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X 3891R

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Daly et al. [45] Jan. 18, 1972

[54] **LASER FACSIMILE SYSTEM FOR ENGRAVING PRINTING PLATES**

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[73] Assignee: **Quantronix Corporation**, Farmingdale, N.Y.

[22] Filed: **Aug. 28, 1968**

[21] Appl. No.: **755,951**

[52] **U.S. Cl.** ....**178/6.6 B,** 178/6.6 R, 331/94.5, 331/331

[51] **Int. Cl.** **H01s 3/09,** H04n 1/08, H04n 1/26

[58] **Field of Search** ....178/6.6, 6.6 B, 6.6 R, 6.7, 178/7.4; 331/94.5; 346/74 E

[56] **References Cited**

UNITED STATES PATENTS

3,197,558	7/1965	Ernst	178/6.6
2,112,010	3/1938	Brimberg	178/6.6
3,374,311	3/1968	Hell	178/6.6

Primary Examiner—Bernard Konick
Assistant Examiner—Steven B. Pokotilow
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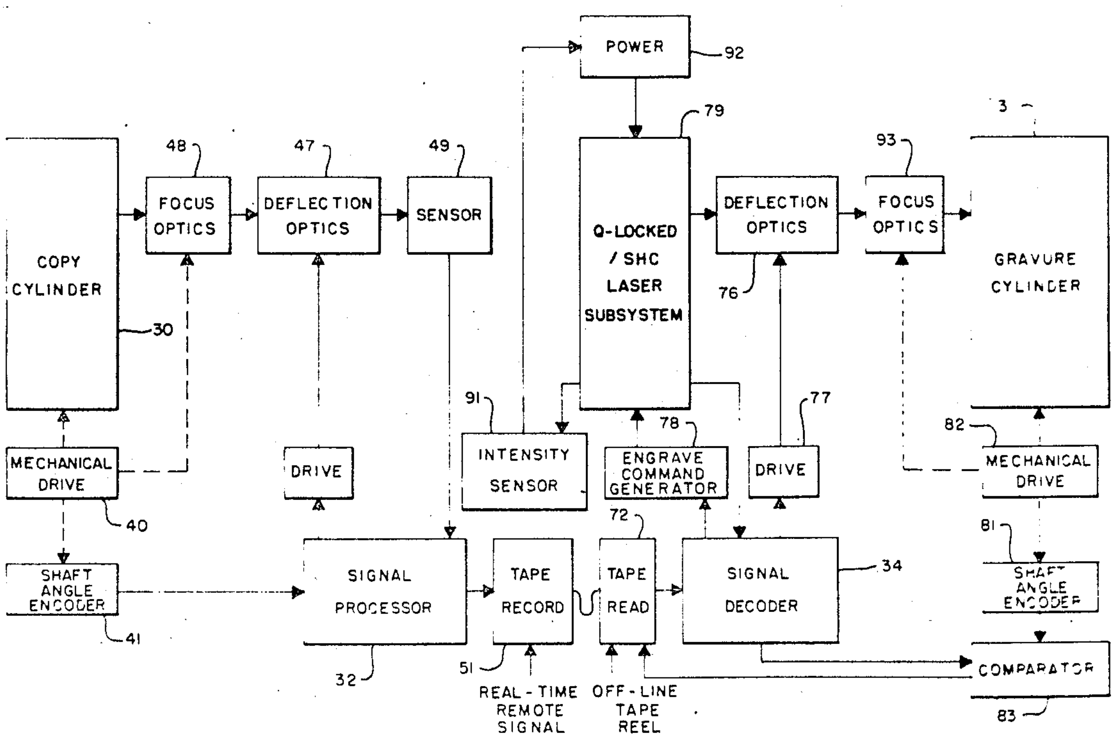
[57] **ABSTRACT**

A system for engraving intaglio printing plates in which tiny uniformly sized cells are formed in the printing plate by the engraving tool, preferably a pulsed output laser, and in which variable tone is rendered by varying the spatial density of the cells.

7 Claims, 20 Drawing Figures



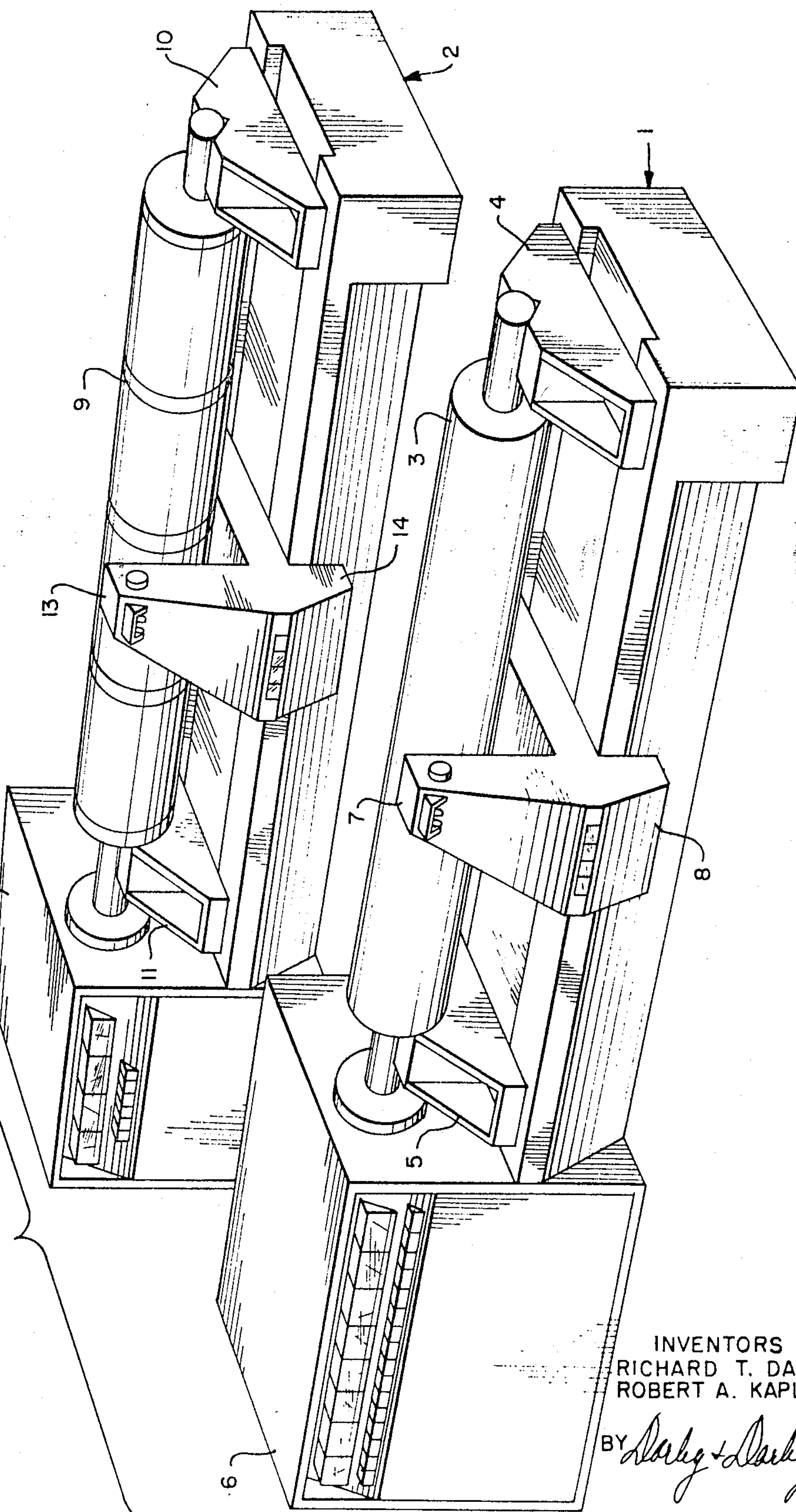


FIG. 1

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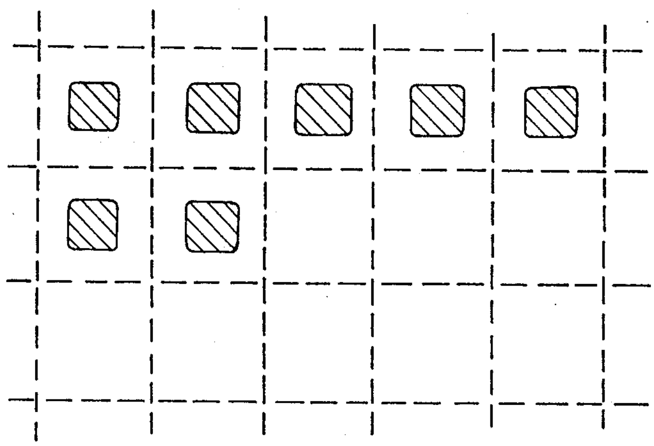


FIG. 2a

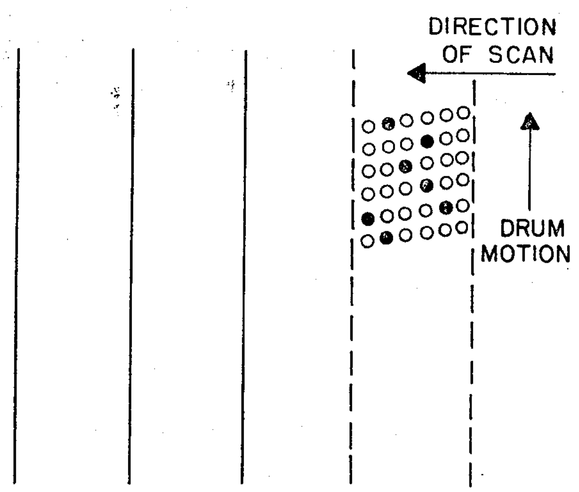
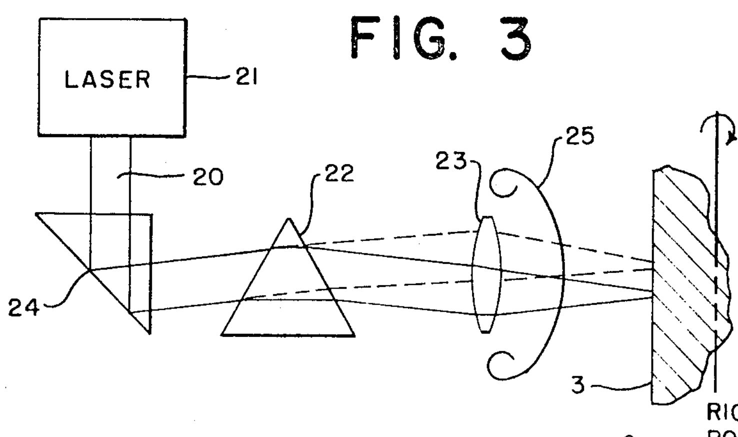


