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(54) Title: DEVICE AND METHOD FOR INSPECTION OF POLYMERIC MATERIAL WITH FERROUS REINFORCEMENT

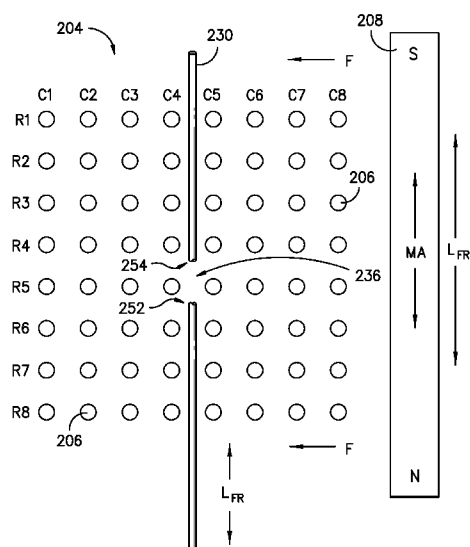


FIG. -6-

(57) Abstract: A device and method for inspection of an article constructed from a polymeric material having elongated, ferrous reinforcements such as e.g., a sheet, belt, tire, or other articles. An array of magnetic flux sensors provide multiple signals that can be compared to determine if one or more reinforcements are damaged. The array can be positioned at select locations along the article and can be used to detect damage without necessarily moving the article and inspection device relative to each other such that undesirable artifacts can be avoided or reduced.



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**DEVICE AND METHOD FOR INSPECTION
OF POLYMERIC MATERIAL WITH FERROUS REINFORCEMENT**

PRIORITY CLAIM

[0001] The present application claims priority to PCT/US15/43047, filed July 31, 2015 in the United States Receiving Office.

FIELD OF THE INVENTION

[0002] The subject matter of the present disclosure relates generally to the detection of damage to elongated, ferrous reinforcement of polymeric materials and articles constructed from such materials.

BACKGROUND OF THE INVENTION

[0003] Polymeric materials reinforced with ferrous material such as steel cables or cords are commonly used in the construction of tires, belts, and other articles of manufacture. By way of example, tissues, belts, or sheets constructed of rubber-based materials with ferrous reinforcements are commonly used in one or more layers that are joined together to manufacture a tire. One known tire construction uses a body ply having reinforcement elements that extend from bead portion to bead portion through opposing sidewall portions, and a crown portion of the tire. Sometimes referred to as the carcass ply or reinforcing ply, the body ply is typically anchored at the beads and maintains the overall shape of the tire as the tire is inflated and used. Multiple elongated reinforcement elements are arranged in a parallel manner within the body ply are usually oriented substantially along the radial direction (a direction orthogonal to the axis of rotation) of the tire. The reinforcement elements commonly include e.g., a ferrous metal.

[0004] Inspection of the elongated, ferrous reinforcements may be desirable during manufacture of an article or during its use. For example, in manufacturing a tire from reinforced sheets or layers, it may be useful to inspect the ferrous reinforcements during the manufacturing process. During use of the tire, these reinforcement elements (sometimes referred to as cords) may be damaged e.g., from impact with objects in the roadway, travel over curbs, and other damaging events. In some situations, the reinforcement elements may be completely broken as a result of such an event.

[0005] Whether during manufacture or use, inspection of the reinforcement elements for damage such as breaks may not be possible by visual inspection alone because the reinforcement elements are enclosed within polymeric material. For example, a visual inspection of the exterior of the tire may not reveal breaks in the ferrous reinforcements that are contained within the rubber materials used to construct the tire. A similar problem exists with certain components used to make the tire.

[0006] Commercial tires are commonly reused after a process referred to as retreading. With retreading, worn tread is removed from the tire and a new tread belt or tread section is installed onto the tire. Replacement of the tread is less expensive than replacing the whole tire and allows additional mileage to be obtained using the same tire carcass. This practice is common particularly with commercial tires for heavy trucks.

[0007] Before replacing the tread, however, it is advantageous to inspect the tire, including the reinforcement elements of the body ply, for damage or wear. In certain situations, inspection may reveal that replacement of the tire is required rather than retreading. Alternatively, repair of the tire may be required. As stated above, not all damage to interior elements such as e.g., the reinforcement elements of the body ply, are readily apparent from a visual inspection alone.

[0008] To operate properly, some inspection devices for ferrous-reinforced polymeric articles may require relative movement of the inspection device and the article being inspected. For example, some tire inspection devices may require the tire to be rotated past the inspection device in order to detect defects along the tire surface or hidden components such as the reinforcements. However, this may not be

desirable or practical in all applications. In certain instances, only a portion of the tire may need inspection or a machine for rotating the tire relative to the sensor may be available or affordable. Similarly, for a sheet of ferrous-reinforced material, inspection only at certain locations along the sheet may be all that is needed. With a tire, inspection may only be needed at certain locations of the tire such as e.g., locations where breaks in the reinforcements are suspected.

[0009] In addition, depending upon the type of sensors used, relative movement of the inspection device and the article being inspected can introduce noise or other undesirable artifacts. For example, rotation of the tire past the inspection device can cause vibrations or mechanical agitation that, in turn, causes the signals received from the sensor to be undecipherable or provide false indications of breaks in the hidden reinforcements.

[0010] Accordingly, a device and method for inspection of an article constructed of a polymeric material having ferrous reinforcement would be useful. Such a device and method that can be used to detect damage to such ferrous reinforcement at select locations on the article would also be useful. Such a device and method that can be used without necessarily rotating or moving the article relative the inspection device would also be beneficial.

SUMMARY OF THE INVENTION

[0011] The present invention provides a device and method for inspection of an article constructed from a polymeric material having elongated, ferrous reinforcements such as e.g., a sheet, belt, tire, or other articles. An array of magnetic flux sensors provide multiple signals that can be compared to determine if one or more reinforcements are damaged. The array can be positioned at select locations along the article and can be used to detect damage without necessarily moving the article and inspection device relative to each other such that undesirable artifacts can be avoided or reduced. Additional objects and advantages of the invention will be set forth in part in the following description, or may be apparent from the description, or may be learned through practice of the invention.

[0012] In one exemplary embodiment, the present invention provides an inspection device for inspecting a polymeric material that includes one or more elongated, ferrous reinforcements. The inspection device includes an inspection surface and a two-dimensional array of magnetic flux sensors positioned at the inspection surface that are configured for placing along a surface of the polymeric material. At least one magnet is positioned adjacent to the inspection surface with the inspection surface and the array of magnetic flux sensors located between at least a portion of the magnet and the polymeric material when the device is positioned for inspection of the polymeric material.

[0013] In another exemplary aspect, the present invention provides a method of inspecting a polymeric material that includes one or more elongated, ferrous reinforcements. The steps includes applying a magnetic field to the ferrous reinforcements so as to cause a change in magnetic flux polarity at a break in one or more of the ferrous reinforcements; positioning a two-dimensional array of magnetic flux sensors near the break; and detecting the change in magnetic flux polarity.

[0014] These and other features, aspects and advantages of the present invention will become better understood with reference to the following description and appended claims. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] A full and enabling disclosure of the present invention, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures, in which:

[0016] FIG. 1 provides a front view of an exemplary embodiment of an inspection device of the present invention.

[0017] FIG. 2 is partial, cross-sectional side view of the exemplary embodiment of FIG. 1 with partial cross-section taken along line 2-2 of FIG. 1.

[0018] FIG. 3 is a perspective, back view of the exemplary embodiment of FIG. 1.

[0019] FIG. 4 is another side view of the exemplary embodiment of FIG. 1.

[0020] FIG. 5 is a cross-sectional view of the exemplary embodiment of FIG. 1 taken along line 5-5 of FIG. 4.

[0021] FIG. 6 is a schematic view of an exemplary two-dimensional array of magnetic flux sensors inspecting a broken reinforcement.

[0022] FIG. 7 is a schematic view of the magnetic fields created by the presence of a magnet near an example of a damaged reinforcement.

[0023] FIGS. 8 and 9 are schematic views of sensor arrays as may be used in exemplary embodiments of an inspection device of the present invention.

[0024] FIG. 10 is a schematic representation of an exemplary processing system device as may be used with the present invention.

[0025] FIGS. 11, 12, and 13 are data plots as more fully described herein.

[0026] The use of the same or similar reference numerals in the figures denotes the same or similar features.

DETAILED DESCRIPTION

[0027] For purposes of describing the invention, reference now will be made in detail to embodiments of the invention, one or more examples of which are illustrated in the drawings. Each example is provided by way of explanation of the invention, not limitation of the invention. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope or spirit of the invention. For instance, features illustrated or described as part of one embodiment, can be used with another embodiment to yield a still further embodiment. Thus, it is intended that the present invention covers such modifications and variations as come within the scope of the appended claims and their equivalents.

