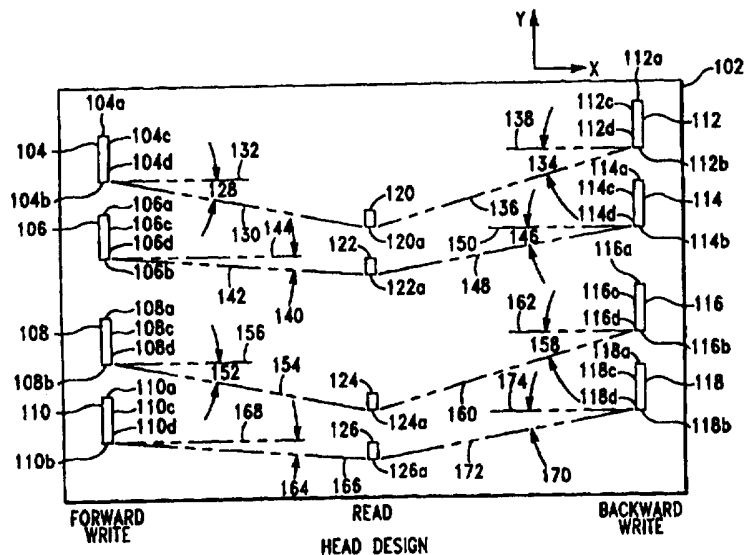




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(54) Title: FOUR CHANNEL AZIMUTH AND TWO CHANNEL NON-AZIMUTH READ-AFTER-WRITE LONGITUDINAL MAGNETIC HEAD



(57) Abstract

A read-after-write head (100) for four channel azimuth recording in one mode of operation and two channel non-azimuth recording in another mode of operation. Four forward write head gaps (104, 106, 108, 110), four read head gaps (120, 122, 124, 126), and four backward write head gaps (112, 114, 116, 118) are geometrically positioned within a rotatable and laterally indexable face plate (102) of a recording head housing. The read and write head gaps collectively provide four forward write channels, four read channels, and four backward write channels. During the azimuth mode of operation, the head is rotated to the preselected positive or negative azimuth angle and all of the read and write channels are utilized. During the non-azimuth, or vertical, mode of operation, write channels two and four are used in combination with read channels one and three to provide two channel non-azimuth, or vertical, operation.

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FOUR CHANNEL AZIMUTH AND TWO CHANNEL NON-AZIMUTH READ-AFTER-WRITE LONGITUDINAL MAGNETIC HEAD

Reference to Related Application

5 This application claims the benefit of U.S. Provisional Patent
Application Serial No. 60/009,708, filed on January 11, 1996.

Field of the Invention

10 This invention relates in general to magnetic storage devices. More
particularly this invention relates to a method and apparatus that efficiently
provides azimuth as well as non-azimuth recording in a longitudinal
magnetic tape recording system.

Background of the Invention

15 The constantly increasing operational speeds of digital computers are
creating a demand for corresponding increases in the data storage capacities
of magnetic tape recording and reproducing systems, while maintaining the
special requirements of high speed digital tape systems.

20 It is desirable that tape recording and reproducing systems for use as
computer data storage devices provide high data transfer rates and perform a
read check on all written data. Toward those ends, conventional tape
systems typically employ methods of recording known as longitudinal
25 recording, as illustrated in Figure 1a, in which the tracks of data lie parallel
to each other and parallel to the edges of the tape; or helical scan recording,
as illustrated in Figure 1b, in which the tracks of data lie parallel to each
other but diagonal to the edges of the tape. The longitudinal recording
method offers higher data transfer rates; but it would be desirable to obtain
30 still higher data densities while retaining the advantages of the longitudinal
recording method.

35 One limitation on track densities is crosstalk, which occurs when
reading of data from one track is interfered with by data recorded on an
adjacent track. Crosstalk is further exacerbated by error in head gap
alignments. Some methods have been implemented to reduce this effect,
such as leaving guard bands between tracks, or by using wider write head

gaps. These methods, however, also tend to limit track densities, thereby limiting data densities.

5 A method of recording known as azimuth recording has been used in helical scan systems in order to decrease the effects of crosstalk and thus increase the track density of these systems. Azimuth recording results in a recorded track pattern in which the magnetization directions of adjacent data tracks lie at different azimuth angles to each other, as illustrated in Figure 1c. This method greatly reduces inter-track crosstalk, enabling tracks to be placed closer together. The need for guard bands or wide write heads is thus reduced or eliminated. The helical scan method, however is subject to limited data transfer rates.

Summary of the Invention

15 The present invention reduces the effects of one or more of the problems set forth above. In particular, the present invention provides a read-after-write longitudinal recording head so configured and operated as to be capable of four channel azimuth recording and playback, as well as two channel non-azimuth recording and playback operation, thereby enabling newer tape recorders equipped with the head to perform more-efficient four channel azimuth recording and playback, as well as to perform the older, less-efficient two channel non-azimuth recording thereby providing a backward compatibility with tapes recorded on the older generation of non-azimuthal longitudinal tape recording machines.

25 In accordance with one aspect of the present invention, a read-after-write tape recording head is provided which operates in a first mode to provide four channel azimuth recording and also operates in a second mode to provide two channel non-azimuth recording onto a magnetic tape recording medium.

35 These and other objects, advantages, aspects and features of the present invention will be more fully understood and appreciated upon consideration of the following detailed description of a preferred embodiment, presented in conjunction with the accompanying drawings.

Brief Description of the Drawings

In the Drawings:

5 Figures 1a, 1b, and 1c illustrate respectively longitudinal, helical, and azimuth recording methods known in the art.

10 Figure 2 is a front view of the bottom face of one embodiment of the read-after-write head of the present invention including four write heads for forward writing, four write heads for backward writing, and four read heads for read-after-writing and regular reading with the read and write heads positioned to permit operation in four-channel azimuth mode and two channel non-azimuth mode.

15 Figure 3 illustrates writing onto a magnetic tape recording medium using the read-after-write head of Figure 2 in a four channel azimuth mode of operation with the read-after-write head rotated approximately 9.4 degrees from the vertical direction.

20 Figure 4 illustrates writing onto track zero of the magnetic tape recording medium of Figure 3 using the channel four write head gap of the read-after-write head of Figure 2 in the four channel azimuth mode of operation.

25 Figure 5 illustrates writing onto longitudinal tracks zero, one, two, and three of the magnetic tape storage medium in sequence using the channel four forward and backward write head gaps of the read-after-write head of Figure 2 in the azimuth recording mode of operation.

30 Figure 6 illustrates reading tracks zero, one, two, and three of the magnetic tape storage medium using the channel four read head gap of the read-after-write head of Figure 2 in the azimuth recording mode of operation and also indicating the direction of tape motion during this mode of operation.

35 Figure 7 illustrates writing onto the magnetic tape storage medium using write channels two and four of the read-after-write head of Figure 2

with regular read and read-after-write provided by read channels one and three in the two channel non-azimuth recording mode of operation.

5 Figure 8 illustrates reading the magnetic tape storage medium using read channel one of the read-after-write head of Figure 2 in the non-azimuth mode of operation.

Detailed Description of a Preferred Embodiment

10 The following descriptions of illustrative embodiments of the invention are presented as a description of structural elements contained in an illustrative apparatus and as operational steps performed in an illustrative method. The descriptions are derived from certain claims in the application as originally filed, but of course the claims are not intended and should not
15 be deemed to be limited to the illustrative embodiments so described.