FIG. 2b

FIG. 3



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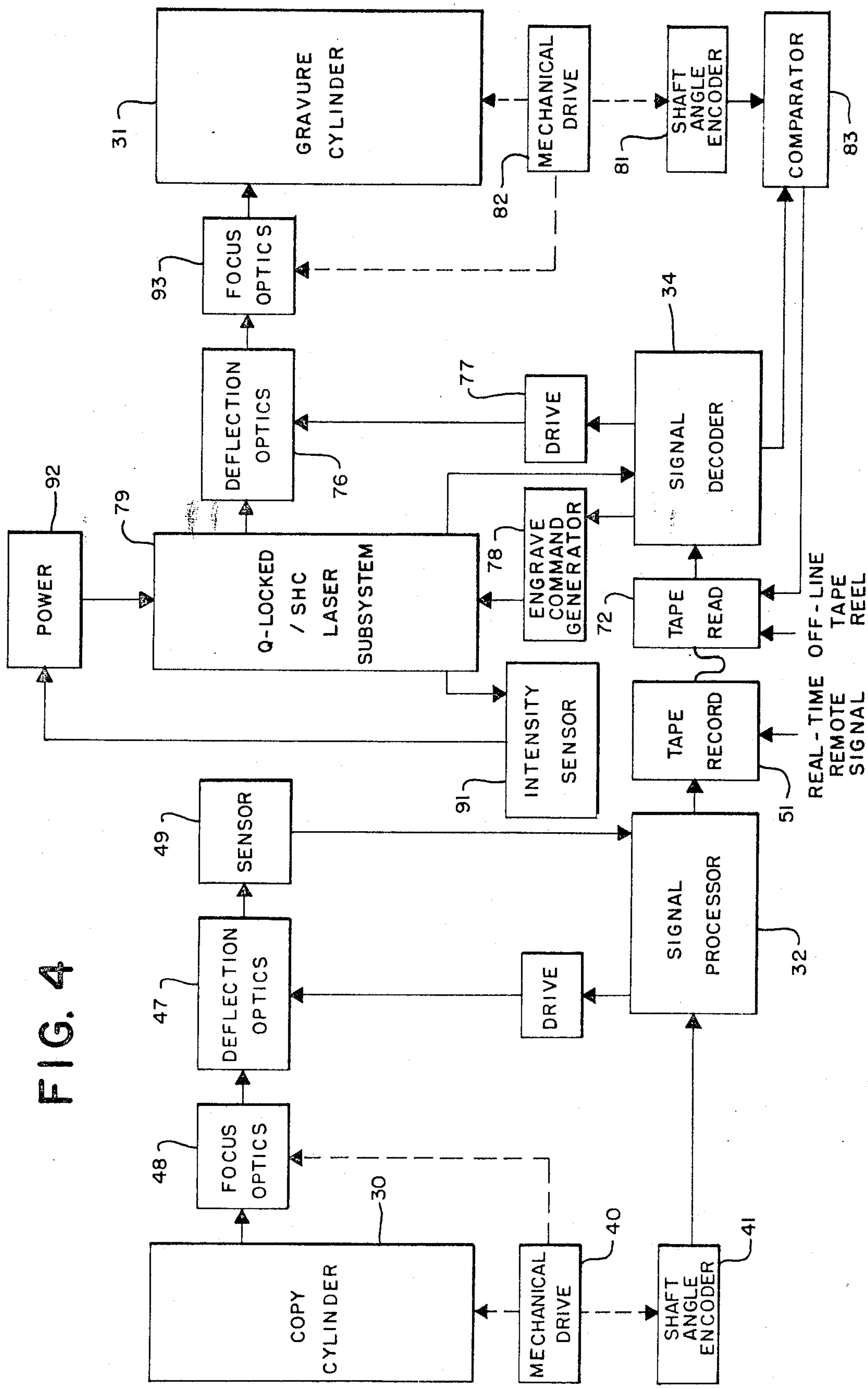

GRAVURE CYLINDER
31
MECHANICAL DRIVE
82
SHAFT ANGLE ENCODER
81
COMPARATOR
83
FOCUS OPTICS
93
DEFLECTION OPTICS
76
DRIVE
77
SIGNAL DECODER
34
POWER
92
Q-LOCKED / SHC LASER SUBSYSTEM
79
ENGRAVE COMMAND GENERATOR
78
TAPE READ
72
OFF-LINE TAPE REEL
INTENSITY SENSOR
91
TAPE RECORD
51
REAL-TIME REMOTE SIGNAL
SENSOR
49
SIGNAL PROCESSOR
32
DEFLECTION OPTICS
47
DRIVE
FOCUS OPTICS
48
COPY CYLINDER
30
MECHANICAL DRIVE
40
SHAFT ANGLE ENCODER
41

FIG. 4

FIG. 5

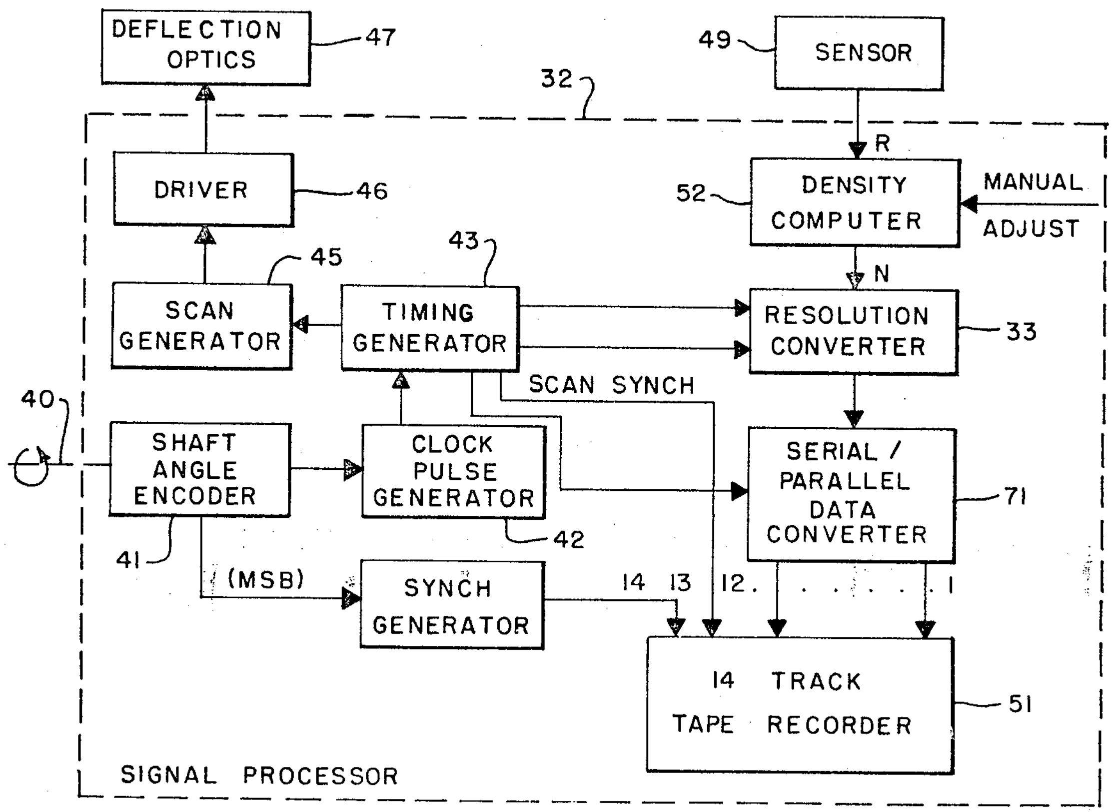

DEFLECTION OPTICS
47
SENSOR
49
32
R
DRIVER
46
DENSITY COMPUTER
52
MANUAL ADJUST
N
45
43
SCAN GENERATOR
TIMING GENERATOR
RESOLUTION CONVERTER
33
SCAN SYNCH
40
SHAFT ANGLE ENCODER
CLOCK PULSE GENERATOR
SERIAL / PARALLEL DATA CONVERTER
71
41
42
(MSB)
SYNCH GENERATOR
14 13 12 1
14 TRACK TAPE RECORDER
51
SIGNAL PROCESSOR

FIG. 6

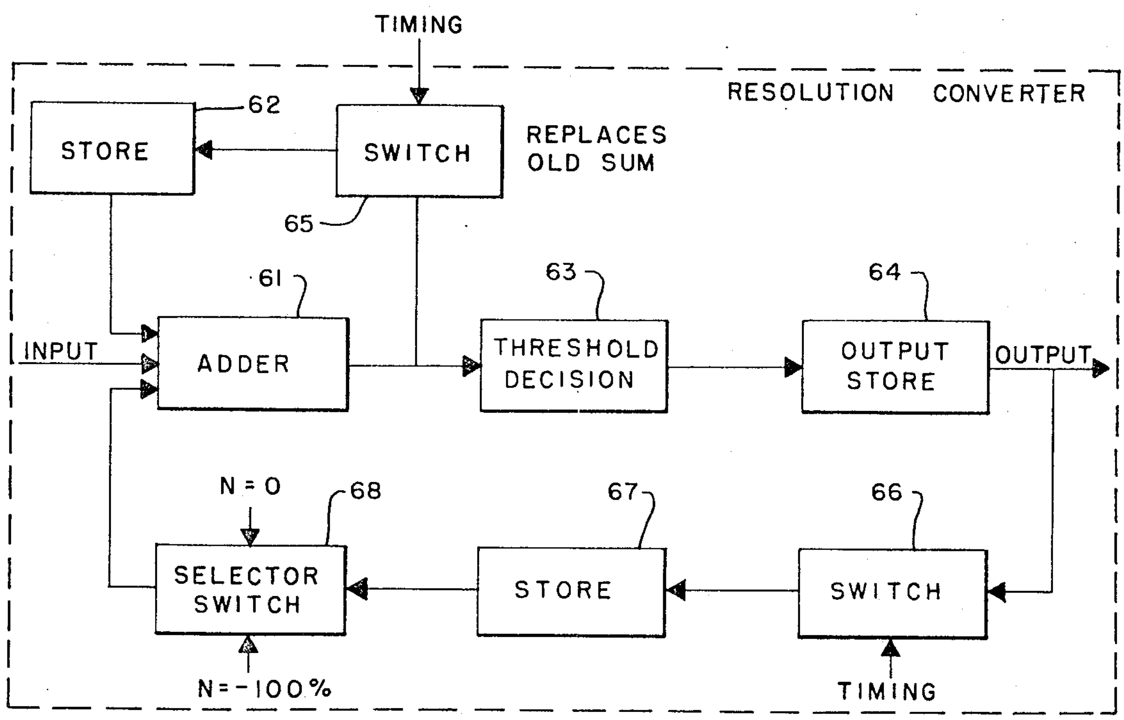

TIMING
RESOLUTION CONVERTER
STORE
62
SWITCH
REPLACES OLD SUM
65
61
63
64
INPUT
ADDER
THRESHOLD DECISION
OUTPUT STORE
OUTPUT
N = 0
68
67
66
SELECTOR SWITCH
STORE
SWITCH
N = -100%
TIMING

