

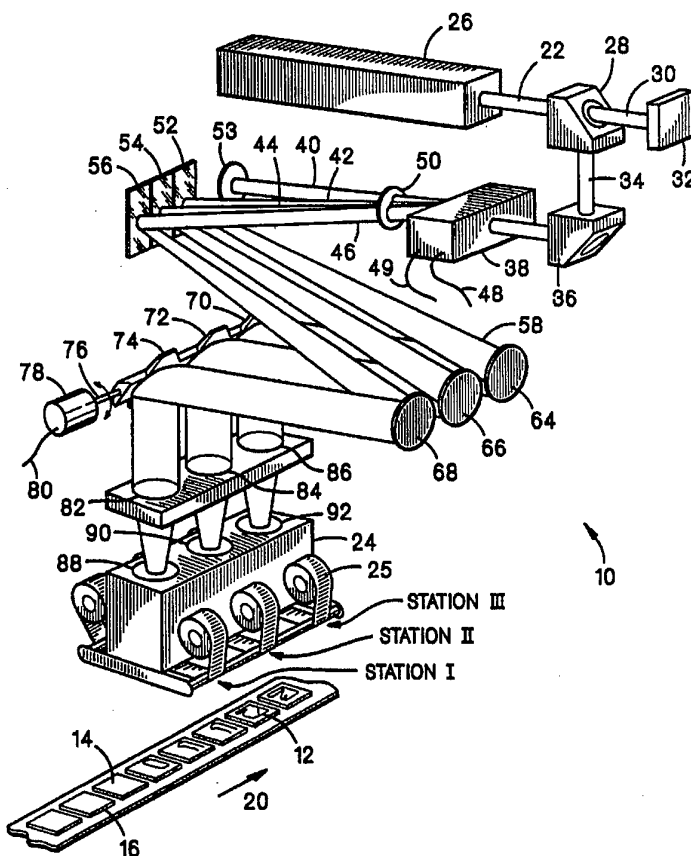


INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : G06K 15/02, B23K 26/06	A2	(11) International Publication Number: WO 95/13593 (43) International Publication Date: 18 May 1995 (18.05.95)
(21) International Application Number: PCT/US94/11407 (22) International Filing Date: 6 October 1994 (06.10.94) (30) Priority Data: 08/149,551 9 November 1993 (09.11.93) US (71) Applicant: MARKEM CORPORATION [US/US]; 150 Congress Street, Keene, NH 03431 (US). (72) Inventors: EMGE, Garry, J.; 42 Reservoir Street, Keene, NH 03431 (US). CARTER, Stephen, W.; 79 Gap Mountain Road, Troy, NH 03465 (US). (74) Agent: FEIGENBAUM, David, L.; Fish & Richardson, 225 Franklin Street, Boston, MA 02110-2804 (US).		(81) Designated States: CA, KR, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>Without international search report and to be republished upon receipt of that report.</i>

(54) Title: SCANNED MARKING OF WORKPIECES**(57) Abstract**

A technique for marking pixels on workpieces by routing a scanned beam to different markings stations to mark individual pixels on selected ones of the workpieces. Angular position of a scanning mirror in a raster scanner is determined by moving a beam, reflected from the scanner, across rulings on an optical element during scanning. A print head for printing spots on a surface of a workpiece has a walled, internally pressurized chamber with an external curved surface and structure for causing an inked web to conform to the contour of the external curved surface and to be pulled along the external curved surface. Two workpieces may be marked at two marking stations by two-directional scanning.



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SCANNED MARKING OF WORKPIECESBackground of the Invention

This invention relates to scanned marking of
5 workpieces.

A typical raster scanned printing system scans a laser beam along a succession of parallel rows on a workpiece, one row at a time, to form a pixel pattern representing a two-dimensional image. Scanning is done
10 by an oscillating mirror. During one direction of an oscillation a single row is scanned. The mirror is then quickly returned to its original position to begin scanning the next row. An optical encoder may be used to gauge the angular position of the mirror, to aid placing
15 the pixel marks at precise locations along each scan row.

The pixel mark may be formed using an ink coated foil that transfers a spot of ink onto the workpiece in response to receiving laser beam energy at a pixel site.

Summary of the Invention

20 In general, in one aspect, the invention features a technique for marking pixels on workpieces. The workpieces are positioned at respective marking stations for marking. A beam of radiation is directed along an optical path toward the workpieces. The beam is scanned
25 (e.g., raster scanned) to define an array of pixel positions. A switch routes the beam during the scanning so that for each of the pixel positions the beam may be routed to a selected one of the marking stations to mark one of the pixels on one of the workpieces.

30 Embodiments of the invention include the following features. The pixels marked on the workpieces are organized as partial prints associated respectively with the different marking stations. A processor causes each of the workpieces to be positioned at each of the marking
35 stations for a period which spans a complete scanning

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cycle of the beam. There is printing apparatus which responds to the beam for printing different colors of the pixels respectively at different ones of the marking stations. In some examples, the partial prints are
5 different for different workpieces. The marking stations include printing foils which respond to radiation from the beam by depositing pigment or dye. The switch may be an acousto-optic deflector controlled by the processor in response to stored information corresponding to the
10 pixels. The scanning apparatus includes an optical element for sweeping the beam along a scan line, and a mechanical element for moving each of the workpieces in a direction normal to the scan line. The processor causes each workpiece to be moved in succession to each of the
15 marking stations for marking with corresponding ones of the partial prints. In some examples, there are two of the marking stations and the scanning apparatus raster scans a series of scan lines; every other line is scanned in one direction and the intervening lines are scanned in
20 the opposite direction. The switch is arranged to cause marking of pixels on every other line at one of the marking stations, and marking of pixels on the intervening lines at the other of the marking stations. In some examples, the prints for the workpieces at the
25 two marking stations are identical, monochrome prints. In some examples, portions of the partial prints are identical for at least two of the workpieces and other portions (e.g., serial numbers) are different.

The stored image information comprises, for each
30 pixel location, a deflection value and an amplitude value. The stored information is fetched via a DMA channel of a computer during printing. The stored information is represented in a file format (e.g., .TIF) which has an associated palette matrix to which the
35 stored information points.

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In general, in another aspect, the invention features a technique for determining an angular position of a scanning mirror in a raster scanner. A source of a beam of radiation is aimed to be reflected from the scanning mirror during scanning. A ruled optical element receives the beam of radiation after reflection from the scanning mirror during scanning. The beam moves across rulings on the optical element during scanning. A detector receives the beam after it impinges on the ruled optical element for detecting when the beam moves across successive rulings during scanning.

Embodiments of the invention include the following features. The ruled optical element comprises a transparent substrate bearing parallel lines which obstruct the passage of the beam. A lens focuses the beam in the vicinity of the ruled optical element, and another lens defocuses and redirects the beam after it has passed through the ruled optical element, the beam being redirected to fall on the detector during scanning.

In general, in another aspect, the invention features a print head for printing spots on a surface of a workpiece. An ink medium in continuous web form is capable of responding to an intense beam of radiation by transferring spots of ink onto the surface. There is a walled, internally pressurized chamber having an external curved surface and structure for causing the continuous web to conform to the contour of the external curved surface and to be pulled along the external curved surface. The external curved surface is interrupted by an aperture permitting internal pressure in the chamber to be applied against the web as it is pulled along the external curved surface. The chamber has a transparent window for allowing the beam to pass within the chamber and strike the continuous web at the aperture, elements for causing the workpiece to be held with its surface in

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an orientation to receive spots of ink from the ink medium and to be moved towards and past the aperture at a distance near enough to the aperture to cause the surface to contact the continuous web along a linear contact
5 region and to disrupt the conformity of the web to the external surface at the contact region.

Embodiments of the invention include the following features. The external curved surface is parabolic. The aperture is located at an apex of the external curved
10 surface. The external curved surface is flat in a dimension normal to the dimension in which the curved surface is parabolic, and the aperture extends across the flat dimension. The aperture does not extend completely across the curved surface. The continuous web is pulled
15 along at a velocity which is approximately the same as a velocity of motion of the workpiece relative to the print head, or the velocity at which the web is pulled is sufficiently different from the velocity of motion of the workpiece to impart a small shear force between the web
20 and the workpiece.

In general, in another aspect, the invention comprises a technique for marking two workpieces in which two-directional scanning apparatus scans the beam to define successive rows of pixel positions in an array,
25 some of the rows being scanned by scanning motion in a first direction, others of the rows being scanned by scanning motion in an second direction opposite to the first direction. The beam is directed to scan some of the rows at one of the marking stations and others of the
30 rows at another of the marking stations. In embodiments of the invention, every other one of the rows is scanned in the one direction at one of the marking stations, and the intervening rows are scanned in the opposite direction at the other one of the marking stations.

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Among the advantages of the invention are the following.

The invention is capable of producing an n color image by operation at n printing sites on a wide variety of substrates limited only by mechanical space and timing constraints. Variations are capable of producing process color with some degradation of throughput by overwriting existing scan lines (which would require two or more images with differing pixel parameters and would be slow). The n colors are realized with only a single laser and optical beam deflection/modulation mechanism, instead of n lasers/modulators, while high process rates are maintained.

The use of standard 256 color/indexed color .TIF file formats to define the image pixels has the advantage of permitting a variety of available software packages to be used to create the images. Use of the .TIF palette cells to directly define color/deflection, and amplitude eliminates the software and hardware overhead needed for look up table operations. Because only one byte is fetched per pixel, hardware bandwidth requirements are low and data transfer is very fast. Sixteen level grey scale printing will be possible using appropriate printing foils (coated webs). The .TIF format tag fields may be used for automatic setup to print a variety of dot densities, scan line lengths and number of scan lines. Images could be printed as composites of different files.

