A calibration method and apparatus is disclosed that includes a power stabilized laser diode to generate a laser beam that is passed through the hologon scanner to be calibrated and a mechanism for measuring the power intensity of the laser beam at a plurality of positions at an exposure plane for each facet of the hologon scanner. The measured light levels are converted to correction factors that are stored in a corresponding programmable read only memory (PROM) as a function of facet number and scan position. The hologon scanner and its corresponding programmable PROM are then installed in a laser scanning apparatus. The laser scanning apparatus adjusts the output of its light source in accordance with the correction factors stored in the PROM in order to compensate for variations in the light transmission efficiency of the facets of the hologon scanner.
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METHOD AND APPARATUS FOR PROVIDING CORRECTION
OF HOLOGON TRANSMISSION EFFICIENCY VARIATIONS

Field of the Invention

The invention relates generally to methods and devices that provide correction for fluctuations in the power intensity of a scanning laser beam caused by hologon transmission efficiency variations. In particular, the invention provides a method and apparatus for detecting and correcting facet-to-facet and intrafacet or in-line variations in the light transmission efficiency of a hologon scanner used to generate the scanning laser beam.

Background of the Invention

Laser printing devices that employ a hologon film scanner to generate a scanning laser beam are well known in the art. The hologon film scanner typically includes a hologon disc containing a number of facets. A laser beam is directed to the hologon disc as the disc is rotated by a drive motor. The laser beam is deflected as it passes through the facets of the rotating hologon disc and the deflected beam is used to scan a line on a photoreceptor, such as a photosensitive drum or belt utilized in some electrostatic printing devices or a photographic film in a film scanner printing device. The power intensity of the laser beam can be modulated to create either a continuous tone image or a number of discrete image pixels.

There is a problem, however, associated with the above-described laser printing devices, namely, print quality can be seriously degraded due to line-to-line and intraline fluctuations in the power intensity of the scanned laser beam. The power intensity fluctuations are caused by facet-to-facet and intrafacet variations in the light transmission efficiency of the hologon disc. The fluctuations in light transmission efficiency, and the
problems associated therewith, can be minimized if the hologon disc is manufactured to exacting tolerances. The manufacturing precision required to eliminate the above-described power intensity fluctuations, however, is very expensive and greatly increases the overall cost of a hologon scanner.

In view of the above, it is an object of the invention to provide a method and apparatus for detecting and correcting facet-to-facet and infrasfaculty variations in the light transmission efficiency of a hologon scanner, thereby improving printing quality while simultaneously lowering the manufacturing expense of the hologon scanner. Other objects and advantages of the invention will become apparent after further study of the detailed description of the preferred embodiments of the invention provided below.

Summary of the Invention

The invention provides a method and apparatus for detecting and correcting facet-to-facet and intrafacet variations in the light transmission efficiency of a hologon scanner. More specifically, a calibration method and apparatus is disclosed which utilizes a power stabilized laser diode to generate a laser beam that is passed through the hologon scanner to be calibrated, and a mechanism for measuring the power intensity of the laser beam at a plurality of positions at an exposure plane for each facet of the hologon scanner undergoing the calibration process. The measured light levels are converted to correction factors that are stored in a corresponding programmable memory device, for example a programmable read only memory (PROM), as a function of facet number and scan position. The hologon scanner and its corresponding programmable memory device are then installed in a laser scanning apparatus. The laser
scanning apparatus adjusts the output of its light source in accordance with the correction factors stored in the programmable memory device in order to compensate for variations in the light transmission efficiency of the facets of the hologon scanner.

