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(54) **Title**: SYNCHRONIZATION OF SYMMETRIC TIMING BASED SERVO BURSTS

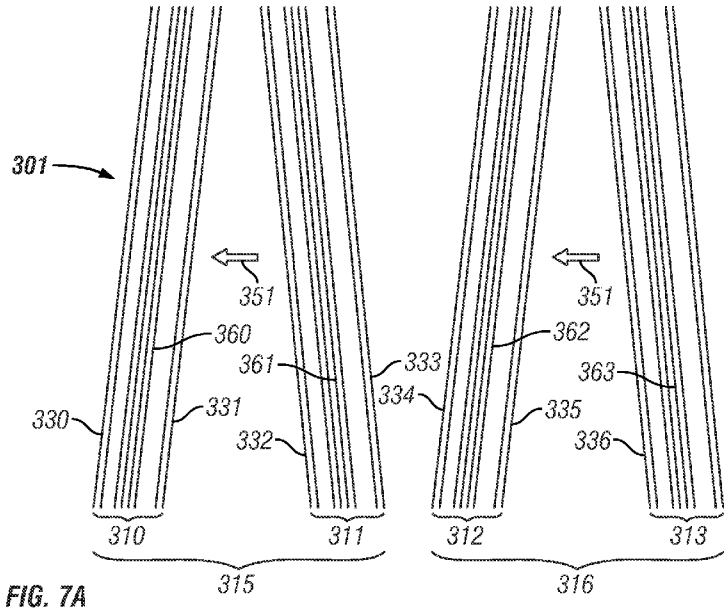

FIG. 7A

(57) **Abstract**: Timing based servo bursts of servo frames, in which the frames are arranged to be symmetric with the same number of servo stripes in each burst of a frame, are synchronized by shifting selected bits. For example, servo frames are arranged with four servo bursts with an equal number of servo stripes in each burst, the servo frames comprising two symmetric subframes, each sub-frame comprising two bursts of servo stripes that are parallel to each other within a burst, and the bursts are non-parallel with respect to each other; each servo burst is arranged to comprise at least one reference servo stripe; and each servo burst is arranged to comprise at least one shifted servo stripe, wherein the shift is in the same longitudinal direction with respect to at least one reference servo stripe for each burst of a frame and the opposite longitudinal direction for bursts of sequentially adjacent frames.

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SYNCHRONIZATION OF SYMMETRIC TIMING BASED SERVO BURSTS

FIELD OF THE INVENTION

This invention relates to linear tape media, and more particularly to track following timing based servo arrangements.

BACKGROUND OF THE INVENTION

Timing based servo arrangements are employed with respect to linear tape media, for example, in magnetic tape systems, to provide track following capability. Recorded servo patterns comprise dual magnetic transitions called "servo stripes" arranged as pairs recorded at more than one azimuthal orientation across the tape media. The technology is discussed in the incorporated 5,689,384 patent. Reading a servo pattern by a servo read head yields a sequence of pulses called "dibits", where each dibit corresponds to the transitions at both edges of a servo stripe written on the magnetic medium. The timing between dibits that correspond to any pair of servo stripes with different azimuthal orientation thus varies continuously as the servo read head is moved in the lateral direction across the servo band. The pattern is read by a servo read head whose width is small compared to the servo band pattern, and servo head position is derived from the relative timing of pulses generated by the servo head reading the servo pattern as the tape is moved in the longitudinal direction. Position sensing with this system is achieved by deriving a ratio of two servo pattern intervals, one pattern interval comprising the timing between dibits corresponding to a pair of servo stripes having different azimuthal orientation, and the other pattern interval comprising the timing between dibits corresponding to a pair of servo stripes having the same azimuthal orientation. Thus, the position sensing is ratio dependent and is insensitive to tape speed.

A typical way to determine which servo stripe is being read is to arrange the servo stripes into servo frames, each frame having two sub-frames, each with two bursts of servo stripes arranged in patterns with different azimuthal orientations. A pattern interval between dibits in the servo signal is provided for servo stripes within a sub-frame, and another pattern

interval is between sub-frames. Typically, frames and sub-frames are distinguished by having a different number of servo stripes in the bursts of one sub-frame as compared to the other sub-frame. As one example, the frames and sub-frames are easily distinguished by observing the counts of servo stripes in each burst, such as 5, 5, 4, 4, within a frame, the 5, 5 count bursts comprising one sub-frame, and the 4, 4 count bursts comprising the other sub-frame.

A drawback of asymmetric numbers of servo stripes in each frame is that the extra servo stripes result in longer frames, reducing the rate of generation of lateral position estimates from the servo signals, as the lateral position estimates are generated on a frame by frame basis.

SUMMARY OF THE INVENTION

Methods, magnetic tape media, sensible transition patterns, a magnetic tape servo writer, and a magnetic tape servo detection system are provided with respect to synchronization of timing based servo bursts of servo frames of a servo band, in which the frames are arranged to be symmetric with the same number of servo stripes in each burst of a frame.

In one embodiment, servo frames are arranged with four servo bursts with an equal number of servo stripes in each burst, the servo frames comprising two symmetric sub-frames, each sub-frame comprising two bursts of servo stripes that are parallel to each other within a burst, and the bursts are non-parallel with respect to each other; each servo burst is arranged to comprise at least one reference servo stripe; and each servo burst is arranged to comprise at least one shifted servo stripe, wherein the shift is in the same longitudinal direction with respect to at least one reference servo stripe for each burst of a frame and in the opposite longitudinal direction for bursts of sequentially adjacent frames.

In a further embodiment, the step of arranging reference servo stripes comprises arranging the reference servo stripes to be in the same servo stripe count position within each burst; and the step of arranging the shifted servo stripes comprises arranging the shifted servo stripes to be in the same servo stripe count position within each burst.

In another embodiment, the step of arranging reference servo stripes comprises arranging the one reference servo stripe at the same outer edge of each said burst.

In a further embodiment, the shifted servo stripe of each burst is independent of any modulated longitudinal position (LPOS) servo stripe in the burst.

In another embodiment, wherein each burst comprises three servo stripes; the step of arranging the reference servo stripes comprises arranging at least one reference servo stripe of each burst at the interior position of the burst; and the step of arranging the shifted servo stripe comprises arranging the shifted servo stripe at an edge of each burst, adjacent the reference servo stripe.

In still another embodiment, wherein the step of arranging the reference servo stripes comprises arranging the reference servo stripes as the outer servo stripes of each burst; and the step of arranging the shifted servo stripes comprises arranging at least one shifted servo stripe as an interior servo stripe of each burst.

In a further embodiment, wherein each burst comprises four servo stripes; the step of arranging the shifted servo stripes comprises arranging at least one shifted interior servo stripe of each burst to be adjacent one of the reference servo stripes.

In another embodiment, wherein each burst comprises five servo stripes; the step of arranging the shifted servo stripes comprises arranging at least one shifted interior servo stripe of each burst adjacent one of the reference servo stripes.

For a fuller understanding of the present invention, reference should be made to the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an illustration of a magnetic tape cartridge;

FIG. **2** is an illustration of a reel of magnetic tape of the magnetic tape cartridge of FIG. **1**, which implements the present invention;

FIG. **3** is an illustration of a data storage drive which operates with the magnetic tape cartridge of FIGS. **1** and **2**;

FIG. **4** is a block diagrammatic illustration of the data storage drive of FIG. **3**;

FIG. **5** is a schematic and block diagram of a magnetic head and servo system of the data storage drive and the magnetic tape cartridge of FIGS. **1** – **4**;

FIG. **6** is a representation of an exemplary servo pattern of the prior art;

FIGS. **7A** and **7B** are representations of a servo pattern in accordance with the present invention;

FIG. **8** is a representation of another servo pattern in accordance with the present invention;

FIG. **9** is a representation of still another servo pattern in accordance with the present invention;

FIG. **10** is a representation of another servo pattern in accordance with the present invention;

FIG. **11** is a perspective representation of a prior art multi-gap head that can write servo stripes of the present invention;

FIG. **12** is a schematic and block diagram representation of a writing generator for writing the servo stripes of the present invention;

FIG. **13** is an overall schematic representation of the writing system of FIGS. **11** and **12**; and

FIG. **14** is a flow chart depicting an exemplary method of operating the system of FIGS. **11** - **13**.

DETAILED DESCRIPTION OF THE INVENTION

This invention is described in preferred embodiments in the following description with reference to the Figures, in which like numbers represent the same or similar elements. While this invention is described in terms of the best mode for achieving this invention's objectives, it will be appreciated by those skilled in the art that variations may be accomplished in view of these teachings without deviating from the spirit or scope of the invention.

Referring to FIGS. **1** and **2**, an example of removable data storage media, such as a magnetic tape cartridge **100**, comprises a cartridge body **101**, cartridge door **106** and a data storage medium **121**.

The data storage medium **121**, for example comprising a rewritable magnetic tape, is wound on a reel **110**, and a leader pin **111** is used to thread the magnetic tape **121** through the tape path of a magnetic tape drive. As is understood by those of skill in the art, a magnetic tape data storage cartridge comprises a length of magnetic tape wound on one or two reels, an example of which is those adhering to the Linear Tape Open (LTO) format. The illustrated magnetic tape cartridge **100** is a single reel cartridge. Magnetic tape cartridges may also comprise dual reel cartridges in which the tape is fed between reels of the cartridge.

One example of a magnetic tape data storage cartridge **100** is the IBM® 3580 Ultrium magnetic tape cartridge based on LTO technology. A further example of a single reel magnetic tape data storage cartridge is the IBM® 3592 TotalStorage Enterprise magnetic tape cartridge and associated magnetic tape drive. An example of a dual reel cartridge is the IBM® 3570 magnetic tape cartridge and associated drive.

In the tape cartridge **100**, a brake button **112** is used to hold the tape reel **110** in place and to prevent it from rotating when tape cartridge **100** is not loaded in a tape drive. An optional tape leader **120** may be interposed between the leader pin **111** and the magnetic tape **121**.

An auxiliary non-volatile memory **103**, also called a cartridge memory (CM), for example, may be provided and retained in the cartridge **100**, for example, by being encapsulated by the cartridge when it is assembled, as is understood by those of skill in the art.

Referring to FIGS. **3** and **4**, a data storage drive, such as a magnetic tape drive **200**, is illustrated. One example of a magnetic tape drive in which the present invention may be employed is the IBM 3580 Ultrium magnetic tape drive based on LTO technology, with microcode, etc., to perform desired operations with respect to the magnetic tape cartridge **100**.

