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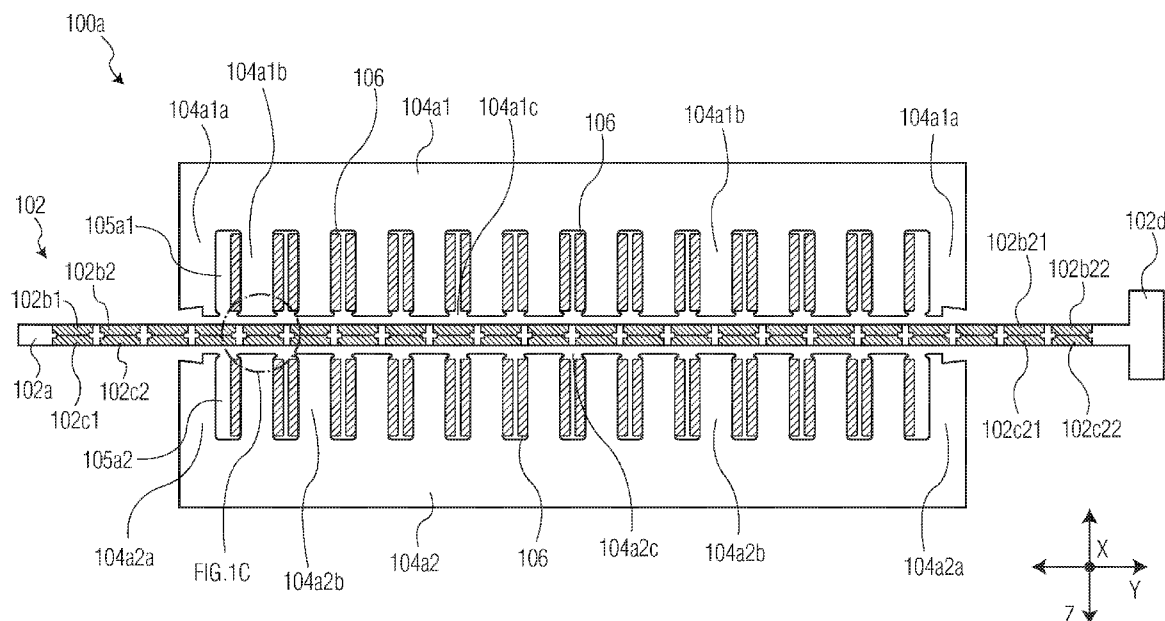


FIG. 1A

(57) Abstract: A linear motor is provided. The linear motor includes a moving magnet assembly including (i) a magnet track, (ii) a first plurality of permanent magnets coupled to the magnet track, and (iii) a second plurality of permanent magnets coupled to the magnet track and arranged below the first plurality of permanent magnets. The linear motor also includes a first coil assembly arranged above the moving magnet assembly. The first coil assembly includes a first plurality of teeth having first slots therebetween. The first coil assembly also includes a first plurality of coils at least partially disposed in at least a portion of the first slots. The linear motor also includes a second coil assembly arranged below the moving magnet assembly. The second coil assembly includes a second plurality of teeth having second slots therebetween. The second coil assembly includes a second plurality of coils at least partially disposed in at least a portion of the second slots.

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LINEAR MOTORS AND WIRE BONDING MACHINES INCLUDING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 62/840,039, filed April 29, 2019, the content of which is incorporated herein by reference.

FIELD

[0002] The invention relates to linear motor systems, and more particularly, to improved linear motors including moving magnet assemblies.

BACKGROUND

[0003] Linear motors are well known in the art and used in many different industries. For example, linear motor systems are used in wire bonding machines to provide high speed linear motion along various axes. For example, in certain wire bonding machines, linear motors are used to provide precise high speed motion along an x-axis and a y-axis of the machine. Exemplary patents illustrating examples of linear motion systems include: U.S. Patent No. 7,825,549 to Wang (titled "LINEAR MOTOR WITH REDUCED COGGING"), U.S. Patent No. 4,912,746 to Oishi (titled "LINEAR DC BRUSHLESS MOTOR"), U.S. Patent No. 5,642,013 to Wavre (titled "PERMANENT-MAGNET SYNCHRONOUS MOTOR") and U.S. Patent No. 5,910,691 to Wavre (titled "PERMANENT-MAGNET LINEAR SYNCHRONOUS MOTOR").

[0004] There is continuous interest in providing improvements in the operation of linear motors, in areas such as noise reduction, vibration reduction, speed, force, efficiency, accuracy, and cost of the motor. Thus, it would be desirable to provide improved linear motors.

SUMMARY

[0005] According to an exemplary embodiment of the invention, a linear motor is provided. The linear motor includes a moving magnet assembly including (i) a magnet track, (ii) a first plurality of permanent magnets coupled to the magnet track, and (iii) a second plurality of permanent magnets coupled to the magnet track and

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arranged below the first plurality of permanent magnets. The linear motor also includes a first coil assembly arranged above the moving magnet assembly. The first coil assembly includes a first plurality of teeth having first slots therebetween. The first coil assembly also includes a first plurality of coils at least partially disposed in at least a portion of the first slots. The linear motor also includes a second coil assembly arranged below the moving magnet assembly. The second coil assembly includes a second plurality of teeth having second slots therebetween. The second coil assembly includes a second plurality of coils at least partially disposed in at least a portion of the second slots.

[0006] According to another exemplary embodiment of the invention, a wire bonding system is provided. The wire bonding system includes a bond head assembly carrying a wire bonding tool and a linear motor system for driving the bond head assembly along a first horizontal axis. The linear motor system includes a moving magnet assembly having (i) a magnet track, (ii) a first plurality of permanent magnets coupled to the magnet track, and (iii) a second plurality of permanent magnets coupled to the magnet track and arranged below the first plurality of permanent magnets. The linear motor system also includes a first coil assembly arranged above the moving magnet assembly. The first coil assembly includes a first plurality of teeth having first slots therebetween. The first coil assembly also includes a first plurality of coils at least partially disposed in at least a portion of the first slots. The linear motor system also includes a second coil assembly arranged below the moving magnet assembly. The second coil assembly includes a second plurality of teeth having second slots therebetween. The second coil assembly includes a second plurality of coils at least partially disposed in at least a portion of the second slots.

[0007] Other machines (besides wire bonding machines) are contemplated within the scope of the invention, to include the inventive linear motors. Examples of such machines include die attach machines, flip chip bonding machines, thermocompression bonding machines, pick and place machines, and other semiconductor packaging machines.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The invention is best understood from the following detailed description when read in connection with the accompanying drawings. It is emphasized that, according to common practice, the various features of the drawings are not to scale.

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On the contrary, the dimensions of the various features are arbitrarily expanded or reduced for clarity. Included in the drawings are the following figures:

- [0009]** FIG. 1A is a cross-sectional view of a linear motor in accordance with an exemplary embodiment of the invention;
- [0010]** FIG. 1B is a combination side and cross-sectional view of the linear motor of FIG. 1A;
- [0011]** FIG. 1C is a detailed view of a portion of FIG. 1A;
- [0012]** FIG. 2A is a cross-sectional view of another linear motor in accordance with another exemplary embodiment of the invention;
- [0013]** FIG. 2B is a combination side and cross-sectional view of the linear motor of FIG. 2A;
- [0014]** FIG. 3A is a cross-sectional view of yet another linear motor in accordance with another exemplary embodiment of the invention;
- [0015]** FIG. 3B is a combination side and cross-sectional view of the linear motor of FIG. 3A;
- [0016]** FIG. 4A is a cross-sectional view of yet another linear motor in accordance with another exemplary embodiment of the invention;
- [0017]** FIG. 4B is a combination side and cross-sectional view of the linear motor of FIG. 4A;
- [0018]** FIG. 5A is a cross-sectional view of a moving magnet assembly in accordance with an exemplary embodiment of the invention;
- [0019]** FIG. 5B is a detailed view of a portion of FIG. 5A;
- [0020]** FIG. 5C is a perspective cross-sectional view of the moving magnet assembly of FIG. 5A;
- [0021]** FIG. 5D is a detailed view of a portion of FIG. 5C;
- [0022]** FIG. 5E is a top view of the moving magnet assembly of FIG. 5A;

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[0023] FIG. 6 is a cross-sectional view of another linear motor in accordance with an exemplary embodiment of the invention;

[0024] FIG. 7 is a cross-sectional view of yet another linear motor in accordance with an exemplary embodiment of the invention;

[0025] FIG. 8 is a cross-sectional block diagram of a wire bonding machine including the linear motor of FIG. 7 in accordance with an exemplary embodiment of the invention; and

[0026] FIGS. 9A-9C are various cross-sectional block diagram views of the wire bonding machine of FIG. 8 in accordance with an exemplary embodiment of the invention.

DETAILED DESCRIPTION

[0027] As used herein, the terms "linear motor", "linear motor system", and "linear motion system" may be considered synonyms. For example, FIGS. 1A-1C, 2A-2B, 3A-3B, and 4A-4B illustrate respective linear motors 100a, 100b, 100c, and 100d. While FIG. 6 refers to a linear motor system 600, and FIG. 7 refers to a linear motion system 700, each of these may also be considered a "linear motor" within the scope of the invention.