It is to be understood that the particular implementations described are intended as illustrations of, and not as limiting the scope of, the claims. In the interest of clarity, not all the routine features of the implementations
20 are described. It will be appreciated that in the development of any such actual implementation, numerous implementation-specific decisions must be made to achieve the developers' specific goals such as compliance with system and business related constraints and that these goals will vary from one implementation to another. Moreover, it will be appreciated that such a
25 development effort might be complex and time-consuming, but would never the less be a routine undertaking of engineering for those of ordinary skill having the benefit of this disclosure.

30 Figures 2-8 show the context of an illustrative longitudinal recording apparatus implementing a read-after-write head 100 for recording information onto and reading information from a magnetic tape storage medium (not shown) moving past the head 100 in a longitudinal forward or reverse direction. The magnetic tape storage medium stores information by means of particulate matter on (or in close proximity to) its surface that is
35 selectively magnetized. The write head gaps "write" data onto the magnetic tape by selectively magnetizing the particulate matter in a well known manner, while the read head gaps "read" the magnetization of the

particulate matter in a well known manner. The magnetic tape is drawn longitudinally past the head 100 in forward and reverse directions (in alignment with axis x of Figure 2).

5 As is well known in the art, a read-after-write head provides error detection after writing in a given direction on a specific channel by means of a write head gap with a read head gap positioned in substantial alignment with the longitudinal direction of the magnetic tape medium on the specific channel. The read-after-write head 100 records information onto, and reads
10 information from, longitudinal tracks defined on the magnetic tape storage medium either in a four-channel azimuth mode, or in a two-channel non-azimuth mode. The read-after-write head 100 while operating in two-channel non-azimuth mode provides backward compatibility with existing non-azimuthal tape recording devices and with tapes recorded on such
15 devices.

 Generally speaking, the read-after-write head 100 provides four-channel azimuthal recording as well as two-channel non-azimuthal recording by following the Figure 2 geometric layout of four forward write
20 head gaps 104, 106, 108 and 110, four read head gaps 112, 114, 116 and 118, and four backward write head gaps 120, 122, 124 and 126. The read-after-write head 100 may be utilized in the azimuth and non-azimuth modes of operation by its use in conjunction with a conventional tape head controller that provides indexing of the tape head laterally across (along axis
25 y in Figure 2) the magnetic tape medium as well as rotation of the tape head relative to the tape for azimuth or non-azimuth operation. An exemplary head positioning structure is described in commonly assigned, copending U.S. Patent Application Serial No. 08/557,662 to Kumar Kasetty, filed on November 13, 1995 and entitled: "Tape Drive Head Positioning Device for
30 Adjusting Head Tilt And Azimuth", the disclosure of which is incorporated herein by reference; and, an exemplary head controller is described in United States Patent No. 5,307,217, issued to co-inventor George A. Saliba, on April 26, 1994, the disclosure of which is also incorporated herein by reference.

35

 As shown in Figure 2, the read-after-write head apparatus 100 generally comprises a surface 102. In one illustrative embodiment, the

surface 102 comprises a face plate which provides a rigid supporting structure for the read and write head gaps. The face plate will be attached to a conventional read-after-write head housing which in indexed laterally across the surface of the magnetic tape and also rotated to provide azimuth or non-azimuth modes of operation in a well known manner by a tape recorder controller of the type disclosed in United States Patent No. 5,307,217 issued to George A. Saliba.

The surface 102 defines first 104, second 106, third 108, and fourth 110 laterally spaced apart forward-direction write head gaps including upper edges 104a, 106a, 108a, and 110a, lower edges 104b, 106b, 108b, and 110b, upper portions 104c, 106c, 108c, and 110c, and lower portions 104d, 106d, 108d, and 110d opening into the surface 102. The forward write head gaps 104, 106, 108, and 110 write data onto the magnetic tape recording medium in a well known manner during movement of the magnetic tape in the forward direction indicated by the arrow 205 in Figure 3. In the four-channel azimuthal mode the forward-direction write head gaps 104, 106, 108, and 110 provide four forward write channels numbered consecutively 1, 2, 3, and 4 from top to bottom and simultaneously write to four longitudinal tracks defined on the forward moving magnetic tape.

The surface 102 also defines first 112, second 114, third 116, and fourth 118 laterally spaced apart backward-direction write head gaps including upper edges 112a, 114a, 116, and 118a, lower edges 112b, 114b, 116b, and 118b, upper portions 112c, 114c, 116c, and 118c, and lower portions 112d, 114d, 116d, and 118d opening into the surface 102 and spaced apart from the forward write head gaps 104, 106, 108, and 110. The forward write head gaps 104, 106, 108, and 110 and the backward write head gaps 112, 114, 116, and 118 are laterally offset. The backward write head gaps 112, 114, 116, and 118 write data onto the magnetic tape recording medium in a well known manner during movement of the magnetic tape in a direction opposite to that indicated by the arrow 205 in Figure 3. In this manner, the backward-direction write head gaps 112, 114, 116, and 118 provide four backward write channels numbered consecutively 1, 2, 3, and 4 from top to bottom and simultaneously write to four additional longitudinal tracks defined on the reverse moving magnetic tape.

The surface 102 also defines first 120, second 122, third 124, and fourth 126 laterally spaced apart read head gaps including lower edges 120a, 122a, 124a, and 126a opening into the surface 102 and located between the forward write head gaps 104, 106, 108, and 110 and the backward write head gaps 112, 114, 116, and 118. The read head gaps 120, 122, 124, and 126 extend generally parallel to, and are laterally offset from, the forward head gaps 104, 106, 108, and 110 and backward write head gaps 112, 114, 116, and 118 and are unequally spaced apart from the forward write head gaps 104, 106, 108, and 110 and the backward write head gaps 112, 114, 116, and 118. The read head gaps 120, 122, 124, and 126 read data from the magnetic tape recording medium in a well known manner during movement of the magnetic tape in either direction. In this manner, the read head gaps 120, 122, 124, and 126 provide four forward/backward read channels numbered consecutively 1, 2, 3, and 4 from top to bottom.

The read head gaps 120, 122, 124, and 126 are positioned between the forward write head gaps 104, 106, 108, and 110, and the backward write head gaps 112, 114, 116, and 118. The read head gaps 120, 122, 124, and 126 may or may not be equally spaced from the forward and backward write head gaps depending upon the particular geometry influenced by the need for backward compatibility with existing model tape recording devices.

As illustrated in Figure 3, during the azimuth mode of operation with the read-after-write head 100 rotated positively relative to the vertical direction, the four forward write head gaps 104, 106, 108, and 110 (forward write channels one to four) and the four read head gaps 120, 122, 124, and 126 (read channels one to four) are substantially aligned with the longitudinal direction of the magnetic tape medium. Furthermore, the four read head gaps 120, 122, 124, and 126 (read channels one to four) are also positioned to provide read-after-write for the four forward write head gaps 104, 106, 108, and 110 (forward write channels one to four) to thereby provide a four channel read-after-write recording head. Likewise, during the azimuth mode of operation with the read-after-write head 100 rotated negatively relative to the vertical direction, the four backward write head gaps 112, 114, 116, and 118 (backward write channels one to four) and the four read head gaps 120, 122, 124, and 126 (read channels one to four) are substantially aligned with the longitudinal

direction of the magnetic tape medium. Furthermore, the four read head gaps 120, 122, 124, and 126 (read channels one to four) are positioned to provide read-after-write for the four backward write head gaps 112, 114, 116, and 118 (backward write channels one to four) to thereby provide a four channel read-after-write recording head. Thus, the read-after-write head 100 provides four channel azimuth operation in both directions of tape motion.