Referring to FIGS. **1** – **4**, in the instant example, the magnetic tape cartridge **100** is inserted into opening **202** of the magnetic tape drive **200** along direction **107**, and loaded in the magnetic tape drive **200**.

The magnetic tape is threaded and fed between the cartridge reel **110** and a take up reel **130** in the magnetic tape drive. Alternatively, both reels of a dual reel cartridge are driven to feed the magnetic tape between the reels.

The magnetic tape drive comprises a memory interface **140** for reading information from, and writing information to, the auxiliary non-volatile memory **103** of the magnetic tape cartridge **100**, for example, in a contactless manner.

A read/write system is provided for reading and writing information to the magnetic tape, and, for example, may comprise a read/write and servo head system **180** with a servo system for moving the head laterally of the magnetic tape **121**, a read/write servo control **190**, and a drive motor system **195** which moves the magnetic tape **121** between the cartridge reel **110** and the take up reel **130** and across the read/write and servo head system **180**. The read/write and servo control **190** controls the operation of the drive motor system **195** to

move the magnetic tape **121** across the read/write and servo head system **180** at a desired velocity, and, in one example, determines the longitudinal location of the read/write and servo head system with respect to the magnetic tape **121**, as will be discussed.

A control system **240** communicates with the memory interface **140**, and communicates with the read/write system, e.g., at read/write and servo control **190**. The control system **240** may comprise any suitable form of logic, including a processor operated by software, or microcode, or firmware, or may comprise hardware logic, or a combination, as discussed in greater detail hereinafter.

The control system **240** typically communicates with one or more host systems **250**, and operates the magnetic tape drive **200** in accordance with commands originating at a host. Alternatively, the magnetic tape drive **200** may form part of a subsystem, such as an automated data storage library, and may also receive and respond to commands from the subsystem

As illustrated, the control system **240** operates the magnetic tape drive **200** to perform operations in accordance with received commands. Examples comprise moving the tape to a desired location, reading data such as a file from the tape, writing data such as new data files to the tape, or appending new data to existing files or appending new data or data files to an existing data file of a partition, rewriting or appending indexes, etc.

Referring to FIG. **5**, the magnetic tape **121** is drawn across a head system **180**, which comprises a servo read head **226** that detects a servo pattern recorded in a servo band **227** of the tape. A data head **228** of the head system **180** is positioned over a data track region **229** of the tape, for example comprising multiple data tracks for reading data recorded in a data track or tracks, or for writing data in a data track or tracks. FIG. **5** shows a single servo read head and a single data head for simplicity of illustration. Those skilled in the art will appreciate that most tape systems have multiple parallel servo bands, multiple servo read heads, and multiple data read and write heads.

The servo band centerline **230** is shown as extending along the length of the tape **121**. As discussed in the incorporated 5,689,384 patent, the servo band is employed for track following in that magnetic transitions on the servo band are sensed by the servo head and provided on servo signal line **234** to a signal decoder **236**. The signal decoder processes the servo read head signal and generates a position signal that is transmitted via position signal lines **238** to a servo controller **241**. The servo controller generates a servo control signal and provides it on control lines **242** to a servo positioning mechanism at head system **180** which moves the head assembly laterally with respect to the servo band centerline **230** to a desired lateral position or to maintain the servo head at a desired lateral position with respect to the servo band **227** during track following.

The terms "servo band" and "servo track" have been used interchangeably as the term to identify a linear stream of servo stripes. Since the servo head may be positioned at any of several lateral positions across the servo band and the servo signals may be employed to track follow at a particular lateral position, the term "servo band" is employed herein to indicate a physical region which is occupied by servo stripes and avoid confusion arising from the expression "track following".

FIG. **6** illustrates a timing based servo pattern in accordance with the prior art. A timing based servo arrangement provides track following capability. In the example, a recorded servo pattern comprises dual magnetic transitions called a "servo stripe" of width **250**, and having leading or trailing (depending on the direction of movement of the tape) edges nominally separated by a distance **252**. Servo stripes are arranged as pairs **260** recorded at more than one azimuthal orientation **262** across **265** the tape media. The technology is discussed in the incorporated 5,689,384 patent. The servo read head traverses the servo stripes, generating a dibit for each servo stripe. The timing between the dibits of any pair, which are obtained from the servo read head, one from each burst within a subframe, thus varies continuously as a read head is moved in the lateral direction across the servo band. The pattern is read by a servo read head whose width is small compared to the servo band pattern, and servo head position is derived from the relative timing of pulses generated by the head reading the servo pattern as the tape is moved in the longitudinal direction. Position sensing with this system is achieved by deriving a ratio of two servo pattern intervals, one

pattern interval comprising the timing between dibits obtained from servo stripes **260** having different azimuthal orientation, and the other pattern interval comprising the timing between dibits obtained from servo stripes **270** having the same azimuthal orientation. Thus, the position sensing is ratio dependent and is insensitive to tape speed.

A typical way to determine which servo stripe is being read is to arrange the servo stripes into patterns of servo frames **275**, each frame having two sub-frames **276**, **277**, each with two bursts **280**, **281** and **282**, **283** of servo stripes arranged in different azimuthal orientations. A pattern interval is provided within a sub-frame, and another pattern interval is between sub-frames. Typically, frames and sub-frames are distinguished by having a different number of servo stripes in the bursts of one sub-frame as compared to the other sub-frame. As one example, the frames and sub-frames are easily distinguished by observing the counts of dibits in the servo signal obtained from each burst, such as 5 dibits in each burst **280**, **281** of sub-frame **276**, and 4 dibits in each burst **282**, **283** of sub-frame **277**, within a frame **275**. Counting the different numbers of dibits in each burst allows the servo system to distinguish the frame boundaries.

As pointed out by the incorporated 5,930,065 patent, some of the servo stripes may be shifted longitudinally **290** to provide additional information, such as the longitudinal position along the tape.

A drawback of asymmetric numbers of servo stripes in each frame is that the extra servo stripes result in longer frames, reducing the rate of generation of lateral position estimates from the servo signals, as the lateral position estimates are generated on a frame by frame basis.

FIGS. **7A** and **7B** comprise a representation of a servo pattern in accordance with the present invention.

The servo frames **301** and **302** are arranged with four servo bursts with an equal number of servo stripes in each burst. Servo frame **301** comprises servo bursts **310**, **311**, **312**, **313**, and servo frame **302** comprises servo bursts **320**, **321**, **322**, **323**. The servo frames comprise two

symmetric sub-frames, servo frame **301** comprising sub-frames **315**, **316**, and servo frame **302** comprising sub-frames **325**, **326**. Each sub-frame comprises two bursts of servo stripes that are parallel to each other within a burst, and the bursts are non-parallel with respect to each other. By having the same number of servo stripes in each burst of the frame, the frames **301** and **302** are symmetric, as opposed to the asymmetric frame of FIG. **6**.

Still referring to FIGS. **7A** and **7B**, in accordance with the present invention, each servo burst is arranged to comprise at least one reference servo stripe. For example, in burst **310** of frame **301**, servo stripes **330** and **331** comprise reference servo stripes. In one embodiment, the reference servo stripes are arranged to be in the same servo stripe count position within each burst. For example, burst **311** comprises reference servo stripes **332** and **333**, burst **312** comprises reference servo stripes **334** and **335**, and burst **313** comprises reference servo stripes **336** and **337**. Thus, servo stripes **330**, **332**, **334** and **336** are in the same (first) count position of each burst; and servo stripes **331**, **333**, **335** and **337** are in the same (last) count position of each burst.

Additionally, for example, in burst **320** of frame **302**, servo stripes **340** and **341** comprise reference servo stripes. With the reference servo stripes arranged to be in the same servo stripe count position within each burst, burst **321** comprises reference servo stripes **342** and **343**, burst **322** comprises reference servo stripes **344** and **345**, and burst **323** comprises reference servo stripes **346** and **347**. Thus, servo stripes **340**, **342**, **344** and **346** are in the same (first) count position of each burst; and servo stripes **341**, **343**, **345** and **347** are in the same (last) count position of each burst.

Further in accordance with the present invention, each servo burst is arranged to comprise at least one shifted servo stripe, wherein the shift is in the same longitudinal direction with respect to at least one reference servo stripe for each burst of a frame and the opposite longitudinal direction for bursts of sequentially adjacent frames. In the example, frames **301** of FIG. **7A** and **302** of FIG. **7B** are placed sequentially adjacent one another in the servo band. Thus, the shifted servo stripes of frame **301** are shifted in the plus (+) direction **351** in both sub-frames **315** and **316**, and the shifted servo stripes of frame **302** are shifted in the minus (-) direction **352** in both sub-frames **325** and **326**.

In one embodiment, the shifted servo stripes are arranged to be in the same servo stripe count position within each burst, and, with respect to frame **301**, shifted servo stripe **360** of burst **310**, shifted servo stripe **361** of burst **311**, shifted servo stripe **362** of burst **312**, and shifted servo stripe **363** of burst **313** are all shifted in the direction **351**. With respect to frame **302**, shifted servo stripe **370** of burst **320**, shifted servo stripe **371** of burst **321**, shifted servo stripe **372** of burst **322**, and shifted servo stripe **373** of burst **323** are all shifted in the direction **352**. Shifted servo stripes **360**, **361**, **362**, **363**, **370**, **371**, **372** and **373** are all in the same (third) count position of each burst.

The timing between each of the corresponding pairs of servo stripes remains the same, so that the timing based ratios identify the lateral position of a servo head with respect to the servo band.

The frames and sub-frames are easily distinguished by observing the shift directions of shifted servo stripes in each burst, such as the shift direction **351** for shift servo stripes in each burst **310**, **311**, of sub-frame **315**, and each burst 312, **313** of sub-frame **316**, within a frame **301**, and the shift direction **352** for shift servo stripes in each burst **320**, **321**, of sub-frame **325**, and each burst **322**, **323** of sub-frame **326**, within a frame **302**. Sequentially adjacent sub-frames within the same frame thus have the same shift direction, and sequentially adjacent frames have the opposite shift direction, allowing the servo system to distinguish the frame boundaries.

FIGS. **8**, **9**, and **10** illustrate further embodiments.

In one embodiment, the reference servo stripes are arranged as the outer servo stripes of each burst; and the shifted servo stripe(s) is arranged as an interior servo stripe of each burst. Thus, in frame **379** of FIG. **8**, having 5 servo stripes in each burst, servo stripes **380** comprise outer servo stripes at one edge of each burst, while servo stripes **381** comprise outer servo stripes at the opposite edge of each burst.