[0028] As used herein, the term "magnet track" is intended to refer to any of a number of structures in a linear motor carrying a plurality of permanent magnets arranged to magnetically interact with a coil assembly of the linear motor such that a desired linear motion of at least one of the magnet track and the coil assembly is provided. As such, the magnet track is not intended to be limited, for example, to any particular arrangement or spacing of the permanent magnets, nor is the magnet track intended to be limited to any particular support structure for the permanent magnets.

[0029] FIG. 1A is a cross sectional view of linear motor 100a. Linear motor 100a includes moving magnet assembly 102, first coil assembly 104a1, and second coil assembly 104a2. As is understood by those skilled in the art, certain components of linear motor 100a (e.g., electrical connections, etc.) have been omitted for simplicity. Moving magnet assembly 102 includes (i) a magnet track 102a, (ii) a first plurality of permanent magnets 102b1, 102b2, . . . , 102b21, 102b22 coupled to magnet track 102a, and (iii) a second plurality of permanent magnets 102c1, 102c2, . . . , 102c21, 102c22 coupled to magnet track 102a and arranged below the first plurality of

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permanent magnets 102b1, 102b2, . . . , 102b22. As shown in FIG. 1A, the permanent magnets are arranged in magnet pairs, one disposed directly above the other. For example, permanent magnet 102b1 is positioned directly above permanent magnet 102c1, such that permanent magnets 102b1 and 102c1 form a "magnet pair". According to exemplary aspects of the invention, magnetic attraction forces may exist between each magnet pair.

[0030] Magnet track 102a (and any of the other magnet tracks described in this patent application) may be formed from a non-magnetic material (e.g., a material including aluminum such as aluminum or an aluminum alloy). Other exemplary non-magnetic materials include carbon fiber, beryllium, as well as many others.

[0031] Each of the first plurality of permanent magnets 102b1, 102b2, . . . , 102b22, and each of the second plurality of permanent magnets 102c1, 102c2, . . . , 102c22, are connected (directly or indirectly) to magnet track 102a using any of a number of techniques such as an adhesive, fasteners, etc. Magnet track 102a includes a coupling portion 102d for connecting to another structure to be moved along the desired axis by linear motor 100a. For example, coupling portion 102d may be connected to a y-axis slide of a wire bonding machine for moving a bond head assembly along the y-axis (e.g., see FIG. 8).

[0032] Linear motor 100a also includes a first coil assembly 104a1 (which may also be referred to as stator 104a1) arranged above moving magnet assembly 102. First coil assembly 104a1 includes a first plurality of teeth having first slots 105a1 therebetween. The first plurality of teeth include end teeth 104a1a at each end of first coil assembly 104a1, and a plurality of teeth 104a1b disposed between the two end teeth 104a1a. First coil assembly also includes coils 106 at least partially disposed in at least a portion of the first slots 105a1. As shown in FIG. 1A (and more clearly shown in FIG. 1B), each slot 105a1 (except the end slots adjacent end teeth 104a1a, which has received a portion of only one coil 106) has received a portion of two adjacent coils 106. Linear motor 100a also includes a second coil assembly 104a2 (which may also be referred to as stator 104a2) arranged below moving magnet assembly 102. Second coil assembly 104a2 includes a second plurality of teeth having second slots 105a2 therebetween. The second plurality of teeth include end teeth 104a2a at each end of second coil assembly 104a2, and a plurality of teeth 104a2b disposed between the two end teeth 104a2a. Second coil assembly 104a2 also includes coils 106 at least partially disposed in at least a portion of the second slots 105a2. As shown in FIG. 1A (and more clearly shown in FIG. 1B), each slot 105a2 (except the end slots adjacent end

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teeth 104a2a, which has received a portion of only one coil 106) has received a portion of two adjacent coils 106.

[0033] Each of first coil assembly 104a1 and second coil assembly 104a2 may include a plurality of laminations stacked together as is known to those skilled in the art. Thus, the stacked laminations define the respective first plurality of teeth 104a1a, 104a1b and the second plurality of teeth 104a2a, 104a2b.

[0034] As shown in FIG. 1C, an exposed surface of each of the first plurality of permanent magnets 102b1, 102b2, . . . , 102b22 is positioned adjacent first coil assembly 104a1 at a first distance d1, and an exposed surface of each of the second plurality of permanent magnets 102c1, 102c2, . . . , 102c22 is positioned adjacent the second coil assembly 104a2 at a second distance d2. The first distance d1 is substantially the same as the second distance d2.

[0035] To the extent possible, the features described above with respect to FIGS. 1A-1C are applicable to the additional embodiments of the invention described herein (and other embodiments within the scope of the invention). Thus, in connection with the remaining embodiments, certain details are omitted for simplicity, and certain reference numerals are duplicated across the various illustrated embodiments of the invention.

[0036] FIGS. 1A-1C illustrate first coil assembly 104a1 and second coil assembly 104a2, having teeth 104a1a, 104a1b, 104a2a, and 104a2b. End teeth 104a1a, 104a2a have a shape as shown in U.S. Patent No. 7,825,549. Teeth 104a1b, 104a2b have a "T" shaped configuration where the end of each tooth is wider than the body of the respective tooth (see FIG. 1A, where gap 104a1c, and gap 104a2c, between adjacent teeth are smaller at the end because of the "T" shape). Of course, these teeth designs are exemplary in nature, and the invention is not limited to such configurations.

[0037] FIGS. 2A-2B illustrate linear motor 100b which is very similar to linear motor 100a described above with respect to FIGS. 1A-1B. Linear motor 100b includes a magnet assembly 102 which is the same as magnet assembly 102 from FIGS. 1A-1B. Linear motor also includes first coil assembly 104b1 (including teeth 104b1a, 104b1b) and second coil assembly 104b2 (including teeth 104b2a, 104b2b), which are very similar to first coil assembly 104a1 and second coil assembly 104a2 from FIGS. 1A-1B. One difference is that in FIGS. 2A-2B teeth 104b1b, 104b2b do not have the "T" shaped configuration described above. Rather, teeth 104b1b, 104b2b have the same (or

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substantially the same) width along their entire length, which makes positioning of coils 106 relatively simple.

[0038] FIGS. 3A-3B illustrate linear motor 100c which is very similar to linear motor 100a described above with respect to FIGS. 1A-1B. Linear motor 100c includes a magnet assembly 102 which is the same as magnet assembly 102 from FIGS. 1A-1B. Linear motor also includes first coil assembly 104c1 (including teeth 104c1a, 104c1b) and second coil assembly 104c2 (including teeth 104c2a, 104c2b), which are very similar to first coil assembly 104a1 and second coil assembly 104a2 from FIGS. 1A-1B. However, in FIGS. 3A-3B, only one coil 106 is provided in each slot (See FIG. 3B for clarity). Thus, in the example shown in FIGS. 3A-3B, six coils 106 are provided, whereas in FIGS. 1A-1B twelve coils 106 are provided.

[0039] FIGS. 4A-4B illustrate linear motor 100d which is very similar to linear motor 100a described above with respect to FIGS. 1A-1B. Linear motor 100d includes a magnet assembly 102 which is the same as magnet assembly 102 from FIGS. 1A-1B. Linear motor 100d also includes first coil assembly 104d1 (including teeth 104d1a, 104d1b) and second coil assembly 104d2 (including teeth 104d2a, 104d2b), which are very similar to first coil assembly 104a1 and second coil assembly 104a2 from FIGS. 1A-1B. However, like FIGS. 3A-3B, in FIGS. 4A-4B, only one coil 106 is provided in each slot (See FIG. 4B for clarity). Thus, in the example shown in FIGS. 4A-4B, six coils 106 are provided, whereas in FIGS. 1A-1B twelve coils 106 are provided. Another difference is that in FIGS. 4A-4B teeth 104d1b, 104d2b do not have the "T" shaped configuration described above with respect to FIGS. 1A-1B. Rather, teeth 104d1b, 104d2b have the same (or substantially the same) width along their entire length, which makes positioning of coils 106 relatively simple.

[0040] FIGS. 5A-5E illustrate various details of magnet assembly 102. FIG. 5A illustrates a cross-sectional view of magnet assembly 102 shown in FIGS. 1A-1C, 2A-2B, 3A-3B, and 4A-4B, along with the direction of motion (along the y-axis in the examples shown in the application). FIG. 5B is a detailed view of a portion of FIG. 5A, which clearly illustrates certain features of magnet assembly. Specifically, FIG. 5B illustrates that magnet track 102a defines a plurality of tab portions 102e. As shown in FIG. 5B, each of the first plurality of permanent magnets 102b1, 102b2, . . . , 102b22 and the second plurality of permanent magnets 102c1, 102c2, . . . , 102c22 includes a stepped portion "ST" configured to mate with corresponding ones of the plurality of tab portions 102e. FIGS. 5C-5D provide additional perspective cross sectional views of magnet assembly 102. FIG. 5E illustrates a top view of magnet assembly 102 (not a

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cross sectional view, as in FIGS. 5A-5D). In FIG. 5E, connection portions 102f of magnet assembly 102 are visible. Connection portions 102f are used to engage some type of bearing assembly (see bearings 606, and bearing block 604, shown in FIG. 6) to assist in the motion of moving magnet assembly 102. For example, the bearing assembly could be a linear bearing block engaged with a linear bearing rail. Of course, other types of bearing assemblies are contemplated.

