

CALIBRATING FINE ACTUATOR USING A REFERENCE PATTERN

RELATED APPLICATIONS

5 This patent application is a continuation-in-part of U.S. Patent Application serial no. 10/347,074, which was filed on January 17, 2003, and titled "Radial Position Registration For A Trackless Optical Disc Surface", and which is hereby incorporated by reference.

BACKGROUND

 An optical disc, such as a compact disc (CD), is an electronic data storage medium that can be written to and read using a low-powered laser beam. A CD is typically used for electronically recording, storing, and playing back audio, video, text, and other information in digital form. A digital
15 versatile disc (DVD) is another more recent type of optical disc that is generally used for storing and playing back movies because of its ability to store much more data in the same space as a CD.

 CDs were initially a read-only storage medium that stored digital data as a pattern of bumps and flat areas impressed into a piece of clear polycarbonate
20 plastic through a complex manufacturing process. Thus, the average consumer often owned a number of CD's that had both desired data (e.g., a few songs they enjoyed on a CD) and undesired data (e.g., the remaining songs on the CD that they disliked). However, average consumers can now put their own data on their own CDs with CD players capable of burning digital data into CD-Rs
25 (CD-recordable discs) and CD-RWs (CD-rewritable discs).

As more and more consumers burn their own CDs, the need for convenient ways to identify the data on such CDs has increased. Methods for labeling the non-data side of optical discs (e.g., CDs, DVDs) with text and images, for example, have continued to develop. Basic methods for labeling a disc include physically writing on the non-data side with a permanent marker (e.g., a Sharpie marker) or printing out a paper sticker label and sticking it onto the non-data side of the disc. Other physical marking methods developed for implementation in conventional CD players include ink jet, thermal wax transfer, and thermal dye transfer methods. Still other methods use the laser in a conventional CD player to mark a specially prepared CD surface. Such methods apply equally to labeling CDs and DVDs.

A label image can be rendered on the label surface (i.e., the non-data side, or top side) of an optical disc by marking the label surface with a laser beam along concentric circles around the disc. For each circle, spots of constant size and optical density are marked by the laser according to the marking data for that circle. One difficulty in rendering a label image on the non-data side (i.e., label surface) of an optical disc is that there are no markings such as pre-engraved tracks on the non-data side from which radial positioning can be determined. One method for determining radial positioning on the non-data side of an optical disc is the use of a reference pattern on the non-data side. This method is discussed in the related application, "Radial Position Registration For A Trackless Optical Disc Surface", noted above. Still more accuracy in radial positioning may be required for higher label densities.

25 **SUMMARY**

A reference pattern on an optical disc is used to calculate the gain of a fine actuator.

5 **BRIEF DESCRIPTION OF THE DRAWINGS**

The same reference numbers are used throughout the drawings to reference like components and features.

Fig. 1 illustrates an exemplary disc media marking system.

Fig. 2 illustrates an exemplary embodiment of a disc drive system as a
10 component of the exemplary disc media marking system of Fig. 1.

Fig. 3 illustrates an exemplary embodiment of optical disc media having an exemplary reflectivity pattern.

Figs. 4 illustrates an exemplary calibration process including different scanning paths across a sawtooth reference pattern and exemplary reflectivity
15 signals.

Fig. 5 illustrates and exemplary table of radii data and DAC count data.

Figs. 6 - 8 illustrate exemplary sawtooth patterns and a reflectivity signal responses generated by an optical pickup unit.

Fig. 9 illustrates an exemplary plot of DAC count data, radii data, and a
20 best fit line calculated using the DAC count data and the radii data.

Figs. 10 - 11 are flow diagrams illustrating exemplary methods for calibrating a fine actuator using a sawtooth pattern.

DETAILED DESCRIPTION

25 **Overview**

The following discussion is directed to disc media marking systems and methods that facilitate optical disc labeling through calibration of a fine actuator to accurately control the radial movement of a marking laser. A reference pattern (e.g., a sawtooth pattern) on the non-data side (or label side) of an optical data storage disc enables optical disc devices to calibrate a fine actuator. The fine actuator controls small radial movements of a focusing lens and marking laser in between larger radial movements provided by a coarse actuator. The sawtooth pattern has a linear variation with the disc radius that is measurable and convertible to distance, enabling calibration of the fine actuator. Other patterns having linear variation with the disc radius are also contemplated such as triangular patterns (i.e., half of a sawtooth pattern), stair step patterns, and so on. Calibration of the actuator is achieved by measuring the pattern, calculating the implied radius from the pattern measurement, stepping the actuator, and repeating the process.