In frame **379**, servo stripes **383** comprise the interior shifted servo stripe of each burst of the frame **379**. In another embodiment, the shifted servo stripe **383** of each burst is independent

of any modulated longitudinal position (LPOS) servo stripe **385** in the burst. The shifted servo stripes **383** are located by their longitudinally positioned relationship with respect to reference servo stripes **380** and **381**, such that, if the direction of tape motion makes reference servo stripes **380** the leading edge of each burst, the shifted servo stripe **383** is expected to be the third servo stripe after the reference servo stripe **380**. If the direction of tape motion makes reference servo stripes **381** the leading edge of each burst, the shifted servo stripe **383** is expected to be the first servo stripe after the reference servo stripe **381**.

In frame **389** of FIG. **9**, having 4 servo stripes in each burst, servo stripes **390** comprise outer servo stripes at one edge of each burst, while servo stripes **391** comprise outer servo stripes at the opposite edge of each burst.

In frame **389**, servo stripes **393** comprise the interior shifted servo stripe of each burst of the frame **389**. In another embodiment, the shifted servo stripe **393** of each burst is independent of any modulated longitudinal position (LPOS) servo stripe **395** in the burst. The shifted servo stripes **393** are located by their longitudinally positioned relationship with respect to reference servo stripes **390** and **391**, such that, if the direction of tape motion makes reference servo stripes **390** the leading edge of each burst, the shifted servo stripe **393** is expected to be the second servo stripe after the reference servo stripe **390**. If the direction of tape motion makes reference servo stripes **391** the leading edge of each burst, the shifted servo stripe **393** is expected to be the first servo stripe after the reference servo stripe **391**.

In another embodiment illustrated by frame **395** of FIG. **10**, wherein each burst comprises three servo stripes, a reference servo stripe **396** of each said burst is arranged at the interior position of the burst, and a shifted servo stripe **397** is arranged at an edge of each burst, adjacent the reference servo stripe **396**. In another embodiment, the shifted servo stripe **397** of each burst is independent of any modulated longitudinal position (LPOS) servo stripe **398** in the burst. The shifted servo stripes **397** are located by their longitudinally positioned relationship with respect to reference servo stripes **396** or with respect to the edge of the burst, such that, if the direction of tape motion makes servo stripes **398** the leading edge of each burst, the shifted servo stripe **397** is expected to be the first after the reference servo stripe **396**. If the direction of tape motion makes the shifted servo stripes **397** the leading

edge of each burst, the shifted servo stripe **397** is expected to be the first servo stripe encountered for the burst.

FIG. **11** illustrates a prior art magnetic head assembly **400**, taken from the incorporated 5,689,384 patent, that may be employed, in one example, for recording the servo pattern of the present invention. The illustrated head comprises a ferrite ring **402** with a patterned pole piece region **404**. Two ferrite blocks **406**, **408** form the bulk of the magnetic head and are separated by a spacer **411**. A cylindrical contour of the surface is provided, and cross slots **412** are cut into the head to remove included air when the head is in operation with magnetic tape. A pattern **414** representing a pair of servo stripes is created in the tape head. A coil **420** is wound around one of the ferrite blocks **408** through a wiring slot **422** to complete the head. The head assembly **400** is illustrated as having two sets of servo patterns, and may have a greater or lesser number of patterns **414**. Further, the patterns **414** may be offset relative to one another in the longitudinal direction of the tape.

In FIGS. **12** and **13**, a tape **504** is moved between reels **520** and **522** in the direction of arrow **512**. Pattern generator **516** comprises a controller **432** and encoder **433**. The encoded information to conduct the plus (+) and minus (-) shifts of the shifted servo stripes are loaded from the encoder to the shift register **435** under the control of the controller and is shifted to pulse generator **518**. The LPOS information may also be loaded from the encoder to the shift register. The shift register represents the timing of the supply of pulses by the pulse generator **518** to cause head **402** to write each pair of servo stripes on the tape **504**. Thus, the shift register controls the timing of the pulses that create the servo stripes and thereby controls the plus (+) and minus (-) shifts of the shifted servo stripes.

The shift register also controls the shifts of the LPOS information. As discussed in the incorporated 5,930,065 patent, longitudinal positioning information may be encoded into the patterns by longitudinally shifting a selected servo stripe in one or multiple bursts, modifying the timing of the selected servo stripe.

After the tape **504** is written with the servo bands, the servo pattern is verified by a servo read head **524** reading the just-recorded servo pattern and provides the signal to a pre-

amplifier **526** and a pattern verifier **528** that, among other tests, verifies that every other frame (such as every even frame) has shifted servo stripes that are shifted in a first direction, and every sequentially adjacent frame (such as every odd frame) has shifted servo stripes that are shifted in the opposite direction.

In one example, the pattern generator **516** and pattern verifier **528** may comprise hardware elements and may comprise any suitable form of logic, including a processor operated by software, or microcode, or firmware, or may comprise hardware logic, or a combination.

In FIG. **14**, the method for providing a servo band is illustrated as beginning at step **550**. Step **555** comprises writing a frame of four servo bursts with an equal number of servo stripes in each burst, the servo frame comprising two symmetric sub-frames, each sub-frame comprising two bursts of servo stripes that are parallel to each other within a burst, and the bursts are non-parallel with respect to each other. Each servo burst is arranged to comprise at least one reference servo stripe; and each servo burst is arranged to comprise at least one shifted servo stripe, wherein the shift is in the same longitudinal direction with respect to at least one reference servo stripe for each burst of a frame. The shift direction may be called the plus (+) direction.

Step **556** comprises writing the sequentially adjacent frame, also with four servo bursts with an equal number of servo stripes in each burst, the servo frame comprising two symmetric sub-frames, each sub-frame comprising two bursts of servo stripes that are parallel to each other within a burst, and the bursts are non-parallel with respect to each other. Each servo burst is arranged to comprise at least one reference servo stripe; and each servo burst is arranged to comprise at least one shifted servo stripe, wherein the shift is in the opposite longitudinal direction. The shift direction may be called the minus (-) direction.

Step **560** determines whether the servo band is complete, and if not, returns to step **555** to write the next frame.

If the servo band is complete, per step **560**, the process ends at step **570**.

Referring to FIG. **4**, a tape with a completed servo band is read by head **180**, and read/write and servo control **190** detects the timing based spacing between selected sensed servo stripes; and comprises a decoder configured to respond to the detected spacing to identify reference servo stripes of the bursts; to detect position shifts of servo stripes of each burst, wherein the shift is in the same longitudinal direction with respect to at least one reference servo stripe for each burst of a frame, and the opposite longitudinal direction for bursts of sequentially adjacent frames, and decodes the detected position shifts to identify the frames.

Once the frames are identified, the read/write and servo control **190** is able to detect the timing between pairs of dibits obtained from corresponding pairs of servo stripes, and thereby detect the lateral position of the head **180** with respect to the servo band. Additionally, the read/write and servo control **190** is able to detect the timing of the LPOS dibits and hence recover the longitudinal information encoded into the LPOS dibits, as known in the art.

In one example, the read/write and servo head system **180** and read/write and servo control **190** may comprise hardware elements and may comprise any suitable form of logic, including a processor operated by software, or microcode, or firmware, or may comprise hardware logic, or a combination.

Those of skill in the art will understand that changes may be made with respect to the methods discussed above, including changes to the ordering of the steps. Further, those of skill in the art will understand that differing specific component arrangements may be employed than those illustrated herein.

While the preferred embodiments of the present invention have been illustrated in detail, it should be apparent that modifications and adaptations to those embodiments may occur to one skilled in the art without departing from the scope of the present invention as set forth in the following claims.

CLAIMS

1. A method for synchronization of timing based servo bursts of servo frames of a longitudinal servo band, comprising:

arranging said servo frames with four servo bursts with an equal number of servo stripes in each burst, said servo frames comprising two symmetric sub-frames, each sub-frame comprising two bursts of servo stripes that are parallel to each other within a burst, and said bursts are non-parallel with respect to each other;

arranging each said servo burst to comprise at least one reference servo stripe; and

arranging each said servo burst to comprise at least one shifted servo stripe, wherein said shift is in the same longitudinal direction with respect to said at least one reference servo stripe for each burst of a frame and the opposite longitudinal direction for bursts of sequentially adjacent frames.

2. The method of Claim **1**, wherein said step of arranging said reference servo stripes comprises arranging said reference servo stripes to be in the same servo stripe count position within each said burst; and said step of arranging said shifted servo stripes comprises arranging said shifted servo stripes to be in the same servo stripe count position within each said burst.

3. The method of Claim **2**, wherein said step of arranging said reference servo stripes comprises arranging said at least one reference servo stripe at the same outer edge of each said burst.

4. The method of Claim **3**, wherein said at least one shifted servo stripe of each said burst is independent of any modulated longitudinal position (LPOS) servo stripe in said burst.

5. The method of Claim **3**, wherein each said burst comprises three servo stripes; said step of arranging said reference servo stripes comprises arranging at least one said reference servo stripe of each said burst at the interior position of said burst; and said step of arranging

said shifted servo stripe comprises arranging said shifted servo stripe at an edge of each said burst, adjacent said reference servo stripe.

6. The method of Claim **3**, wherein said step of arranging said reference servo stripes comprises arranging said reference servo stripes as the outer servo stripes of each said burst; and said step of arranging said shifted servo stripes comprises arranging said at least one shifted servo stripe as an interior servo stripe of each said burst.

7. The method of Claim **6**, wherein each said burst comprises four servo stripes; and said step of arranging said shifted servo stripes comprises arranging at least one said shifted interior servo stripe of each said burst adjacent one of said reference servo stripes.

8. The method of Claim **6**, wherein each said burst comprises five servo stripes; and said step of arranging said shifted servo stripes comprises arranging at least one said shifted interior servo stripe of each said burst adjacent one of said reference servo stripes.

9. A magnetic tape medium having prerecorded servo information recorded in magnetic flux servo stripe patterns of timing based servo bursts of servo frames, defining at least one longitudinal servo band, comprising:

said servo frames having four servo bursts with an equal number of servo stripes in each burst, said servo frames comprising two symmetric sub-frames, each sub-frame comprising two bursts of servo stripes that are parallel to each other within a burst, and said bursts are non-parallel with respect to each other;

each said servo burst comprising at least one reference servo stripe; and

each said servo burst comprising at least one shifted servo stripe, wherein said shift is in the same longitudinal direction with respect to said at least one reference servo stripe for each burst of a frame and the opposite longitudinal direction for bursts of sequentially adjacent frames.

10. The magnetic tape medium of Claim **9**, wherein said reference servo stripes are in the same servo stripe count position within each said burst; and said shifted servo stripes are in the same servo stripe count position within each said burst.