FIG. 7

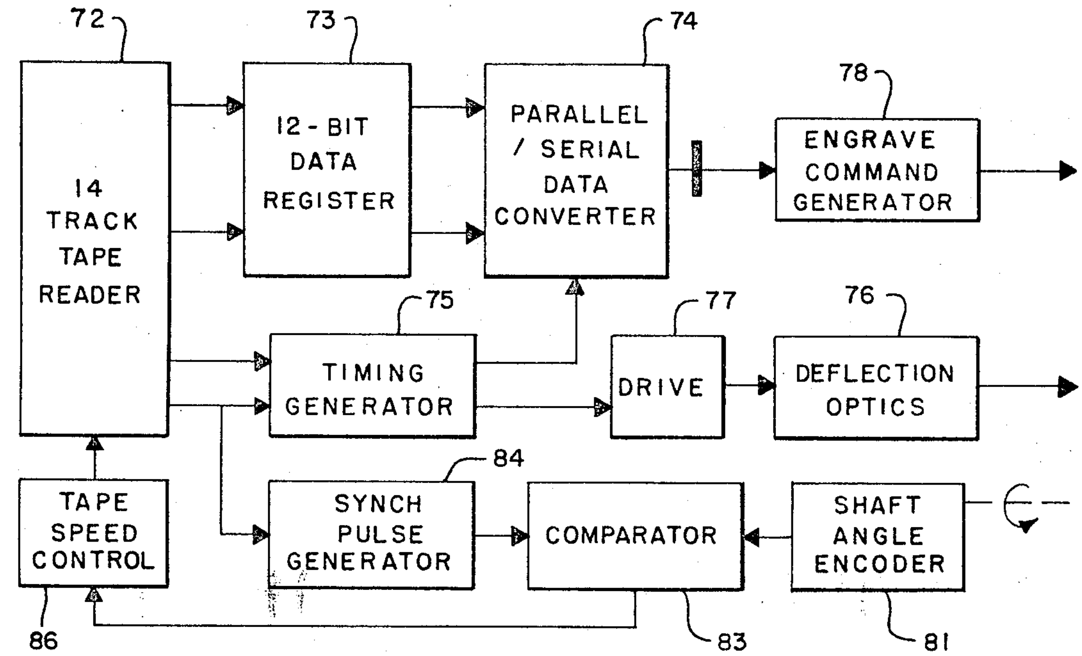


FIG. 8a

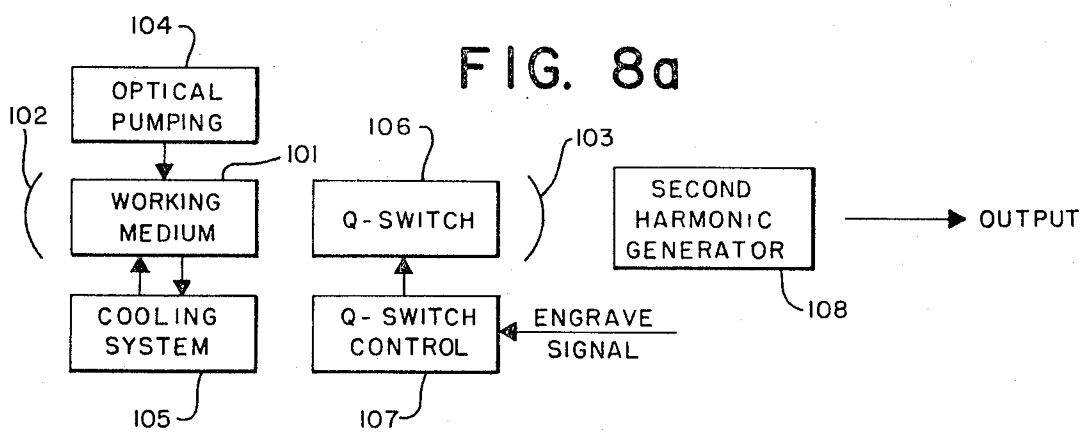


FIG. 8b

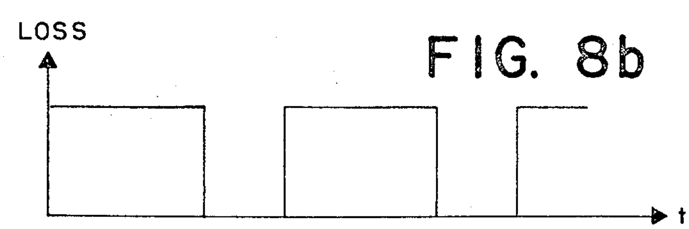
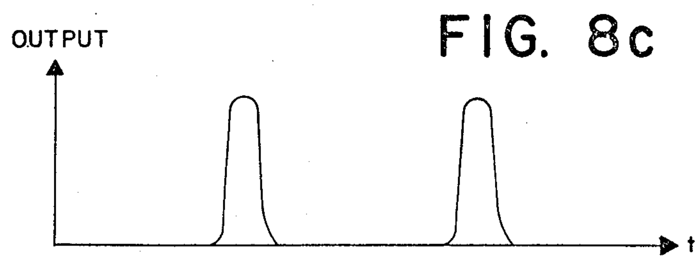


FIG. 8c



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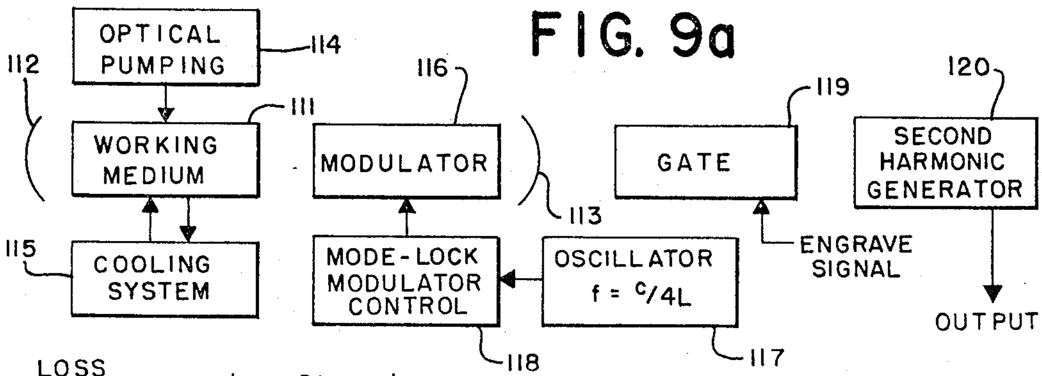