[0041] According to certain aspects of the invention, the design of the substrate (i.e., the magnet track) carrying the plurality of permanent magnets (including both the first and second plurality of permanent magnets) of the moving magnet assembly 102 is important. It may be particularly beneficial that the magnets are carried without a cover or skin between the magnets and the respective stator (i.e., between the first plurality of permanent magnets and the first coil assembly, and between the second plurality of permanent magnets and the second coil assembly). This lack of an inclusion of a cover or skin substantially reduces the electrical and mechanical gap between the magnets and the respective stator, and further reduces unnecessary mass in the linear motor. Further still, such a substrate (i.e., the magnet track) does not appreciably interfere with the magnetic flux path.

[0042] Further still, the design of moving magnet assembly 102 (including symmetric magnet pairs disposed one above the other), along with the dual stator design (including the first coil assembly and the second coil assembly) desirably creates a substantially equal force constant for each stator, and creates a substantially equal and opposite magnetic attraction force to each stator. This results in a minimal (substantially net zero) load on the moving magnet assembly 102 and the associated bearings.

[0043] FIG. 6 illustrates a linear motor system 600 with additional components. While linear motor system 600 includes linear motor 100b from FIGS. 2A-2B, it is understood that any other linear motor within the scope of the invention (e.g., linear motor 100a, 100c, 100d, or any other linear motor within the scope of the invention) may be included in linear motor system 600. Linear motor system 600 includes housing portions 602a, 602b, and 602c. Collectively, housing portions 602a, 602b, and 602c are part of a common housing, where the common housing couples (either directly or indirectly) first coil assembly 104b1 with second coil assembly 104b2 to provide a combined coil assembly. For example, first coil assembly 104b1 and second coil assembly 104b2 may be secured in the common housing using adhesive, fasteners, a combination of both, among other techniques. It is understood that a common

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housing for first coil assembly 104b1 and second coil assembly 104b2 may take any desired configuration (e.g., a single piece, or multiple different pieces, of material and not three distinct housing portions as shown). FIG. 6 also illustrates bearings 606 supported by bearing blocks 604 (where bearing blocks 604 may be considered to be part of the combined coil assembly). Through operation of linear motor system 600, moving magnet assembly 102 moves along the Y axis, while riding along bearings 606.

[0044] FIG. 7 illustrates linear motion system 700 which includes linear motor system 600 from FIG. 6. While FIG. 7 illustrates linear motor system 600 including linear motor 100b from FIGS. 2A-2B, it is understood that any other linear motor within the scope of the invention (e.g., linear motor 100a, 100c, 100d, or any other linear motor within the scope of the invention) may be included in linear motor system 600. During operation of linear motion system 700, motion of the moving magnet assembly 102 along a horizontal axis (the Y axis shown in FIG. 7) results in some resultant motion of the combined coil assembly (including housing portions 602a, 602b, and 602c, as well as first coil assembly 104b1 and second coil assembly 104b2) along the same horizontal axis. In the block diagram view of FIG. 7, this motion is provided for via bearings 702e. More specifically, linear motion system 700 includes base structure 702a, side block portions 702b, dampers 702c, springs 702d, and bearings 702e. Bearings 702e are supported by base structure 702a. Springs 702d and dampers 702c are provided between the common housing (including housing portions 602a, 602b, and 602c, and the combined coil assembly) and side block portions 702b. Springs 702d assist in re-centering the common housing (including the combined coil assembly of first coil assembly 104b1 and second coil assembly 104b2) after motion of moving magnet assembly 102. Dampers 702c assist in controlling stability of linear motion system 700 in connection with motion of moving magnet assembly 102.

[0045] FIG. 7 also illustrates a position encoder system 702f for providing position information related to the combined coil assembly (including first coil assembly 104b1 and second coil assembly 104b2). Position encoder system 702f (including elements 702f1 and 702f2) may be any of a number of types of position encoder systems (e.g., an optical encoder system, a magnetic encoder system, etc.). Position encoder system 702f, shown in FIG. 7, may be considered of varying type of position encoder system. For example, in an optical encoder system, a scale portion 702f1 is provided coupled (either directly or indirectly) to the combined coil assembly, and an optical portion 702f2 is provided for imaging the scale portion. In such an example, optical portion 702f2 is coupled (either directly or indirectly) to another portion of linear motion 700 (e.g., base portion 702a) that does not move with the combined coil

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assembly. In another example, elements 702f1 and 702f2 may be portions of a magnetic encoder system.

[0046] In any event, inclusion of position encoder system 702f may be particularly beneficial if linear motor 100b is a three phase motor, where the position information provided by position encoder system 702f is used to control a commutation angle of linear motor 100b.

[0047] FIG. 8 illustrates wire bonding system 800 including linear motion system 700 from FIG. 7. Wire bonding system 800 also includes bond head assembly 804 (carrying wire bonding tool 806), y-axis slide 802, bearing block 810 (for supporting y-axis slide 802), and bearings 812. As will be appreciated by those skilled in the art, y-axis slide 802 may incorporate bearing block 810 (i.e., y-axis slide 802 would be carried on bearings 812 directly). Motion of moving magnet assembly 102 along the y-axis results in corresponding motion of bond head assembly 804. Wire bonding system 800 also includes linear motion system 700' which carries y-axis slide 802 and bearing block 810 along bearings 812. While shown as a block in FIG. 8, it is understood that linear motion system 700' is a linear motion system within the scope of the invention, such as a duplicate of linear motion system 700. Linear motion system 700' provides linear motion of bond head assembly 804 along the x-axis of wire bonding system 800 (where the x-axis is substantially perpendicular to the y-axis). Wire bonding system 800 also includes a decoupling element 808 for decoupling operation of linear motion system 700 from operation of linear motion system 700'. Thus, operation of linear motion system 700 is decoupled from operation of linear motion system 700'.

[0048] FIGS. 9A-9C illustrate operation of linear motor 100b along the y-axis of wire bonding machine 800. In FIG. 9A, wire bonding tool 806 (carried by bond head assembly 804) is moved to the right ("FORWARD") in the drawing, resulting in a reverse motion of the common housing (shown as compression of the left spring element 702d). In FIG. 9B, wire bonding tool 806 is shown in its centered position. In FIG. 9C, wire bonding tool 806 (carried by bond head assembly 804) is moved to the left ("BACKWARD") in the drawing, resulting in a reverse motion of the common housing (shown as compression of the right spring element 702d).

[0049] The linear motors of the invention may find application in a number of technical fields. One exemplary area of use is with a wire bonding machine, wherein a linear motor according to the present invention may be used to provide linear motion along the x-axis or the y-axis, or both. More specifically, for example, such linear

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motors may be used to provide linear motion to a bond head assembly of a wire bonding machine along the x-axis of the bond head assembly, the y-axis of the bond head assembly, or both. Of course, the linear motors of the invention will find use in any of a number of other technical fields.

[0050] Although certain embodiments (see FIG. 8) of the invention show the y-axis slide 802 carried by the x-axis linear motion system 700', it is understood that this is exemplary in nature. In a different embodiment within the scope of the invention, an x-axis slide may be carried by a y-axis linear motion system.

[0051] Although aspects of the invention are illustrated with respect to linear motors including 6 coils and 12 coils, the invention is not limited thereto. These are examples, and any number of coils may be provided, as desired, within the scope of the invention.

[0052] Although the invention is illustrated with respect to exemplary tooth designs (including end teeth, and intermediate teeth between the end teeth), it is understood that all tooth designs are exemplary in nature – and any other tooth design may be incorporated, as desired, within the scope of the invention.

[0053] Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention.

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What is Claimed:

1. A linear motor comprising:

a moving magnet assembly including (i) a magnet track, (ii) a first plurality of permanent magnets coupled to the magnet track, and (iii) a second plurality of permanent magnets coupled to the magnet track and arranged below the first plurality of permanent magnets;

a first coil assembly arranged above the moving magnet assembly, the first coil assembly including a first plurality of teeth having first slots therebetween, the first coil assembly also including a first plurality of coils at least partially disposed in at least a portion of the first slots; and

a second coil assembly arranged below the moving magnet assembly, the second coil assembly including a second plurality of teeth having second slots therebetween, the second coil assembly also including a second plurality of coils at least partially disposed in at least a portion of the second slots.

2. The linear motor of claim 1 wherein the first coil assembly includes a plurality of laminations defining each of the first plurality of teeth, and the second coil assembly includes a plurality of laminations defining each of the second plurality of teeth.