11. The magnetic tape medium of Claim **10**, wherein said at least one reference servo stripe is at the same at least one outer edge of each said burst.

12. The magnetic tape medium of Claim **11**, wherein said at least one shifted servo stripe of each said burst is independent of any modulated longitudinal position (LPOS) servo stripe in said burst.

13. The magnetic tape medium of Claim **11**, wherein each said burst comprises three servo stripes; at least one reference servo stripe is at the interior position of each said burst; and said shifted servo stripe is at an edge of each said burst, adjacent said reference servo stripe.

14. The magnetic tape medium of Claim **11**, wherein reference servo stripes are the outer servo stripes of each said burst; and said at least one shifted servo stripe is at least one interior servo stripe of each said burst.

15. The magnetic tape medium of Claim **14**, wherein each said burst comprises four servo stripes; and at least one said shifted interior servo stripe of each said burst is adjacent one of said reference servo stripes.

16. The magnetic tape medium of Claim **14**, wherein each said burst comprises five servo stripes; and at least one said shifted interior servo stripe of each said burst is adjacent one of said reference servo stripes.

17. A sensible transition pattern of timing based servo stripes recorded as bursts in frames defining at least one longitudinal track, comprising:

said frames having four bursts with an equal number of servo stripes in each burst, said frames comprising two symmetric sub-frames, each sub-frame comprising two bursts of servo stripes that are parallel to each other within a burst, and said bursts are non-parallel with respect to each other;

each said burst comprising at least one reference servo stripe; and

each said burst comprising at least one shifted servo stripe, wherein said shift is in the same longitudinal direction with respect to said at least one reference servo stripe for each burst of a frame and the opposite longitudinal direction for bursts of sequentially adjacent frames.

18. The sensible transition pattern of servo stripes of Claim **17**, wherein said reference servo stripes are in the same servo stripe count position within each said burst; and said shifted servo stripes are in the same servo stripe count position within each said burst.

19. The sensible transition pattern of servo stripes of Claim **18**, wherein said at least one reference servo stripe is at the same at least one outer edge of each said burst.

20. The sensible transition pattern of servo stripes of Claim **19**, wherein each said burst comprises three servo stripes; at least one reference servo stripe is at the interior position of each said burst; and said shifted servo stripe is at an edge of each said burst, adjacent said reference servo stripe.

21. The sensible transition pattern of servo stripes of Claim **19**, wherein reference servo stripes are the outer servo stripes of each said burst; and said at least one shifted servo stripe is at least one interior servo stripe of each said burst.

22. The sensible transition pattern of servo stripes of Claim **21**, wherein each said burst comprises four servo stripes; and at least one said shifted interior servo stripe of each said burst is adjacent one of said reference servo stripes.

23. The sensible transition pattern of servo stripes of Claim **21**, wherein each said burst comprises five servo stripes; and at least one said shifted interior servo stripe of each said burst is adjacent one of said reference servo stripes.

24. A magnetic tape servo writer, comprising:

at least two spaced apart write elements configured to write magnetic flux timing based servo stripes;

a drive configured to move a magnetic tape longitudinally across said write elements at a predetermined velocity;

a source of timed pulses configured to cause said spaced apart write elements to write said magnetic flux servo stripes; and

an encoder configured to shift the timing of said source of timing pulses to write patterns of timing based servo bursts of servo frames, defining at least one longitudinal servo band, comprising:

said servo frames having four servo bursts with an equal number of servo stripes in each burst, said servo frames comprising two symmetric sub-frames, each sub-frame comprising two bursts of servo stripes that are parallel to each other within a burst, and said bursts are non-parallel with respect to each other;

each said servo burst comprising at least one reference servo stripe; and

each said servo burst comprising at least one shifted servo stripe, wherein said shift is in the same longitudinal direction with respect to said at least one reference servo stripe for each burst of a frame and the opposite longitudinal direction for bursts of sequentially adjacent frames.

25. A magnetic tape servo detection system configured to be responsive to sensed servo stripes of a longitudinal servo band having timing based bursts of said servo stripes arranged in frames recorded on a magnetic tape media, comprising:

a detection system configured to detect the timing based spacing between selected said sensed servo stripes; and

a decoder configured to respond to said detected spacing to identify said timing based bursts, to identify reference servo stripes of said bursts; to detect position shifts of servo stripes of each said burst, and to detect the longitudinal direction of said detected shifted servo stripes, wherein said shift is in the same longitudinal direction with respect to said at least one reference servo stripe for each burst of a frame and the opposite longitudinal direction for bursts of sequentially adjacent frames, and to decode said detected longitudinal directions of said position shifts to identify said frames.