Brief Description of the Drawings

With the above as background, reference should now be made to the following detailed description of the preferred embodiment of the invention and the accompanying drawings in which:

Fig. 1 is a basic schematic diagram illustrating a hologon scanner calibration assembly in accordance with the present invention;

Fig. 2 is a basic flow diagram of a calibration correction routine used by the hologon scanner calibration assembly of Fig. 1 to generate correction factors in accordance with a first embodiment of the invention;

Fig. 3 illustrates a laser scanner apparatus that utilizes a PROM containing the correction factors generated by the hologon scanner calibration assembly illustrated in Fig. 1 to correct the light output of its light source in accordance with a first embodiment of the invention;

Fig. 4 is a block diagram of an address generator employed in the laser scanner apparatus illustrated in Fig. 3;

Fig. 5 is a representative timing diagram of the signals employed by the address generator illustrated in Fig. 4;

Fig. 6 is a basic flow diagram of a calibration correction routine used by the hologon scanner calibration assembly of Fig. 1 to generate correction
factors in accordance with a second embodiment of the invention; and

Fig. 7 illustrates a laser scanner apparatus in accordance with a second embodiment of the invention that utilizes a multiplier instead of the divider utilized in the first embodiment illustrated in Fig. 3.

Detailed Description of the Preferred Embodiment

As described above, the invention is directed to a method and apparatus for detecting and correcting facet-tofacet and intrafacet variations in the light transmission efficiency of a hologon scanner, thereby enabling less expensive manufacturing techniques to be employed in the production of the hologon scanner. The invention is based on the recognition that the transmission characteristics of each individual hologon scanner can be determined prior to the installation of the hologon scanner in a laser scanner apparatus. Once the transmission characteristics are known, correction factors can be generated to compensate for facet-to-facet and intrafacet variations in the light transmission efficiency of the hologon scanner. The correction factors can be stored in corresponding programmable read only memory (PROM) devices as a function of facet number and scan position. Once a hologon scanner and its corresponding programmable PROM are installed in a laser scanning apparatus, the laser scanning apparatus adjusts the output of its light source in accordance with the correction factors stored in the PROM in order to compensate for variations in the light transmission efficiency of the facets of the hologon scanner.

Referring now to Fig. 1, a basic schematic diagram illustrating a hologon scanner calibration assembly in accordance with the present invention is shown including a laser driver 10 that controls the operation of a laser
source 12. The output beam from the laser source 12 is passed through a stationary grating 14, a hologon scanner 16 to be calibrated, and is focused on an exposure plane EP via output optics 18. A light measurement device 20, for example a Photodyne Model 44XLA Optical Power Meter with Model 600 photodetector and integrating sphere, is mounted on a transport mechanism 22 that preferably includes a lead screw coupled to a stepper motor drive unit. The output signal from the light measurement device 20 is supplied to a control circuit 24. The control circuit 24 includes a processor unit 26 coupled to a memory unit 28, that contains an operating program for the processor unit 26, and an A/D converter 30.

The control circuit 24 coordinates the operation of the hologon scanner 16, the transport mechanism 22, and the operation of the light measurement device 20, in order to obtain a samples of the scanned light beam at a number of points (x) of the exposure plane EP for each of the facets of the hologon scanner 16 to be calibrated.

More specifically, the control circuit 24 sends a control signal to the transport mechanism 22 that causes the transport mechanism 22 to move the light measurement device 20 along the exposure plane EP in unison with the scanned light beam. The light measurement device 20 is activated at preselected positions or sample points to sample the intensity of the scanned light beam. The light samples are indicative of the in-line or intrafacet light transmission efficiency of each facet of the hologon scanner 16. Analog signals sampling signals generated by the light measurement device 20 are converted into digital data by the A/D converter 30 which are stored in the memory unit 28 under control of the processor unit 26. The processor unit 26 then performs a calibration correction routine on the stored digital data, in accordance with a calibration correction program.
previously stored in the memory unit 28, to generate a plurality of correction factors that correspond to the sampled scanning point for each facet of the holocon scanner 16. The correction factors generated by the processor unit are stored in a PROM 32 that is coupled to the control circuit 24.