FIG. 9a

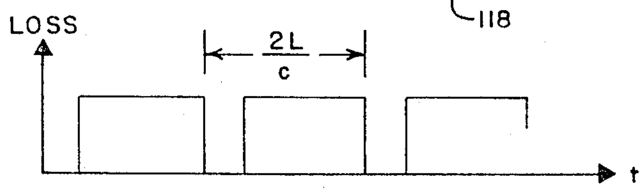

FIG. 9b

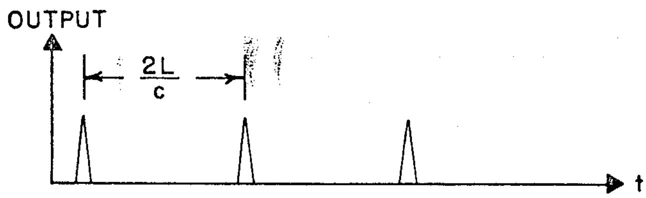

FIG. 9c

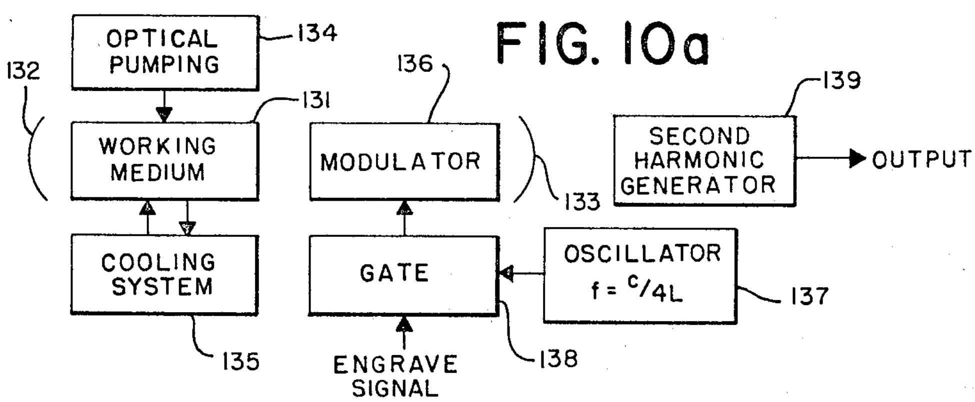

FIG. 10a

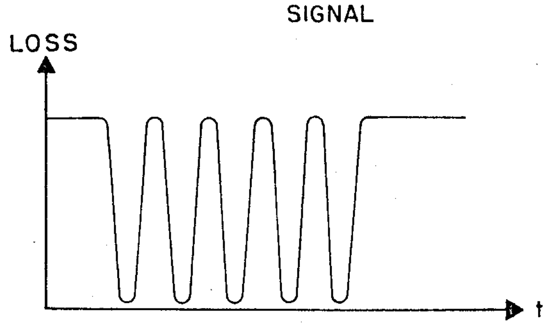

FIG. 10b

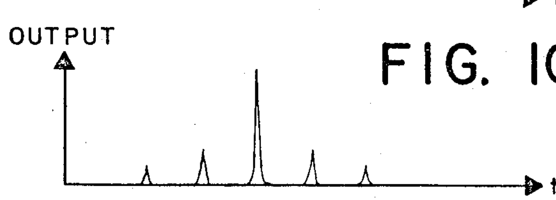

FIG. 10c

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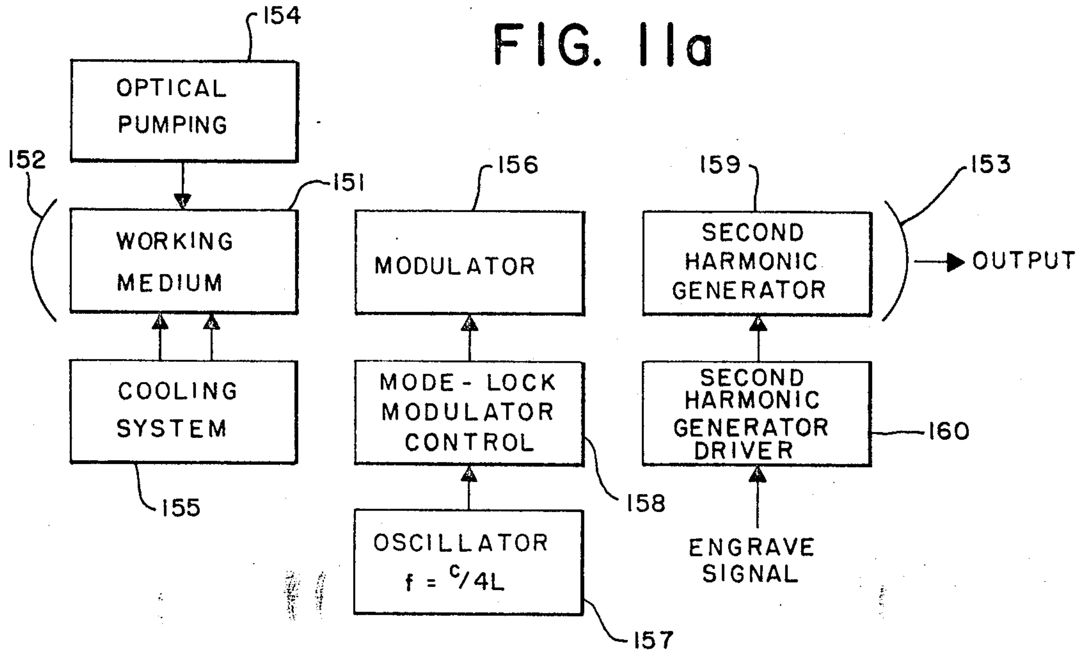
FIG. 11a



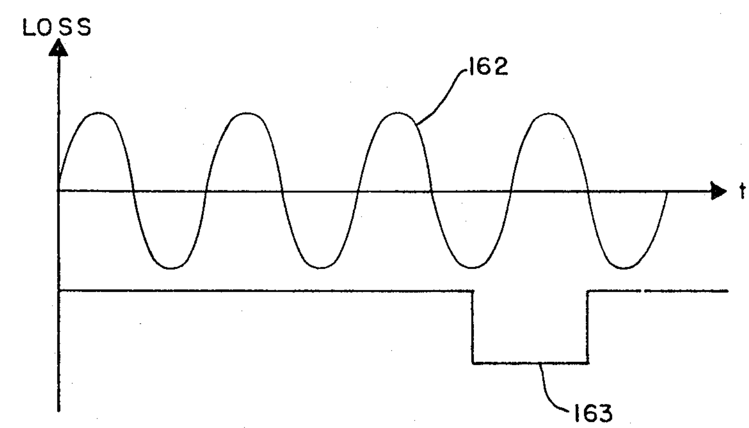


FIG. 11b

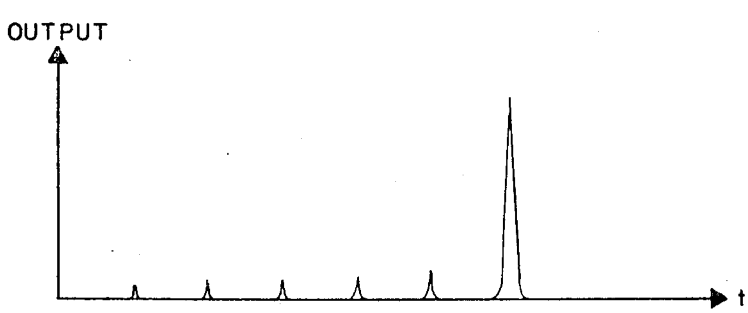


FIG. 11c

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LASER FACSIMILE SYSTEM FOR ENGRAVING PRINTING PLATES

This invention relates to systems for engraving intaglio printing plates. More particularly this invention relates to an engraving system which is uniquely suited to the capabilities of the laser as a tool for engraving intaglio printing plates.

Intaglio printing involves the laying down on paper or other stock of tiny ink dots from tiny ink-filled depressions or cells in the otherwise smooth nonprinting surface of a printing plate. Normally, the spatial density of these cells, i.e., the number of cells per unit surface area, is uniform over the plate but the cells vary in size, and therefore in ink capacity, from point to point according to the tone or optical density level required to be rendered. In conventional intaglio engraving, the cells vary in depth only, while the dimensions measured in the plane of the printing plate remain fixed. In halftone engraving, on the other hand, the cell size varies in all three dimensions. Halftone engraving is the presently preferred form and is widely used in printing magazines, color newspaper supplements and the like.

The most common method of producing halftone printing plates is the photogravure process in which the ink-carrying cells are formed in the surface of a printing plate, sometimes called a gravure plate or cylinder, by chemical etching through a suitably exposed photoresist coating.

While it has long been recognized that the laser is potentially capable of producing the cell pattern of a gravure plate, attempts to use the laser as an engraving tool for gravure plates have been faced with two problems. The first problem was the result of attempting to reproduce the various sizes and shapes of cells which result from chemical etching. To do this required a degree of control and modulation of beam shape and energy which was difficult to obtain. The second problem was simply that of obtaining sufficient output power, or equivalently, engraving speed. To be useful, an engraving system must measure its output in plates per hour, rather than plates per week.

It is therefore an object of this invention to provide a laser engraving system which overcomes the problems of control of the beam shape and modulation of the beam energy.

It is also an object of this invention to provide a laser engraving system which overcomes the problem of obtaining sufficient output power.

It is a further object of this invention to provide a laser engraving system the performance of which compares favorably with present chemical etching techniques.

According to the above objects, the present invention provides an engraving system which utilizes a novel engraving principle uniquely suited to the capabilities of the laser as an engraving tool rather than to those of chemical etching. According to this novel engraving principle, hereinafter called the Polychotic (from the Greek "many divisions or parts") engraving principle, a multiplicity of tiny, uniformly sized, nonoverlapping cells are engraved in an area of the printing plate which would formerly have been covered by a single chemically etched cell. Darker or lighter tones are rendered by increasing or decreasing the local spatial density of the uniformly sized cells rather than by increasing or decreasing the size of the cells as done in chemical etching processes.

The system includes an engraver, preferably a pulsed output laser, for removing discrete amounts of material from the surface of a printing plate so as to form separate cells of substantially equal size, and means for controlling the operation of the engraver to vary the local spatial density of cells according to the desired local tone of the image to be printed.

The Polychotic engraving principle greatly facilitates the application of laser engraving to the preparation of gravure plates because it simultaneously solves two critical problems of this application. First, the laser power requirement is proportionately reduced because it requires significantly less energy to engrave many small, closely spaced cells which print the equivalent weight of a single large cell. Second, finely quantized control of printing weight is achieved by simply adding or omitting cells, rather than performing the more difficult task of controlling the laser beam shape or pulse energy.

Additionally, the laser performance requirements of Polychotic engraving match closely those of a relatively new, economic and reliable laser system utilizing a yttrium-aluminum-garnet (YAG), working medium and a barium-sodium-niobate crystal for converting the near-infrared YAG laser radiation to green light which, because of its shorter wavelength, is more efficiently absorbed by the gravure plate which is generally made of metal.

Other objects and advantages of the present invention will be apparent from the following detailed description and accompanying drawings which set forth the principle of the present invention and, by way of example, the best mode contemplated of carrying out that principle.

In the drawings:

FIG. 1 is a perspective view of the engraving system of the present invention showing the engraving unit and the copy scanner unit;

FIG. 2*a* is a plan view of an array of chemically etched halftone cells;

FIG. 2*b* is a plan view of an array of laser engraved Polychotic cells for producing the same print density as the halftone cells of FIG. 2*a*;

FIG. 3 is a schematic diagram of the laser beam deflection optics;

FIG. 4 is a block diagram of the overall engraving system of the present invention;

FIG. 5 is a block diagram of the signal processor shown in the block diagram of FIG. 4;

FIG. 6 is a block diagram of the resolution converter shown in the block diagram of FIG. 5;

FIG. 7 is a block diagram of the signal decoder and processor for controlling the laser engraver;

FIGS. 8*a–c* are, respectively, a block diagram of a Q-switched laser, a graph of the applied engrave signal and a graph of the corresponding laser output;

FIGS. 9*a–c* are, respectively, a block diagram of a mode-locked laser, a graph of the mode-lock modulator control signal and a graph of the corresponding laser output,

FIGS. 10*a–c* are, respectively, a block diagram of a Q-switched, mode-locked laser, a graph of the modulator control signal and a graph of the corresponding laser output;

FIGS. 11*a–c* are, respectively, a block diagram of another Q-switched, mode-locked laser, graphs of the modulator control and engrave signals and a graph of the corresponding laser output.