[0028] FIGS. 1 through 5 are various views of an exemplary inspection device 100 of the present invention. Device 100 can be used to detect damage such as e.g., breaks in elongated, ferrous reinforcements in a variety of polymeric materials. For example, device 100 could be used on a sheet or tissue of rubber material that has one or more ferrous reinforcements arranged or extending along a direction of the material. Device 100 could be used to inspect a tire or other article of manufacture

constructed from such polymeric materials. For a tire, as previously described, certain layers of the tire such as the carcass may be constructed from rubber materials containing multiple elongated, ferrous reinforcements arranged in an adjacent and substantially parallel manner along a portion of the tire such as e.g., the sidewall. A similar construction may be used in other ferrous-reinforced, polymeric articles. Inspection device 100 can be used to detect breaks in the elongated, ferrous reinforcements.

[0029] Additionally, accuracy can be improved as relative movement between inspection device 100 and the tire or article is not required: Device 100 must only be placed adjacent to a select point on the tire or other article where inspection is desired. By moving the inspection device 100 to different places on the tire or other article, multiple locations may be inspected. However, movement for purposes of inspection at a particular location along the article is not required.

[0030] For this exemplary embodiment, device 100 includes an inspection surface 102 onto which a two-dimensional array 104 of magnetic flux sensors 106 has been positioned as shown. In this embodiment, magnetic flux sensors 106 are mounted on a circuit board 142 that is attached to a body 112 of device 100 using fasteners 144 as shown. Other constructions may be used as well. For example, sensors 106 could be mounted directly onto inspection surface 102, or circuit board 142 could be adhered or integrally formed with body 112.

[0031] Body 112 is formed from a series of stacked plates 112a, 112b, 112c, and 112d attached to each other. A recess 114 (FIGS. 2, 4, and 5) is formed in plates 112b and 112c. A plurality of magnets 108 are included in recess 114. More particularly, a first plurality of magnets 108b are located in recess 114b of plate 112b, and a second plurality of magnets 108c are located in recess 114c of plate 112c. Notably, the magnets 108 are positioned adjacent to inspection surface 102. The arrangement is such that, during use, array 104 of magnetic flux sensors 106 and inspection surface 102 will be between magnets 108 and an article to be inspected such as e.g., rubber sheet 132 with ferrous reinforcements 130 as shown in FIG. 3.

[0032] In other embodiments of the invention, body 112 may be formed as e.g., a single piece, a chambered housing, or other constructions as well. In addition, the

present invention does not require a plurality of magnets 108 as shown. Instead, only one magnet (i.e. at least one magnet) or a magnetic field producing device may be used provided an amount of magnetic flux sufficient to identify damage can be applied to the ferrous reinforcement(s) of the article to be inspected. Additionally, the magnet or device may be straight or shaped as needed depending upon e.g., the shape of the articles to be inspected. For the embodiment shown in FIG. 2, a wedge 110 constructed from a ferrous material is used to bridge or communicate magnetic flux between a first portion FP and second portion SP of magnets 108. A plurality of magnets 108 are used in order to provide for a non-linear shape for body 112. Again, however, other constructions may be used as well.

[0033] FIG. 3 illustrates the positioning of inspection device 100 onto an inspection surface 134 of a sheet 132 of polymeric material having multiple, ferrous reinforcements 130. For this exemplary embodiment of inspection device 100, several features are provided in order to facilitate application of a magnetic flux to one or more ferrous reinforcements 130 in order to detect breaks therein. By way of example, body 112 includes a recess 116 into which array 104 of sensors 106 is positioned. Such configuration can be conducive to the use of inspection device 100 for inspecting articles that are not flat e.g., tires. Recess 116 allows e.g., a closer positioning of array 104 and magnets 108 – particularly for non-planar surfaces such as e.g., a tire bead or tire shoulder.

[0034] Additionally, magnets 108 (or at least one magnet 108) extend along a magnet axis MA between a first end 126 having a north pole (N) polarity and a second end 128 having a south pole (S) polarity. Referring to FIGS. 1, 2 and 4, ends 126 and 128 extend past the outermost rows 122 and 124 of the sensor array 104 along a longitudinal direction L of body 112. More specifically, as shown in FIG. 2, the pair of outermost rows 122 and 124 of array 104 are separated from each other by a first distance D_1 . First end 126 and second end 128 of array 104 are separated from each other by a second distance D_2 that is greater than the first distance D_1 . This configuration for inspection device 100 assists in ensuring that sufficient magnetic flux from magnet 108 is able to flood the one or more ferrous reinforcements 130 in sheet 132 or some other article under inspection.

[0035] As shown in FIGS. 2 and 4, magnet axis MA follows the centerline of magnets 108 and, for this exemplary embodiment, forms an acute angle α that faces array 104. Along with recess 116, such construction further facilitates the inspection of articles having non-planar surface or shapes. However, in other embodiments of the invention, magnet axis MA may be linear and recess 116 can be eliminated. The value used for angle α and the depth of recess 116 along transverse direction T can vary and will depend upon the shapes of the articles for which inspection is needed as will be understood by one of ordinary skill in the art using the teachings disclosed herein.

[0036] Referring to FIG. 4, magnet axis MA is also separated from the two-dimensional array 104 of sensors 106 by a distance D_3 . Due to angle α and recess 116, such distance D_3 varies depending upon the location along magnet axis MA at which such distance is determined. Regardless, depending upon the sensitivity of sensors 106, angle α and the distance D_3 between magnets 108 relative to the array 104 of sensors 106 may need adjustment to prevent saturation of sensor 106 by the magnetic flux provided by magnets 108. For example, if sensors 106 have a sensitivity range between a certain minimum and maximum level of magnetic flux (measured in e.g., units of Gauss), placing magnets 108 too close or too distant from array 104 of sensors 106 can preclude proper operation and detection. As will be readily understood using the teachings disclosed herein, the amount of separation or distance D_3 needed will depend upon e.g., the relative strength of magnets 108 and the sensitivity range of sensors 106.

[0037] For this exemplary embodiment, sensors 106 are constructed as Hall effect sensors. As is well known, Hall effect sensors can detect magnetic flux and provide a signal indicative of the amount of magnetic flux. For example, Hall effect sensors can provide a voltage output that increases as the strength of the magnetic field increases in a South polarity (or deflects from a North polarity) and decreases as the strength of the magnetic field increases in a North Polarity (or deflects from a South polarity).

[0038] FIG. 6 provides a schematic representation of a two-dimensional array 204 of magnetic flux sensors 206 as may be used with exemplary embodiments (such as device 100) of an inspection device of the present invention. For this embodiment,

two-dimensional array 204 is an eight by eight array that includes 64 magnetic flux sensors 206 arranged along eight rows (R1, R2, R3, R4, R5, R6, R7, and R8) and eight columns (C1, C2, C3, C4, C5, C6, C7, and C8).

[0039] As shown, for this exemplary embodiment, the rows and columns are linear and are orthogonal to one another. However, the present invention is not limited to an eight by eight array and other arrays with a different number of sensors and an unequal number of columns and rows may be used as well. For example, a three by three array 304 (FIG. 8), two by three array 404 (FIG. 9) and arrays of other configurations may be used as well. Additionally, arrays where the sensors are not linearly arranged along orthogonal rows and columns may also be used.

[0040] Continuing with FIGS. 6 and 7, in one exemplary method of the present invention, a magnet such as e.g., magnet 208 (or multiple magnets or another magnetic device) is used to apply a magnetic field F to one or more ferrous reinforcements 230. Magnet 208 has a North Pole N and a South Pole S. By way of additional example, inspection device 100 with magnets 108 could be used to apply magnetic field F . Such magnetic field F will be transmitted to one or more ferrous reinforcements such as ferrous reinforcement 230. Preferably, the magnet axis MA extends more or less parallel to the longitudinal axis L_{FR} of the one or more ferrous reinforcements 230 to be inspected.

[0041] Because magnet 208 is positioned to apply a magnetic field F to reinforcement 230, if ferrous reinforcement 230 has a break 236, plumes 248 and 250 (FIG. 7) of opposing magnetic flux polarity will be generated about the ends 252 and 254 created by break 236. Along the length (or longitudinal axis L_{FR}) of ferrous reinforcement 230 this creates a change in magnetic flux polarity (from North to South, or South to North) in the vicinity of break 236. The detection of the change in the polarity of the magnetic flux or magnetic flux intensity can be used to identify and locate break 236 even though ferrous reinforcement 230 is otherwise hidden within a polymeric material.

[0042] In order to detect break 236, the two-dimensional array 204 of magnetic flux sensors 206 is also placed or positioned near break 236 to detect magnetic flux on both sides of the break with different polarities. The location of break 236 may not be

known beforehand. Thus, the positioning of magnetic flux sensors such as found in array 104 or array 204 may be part of an inspection process where the inspection device (e.g., device 100) is repeatedly positioned at multiple locations along a ferrous-reinforced, polymeric material in order to inspect for breaks.