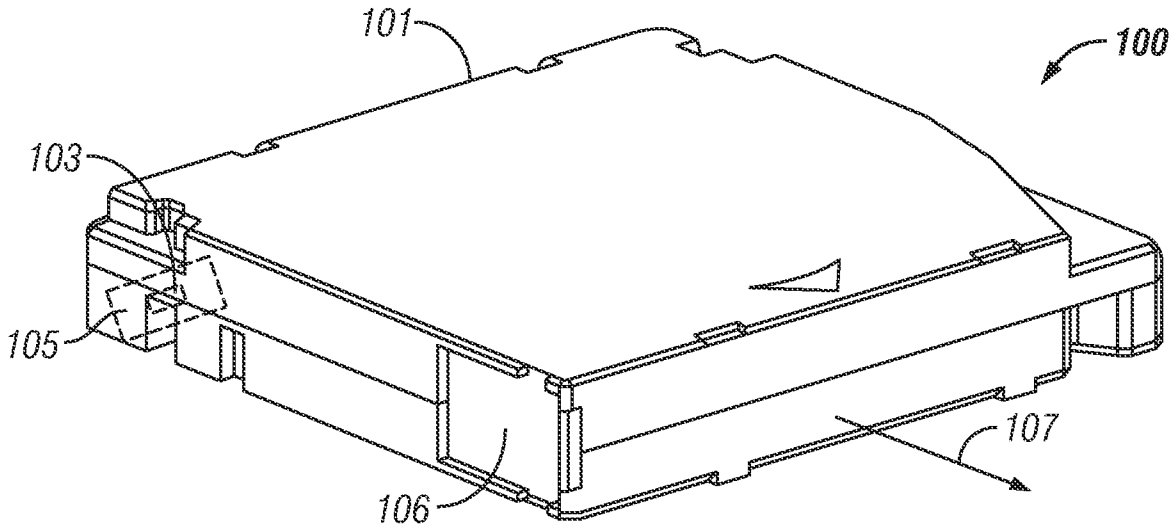


FIG. 1

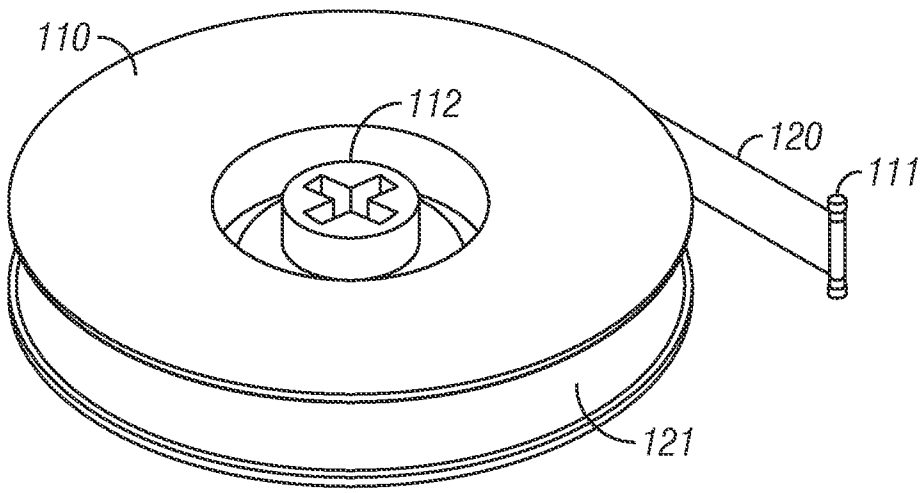


FIG. 2

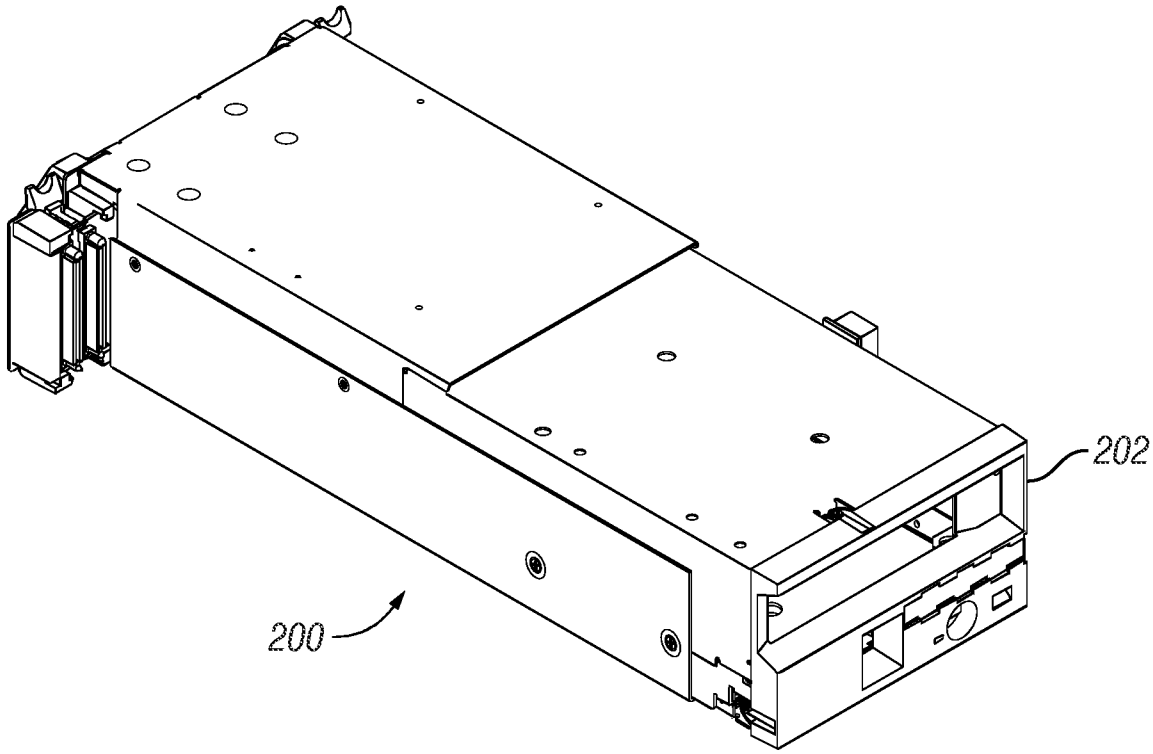

202
200

FIG. 3

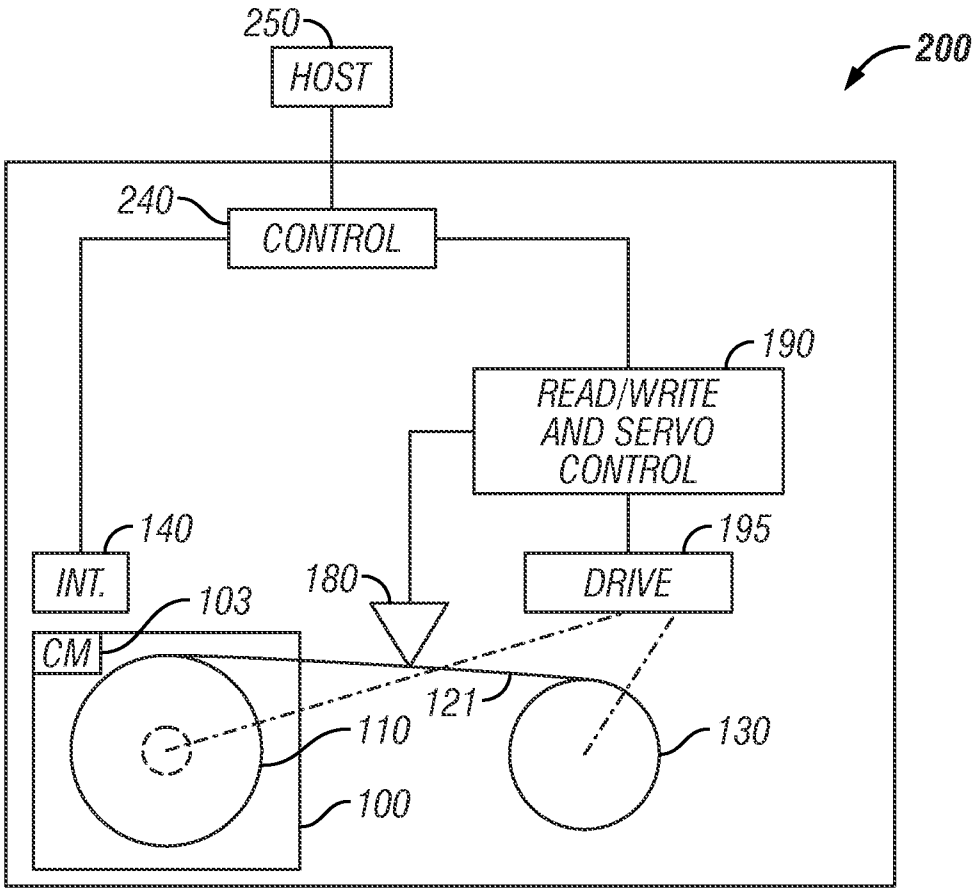

250
HOST
200
240
CONTROL
190
READ/WRITE AND SERVO CONTROL
140
INT.
180
195
DRIVE
103
CM
121
110
130
100

FIG. 4

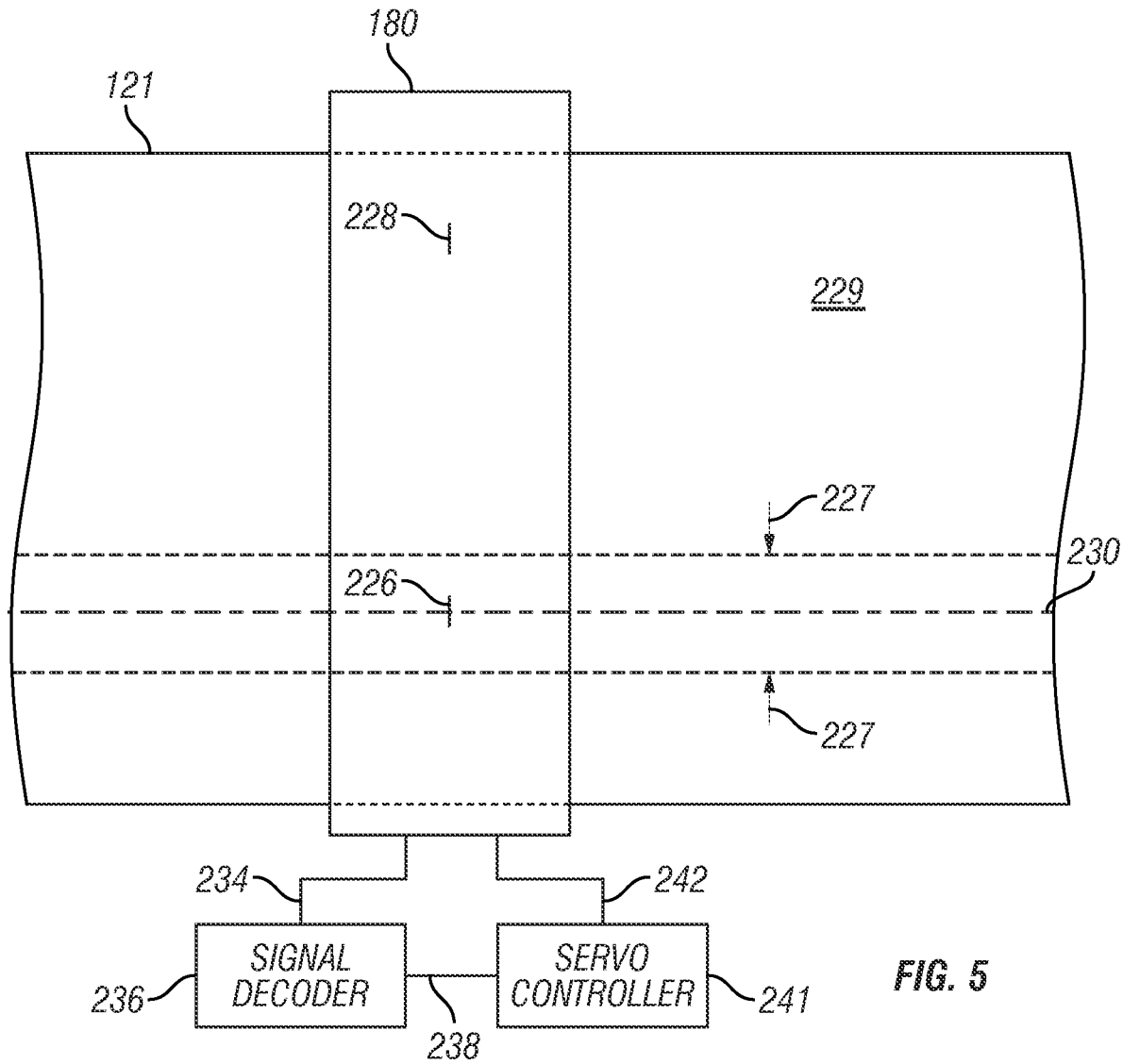

180
121
228
229
227
230
226
227
234
242
SIGNAL DECODER
SERVO CONTROLLER
236
238
241

FIG. 5

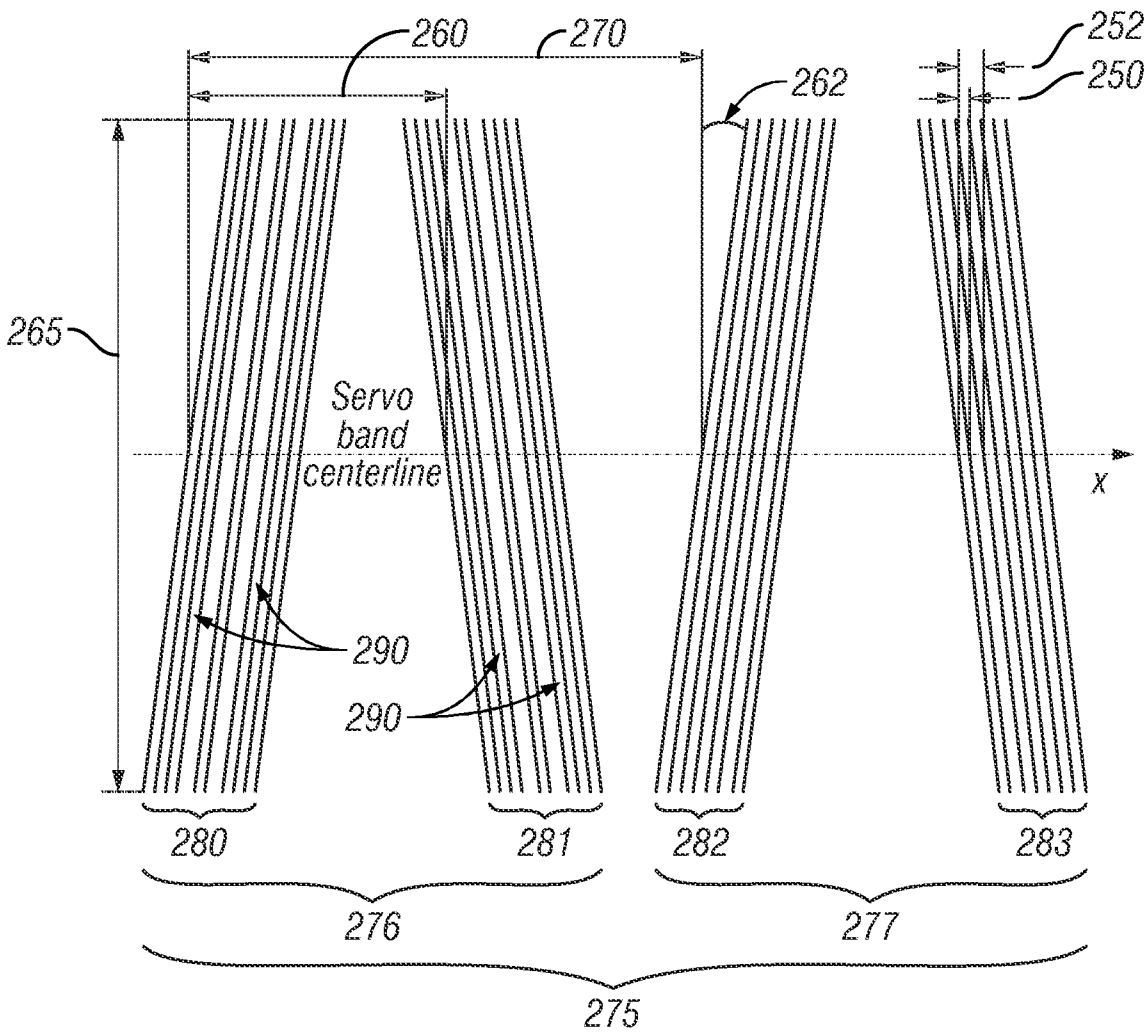


FIG. 6
(Prior Art)