3. The linear motor of claim 1 wherein each of the first plurality of permanent magnets is positioned directly above a corresponding one of the second plurality of permanent magnets in connection with the magnet track to form a magnet pair.

4. The linear motor of claim 3 wherein magnetic attraction forces exist between each magnet pair.

5. The linear motor of claim 1 wherein each of the first plurality of permanent magnets and each of the second plurality of permanent magnets is connected to the magnet track using at least one of an adhesive and a fastener.

6. The linear motor of claim 1 wherein the magnet track is formed from a non-magnetic material.

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7. The linear motor of claim 6 wherein the non-magnetic material includes aluminum.

8. The linear motor of claim 1 wherein an exposed surface of each of the first plurality of magnets is positioned adjacent the first coil assembly at a first distance, and an exposed surface of each of the second plurality of magnets is positioned adjacent the second coil assembly at a second distance, wherein the first distance is substantially the same as the second distance.

9. The linear motor of claim 1 wherein the magnet track defines a plurality of tab portions, and each of the first plurality of permanent magnets and the second plurality of permanent magnets includes a stepped portion configured to mate with corresponding ones of the plurality of tab portions.

10. The linear motor of claim 1 wherein the first coil assembly and the second coil assembly are coupled together as a combined coil assembly.

11. The linear motor of claim 10 wherein motion of the moving magnet assembly along a horizontal axis results in motion of the combined coil assembly along the horizontal axis.

12. The linear motor of claim 10 further comprising at least one damper element, and at least one spring element, positioned between the combined coil assembly and a base structure of the linear motor.

13. The linear motor of claim 10 further comprising a position encoder system, the position encoder system for providing position information related to the combined coil assembly.

14. The linear motor of claim 13 wherein the position encoder system is selected from the group consisting of an optical encoder system and a magnetic encoder system.

15. The linear motor of claim 10 further comprising a position encoder system, the position encoder system including (i) a scale portion coupled to the combined coil assembly, and (ii) an optical portion for imaging the scale portion, the optical portion being coupled to another portion of the linear motor that does not move with the combined coil assembly.

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16. The linear motor of claim 13 wherein the linear motor is a three phase motor, and wherein the position information provided by the position encoder system is used to control a commutation angle of the linear motor.

17. A wire bonding system comprising:

a bond head assembly carrying a wire bonding tool; and

a linear motor system for driving the bond head assembly along a first horizontal axis, the linear motor system including (a) a moving magnet assembly including (i) a magnet track, (ii) a first plurality of permanent magnets coupled to the magnet track, and (iii) a second plurality of permanent magnets coupled to the magnet track and arranged below the first plurality of permanent magnets, (b) a first coil assembly arranged above the moving magnet assembly, the first coil assembly including a first plurality of teeth having first slots therebetween, the first coil assembly also including a first plurality of coils at least partially disposed in at least a portion of the first slots, and (c) a second coil assembly arranged below the moving magnet assembly, the second coil assembly including a second plurality of teeth having second slots therebetween, the second coil assembly also including a second plurality of coils at least partially disposed in at least a portion of the second slots.

18. The wire bonding system of claim 17 further comprising another of the linear motor system for driving the bond head assembly along a second horizontal axis, the second horizontal axis being substantially perpendicular to the first horizontal axis.

19. The wire bonding system of claim 18 further comprising a decoupling element for decoupling the linear motor system from the another of the linear motor system.

