FILM IMAGE DIGITIZER USING OPTICAL FIBER-COUPLED LASER DIODE

Field of the Invention

The present invention relates to film image digitizers, and, more particularly, to laser beam optics for use in such digitizers.

Discussion of Related Art

A film image digitizer converts an image formed on a sheet of film into a set of digital values. Each of the digital values represents a transmittance of the film at a particular pixel in the image. The transmittance provides an indication of an optical density associated with the pixel in the image. The film digitizer may store the digital values obtained from the film as a pixel matrix image file. The image file can be accessed for display on a monitor or archived.

One type of film image digitizer uses a laser as a source of light. The laser emits a focused laser beam that is scanned across the film to illuminate individual pixels. A light collection device, positioned on a side of the film opposite the laser, measures the intensity level of light transmitted through the film in response to illumination by the laser. The intensity level is indicative of the transmittance value of the film at each pixel. A data

acquisition system receives from the light collection device analog signals indicative of the measured transmittance values. The data acquisition system converts the analog signals into digital values, and stores the digital values at the appropriate pixel address in the image file.

The laser used in many existing film image digitizers is a helium-neon gas laser. Unfortunately, helium-neon gas lasers used in film image digitizers suffer from a number of disadvantages. For example, a helium-neon gas laser having power and beam quality specifications suitable for use in a film digitizer can be costly. In addition, the laser beam emitted by such lasers must be carefully shaped and sized by a series of optical elements for precise illumination of discrete pixel locations on the order of 35 to 300 microns in diameter. The optical elements increase the size, cost, and complexity of the digitizer, and present multiple surfaces that can introduce light scattering.

Power stabilization of the helium-neon gas laser typically requires the use of a beam splitter and a photodetector for feedback. The beam splitter directs a portion of the laser beam to the photodetector, which measures the power of the laser beam and provides a feedback signal to control circuitry associated with the laser power supply that is used to correct laser output power variations. Like the optical elements required for beam shaping and sizing, the beam splitter and photodetector occupy additional

space within the film digitizer, present added cost and complexity, and can introduce additional light scattering.

The helium-neon gas laser and its associated power supply also can be very large and cumbersome. The size of the helium-neon gas laser increases the size of the film digitizer, and complicates placement of the laser and optical elements within the digitizer. Further, the durability and service life of the helium-neon gas laser may be less than desirable. The laser tube is susceptible to fracture and/or leakage, rendering the laser less efficient or entirely inoperable. Finally, helium-neon gas lasers produce a laser beam having a narrow wavelength spectrum and a long coherence length. Such laser beams have been observed to produce visible interference fringes in the digitized image due to multiple reflection of the laser beam within the layers of the film. The interference fringes can produce noticeable artifacts in the digitized image, undermining diagnostic utility.

As an alternative to the helium-neon laser, some existing film image digitizers employ a laser diode. The laser diode overcomes several of the problems associated with the use of a helium-neon laser. For example, the laser diode is much smaller and less costly than the helium-neon laser. In addition, the laser diode generally is more durable than the helium-neon laser. Further, the laser diode includes a built-in back facet monitor that enables laser beam

power to be measured without the need for a beam splitter.

Like the helium-neon laser, however, the laser diode requires a series of optical elements to precisely size and shape the laser beam for high spatial resolution. The optical elements add to the cost and complexity of the film image digitizer and can introduce scattering. In addition, single longitudinal-mode laser diodes produce light with a narrow wavelength spectrum and long coherence length. Thus, laser diodes are capable of producing interference fringes in the digitized image.

In view of the foregoing disadvantages associated with both helium-neon gas lasers and laser diodes, there exists a need for an improved light source for use in film image digitizers.

Summary of the Invention

The present invention, in a first embodiment, is directed to an apparatus for digitizing an image formed on a sheet of film. In accordance with the first embodiment of the present invention, the apparatus comprises a laser diode for emitting a laser beam, an optical fiber, coupled to the laser diode, for transmitting the laser beam, a scanning mechanism for receiving the laser beam from the optical fiber and scanning the laser beam across the sheet of film, and a light collection device for detecting light transmitted through the sheet of film in response to

the scanning of the laser beam across the sheet of film.