[0043] During inspection, each sensor 206 provides a signal. For example, such signal may be a voltage output that varies based on the magnetic flux intensity of the field in which it is placed. For example and for purposes of convention, in the present disclosure, assume magnetic flux sensors are used that provide a signal that increases in voltage as the magnetic flux intensity changes from a North polarity to a South polarity with the magnitude of the increase depending upon e.g., the intensity of the field of magnetic flux. Conversely, the signal decreases as the magnetic flux intensity changes from a South polarity to a North polarity. By comparing the signals of at least two adjacent sensors in the array or comparing the signals of at least two adjacent rows or columns of sensors, a change in magnetic flux polarity can be detected that is indicative of at least one break 236 in one or more ferrous reinforcements 230.

[0044] FIG. 10 provides a schematic example of a detection system that could be employed with inspection device 100. Array 104 of sensors 106 provides multiple signals S_i to at least one processing device 138. In turn, device 138 compares these signals to determine if a break has been detected as will be further described. One or more outputs O_i can be provided to e.g., a display device 140 or other indicator 140 (visual or audible) to indicate e.g., whether a break has been detected, where the break is located, or both.

[0045] FIGS. 11, 12, and 13 provide plots of data from a sensor array of an inspection device used to inspect a sheet of polymeric material having ferrous reinforcements. The inspection device had a construction similar to device 100 and included an array of 64 sensors arranged in an eight by eight array 204 as depicted schematically in FIG. 6. The magnetic flux sensors used for testing were Hall effect sensors, model number A1395SEHLT-T, manufactured by Allegro Microsystems, Inc. of 115 Northeast Cutoff, Worcester, MA 01606.

[0046] During testing, the inspection device was placed against a surface of a sheet of polymeric material in a manner similar to the positioning of inspection device 100 on surface 132 as shown in FIG. 3 and at a location where a known break in a ferrous reinforcement (such as e.g., break 236) was located. Each sensor 206 provided a signal in the form of a voltage output indicative of the level of magnetic flux intensity detected as previously described.

[0047] FIG. 11 provides a 3-dimensional plot of signal output received from an array 204 of sensors 206. R1 through R8 represents the eight sensor rows while C1 through C8 represents the eight sensor columns. By way of example, each intersection (four of which are labeled A, B, C, and D) represents the output of one sensor 206 - each of which is uniquely located along the intersection of one row and one column. The orientation of the array 204 relative to the ferrous reinforcement 236 was such that columns C1 through C8 were parallel to longitudinal axis L_{FR} and rows R1 through R8 were orthogonal to longitudinal axis L_{FR} as noted on FIG. 11. Of course, the nomenclature of rows and columns is arbitrary and array 204 could also be positioned at an angle of ± 90 degrees from what is shown. Notably, a peak occurs at intersection C and a reverse peak occurs at intersection D, which represents a change in flux polarity that is in turn indicative of a break in ferrous reinforcement 236 that has been subjected to magnetic field F.

[0048] FIG. 12 is a two-dimensional plot of the same data from array 204 as shown in FIG. 11. The output of each sensor 206 by columns in array 204 is shown. The x-axis of the plot in FIG. 12 is labeled "Parallel Columns" because as shown in FIG. 6, the inspection device with array 204 was positioned knowing that columns C1 through C8 were parallel to the longitudinal direction of axis L_{FR} ferrous reinforcement 230. During inspection of an article of manufacture, the general longitudinal direction the ferrous reinforcements inspected would be known.

[0049] At column R2, there are eight plot lines with each line representing the output of each sensor 206 in column R2. As shown in the plot, a peak occurs at points C and D. In addition, a change in direction of the slope of the plot occurs at points C and D. At point D, the slope changes from a negative slope M1 to a positive slope M2, while at point C the slope changes from a positive slope M2 to a negative slope

M3. The pair of changes in the direction of the slope between sensor columns parallel to longitudinal direction L_{FR} indicates that a change in the polarity of the magnetic flux field has been detected. In turn, this change indicates a break in the ferrous reinforcement located between row R4 and row R5 as shown in FIG. 6. By way of example, if processor 138 receives signals S_i from array 204 indicating at least two changes (e.g., either a) from increasing to decreasing to increasing or b) from decreasing to increasing to decreasing) in the magnitude of the signals between sensors 206 in different rows, then a break in reinforcement 230 is indicated.

[0050] FIG. 13 is a two-dimensional plot of the same data from array 204 as shown in FIG. 11. The output of each sensor 206 by rows in array 204 is shown. The x-axis of the plot in FIG. 13 is labeled “Orthogonal Rows” because as shown in FIG. 6, the inspection device with array 204 was positioned knowing that rows R1 through R8 were orthogonal to the longitudinal direction of axis L_{FR} ferrous reinforcement 230

[0051] For example, at C3, there are eight plot lines with each line representing the output of each sensor 206 in row R3. As shown in the plot, a peak occurs point C and a peak occurs at point D – albeit in an opposing manner. In addition, a change in direction of the slope of the plots occurs at both points C and D. At point C, the slope changes from a positive slope S1 to a negative slope S2 while at point D the slope changes from a negative slope S3 to a positive slope S4.

[0052] Because rows R1 through R8 or oriented orthogonal to longitudinal direction L_{FR} , the pair of opposing peaks C and D within a span of at least three sensors (here C4, C5, and C6) indicates that a change in the polarity of the magnetic flux field has been detected and is located between column 4 and column 6. Accordingly, a break in ferrous reinforcement 230 is located between column 4 and column 6 as shown in FIG. 6. By way of example, if processor 138 receives signals S_i from array 204 indicating at least 2 sets of row data have waveforms characterized by opposing peaks, then damage in reinforcement 230 is indicated. In this example the line formed by the R5 data set has local peak (maximum) C at the intersection of opposing slopes S1 and S2. Data set R4 has local peak (minimum) D at the intersection of slopes S3 and S4.

[0053] While the present subject matter has been described in detail with respect to specific exemplary embodiments and methods thereof, it will be appreciated that those skilled in the art, upon attaining an understanding of the foregoing may readily produce alterations to, variations of, and equivalents to such embodiments. Accordingly, the scope of the present disclosure is by way of example rather than by way of limitation, and the subject disclosure does not preclude inclusion of such modifications, variations and/or additions to the present subject matter as would be readily apparent to one of ordinary skill in the art using the teachings disclosed herein.

WHAT IS CLAIMED IS:

1. An inspection device for inspecting a polymeric material that includes one or more elongated, ferrous reinforcements, the inspection device comprising:
 - an inspection surface;
 - a two-dimensional array of magnetic flux sensors positioned at the inspection
 - 5 surface and configured for placing along a surface of the polymeric material; and
 - at least one magnet positioned adjacent to the inspection surface with the inspection surface and the array of magnetic flux sensors located between at least a portion of the magnet and the polymeric material when the device is positioned for inspection of the rubber material.
2. The inspection device of claim 1, wherein the array of magnetic flux sensors has rows on opposing sides of the array, and wherein the at least one magnet has a first end comprising a north pole and a second end comprising a south pole, wherein the first end and second end extend beyond the rows of the two-dimensional array.
3. The inspection device of claim 1, wherein the two-dimensional array of magnetic flux sensors comprises a pair of rows on opposing sides of the array that are separated by a first distance, and wherein the at least one magnet has a first end comprising a north pole that is separated by a second distance from a second end comprising a south pole, and wherein the second distance is greater than the first distance.
4. The inspection device of claim 1, wherein the at least one magnet is separated from the two-dimensional array of magnetic flux sensors by a distance that prevents saturation of the two-dimensional array of magnetic flux sensors with magnetic flux.
5. The inspection device of claim 1, further comprising a body on which the array of magnetic flux sensors and the at least one magnet are supported.

6. The inspection device of claim 1, wherein the at least one magnet comprises a plurality of magnets arranged along a magnet axis extending between the first and the second end.
7. The inspection device of claim 6, wherein the magnet axis forms an acute angle facing the two-dimensional array of magnetic flux sensors.
8. The inspection device of claim 1, wherein the magnetic flux sensors comprise Hall effect sensors.
9. The inspection device of claim 1, wherein the two-dimensional array of magnetic flux sensors comprises rows and columns of magnetic flux sensors, with the rows and columns in an orthogonal relationship to each other.
10. The inspection device of claim 1, wherein the two-dimensional array comprises an equal number of rows and columns.
11. The inspection device of claim 1, wherein the two-dimensional array of magnetic flux sensors comprises two rows and three columns containing at least six magnetic flux sensors.
12. The inspection device of claim 1, further comprising at least one processing device configured for:
 - receiving signals from the two-dimensional array of magnetic flux sensors;
 - and
- 5 using the signals to determine if a change of magnetic flux polarity is detected that is indicative of at least one break in the one or more ferrous reinforcements of the rubber material.
13. The inspection device of claim 1, wherein the step of using comprises comparing signals from at least two different magnetic flux sensors in the array to determine if a change of magnetic flux polarity is detected.
14. A method of inspecting a polymeric material that includes one or more elongated, ferrous reinforcements, the steps comprising:

applying a magnetic field to the ferrous reinforcements so as to cause a change in magnetic flux polarity at a break in one or more of the ferrous reinforcements;

- 5 positioning a two-dimensional array of magnetic flux sensors near the break;
and
detecting the change in magnetic flux polarity.