As illustrated in Figure 7, during the non-azimuth (or vertical) mode of operation with the read-after-write head 100 in the neutral (or vertical position), the channel two forward write head gap 106, the channel one read head gap 120, and the channel two backward write head gap 114 are substantially aligned with the longitudinal direction of the magnetic tape medium, and the channel four forward write head gap 110, the channel three read head gap 124, and the channel four backward write head gap 118 are substantially aligned with the longitudinal direction of the magnetic tape medium. Furthermore, the channel one read head gap 120 is also positioned in opposing relationship to the upper portion 106c of the channel two forward write head gap 106 and also in opposing relationship to the lower portion 114d of the channel two backward write head gap 114 while the channel three read head gap 124 is positioned in opposing relationship to the upper portion 110c of the channel four forward write head gap 110 and also in opposing relationship to the lower portion 118d of the channel four backward write head gap 118. In this manner, the read-after-write head 100 provides a two-channel read-after-write recording operation in the non-azimuth mode of operation for tape motion in both directions using write channels two and four and read channel one and three.

The first read head gap 120 is positioned in opposing relationship to the upper portion 106c of the second forward write head gap 106 and the lower portion 114d of the second backward write head gap 114. As illustrated in Figures 2 and 7, the channel one read head gap 120 is positioned in opposing relationship to the upper portion 106c of the channel two forward write head gap 106 and also in opposing relationship to the lower portion 114d of the channel two backward write head gap 114.

The third read head gap 124 is positioned in opposing relationship to the upper portion 110c of the fourth forward write head gap 110 and the lower portion 118d of the fourth backward write head gap 118. As illustrated in Figures 2 and 7, the channel three read head gap 124 is positioned in opposing relationship to the upper portion 110c of the channel four forward write head gap 110 and also in opposing relationship to the lower portion 118d of the channel four backward write head gap 118.

An angle 128 between a line 130 tangent to the lower edge 104b of the first forward write head gap 104 and the lower edge 120a of the first read head gap 120 and a line 132 perpendicular to gap 104 at the lower edge 104b is substantially equal to an angle 134 between a line 136 tangent to the lower edge 112b of the first backward write head gap 112 and the lower edge 120a of the first read head gap 120 and a line 138 perpendicular to gap 112 at the lower edge 112b. As illustrated in Figures 2 and 5, the geometric relationship between the channel one forward write head gap 104, the channel one read head gap 120, and the channel one backward write head gap 112 positions the channel one read head gap 120 to provide read-after-write (and regular read for that track) for the channel one forward write head gap 104 during positive rotation of the read-after-write head 100 to the preselected azimuth angle and read-after-write (and regular read for that track) for the channel one backward write head gap 112 during negative rotation of the read-after-write head 100 to the preselected azimuth angle. Positive rotation of head 100 is in a counter-clockwise sense while negative rotation is in a clockwise sense, as shown in Figure 3.

An angle 140 between a line 142 tangent to the lower edge 106b of the second forward write head gap 106 and the lower edge 122a of the second read head gap 122 and a line 144 perpendicular to gap 106 at the lower edge 106b is substantially equal to an angle 146 between a line 148 tangent to the lower edge 114b of the second backward write head gap 114 and the lower edge 122a of the second read head gap 122 and a line 150 perpendicular to gap 114 at the lower edge 114b. As illustrated in Figures 2 and 5, the geometric relationship between the channel two forward write head gap 106, the channel two read head gap 122, and the channel two backward write head gap 114 positions the channel two read head gap 122

to provide read-after-write (and regular read for that track) for the channel two forward write head gap 106 during positive rotation of the read-after-write head 100 to the preselected azimuth angle and read-after-write (and regular read for that track) for the channel two backward write head gap 114 during negative rotation of the read-after-write head 100 to the preselected azimuth angle.

An angle 152 between a line 154 tangent to the lower edge 108b of the third forward write head gap 108 and the lower edge 124a of the third read head gap 124 and a line 156 perpendicular to gap 108 at the lower edge 108b is substantially equal to an angle 158 between a line 160 tangent to the lower edge 116b of the third backward write head gap 116 and the lower edge 124a of the third read head gap 124 and a line 162 perpendicular to gap 116 at the lower edge 116b. As illustrated in Figures 2 and 5, the geometric relationship between the channel three forward write head gap 108, the channel three read head gap 124, and the channel three backward write head gap 118 positions the channel three read head gap 124 to provide read-after-write (and regular read for that track) for the channel three forward write head gap 108 during positive rotation of the read-after-write head 100 to the preselected azimuth angle and read-after-write (and regular read for that track) for the channel three backward write head gap 116 during negative rotation of the read-after-write head 100 to the preselected azimuth angle.

An angle 164 between a line 166 tangent to the lower edge 110b of the fourth forward write head gap 110 and the lower edge 126a of the fourth read head gap 126 and a line 168 perpendicular to gap 110 at the lower edge 110b is substantially equal to an angle 170 between a line 172 tangent to the lower edge 118b of the fourth backward write head gap 118 and the lower edge 126a of the fourth read head gap 126 and a line 174 perpendicular to gap 118 at the lower edge 118b. As illustrated in Figures 2 and 5, the geometric relationship between the channel four forward write head gap 110, the channel four read head gap 126, and the channel four backward write head gap 118 positions the channel four read head gap 126 to provide read-after-write (and regular read for that track) for the channel four forward write head gap 110 during positive rotation of the read-after-write head 100 to the preselected azimuth angle and read-after-write (and regular read for that track) for the channel four backward write head gap 118

during negative rotation of the read-after-write head 100 to the preselected azimuth angle.

5 Thus, the angles 128, 134, 140, 146, 152, 158, 164, and 170 are all substantially equal to the selected azimuth angle thereby to provide proper alignment of the forward write head gaps, read head gaps, and backward write head gaps during the four-channel azimuth mode of operation.

10 The method of the present invention advantageously enables a single conventional tape recording apparatus to selectively provide azimuth and non-azimuth modes of operation. The read-after-write head 100 may be controllably positioned (including the conventional recording head motions of indexing and rotation) by adapting a conventional tape recording machine to incorporate the control system disclosed in United States Patent No.
15 5,307,217 issued to George A. Saliba. Such a control system is adapted in a known manner to provide azimuth and non-azimuth (or vertical) operational control of the read-after-write head 100 as, for example, in accordance with a head positioning structure described in the commonly assigned, copending U.S. Patent Application Serial No. 08/557,662 referred to above.