Using a non-rotating data storage medium to pass the image files from the image generation computer to the print control processor allows a separation of the two functions between an office and a printing location; but also permits them to coexist side by side at the printing location. In some environments it may be useful to isolate the machine operator from access to image generation functions, for quality control.

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The scanner encoder which reads directly from a beam reflected from the scanner itself is more accurate, repeatable and linear than analog position sensors (e.g., variable capacitors). The encoder is also accurate in
5 the face of a need for extremely high resolution, is generally invulnerable to vibrational modes of the scanner, and is unaffected by shaft flexibilities.

Other advantages and features will become apparent from the following description and from the claims.

10 Description

Figure 1 is a perspective schematic view of a scanned marking system.

Figure 2 is a schematic plan view of fragments of workpieces being marked.

15 Figure 3 is a schematic side view of a scanner angle encoder.

Figure 4 is a block diagram of control circuitry.

Figures 5, 6, 7, and 8, are perspective, side, bottom, and side views, respectively of a print head.

20 Figures 9, 10, and 11 are side views of an alternative print head.

Figure 12 is a side view of an alternative print head.

Figures 13 and 14 are diagrams of the motion of a
25 scanning over time for one directional and bi-directional scanning.

Figure 15 is an alternative scanning scheme using a single scanning mirror and scan lens.

Figure 16 is a top view of an image on a
30 workpiece.

In a scanned marking system 10 (Figure 1) for marking three-color images 12 on the surfaces 14 of a series of integrated circuit packages 16 being stepped along a production line in a direction 20, a laser beam

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22 is routed through a series of optical elements and ultimately through a print head 24 where it strikes print foils 25 to apply ink to the surfaces. (In Figure 1, for clarity, the packages 16 are shown at a distance below the print head. During actual printing, the bottom of the print head is adjacent to, and the foil contacts, the surfaces of the packages.)

Laser beam 22 is a beam supplied from a relatively inexpensive 25 watt CO₂ laser 26. Beam 22 has a diameter of about 3 mm. In a beam splitter 28, the beam is divided into two beams at right angles to one another. One beam 30 is delivered to a power meter 32 which detects the power in the beam and delivers an output signal in a feedback loop to control operating parameters to keep the output power of the laser at a desired level (e.g., 25 watts). The second beam 34 is reflected at a right angle by a plane mirror and delivered through an acousto-optical deflector 38. The deflector is spaced along the optical axis of the system at a sufficient distance from the laser not to be within its near field (e.g., 8"). The deflector is capable of allowing the beam to pass through along direction 40, and of redirecting (switching) a portion of the beam to any one of at least three predetermined new directions 42, 44, 46 at high speed under control of a deflection input signal 48. The deflector is also capable of altering the amplitude of energy delivered by the beam by controlling what fraction of the beam is redirected in response to an amplitude signal 49. Although the figure shows three simultaneous output beams 42, 44, 46 for clarity, in operation there is a single beam which may be switched among the three paths shown.

When the beam passes in the unswitched direction 40, it strikes a beam stop 53; this is done when the deflection input signal 48 indicates that no pixel is to

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be marked. Switching the beam to any of the other directions 42, 44, 46 causes it to form a mark at a pixel location on a selected one of three of the integrated circuit packages located at one of three printing
5 stations defined by the print head.

All paths leading from the deflector pass through a long focal length plano-convex lens 50. When the beam is directed along path 42, 44, or 46, lens 50 serves to focus the beam as a small spot on a corresponding one of
10 three convex mirrors 52, 54, 56 at a distance of about 30" from lens 50.

The three mirrors are configured and mounted so that they respectively reflect the beam along one of three slightly divergent paths 58, 60, 62 causing it to
15 strike a corresponding one of three concave mirrors 64, 66, 68. The convexity of each of the mirrors 52, 54, 56 causes the beam to diverge as it passes to the corresponding one of the mirrors 64, 66, 68. Mirrors 64, 66, 68 collimate the beam to a diameter of about one inch
20 and direct the beam to a corresponding one of three planar mirror sections 70, 72, 74 of an oscillating machined aluminum scanner 76. Scanner 76 is driven to swing back and forth about an axis of a shaft by a brushless DC motor 78 operated so as to simulate a
25 galvanometer scanner and controlled by a signal 80.

Each of the scanning mirror sections reflects the beam through a corresponding one of three focusing lenses 88, 90, 92 and into a corresponding one of three printing sections of print head 24. Each lens 88, 90, 92 is a
30 flat field scanning lens. Lenses 88, 90, and 92 are custom designed for use at the wavelength of a CO₂ laser.

Other lasers could be used, for example, a YAG laser or a HeNe laser.

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Three-Color Marking

In a finished image 90 (Figure 2) marked by the system shown in Figure 1, each pixel location may have any one of three colors (A, B, or C) or may have no
5 color. The pixels which are to be in color A are printed at station I, the pixels which are to be in color B are printed at Station II, and the pixels which are to be in color C are printed at station III. During printing, all three stations may be occupied simultaneously by surfaces
10 to be printed. The printing of pixels at the three stations is interleaved.

A complete marking cycle for printing a full-color image on a surface includes three subcycles in which the surface successively occupies positions at the three
15 stations I, II, and III. For example, in a first subcycle a surface 92 receives color A at station I (in the form of a partial print corresponding to color A), while a second surface 94 receives a color B at station II (in the form of a partial print corresponding to color
20 B), and a third surface 96 receives color C at station III (a partial print for color C). In the second subcycle, surface 92 receives color B at station II, and so on. At the end of one complete marking cycle, one surface is fully printed with the three partial prints
25 making a complete print 90, a second surface has two colors printed, and a third surface has one color printed.

Interleaved (parsed) printing of the three colors is achieved by control of the acousto-optic deflector.
30 The scanning mirror causes scanning of the laser beam along a conceptual row of image pixels, e.g., row 1, beginning at the top of the Figure and progressing to the bottom. Each pixel of conceptual row 1 actually has three possible incarnations as a partial print pixel
35 lying along one of the three rows--row 1(I), row 1(II),

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and row 1(III)--at the three stations. As the scanned beam reaches any of the columns (pixel positions) along the row, the acousto-optic deflector is capable of directing the beam to any one of the three stations so that the corresponding partial print pixel on that row may be printed. For example, pixels 102 through 114 are printed one after the other in the course of scanning row 1. The progress of the printing represented in Figure 2 is the completion of only row 1. Also, in Figure 2, for clarity, only fragments of the surfaces being printed are shown and they are spaced closer than would be possible in the actual system. Surface 98 shows all of the printed pixels of the image fragment.

Scanner Angular Position Encoder

To assure that the pixels marked along each scan line on the workpiece are evenly spaced and accurately positioned, a low power (1 to 3 milliwatts) secondary laser (HeNe or diode laser, preferably visible) beam (Figure 3) is reflected from the flat mirror surface of the middle mirror element 72 of the scanning mirror (Figure 1; but for clarity the position encoder is not shown in Figure 1). Another mirror surface (for example, one at a different angle) dedicated to use by the encoder could be used instead.

As the scanning mirror swings (through an angular range of + or - 3.183 degrees on either side of a central angular position) to reach successive pixel locations along the scan line, a focused version of the beam scans back and forth across successive parallel rulings formed on a transparent substrate (also shown head on at the top of Figure 3), and is then projected onto a wide aperture (0.250 inches diameter) light detector.

The widths of the rulings compared to the diameter of the focused reflected beam are appropriate to assure

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that the detector output signal 526 will indicate when each line is passed. The number of rulings is at least as large as the number of pixels to be placed along a scan line and their spacing is representative of the
5 spacing of the pixels along the scan line. During setup, the position of the ruling substrate is set so that at the moment when the focused reflected beam crosses the first ruling, the first dot position on the scan line on the workpiece is reached.

10 During scanning, output signal 526 provides an indication for each ruling that is crossed. The output signal 526 is fed to the DMA controller portion 610 of processor 120. When each pixel position is reached, signal 526 causes the DMA controller to fetch an
15 associated image byte which determines whether marking is to occur at that pixel site; if so it signals the deflector to direct the pixel to be printed at the desired surface (color) 92, or 94, or 96 (Figure 2). In this way, the marking of dots along the scan line is
20 triggered simply and accurately based on a light beam reflected from the same surface (or at least a mirror surface fabricated on or affixed to the same structure) which reflects the marking beam.

In Figure 3, beam 510 is originated from a He-Ne
25 laser 530. Its output beam 532 is routed through a beam expander 534 and a collimating lens 536. The resulting beam has about a 1/2-inch spot size and is then reflected from a plane right angle mirror 538 onto the scanning mirror. The reflected beam from the scanning mirror is
30 passed through a focusing lens 540 which focuses it on the ruling substrate. The beam that emanates from the ruling substrate is defocused and aimed at the detector by a lens 542. As indicated in dashed line, when the scanner is at the upper end of its stroke beam 14 is
35 aimed near the top of the ruling substrate. As the

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scanner sweeps through its full range, beam 14 is swept across the ruling substrate. Lens 542 redirects and diffuses the beam in such a way that a single wide aperture detector continues to receive the beam as the scanning mirror is swept through its full range.