15. The method of inspecting a rubber material as in claim 14, wherein the step of detecting comprises:

receiving signals from the two-dimensional array of magnetic flux sensors;
and

- 5 comparing signals to determine if a change in magnetic flux polarity is indicated.

16. The method of inspecting a rubber material as in claim 14, wherein the two dimensional array of magnetic flux sensors are arranged along rows and columns in an orthogonal relationship to each other.

17. The method of inspecting a rubber material as in claim 16, wherein the one or more elongated, ferrous reinforcements extend along a longitudinal direction, and wherein the step of positioning comprises placing the two dimensional array such that either the rows or the columns are substantially orthogonal to the longitudinal
5 direction of the one or more ferrous reinforcements.

18. The method of inspecting a rubber material as in claim 17, wherein the step of detecting comprises:

receiving signals from the two-dimensional array of magnetic flux sensors;
and

- 5 comparing signals from either the rows or the columns that are orthogonal to the longitudinal direction to determine if a change in magnetic flux polarity is indicated.

19. The method of inspecting a rubber material as in claim 17, wherein the step of comparing signals comprises determining if the signals are both increasing and decreasing between either the rows or the columns.

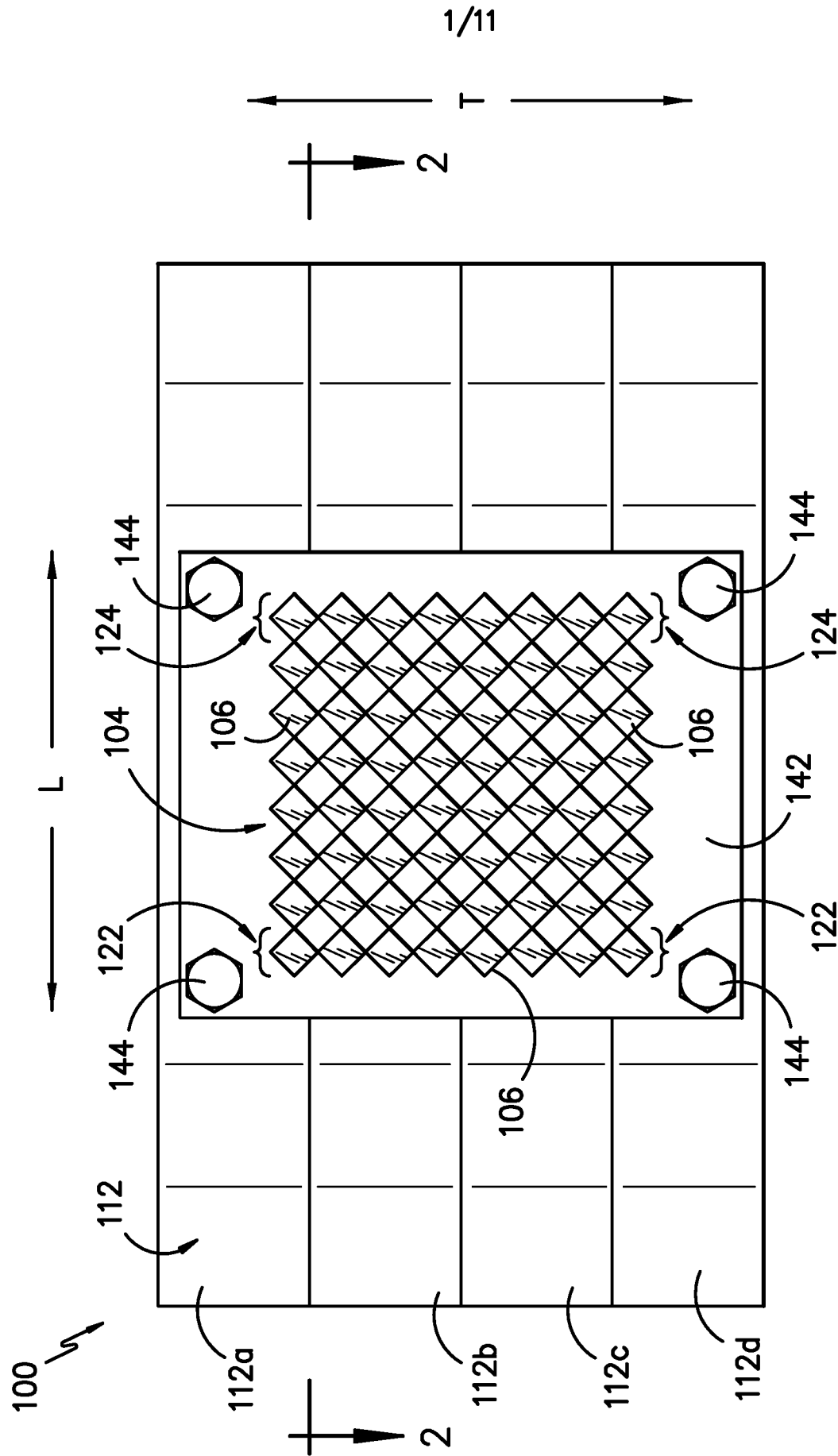


FIG. -1-

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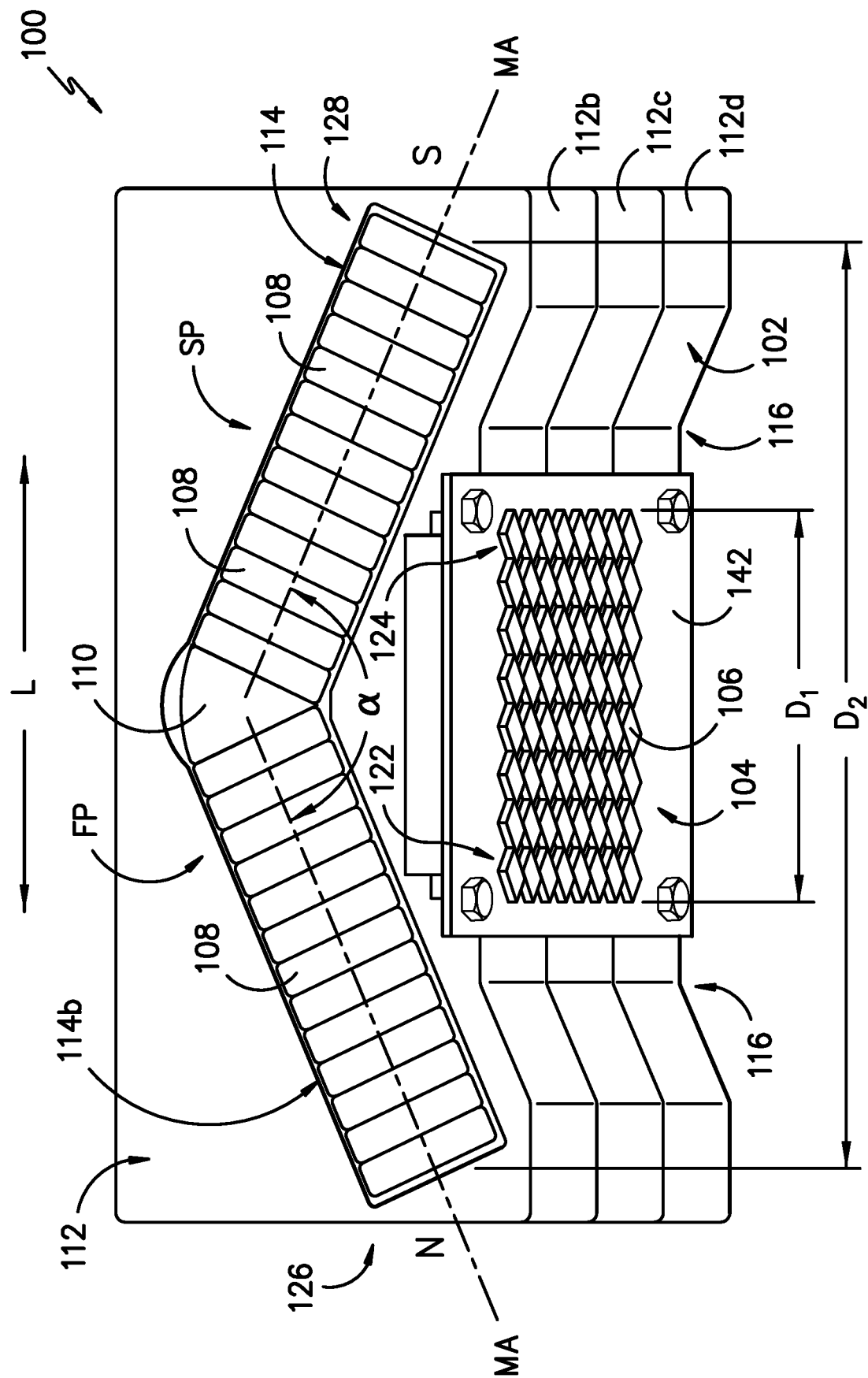