20 As illustrated in Figures 3-6, in the azimuth mode of operation the read-after-write head 100 is indexed to a preselected position over the selected tracks of the magnetic tape medium which is moving in a forward direction (as indicated by the arrow 205 in Figure 3) relative to the read-
25 after-write head 100. The read-after-write head 100 is then rotated to the preselected positive azimuth angle. In this position, the forward write head gaps 104, 106, 108, and 110 (forward write channels 1-4) are substantially aligned with the longitudinal direction of the moving magnetic tape medium. Furthermore, the read head gaps 120, 122, 124, and 126 (read
30 channels 1-4) are also substantially aligned with the longitudinal direction of the moving magnetic tape medium and also positioned to provide read-after-write (and regular read for those tracks) for the forward write head gaps 104, 106, 108, and 110. The read-after-write head 100 may now write to the tracks of the moving magnetic tape medium and/or read the tracks of
35 the magnetic tape medium in a well known manner

The tape direction is then selectively reversed to move the backward direction (opposite to the direction indicated by the arrow 205 in Figure 3). The read-after-write head 100 is again indexed to another preselected position over the selected tracks of the magnetic tape medium which is now
5 moving in the backward direction (as indicated by a direction opposite to the arrow 205 in Figure 3) relative to the read-after-write head 100. The read-after-write head is then rotated to the preselected negative azimuth angle. In this position, the backward write head gaps 112, 114, 116, and 118 (backward write channels 1-4) are substantially aligned with the
10 longitudinal direction of the moving magnetic tape medium. Furthermore, the read head gaps 120, 122, 124, and 126 (read channels 1-4) are also substantially aligned with the longitudinal direction of the moving magnetic tape medium and also positioned to provide read-after-write (and regular read for those tracks) for the backward write head gaps 112, 114, 116, and
15 118. The read-after-write head 100 may now write to the tracks of the moving magnetic tape medium and/or read the tracks of the magnetic tape medium in a well known manner.

This operation is selectively controlled in a well known manner by
20 the tape recorder control system. As illustrated in Figure 5, the azimuth mode typically produces a criss-cross overlapping pattern on the magnetic tape storage medium.

Thus, the read-after-write head 100 provides four channels of read
25 and write during the azimuthal mode of operation in both the forward and backward directions of magnetic tape motion. This operation is selectively controlled in a well known manner by the tape recorder control system. As illustrated in Figure 5, the azimuth mode typically produces a criss-cross overlapping pattern on the magnetic tape storage medium.

30

As illustrated in Figures 7 and 8, in the non-azimuth mode of operation, the read-after-write head 100 is indexed to a preselected position over the selected tracks of the magnetic tape medium which is moving in a forward direction (as indicated by the arrow 605 in Figure 7) relative to the
35 read-after-write head 100. The read-after-write head is then rotated to, or maintained at, the neutral or laterally aligned angular position illustrated in Figure 7 (azimuth angle equals zero). In this position the forward write

head gaps 106 and 110 (forward write channels two and four) are substantially aligned with the longitudinal direction of the moving magnetic tape medium. Furthermore, the read head gaps 120 and 124 (read channels one and three) are also substantially aligned with the longitudinal direction of the moving magnetic tape medium and also in opposing relationship to the forward write head gaps 106 and 110 (forward write channels two and four). The read-after-write head 100 may now write to the tracks of the moving magnetic tape medium and/or read the tracks of the magnetic tape medium in a well known manner

The tape direction is then selectively reversed to move the backward direction (opposite to the direction indicated by the arrow 605 in Figure 7). The read-after-write head 100 is again indexed to another preselected position over the selected tracks of the magnetic tape medium which is now moving in the backward direction (as indicated by a direction opposite to the arrow 605 in Figure 7) relative to the read-after-write head 100. The read-after-write head is again maintained in the neutral or vertical angular position as illustrated in Figure 7. In this position, the backward write head gaps 114 and 118 (backward write channels two and four) are substantially aligned with the longitudinal direction of the moving magnetic tape medium. Furthermore, the read head gaps 120 and 124 (read channels one and three) are also substantially aligned with the longitudinal direction of the moving magnetic tape medium and also in opposing relationship to the backward write head gaps 112, 114, 116, and 118. The read-after-write head 100 may now write to the tracks of the moving magnetic tape medium and/or read the tracks of the magnetic tape medium in a well known manner.

Thus, the read-after-write head 100 provides two channels of read (using read channels one and three) and write (using forward and backward write channels two and four) during the non-azimuthal (or vertical) mode of operation in both the forward and backward directions of magnetic tape motion.

In summary, Figures 2-8 show the illustrative dual-mode method of recording data onto azimuthal and non-azimuthal magnetic tapes by using the read-after-write head 100. The illustrative method generally comprises the steps of:

positioning the head 100 at a predetermined azimuth angle for four-channel azimuth mode recording, and then

writing data onto a first magnetic tape in the four channel azimuth mode using the read-after-write recording head 100, etc.; as well as

5 positioning the head 100 at the nominal, non-azimuth null position for two-channel non-azimuth recording, and then

writing data onto a second magnetic tape in two channel non-azimuth mode using the read-after-write recording head 100, etc.

10 During azimuth mode bidirectional recording the method includes the steps of positioning the head 100 at a positive predetermined angle for forward-direction four channel azimuth mode recording, and repositioning the head 100 at a negative or complementary azimuth angle for backward-direction four-channel azimuth mode recording, in addition to the writing
15 steps. In both modes, the head 100 advantageously performs reading after writing during each writing operation in order to verify that the data pattern intended for writing has actually been recorded onto the tape.

The illustrative embodiment includes four forward write head gaps, four read head gaps, and four backward write head gaps. It will be apparent
20 to a person of ordinary skill in the art, having the benefit of this disclosure, that the teachings of the disclosure may provide a read-after-write head for azimuth and non-azimuth modes of operation with any number and combination of read and write head gaps.

25 It will be appreciated by those of ordinary skill having the benefit of this disclosure that numerous variations from the illustrations in the notes will be possible without departing from the inventive concept described herein.

What is claimed is:

1. A method of storing data on magnetic tape using a read-after-write recording head including four forward write head gaps, four read head gaps, and four backward write head gaps, comprising:

5 positioning said recording head at a predetermined azimuth angle and writing data onto and reading data from a relatively moving first magnetic tape in azimuth mode using said four forward and backward write head gaps and said four read head gaps; and

10 positioning said recording head at a non-azimuth, null angle and writing data onto and reading data from a relatively moving second magnetic tape in non-azimuth mode using two of said forward write head gaps, two of said backward write head gaps, and two of said read head gaps.

15 2. A method of storing data on magnetic tape using a read-after-write recording head including forward write head gaps, read head gaps, and backward write head gaps, comprising:

20 writing data onto and reading data from a first magnetic tape in azimuth mode using said all of said forward write head gaps, backward write head gaps, and read head gaps; and

writing data onto and reading data from a second magnetic tape in non-azimuth mode using a portion of said forward write head gaps, backward write head gaps, and read head gaps.

25 3. The method of claim 2, wherein said read-after-write head includes four forward write head gaps, four read head gaps, and four backward write head gaps.