Controller (Processor)

The coordination of the elements of the system is performed by a controller (processor) 120 (Figure 4). An image file 122 stored in RAM contains information sufficient to specify the colors and intensities of each of the pixels in the image to be marked. The computer controls a stage driver 124 to cause motion of a stage 129 on which the workpieces are mounted. The stage 129 is controlled both to cause large motion to relocate the workpieces at the successive printing stations after each marking sub-cycle, and finer scanning motion to move the workpieces row by row during marking. The controller also controls the scanner driver 79 to cause the scanner to swing back and forth along each of the rows of the image. By coordinating the stage driver and the scanner driver, the controller is able to cause the laser beam to raster scan all of the pixels of the image. By also controlling the acousto-optical deflector 38, the controller is able to parse the image pixels into partial prints by directing the beam to any of the three printing stations or to no station in order to print at each pixel the intended color or no color, as indicated in the image file.

The first pixel of a scan line is marked on a workpiece at the time when the scanner causes the measuring beam to reach the first ruling on the substrate. In the case of a 300-by-300 pixel image, when the 300th ruling is crossed by the measuring beam, the controller triggers the scanning mirror to reverse its motion and re-position itself to begin the next scan

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line. When the 300th scan line is completed, ending a marking subcycle, the controller halts the scanning process, re-positions the workpieces at their new stations and restarts the scanning.

5 Image file 122 is a .TIF format file and is held in a form of RAM for use during marking. The RAM may be an EPROM or SRAM (e.g., PCMCIA card) or other fast access memory, i.e., flash or D-RAM. The .TIF file data is arranged to represent the color and intensity to be
10 marked at each pixel in the 300-by-300 pixel image field. The encoder signal 526 is routed to the DMA circuitry 610 of the control processor. As the signal indicates the arrival of the encoder beam at each successive pixel location along the scan line, the DMA circuitry causes a
15 direct memory access of the pixel color (deflection of the beam) and intensity from the RAM. The DMA channel contains its own addressing circuitry and may run independently of any CPU involvement except for the initial setting of the channel's control words. During
20 the encoder's deadband time, the CPU sets up the DMA control words to start on the first encoder transition signal 526. By deadband we mean the time beginning when the scanned beam, during its retrace, just passes the first ruling and ending when, at the beginning of the
25 next forward trace, the scanned beam just reaches the first ruling. At the beginning of a new scan, the encoder transition is deglitched to insure validity and then triggers a DMA request to transfer the first image byte from EPROM or PCMCIA memory into dual D/A converters
30 614, 616. The high order four bits of the byte (the deflection information) are sent to one D/A converter and the low order four bits (the amplitude information) are sent to the other D/A converter. The outputs 48, 49 of the two D/A converters are respectively fed to the

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deflection and amplitude ports of the acousto-optical deflector 38.

Each encoder transition signal 526 resets a predetermined CPU timer value. When the timer expires, 5 the D/A amplitude channel is reset. This in effect controls the pixel "on time" or dwell. The DMA channel expects to receive the appropriate number of transitions for each scan line. Upon detecting the last pixel in the scan line the channel automatically shuts down and waits 10 until its control word is reinitialized for the next scan line after scanner retrace.

The .TIF file contains 8-bit pixel values each of which is capable of specifying 256 colors. The .TIF file is generated by, e.g., Photo Finish (a software package 15 available from ZSoft Corp, of Marietta, Georgia which runs under Microsoft Windows). The file's tag fields contain the necessary information defining the image's pixel density (dots/inch), and line and column sizes. The image file is uncompressed and presented to the 20 marking control computer on the EPROM or PCMCIA memory card.

A palette is defined for use in encoding pixels in the .TIF format. The standard .TIF palette is a 16-by-16 matrix; each entry in the matrix is a pointer to a color 25 value in a color table. This arrangement is modified for use in driving the scanned marking system. Photo Finish offers the user the capability of editing the color palette. Here the color palette is edited to include all blank cells except for four cells. One of the non-blank 30 cells is used to represent nonprinted color, and the other three to represent print colors. For example, if the three print colors are red, white, and blue, the palette would be configured to represent the non-print color (black) by cell 00 (hexadecimal), red by cell 3f 35 (hexadecimal), blue by cell 9f (hexadecimal), and white

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by cell ff (hexadecimal). No other cells would be used. The eight-bit value in each of the four cells is specially encoded. The high order four bits of the value is used to determine deflection information. The lower
5 order four bits represent amplitude and control the amount of laser energy delivered, or may be used to print the desired color in grey scale by using an ink medium which is sensitive to grey scale information and an associated grey-scale image file and palette.

10 The control processor 120 (an Intel 80188) also controls airvalves and AC power 525, servo and stepper motors 527, and a touch screen display 529 for production worker interaction.

 Marking begins when the CPU starts the laser
15 scanner. All marking functions are slaved to the laser scanner cycle (approximately 90 Hz). Some dummy scans are performed to stabilize the scanner before marking scans are performed. There are two rules which should not be violated. One rule is that at least the same
20 number of encoder transitions as pixels per scan must be received (this may require mechanical adjustment). The second is that the encoder must be in the deadband at a specified time, i.e., with no encoder transitions occurring during the deadband.

25 Print head

 Referring to Figures 5 and 6, in one version of a print head 400 for each print station, the foil 402 is delivered from a feed roll 404 with the ink side down and pulled against a parabolic surface 406 of a hollow
30 pressurized chamber 407 by a tension roller 408. The foil then is drawn over and conforms in contour to the parabolic surface, eventually reaching a pair of outfeed tension rollers 410, 412, and from there a take up roll (not shown). As the workpiece 415 to be marked is moved
35 in the direction 416 during scanning, the foil is fed in

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direction 417 at the same or nearly the same velocity as the workpiece. Using a slightly different velocity has the advantage of setting up small shear forces at the interface between the foil and the part, which may
5 improve the print quality. As seen in Figure 7, the apex of the parabolic surface of the print head has an aperture 420 which extends across the print head leaving parabolically contoured bordering sections 422, 424, which maintain the contour of the foil.

10 As seen in Figure 8, when the leading edge of workpiece 415 reaches the foil it causes the foil to contact the top surface of the workpiece along a small region 426 which runs linearly across the print head (into the page). At the same time, air pressure from
15 within the hollow print head chamber presses the foil against the part. Tension on the foil (imparted by the tension rollers) balances the force exerted by the air pressure. The air pressure in the head may be at any level up to the equivalent pressure provided by the
20 tension of the foil over the curved head. As the workpiece moves along to the left, the limited linear contact area 126 moves across the top surface, with the foil being peeled away shortly after it first makes contact with the surface. The laser marking occurs along
25 the scan line along the linear contact line between the foil and the top surface.

There is a controlled time between the scanning of a line and the stripping of the foil from the workpiece along that line, and the contact time is constant for all
30 scan lines. This improves the uniformity of the printing. Because the foil is stripped continuously at a relatively narrow strip line, the peak strip force is reduced and the workpiece does not need to be held. Because the area of contact between the foil and the
35 workpiece is small, the amount of force required to hold

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the foil against the workpiece is small. No metal parts contact the workpiece; only the foil does.

This version also has disadvantages. The head must extend below the surface of the workpiece on either
5 side, which makes it difficult to print workpieces held in trays. The scheme requires uniformity of workpiece height because the vertical interference (429 in Figure 8) between the workpiece and the foil is on the order of only .005 inches to .020 inches. One possible solution
10 to this disadvantage would be to make the head the same width as the workpiece but form the head of compressible rubber. With multiple printing stations of different colors, the routing of the foils to avoid interference with one another also must be addressed.

15 Referring to Figures 9, 10, and 11, in an alternative print head 430, foil 432 is fed over a contoured edge 434 of a wall 436 of a hollow pressurized (0.5 to 5.0 psi) chamber 438, past a rubber sealing flap 440, past a foil guide 442, across an opening 444 which
20 is broad enough to span the entire image, past a second foil guide 446, a second rubber flap 448, and a second contoured edge 450. Opening 444 is defined in a window 449 which has two contoured surfaces 445, 447 that support the foil. Prior to workpiece 452 being moved
25 into contact with foil 432, the portion of the foil the spans the opening 444 has a convex curved contour formed in it by the internal air pressure in the head. As the workpiece is moved toward the head, the first contact is made at the center point 454, and the area of contact
30 then spreads outward. This helps to prevent the capture of any air bubbles between the workpiece and the foil which could degrade the print quality. Once the foil is in full contact with the upper surface of the workpiece (Figure 10), the entire image is scanned. Because the
35 workpiece is being moved in direction 460 to reach

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successive scan lines, the head must also be moved at the same velocity. Alternatively, two dimensional laser beam scanning may be used.

After the image has been fully scanned, the foil
5 is stripped from the workpiece all at once (Figure 11) by pulling the head away from the workpiece. As shown the window may be moved away from the head to aid the stripping. Then the foil is advanced to expose a new ink area for use in printing the next workpiece.

10 A third alternative print head, Figure 12, is a simplified version of the second alternative. Pressurized chamber 470 has a top window 472. A rubber pad 474 in the shape of a window frame is attached at the bottom of the chamber. Foil 476 is stretched across the
15 rubber window. Only minimal pressure may be achieved against the foil before the workpiece is moved into contact because air escapes at both edges of the rubber window. But the minimal pressure which may be achieved causes the foil to curve downward lightly at its center
20 478. Once the foil is pressed against the rubber window, the pressurization inside the head provides a substantial force to hold the foil against the surface of the workpiece. The third alternative is simpler than the second, the foil is easier to load, and there is less
25 chance of damage to the foil surface. But the workpiece must be able to be pulled from the foil, as there is no movable window to aid that process, more force must be applied to the workpiece, and bubbles may not be as easily eliminated.

30 The laser beam is delivered via a lens or window on top of the print head and passes through the hollow chamber to reach the foil.