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Exemplary System Environment

Fig. 1 illustrates an exemplary disc media marking system 100 suitable for calibrating a fine actuator using a sawtooth pattern. The exemplary disc media marking system 100 includes a disc media marking device 102 and a display device 104. The disc media marking device 102 can be implemented as a stand-alone appliance device for labeling disc media. Alternatively, the disc media marking device 102 can be integrated as part of an optical media player or drive, such as a writable compact disc (CD) player that is implemented to label an optical disc as well as record data onto a CD-R (CD-recordable disc) and/or a CD-RW (CD-rewritable disc). Such writable CD devices may include, for example, a stand-alone audio CD player that is a

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peripheral component in an audio system, a CD-ROM drive integrated as standard equipment in a PC (personal computer), a DVD (digital versatile disc) player, and any number of similar embodiments.

Disc media marking device 102 includes one or more processors 106 (e.g., any of microprocessors, controllers, and the like) that process various instructions to control the operation of disc media marking device 102 and communicate with other electronic and computing devices. Disc media marking device 102 can be implemented with one or more memory components, examples of which include a random access memory (RAM) 108, a disk storage device 110, and non-volatile memory 112 (e.g., any one or more of a read-only memory (ROM) 114, flash memory, EPROM, EEPROM, etc.).

Disk storage device 110 can include any type of magnetic or optical storage device, such as a hard disk drive, a magnetic tape, a recordable and/or rewriteable compact disc (CD), a DVD, DVD+RW, and the like. The one or more memory components provide data storage mechanisms to store various information and/or data such as configuration information for disc media marking device 102, graphical user interface information, and any other types of information and data related to operational aspects of disc media marking device 102. Alternative implementations of disc media marking device 102 can include a range of processing and memory capabilities, and may include any number of differing memory components than those illustrated in Fig. 1.

Disc media marking device 102 includes a firmware component 116 that is implemented as a permanent memory module stored on ROM 114, or with other components in disc media marking device 102, such as a component of a processor 106. Firmware 116 is programmed and distributed with disc media marking device 102 to coordinate operations of the hardware

within disc media marking device 102 and contains programming constructs used to perform such operations.

An operating system 118 and one or more application programs can be stored in non-volatile memory 112 and executed on processor(s) 106 to provide a runtime environment. A runtime environment facilitates extensibility of disc media marking device 102 by allowing various interfaces to be defined that, in turn, allow the application programs to interact with disc media marking device 102. In this example, the application programs include a label design application 120, an image processing application 122, and a print control application 124.

The label design application 120 generates a label design user interface 126 for display on display device 104 from which a user can create a label image to be rendered on a disc media, such as on an optical disc. A user can specify, or otherwise drag-and-drop text, a bitmap image for background, a digital photo, a graphic or symbol, and/or any combination thereof to create the label image on the user interface 126.

The image processing application 122 processes the label image created with the label design user interface 126 to produce a data stream of label image data and laser control data to control rendering the image on concentric circular or spiral tracks of a disc media, such as disc media 216 (Figs. 2 & 3). For example, a continuous tone RGB (red, green, and blue) rectangular raster graphic of the label image can be converted to concentric circular tracks. The curved raster is color mapped and separated into the printing color channels KCMY (black, cyan, magenta, and yellow), or grayscale. This data stream is formatted as laser control data and is augmented with other control commands to control the disc media marking device 102 rendering a label on the disc

media 216 (Figs. 2 & 3). A label file is generated that can be communicated to a controller where the label file is parsed to control a labeling mechanism. Alternatively, the concentric circular tracks may be generated and streamed to the disc media marking device 102 one track at a time to utilize host
5 processing with the device's rendering process.

The print control application 124 determines the radius of the first track and the subsequent track spacing. After the radius of the first track and the track spacing is determined, the print control application 124 determines which label image data will correspond to each respective track. The laser
10 mark locations along a particular track are specified in a coordinate system where the concentric circular tracks are defined in coordinates of the radial distance and the distance along each respective track.

Disc media marking device 102 includes a disc drive system 128 that can be implemented to mark on a surface of a disc media (i.e., optical disc),
15 such as to render a label image on a label surface 214 (e.g., the non-data side) of optical disc 216 (Figs. 2 & 3). The disc drive system 128 is described in greater detail herein below with reference to Fig. 2.

Disc media marking device 102 further includes one or more communication interfaces 130 that can be implemented as any one or more of
20 a serial and/or parallel interface, as a wireless interface, any type of network interface, and as any other type of communication interface. A wireless interface enables disc media marking device 102 to receive control input commands and other information from an input device, such as from a remote control device or from another infrared (IR), 802.11, Bluetooth, or similar RF
25 input device. A network interface provides a connection between disc media marking device 102 and a data communication network which allows other

electronic and computing devices coupled to a common data communication network to send label image data and other information to disc media marking device 102 via the network. Similarly, a serial and/or parallel interface provides a data communication path directly between disc media marking
5 device 102 and another electronic or computing device.