Fig. 2 is a general flow diagram of the calibration correction routine performed by the processor unit 26 in accordance with a first embodiment of the invention. At step S1, the processor unit 26 reads in an array of light power measurements corresponding to sample points \((x)\) which are supplied by the light measurement device 20. The processor unit 26 then determines the maximum power transmission point \(P_{max}\) and the minimum power transmission point \(P_{min}\) from the stored array in step S2. At step S3, the processor unit 26 determines a null power level point \(P_n\) based on the maximum transmission point \(P_{max}\) and the minimum transmission point \(P_{min}\). The null power level point is the power level which requires no correction and all sample points are corrected to this value. At step S4, a correction divisor \(D_x\) is calculated for each sample point by dividing the power measured at the sample point \(P_x\) by the null power \(P_n\). This yields an array of correction divisors \(D_x\) which, when divided into the power measured at a sample point \(P_x\), will yield the null power \(P_n\). In order to map the correction divisors into the PROM 32, the processor unit 26 calculates a mapping factor \(K\) in step S5 by dividing the number of available storage locations by the difference between the largest correction divisor \(D_{max}\) and the smallest correction divisor \(D_{min}\). A linear array of integer correction divisors \(C_x\) is then created in step S6 by taking the absolute value, rounded to the nearest integer (RI), of the mapping factor multiplied by the difference between the a given correction divisor \(D_x\) and the
smallest correction divisor Dmin. The array of integer
correction divisors Cx is then stored in PROM 32 at step
S7.

The hologon 16 and the PROM 32 corresponding thereto
are removed from the hologon scanner calibration assembly
after completion of the calibration correction routine.
The PROM 32 is stored or packaged with the hologon
scanner 16 until they are both installed in the same
laser scanning apparatus. The laser scanning apparatus
utilizes the correction factors stored in the PROM 32 to
control the output of its light source in order to
compensate for the facet-to-facet and intrafacet
variations in the light transmission efficiency of the
hologon scanner 16.

An example of a laser scanning apparatus in
accordance with the invention is illustrated in Fig. 3.
The laser scanning apparatus includes an address
generator 40 that generates memory addresses which are
supplied to the PROM 32 in order to retrieve the stored
correction factors. The digitally stored correction
factors are output from the PROM 32 in response to the
memory addresses generated by the address generator 40
and supplied to a digital-to-analog (D/A) converter 42.
The D/A converter 42 converts the digital correction
factors into analog output signals that are supplied to
an attenuator 44, which in turn adjusts the amplitude
levels of the analog output signals to appropriately
match desired analog correction factor signal levels.
For example, in the illustrated embodiment, the
attenuator 44 effectively divides the amplitude level of
the analog output signals by the factor K which was used
in the generation of the array Cx. The attenuated signal
from the attenuator 44 is added to a predetermined offset
voltage by an offset device 46 which effectively adjusts
the null value of the system. The resulting analog
correction factor signal is supplied to a divider 48 which is also coupled to a laser power controller 50. The divider 48 divides a laser power signal, which is generated by the power controller 50, by the analog correction factor signal to generate a corrected laser power signal. The corrected laser power signal is supplied to a laser driver 52 that controls the operation of a laser source 54 in response to the corrected laser power signal. A feedback circuit 56 is also provided to regulate the output of the laser source 54.

As shown in greater detail in Fig. 4, the address generator 40 is responsive to a start-of-scan (SOS) signal generated by photodiode sensor placed at the start position of an active scan line within the laser scanning apparatus and an index signal (I) that is generated by the hologon scanner 16 when it reaches an initial starting position. The index signal (I) is generated, for example, by an optical sensor that reads an index mark placed on the hologon scanning disc of the hologon scanner 16. The SOS signal is supplied to an SOS multiplier 58 that generates and supplies a clocking signal to a scan position counter 60. The scan position counter 60 supplies a scan position address to the PROM 36 which designates a specific point (X) in a scan line. The SOS signal is also supplied to the reset input of the scan position counter 60, so that the scan position counter 60 is reset at the beginning of each scan, and to the clock input of a facet counter 62. The facet counter 62 is therefore clocked at the beginning of each scan line and generates a facet address indicative of which facet of the hologon scanner is being employed. The facet address, as with the scan position address, is supplied to the PROM 36. The facet counter 62 is reset when the index signal (I) is generated. As previously stated, the PROM 36 is loaded with an array of correction
factors that are addressed by facet number and scan position. Thus, the correction factor for a given facet and scan position is supplied to the D/A converter 42 from the PROM 36 when the address generator 40 supplies the corresponding facet and scan position addresses. A representative timing diagram illustrating signal generation during a scanning operation is shown in Fig. 5.