Optimized Raster Scanning

Although the marking of a scan line of the image
35 is typically done only during oscillation of the scanning

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mirror in only one direction, and no marking is done during the reverse scan or retrace, an alternative scheme performs marking of one line of a print of a given scan line on one workpiece during one direction of oscillation
5 and another line of a print of the given scan line on a second workpiece during the return oscillation. In the example of Figure 1, two identical monochrome images, for example, could be simultaneously marked on two surfaces at two of the printing stations by directing the scanned
10 beam to one station during one direction of scanning and directing the scanned beam to the other printing station during the reverse direction of scanning. This allows essentially two images to be created in almost the same time that it would take to mark a single image in one
15 direction scan marking.

Referring to Figure 13, in one directional scanning, scanning occurs during a period 702 of relatively gradual motion 703. Scanning time is wasted during a period 704 of relatively rapid retrace motion
20 705. The percentage of wasted time may be on the order of 33%.

In Figure 14, with two-directional scanning, the return scan motion 707 is symmetrical with the forward scan motion 709. The percentage of wasted time 708 is
25 considerably less, largely because the retrace time is not wasted, but also because the wasted time 708 is somewhat shorter. It is shorter because change in velocity between forward and return scans is reduced, allowing a greater portion of each scan to be used, and a
30 smaller portion to be wasted.

Both forward and return scans in theory could be used to paint a single print more rapidly, but that would produce a zig zag appearance of the scan lines as the workpiece is moved along during scanning. Parsing the
35 forward and return scans between two marking stations

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precludes the zig-zag effect while retaining the speed advantage.

Referring to Figure 15, in an alternative scanning scheme for use with a YAG laser 720, a single flat
5 scanner mirror 500 and a single f_{Theta} lens 502 are used to feed the beam to the three printing stations. The three mirrors 64, 66, 68, all direct the beam to the single scanner mirror 500 which is driven by a galvo 503. In this scheme, there is a single long printhead 512 for
10 all three marking stations and the three workpieces 506, 508, 510 are moved in parallel for successive scan lines. The staging must then move each workpiece in a perpendicular direction after each partial print is finished in order to position it at the next marking
15 station. Three foils 514, 516, 518 are also moved in parallel.

Other embodiments are within the scope of the following claims.

A wide spectrum of marking modes may be achieved
20 because the system provides the ability to mark any pixel of an image at any one of several marking stations in each of several marking sub-cycles within a marking cycle and in each of the successive marking cycles. The printing of identical monochrome images on two workpieces
25 and the printing of color images at three workstations (described above) are but two of possibilities. Other possibilities include the following.

More than three marking stations may be provided, offering the possibility of more than three colors in an
30 image.

In a high mix mode production line, it would be possible to frequently change what is being printed on the workpieces being stepped along the line. For example, a chip manufacturer could "private label" chips
35 in groups as small as a few each. Once the first batch,

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bearing the first logo image passes completely through the marking stations, a new logo image could be loaded into memory and the chips in the next group marked, and so on.

5 Serialization of the workpieces could be achieved by providing a window 802 in an image 804 for inclusion of the serial number 806 (Figure 16). After each marking cycle, a subimage containing the new serial number is inserted into an image buffer at the location of the
10 window for printing the next workpiece. In the case of three station printing, the third station could be the location where the serial number is printed. The partial prints at the first two stations would have non-printed windows to leave space for the serial number to be added
15 at the third station. The main parts of the image and the serial number could be of different resolutions.

 In some implementations a bar code reader could scan a unit/lot traveler record and automatically download an appropriate image for that unit or lot from a
20 network server.

 In another example, a global memory could serve as the image transfer medium between the image generation software and the machine control processor in a Windows NT environment.

25 A wide variety of workpieces and surfaces may be marked.

 There may be more or fewer than three marking stations.

 Marking could be done by ablation of the surfaces
30 without use of inks.

 What is claimed is:

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1. Apparatus for marking pixels on workpieces, comprising
 - marking stations at which said workpieces are respectively positioned for marking,
 - a beam of radiation directed along an optical path toward said workpieces,
 - scanning apparatus for scanning said beam to define an array of pixel positions, and
 - a switch for routing said beam during said scanning so that for each of said pixel positions said beam may be routed to a selected one of said marking stations to mark one of said pixels on one of said workpieces.
2. The apparatus of claim 1 wherein said pixels marked on said workpieces are organized as partial prints associated respectively with said marking stations.
3. The apparatus of claim 1 wherein said scanning apparatus is configured to raster scan said beam.
4. The apparatus of claim 1 further comprising
 - a processor for causing each of said workpieces to be positioned at each of said marking stations for a period which spans a complete scanning of said beam.
5. The apparatus of claim 1 further comprising printing apparatus responsive to said beam for printing different colors of said pixels respectively at different ones of said marking stations.
6. The apparatus of claim 2 wherein said partial prints are different for different ones of said marking stations.
7. The apparatus of claim 1 wherein said marking stations comprise printing foils which respond to radiation from said beam by depositing pigment or dye.
8. The apparatus of claim 1 wherein said switch comprises an acousto-optic deflector.

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9. The apparatus of claim 8 further comprising a processor for controlling said acousto-optic deflector in response to stored information corresponding to said pixels.

10. The apparatus of claim 1 wherein said scanning apparatus comprises an optical element for sweeping said beam along a scan line, and a mechanical element for moving each of said workpieces in a direction normal to said scan line.

11. The apparatus of claim 2 further comprising a processor for causing each said workpiece to be moved in succession to each of said marking stations for marking with corresponding ones of said partial prints.

12. The apparatus of claim 2 wherein there are two of said marking stations, said scanning apparatus is arranged to raster scan a series of scan lines, every other line being scanned in one direction and the intervening lines being scanned in the opposite direction, and said switch is arranged to cause marking of pixels on said every other line at one of said marking stations, and marking of pixels on said intervening lines at the other of said marking stations.

13. The apparatus of claim 12 wherein the partial prints for the workpieces at said two marking stations comprise identical, monochrome prints.

14. The apparatus of claim 1 wherein portions of said partial prints are identical for at least two of said workpieces and other portions are different for said partial prints.

15. The apparatus of claim 14 wherein said portions which are different comprise different serial numbers.

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16. Apparatus for marking pixels on workpieces, comprising

marking stations at which said workpieces are respectively positioned for marking, said pixels marked on said workpieces being organized as partial prints associated with respective ones of said marking stations,

a beam of radiation directed along an optical path toward said workpieces,

scanning apparatus for raster scanning said beam to define an array of pixel positions,

a switch for routing said beam during said scanning so that for each of said pixel positions said beam may be routed to a selected one of said marking stations to mark one of said pixels on one of said workpieces,

a processor for causing each of said workpieces to be positioned at each of said marking stations for a period which spans a complete scanning of said beam, and

printing apparatus responsive to said beam for printing different colors of said pixels respectively at different ones of said marking stations, said marking stations comprising printing foils which respond to radiation from said beam by depositing pigment or dye.

17. A method for marking pixels on workpieces, comprising

positioning said workpieces at respective stations for marking,

directing a beam of radiation along an optical path toward said workpieces,

scanning said beam to define an array of pixel positions, and

routing said beam during said scanning so that for each of said pixel positions said beam may be routed to a selected one of said marking stations to mark one of said pixels on one of said workpieces.

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18. Apparatus for determining an angular position of a scanning mirror in a raster scanner, comprising
a source of a beam of radiation aimed to be reflected from said scanning mirror during scanning,
a ruled optical element for receiving said beam of radiation after reflection from said scanning mirror during scanning, said beam moving across rulings on said optical element during scanning, and
a detector for receiving said beam after it impinges on said ruled optical element for detecting when said beam moves across successive said rulings during scanning.

19. The apparatus of claim 18 wherein
said ruled optical element comprises a transparent substrate bearing parallel lines which obstruct the passage of said beam.

20. The apparatus of claim 18 further comprising
a lens which focuses said beam in the vicinity of said ruled optical element, and
a lens which defocuses and redirects said beam after it has passed through said ruled optical element, said beam being redirected to fall on said detector during scanning.

21. A print head for printing spots on a surface of a workpiece comprising
an ink medium in continuous web form and capable of responding to an intense beam of radiation by transferring spots of ink onto said surface,
a walled, internally pressurized chamber having an external curved surface,
structure for causing said continuous web to conform to the contour of said external curved surface and to be pulled along said external curved surface,
said external curved surface being interrupted by an aperture permitting internal pressure in said chamber

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to be applied against said web as it is pulled along said external curved surface, said chamber having a transparent window for allowing said beam to pass within said chamber and strike said continuous web at said aperture,

elements for causing said workpiece to be held with its surface in an orientation to receive spots of ink from said ink medium and to be moved towards and past said aperture at a distance near enough to said aperture to cause said surface to contact said continuous web along a linear contact region and to disrupt the conformity of the web to the external surface at the contact region.

22. The print head of claim 21 wherein said external curved surface is parabolic.

23. The print head of claim 21 wherein said aperture is located at an apex of said external curved surface.

24. The print head of claim 21 wherein said external curved surface is flat in a dimension normal to the dimension in which said curved surface is parabolic, and said aperture extends across said flat dimension.

25. The print head of claim 24 wherein said aperture does not extend completely across said curved surface.

26. The print head of claim 21 wherein said continuous web is pulled along at a velocity which is approximately the same as a velocity of motion of the workpiece relative to the print head.

27. The print head of claim 26 wherein said velocity at which said web is pulled is sufficiently different from said velocity of motion of the workpiece to impart a small shear force between said web and said workpiece.