Referring now to FIG. 1 of the drawings, there is shown a perspective view of the overall engraving system of the present invention including an engraving unit, generally designated **1**, and a copy-scanning unit, generally designated **2**. The engraving unit **1** carries a gravure cylinder **3**, generally made of copper, journaled for rotation on a pair of supports **4** and **5**. Gravure cylinder **3** is driven at approximately constant speed by a motor located in the control section **6** of engraving unit **1**. A laser or other suitable engraving tool is mounted within the engraving head **7** which is mounted on a travelling carriage **8** which is movable axially along the length of gravure cylinder **3** so that by the combined rotation of cylinder **3** and axial movement of carriage **8**, the engraving head **7** may be brought to bear sequentially over the entire surface of cylinder **3**.

The copy-scanning unit **2** carries a copy cylinder **9** which is journaled for rotation on a pair of supports **10** and **11** and which is driven at approximately constant speed by a motor located within control section **12**. A photoelectric scanner is located within copy scanner head **13** which is mounted on travelling carriage **14** which is movable axially of copy cylinder **9**, so that by the combined rotation of cylinder **9** and axial movement of carriage **14**, the copy-scanning head **13** can be made to scan the entire surface of cylinder **9**.

The photoelectric scanner in copy scanner head **13** produces signals indicative of the tone or optical density level of each successive area of copy cylinder **9** which is scanned. After further processing these signals are stored, preferably on magnetic tape, together with timing signals which can be used to determine the particular area of the copy cylinder **9** with which each tone-indicating signal is associated. The stored signals are subsequently transmitted to the engraver unit 1 where the tone-indicating signals are utilized to control the spatial density of the Polychotic cells formed on the gravure cylinder 3 by the engraving tool in engraving head 7. The timing signals serve to synchronize the operation of the engraving tool to the rotation of gravure cylinder 3.

While FIG. 1 shows separate copy-scanning and engraving units, it will be apparent to those skilled in the art that other system configurations may be employed within the spirit and scope of the present invention. For example, the copy cylinder and the gravure cylinder might be coaxially mounted on a single shaft, and the scanning and engraving heads might be connected by a rigid mechanical link in order to synchronize the scanning and engraving operations. The separate copy-scanning and engraving units lend flexibility to the system by permitting off-line operation of the engraving unit 1 from prerecorded tapes as well as real-time on-line operation in which the copy-scanning unit 2 is simply connected to the engraving unit 1 by a short tape loop.

Because the Polychotic cell structure produced by the engraving system of the present invention differs from that produced by chemical etching, it is desirable to discuss the observed effects of cell size on the printed product before proceeding with the detailed description of the apparatus.

To a first approximation, the optical density level rendered on the printed product depends upon two parameters, namely (1) the fractional area of the stock covered by the "dots," and (2) the ratio of diffuse reflectivities of the inked and noninked area. These parameters in turn depend on cell aperture size and depth. Based on experimental date the relationships of the various parameters may be summarized as follows:

1. A gravure cell of area A_c, depth greater than "critical" depth, prints a dot of approximate area several times A_c (depending on ink viscosity, stock surface conditions, etc.);
2. The critical cell depth, h_c, is linearly proportional to cell aperture linear dimensions; h_c is the minimum depth for which the dot prints at approximately its maximum density;
3. Printed dots, when sufficiently large, overlap, and these overlap areas do not make significant additional contribution to density.

Failure of the cell depth to equal or exceed the critical depth results in a decrease in effective dot area. From the analysis of available data, it appears that

(Eq. 1) $h_c = \text{constant } x\sqrt{A_c}$.

That is, the critical depth of the cell increases proportionately to the linear dimensions of the cell aperture.

From the above, one may reason correctly that for constant printed density the smaller the size of the Polychotic cells, the less will be the volume of material that needs to be removed in order to engrave a given area of the printing plate, and, hence, the lower will be the laser output energy required to engrave a given area of the printing plate.

However, there is a practical lower limit to cell size which is determined, in part, by the properties of the printing stock. A cell having an aperture dimension of 25μ (microns) has been found acceptable in this regard, and at the same time provides a sufficiently small "quantum" to permit the precise rendering of contrast although other sizes are equally feasible. Examples herein will use 25μ as a typical diameter. Equation 1 indicates that the critical depth for a 25μaperture is approximately 5μ. This conical hole has a volume of 820μ^3.

Each elementary area of a continuous tone (monotone) original diffusely reflects a certain amount of light. Dark areas reflect little light while the highlight areas tend toward the reflectivity of the original stock. On the final printed copy, this reflectivity level of original tone is rendered, according to present halftone engraving method, by a corresponding adjustment in size and reflectivity of the printed "dots." The dots are printed with a fixed spatial frequency near the limit of resolution of the human eye and thus "fuse" to give the impression of tone.

The ability of any system to faithfully reproduce the original tones depends upon its linearity and stability, i.e., on the degree to which distortion, drift and noise are absent. Fluctuations in ink properties, engraving hole size or shape, etc., all contribute variations in tone on the final print not present in the original. One of the measures of quality in the overall process (continuous tone original to printed rendering) is the number of distinct and reproducible tone levels; which is in a sense, the signal-to-noise ratio. Thus, while chemical etching may appear to be intrinsically capable of continuous variation in cell size, there is, in fact, a limit to the number of different tone levels which can be consistently rendered. This limit is determined by the degree of control which can be exercised over the etching process parameters. The present Polychotic engraving system, on the other hand, provides only a predetermined number of fixed for "quantized" tone levels. These fixed tone levels are, however, highly stable so that the quality of the overall process compares favorably with chemical etching.

In the case of conventional chemical etching methods, resolution and contrast are separate parameters because resolution is primarily fixed by the spatial frequency of the dot pattern, which is set beforehand by the selection of the screen, while contrast or tone is determined by the size and reflectivity of the printed dot. On the other hand, in the present Polychotic engraving system, an interesting and useful coupling occurs between contrast and resolution. As explained above, all dots print with exactly the same weight in the Polychotic system. The equivalent "screen," however, is about an order of magnitude finer and the desired tone levels are achieved simply by the omission of one or more of the dots within any given area. Thus, the rendition of tone is "quantized," leading to precise and reproducible control. The number of distinct tone levels which may be rendered in any arbitrarily chosen area is one more than the maximum number of dots which could be printed in that area. The size of the area chosen determines the resolution of the system.

For example, elementary laser-etched cells of 25μ diameter can be laid down in a pattern equivalent to a "screen" of about 1,000 lines per inch (l.p.i.). In this case a resolution of 1,000 l.p.i. can indeed be obtained, but with only two contrast or tone levels corresponding to engraving or not engraving each cell. If, on the other hand, it is desired to approximate continuous tone with, for example 37 tone levels, then one must necessarily accept a lower resolution corresponding to a "screen" which encloses about 36 possible dots, i.e., about 150 l.p.i. The "screen" concept is, of course, merely descriptive in connection with the present Polychotic engraving system. No screen is actually used.

The differences between conventional chemically etched cells and the Polychotic cells produced by the engraving system of the present invention are illustrated in FIGS. 2*a* and *b*. FIG. 2*a* shows, in greatly enlarged form, a plurality of chemically etched cells having a screen or resolution of about 153 l.p.i. and a fractional area of about 20 percent. FIG. 2*b* shows the equivalent Polychotic cell pattern in which 36 possible Polychotic cells of 25μ diameter are enclosed in the resolution area equivalent to that occupied by a single chemically etched cell in FIG. 2*a*. Only about one Polychotic cell in five is actually engraved (shown dark) in order to produce the desired 20 percent fractional area and equivalent optical density.

In order to form Polychotic cells of the desired size, the engraving tool used in the present engraving system must be capable of drilling holes having a diameter on the order of 25μ. If a laser is used as the engraving tool, the diameter of the focal spot must be 25μ. Referring to FIG. 3 of the drawings, there is shown in schematic form the output optical system of the engraving system of the present invention. The output beam 20 from laser 21 passes through an electro-optical deflector 22 and a lens 23 and is brought to a focus on the surface of gravure cylinder 3. A prism 24 may optionally be provided to reflect the laser beam 20 through deflector 22 and lens 23 in order to facilitate a more convenient relative positioning of the components. A plume shield **25** may be provided to protect the optical system from molten matter ejected from the surface of the cylinder 3.

The diameter of the focal spot is given by

$$d=fD\theta$$

where f is the speed of the optical system, θ is the laser-radiated angular beamwidth and D is the diameter of the laser aperture. For example, if the laser exhibits an angular beamwidth of approximately 1 milliradian, $f/4$ optics will be required for a diameter, D of about 0.5 cm.

The depth of the field of the optical system must be sufficiently large so that variations in drum diameter, runout or motion due to vibrations will not result in substantial defocusing. For the above-described optical system, the focal length of the final optics is 1 inch and the depth of field, x, for a variation of unit cell weight of less than ±10 percent (i.e., one-tenth of the minimum contrast level) is given by:

(Eq. 2) $x=\pm(f/\sqrt{10})\,)d=\pm 0.0013$ inch

This tolerance value of ±1 mil is sufficiently large so as not to cause significant difficulties with regard to gravure cylinders.

In addition to focusing the laser beam as described above, the optical system must also provide for one-dimensional deflection of the focal spot to permit the drilling of up to six cells along a side of the resolution area as shown in FIG. 2*b*. This deflection can be provided by a $BaTiO_3$ electro-optical crystal. Such crystals may readily be operated at frequencies on the order of 100 kHz. and can easily accomplish the desired deflection which extends over only ±3 cell widths.

FIGS. 4–7 are block diagrams, at various levels of detail, of the electronic control and signal-processing components of the engraving system of the present invention. FIG. 4 is a simplified block diagram of the overall engraving system showing the flow of signals from the copy cylinder **30** to gravure cylinder **31**. FIG. **5** is a more detailed block diagram of the signal processor **32** shown in FIG. 4. FIG. **6** is a more detailed block diagram of the resolution converter **33** shown in FIG. 5. FIG. **7** is a more detailed block diagram of the signal decoder **34** shown in FIG. 4.

As shown in FIG. **5** the timing for signal processing in the copy-scanning unit is derived from the mechanical drive **40** of the copy cylinder **30**. The output of a shaft angle encoder **41** is fed to clock pulse generator **42** and the resulting clock pulses are provided to timing generator **43** which controls and synchronizes the operations of the copy scanner unit. Rather than the usual shaft-angle-indicating signals, encoder **41** produces a signal for every 15 microns of travel of the surface of copy cylinder **30**. Hence the synchronization of the copy scanner unit is independent of variations in the diameter of the copy cylinder **30** and depends only upon its surface measurements.

