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Optical Fibers for Scanning Digitizers

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Automated graphic activities such as computer cartography and computer-aided design require document-scanning systems that are stable, fast, and capable of handling large drawings and maps. In such a system the scanning assembly should accept documents readily and be compact and inexpensive enough to encourage wide usage. An attractive method for such automatic scanning and digitizing of engineering drawings combines optical fibers with a solid-state imaging array and a stepped friction feed. In this paper we describe an assembly of these elements employing a light-guide illuminator and receiver that are in direct contact with the drawing. Light signals, modulated by the dark areas on the drawing, are transmitted from the linear end of the lightguide to a grid configuration at the opposite end. The signals are optically coupled to and detected by a solid-state array sensor that scans the grid of optical fibers. The dimensional control necessary for fabricating the fiber grid to match the configuration of the solid-state array is critically important for the operation of this type of scanner. We therefore emphasize in this paper the dimensional requirements for the glass fiber assembly, the signals detection, and the accuracy of scanning.

I. INTRODUCTION

Document scanning systems for automated activities such as electronic mail, computer cartography, and computer graphics require an image-guiding system to capture visual details for conversion to electronic signals. The image arrangement is combined closely with, and influences the design of, the document-positioning mechanism. The document can be illuminated by diffused light in the general scanning area, the bounced light optically projected through a tiny aperture onto an appropriate sensor (flying aperature scanners), or by spot lighting where a tiny spot of light is projected onto the copy and the bounced spot is picked up directly by the sensor (flying spot scanners).

The surface condition alters the light that is reflected to the photoelectric detector during the scanning. Documents are scanned electronically, mechanically, or in combination, with the portion of the document being scanned mounted flat or in a circular arc.

The physical dimensions of scanning assemblies are controlled by the size of the document and the light paths required to scan the surface. In most assemblies, lenses and mirrors are combined with rotating or translating document holders.[1] In more recent assemblies, stationary copy is scanned by a flying spot from a cathode-ray tube,[1] a charge-coupled photodiode array,[2] or an acousto-optically modulated laser.[3,4] Optical fibers are also used to pipe light from the document to a rotary scan head or solid state image sensor.[5] In this paper, we describe the performance characteristics of a flying-spot type of optical fiber scanner that has inherent advantages for digitizing large documents. This paper gives special attention to glass fiber characteristics required to construct this new potentially low-cost scanning digitizer.

II. OPTICAL FIBER SCANNER

A digitizer must scan the document to resolve the line and character information into small picture cells or pixels. The optical response at each pixel is then used to control detection circuitry to generate positionally defined digital output. In general, the drawing can be scanned in one of three ways: individual pixels can be addressed in a series of parallel sweeps across the drawing surface; groups of pixels can be addressed by a sensor array that is stepped over the drawing; pixels can be addressed sequentially in parallel sweeps to locate lines and marks on the drawing that are subsequently followed or tracked. In all methods, some form of parallel scanning must first be made to locate the line information to a prescribed resolution. As will be shown for scanning large documents, optical fibers, suitably arranged for a raster output (method 1), offer high resolution, geometric fidelity, stability, and mechanical simplicity—all in a very compact assembly.

Figure 1 shows the schematic representation of an optical fiber scanning digitizer. Light is transmitted from the source via a multiplicity of lightguides to uniformly illuminate a narrow strip across the drawing. The fibers at the light source are randomized in a compact circular group and are illuminated with a small lamp. The receiver consists of a similar number of optical fibers as the illuminator. These are oriented in a line at one end and as a matrix or grid at the other end. The linear end of the illuminator and receiver are geometrically similar and located adjacent to each other in the fixed scanner head. Drawings are positioned directly against the fixed head by a spring-loaded pressure plate. The drawing is moved past the read head in small increments by rubber-coated friction rollers driven by a preci-