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28. A method for printing spots on a flat surface of a workpiece comprising

causing a continuous web of ink medium to conform to a contour of an external curved surface of a walled chamber,

pulling said web along said external curved surface,

internally pressurizing the chamber,

applying said internal pressure in said chamber against said web as it is pulled along said external curved surface via an aperture on said external curved surface,

passing a beam within said chamber to strike said continuous web at said aperture,

causing said workpiece to be held with its surface in an orientation to receive spots of ink from said ink medium and to be moved towards and past said aperture at a distance near enough to said aperture to cause said surface to contact said continuous web along a linear contact region which passes along said surface of said workpiece and to disrupt the conformity of the web to the external surface at the contact region.

29. The method of claim 28 further comprising pulling said web at a velocity which is approximately the same as the velocity of motion of the workpiece relative to the print head.

30. A method for controlling a beam deflector to deflect a beam between directions representing respectively different printing colors to be printed at pixel locations on different workpieces comprising

storing image information associating each of said pixel locations with one of said printing colors, and

using a computer to trigger said beam deflector to deflect said beam to one of said directions representing

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said printing colors for each of said pixel locations in accordance with said stored information.

31. The method of claim 30 wherein said stored image information comprises, for each pixel location, a deflection value and an amplitude value.

32. The method of claim 30 wherein said stored information is fetched via a DMA channel of a computer during printing.

33. The method of claim 30 wherein said stored information is represented in a file format which has an associated palette matrix to which the stored information points.

34. Apparatus for marking two workpieces comprising

marking stations at which said workpieces are respectively positioned for marking,

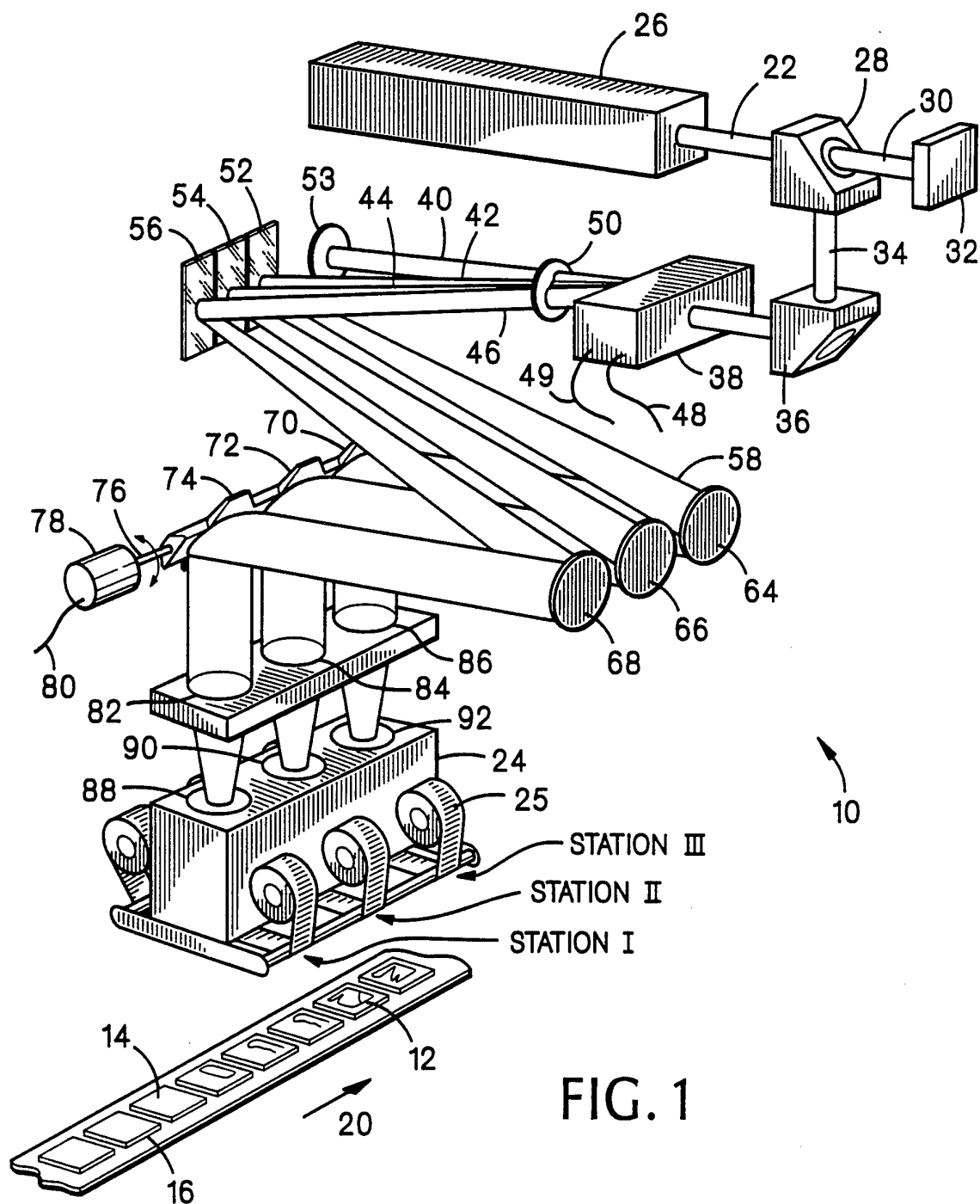
a beam of radiation directed along an optical path toward said workpieces,

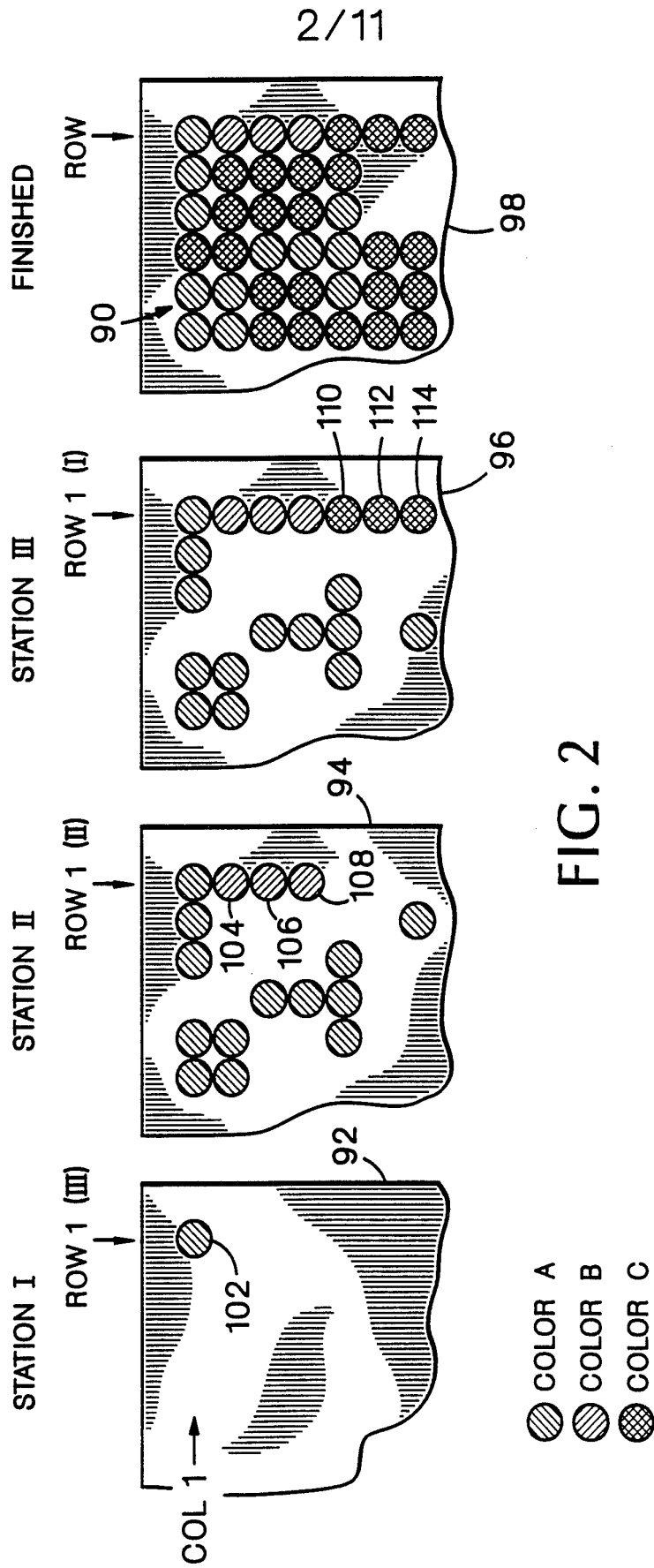
two-directional scanning apparatus for scanning said beam to define successive rows of pixel positions in an array, some of said rows being scanned by scanning motion in a first direction, others of said rows being scanned by scanning motion in an second direction opposite to said first direction, and

switching elements for directing said beam to scan some of said rows at one of said marking stations and others of said rows at another of said marking stations.

35. The apparatus of claim 34 wherein every other one of said rows is scanned in said one direction at one of said marking stations, and said intervening rows are scanned in said opposite direction at said other one of said marking stations.