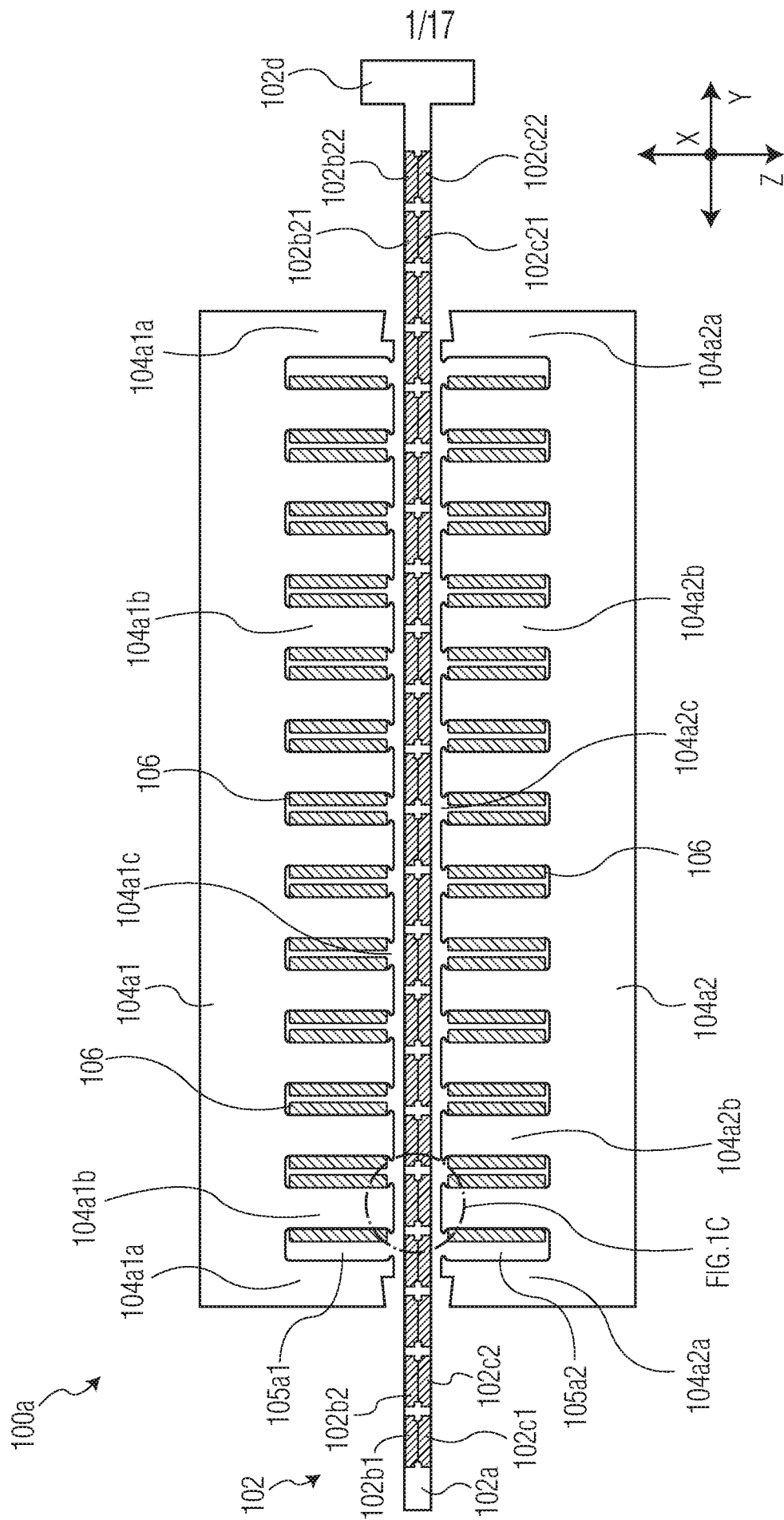


FIG. 1A

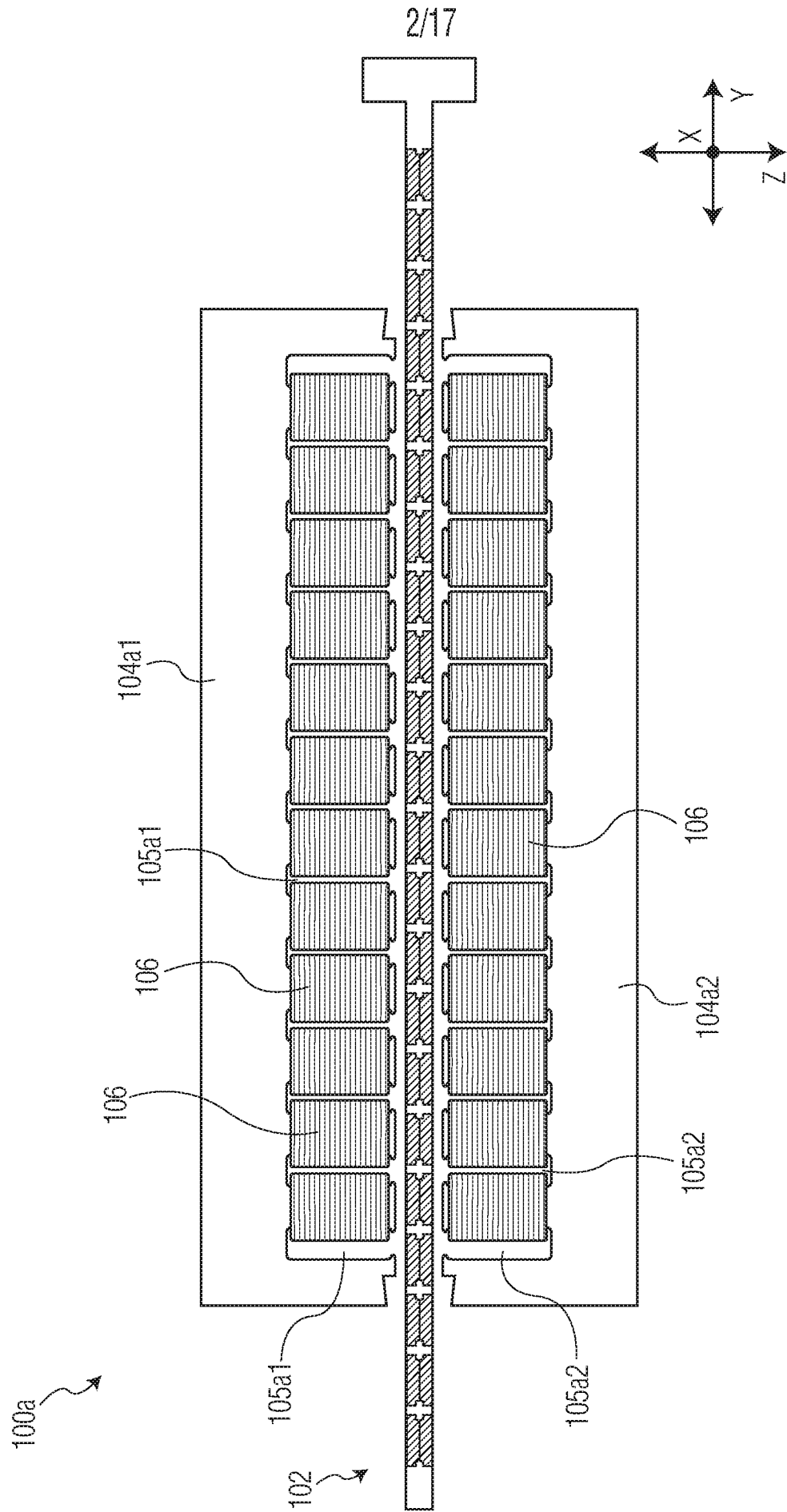


FIG. 1B

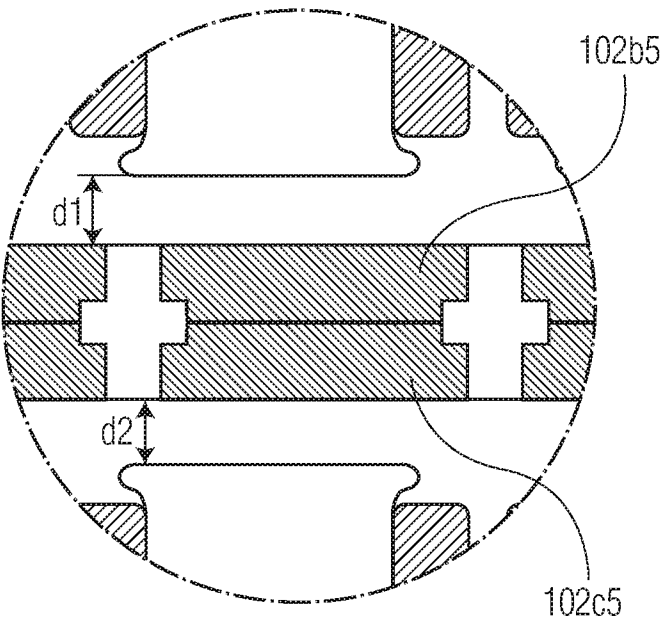