FIG. -2-

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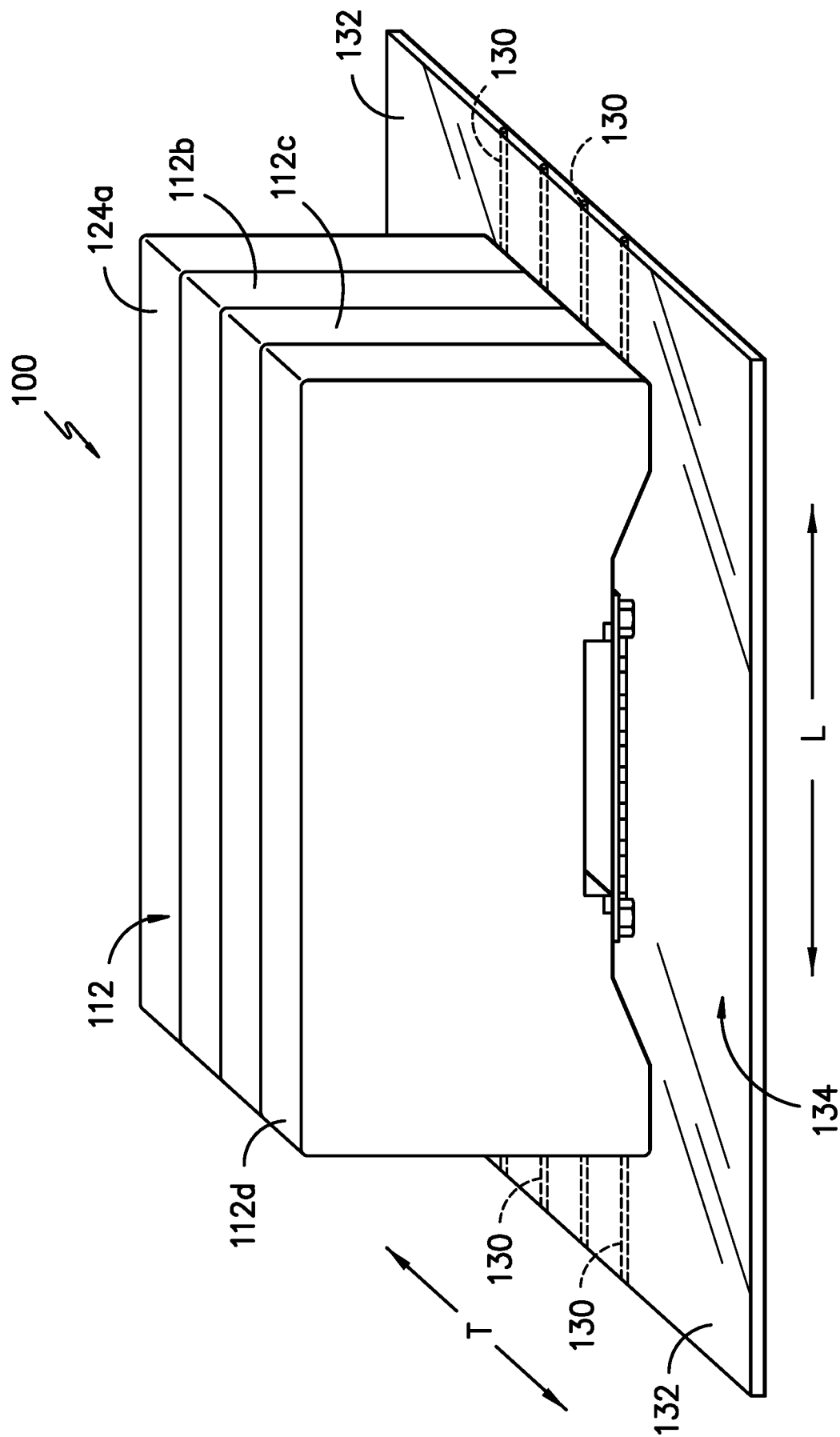


FIG. -3-

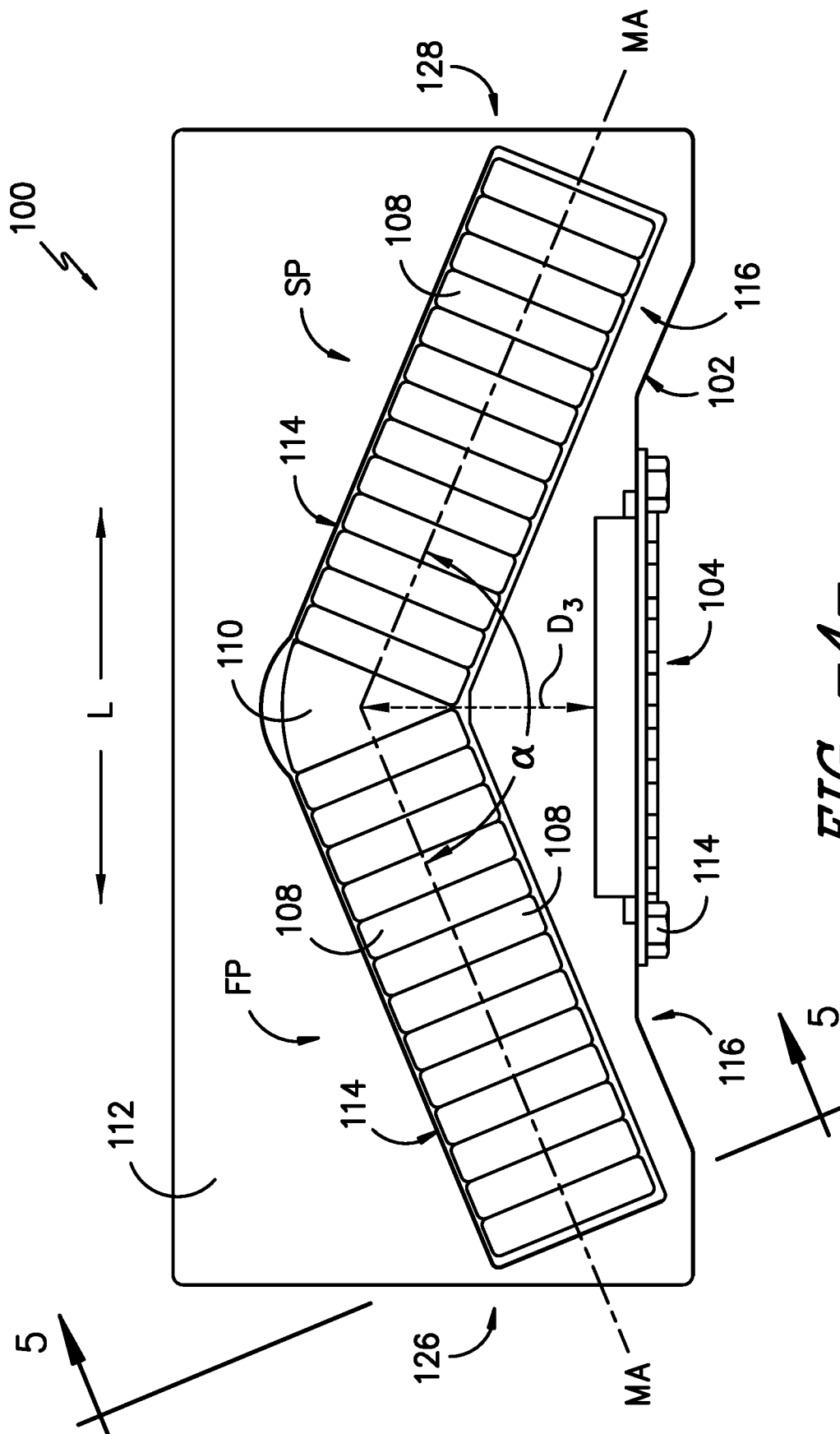
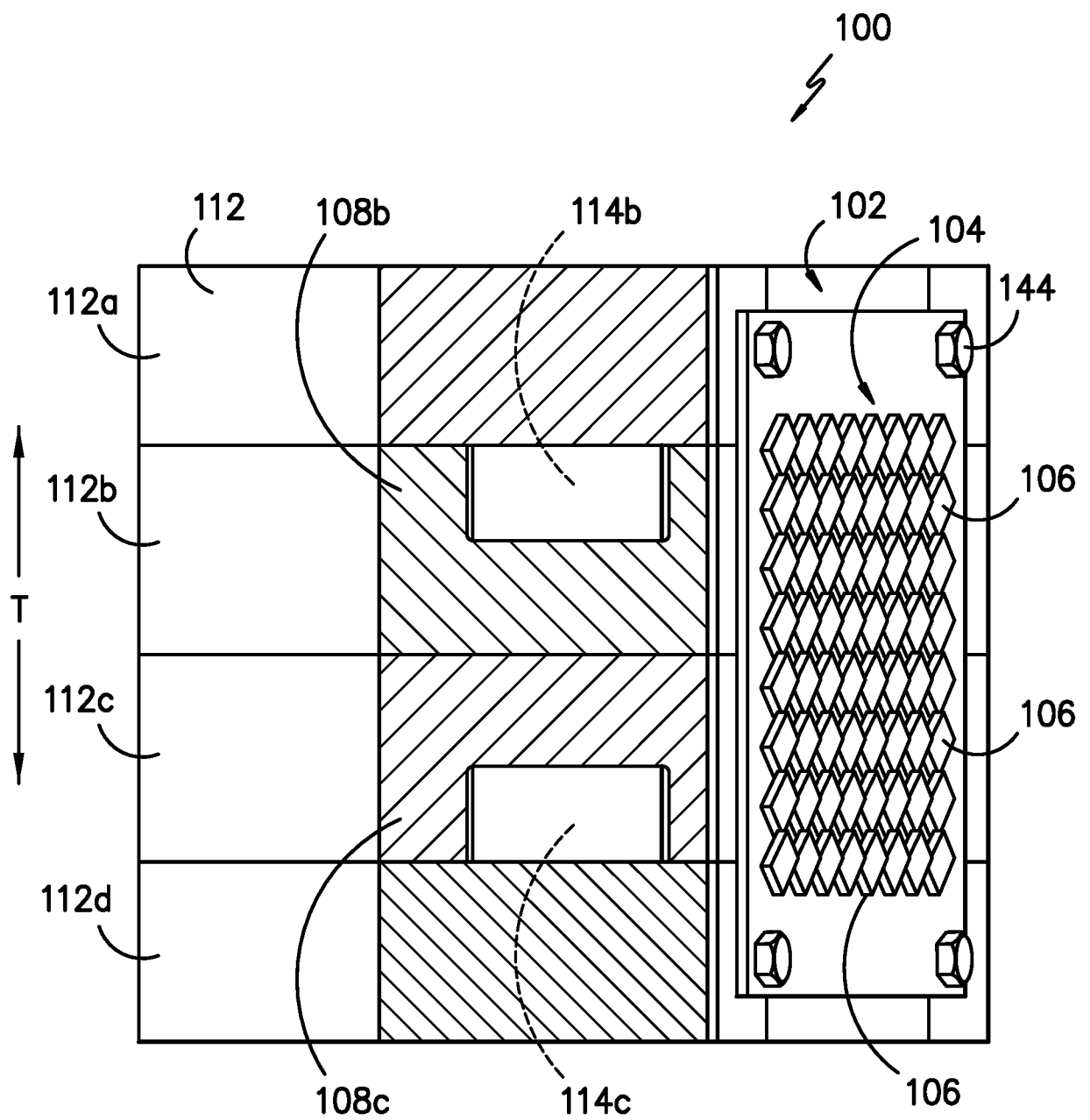