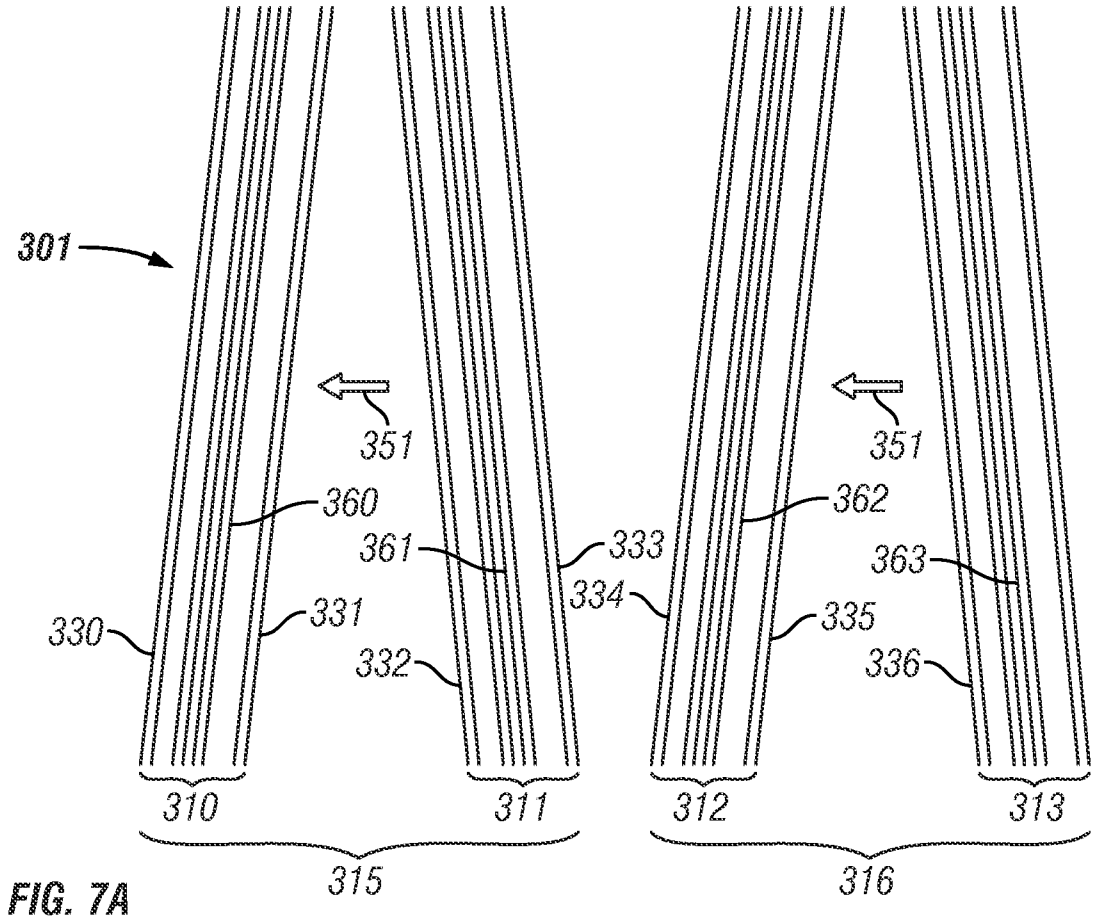
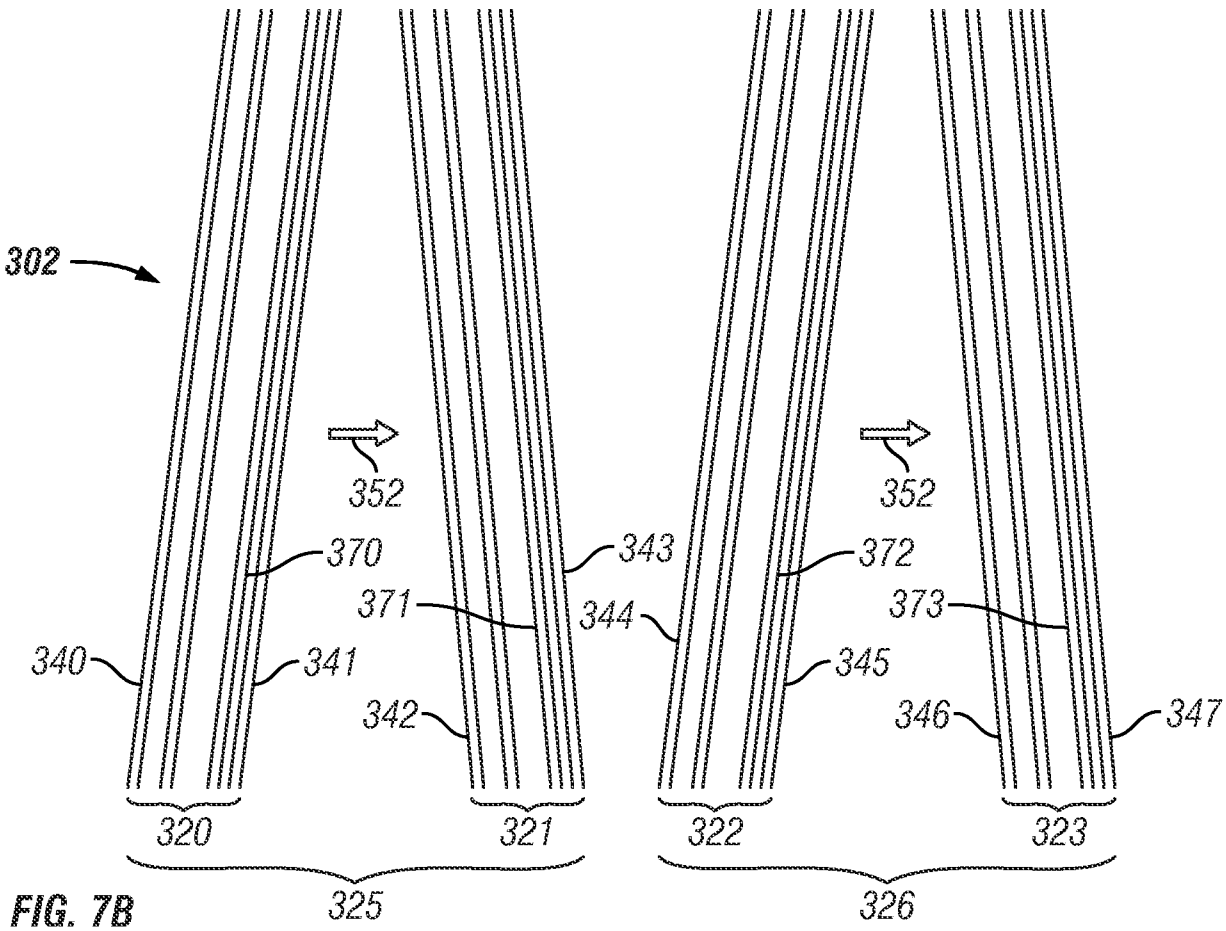

301
351
351
360
361
333
362
363
330
331
334
335
332
336
310
311
312
313
315
316

FIG. 7A


302
352
352
370
371
343
372
373
340
341
344
345
342
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347
320
321
322
323
325
326

FIG. 7B

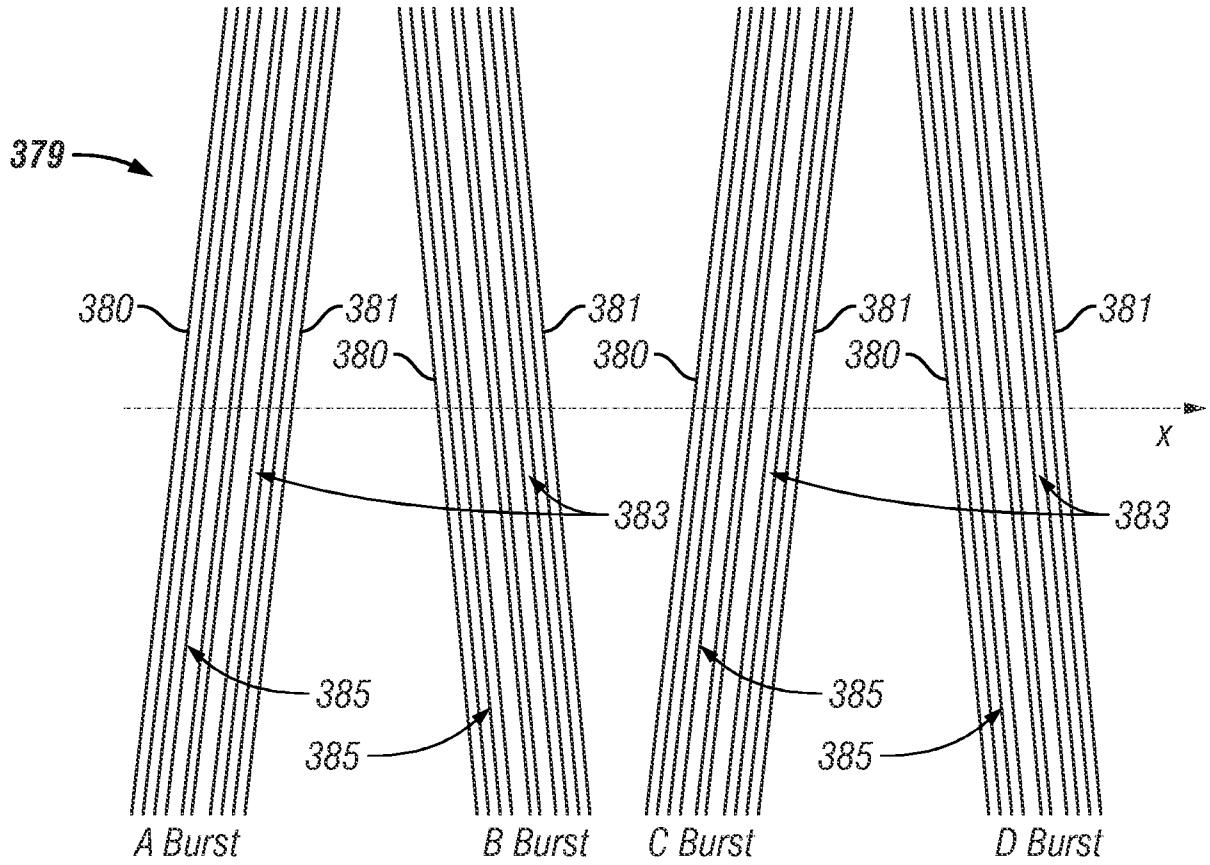
379
380
381
381
380
380
381
381
380
X
383
383
385
385
385
385
A Burst
B Burst
C Burst
D Burst