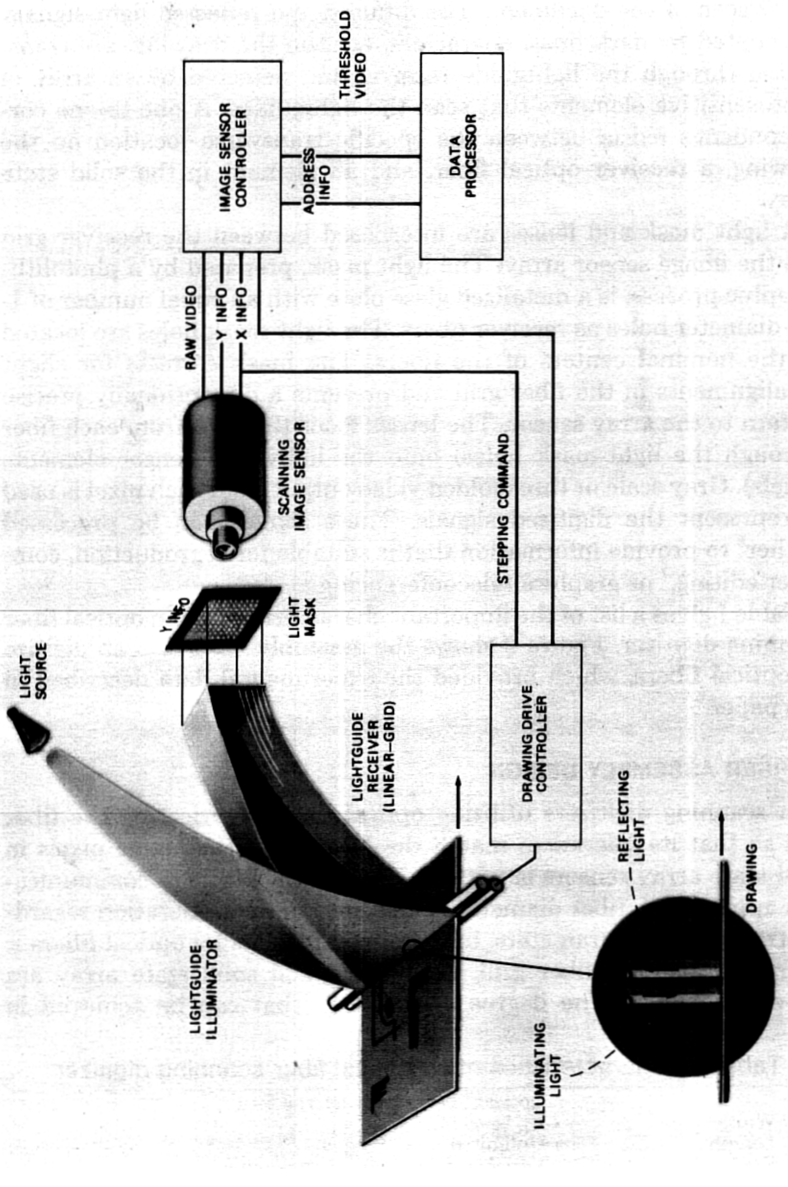

Fig. 1—Schematic representation of an optical fiber scanning digitizer.

sion-stepping motor. The stepping motor, operating at a few milliseconds per incremental movement, is driven by a sensor controller. The paper is moved when the controller signals that it has completed a linear scan of the document. The diffused and reflected light signals, attenuated by dark lines, characters, etc., on the drawing, are transmitted through the lightguide receiver and detected by an array of photosensitive elements that scan the lightguides. A one-to-one correspondence exists between the specific transverse location on the drawing, a receiver optical fiber, and an element in the solid state array.

A light mask and lenses are interposed between the receiver grid and the image sensor array. The light mask, prepared by a photolithographic process, is a metalized glass plate with an equal number of 1-mil-diameter holes as receiver fibers. The light-mask holes are located on the nominal centers of the fibers. The mask corrects for slight misalignments in the fiber grid and presents a dimensionally precise pattern to the array sensor. The lenses focus the light from each fiber (through the light-mask holes) onto the individual sensor elements (pixels). Gray scale or thresholded video output from each pixel is used to represent the digitized signals. These signals can be processed further[6] to provide information that is suitable for reproduction, computer editing,[7] or graphics teleconferencing.[8]

Table I gives a list of the important characteristics of an optical fiber scanning digitizer. Figure 2 shows the assembly used to scan digitize by optical fibers, which provided the experimental data described in this paper.