FIG. -4-

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*FIG. -5-*

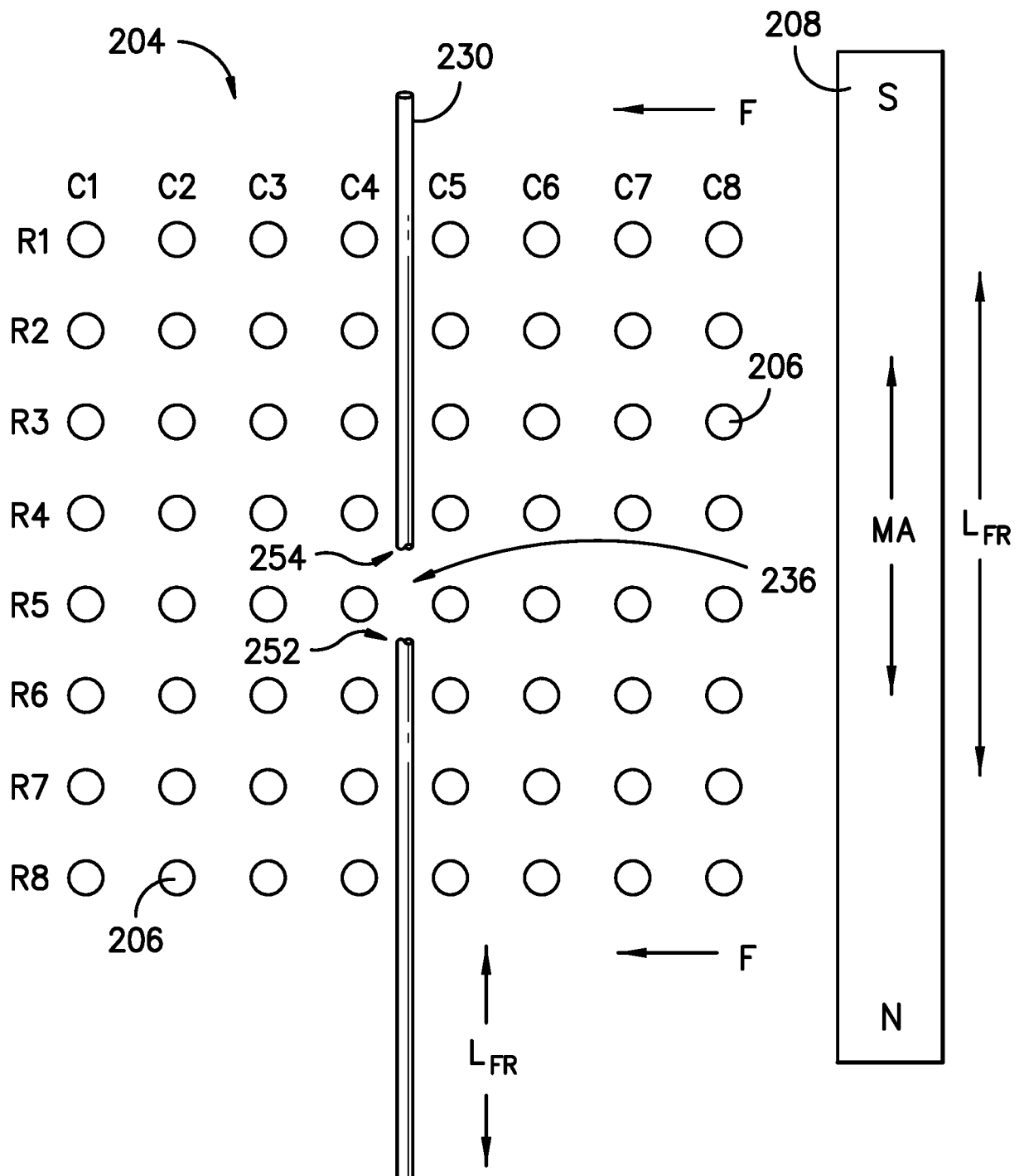
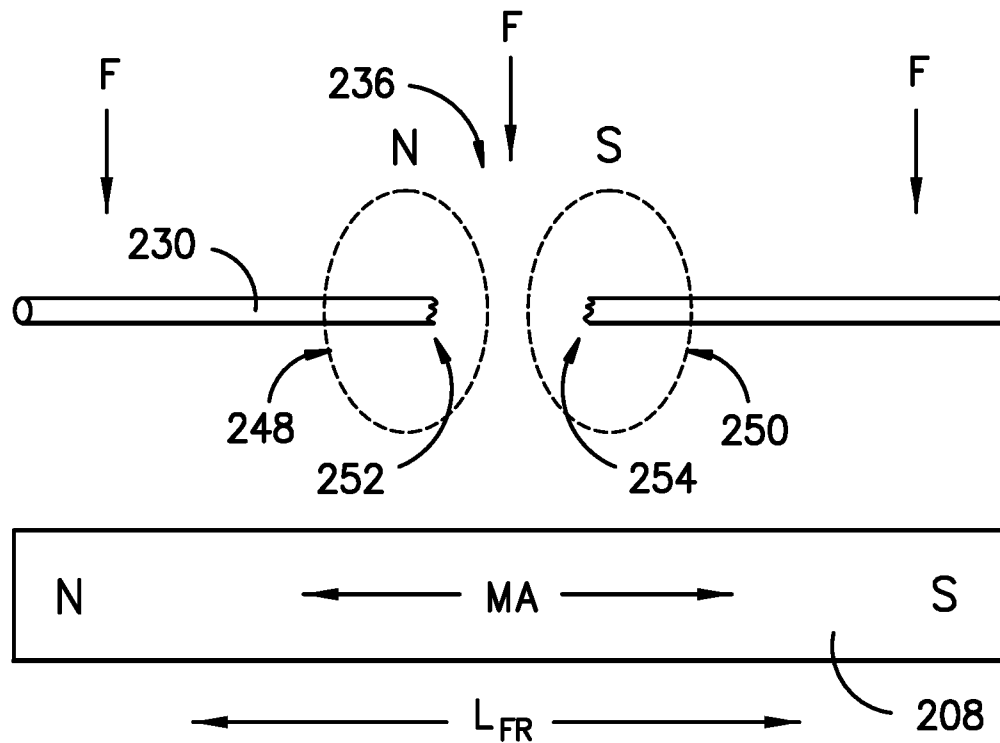
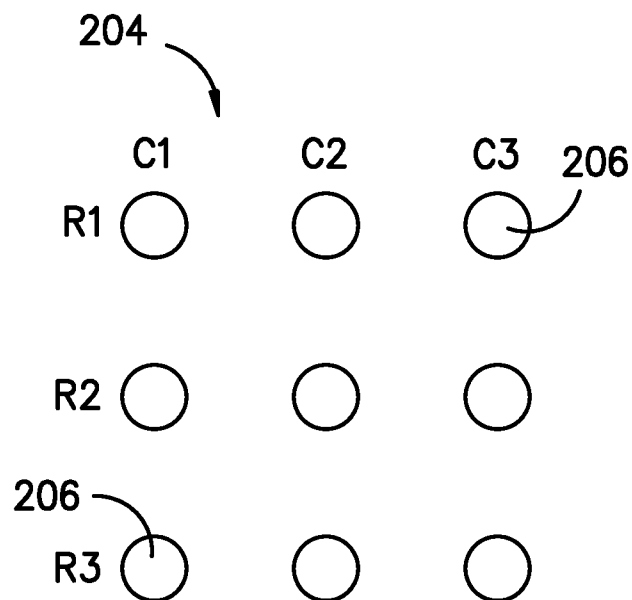