Disc media marking device 102 may include user input devices 132 that can include a keyboard, pointing device, selectable controls on a user control panel, and/or other mechanisms to interact with, and to input information to disc media marking device 102. Disc media marking device 102 also includes
10 an audio / video processor 134 that generates display content for display on display device 104, and generates audio content for presentation by a presentation device, such as one or more speakers (not shown). The audio / video processor 134 can include a display controller that processes the display content to display corresponding images on display device 104. A display
15 controller can be implemented as a graphics processor, microcontroller, integrated circuit, and/or similar video processing component to process the images. Video signals and audio signals can be communicated from disc media marking device 102 to display device 104 via an RF (radio frequency) link, S-video link, composite video link, component video link, or other
20 similar communication link.

Although shown separately, some of the components of disc media marking device 102 may be implemented in an application specific integrated circuit (ASIC). Additionally, a system bus (not shown) typically connects the various components within disc media marking device 102. A system bus can
25 be implemented as one or more of any of several types of bus structures, including a memory bus or memory controller, a peripheral bus, an accelerated

graphics port, or a local bus using any of a variety of bus architectures. Furthermore, disc media marking device 102 may share a system bus with a host processor.

5 **Exemplary Embodiment**

Fig. 2 illustrates an exemplary embodiment of the disc drive system 128 shown in Fig. 1 as a component of the exemplary disc media marking device 102. The disc drive system 128 has a laser assembly 200 that includes a sled 202 which supports a laser 204, an optical pickup unit (OPU) 206, a laser
10 focusing lens 208, a fine actuator 209, and lens supports 210.

A laser beam 212 is generated by the laser 204 and focused onto a label surface 214 of optical disc media 216. The laser beam 212 creates laser marks that correspond to label image data to render an image of the label on the optical disc media 216.

15 The disc drive system 128 includes a spindle motor 218, a sled motor 220, and a controller 222. In general, controller 222 may be implemented as a printed circuit board employing a combination of various components discussed above with respect to the disc media marking system 100 of Fig. 1. Accordingly, controller 222 includes a processor 224 for processing
20 computer/processor-executable instructions from various components stored in a memory 226. Processor 224 is typically one or more of the processors 106 discussed above with respect to the disc media marking system 100 of Fig. 1. Likewise, memory 226 is typically the non-volatile memory 112 and/or firmware 116 from the disc media marking system 100 of Fig. 1.

25 Drivers 228, including a laser driver, sled driver, and spindle driver are stored in memory 226 and executable on processor 224. Although these

components are represented in the Fig. 2 embodiment as software components stored in memory 226 and executable on processor 224, they may also be firmware or hardware components.

In general, a spindle driver drives the spindle motor 218 to control a rotational speed of disc 216 via spindle 230. Spindle driver operates in conjunction with a sled driver which drives the sled motor 220 to control coarse radial positioning of laser assembly 200 with respect to disc 216 along a sled drive mechanism 232. In a typical implementation, the rotational speed of disc 216 and the radial position of laser assembly 200 are controlled such that laser marks are written on the disc 216 as the label surface 214 moves past the laser beam 212 at a constant linear velocity.

A laser driver controls the firing of laser beam 212 to write laser marks corresponding to a label image onto optical disc media 216. Optical pickup unit (OPU) 206 can be implemented as a photodetector that provides laser focus feedback to the laser driver. Additionally, the laser driver controls the intensity of the laser beam 212 to read data maintained on the data side 234 of the optical disc 216 when the disc is positioned such that the data side 234 passes over the laser beam 212.

A fine actuator driver 236, a radii - DAC count table 238, and a line fitting algorithm 240 are also stored in memory 226. Fine actuator driver 236 and line fitting algorithm 240 are executable on processor 224 to generate and manipulate data in radii - DAC count table 238 to determine the gain of (i.e., to calibrate) fine actuator 209. In general, fine actuator 209 functions to move focusing lens 208 in a radial direction 242 in small increments in between the larger movements from the sled 202 (i.e., coarse actuator). Calibration of fine actuator 209 is achieved through a process involving a DAC 244 (digital to

analog converter), a power amplifier 246, a sawtooth reference pattern located on optical disc 216, and various components of the laser assembly 200. The calibration process is discussed in greater detail herein below. Although fine actuator driver 236 and line fitting algorithm 240 are represented in the Fig. 2
5 embodiment as software components stored in memory 226 and executable on processor 224, they may also be firmware or hardware components.

