Fiber Optic Reading Magnifiers for the Visually Impaired

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Stand magnifiers are popular aids, frequently prescribed in vision rehabilitation services, and are most commonly purchased by patients or their relatives over the counter. Thus, they serve as the only aids for many of the visually impaired who do not gain access to low vision services. The popularity of stand magnifiers is a result of the fact that they are easy to use and simple to learn to use. The fixed object to lens distance provides a stable and focused image at all times. Despite these advantages optical lens stand magnifiers have numerous shortcomings. The main complaint directed at existing stand magnifiers is the need to bend over the magnifier in order to be able to read through it (Spitzberg et al., 1989), which is very tiring for elderly users. The postural problems associated with stand magnifiers also complicate the attainment of proper illumination. The user's head tends to block light from above, while the need for light access through the sides of the magnifier makes for an uncomfortable and difficult grip. One novel design incorporating a prism to tilt the image's angle has been reported by Spitzberg et al. As is the case with all other optical magnifiers, stand magnifiers are also limited by distortions and vignetting. Typically their field of view is smaller than other equivalent power devices (Cohen & Waiss, 1991), preventing binocular use in most cases.

We describe the application of fiber optics technology to provide stand magnifiers with better optical and ergonomic properties specifically designed for use as low vision reading aids. The fiber optic reading magnifier we describe eliminates, or substantially reduces, all of the limitations listed above. The fiber optics magnifiers provide bright, uniformly illuminated, distortion free images. The magnified image may be seen without banding directly over the magnifier and can be easily combined with spectacle reading aids, thus providing significantly improved stand magnifiers for use by the visually impaired.

Optical Characteristics of Fiber Optics Tapers

Fiber optic tapers consist of a large number of optical fibers fused together to form a coherent bundle that can transmit an image from one end to the other. The bundle is heat formed by stretching such that its diameter varies from one end to the other. In this process, each individual fiber is stretched and tapered as well. When such a fiber optic taper is placed with its small face in contact with an object, an enlarged image appears on the larger upper face. The magnification is simply the ratio of the diameters of the end faces. Magnifications of 3x–5x are practical. A taper used as a magnifier also efficiently gathers ambient light from the surroundings (such as ceiling lights). The illumination thus obtained often exceeds the illumination reaching the same object (the printed page) without the taper. This light gathering capability is proportional to the square of the magnification of the taper.

The numerical aperture (N.A.) of optical fibers is a measure of the angular width of the cone of light which is captured by the fibers. This is a measure of the angle of obliquity at which an image is still observable on the face of the bundle. Beyond this angle, the image fades off. For a fiber of uniform diameter, the nominal or intrinsic numerical aperture is determined by the refractive indices of the glasses which comprise the fiber core and the cladding. It is given by:

$$N.A. = n_0 \sin\alpha = \sqrt{n_1^2 - n_2^2} \qquad (1)$$

where n_0 is the refractive index of the external medium (for air $n_0 = 1$), n_1 is the refractive index of the fiber core, and n_2 is the refractive index of the cladding. The angle α is the half angle of the cone of light "captured" by the fiber. This parameter is important in the use of a taper as magnifier

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$$\therefore \mathrm{N.A.}_{\text{large face}} = \frac{\mathrm{N.A.}_{\text{small face}}}{\mathrm{M}} \tag{2}$$

where M, is the magnification

The object field is the width or diameter of the small end of the taper, and is expressed in linear terms (e.g. 1.0 in). Typical newsprint is about 15-17 letters/inch. Thus the size of the bottom face is determined by the number of letters that need to be displayed simultaneously. As a magnifier is scanned across a page of text, one can define the total field of text that can be read through the magnifier without change in body posture. This scannable field is very small for a typical optical stand magnifier. In the case of the Fiber Optic Reading Magnifier (FORM), it is determined by the $\mathrm{N.A.}_{\mathrm{Eff}}$. The innovation presented below of tilting the face of the FORM towards the observer allows for a doubling of the scannable field. The large scannable field is one of the main advantages of the FORM over an optical lens magnifier.