III. FIBER ASSEMBLY DESIGN

In scanning digitizers utilizing optical fibers, fabricating the fiber grid so that its tolerances match the location of the active pixels in solid state array sensors is critically important. While in communication applications fiber diameter is an important consideration regarding transmission parameters, in scanning digitizers by optical fibers it is crucial that the fiber grid, hole mask, and solid state array are correctly aligned. The degree of precision that can be achieved in

Table I—Characteristics of an optical fiber scanning digitizer

Type	Optical fiber/CCD array/roll feed
Copy Width	Up to 40 in.
Copy Length	Unlimited
Copy Feed	Variable, 1 ms/0.004 in. maximum
Scan Resolution	Variable, dependent on fiber diameter and spacing
Maximum Pixel Rate	10 mH (present maximum)
Output	Gray scale or threshold video
Size	Desk top (10 in. high, 20 in. deep, and 50 in. wide)

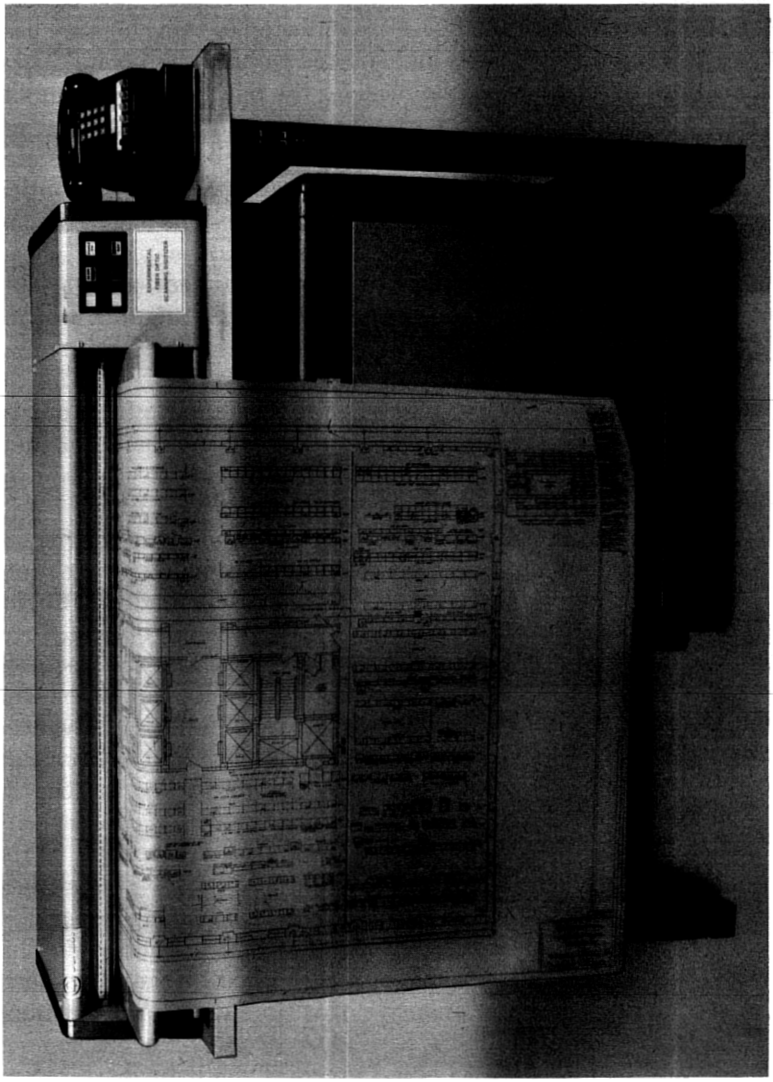

Fig. 2—Feasibility model of an optical fiber scanning digitizer.

positioning the fibers in a grid depends on the dimensional control of the fiber elements and the mode of fabrication of the assembly.