The embodiment described above yields a linear array of divisors which map well into the linear array of PROM space that is available. At high scanning speeds, however, it may be easier and less expensive to utilize multiplication factors as fast multiplier devices are readily available. Thus, the operation of the hologon scanner calibration assembly illustrated in Fig. 1 can be modified to produce correction multipliers Mx instead of correction divisors Dx as shown in Fig. 6. The structure of a laser scanning apparatus employing correction multipliers remains the same, except the divider 48 is replaced by a multiplier 70 which multiplies the laser power signal by the analog correction factor signal supplied by the offset device 44 as shown in Fig. 7. It should be noted that the use of correction multipliers yields a nonlinear array which is difficult to map into the PROM 32. The results can be skewed, however, to yield the best mapping fit.

The invention has been described with reference to certain preferred embodiments thereof. It will be understood, however, that variations and modifications are possible within the spirit and scope of the appended claims. For example, a multiplying D/A converter can be employed to perform the functions of the D/A converter 42 and the attenuator 44. A number of discrete detection devices can also be used to measure the light levels at the exposure plane instead of a single device that is
moved along the exposure plane with the scanning beam as illustrated in Fig. 1.
CLAIMS:

1. A method of correcting for hologon scanner transmission efficiency variations, said method characterized by:
   a. generating a source laser beam;
   b. applying the source laser beam to a hologon scanner to generate a scanning laser beam;
   c. directing the scanning laser beam to an exposure plane;
   d. measuring the intensity of the scanning laser beam at a plurality of points at the exposure plane;
   e. generating correction factors based on the measured intensity of the scanning laser beam at the plurality of points; and
   f. storing the correction factors in a programmable memory device that corresponds to the hologon scanner.

2. A method of correcting for hologon scanner transmission efficiency variations as claimed in Claim 1, wherein the step of generating correction factors includes generating a plurality of correction divisors.

3. A method of correcting for hologon scanner transmission efficiency variations as claimed in Claim 1, wherein the step of generating correction factors includes generating a plurality of correction multipliers.

4. A method of correcting for hologon scanner transmission efficiency variations in a scanning apparatus, characterized by the steps of:
   a. retrieving at least one digital correction factor from a memory device and generating a corresponding correction factor signal;
   b. generating a laser power control signal;
c. combining the laser power control signal with the correction factor signal to produce a corrected laser power control signal; and

d. applying the corrected laser power control signal to a laser source.

5. A method of correcting for hologon scanner transmission efficiency variations in a scanning apparatus as claimed in Claim 4, wherein the step of combining the laser power control signal with the correction factor signal includes dividing the laser power control signal by the correction factor signal.

6. A method of correcting for hologon scanner transmission efficiency variations in a scanning apparatus as claimed in Claim 4, wherein the step of combining the laser power control signal with the correction factor signal includes multiplying the laser power control signal by the correction factor signal.

7. An apparatus for correcting hologon scanner transmission efficiency variations characterized by: means for generating a source laser beam; means for applying the source laser beam to a hologon scanner to generate a scanning laser beam; means for directing the scanning laser beam to an exposure plane; means for measuring the intensity of the scanning laser beam at a plurality of points at the exposure plane; means for generating correction factors based on the measured intensity of the scanning laser beam at the plurality of points; and means for storing the correction factors in a programmable memory device that corresponds to the hologon scanner.

8. An apparatus as claimed in Claim 7, wherein the means for generating correction factors
generates a plurality of correction divisors.