Computing device interface 248 interfaces the controller 222 of the disc drive system 128 with another electronic or computing device to receive label image data or a label file (not shown). The computing device interface 248
10 can be implemented as an ATAPI (Advanced Technology Attachment Packet Interface), which is one of many small computer parallel or serial device interfaces. Another common computer interface is SCSI (small computer system interface), which is a generalized device interface for attaching peripheral devices to computers. SCSI defines the structure of commands, the
15 way commands are executed, and the way status is processed. Various other physical interfaces include the Parallel Interface, Fiber Channel, IEEE 1394, USB (Universal Serial Bus), and ATA/ATAPI. ATAPI is a command execution protocol for use on an ATA interface so that CD-ROM and tape drives can be connected via the same ATA cable with an ATA hard disk drive.
20 ATAPI devices generally include CD-ROM drives, CD-recordable drives, CD-rewritable drives, DVD (digital versatile disc) drives, tape drives, super-floppy drives (e.g., ZIP and LS-120), and the like.

As mentioned above, fine actuator driver 236 and line fitting algorithm 240 are configured to generate and manipulate data in radii - DAC count table
25 238 in order to calibrate fine actuator 209 in a process that involves DAC 244, power amplifier 246, a sawtooth reference pattern located on optical disc 216,

and various components of the laser assembly 200. The process generally includes moving the laser assembly 200 to a position so that the laser beam 212 is focused at a known radial location on optical disc 216 and then incrementing the radial location while recording current values used for
5 incrementing the radial location. The known radial location and incremented radial locations each permit the laser beam 212 to scan a sawtooth reference pattern located on the label surface 214 of disc 216.

The fine actuator driver 236 increments a DAC count (i.e., a digital number) being input to the DAC. The DAC count is recorded into table 238.
10 Incrementing the DAC count adjusts the voltage out of the DAC which drives power amplifier 246. In turn, current supplied to fine actuator 209 by power amplifier 246 is incremented. Changes in the fine actuator 209 current cause the fine actuator 209 to make small adjustments to the focusing lens 208 in the radial direction 242. The small adjustments alter the radius position of laser
15 beam 212 on the sawtooth pattern of disc 216.

When the sawtooth pattern is scanned at various radial positions by the laser beam 212, the OPU 206 generates a reflectivity signal corresponding to the sawtooth pattern. The duty cycle of the reflectivity signal changes each time the fine actuator 209 adjusts the radial scan location of the laser beam 212
20 on the sawtooth pattern. The fine actuator driver 236 converts the duty cycle of the reflectivity signal into a radius value based on the duty cycle information, the known height of the sawtooth pattern, and the radial position of the sawtooth pattern, and stores the radius value in table 238 along with the corresponding DAC count. The process of incrementing the DAC count
25 (which in turn, increments the fine actuator 209 current) and calculating radii from the duty cycle of the resultant reflectivity signal is repeated a number of

times until the table 238 has stored a number of samples of the DAC count and the corresponding radii.

Line fitting algorithm 240 then uses the DAC count and the corresponding radii data from table 238 as coordinate data to calculate a line with a slope that best fits the coordinate data. The slope of the best fit line is the gain of the fine actuator 209. That is, the slope of the best fit line calibrates the radial distance that the fine actuator 209 moves the focusing lens 208 for a known current value (i.e., a known current value corresponding to a recorded DAC count) applied to the fine actuator 209.

Fig. 3 illustrates one embodiment of an optical data storage disc 216 having an exemplary reference pattern 300 on a non-data side 214 that enables calibration of fine actuator 209. The non-data side 214 (i.e., the label side) of the optical disc 216 is displayed in Fig. 3. The Fig. 3 embodiment shows reference pattern 300 as a sawtooth pattern 300 located in a region on disc 216 at an extreme outer diameter 302 and an extreme inner diameter 304. The sawtooth pattern 300 includes two sections of the pattern spaced 180 degrees apart around either the extreme outer diameter 302 or the extreme inner diameter 304 of the disc 216. Although the sawtooth reference pattern 300 is shown in both locations 302 and 304 in Fig. 3, in typical circumstances the pattern 300 may only be located in one or the other of these locations, and not both. Furthermore, the inner and outer diameters, 302 and 304, are preferred locations for a reference pattern 300 in order that the label area of the disc 216 can remain free for labeling. However, it is noted that this description is not intended to limit the location of reference patterns to the inner and outer diameters 302 and 304 of disc 216, and that such patterns might also be located elsewhere on disc 216.