Image resolution in fiber bundles is determined by the fiber size. Typical tapers produced for medical and military applications have very high resolution with fiber diameters of 6-10 µm at the large end. For persons with low vision, the image resolution of the magnifier need not be as high, and thus tapers of lower resolution (that is larger fibers) may be used to reduce the cost of the device. For low vision observers, even the resolution obtained with 250 µm fibers may be unnecessarily high. We have constructed tapers with fibers of 240–300 µm diameter. Such tapers require as little as 1/1000th of the number of fibers require for high resolution tapers of the same size and thus permit significant reduction in manufacturing costs.

Each fiber in the taper is composed of a high index core glass covered by a lower index cladding glass. Only the cores transmit imaging light. The imaging light transmission of a fiber optic taper is given in terms of the internal transmittance of the core glass of the fibers, the Fresnel reflection losses at the faces, and the packing fraction (P.F.). The Fresnel factor is a function of the refractive index of the core glass n. For $n = 1.8$, light transmission is reduced by as much as $1\text{-}0.92^4 = 29\%$. Light transmission may be increased if anti-reflection coating is used. The P.F. is the ratio of core area to the total taper face area (i.e. core + cladding). The thinner the cladding is the higher the P.F. The P.F. of commonly used tapers is on the order of 75%. The large cladding ratio of non imaging scattered light which in turn limits the contrast transferred through the taper. Due to the lower resolution requirements of the FORM, the fiber may be quite large, while the actual cladding thickness can be maintained, and thus the packing fraction can be high (> 90%), resulting in a concomitant improvement in contrast ratio transfer through the taper. We have demonstrated such improvement.

Increasing the Scanning Field of a Taper Magnifier

One of the major advantages of the FORM is its ability to be moved, i.e. scanned, across a relatively large area of an object, such as a printed page, and still display a bright, sharp image. We have defined the scanning field as the distance the magnifier can be moved (L in Fig. 1) while the head is fixed in one position (head or eye tilt is allowed). The scanning field can be increased by slanting the taper to tilt the image towards the observer. Such slanting can be achieved in a variety of ways (Peli, 1994). The simplest method of tilting the upper face of the taper toward the users is by cutting and polishing the smaller bottom face of the taper at a bias (Fig. 1). From Fig. 1 it can be shown that

$$\begin{aligned} \mathrm{D}+\mathrm{L} &= \mathrm{H}\tan(\theta+\alpha) \\ \mathrm{D} &= \mathrm{H}\tan(\theta-\alpha) \\ \therefore \mathrm{L} &= \mathrm{H}\left[\tan(\theta+\alpha)-\tan(\theta-\alpha)\right] \end{aligned} \tag{3}$$

where $\sin\alpha = \mathrm{N.A.}_{\mathrm{Eff}}$ and θ = tilt angle of taper.

For the nominal case when $\mathrm{D} = 0$ and the FORM is scanned from just under the eyes and away from the observer, the optimal tilt angle is $\theta = \alpha$. Smaller tilt angles ($\theta < \alpha$) will result in a loss of scanning range, and larger angles are possible but will force the scanning range away from the user (D > 0). Table 1 gives the calculated and measured scanning fields for a number of the low resolution tapers we have developed.

In addition to providing an increased scanning range, these tilted tapers also provide better control of illumination. Control of illumination is achieved both in collecting the ambient light and in avoiding the glare resulting from specular reflections from the upper face of the taper. Due to the tilt of the upper face, rotation of the taper around a vertical axis permits the user to include within the taper's admittance cone an off-axis light source (a window or a ceiling light fixture) which would otherwise be outside the admittance cone of the same taper without the tilt. Once a source lies within the admittance cone its light is concentrated by the taper and results in a brighter image. Specular reflections from bright sources which would be reflected from the polished upper surface of the taper can also be redirected by the same slight rotation of the taper away from the user's eyes. Such reflections are almost impossible to remove from the curved surface (or surfaces) of a lens magnifier.