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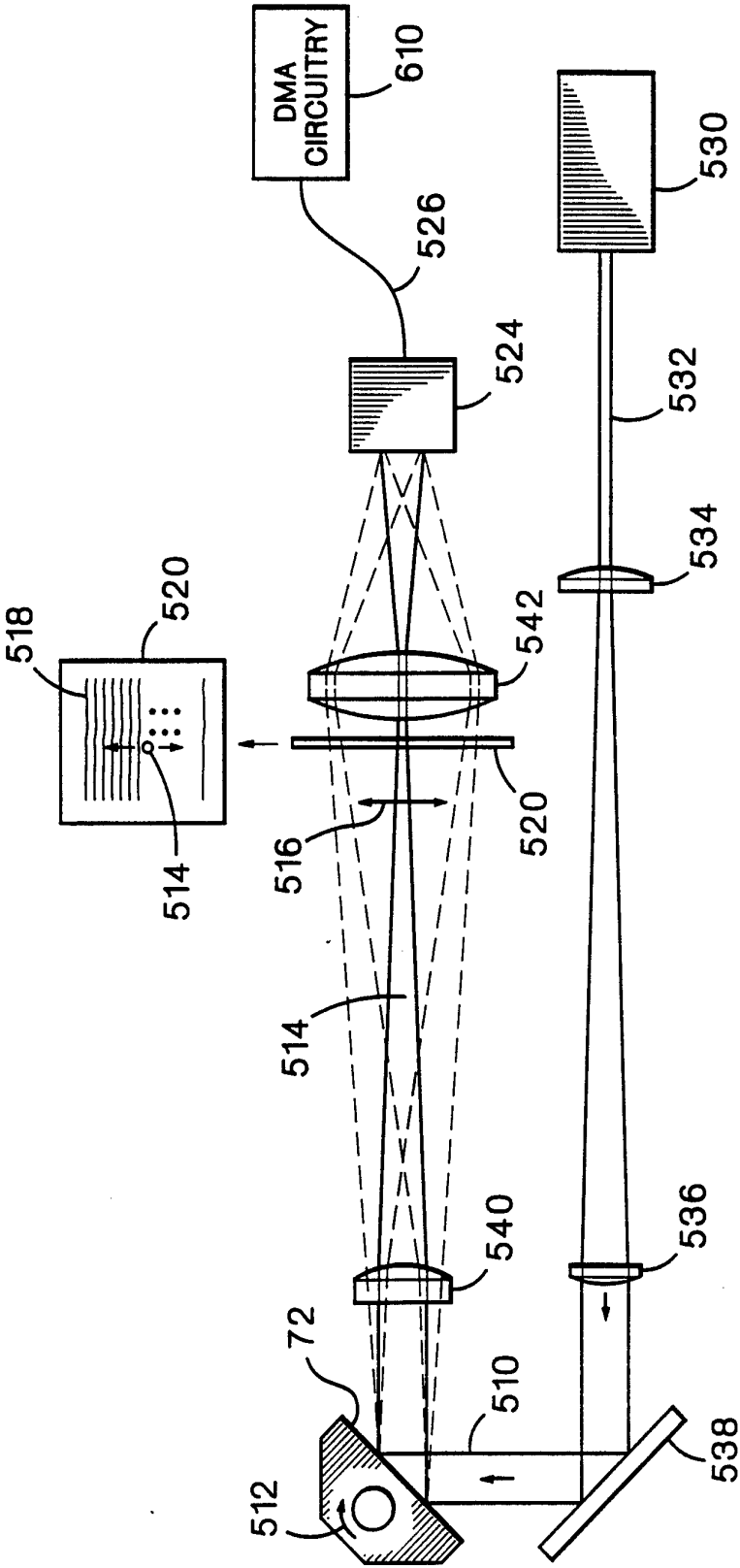


FIG. 3

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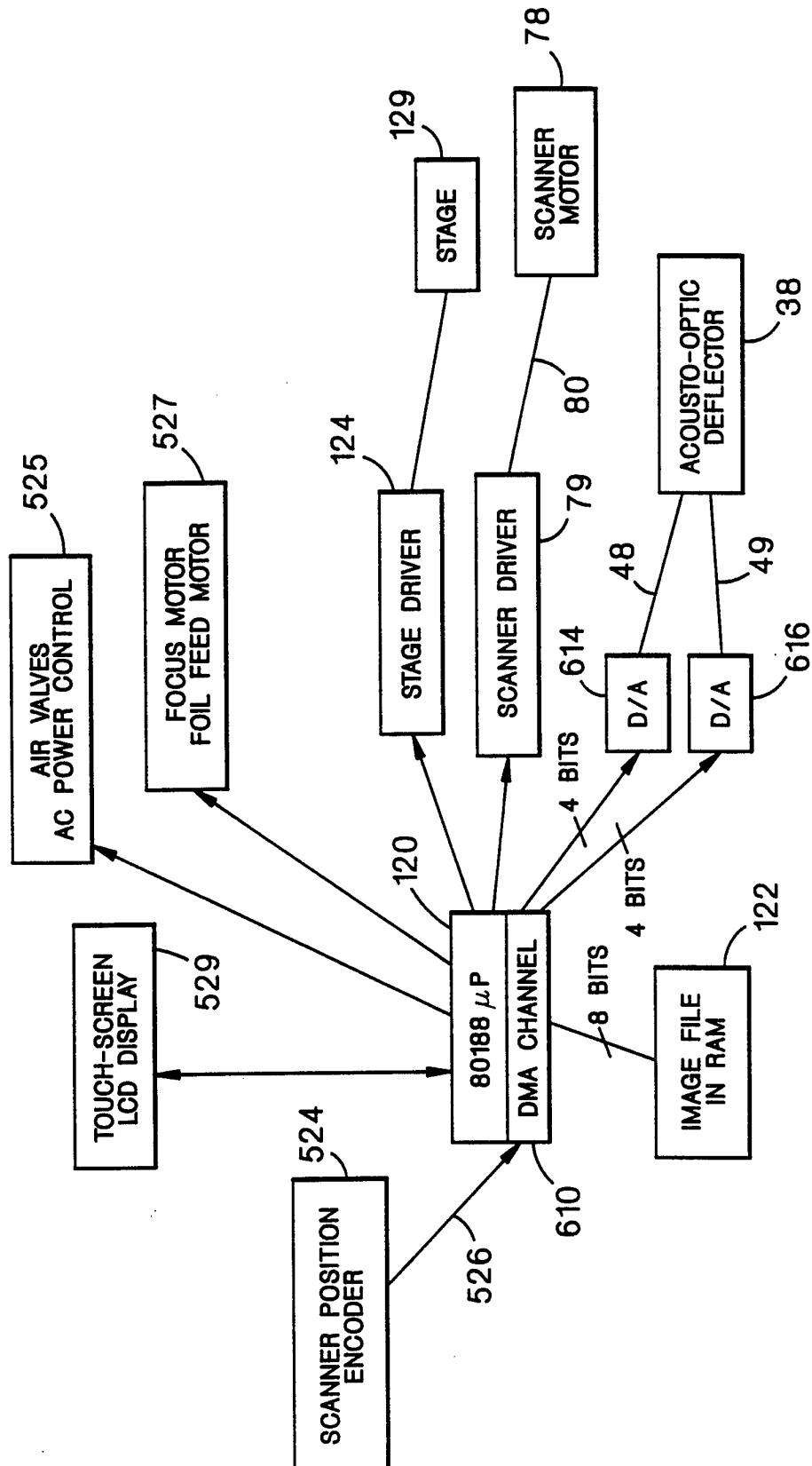


FIG. 4

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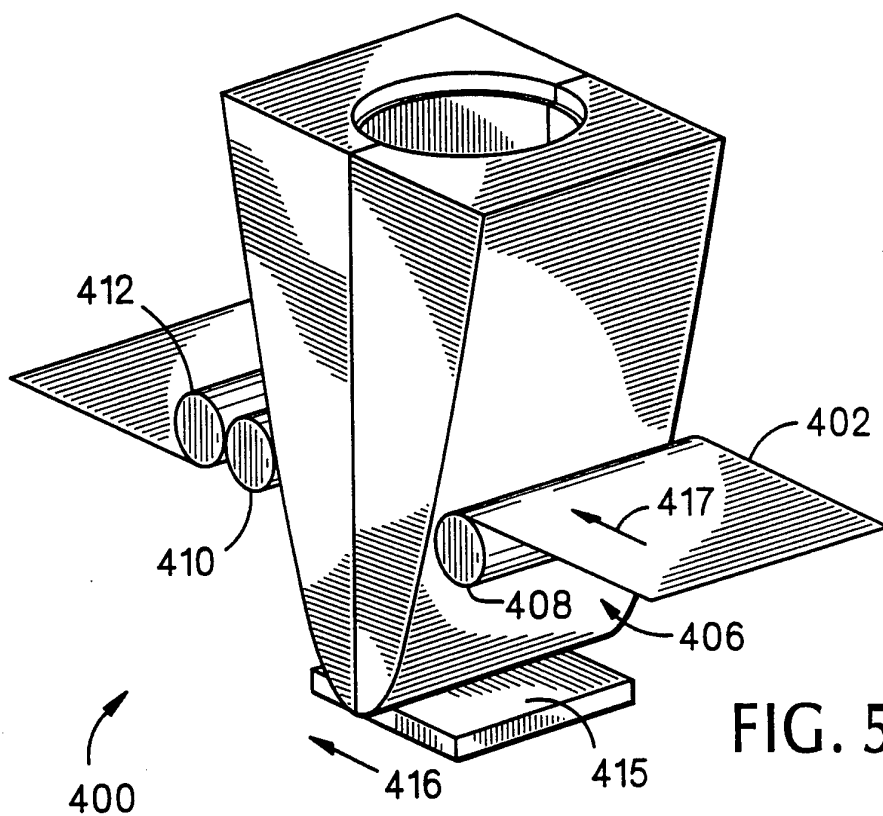