Fig. 3 further illustrates part of the sled mechanism 232 shown in Fig. 2 over which a sled 202 carries a laser assembly 200. At either end of this sled mechanism 232, and in both the extreme outer diameter 302 and extreme inner diameter 304 regions of disc 216, a laser spot 306 is shown. Direction arrows 308 indicate the direction of rotation of disc 216. Although not to scale, laser spot 306 is intended to illustrate how a reference pattern 300 is scanned as the disc 216 rotates the pattern 300 past the laser spot 306, either on the extreme inner diameter 304 or the extreme outer diameter 302 of the disc 216.

The sawtooth reference pattern 300 (see also Figs. 4-7) can be formed on disc 216 by various processes such as silk screening, etching or embossing. The dark patterned areas of reference pattern 300 represent dull areas of low reflectivity on disc 216 (as shown in Figs. 4-7), while the light patterned areas (i.e., the areas that are not marked) represent shiny areas of high reflectivity on disc 216 (also shown in Figs. 4-7). In general, scanning areas of varying reflectivity on a disc 216 generates a reflectivity signal through the OPU 206 (Fig. 2) whose amplitude changes in response to the changing reflectivity of the disc 216.

As illustrated in Fig. 4, the sawtooth pattern 300 has a known height and is located at a known radial position on optical disc 216. The sawtooth pattern 300 is shown in Fig. 4 beginning at 23.0 millimeters from the inner diameter edge (i.e., the hole) of the optical disc 216. The height of the sawtooth pattern 300 shown in Fig. 4 is 1.2 millimeters (i.e., from 23.0 mm to 24.2 mm). Although the location and height of the sawtooth pattern 300 illustrated in Fig. 4 express a preferred implementation of the sawtooth pattern 300, they are not intended as a limitation. Thus, sawtooth pattern 300 might be located closer or farther from the inner edge of optical disc 216 and may be

taller or shorter in height. Furthermore, although pattern 300 is illustrated and discussed throughout as being a sawtooth pattern 300, it is to be understood that other patterns that can provide a linear variation with the disc radius that is measurable and convertible to distance, enabling calibration of the fine
5 actuator are also contemplated. Such patterns include, for example, triangular patterns (i.e., half of a sawtooth pattern), stair step patterns, and so on.

Figs. 4 and 5 illustrate an exemplary calibration process for a fine actuator 209 involving 9 increments or steps of the fine actuator 209. Fig. 4 shows 9 different paths across a sawtooth pattern 300 that a scanning laser
10 beam 212 can take during the calibration process. To begin with, a laser beam 212 is moved to a 1st location within the sawtooth pattern 300. Typically, the 1st location is one that is a number of fine actuator 209 increments away from a “zero current” location. The “zero current” location is where there is no current being applied to the fine actuator 209 from power amplifier 246, and
15 thus, where the focusing lens 208 is in a normal resting position.

As illustrated in the radii-DAC count table 238 of Fig. 5, a DAC count of zero corresponds to the “zero current” location (i.e., 5th at 23.6 mm) of the sawtooth pattern 300. In order to reduce motion stress on the focusing lens 208 and fine actuator 209, incremental steps are made on either side of the
20 “zero current” location rather than being made all on one side or the other. Accordingly, the calibration process begins by applying a DAC count to DAC 244 that moves the focusing lens 208 (via fine actuator 209) to focus the laser beam 212 at an innermost radial location. This 1st radial location is shown in Fig. 4 as being 23.467 mm from the inner diameter edge of optical disc 216.

25 The applied DAC count is known, and it corresponds with a known DAC output voltage that will produce a known current value from power

amplifier 246 that will drive the fine actuator 209. Thus, the known DAC count is recorded into table 238 as shown in Fig. 5. However, it is understood that a known current value driving the fine actuator 209 might just as readily be recorded and shown in table 238. Furthermore, although the decimal value of “-400” is illustrated as the DAC count value for the 1st step of table 238, the number actually applied to the DAC 244 will be a binary number. However, for illustrative purposes, it is easier to show the DAC count numbers in their decimal equivalent values.

The lower portion of Fig. 4 illustrates two examples of a reflectivity signal 400 that might be generated by OPU 206 from scanning the sawtooth pattern 300 with laser beam 212. Depending on where the scan occurs over the sawtooth pattern 300, the duty cycle of the reflectivity signal 400 changes. For example, Fig. 4 illustrates two different duty cycles for the reflectivity signal 400 when the sawtooth pattern is scanned at inner (e.g., 23.467 mm) and outer (e.g., 23.725 mm) radial locations. Each time the DAC count is incremented, such as shown in table 238 of Fig. 5, the reflectivity signal 400 has a different duty cycle. For each duty cycle, the fine actuator driver 236 is configured to calculate the corresponding radius and record the radius into table 238, along with the corresponding DAC count (or current value) that generated that radius. The radius calculation is based on the known height (e.g., 1.2 mm) of the sawtooth pattern. Thus, Figs. 4 and 5 illustrate 9 different radii that have been calculated and recorded based on 9 different DAC counts stepped into DAC 244.