FIG. 1C

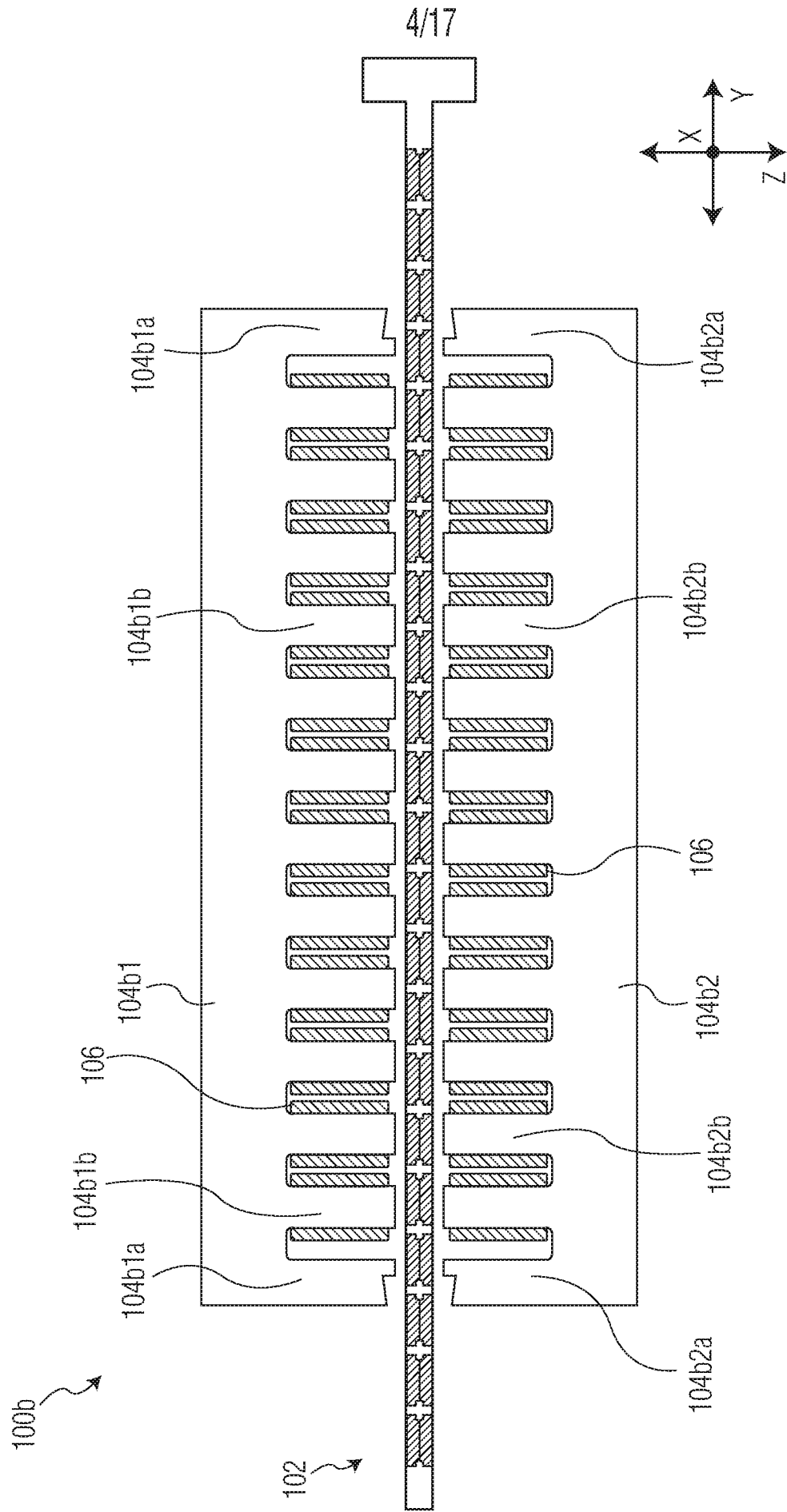


FIG. 2A

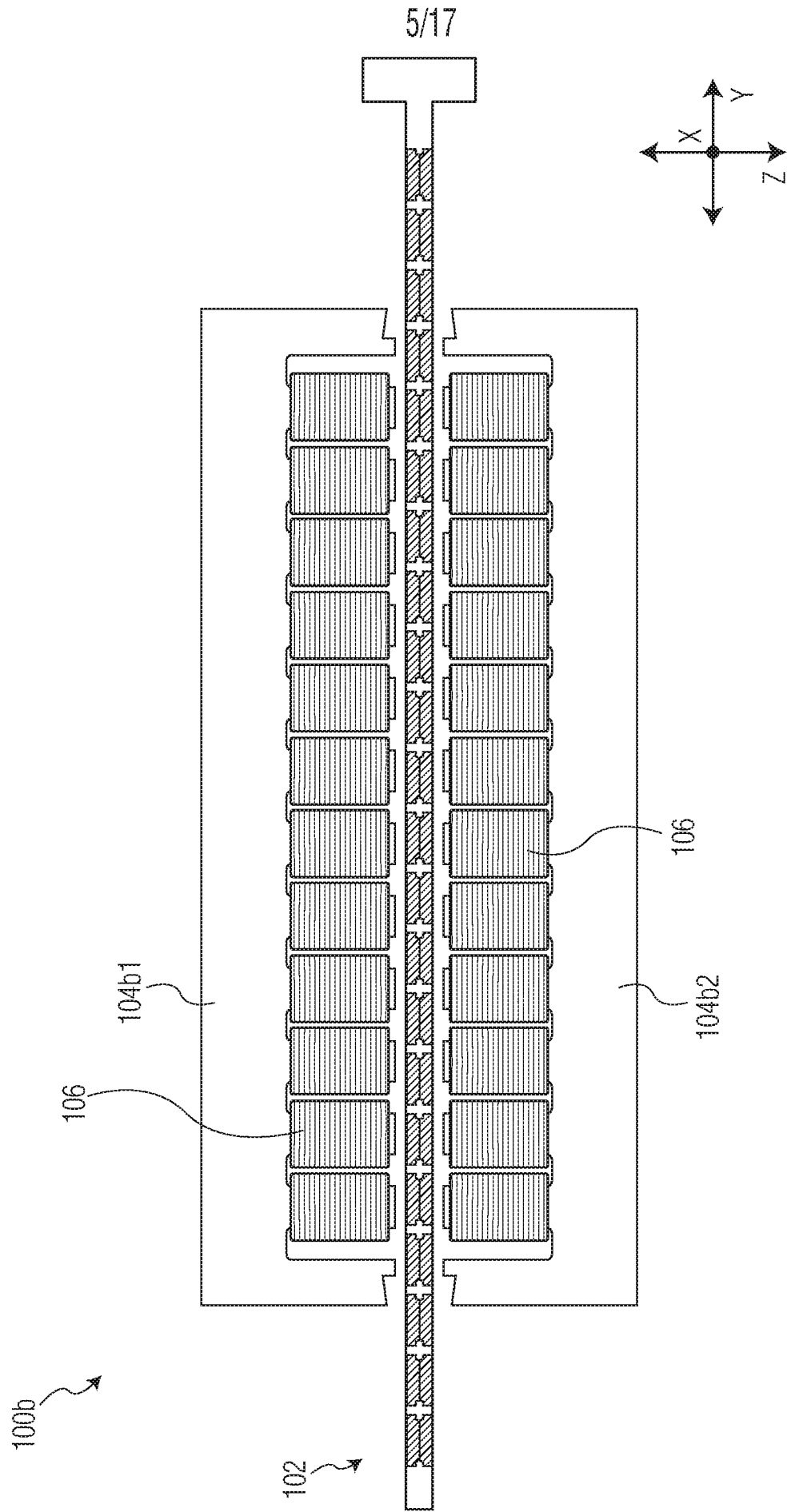


FIG. 2B

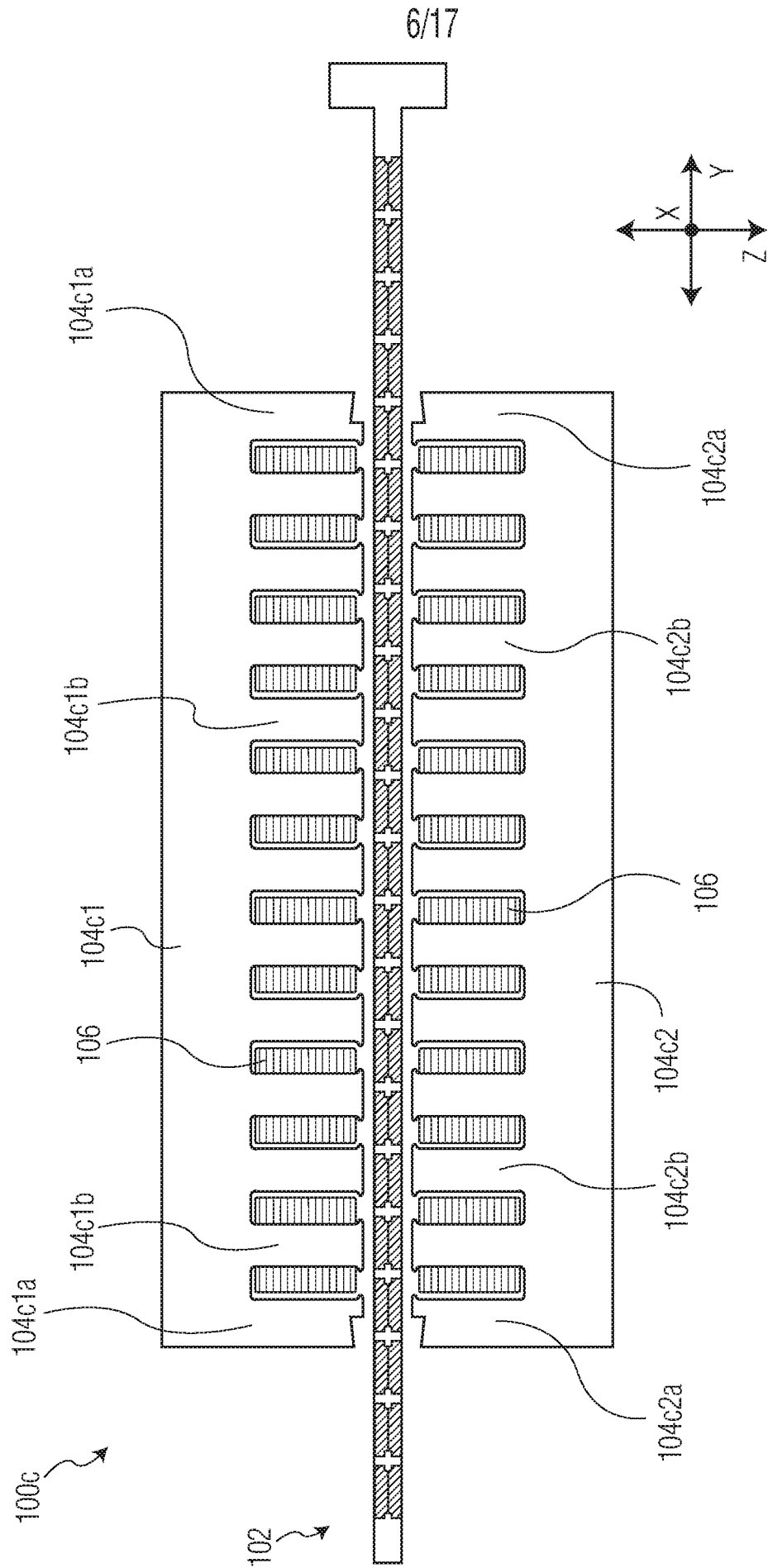