Problems arise in the construction of scanner grid assemblies that are similar to problems with fiber optic array connectors. In two-dimensional array connectors, the alignment mechanism is either a hole mask through which the fibers are threaded or thin chips are used that are grooved on both sides and stacked to hold the fibers.[9] These methods work well and are economical for the relatively small number of fibers in cable. However, for aligning fibers for scanners that use many thousands of fibers, construction processes should be automated to avoid handling individual fibers. A method of forming plastic optical waveguide by selective photopolymerization[10] offers one means of mass fabricating large linear arrays.[11] Unfortunately, the plastic sheets would cause fabrication problems. For example, dimensional variability of the sheet thickness would cause an imprecise alignment of the lightguides in the grid. A method that can be used successfully involves wrapping continuous fiber on a drum with a transverse groove for the subsequent injection of adhesive to fuse the assembly to form precise linear arrays. Further, the linear array can be split into bands of equal amounts of fibers for subsequent stacking into grids of the required configuration.

Figure 3 shows dimensional requirements for individual fibers and for the cross section of bands of fibers that are assembled by the drum method. In this example, there are 100 fibers in each band (250 fibers/in.). The 0.004 in. diameter (101.6 μm) is typical for optical fibers currently fabricated for communication systems, but the required tolerance of ±0.00001 in. (±0.25 μm) standard deviation is well beyond normal practice. To achieve this precision requires using advanced fiber drawing control[12] and instrumentation systems that use noncontacting on-line diameter measuring.[13,14] As shown in Fig. 3, fibers in the band are uncoated and are positioned in tangential contact with each other. Epoxy fills the interstitial spaces on the bottom of the band. The adhesive joins the fibers together and forms a flat surface that is used to support the stack of other bands in making the grid.

Figure 4 shows an enlarged portion of a grid assembly. In this assembly, the vertical dimension is also controlled by the fiber diameter. A second application of adhesive, this time to fill the remaining interstitial spaces between fibers, is used to secure the bands to form a compact and precise grid. As noted previously, a light mask placed over the grid can compensate for minor misalignment induced by slight variations in fiber diameter and processing. The light mask consists of an array of 10,000 0.001-in. holes, located on 0.004-in. centers. The mask is fabricated by the same technology used for solid state sensor arrays. The final assembly therefore provides a grid of tiny emitting