In another embodiment, the two sections of the sawtooth pattern 300 spaced 180 degrees apart are used to eliminate errors that might otherwise be generated due to eccentricities in the pattern 300. For example, when the

sawtooth pattern 300 is laid down on the optical disc 216, it is possible that it ends up too far from or too close to the inner diameter edge of the optical disc 216. Therefore, subsequent calculations of radii based on an initial “known” radius of the sawtooth pattern 300 would be in error. However, because the
5 sawtooth pattern 300 is laid down on the optical disc 216 as two sections that are 180 degrees apart, any such error can be averaged out. For example, if one section of the sawtooth pattern 300 is laid down too close to the inner diameter edge, the other section of the pattern 300 which is 180 degrees away will be laid down too far from the inner diameter edge by the same amount. Thus,
10 when the fine actuator driver 236 calculates radii from both of the duty cycles of the resultant reflectivity signals, the radii can be averaged to remove this error.

The exemplary sawtooth pattern 300 of Fig. 3 and the generation of a reflectivity signal 400 having a varying duty cycle is further illustrated in Figs.
15 6-8. Each of the Figs. 6-8 illustrates the exemplary sawtooth pattern 300, a reflectivity signal 400 response generated by the OPU 206 (Fig. 2) when the laser assembly 200 scans the pattern with a laser beam 212, and the relative pulse durations (i.e., duty cycles) of the reflectivity signals 400. As shown in Figs. 6-8, the peaks and valleys of the sawtooth pattern 300 define a slanted
20 interface between the low reflectivity region and the high reflectivity region of optical disc 216.

Fig. 6 illustrates the case where the laser beam 212 is located at the “zero current” radial position, or 5th position as shown in Figs. 4 and 5. As the laser beam 212 moves between the low and high reflectivity regions in the
25 sawtooth pattern 300 on disc 216, the OPU 206 generates a reflectivity signal 400 based on the amount of light reflecting off the disc 216. Because the laser

beam 212 in Fig. 6 is centered midway between the peaks and valleys of the sawtooth pattern 300, the reflectivity signal 400 has a (nearly) 50% duty cycle. That is, the ratio of the pulse duration 404 to the pulse period 406 is (nearly) 50%. As indicated above, the radius calculation is made based on the duty
5 cycle and the known height of the sawtooth pattern 300.

The pulses 402 in the reflectivity signal 400 of Fig. 6 are rectangular in shape (i.e., saturated at the top and bottom) because the laser beam 212 is very small by comparison to the sawtooth pattern 300, and it is therefore either completely within a low reflectivity region or completely within a high
10 reflectivity region as it scans the pattern 300. In addition, the laser beam 212 is traveling very fast relative to the sawtooth pattern 300 and therefore traverses the interface between the low and high reflectivity regions virtually instantaneously. Thus, transitions between high and low signal saturations in the reflectivity signal 400 are also virtually instant, and they appear as straight
15 vertical lines.

Fig. 7 illustrates the case where the laser beam 212 is located higher on the sawtooth pattern 300 than the “zero current” radial position. Fig. 7 may represent, for example, the 9th position as shown in Fig. 4 and 5. Thus, the laser beam 212 is at a radial distance that is farther away from the inner
20 diameter of the disc 216. It is evident from Fig. 7 that the duty cycle of the resultant reflectivity signal 400 is less than it is in the Fig. 6 example. The fine actuator driver 236 calculates a corresponding radius based on the duty cycle and the height of the sawtooth pattern 300, and records the radius into table 238 along with the corresponding DAC count (or current value) that generated
25 that radius.

Fig. 8 illustrates the case where the laser beam 212 is located lower on the sawtooth pattern 300 than the “zero current” radial position. Fig. 8 may represent, for example, the 1st position as shown in Fig. 4 and 5. That is, the laser beam 212 is at a radial distance that is closer to the inner diameter of the optical disc 216. Again, it is evident that the duty cycle of the resultant reflectivity signal 400 is different than those of Figs. 6 and 7. The fine actuator driver 236 calculates a corresponding radius based on the different duty cycle and the height of the sawtooth pattern 300, and records the radius into table 238 along with the corresponding DAC count (or current value) that generated that radius.

After the fine actuator driver 236 increments the DAC count a certain number of times (e.g., 9 different increments in this case) and creates the table 238 containing the DAC count and radii data, the line fitting algorithm 240 uses the data as coordinate data to calculate a line with a slope that best fits the coordinate data. The slope of the best fit line calibrates the radial distance that the fine actuator 209 moves the laser beam 212 through focusing lens 208 for a known current value (i.e., a known current value corresponding to a recorded DAC count) applied to the fine actuator 209.