FIG. 5

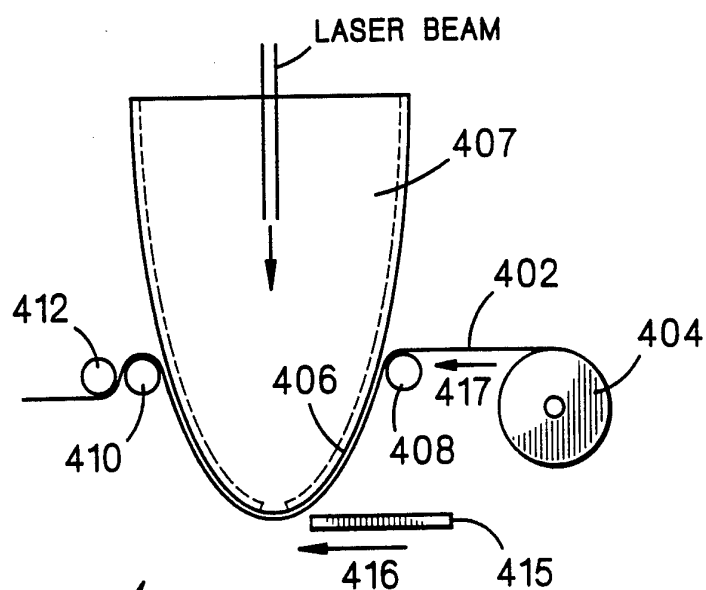


FIG. 6

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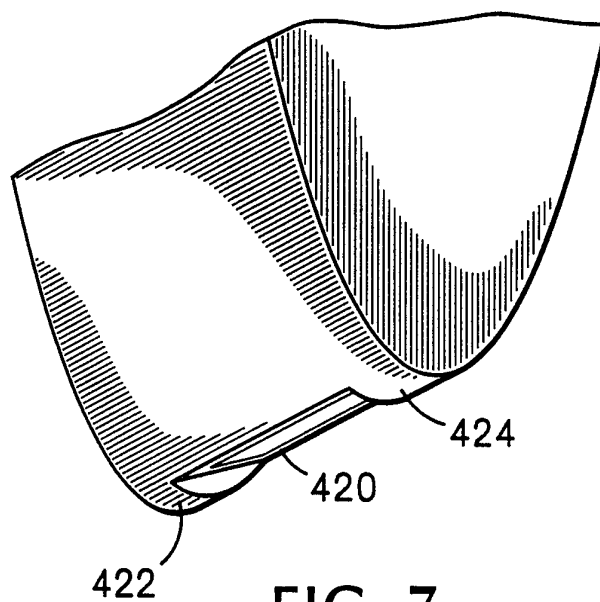


FIG. 7

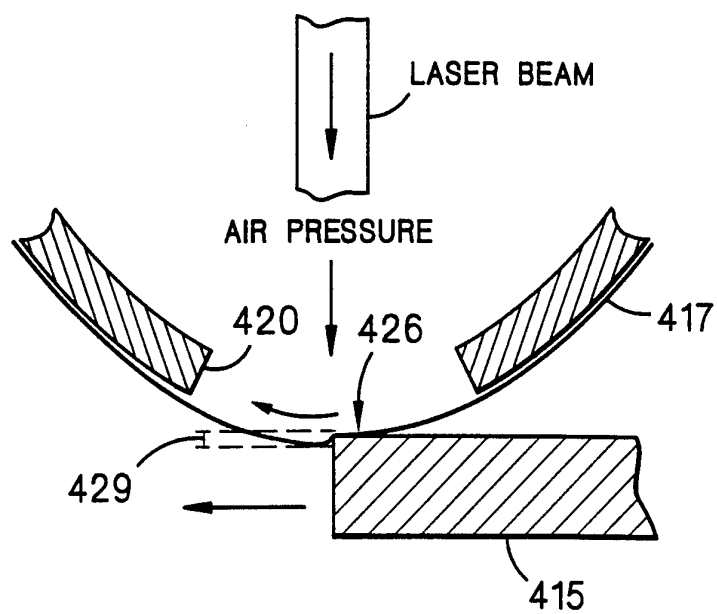


FIG. 8

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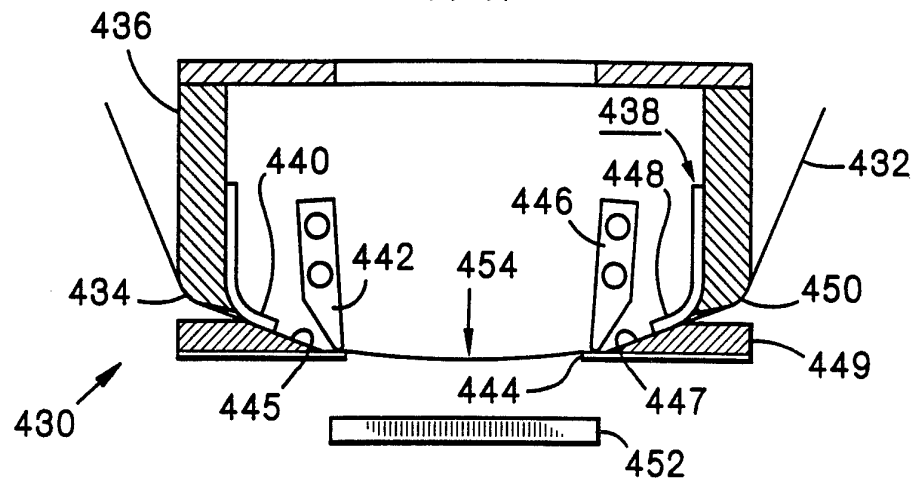