In a second embodiment, the present invention provides an apparatus for scanning a sheet of film for digitization of an image formed on the sheet of film. In accordance with the second embodiment of the present invention, the apparatus comprises a laser diode for emitting a laser beam, an optical fiber, coupled to the laser diode, for transmitting the laser beam, and a scanning mechanism for receiving the laser beam from the optical fiber and scanning the laser beam across the sheet of film.

In a third embodiment, the present invention provides an apparatus for digitizing an image formed on a sheet of film, the apparatus comprising a laser diode for emitting a laser beam, a scanning mechanism for scanning the laser beam across the sheet of film, and a light collection device for detecting light transmitted through the sheet of film in response to the scanning of the laser beam across the sheet of film, and a radio frequency oscillator for modulating the laser diode at radio frequencies to increase a spectral width of the laser beam emitted by the laser diode, thereby reducing interference generated by multiple reflections of the laser beam within the sheet of film.

Brief Description of the Drawing

Fig. 1 is a schematic diagram of an apparatus for digitizing an image formed on a sheet of film, in accordance with the present invention.

Detailed Description of the Preferred Embodiments

Fig. 1 shows an apparatus 10 for digitizing an image formed on a sheet 12 of film. The apparatus 10 comprises a laser diode 14 that emits a laser beam 15 from a front facet 18. An optical fiber 20 has an input end 22 coupled to front facet 18 of laser diode 14. The optical fiber 20 receives laser beam 15 from front facet 18 of laser diode 14 and transmits the laser beam along the length of the optical fiber to an output end 24. An optical module 26, positioned adjacent output end 24 of optical fiber 20, focuses laser beam 15 transmitted from the optical fiber to produce a focused beam 16. A scanning mechanism 28 receives focused beam 16 from optical fiber 20 via optical module 26 and produces a beam 17 that scans film sheet 12.

A light collection device 30 detects light transmitted through sheet 12 of film in response to the scanning of laser beam 17 across the film sheet. The light collection device 30 measures the level of intensity of the light transmitted through film sheet 12 at each pixel and generates analog signals indicative of the measured intensity levels. The measured intensity levels are indicative of the transmittance value of film sheet 12 at each pixel.

The light collection device 30 may include an array of silicon photodiodes within a light collection compartment oriented to receive light transmitted through film sheet 12. A data acquisition system 32 receives the analog signals from light collection device 30 and converts the analog signals into digital values. The data acquisition system 32 then stores the digital values at the appropriate pixel address in an image file.

As further shown in Fig. 1, a radio-frequency (RF) oscillator 34 provides power to laser diode 14, as indicated by line 36. A laser diode controller 38 receives feedback from back facet monitor 40 of laser diode 14, as indicated by line 42. The feedback is an analog signal representing the laser beam output power of laser diode 14, as measured by a built-in photodiode associated with back facet monitor 40. The feedback enables laser diode controller 38 to stabilize the laser beam output power of laser diode 14. Specifically, laser diode controller 38 generates a drive signal as a function of the feedback signal received from back facet monitor 38 to control laser beam output power. The drive signal generated by laser diode controller 38 is summed with the power signal generated by RF oscillator 34, as indicated by summing element 44. The amplitude of the signal generated by RF oscillator 34 is fixed so that, at the selected average output power, the laser diode is driven down below threshold once each cycle by the oscillator. The feedback signal provided to laser

diode controller 38 from back facet monitor 40 eliminates the need for a beam splitter element in the main optical path of the laser beam and an accompanying discrete photodetector for measurement of the split beam.

The film digitizing apparatus 10 uses only a single wavelength to sense film light transmittance, and thus is different from normal human viewing conditions in which a light box is used to illuminate the film with white light. This difference is a concern when selecting a laser wavelength for use in digitizing apparatus 10. In particular, it may be desirable to select a laser wavelength at which the film transmittance is close to the average film transmittance over the visible wavelength spectrum. Laser wavelengths of approximately 780 nanometers are suitable for conventional silver halide X-ray film. Accordingly, laser diode 14 may comprise a commercially available laser diode capable of emitting a laser beam 15 with a wavelength of approximately 780 nanometers. Alternatively, a laser diode capable of emitting a laser beam 15 with a wavelength in the range of approximately 630-690 nanometers may be used.