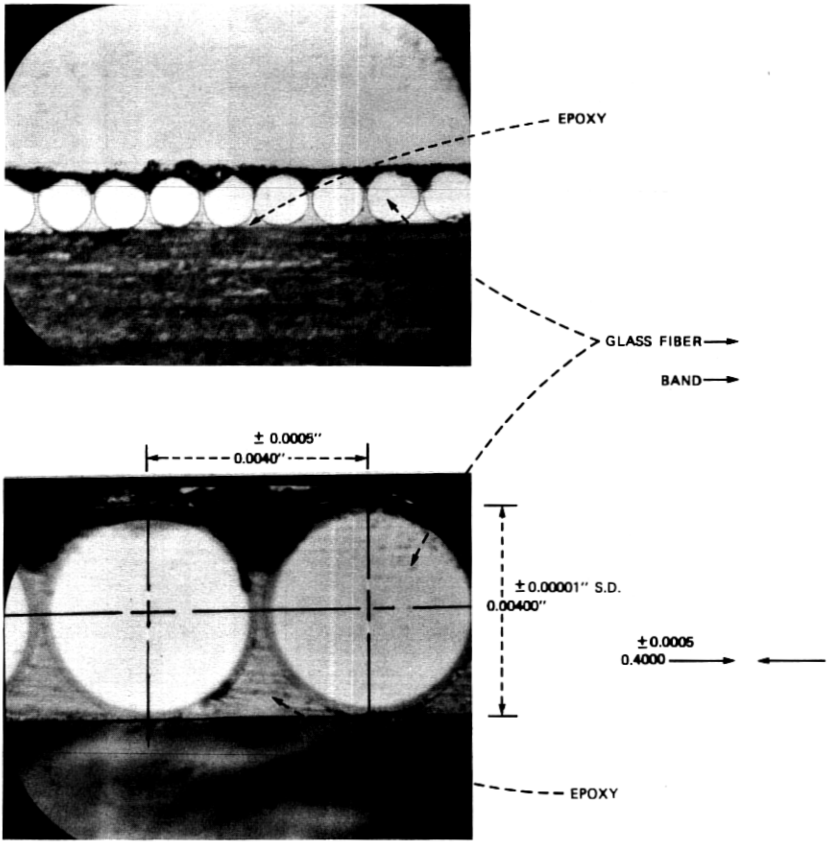

Fig. 3—Dimensional requirements for optical fiber linearly aligned lightguides at 250 bits/inch resolution.

holes with dimensional control similar to that obtained in solid state array fabrication.

IV. SCANNER PERFORMANCE OF FIBER OPTICS

Figure 5 shows the results of scanning a test pattern to evaluate the characteristics of a fiber assembly made by the drum and band method. Lines on the test pattern, varying in width from 0.0040 in. to 0.0145 in. produce detectable signals via the 0.004-in. diameter fibers. Fibers used in this test are of stepped-index type with a 0.7 core to cladding diameter ratio. The fibers are spaced nominally on 0.004-in. centers. As shown in the figure, this dimensional arrangement of fibers can resolve into discrete signal/line widths that are well below the 0.015 in. minimum that is the ANSI Y14.2 recommendation for engineering drawings.

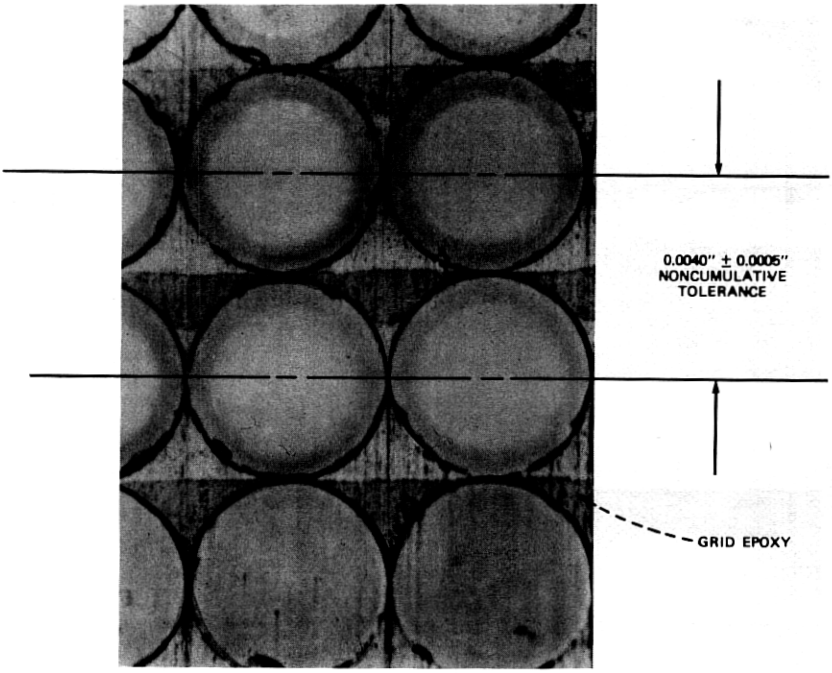

Fig. 4—Portion of optical fiber grid receiver.

