% duty cycle can be obtained. If the disk is 15 cm diam and the grating line spacing is 1.7 μm, a 23-cm format can be scanned at about f/10.

By illuminating the grating simultaneously with two or more beams of light that are tilted with respect to one another at the appropriate angle, more than one line can be drawn simultaneously without line curvature.

A possible problem with the diffraction grating scanner is that in addition to the desired diffraction order, other diffraction orders are produced As long as the sum of the diffraction orders for the two gratings that produce a given diffraction beam is not zero, the focused spot produced by the beam will not fall on the line of interest and can be eliminated by placing a mask in front of the film plane, which has a slit opening only in front of the scan line of interest. If the sum of the diffraction orders is equal to zero, the focused spot will scan along the scan line of interest, but at a different rate than the scan rate of the desired spot. Fortunately, the author's experience using Bausch & Lomb blazed diffraction gratings has been that all the undesired diffraction orders, with the exception of the zero order, have been so dim that they have not produced any problems. The zero order can easily be eliminated by placing a stop at the center of the scan line, since the zero order is stationary.

In conclusion, the diffraction grating scanner gives a nearly linear flat scan over reasonably large scan angles and should be' useful in applications where the nonlinearity of the conventional rotating mirror flat field format scanner is not acceptable.

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