FIG. 8

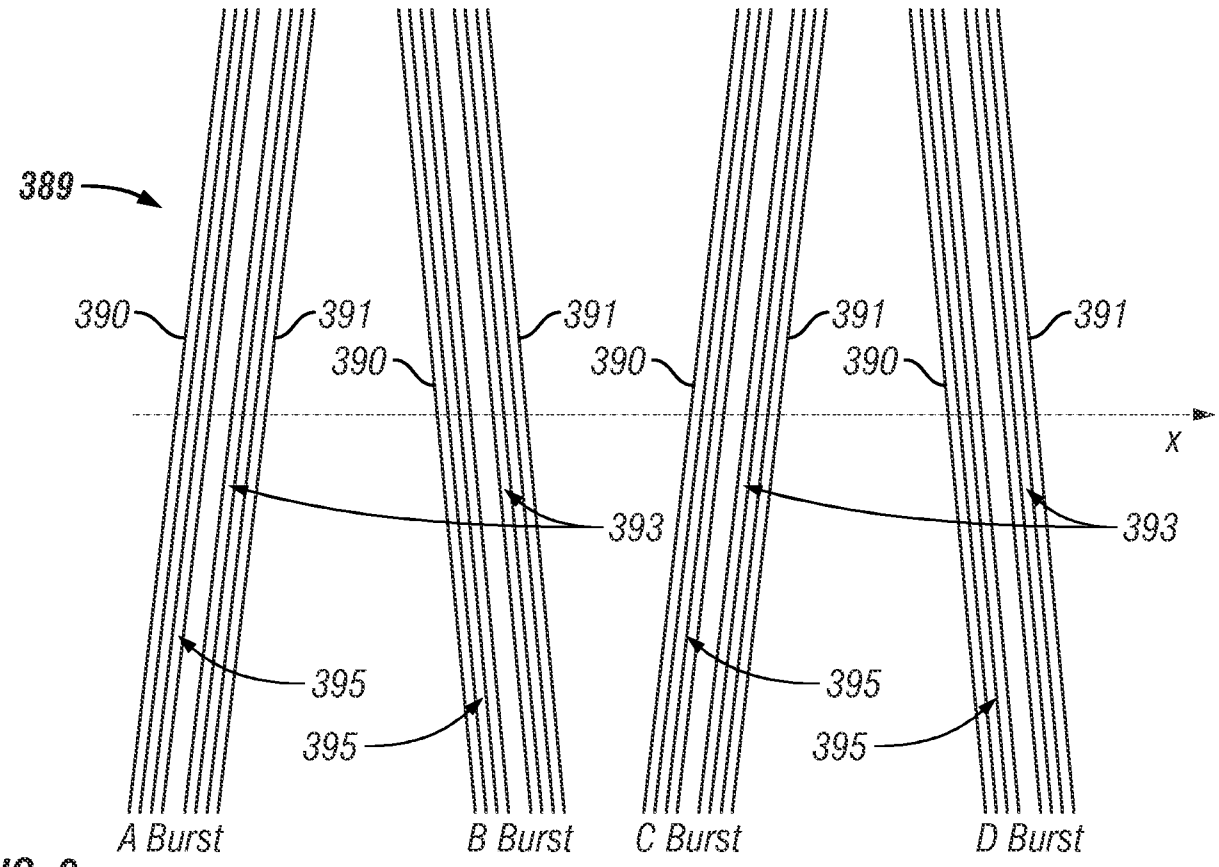
389
390
391
391
390
390
391
391
390
X
393
393
395
395
395
395
A Burst
B Burst
C Burst
D Burst

FIG. 9

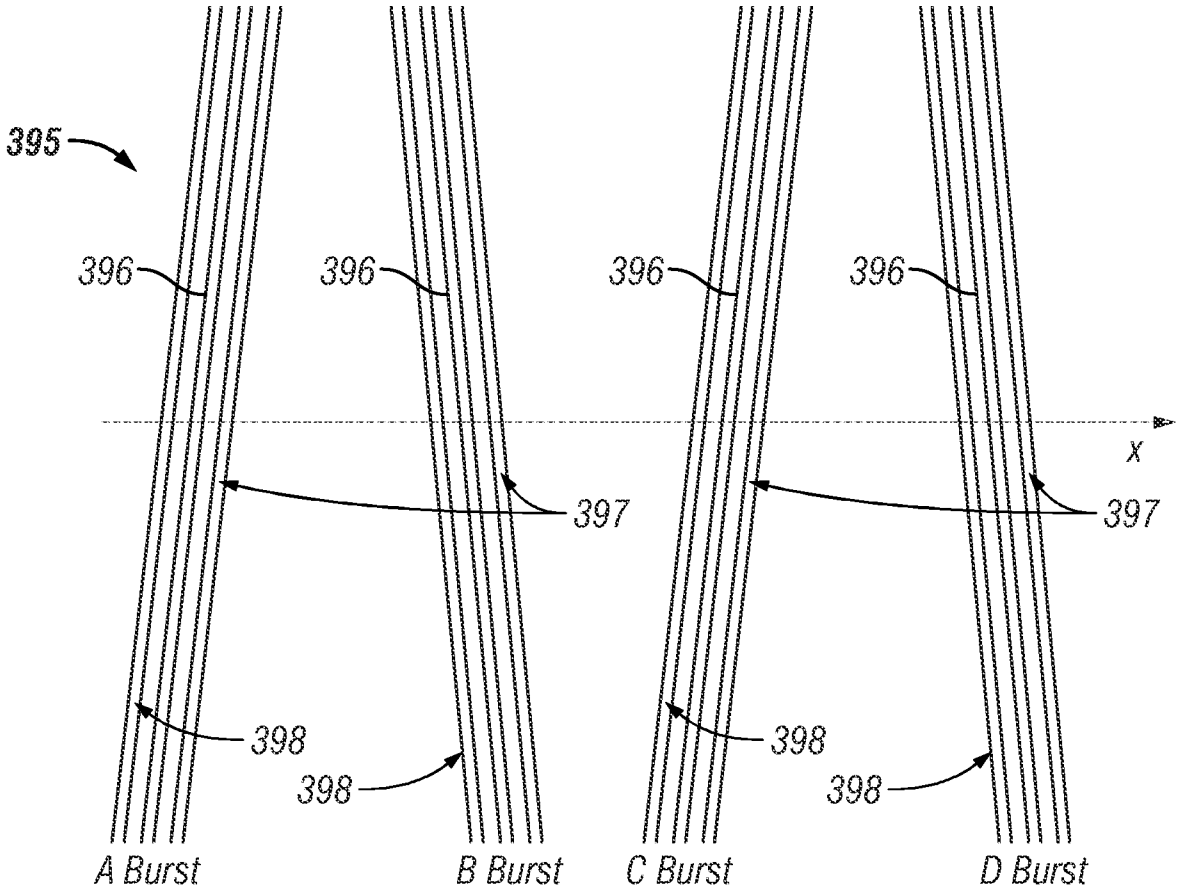
395
396
396
396
396
397
397
398
398
398
398
X
A Burst
B Burst
C Burst
D Burst

FIG. 10

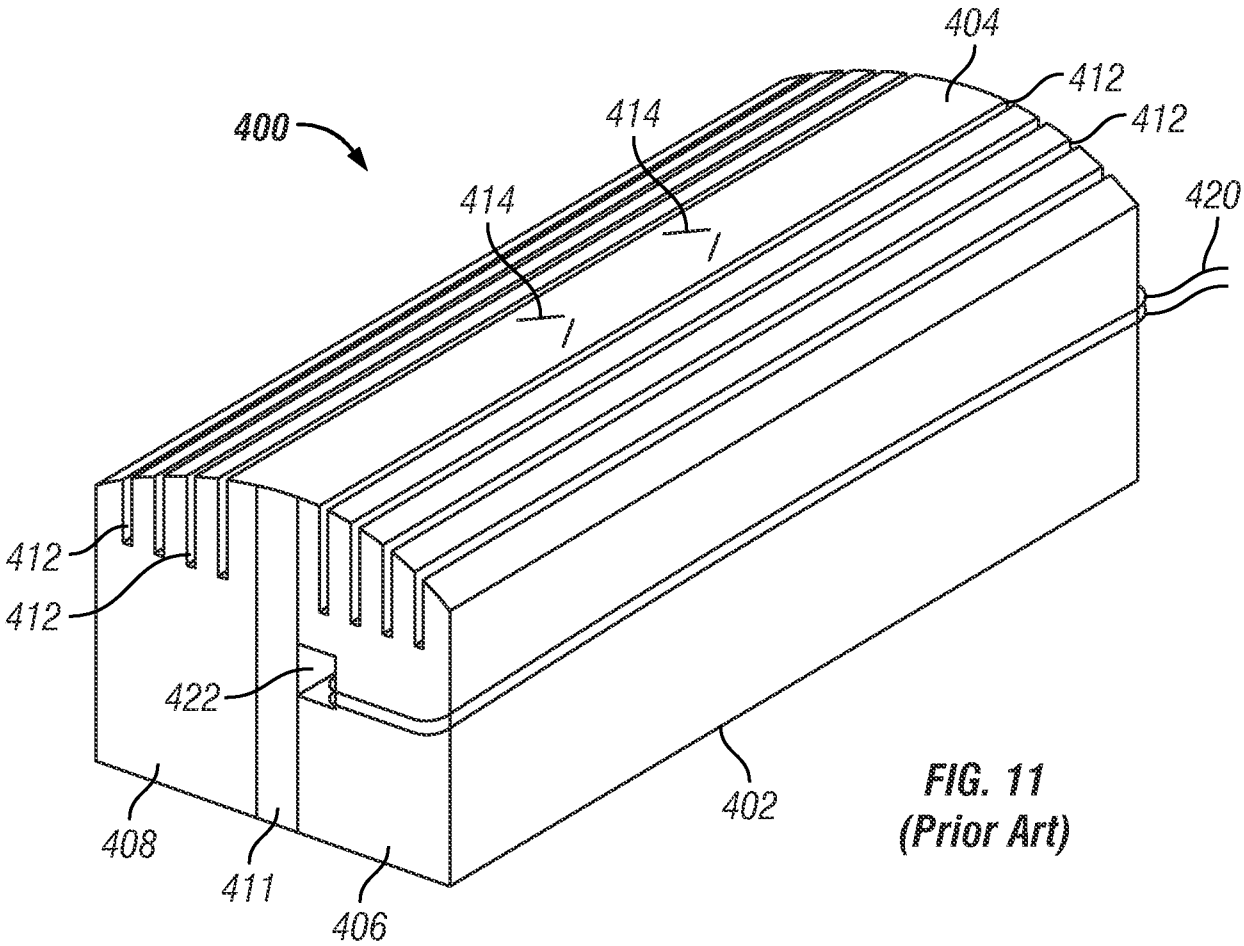

FIG. 11
(Prior Art)