Scanning Range of FORMs and Optical Magnifiers

The scanning ranges of two pairs of tapers were measured and compared with the scanning range of 3 commercially available commonly used lens stand magnifiers. FORMs had the equivalent viewing distance (EVD) of 12.5 and 8.3 cm for the 2.0x and the 3.0x respectively, and for an eye to lens distance of 25 cm (Bailey & Bullimore, 1989). The lens magnifiers tested had EVDs (for the same distance) similar to the EVD of the 2.0x FORM (see Table 2). The results of the ranges measured by three observers are included in Table 1 and show that the FORMs measured scanning range agree well with the calculated range. The advantage of the FORMs over the lens magnifiers is apparent (compare Tables 1 and 2). Note that the range of the tilted FORM (bold entry in Table 1) is almost double that of the equivalent lens magnifiers even though a cut of less than half the optimal angle was used. The actual benefit of the FORMs is even larger than that indicated by the numerical results since the image through the lens magnifiers becomes highly distorted even at distances much less than the scanning range.

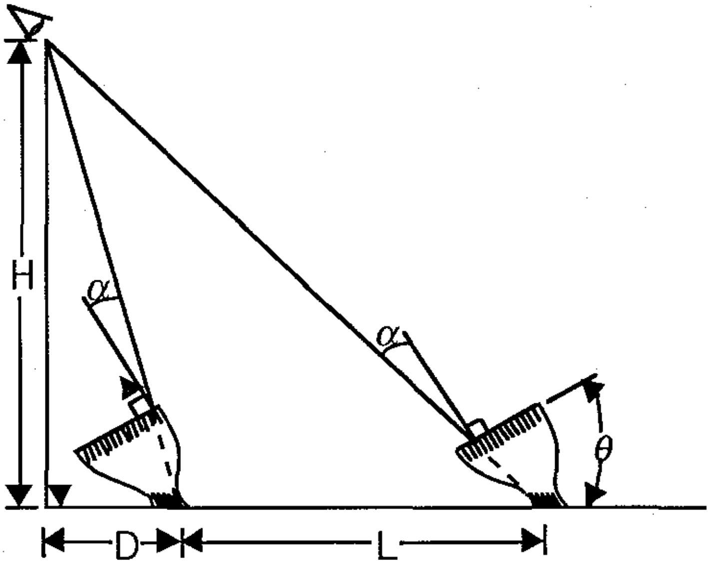

Fig. 1. Parameters associated with the calculation of scanning field.

Table 1: Measured Scanning Fields of FORMs

NA (nominal)	Mag (M)	Admittance (α)	Tilt (θ)	Measured Range	Calculated Range (L+D)
1.0	2.0x	30.0°	0°	6.77"±0.59"	5.77"
1.0	**2.0x**	**30.0°**	**13°**	**9.83"±0.68"**	**9.33"**
1.0	3.0x	19.5°	0°	3.28"±0.25"	3.54"
1.0	3.0x	19.5°	12°	6.08"±0.22"	6.12"

Table 2: Measured Scanning Fields of Lens Stand Magnifiers

Type	Mag(Marked)	EVD(@25 cm)	Measured Range
Eschenbach 2627	4.0x	13.3 cm	4.50"±0.50"
Coil 5214 tilted	4.0x	12.3 cm	5.75"±0.43"
Selsi #402 Jupiter	4.0x	11.1 cm	4.33"±0.29"

Discussion

The outstanding performance of tapers as reading magnifiers are self evident. We believe that the only obstacle to wider use is the high cost. Therefore, we are working to produce 300 fibers per linear inch input FORMs of useful magnification using materials and production designs that will bring the price into an affordable range. The increase in the fiber size allows two or more steps to be eliminated from the manufacturing process. With the simplification of the manufacturing process and the use of lower cost glass for the fibers, the manufacturing cost can be reduced sufficiently to make the device affordable for the many visually impaired persons that could benefit from them.

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