FIG. 3A

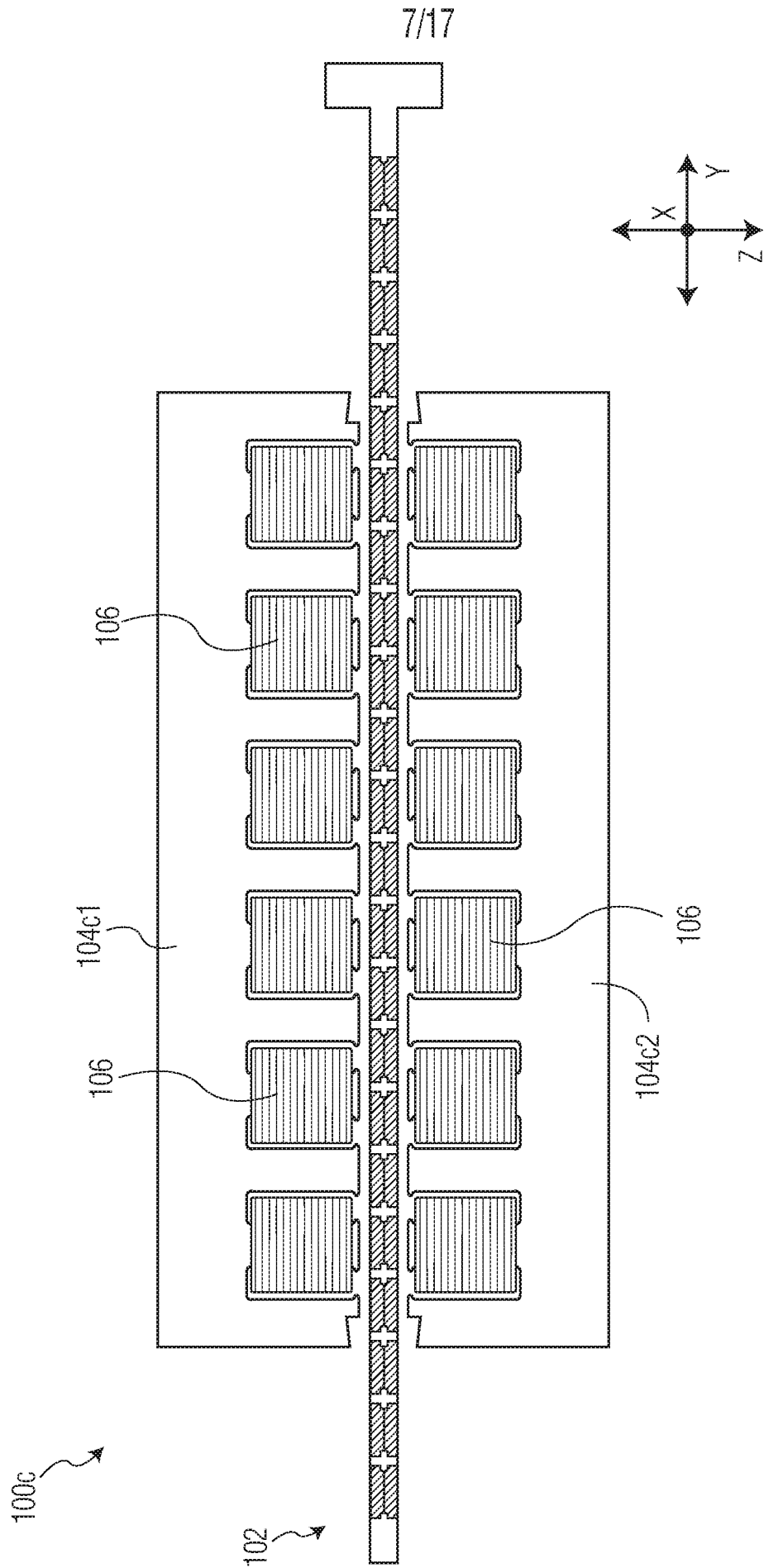


FIG. 3B

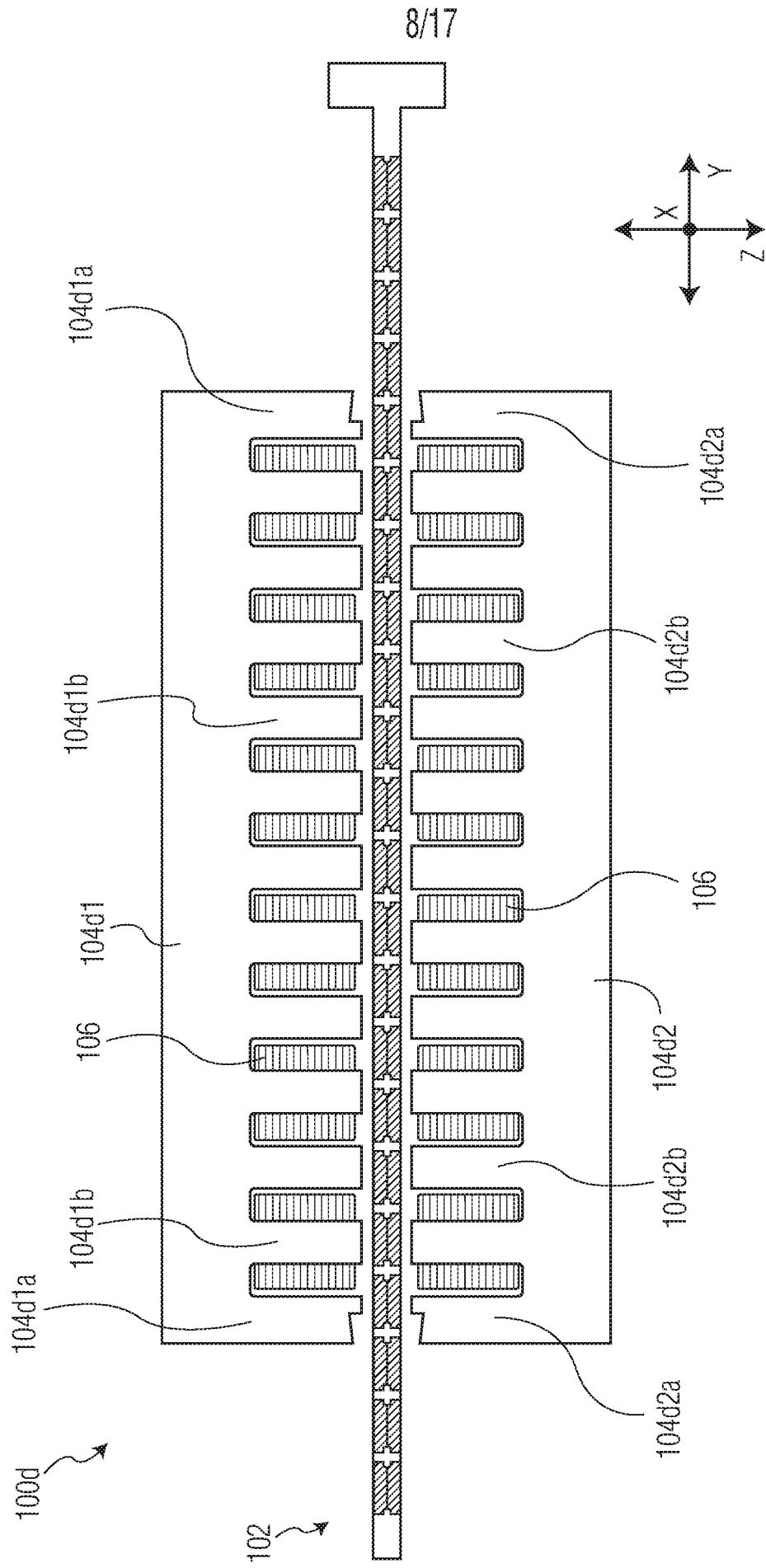
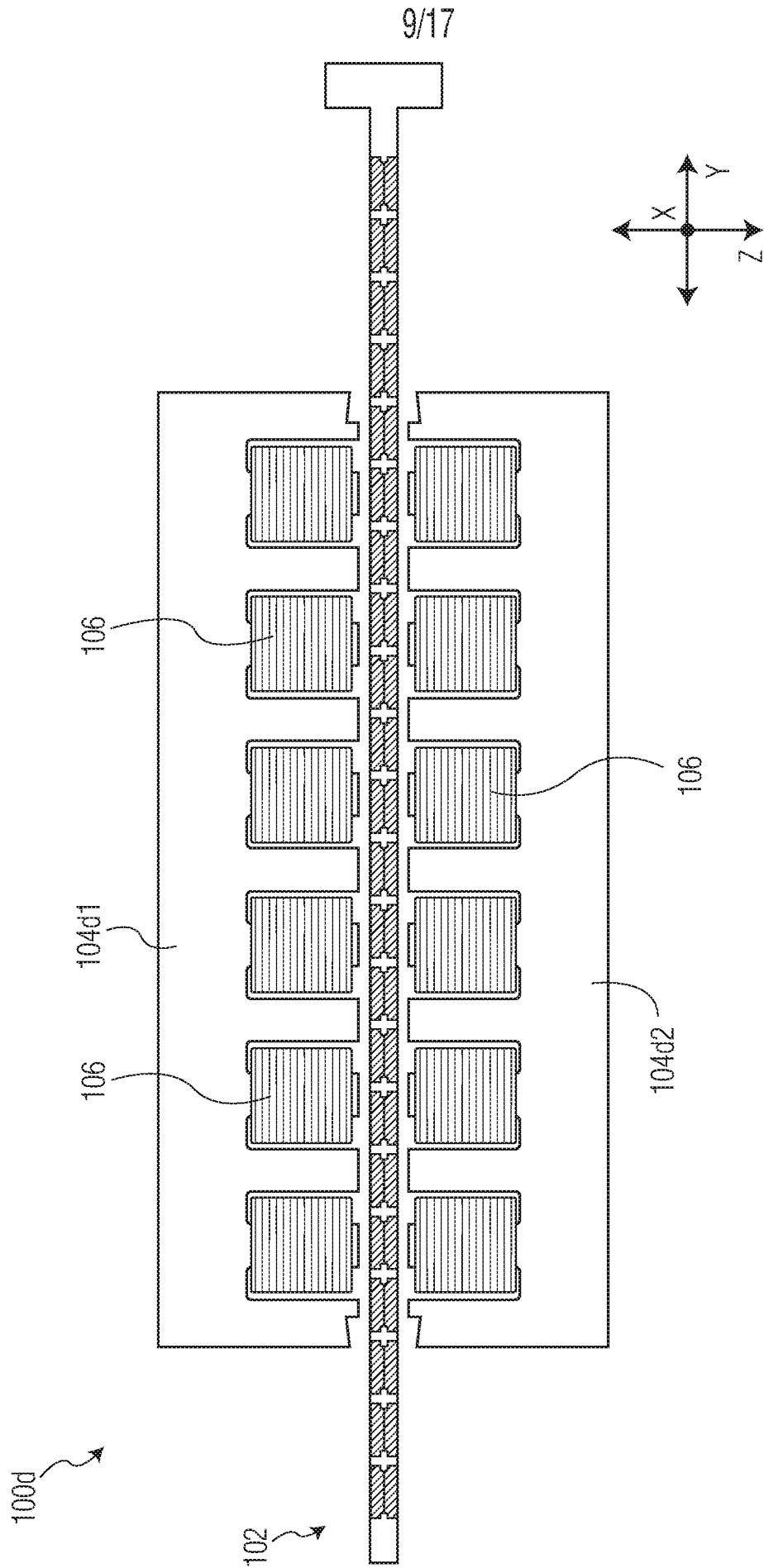