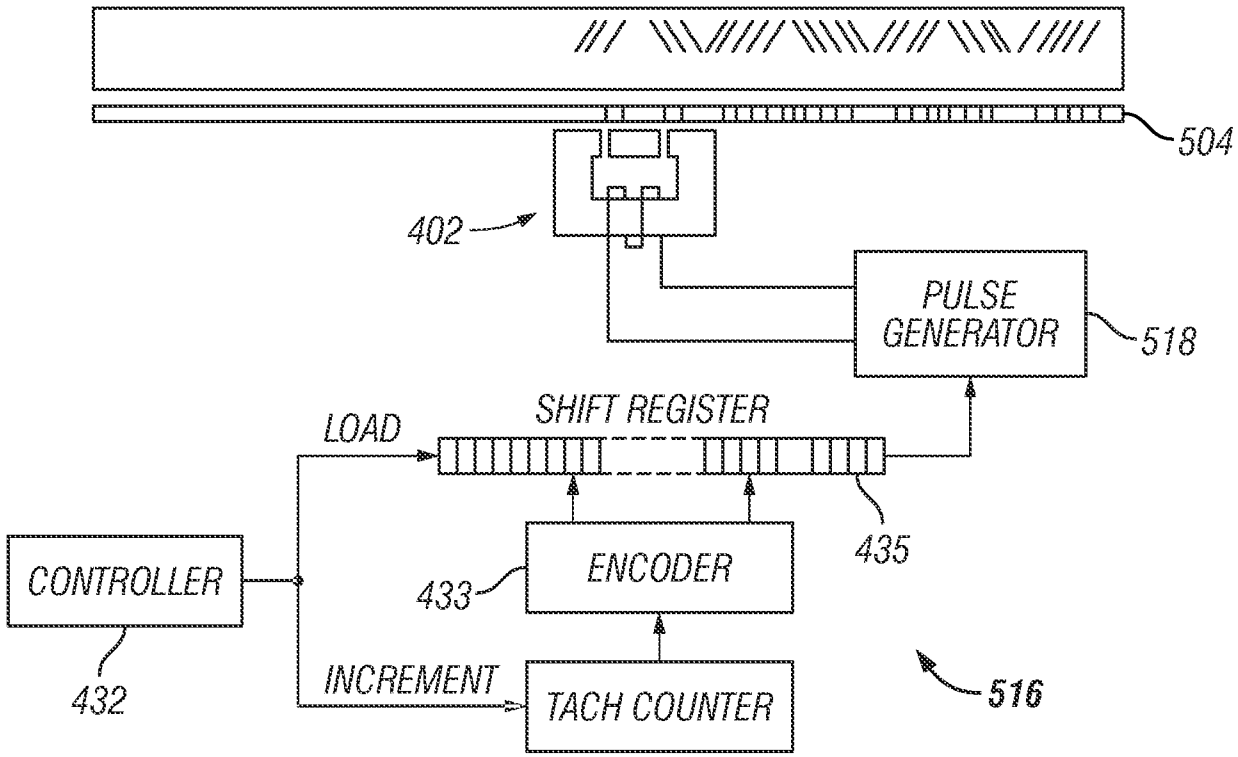
504
402
PULSE GENERATOR
518
LOAD
SHIFT REGISTER
435
CONTROLLER
433
ENCODER
432
INCREMENT
TACH COUNTER
516

FIG. 12

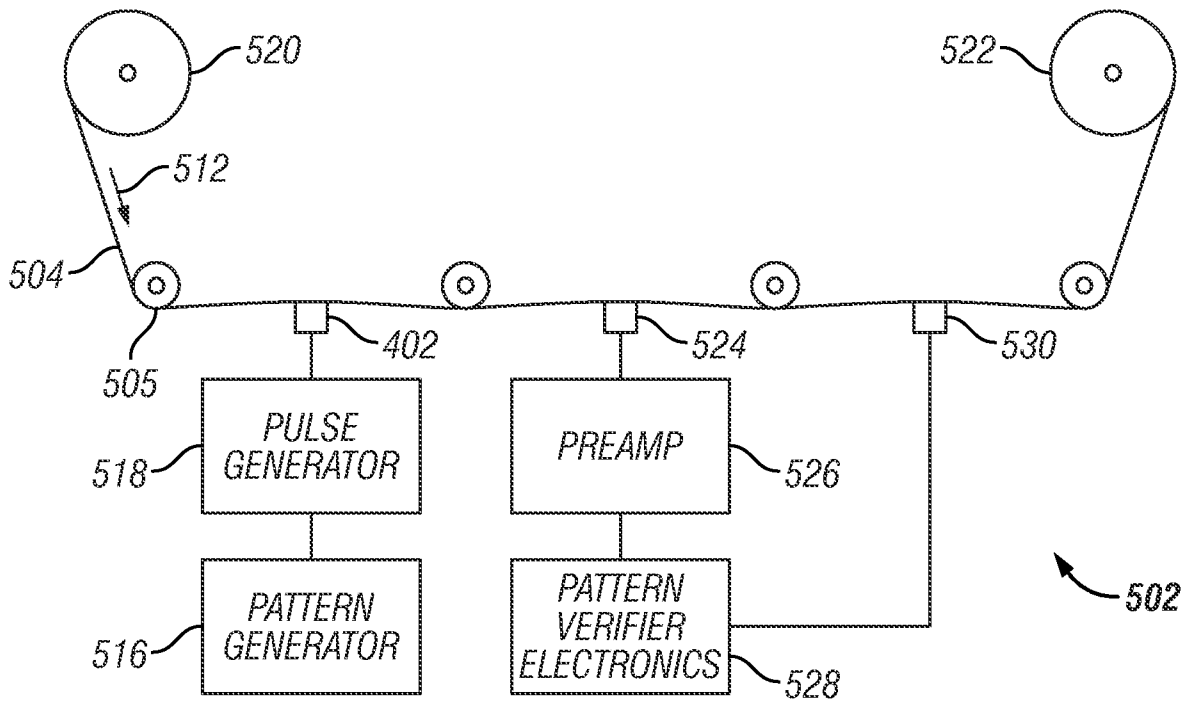
520
522
512
504
505
402
524
530
PULSE GENERATOR
518
PREAMP
526
PATTERN GENERATOR
516
PATTERN VERIFIER ELECTRONICS
528
502

FIG. 13

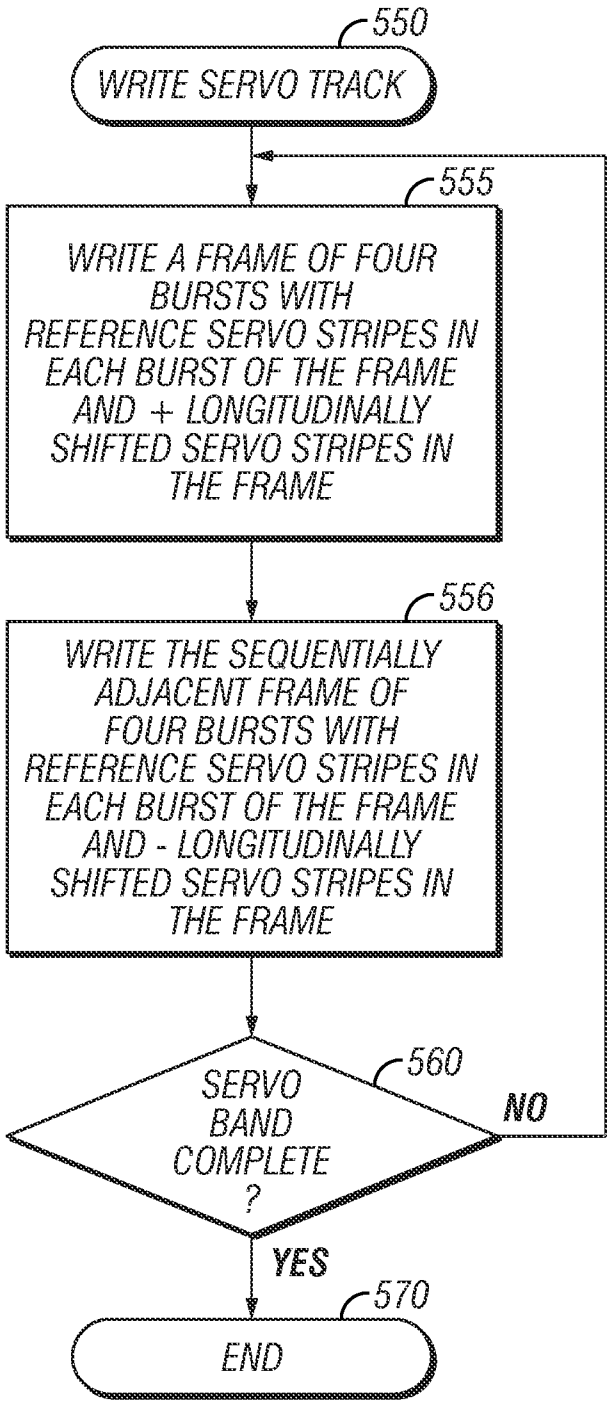
550
WRITE SERVO TRACK
555
WRITE A FRAME OF FOUR BURSTS WITH REFERENCE SERVO STRIPES IN EACH BURST OF THE FRAME AND + LONGITUDINALLY SHIFTED SERVO STRIPES IN THE FRAME
556
WRITE THE SEQUENTIALLY ADJACENT FRAME OF FOUR BURSTS WITH REFERENCE SERVO STRIPES IN EACH BURST OF THE FRAME AND - LONGITUDINALLY SHIFTED SERVO STRIPES IN THE FRAME
560
SERVO BAND COMPLETE ?
NO
YES
570
END

FIG. 14