FIG. 9

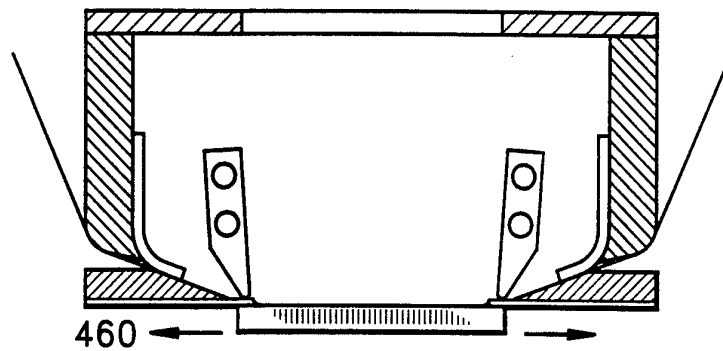


FIG. 10

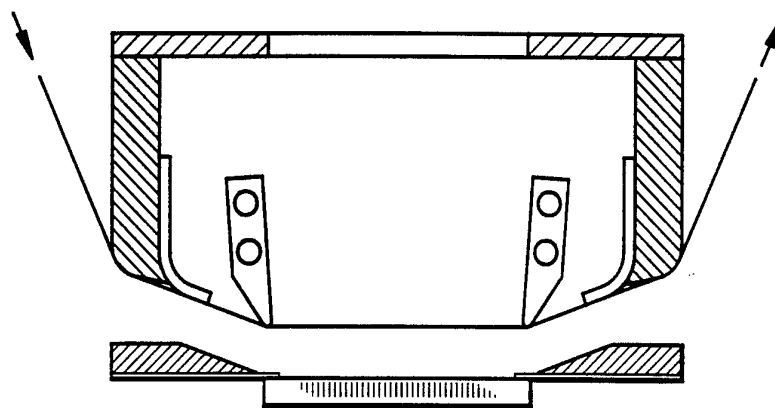


FIG. 11

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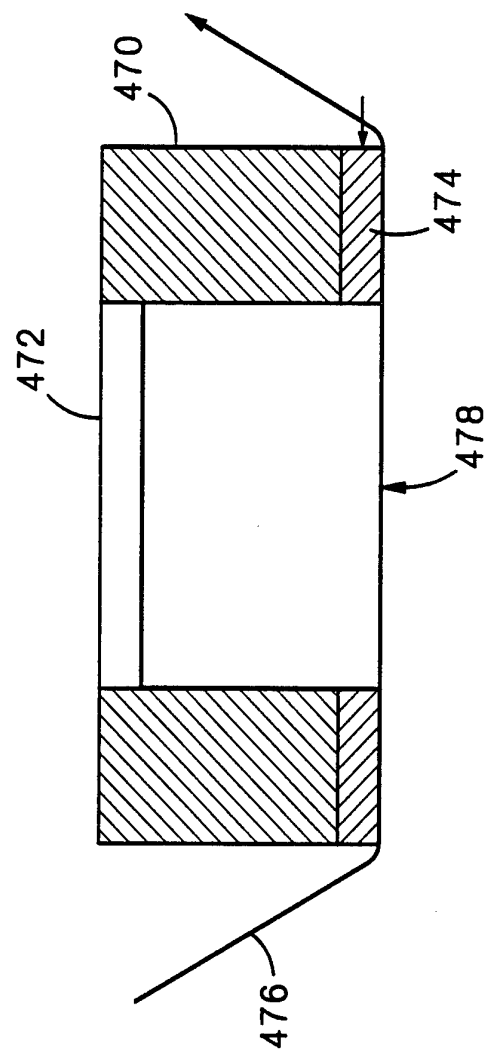
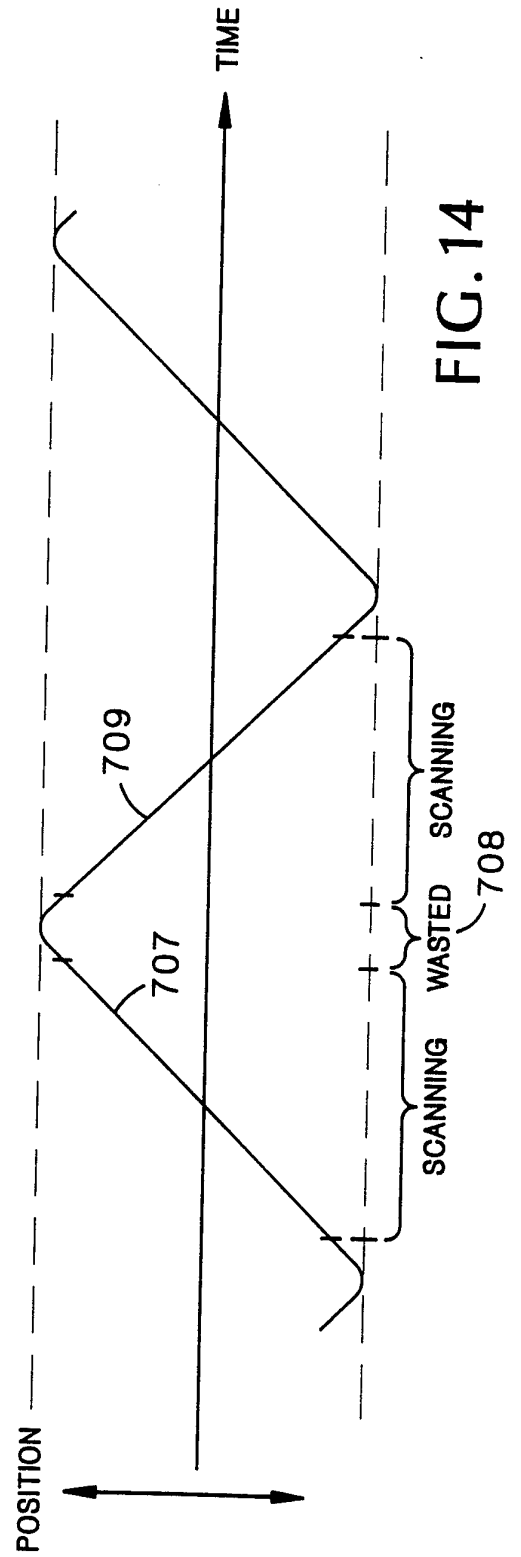
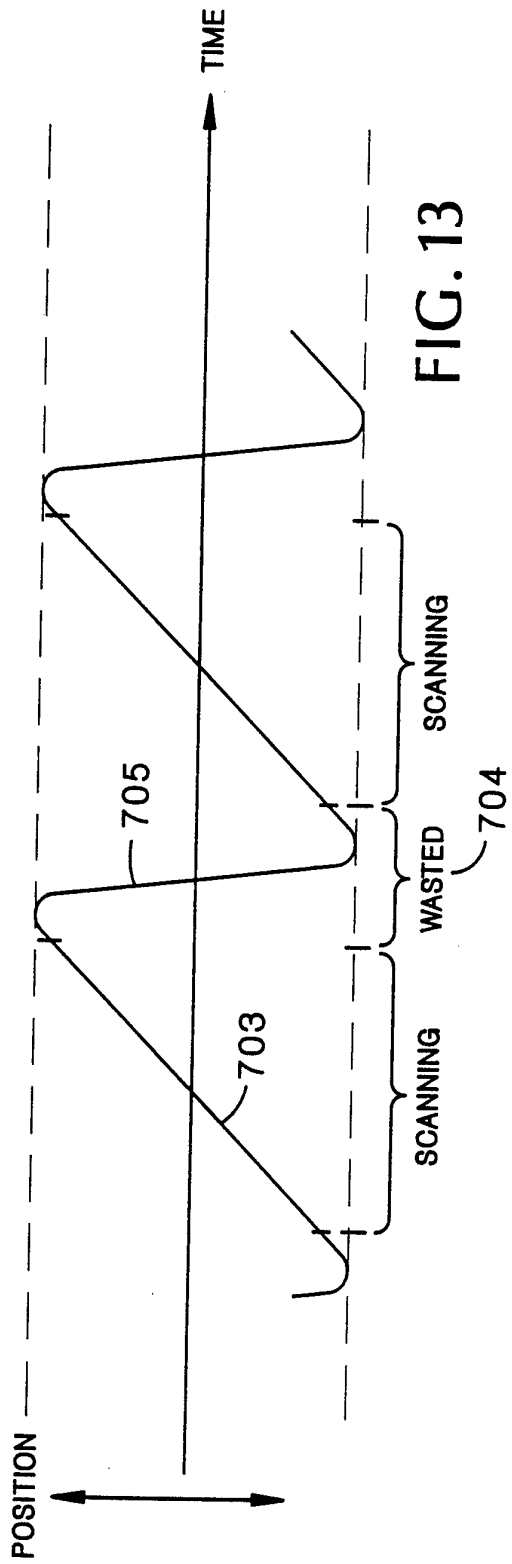


FIG. 12

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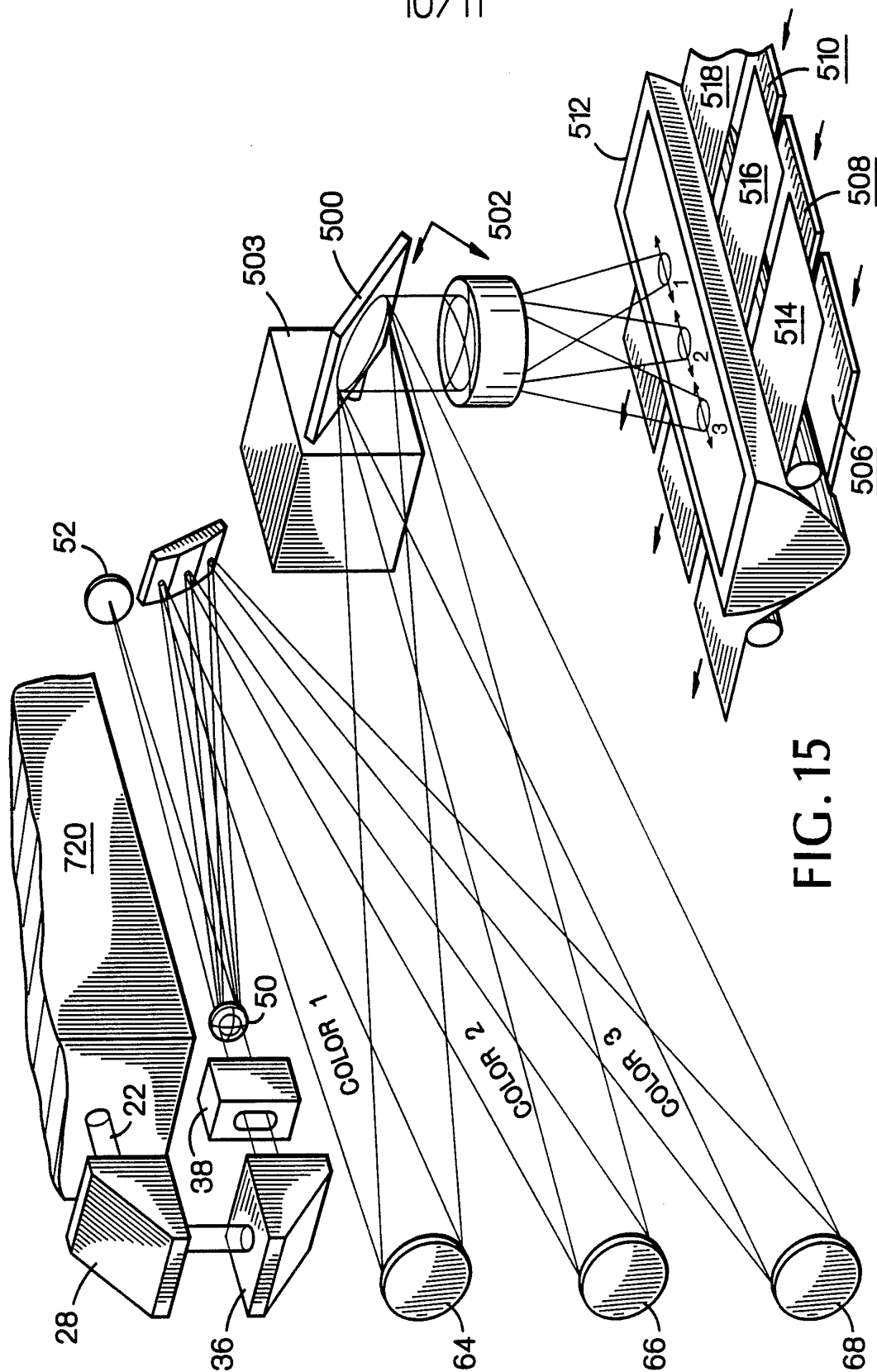


FIG. 15

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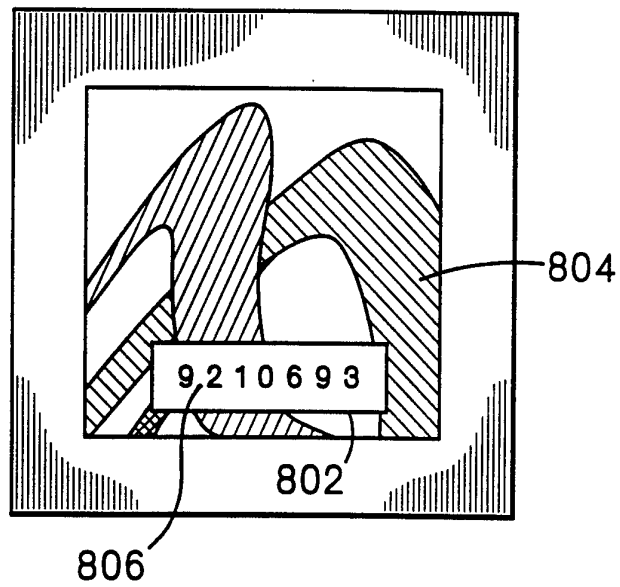


FIG. 16