The use of RF oscillator 34 is desirable to avoid the appearance of visible interference fringes in the digitized image. Specifically, RF oscillator 34 is used to modulate laser diode 14 at high frequencies, e.g., 300 to 1000 megahertz, to broaden the spectrum of laser beam 15. The resulting broad spectrum scanned laser beam 17 produces less laser light

interference arising from multiple reflections within the layers of film sheet 12. The reduced occurrence of interference reduces or eliminates the appearance of visible interference fringes and other artifacts in the digitized image, thereby preserving image quality.

The optical fiber 20 used to transmit laser beam 15 preferably is a single mode fiber. In addition, optical fiber 20 preferably is pigtailed with laser diode 14 for enhanced coupling efficiency and higher film-plane power. In other words, it is preferred that laser diode 14 and optical fiber 20 be packaged together as a fiber pigtail laser diode. Suitable laser diode packages having single mode optical fiber pigtails with collimating optics are commercially available from, for example, Seastar Optics, of Sidney, British Columbia, Canada, and Melles Griot, of Boulder, Colorado. Coupling efficiency for 780 nanometer laser diodes with optical fiber pigtails presently is specified in the range of approximately forty to fifty percent. Laser diodes with 630-690 nanometer wavelengths presently have a coupling efficiency specified in the range of approximately twenty-five percent. The use of a non-pigtailed optical fiber 20 may be acceptable if adequate coupling efficiency for a given set of requirements is obtained.

The use of optical fiber 20 to transmit laser beam 15 provides a number of advantages. The optical fiber 20 not only transmits laser beam 15, but also shapes and sizes the beam. In particular, the profile

of laser beam 16 at output end 22 of optical fiber 20 is determined by the fiber and is free from astigmatism present at front facet 18 of laser diode 14. The profile of laser beam 16 is approximately circular gaussian, and can be readily focused at the imaging plane for digitization of film sheet 12. Further, the size of laser beam 16 is determined by the diameter of optical fiber 20. Thus, optical fiber 20 performs the functions of shaping and sizing laser beam 16, thereby eliminating the need to position a series of optical elements in the main beam path. Elimination of the optical elements reduces the size, cost, and complexity of the overall digitizing apparatus 10, and reduces the number of surfaces capable of introducing light scattering. In addition, optical fiber 20 can be easily manipulated and flexibly placed within the housing of digitizing apparatus 10.

Although optical fiber 20 eliminates the series of optical elements previously necessary for beam shaping and sizing, the incorporation of optical module 26 is desirable to focus laser beam 16 on film sheet 12. The optical module 26 may include both an achromatic lens (doublet, f = 25.4 millimeters) and a plano-convex lens (f = 250.0 millimeters). The achromatic lens and plano-convex lens receive the nearly ideal gaussian shaped laser beam 16 from output end 22 of single mode optical fiber 20 and focus the beam for application to each location on film sheet 12. The scanning mechanism 28 then receives the

focused laser beam from optical module 26, and directs the beam toward film sheet 12 as scanned beam 17. The scanning mechanism 28 may comprise, for example, a polygonal scanner that is rotated to scan laser beam 17 across film sheet 12.

The following non-limiting example is provided to further illustrate the present invention.

EXAMPLE 1

A film image digitizer was constructed using a light source in the form of a laser diode emitting a wavelength of approximately 780 nanometers. The laser diode included a single mode optical fiber pigtail service, and was obtained from Seastar Optics. An achromatic lens (doublet, f = 25.4 millimeters) and a plano-convex lens (f = 250.0 millimeters) were disposed at the output of the optical fiber. Nominal laser beam diameter measured at half maximum intensity value for full width at half maximum (FWHM) at the film plane was approximately 85 microns. Laser diode power was measured to be approximately 30 milliwatts, with a laser beam power of approximately 13.5 milliwatts measured at the output end of the optical fiber. The laser beam was scanned across a 14 by 17 inch (35.56 centimeters by 43.18 centimeters) sheet of silver halide X-ray film with a polygonal scanner, and measured to have a film plane power of approximately 8 milliwatts. The polygonal scanner, obtained from Copal, of Santa Clara, California, exhibited a total beam throw at the center of the scan angle of approximately 600 millimeters. The large beam throw

distance created a relatively long depth of focus, eliminating the need for a field flattening lens.