FIG. -6-

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*FIG. -7-**FIG. -8-*

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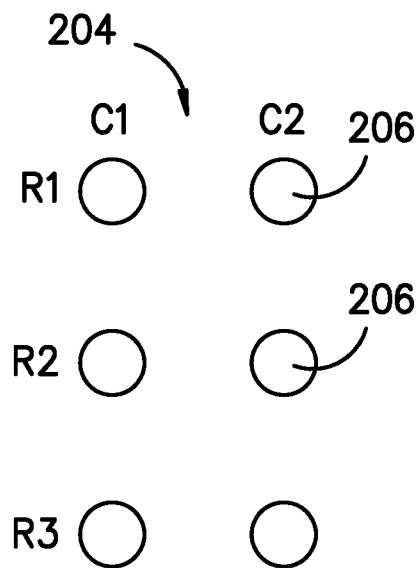


FIG. -9-

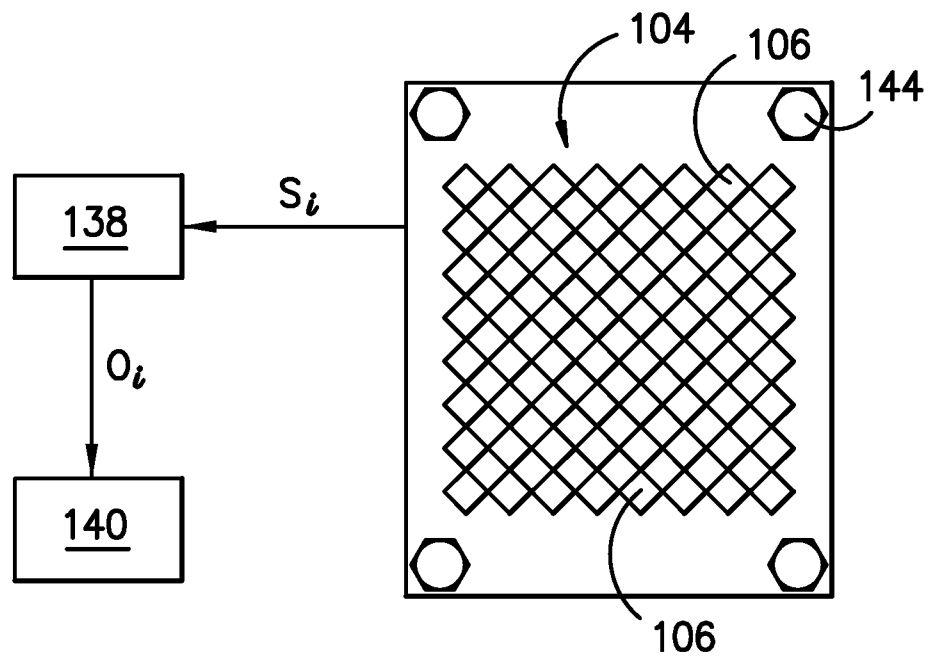


FIG. -10-

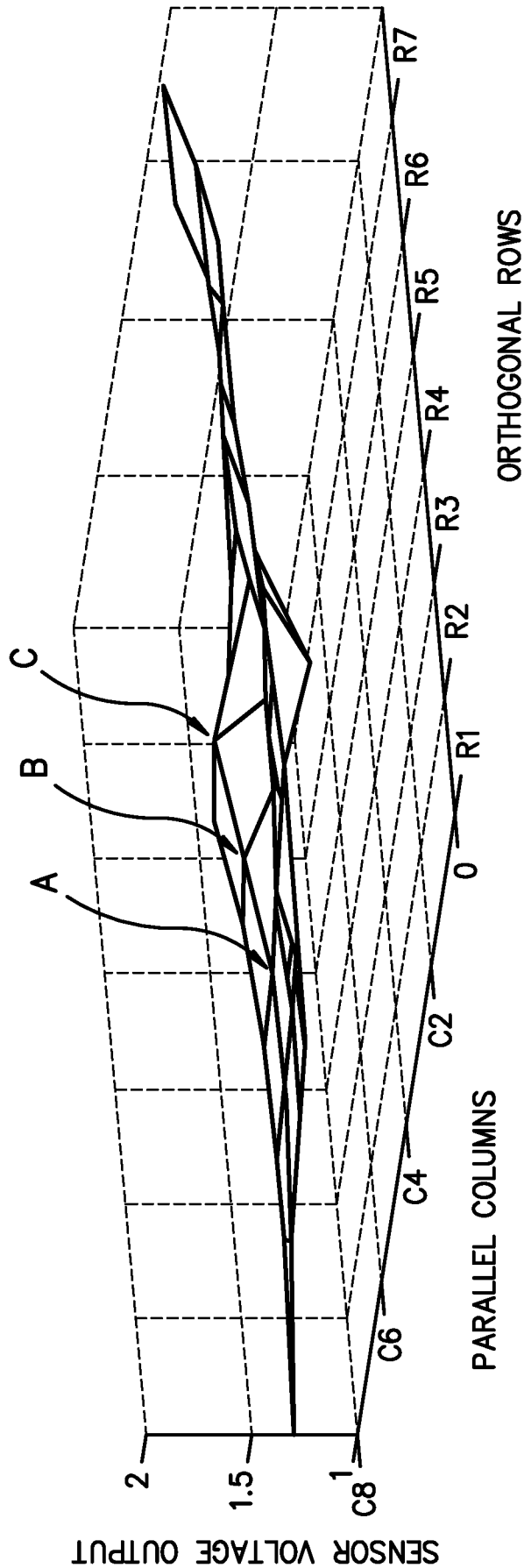


FIG. -11-

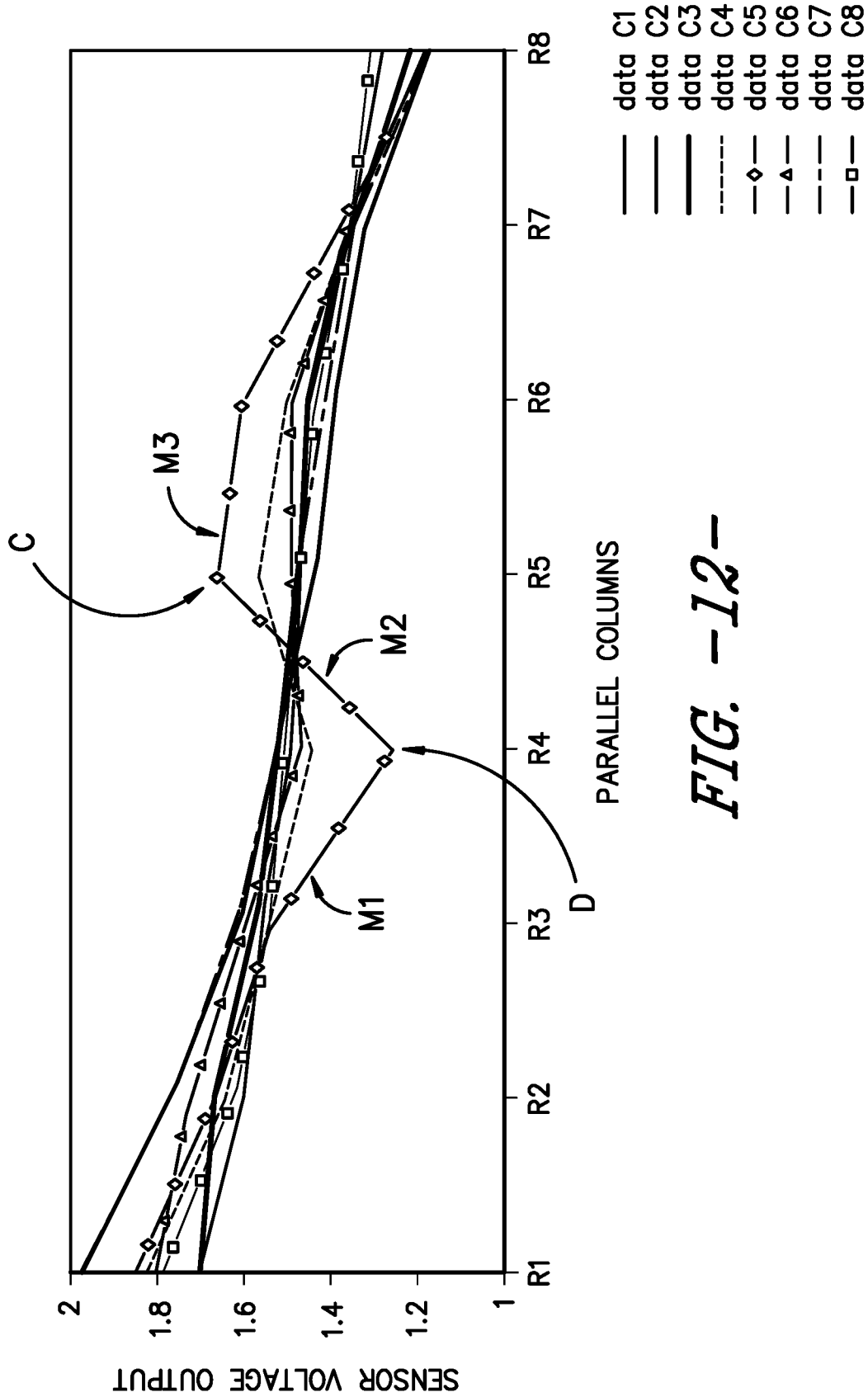
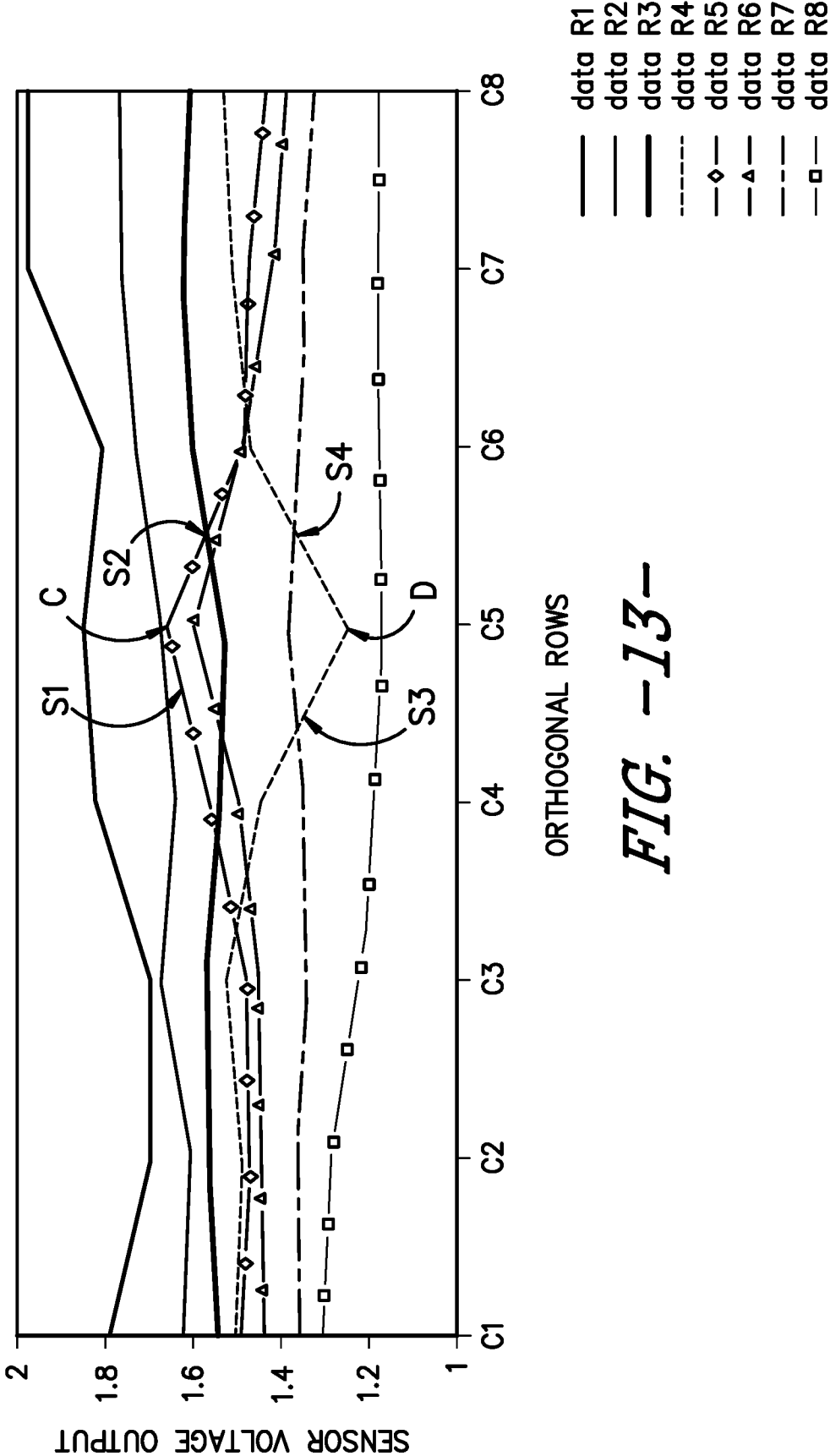


FIG. -12-



ORTHOGONAL ROWS

FIG. -13-

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/042186

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01N 27/82; G01M 5/00; G01M 17/02; G01N 33/44; G01R 33/02 (2016.01)

CPC - G01N 27/82; G01M 5/0033; G01M 5/0091; G01M 17/02; G01N 33/44; G01R 33/0017 (2016.08)

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)

IPC - G01M 5/00; G01M 17/02; G01N 27/82; G01N 33/44; G01R 33/02

CPC - G01M 5/0033; G01M 5/0091; G01M 17/02; G01N 27/82; G01N 33/44; G01R 33/0017; G01R 33/02; G01R 33/1215

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

USPC - 324/209; 324/216; 324/219; 324/227; 324/259; 324/260; 324/261; 324/207.23; 324/207.22; 324/207.11; 324/207.13; 324/207.2 (keyword delimited)

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

Orbit, Google Patents, Google Scholar

Search terms used: inspection, rubber, magnetic flux, polymeric, array, sensor, Hall, compare, signal, polarity

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3,750,129 A (TAKENO et al) 31 July 1973 (31.07.1973) entire document	1, 3, 5, 9, 11
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Y		2, 4, 6-8, 10, 12-19
Y	US 5,336,998 A (WATTS et al) 09 August 1994 (09.08.1994) entire document	2, 8, 12-19
Y	US 2014/0084906 A1 (NXP B.V.) 27 March 2014 (27.03.2014) entire document	4, 10
Y	US 2009/0027048 A1 (SATO et al) 29 January 2009 (29.01.2009) entire document	6-8



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

"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

"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

"&" document member of the same patent family

Date of the actual completion of the international search

02 September 2016

Date of mailing of the international search report

26 SEP 2016

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