30 4. A read-after-write recording head for recording information onto and reading information from a magnetic tape storage medium, comprising:

(a) a surface against which the magnetic tape storage medium is drawn in a forward direction and in a backward direction;

35 (b) first, second, third, and fourth laterally spaced apart forward write head gaps including upper and lower edges and upper and lower portions opening into said surface;

(b) first, second, third, and fourth laterally spaced apart backward write head gaps including upper and lower edges and upper and lower

portions opening into said surface spaced apart from said forward write head gaps, said forward and backward write head gaps being laterally offset; and

5 (c) first, second, third, and fourth laterally spaced apart read head gaps including lower edges opening into said surface and located between said forward and backward head gaps, said read head gaps extending generally parallel to and laterally offset from said forward and backward write head gaps and unequally spaced apart from said forward and backward write head gaps;

10 (d) wherein said first read head gap is positioned in opposing relationship to said upper portion of said second forward write head gap and said lower portion of said second backward write head gap;

(e) wherein said third read head gap is positioned in opposing relationship to said upper portion of said fourth forward write head gap and said lower portion of said fourth backward write head gap;

15 (f) wherein an angle between a line tangent to said lower edge of said first forward write head gap and said lower edge of said first read head gap and a line perpendicular to said lower edge of said first forward write head gap is substantially equal to an angle between a line tangent to said lower edge of said first backward write head gap and said lower edge of said first read head gap and a line perpendicular to said lower edge of said first backward write head gap;

20 (g) wherein an angle between a line tangent to said lower edge of said second forward write head gap and said lower edge of said second read head gap and a line perpendicular to said lower edge of said second forward write head gap is substantially equal to an angle between a line tangent to said lower edge of said second backward write head gap and said lower edge of said second read head gap and a line perpendicular to said lower edge of said second backward write head gap;

25 (h) wherein an angle between a line tangent to said lower edge of said third forward write head gap and said lower edge of said third read head gap and a line perpendicular to said lower edge of said third forward write head gap is substantially equal to an angle between a line tangent to said lower edge of said third backward write head gap and said lower edge of said third read head gap and a line perpendicular to said lower edge of said third backward write head gap; and

35 (i) wherein an angle between a line tangent to said lower edge of said fourth forward write head gap and said lower edge of said fourth read

head gap and a line perpendicular to said lower edge of said fourth forward write head gap is substantially equal to an angle between a line tangent to said lower edge of said fourth backward write head gap and said lower edge of said fourth read head gap and a line perpendicular to said lower edge of said fourth backward write head gap.

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5. A read-after-write recording head for recording information onto and reading information from a magnetic tape storage medium, comprising:

(a) a surface against which the magnetic tape storage medium is moving in one of a forward direction and a backward direction;

(b) a plurality of laterally spaced apart forward write head gaps including lower edges and upper and lower portions opening into said surface;

(b) a plurality of laterally spaced apart backward write head gaps including lower edges and upper and lower portions opening into said surface spaced apart from said forward write head gaps; and

(c) a plurality of laterally spaced apart read head gaps including lower edges opening into said surface and located between said forward and backward head gaps, said read head gaps extending generally parallel to and laterally offset from said forward and backward write head gaps.

6. The apparatus of claim 5, wherein said plurality of backward write head gaps are laterally offset from said plurality of forward write head gaps.

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7. The apparatus of claim 5, wherein said plurality of read head gaps are unequally spaced apart from said plurality of forward write head gaps and said plurality of backward write head gaps.

8. The apparatus of claim 5, wherein a first one of said read head gaps is positioned in opposing relationship to both an upper portion of a first one of said forward write head gaps and a lower portion of a first one of said backward write head gaps; and

wherein a second one of said read head gaps is positioned in opposing relationship to both an upper portion of a second one of said forward write head gaps and a lower portion of a second one of said backward write head gaps.

9. The apparatus of claim 5, wherein an angle between a line tangent to a lower edge of a first one of said forward write head gaps and a lower edge of a first one of said read head gaps and a line perpendicular to said lower edge of said first one of said forward write head gaps is substantially
5 equal to an angle between a line tangent to a lower edge of first one of said backward write head gaps and a lower edge of said first one of read head gaps and a line perpendicular to said lower edge of said first one of said backward write head gaps

10 10. The apparatus of claim 5, wherein angles between lines tangent to said lower edges of said forward write head gaps and said lower edges of said read head gaps and lines perpendicular to said lower edges of said forward write head gaps are substantially equal to angles between lines
15 tangent to lower edges of said backward write head gaps and lower edges of said read head gaps and lines perpendicular to said lower edges of said backward write head gaps.

11. A tape recording apparatus, comprising:

20 (a) a base including means for transporting a magnetic recording tape along a longitudinal axis,

(b) a controller;

(c) a head mounting apparatus secured to a base and controlled by the controller; and,

25 (c) a read-after-write head positioned by the head mounting azimuth to confront the magnetic recording tape, said read-after-write head adapted for operation in azimuth and non-azimuth modes of operation by rotation to at least one positive azimuth angle for azimuth mode and to a null angle for non-azimuth mode.

30 12. The tape recorder apparatus of claim 11, wherein said read-after-write head is adapted for four-channel azimuth mode operation.

13. The tape recorder apparatus of claim 11, wherein said read-after-write head is adapted for two-channel non-azimuth mode operation.

1/5

TRACK NO.

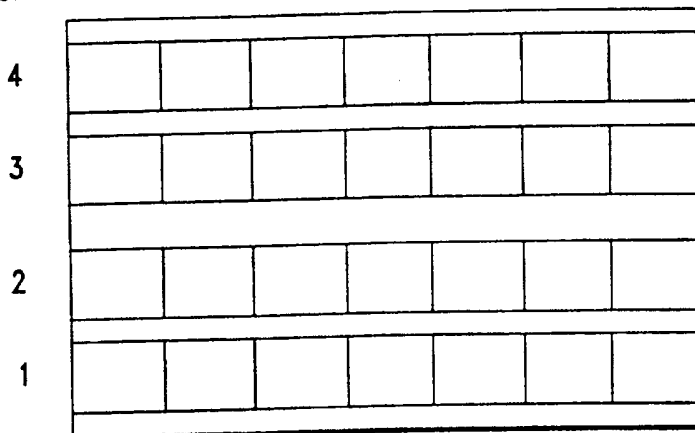


FIG. - 1A

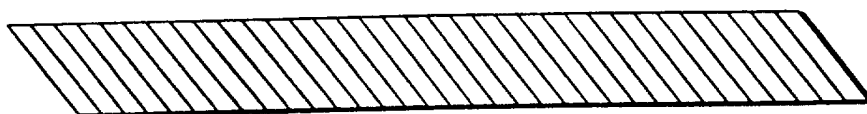


FIG. - 1B

TRACK NO.