Synchronizing signals from timing generator **43** are provided to scan generator **45** which produces a sawtooth scan voltage which is applied to driver **46** to drive deflection optics **47** which may be an electro-optical prism as described in connection with FIG. **3**. The deflection optics **47** operate scan copy cylinder **30** at right angles to the direction of its rotation. The focus optics **48** shown in FIG. **4** presents a 25μ spot or an equivalent cell aperture area of the copy cylinder **30** to the sensor **49**. The deflection optics **47** cause this spot to scan across about 150μ of the copy cylinder **30** at right angles to its direction of rotation, so that six equivalent cell aperture areas are sensed by sensor **49** during each scan.

As shown in FIG. **5**, scan-synchronizing signals are applied from timing generator **43** to the **14** track tape recorder **51** to be recorded on magnetic tape. These synchronizing signals will control the scanning of the deflection optics in the engraving unit. Another synchronizing pulse (MSB) which occurs only once for every revolution of copy cylinder **30** is recorded on magnetic tape by tape recorder **51**. This other synchronizing pulse is recorded for the purpose of slaving the laser engraving apparatus to the rotation of the gravure cylinder **31**, as explained in greater detail hereinafter.

The density computer **52** shown in FIG. **5** strobes the electrical output signal from sensor **49** six times during each sweep of the deflection optics **47** so that an optical density signal is obtained for each equivalent cell area of the copy mounted on copy cylinder **30**. Provision is made for manually adjusting the amplitude of these optical density signals in accordance with paper and ink parameters.

For reasons of stability and accuracy, the adjusted optical density signals are preferably converted into digital form for processing by the resolution converter **33**. In will be apparent, however, that analog optical density signals may be utilized within the spirit and scope of the present invention. In either case the output signals from density computer **52** will range from zero to a maximum value. A zero output signal will correspond to virgin stock and thus requires no laser firing by the engraving unit. A maximum optical density signal will correspond to the darkest possible copy and thus require laser firing by the engraving unit at the maximum rate.

If the optical density signals are converted into digital form, it will be convenient to have the maximum value correspond to the number of Polychotic cells which are to be enclosed in a resolution area, or, stated in another way, one less than the number of tone levels to be rendered. If there are 36 Polychotic cells in a resolution area (37 tone levels) as discussed in connection with FIG. 3, the maximum value of the digital output signal from density computer **52** should preferably be equal to 36.

The resolution converter **33** processes each output optical density signal from density computer **52** and produces one of two discrete output signals, a logical "1" or a logical "0," for recording on the magnetic tape by tape recorder **51**. Logical "1" calls for a laser firing by the engraving unit.

Referring to FIG. 6, the optical density signal is received as an input to adder **61** which adds the optical density signal to the contents of storage device **62** which contains the results of the previous addition. The output from adder **61** is tested by threshold device **63** which produces a logical "1" output signal if the adder output equals or exceeds a preset threshold level, and a logical "0" output if the adder output is less than the threshold level. The threshold level is preferably equal to one-half the maximum value of the optical density signals from density computer **52**. Hence, if the maximum value of the optical density signal is digital **36** the threshold level should preferably be digital **18**. It will be apparent, however, that the resolution converter **33** will operate properly with any arbitrary threshold level. The output signals from threshold device **63** are temporarily stored in output storage device **64**, and the output signals from adder **61** are transferred under control of switch **65** to storage device **62** in preparation for the processing of the next optical density signal from density computer **52**.

The output from threshold device **63** is also transferred by way of a switch **66** to storage device **67** which controls selector switch **68**. If the output from threshold device **63** is a logical "1," selector switch **68** will cause a signal equal to the maximum value of the optical density signals to be subtracted from the combined value of the contents of storage device **62** and the next optical density signal from density computer **52**. If, as a result, the output of adder **61** is less than the threshold level, a logical "0" (no laser firing) will be produced at the output of the resolution converter 33. Logical "0's" will continue to be produced until the accumulated values of the optical density signals again exceed the threshold level at which point another logical "1" (laser-firing command) will be produced.

An interesting and advantageous feature of the resolution converter **33** is that it automatically provides very high resolution for "black or white" copy such as for example, text, while providing moderate resolution when the rendering of multiple tone levels is required as in the case of halftone materials such as photographs. For black-to-white transitions of the copy, the resolution converter **33** immediately switches from logical "1's" to logical "0's" or vice versa. This means that the basic resolution area of printed product is simply the area of the dot printed by a single Polychotic cell. As explained above, this is equivalent to a "screen" resolution on the order of 1,000 l.p.i. For multiple tone level copy, on the other hand, the resolution converter 33 produces a sequence of "1's" and "0's" so as to produce the proper spatial density of dots on the printed product. This means that the basic resolution area of the printed product covers a number of contiguous dot areas. For 37 tone levels the basic resolution area covers 36 dots as shown in FIG. 3. This is equivalent to a "screen" resolution on the order of 150 l.p.i.

The output of resolution converter 33 is fed into a serial-to-parallel converter 71 for conversion to 12-bit parallel form. The output of serial-to-parallel converter 71 is recorded on magnetic tape by the 14 track tape recorder 51 together with the two synchronizing signals described above.

The laser engraver unit is controlled by the signals recorded on magnetic tape by the copy scanner unit. Signals are read from the tape by a 14 track tape reader 72 which is connected to signal decoder 34 as shown in FIG. 4. In the signal decoder 34 the laser control signals are temporarily stored in a 12-bit data storage register 73 shown in FIG. 7. The contents of storage registers 73 are converted from parallel-to-serial form by a parallel/serial converter 74 under control of a timing generator 75. The timing generator 75 receives the two synchronizing signals from the tape by way of tape reader 72 and generates timing signals fro controlling the parallel/serial converter 74 and for driving the engraver deflection optics 76 by way of a driver 77. The result is that the output of the parallel/serial converter 74 is a replica of the output of resolution converter 33 in the copy scanner unit and is properly synchronized to the engraver deflection optics 76. The output of the serial/parallel converter 74 feeds the engrave command generator 78 which controls the operation of the laser subsystem 79 which will be described in greater detail hereinafter.

In order to properly synchronize the operation of the deflection optics 76 and the laser subsystem 79 to the rotation of the gravure cylinder 31, there is provided a shaft angle encoder 81 which is connected to the mechanical drive 82 of cylinder 31, as shown in FIG. 4. A comparator 83 compares the signals from shaft angle encoder 81 with synchronizing signals derived from the magnetic tape by a synch generator 84. The output from comparator 83 is fed back to the tape speed control device 86 which serves to match the speed of tape reader 72 to the speed of the gravure cylinder 31. In this manner the operation of the engraving unit is slaved to the rotation of the gravure cylinder rather than vice versa.

An intensity sensor 91 senses the intensity of the laser output pulses and produces an output signal which is fed back to the laser power supply 92, so as to maintain the intensity of the output pulses at a constant level and thus preserve the "sharpness" of the laser cutting edge.

The movement of the copy scanner head along the length of the copy cylinder 30 is coupled to the rotation of the copy cylinder 30 as indicated by the dotted line connecting the copy scanner unit mechanical drive 40 to the focus optics 48. In practice this is accomplished by conventional means such as for example a worm gear arrangement setup so that the copy-scanning head effectively scans the entire copy cylinder 30 in spiral fashion. The movement of the engraving head along the length of gravure cylinder 31 is coupled to the rotation of the gravure cylinder 31 in the same manner as indicated by the dotted line connecting engraver unit mechanical drive 82 to focus optics 93.

Provision is also made for automatically retracting the laser focus optics 93 from the surface of gravure cylinder 31 unless the cylinder 31 is up to speed. This prevents accidental damage to the optical system and facilitates the changing of gravure cylinders when the drum is stopped. A similar provision is made for the focus optics 48 of the copy scanner unit. The retraction function may be accomplished by conventional means.

Before describing the details of the laser subsystem, it will be helpful to discuss the fundamental problem of drilling cells in a printing plate with laser pulses. The process of drilling cells with laser pulses has a relatively simple theoretical basis. By absorption of the focused pulse, sufficient energy is imparted to a small volume of the material to raise its temperature to the boiling point and to provide the latent heats of fusion and vaporization. In addition to this energy, the laser must provide for parasitic heat losses due to conduction, radiation, convention and reflection. The magnitude of these parasitic effects is a function of the laser pulse duration and wavelength. For very brief, high-power pulses, at short wavelengths, the energy loss is small. Laser pulses shorter than about 10^{-9} seconds (1 nanosecond) qualify as "brief" pulses in a sense that during the pulse interval only an insignificant amount of heat diffuses away from the irradiated region. Reradiation and convection losses from the hot zone have been found to be negligible, but losses due to reflection of the incident laser radiation at the metal surface are significant. Fortunately, the reflectivity of metals tends to decrease at shorter wavelengths, and, in the case of copper, reflectivity falls from about 99 percent in the far infrared to about 52 percent in the green portion of the visible spectrum, which amounts to an important 48 to 1 increase in absorption of the incident radiation.

In discussing the drilling of cells by laser pulses, two different types of interaction must be considered: (1) a quasi-steady state interaction which occurs with laser pulses of moderate peak power, and (2) an explosive interaction occurring with very short, high-power laser pulses.

Rates of material removal involving particle velocities of the order of the speed of sound permit steady state interactions. Substantially higher rates lead to explosive interactions.

In the steady state the interaction, energy is absorbed in a local area of the material at a rate which is sufficiently high to provide the heat needed to raise this area to the boiling point and to supply the heats of fusion and vaporization, and yet at a rate which is low enough that vaporized material can be removed from the surface before the next level is heated. In other words, drilling takes place in a layer-by-layer fashion. Under this condition vaporization takes place at the boiling temperature and the total laser energy required to drill a cell is given by:

$$E_o=(1/1-R)\rho V[(T_v-T_o)+Q_f+Q_v]+E_L \qquad \text{(Eq. 2)}$$

where

R is the reflectivity of the material, ρ is the density of the material, V is the volume of the cell, T_v is the boiling point of the material, T_o is the starting temperature, Q_f is the latent heat of fusion, Q_v is the latent heat of vaporization and E_L is the energy loss due to conduction, reradiation, etc.