In Figure 5 the digitized signals represent a partial scan across the drawing in the X direction. The absolute accuracy of scanned data in the X direction (perpendicular to the document motion), relative to the graphics on the drawing, is controlled by the positional alignment of the optical fibers as shown in Fig. 3. In the experimental unit each fiber is positioned within ±0.0005 in. to adjacent fibers, and each band of 100 fibers varies in width by at most ±0.0005 in. However, the placement of bands adjacent to each other to form the linear portion of the lightguide receiver introduces additional variations that cause apparent stretching or shrinking in the width of the engineering drawing. This effect can be compensated by an appropriate step in subsequent data processing to define the physical location of each lightguide rather than to assume the nomimal spacing.

Accuracy in the Y-direction scan is controlled by the rotational characteristics of the stepping motor and dimensional variation in the friction feed rollers. Commercially available gear-driven stepping motors operate with an accuracy of ±4 arc min. This results in a maximum single-step error of 0.00026 in. per step, but because of gearing, the error is noncumulative. Dimensional variations measured in experimental friction-feed rollers can contribute less than 0.2 percent variation to the individual step distance. This can produce a cumulative error and results in an apparent stretching or shrinking of the drawing in the Y direction. To obtain a more accurate digital rendition of the drawing, this condition can also be corrected by data processing.

Figure 6 shows the output from an experimental scanning digitizer for a portion of an engineering drawing. This display of thresholded video, as recorded in sections on a cathode-ray tube, shows the digiti-

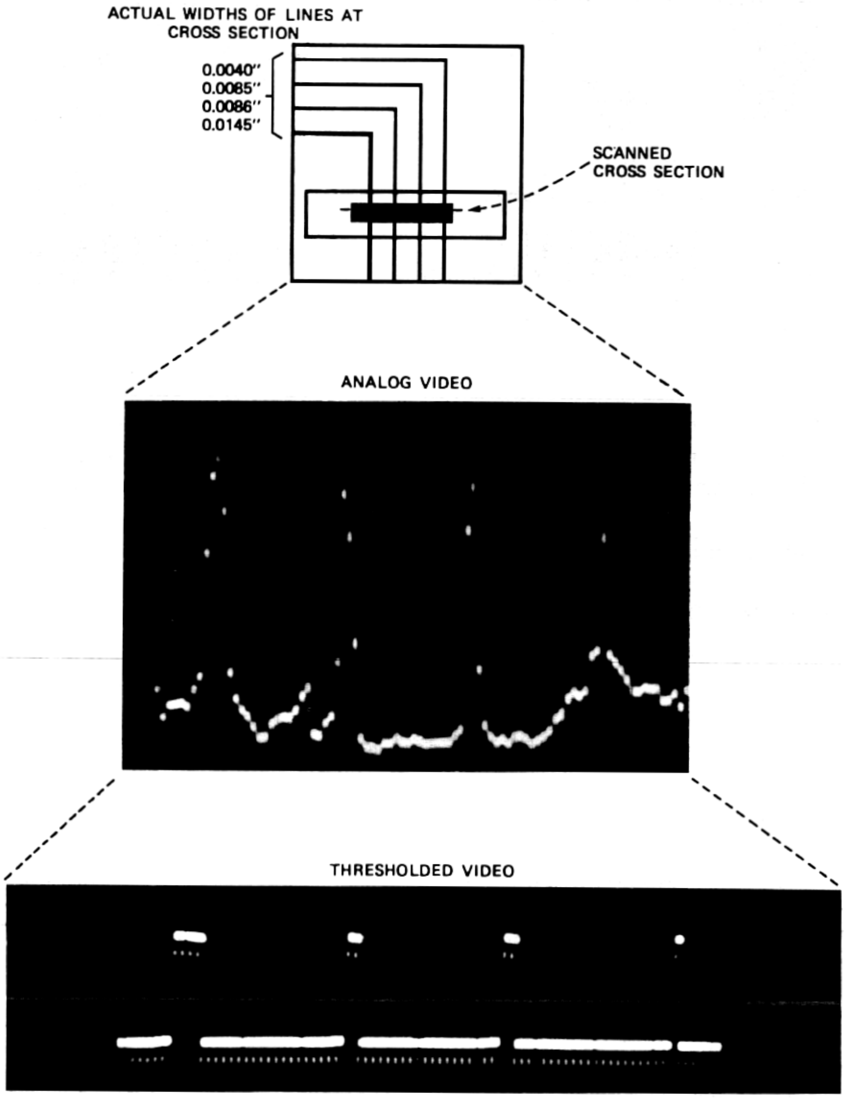

Fig. 5—Signals from a 250 fiber/inch scanner.