9. An apparatus as claimed in Claim 7, wherein the means for generating correction factors generates a plurality of correction multipliers.

10. An apparatus for correcting hologon scanner transmission efficiency variations characterized by: means for retrieving at least one digital correction factor from a memory device and generating a corresponding correction factor signal; means for generating a laser power control signal; means for combining the laser power control signal with the correction factor signal to produce a corrected laser power control signal; and means for applying the corrected laser power control signal to a laser source.

11. An apparatus as claimed in Claim 10, wherein the means for combining the laser power control signal with the correction factor signal includes a divider.

12. An apparatus as claimed in Claim 10, wherein the means for combining the laser power control signal with the correction factor signal includes a multiplier.

13. A programmed read only memory device containing a plurality of correction factors, wherein the correction factors correspond to fluctuations in a power intensity of a scanning laser beam caused by transmission efficiency variations of a hologon scanner.

14. An apparatus characterized by: a laser driver coupled to a laser source, the laser source generating a laser beam in response to a control signal supplied by the laser driver; optical means for passing the laser beam through a hologon scanner to be calibrated to generate a
scanning laser beam; an optical unit for focusing the scanning laser beam at an exposure plane; a light measurement device coupled to a transport mechanism; and a control circuit;

wherein the control circuit controls the operation of the transport mechanism to move the light measurement device along the exposure plane in unison with the scanning laser beam and the light measurement device samples the scanning laser beam at a plurality of points along the exposure plane to generate light sample signals that are supplied to the control circuit; and

wherein the control circuit generates a plurality of correction factors in response to the light sample signals supplied by the light measurement device and stores the correction factors in a programmable memory device.
**FIG. 2**

1. **S1**
   - READ IN ARRAY OF POWER MEASUREMENTS

2. **S2**
   - DETERMINE
     - $P_{\text{max}}$
     - $P_{\text{min}}$

3. **S3**
   - CALCULATE
     - $P_n = \frac{P_{\text{max}} - P_{\text{min}}}{2}$

4. **S4**
   - CALCULATE
     - $D_x = \frac{P_x}{P_n}$

5. **S5**
   - CALCULATE
     - $K = \frac{(2^{N-1})}{D_{\text{max}} - D_{\text{min}}}$

6. **S6**
   - CREATE
     - $C_x = \frac{K(D_x - D_{\text{min}})}{R_I}$

7. **S7**
   - STORE
     - $C_x$ IN PROM
FIG. 4
S1' - READ IN ARRAY OF POWER MEASUREMENTS

S2' - DETERMINE
       Pmax
       Pmin

S3' - CALCULATE
       Pn = \frac{P_{max} \cdot P_{min}}{2}

S4' - CALCULATE
       M_x = \frac{P_n}{P_x}

S5' - CALCULATE
       K = \frac{(2^N - 1)}{M_{min} \cdot M_{max}}

S6' - CREATE
       C_x = \sqrt{\frac{K(M_x \cdot M_{max})}{R_I}}

S7' - STORE
       C_x IN PROM

FIG. 6
FIG. 7

DIAGRAM OF LIGHT OUTPUT SYSTEM

LASER SOURCE 34

FEEDBACK CIRCUIT 56

LASER DRIVER 32

MULTIPLIER 70

OFFSET DEVICE 46

ATTENUATOR 44

DIA 42

PROM 32

ADDRESS GENERATOR 40

LASER POWER CONTROLLER 50
# INTERNATIONAL SEARCH REPORT

**International Application No:** PCT/US 92/02572

## I. CLASSIFICATION OF SUBJECT MATTER

(If several classification symbols apply, indicate all)*

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 G02B26/10

## II. FIELDS SEARCHED

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## IV. CERTIFICATION

**Date of the Actual Completion of the International Search**

20 AUGUST 1992

**Date of Mailing of this International Search Report**

28.8.92

**International Searching Authority**

EUROPEAN PATENT OFFICE

**Signature of Authorized Officer**

GRUNFELD M. Y.

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