The factor $1/1-R$ indicates the degree of absorption of laser radiation by the material. Since the reflectivity depends upon both the material and wavelength, the choice of the optimum laser for a particular system will depend upon this factor.

The power density for which the steady state interaction takes place can be approximated by the product of the vaporization energy requirement per unit volume (equation 2) and the velocity of sound. For copper, power densities up to about 10^9 watts/cm.^{2} result in the steady state interaction.

For laser pulses having a power density over 10^9 watts/cm.^{2}, an explosive interaction is believed to take place. In this case the rate of energy absorption is so great that the vaporized material cannot diffuse away from the surface resulting in a high-temperature vapor layer and extremely high pressure at the surface. This causes the material to be raised above its critical point at which the distinction between liquid and gas phases disappear, and the latent heat of vaporization is zero. The explosive interaction takes place at a much higher temperature than the steady state process and requires an amount of energy

$$E_0=\frac{1}{1-R}\rho V\int_{T_0}^{T_c} C\,dT+E_L \qquad \text{(Eq. 3)}$$

where T_c is the critical temperature and c is the specific heat of the material. The variation of the specific heat, c, with temperature is considered because of the wide range of temperature involved. Since the change of phase at the critical point is a reversible process, the energy required is a minimum. Therefore, the explosive process will require the same or lower energy than the steady state process.

The phase change, occurring at a high temperature results in vapor ejected from the surface at supersonic velocities which causes the explosive sound that accompanies the irradiation of metals by very short, high-power laser pulses. It has been found that a significant portion of the material is also carried away from the surface in the molten state by the explosion, which means that energy requirements are further reduced.

The "plume" of vapor and molten material ejected from the surface of the printing plate is potentially absorptive of the incident laser radiation. It has been found, however, that for short, high-power density pulses of the type described above, the plume is formed by an explosion which occurs several nanoseconds after the end of the irradiating pulse. There is therefore no attenuation of short pulses having a duration of a few nanoseconds or less.

As mentioned above, the heat losses due to convection and radiation are negligible. However, a certain amount of heat is lost by conduction to the material immediately surrounding the cell. The amount of heat loss by conduction depends upon the duration of the laser pulses. For pulses of less than 0.2-nanosecond duration the heat loss, E_L will be less than 10 percent. Returning to equation 2, it is calculated that the energy required to drill a cell of 25μ diameter and 5μ depth in a copper printing plate by the steady-state process is approximately $6\times10^{-5}(1/1-R)$ joules. The explosive process (equation 3) requires approximately $3\times10^{-5}(1/1-R)$ joules. Because the dependence of the energy requirements on reflectivity, R, and because of the dependence of reflectivity on the laser wavelength, it is clearly advantageous to use short-wavelength laser pulses for the purpose of drilling Polychotic cells in a copper printing plate.

As indicated above, the choice of an optimum laser subsystem for the Polychotic engraving system of the present invention depends on a number of factors including pulse duration and wavelength. Additionally, in order co provide high engraving rates the laser subsystem must be capable of high average power and high overall efficiency so that the primary power requirements are practical for typical printing installations. Finally, the laser subsystem should have a simple, reliable configuration so that it requires a minimum of maintenance and provides economical operation.

Although there are a large number of laser working media, only a few are suitable for practical industrial use. These include argon, carbon dioxide, ruby, neodymium-doped glass (Nd: glass)and neodymium-doped yttrium-aluminum-garnet (Nd: Yag While it will be appreciated that the present engraving system is not limited to any particular laser working medium, the neodymium-doped YAG (Nd: YAG) laser, which is simple and rugged in construction and versatile, reliable and economic in operation, is well suited for use in the engraving system of the present invention.

The laser working medium may be a Nd: YAG rod (or series of rods end to end) having an overall length of about 8 inches and a diameter of one-fourth inch. Such a configuration is capable of producing at least 120 watts of continuous wave output power. Since the neodymium ion has its major absorption bands in the near infrared and visible yellow spectra, pumping of the Nd: YAG laser can be effected with long-lived incandescent lamps. Pumping may be provided by two quartz-iodine-tungsten incandescent lamps operating at 10 kw. each. The lamps may be connected in series and driven from a 208-volt 30-amp line through a 3ϕ SCR-controlled transformer and bridge rectifier. The rectified 3ϕ voltage exhibits only 4 percent ripple without filtering and the long thermal line constant of the tungsten filament effectively eliminates this. The Nd: YAG rod may be cooled by flowing water from a 20 kw. capacity recirculating cooling system.

A well-known method of generating short, high-peak power laser pulses is known as Q-switching. Q-switched pulses are generated by inhibiting laser oscillation during the pumping period by substantially lowering the Q of the optical resonator. The pumping energy built up and stored in the laser medium during this period is emitted in extremely short, high-peak power pulses when the resonator Q is again switched to the high-Q state. Solid-state lasers such as ruby, Nd:glass and Nd:NAG all operate well in this Q-switched mode.

Referring now to FIG. 8*a* of the drawings, there is shown a Q-switched laser subsystem for use in the Polychotic engraving system of the present invention. A laser working medium **101**, such as an Nd:YAG rod, is located within the optical resonator formed by a pair of reflectors **102** and **103**. Reflectors **102** and **103** are preferably spherical to reduce the criticality of their alignment. The laser rod **101** is pumped by a suitable optical pumping source **104** such as a pair of tungsten-quartz-iodine incandescent lamps, and is cooled by a suitable cooling system **105**. Also located within the optical resonator formed by reflectors **102** and **103** is a Q-switch **106** which serves to selectively inhibit or permit the buildup of oscillations in the resonator. Q-switch **106** may be any one of a number of devices well known to those skilled in the art, such as, for example, the Kerr cell. The engrave signal from the engrave command generator **78** shown in FIG. 7 operates through Q-switch control **107** and Q-switch **106** to release the laser output pulses through partially transmitting reflector **103**. A graph of the loss introduced into the optical resonator by Q-switch **106** is shown in FIG. 8*b*. The buildup of oscillations is inhibited during high-loss periods but permitted during low-loss periods. FIG. 8*c* is a corresponding graph showing the laser output pulses occuring during the low-loss periods of the Q-switch **106**. Q-switched pulses produced by the above-described Nd:YAG laser would typically have a pulse width on the order of 20 to 50 nanoseconds, a peak power of about 2 megawatts and a pulse separation somewhat greater than 100 microseconds.

For the purpose of improving the absorption of the laser pulses by the metal printing plate, a second harmonic generator **108** may be provided in the output path. The second harmonic generator **108** is preferably a noncentrosymmetric optical crystal having a dielectric constant proportional to the field strength of the incident optical waves. As a result of the nonlinear properties of such crystals they generate optical waves having twice the frequency of the incident optical waves. The amplitude of the second harmonic wave is proportional to the intensity of the incident wave. For efficient generation of the second harmonic wave it is necessary that the phase velocity (index of refraction) of both the fundamental and second harmonic waves be identical in the chosen direction of propagation. Fortunately, for a wide class of materials this can be achieved by choosing the proper direction of propagation within the crystal and/or by adjusting the temperature of the crystal.

Although there are a number of materials capable of providing second-harmonic generation, barium sodium niobate crystals provide the greatest conversion efficiency of materials currently available. Conversion efficiencies up to 50 percent have been demonstrated at low power levels, and conversion efficiencies up to 100 percent have been demonstrated in pulsed devices of moderate (on the order of 1 mv.) peak power.

In the preferred form of the present invention, the second harmonic generator is a crystal of barium-sodium-niobate of approximately 7×7×10 mm. The temperature of the crystal is maintained at 80° C. by a small closed-loop oven. At this temperature there is an index-match condition for the fundamental output wave of the YAG rod (1.06 μ wavelength) and the second harmonic wave (0.53 μ wavelength) with resulting high conversion efficiency, as explained above.

Another method of generating short high peak power pulses is by the mode-locked operation of the laser. Mode-locked operation is achieved by introducing a time-periodic loss into the laser resonator, the time period corresponding exactly to the transit time of a pulse of light back and forth within the resonator. FIG. 9*a* is a diagram of a laser subsystem equipped for mode-locked operation. The laser working medium **111** is disposed within the optical resonator formed by reflectors **112** and **113**. The usual optical pumping apparatus **114** and cooling system **115** are provided. Also disposed within the optical cavity is a variable loss modulator **116** which may be an electro-optic modulator made of KDP or lithium niobate. Alternatively, a lower cost acoustical modulator might be employed.

The modulator **116** is driven by an oscillator **117** operating through appropriate mode-lock modulator control electronics **118**. The frequency of the oscillator is given by $f = c/4L$ where c is the speed of light and L is the effective optical path length between the reflectors **112** and **113**. FIG. 9*b* is a graph of the loss introduced into the optical resonator by modulator **116**. Low-loss time slots occur at intervals of $2L/c$. If the pulse (1 photon, initially) passes through the modulator **116** at a time when the loss is zero it will grow on each succeeding transit through the laser rod **111**. Because of the synchronism between the periodic loss and travel time of the photon packet, there is zero loss (no attenuation) each time the photon packet passes through the modulator **116**. If, on the other hand, a pulse initially passes through the loss modulator **116** at a time when the loss is high, the pulse will rapidly decay to zero amplitude because, even though it is amplified on each transit through the laser medium **111**, it is attenuated even more on each pass through the loss modulator **116**.

The resulting laser radiation is an extremely narrow pulse packet traveling back and forth through the resonator in phase synchronism with the modulator **116**. At each reflection from the partially reflecting output reflector **113**, a small fraction of the pulse passes through to provide a continuous train of pulses as shown in FIG. 9*c*. For the Nd:YAG laser described above with an optical resonator on the order of 45 cm. long, the pulse width of the mode-locked pulses is about 30 to 300 picoseconds, the peak power of the pulses is on the order of 6 to 7 kw. and the pulse separation is on the order of 3 nanoseconds.

It will be appreciated however that the peak power and the pulse separation can be increased by increasing the length of the optical resonator. This can be conveniently accomplished by the use of appropriate reflectors to fold the optical path. An effective optical resonator length on the order of 150 meters could be expected to produce mode-locked pulses having a peak power on the order of 1 mw. and pulse separations of about 1 μ sec. Such pulses would be well suited for drilling Polychotic cells in a printing plate.