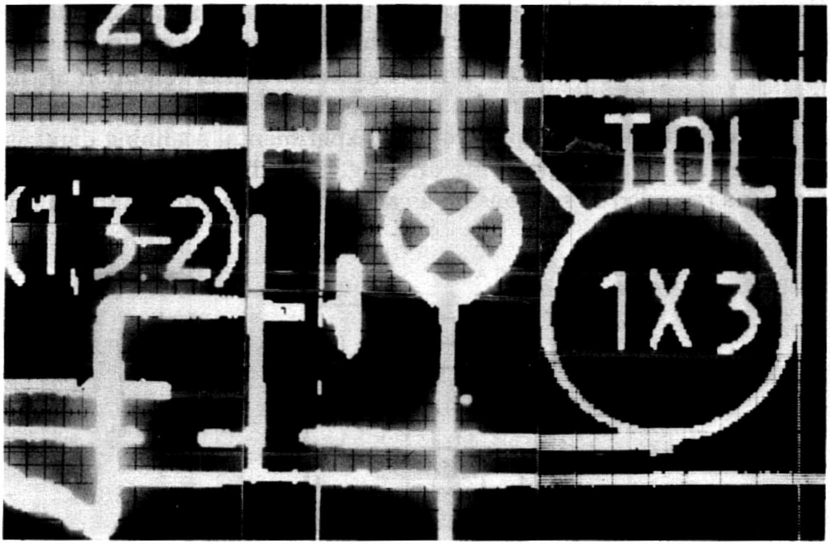

Fig. 6—Digitized output from an experimental optical fiber scanner as recorded in sections on a cathode-ray tube.

zation in the X and Y direction. Irregularities in the boundaries of the lines of the drawing appear as steps because of the digitization process. Files of this type can be processed further by computer for a variety of automated graphics activities. One use of this type of output is to create graphic files for computer-aided design systems.[15]

V. CONCLUSION

This paper has presented an overview of the considerations and requirements in the design of optical fibers for the scanning and digitizing of large documents. It shows that when combined with a solid state array and a roller feed, this type of assembly has distinct advantages. High resolution (250 bits per inch) can be obtained with fiber that has a diameter that is typical for communication systems. Geometric fidelity is inherent in the digitized output of this type of scanner because of the fixed-dimensional arrangement of fibers and the stepping motor-driven rollers. These aspects also contribute to the stability and mechanical simplicity of the assembly. Because the fibers are flexible, they can be folded into a compact arrangement to produce a desktop-size assembly for scanning the widest of engineering drawings. This type of assembly also permits convenient handling of the drawing with entry and exit from the front of the scanner.

Of critical importance to optical fiber scanning digitizers is the fabrication of the fiber grid to tolerances that match those of solid state array sensors. For very large grids construction processes must be automated to avoid handling of individual fibers. We have found that wrapping continuous fiber on a drum with a transverse groove for the subsequent injection of adhesive forms precise and stable linear arrays. Further, the linear array can be split into bands of equal amounts of fibers for stacking and fusing into a grid. To achieve the required precision for the fibers, instruments that use noncontacting on-line diameter measuring, as well as advanced drawing and feedback controls, are necessary.

Using optical fibers for scanning digitizers can open new possibilities for computer-aided design and engineering. The availability of a technology that permits compact, high-resolution, and stable scanners should encourage wider use than now exists for automatic digitizing. Coupled with advanced data compaction software, convenient-to-use low-cost scanners can serve as a new input means for graphics processing systems and can permit the conversion to data of the largest of existing and newly prepared engineering drawings.

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