Fig. 9 illustrates an example of a best fit line calculated by line fitting algorithm 240 based on the values of the DAC count and radii data illustrated in Figs. 4 and 5. Line fitting algorithm 240 may be, for example, a least squares line fit that calculates the slope of a line for coordinate data that will minimize the squared error of the line compared to the coordinate data. Such line fitting algorithms are well known to those skilled in the art. Fig. 9 illustrates a coordinate plot of the data from table 238, with the DAC count data shown along the X axis and the Radius data (in millimeters) shown along

the Y axis. Although the radii data may not all fall exactly in a straight line, the line fitting algorithm 240 generates a best fit line with a slope that best calibrates the gain of the fine actuator 209.

5 **Exemplary Methods**

Example methods for calibrating a fine actuator using a sawtooth pattern in a disc media marking system will now be described with primary reference to the flow diagrams of Figs. 10 - 11. The methods apply generally to the exemplary embodiments discussed above with respect to Figs. 1 - 9.

10 The elements of the described methods may be performed by any appropriate means including, for example, by hardware logic blocks on an ASIC or by the execution of processor-readable instructions defined on a processor-readable medium.

A "processor-readable medium," as used herein, can be any means that

15 can contain, store, communicate, propagate, or transport instructions for use by or execution by a processor. A processor-readable medium can be, without limitation, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, device, or propagation medium. More specific examples of a processor-readable medium include, among others, an

20 electrical connection (electronic) having one or more wires, a portable computer diskette (magnetic), a random access memory (RAM), a read-only memory (ROM), an erasable programmable-read-only memory (EPROM or Flash memory), an optical fiber (optical), and a portable compact disc read-only memory (CDROM) (optical).

25 Fig. 10 shows an exemplary method 1000 for calibrating a fine actuator using a sawtooth pattern in a disc media marking system 100. At block 1002, a

focusing lens 208 is moved to a known radial location of an optical disc 216.

The known radial location enables the scanning of a sawtooth pattern 300 located on the label side 214 of the disc 216.

At block 1004, an updated DAC count number is written to a DAC 244
5 (digital to analog converter). The DAC 244 provides an output voltage in response to the DAC count, and drives a power amplifier 246 as shown at block 1006. At block 1008, the power amplifier 246 supplies current which drives a fine actuator 209. The fine actuator is configured to move the focusing lens in fine steps in a radial direction 242. The current supplied to
10 the fine actuator is associated with, and determined by, the DAC count being input to the DAC by way of the power amplifier 246.

At block 1010, a sawtooth pattern 300 located on the optical disc 216 is scanned by a laser beam 212. The location of the scan across the pattern 300 is controlled in part by the fine actuator which controls movement of the
15 focusing lens 208 in a radial direction 242. In one embodiment, the sawtooth pattern 300 includes two sections that are located 180 degrees apart from one another on the optical disc 216. Both sections of the pattern 300 are scanned in this circumstance. At block 1012, a reflectivity signal is generated from the scanning. The reflectivity signal is generated by an OPU 206 (optical pickup
20 unit) according to the reflectivity pattern of the sawtooth pattern 300. The reflectivity signal may be two reflectivity signals where the sawtooth pattern includes two sections that are located 180 degrees apart from one another on the optical disc 216.

At block 1014, a radius is calculated from the duty cycle of the
25 reflectivity signal. Where there are two reflectivity signals, one from each of two sawtooth pattern sections, two radii are calculated and then averaged in

order to generate the calculated radius for block 1014. The method 1000 continues on Fig. 11, at block 1016. At block 1016, the radius and the DAC count are recorded into a table. The radius and DAC count are associated within the table as corresponding to one another.

5 At block 1018, the table is checked to see if it is full. Whether or not the table is full depends in part on how many DAC count increments will be made in the calibration process. The number of increments is preferably 9, but this is not intended as a limitation. Thus, in the described embodiment, the table is full if 9 DAC counts and 9 radii have been recorded into the table. If
10 the table is not full, the method (i.e., calibration process) returns to block 1004 of Fig. 10, and the previously described steps are performed again. If the table is full, the method continues at block 1020.

 At block 1020, the radii and DAC count numbers recorded in the table are configured as coordinate data. At block 1022, the coordinate data is
15 manipulated by a line fitting algorithm in order to generate a best line fit for the coordinates. The gain of the fine actuator is then calibrated based on the slope of the best fit line, as shown at block 1024.