A gate **119** is provided to control the release of the mode-locked pulses in response to signals from the engrave command generator **78** shown in FIG. 7. Gate **119** may be of a conventional type such as for example a Kerr cell. A second harmonic generator **120** may also be provided in the output path in order to increase the efficiency of absorption of the laser pulses by the printing plate.

The particular laser output pulse requirements of the Polychotic engraving system of the present invention may be most effectively met by a combination of the Q-switched and the mode-locked modes of operation which may be called the Q-locked mode of operation. FIG. 10*a* is a diagram of a laser subsystem equipped for Q-locked operation. The laser working medium **131** is disposed within the optical resonator formed by reflectors **132** and **133**. The usual optical pumping apparatus **134** and cooling system **135** are provided. A variable loss modulator **136** which may be a Kerr cell or KDP or lithium niobate crystal or other well-known optical modulator is also disposed within the optical resonator. Mode-locking signals of frequency $f = c/4L$ are applied to modulator **136** from oscillator **137** through gate **138** under control of the engrave signal from the engrave command generator **78** shown in FIG. 7. The engrave signal thus acts to switch the resonator to its high Q state but with mode-locking signals superimposed.

FIG. 10*b* is a graph of the loss introduced into the optical resonator by modulator **136**. High loss (low Q) is introduced for a period equivalent to about 150 mode-locked pulse periods although no pulses are actually allowed to build up. During that period energy from the optical pumping radiation is stored in the laser working medium **131**. The engrave signal then switches the resonator to its high Q state, but the superimposed mode-locking signals from oscillator **137** control the buildup of the output pulses so as to maintain a narrow pulse width. As shown in FIG. 10*c*, the output pulse builds to a maximum after a few transits of the optical cavity. Smaller pulses escape through the partially reflecting output reflector **133** on each transit of the resonator by the photon packet both before and after the main output pulse. However, the main pulse contains most of the energy which was stored in the working medium **131**. After the engrave signal is removed, the resonator is returned to its low Q state for the equivalent of at least another 150 mode-locked pulse periods until the next engrave signal is applied. In the Nd:YAG laser described above, the main Q-locked output pulse would have a pulse width on the order of 30 to 300 picoseconds and a peak power on the order of 1 mw. A second harmonic generator **139** may be provided for the reasons mentioned above in connection with FIGS. **8** and **9**.

An alternative Q-locked laser subsystem is shown in FIG. 11*a*. The laser working medium **151** is disposed within the optical cavity formed by reflectors **152** and **153**. The usual optical pumping apparatus **154** and cooling system **155** are provided. Also disposed within the optical cavity is a variable loss modulator **156** which may be an electro-optical modulator such as a KDP or lithium niobate crystal or other conventional modulator. A signal of frequency $f = c/4L$ from oscillator **157** is applied through mode lock modulator control **158** to modulator **156**. A graph **162** of the signal applied across the electrodes of electro-optic modulator **156** is shown in FIG. 11*b*. The modulator **156** produces a low loss when the signal shown in FIG. 11*b* is near its axis crossing and a high loss when the signal shown in FIG. 11*b* is near its positive or negative maxima.

The modulator **156** causes a mode-locked photon packet to build up within the optical cavity formed by reflectors **152** and **153**. However, in the laser subsystem of FIG. **11**, output pulses are not permitted to escape at each transit of the photon packet as was the case in the laser subsystem of FIGS. **9** and **10**. Instead, the energy of the photon packet is caused to build up during multiple (about 150 for example) transits of the optical cavity until an output pulse is finally released by a novel pulse-gating arrangement which is combined with the function of second harmonic generation.

A second harmonic generator **159** which may be, for example a barium-sodium-niobate crystal, is disposed within the optical cavity formed by reflectors **152** and **153** together with working medium **151** and modulator **156**. The second harmonic generator **159** is normally detuned from its index-matching condition by the application of an electric field across the crystal. As a result there is substantially no conversion of the oscillating photon packet from its fundamental frequency (1.06 μ wavelength in the case of Nd:YAG) to its second harmonic frequency (0.53 μ wavelength). Since both reflectors **152** and **153** are substantially 100 percent reflective at the 1.06 μ wavelength, the energy remains stored in the 1.06 μ photon packet.

An engrave signal from engrave command generator **78** shown in FIG. 7 operates through second harmonic generator driver **160** to remove the detuning electric field from the second harmonic generator crystal **159**. The oscillating photon packet is therefore substantially entirely converted to its second harmonic frequency (0.53 μ wavelength) on its next transit. Because the output reflector **153** is substantially transparent at 0.53 μ (though 100 percent reflective at 1.06 μ) the entire energy of the stored photon packet will appear as an output pulse of an energy and wavelength suitable for drilling a Polychotic cell in a copper printing plate. A graph **163** of the signal applied to second harmonic generator crystal **159** is shown in FIG. 11*b*. The corresponding laser output is shown in FIG. 11*c*.

Another Q-locked laser subsystem might employ a mode-locking modulator as in the laser subsystem of FIG. 11*a*, but, as an alternative pulse-gating arrangement, might employ the combination of an electro-optical quarter wave rotator and a Nicol prism. The quarter wave rotator and the Nicol prism would be set up to normally transmit the mode-locked photon packet between 100 percent reflective end reflectors, so that there would be a buildup of the pulse energy. The engrave signal would cause the quarter wave rotator to rotate the polarization of the photon packet by 90° so that the entire cross-polarized wave would be dumped out of the optical cavity by the Nicol prism.

It is estimated that, with the above-described Nd:YAG laser operated in the Q-locked mode at an average output power of 120 watts and equipped with a second harmonic generator in order to increase the efficiency of absorption of the laser pulses by a copper printing plate, Polychotic cells 25 μ in diameter and 5 μ deep can be formed at a maximum rate of 10^6/sec. At 36 cells per resolution area of 167 μ, at least 2.7 square meters of printing plate can be engraved in 1 hour. This corresponds to about 20 10 (inch×12 inch pages in 35 minutes.

While the principles of the present invention have been illustrated by reference to a preferred embodiment and several modifications thereof, it will be apparent to those skilled in the art that other modifications and adaptations may be made without departing from the spirit and scope of the invention. For example, although the Polychotic engraving principle was illustrated by reference to the engraving of gravure cylinders, it will be apparent that the apparatus might be modified to engrave flat printing plates or other articles.

It will also be apparent that, although a combination of mechanical scanning and electro-optical scanning is used in both the copy-scanning unit and the engraving unit of the present engraving system, entirely mechanical scanning or entirely electro-optical scanning or the scanning techniques might be employed.

It will further be apparent that other techniques can be employed for controlling the spatial density of the Polychotic cells formed in the printing plate in accordance with the sensed tone level of the original copy. For example, the tone level of a whole resolution area of the original copy might be sensed, and the resulting signal used to control the frequency of operation of the laser, and, hence the spatial density of the Polychotic cells formed in the corresponding resolution area of the printing plate.

It will further be apparent that engraving tools other than the laser may be employed within the spirit and scope of the present invention. For example, an electron beam might be used to form cells in a printing plate according to the principles of Polychotic engraving.

Other and further modifications and adaptations of the present invention may be made without departing from the spirit and scope of the invention as set forth with particularity in the appended claims.

What is claimed is:

1. Apparatus for engraving a printing plate so as to print an image corresponding to a predetermined image comprising:

engraving means for removing discrete amounts of material from the surface of said printing plate so as to form separate cells of substantially equal size;

scanning means for scanning said predetermined image, and for producing signals indicating the position of the cell area portion of said predetermined image being scanned;

means responsive to said position signals for controlling the position of said engraving means relative to said printing plate;

sensing means for producing a digital signal corresponding to the optical density of each cell area portion of said predetermined image scanned;

digital accumulator means for accumulating said digital signals from said sensing means;

threshold means responsive to said accumulator means for producing an output signal when the contents of said accumulator means reach a predetermined value;

means responsive to an output signal from said threshold means for substracting from the contents of said accumulator means a digital amount equal to the maximum optical density of a cell area portion of said predetermined image scanned; and

means responsive to an output signal from said threshold means for causing said engraving means to form a cell in said printing plate.

2. The apparatus of claim 1, wherein said engraving means comprises a laser operated in the pulsed output mode, the output pulses from said laser being of substantially equal energy, each output pulse being operative to form a separate cell in the surface of said printing plate, said cells being of substantially equal size.

3. The apparatus of claim 2 wherein said laser is a Q-switched laser and wherein said Q switch is responsive to said output signal from said threshold means.

4. The apparatus of claim 2 wherein said laser is a mode-locked laser having an output gate, said output gate being responsive to said output signal from said threshold means.

5. The apparatus of claim 2 wherein said laser is a Q-switched, mode-locked laser, said Q switch being responsive to said output signal from said threshold means.

6. Apparatus for engraving a printing plate so as to print an image corresponding to a predetermined image comprising:

laser engraving means operated in the Q-switched mode-locked pulsed output mode for removing discrete amounts of material from the surface of said printing plate, said laser engraving means including

a pair of spaced-apart opposed reflectors forming an optical cavity;

a continuously pumped working medium disposed within said optical cavity;

a first normally lossy variable loss device disposed within said cavity, said first variable loss device providing substantially lossless transmission momentarily at a frequency given by $c/2L$ where c is the speed of light and L is the effective length of the optical path between the two reflectors forming the optical cavity;

a second normally lossy variable loss device disposed within said cavity, said second variable loss device providing substantially lossless transmission in response to a control signal to produce a laser output pulse; and

control means responsive to signals representative of said predetermined image for controlling said engraving means to locally increase the spatial density of said cells in response to signals representative of locally increased optical density of said predetermined image, and to locally decrease the spatial density of said cells in response to signals representative of locally decreased optical density of said predetermined image.

7. The apparatus of claim 6, wherein said second variable loss device comprises:

an electro-optically active nonlinear crystal for generating the second harmonic of the fundamental output frequency of said working medium, said nonlinear crystal being normally disenabled from producing said second harmonic frequency and being enabled to produce said second harmonic frequency to produce a laser output pulse, one of said reflectors forming said optical cavity being substantially totally reflective at the fundamental frequency of said working medium and substantially transparent to the second harmonic of said fundamental frequency.

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