Having described the exemplary embodiments of the invention, additional advantages and modifications will readily occur to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. Therefore, the specification and examples should be considered exemplary only, with the true scope and spirit of the invention being indicated by the following claims.

What is claimed is:

1. An apparatus for digitizing an image formed on a sheet of film, the apparatus comprising:

a laser diode for emitting a laser beam;

an optical fiber, coupled to said laser diode, for transmitting said laser beam;

a scanning mechanism for receiving said laser beam from said optical fiber and scanning said laser beam across said sheet of film; and

a light collection device for detecting light transmitted through said sheet of film in response to said scanning of said laser beam across said sheet of film.

2. The apparatus of claim 1, wherein said optical fiber is a single mode optical fiber.

3. The apparatus of claim 2, wherein said single mode optical fiber shapes said laser beam to produce a substantially circular beam profile.

4. The apparatus of claim 1, wherein said optical fiber is pigtailed from said laser diode.

5. The apparatus of claim 1, further comprising at least one optical focusing element disposed between said output of said optical fiber and said scanning mechanism.

6. The apparatus of claim 1, further comprising a radio frequency oscillator for modulating said laser diode at radio frequencies to increase a spectral width of said laser beam emitted by said laser diode, thereby reducing interference generated by multiple

* C L M S *

reflections of said laser beam within said sheet of film.

7. The apparatus of claim 6, wherein said radio frequencies comprise frequencies in a range of approximately 300 to 1000 megahertz.

8. The apparatus of claim 1, wherein said scanning mechanism comprises a polygonal mirror.

9. An apparatus for scanning a sheet of film for digitization of an image formed on said sheet of film, the apparatus comprising:

a laser diode for emitting a laser beam;

an optical fiber, coupled to said laser diode, for transmitting said laser beam; and

a scanning mechanism for receiving said laser beam from said optical fiber and scanning said laser beam across said sheet of film.

10. The apparatus of claim 9, wherein said optical fiber is a single mode optical fiber.

11. The apparatus of claim 10, wherein said single mode optical fiber shapes said laser beam to produce a substantially circular beam profile.

12. The apparatus of claim 9, wherein said optical fiber is pigtailed from said laser diode.

13. The apparatus of claim 9, further comprising at least one optical focusing element disposed between said output of said optical fiber and said scanning mechanism.

14. The apparatus of claim 9, further comprising a radio frequency oscillator for modulating said laser diode at radio frequencies to increase a spectral

* C L M S *

width of said laser beam emitted by said laser diode, thereby reducing interference generated by multiple reflections of said laser beam within said sheet of film.

15. The apparatus of claim 14, wherein said radio frequencies comprise frequencies in a range of approximately 300 to 1000 megahertz.

16. The apparatus of claim 9, wherein said scanning mechanism comprises a polygonal mirror.

17. A method for digitizing an image formed on a sheet of film, the method comprising the steps of:

emitting a laser beam from a laser diode;

transmitting said laser beam via an optical fiber;

scanning said laser beam transmitted by said optical fiber across a sheet of film; and

detecting light transmitted through said sheet of film in response to said scanning of said laser beam across said sheet of film.

18. A method for scanning a sheet of film for digitization of an image formed on said sheet of film, the method comprising the steps of:

emitting a laser beam from a laser diode;

transmitting said laser beam via an optical fiber; and

scanning said laser beam transmitted by said optical fiber across a sheet of film.

19. An apparatus for digitizing an image formed on a sheet of film, the apparatus comprising:

a laser diode for emitting a laser beam;

* C L M S *

a scanning mechanism for scanning said laser beam across said sheet of film; and

a light collection device for detecting light transmitted through said sheet of film in response to said scanning of said laser beam across said sheet of film; and

a radio frequency oscillator for modulating said laser diode at radio frequencies to increase a spectral width of said laser beam emitted by said laser diode, thereby reducing interference generated by multiple reflections of said laser beam within said sheet of film.

20. A method for digitizing an image formed on a sheet of film, the method comprising the steps of:

emitting a laser beam from a laser diode;

scanning said laser beam across said sheet of film;

detecting light transmitted through said sheet of film in response to said scanning of said laser beam across said sheet of film; and

modulating said laser diode at radio frequencies to increase a spectral width of said laser beam emitted by said laser diode, thereby reducing interference generated by multiple reflections of said laser beam within said sheet of film.