 Although the invention has been described in language specific to structural features and/or methodological acts, it is to be understood that the
20 invention defined in the appended claims is not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as exemplary forms of implementing the claimed invention.

CLAIMS:

1. A processor-readable medium (108, 112, 114, 226) comprising
5 processor-executable instructions configured for:

scanning (1010) a reference pattern (300) on a disc (216) using an optical
pickup unit (206), which is configured to be moved radially relative to said disc (216)
by a course actuator (220) and a fine actuator (209), the fine actuator (209) being
caused to move the optical pickup unit (206) relative to the disc (216) to a radial
10 position in dependence on the value of an actuator control signal, the reference pattern
(300) defining a linear variation with radial position on the disc, the optical pickup
unit (206) being moved during the scanning (1010) only by said fine actuator (209),
so as to generate a respective pattern signal at a plurality of radial positions thereof,
and thereby to create a table (238) of coordinated actuator control signals and radial
15 position data;

performing (1022) a line fitting algorithm (240) on the coordinated data to
generate a best fit line; and

calibrating (1024) the fine actuator (209) based on the slope of the best fit line.

20 2. A processor-readable medium (108, 112, 114, 226) as recited in
claim 1, wherein the scanning (1010) comprises:

generating (1012) a reflective signal (400) based on the reference pattern
(300);

converting (1014) a duty cycle of the reflective signal (400) into a radius
25 value; and

recording (1016) the radius value and an associated DAC (digital to analog
convert) count in the table (238).

3. A processor-readable medium (108, 112, 114, 226) as recited in claim 1, wherein the scanning (1010) comprises:

- writing (1004) a number to a DAC (digital to analog converter) (244);
- 5 driving (1006) a power amplifier (246) with a DAC output voltage;
- driving (1008) an actuator current with the power amplifier (246);
- altering (1004) the number written to the DAC (244) by a known amount n times;
- for each number written to the DAC (244), calculating (1014) a radius from a
- 10 duty cycle of a reflective signal (400) generated from the reference pattern (300); and
- recording (1016) into the table, each radius and each number written to the DAC (244).

4. A processor-readable medium (108, 112, 114, 226) as recited in claim 1, wherein the scanning (1010) comprises:

- scanning (1010) a first half of the reference pattern (300);
- calculating (1014) a first radius based on the first half of the reference pattern (300);
- scanning (1010) a second half of the reference pattern (300);
- 20 calculating (1014) a second radius based on the second half of the reference pattern (300); and
- averaging (1014) the first radius and the second radius to generate coordinate data.

5. A processor-readable medium (108, 112, 114, 226) as recited in claim 4, wherein the first half of the reference pattern (300) and the second half of the

reference pattern (300) are 180 degrees apart from one another on the non-data side (214) of the disc (216).

5 **6.** A processor-readable medium (108, 112, 114, 226) as recited in claim 1, wherein the reference pattern (300) is a sawtooth reference pattern.

7. An optical disc read-write device (102) comprising the processor-readable medium (108, 112, 114, 226) as recited in claim 1.

10

8. A disc drive system (128) comprising:

 a scanner (206, 208, 212) configured to read a reference pattern (300) on an optical disc (216) which exhibits a linear variation with radial position on the disc (216), the scanner comprising an optical pickup unit (206), which is configured to be
15 moved radially relative to said disc (216) by a course actuator (220) and a fine actuator (209) configured to control small radial movements (242) of the scanner (206, 208, 212), the fine actuator (209) being caused to move the optical pickup unit (206) relative to the disc (216) to a radial position in dependence on the value of an actuator control signal, the optical pickup unit (206) being moved during a calibration
20 scan (1010) by only said fine actuator (209), so as to detect said reference pattern (300) and thereby to generate a respective pattern signal at a plurality of radial positions thereof and to create a table (238) of coordinated actuator control signals and radial position data;

 means for performing a line fitting algorithm (240) on the coordinated data to
25 generate a best fit line, and

 means for calibrating (1024) the fine actuator (209) based on the slope of the best fit line.

9. A disc drive system (128) as recited in claim 8, further comprising:

a processor (224) configured to write a binary number to a DAC (244) and increment the binary number in equal steps;

5 the DAC (244), configured to generate an output voltage for each binary number; and

a power amplifier (246) configured to drive the fine actuator (209) with current values based on each output voltage.

10 **10.** A disc drive system (128) as recited in claim 9, further comprising:

a table (238) of coordinate data including the binary numbers and a radius value calculated from the reference pattern (300) for each binary number; and

a line fitting algorithm (240) configured to generate a best fit line from the coordinate data and to determine the slope of the best fit line.

15

11. An optical disc read-write device (102) comprising the disc drive system (128) as recited in claim 9.