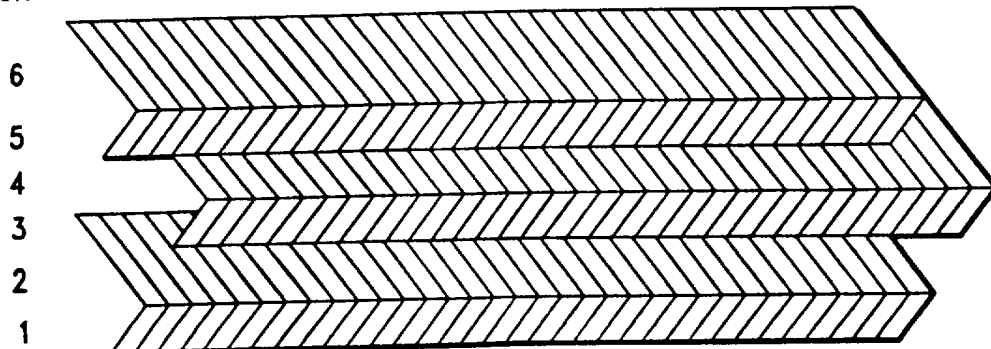


FIG. - 1C

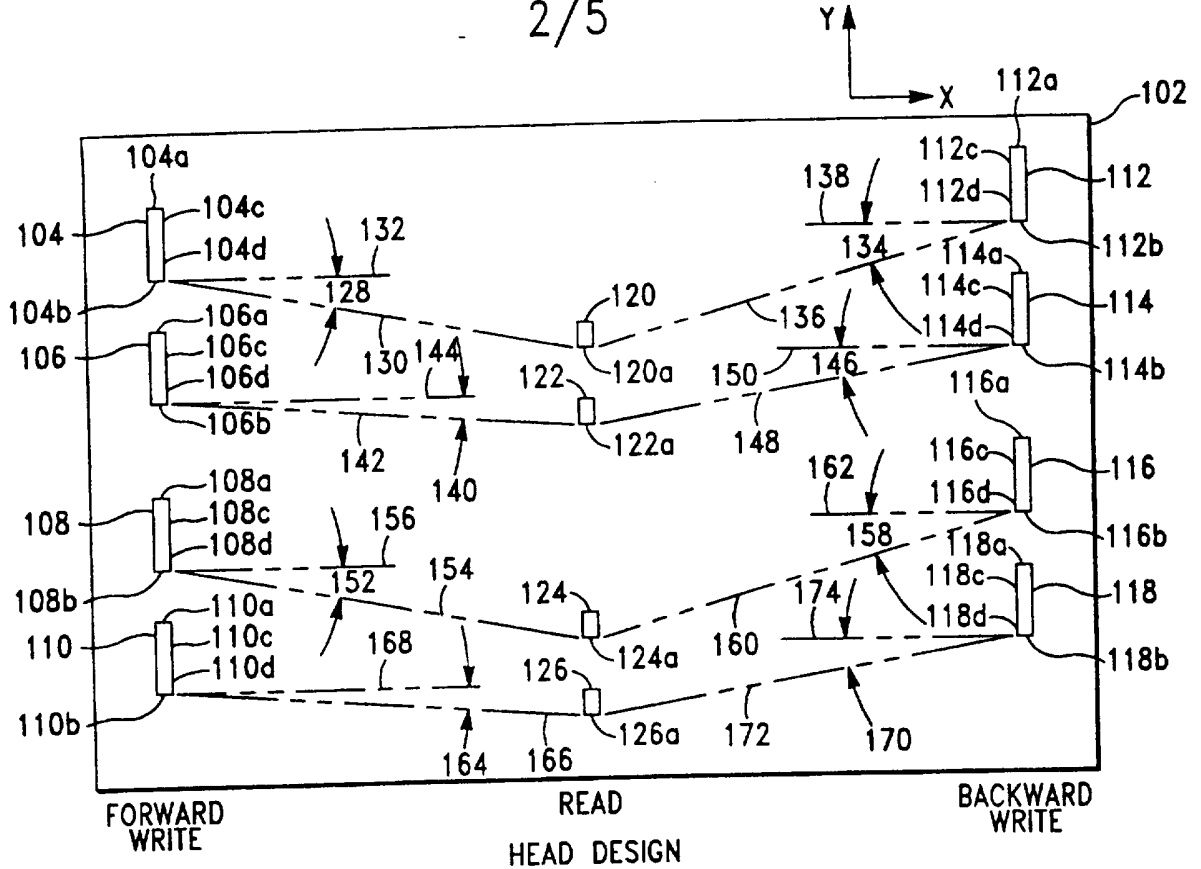


FIG. -2

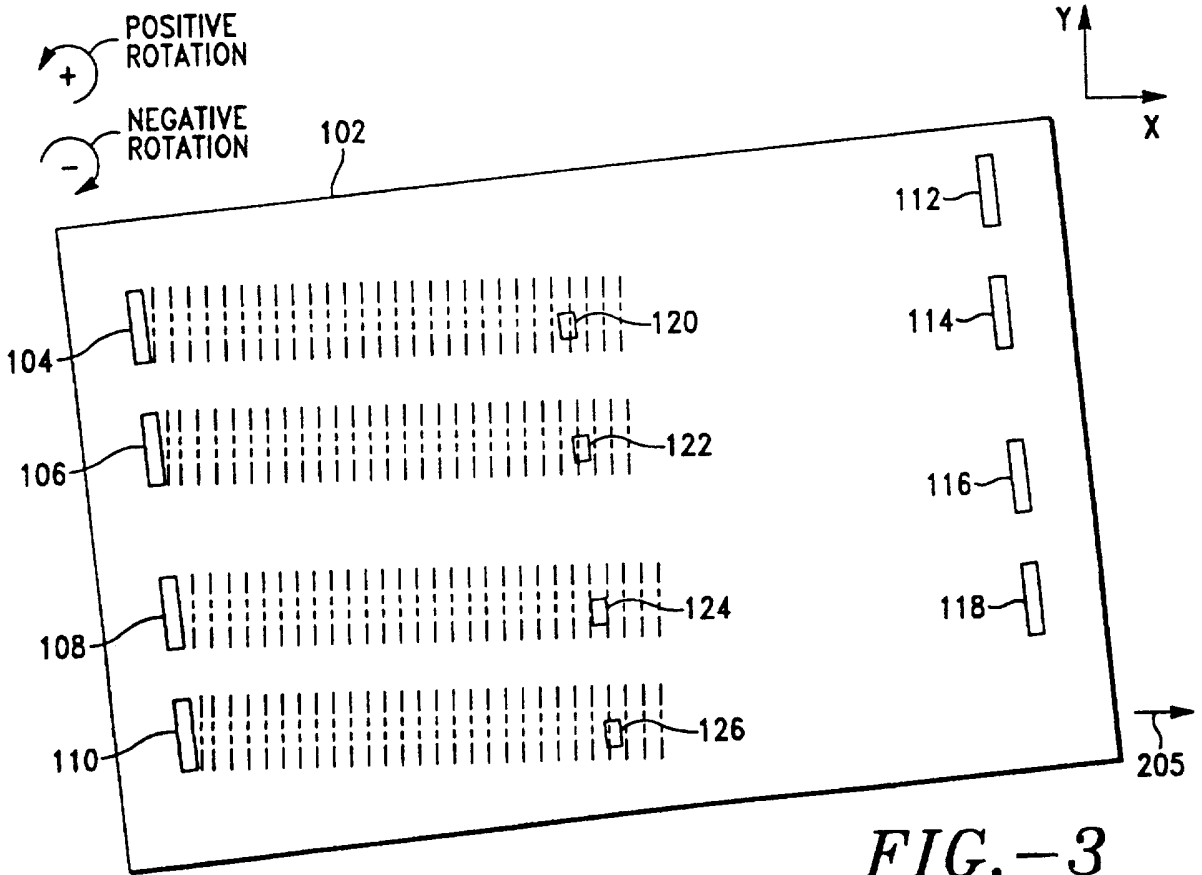


FIG. -3

3/5

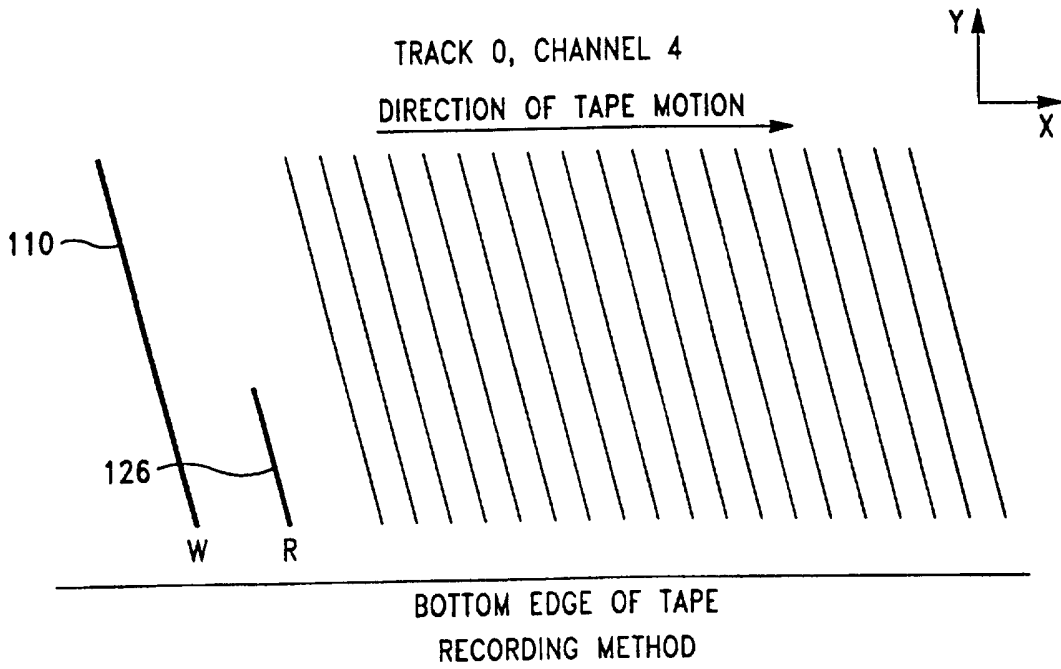


FIG.-4

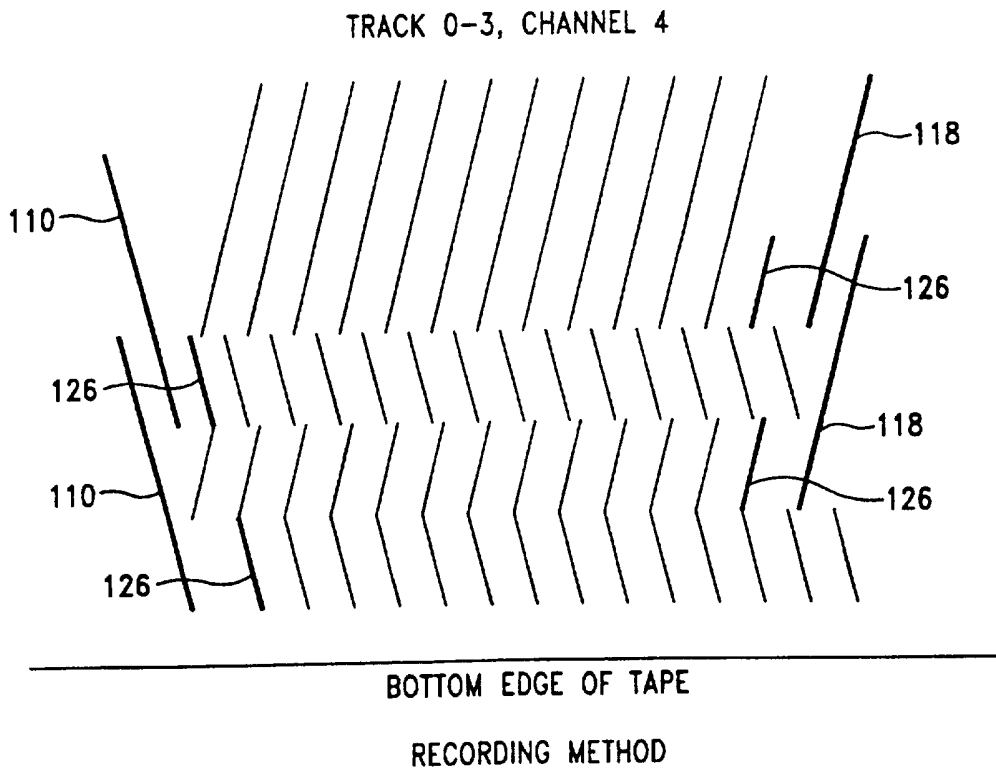


FIG.-5

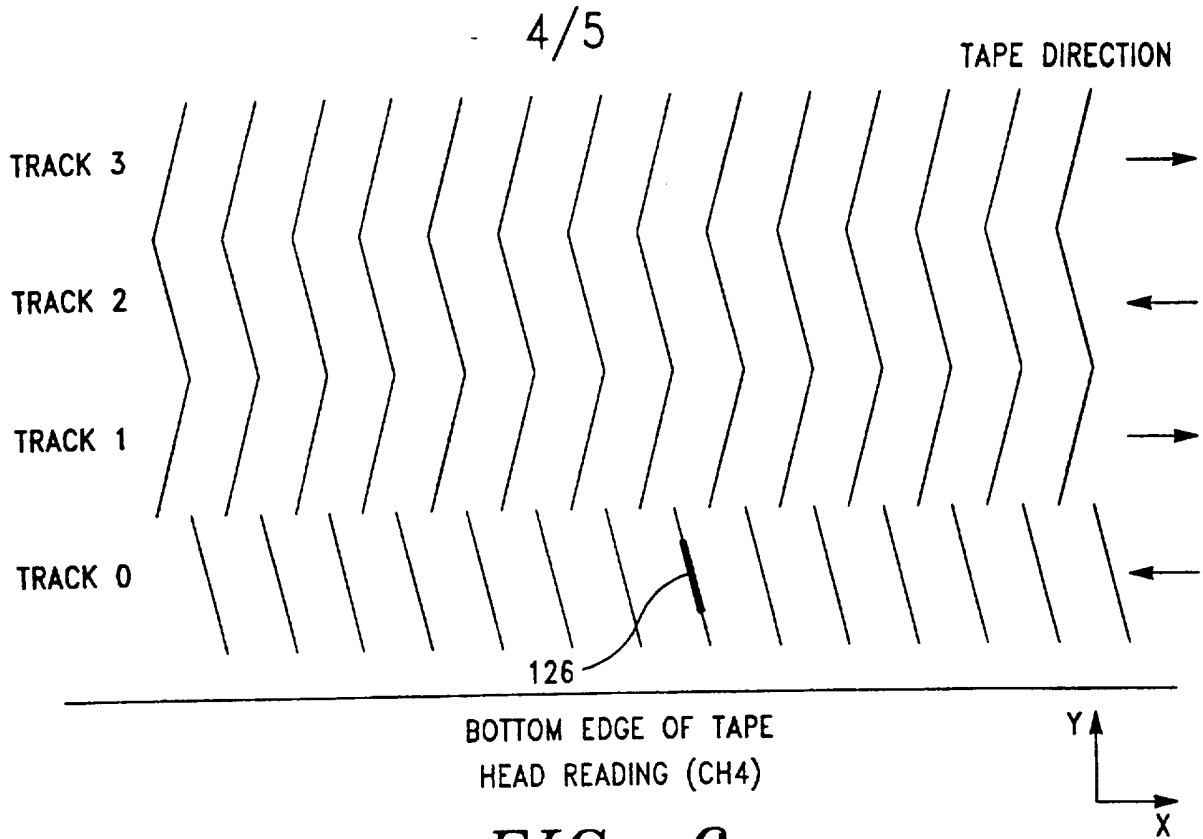
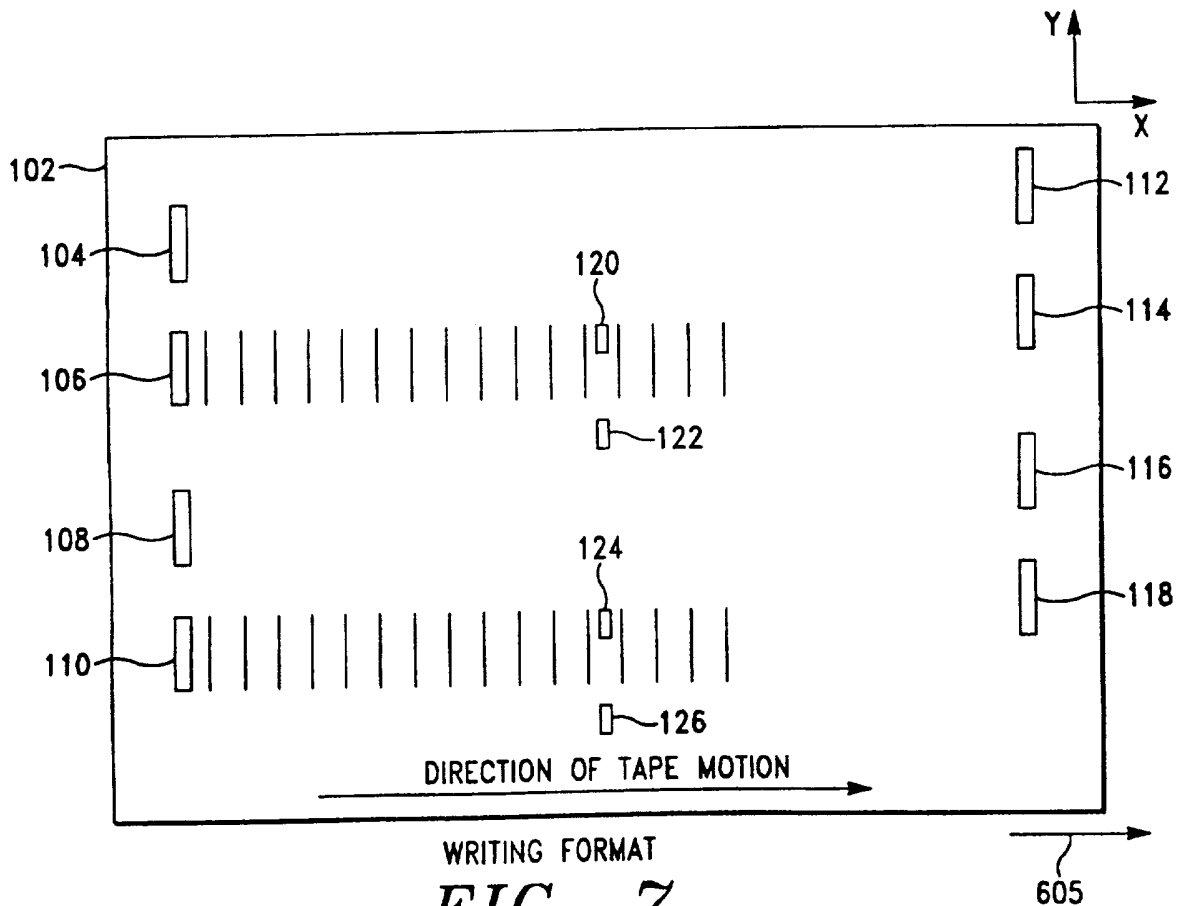
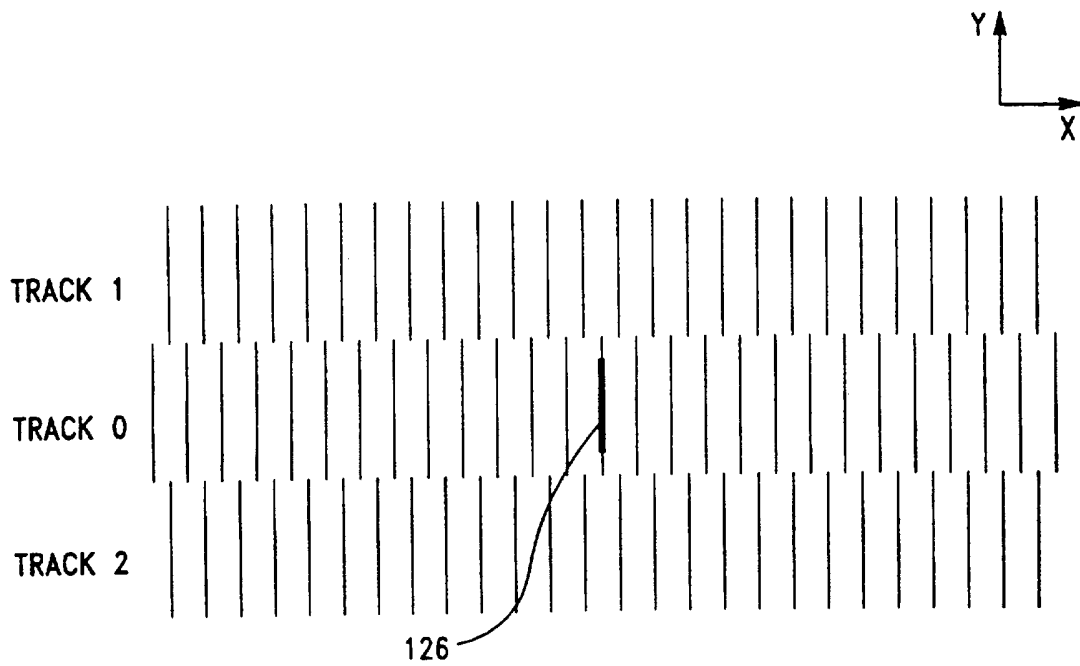


FIG.-6



WRITING FORMAT
FIG.-7

SUBSTITUTE SHEET (RULE 26)



READING FORMAT (CH1)

FIG.-8

INTERNATIONAL SEARCH REPORT

international application No.
PCT/US97/00344

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G11B 5/55, 5/265, 5/29
US CL :360/76, 121

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 360/76, 121, 78.02, 109

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y, P	US 5,523,904 A (SALIBA) 04 June 1996, Figures 2-5.	1-13
Y	US 5,371,638 A (SALIBA) 06 December 1994, Figures 2-7.	1-13
Y	US 5,307,217 A (SALIBA) 26 April 1994, Figures 2-7.	1-13
Y	4,539,615 A (ARAI et al.) 03 September 1985, Figures 16-18.	1-13
A	US 2,938,962 A (KONINS et al.) 31 MAY 1960	1-13

Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

06 MAY 1997

Date of mailing of the international search report

14 MAY 1997

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

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Telephone No. (703) 305-3498

INTERNATIONAL SEARCH REPORT

international application No.
PCT/US97/00344

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

international application No.
PCT/US97/00344

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING

This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I, claims 1-3 and 11-13, drawn to controlling the angle between head gaps and the record track, classified in class 360/76.

Group II, claims 4-10, drawn to the specific structure of a transducer, classified in class 360/110+.

The inventions listed as Groups I and II do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: The invention of Group II could be used to read-after-write on a magnetic tape storage medium that maintains a fixed angle between the head gaps and record tracks.