FIG. 4A



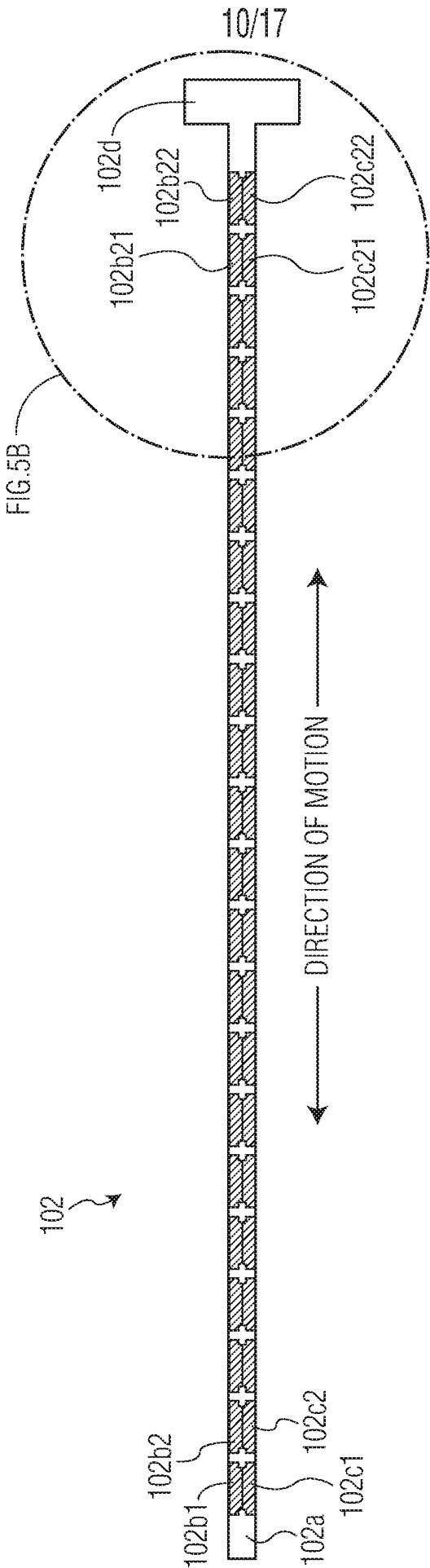


FIG. 5A

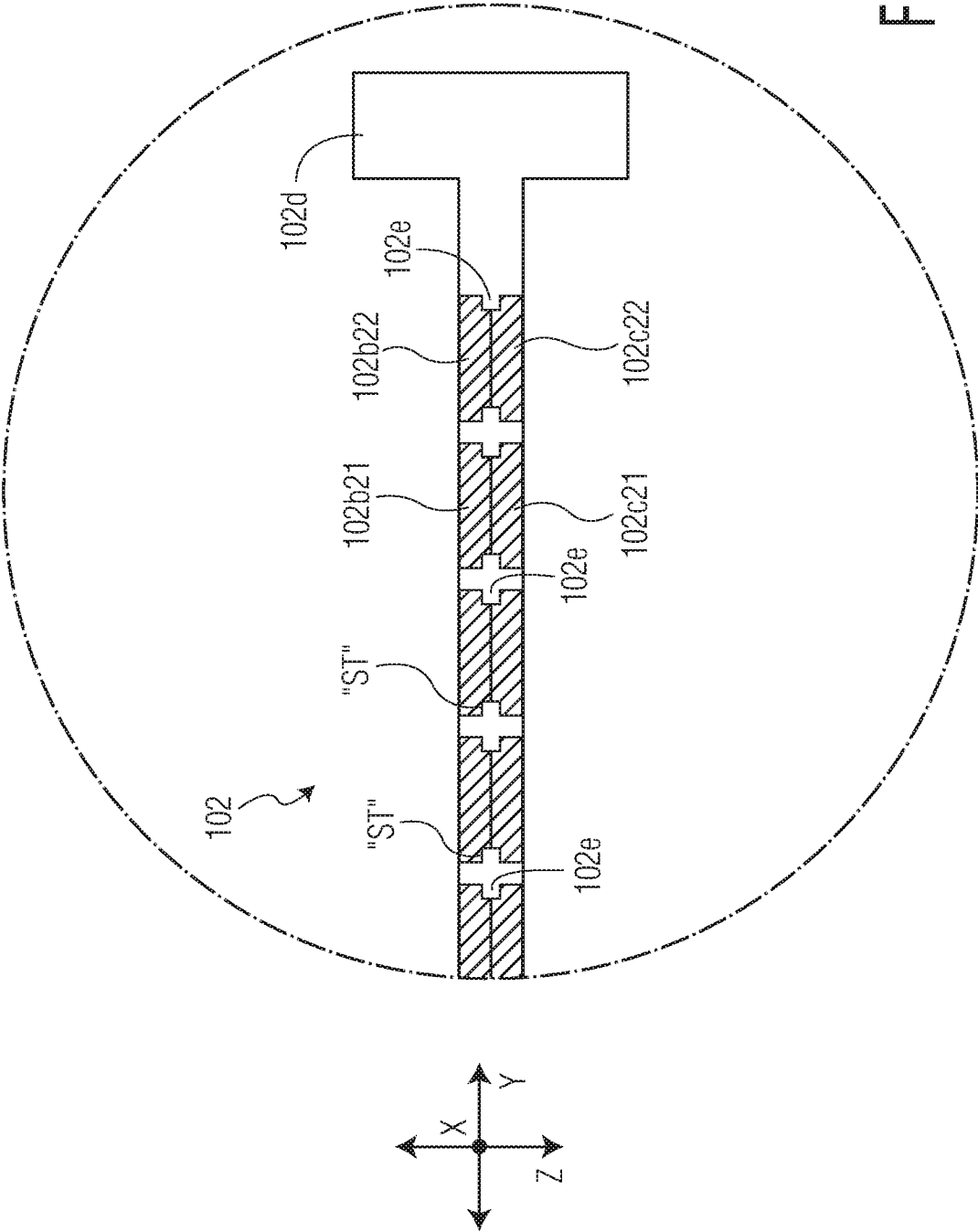
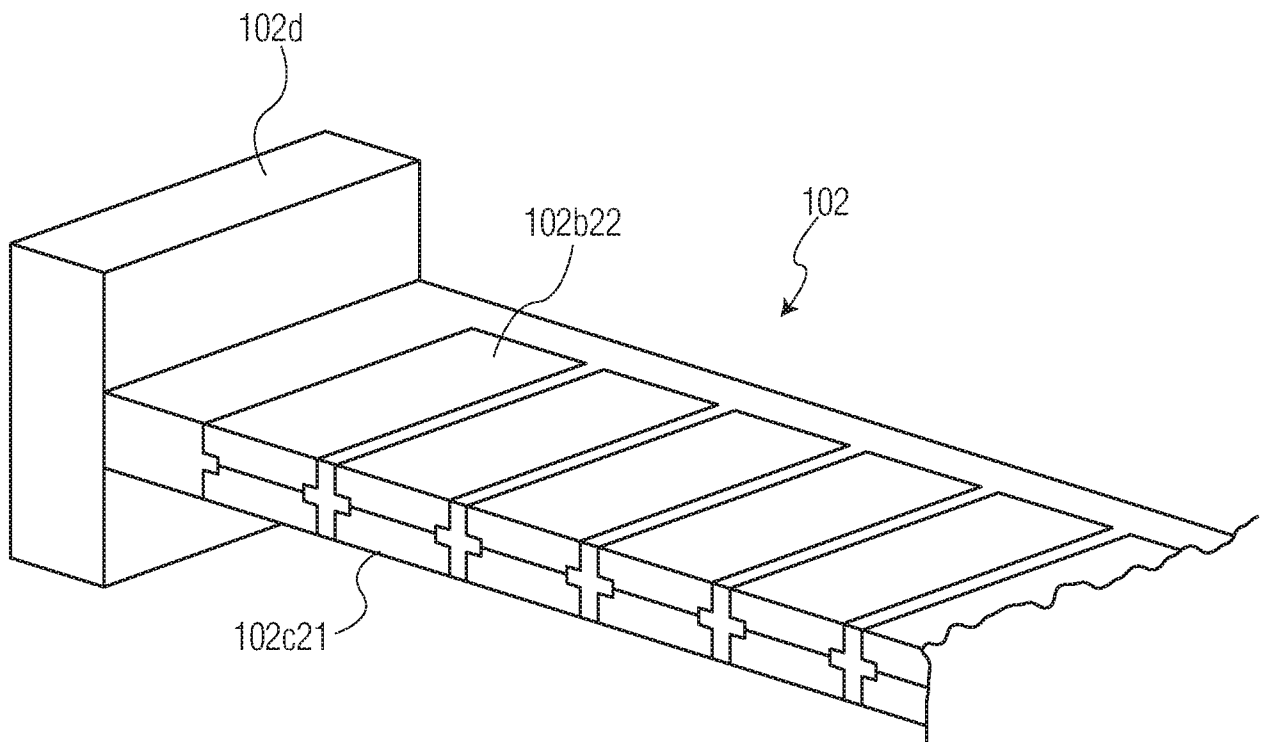
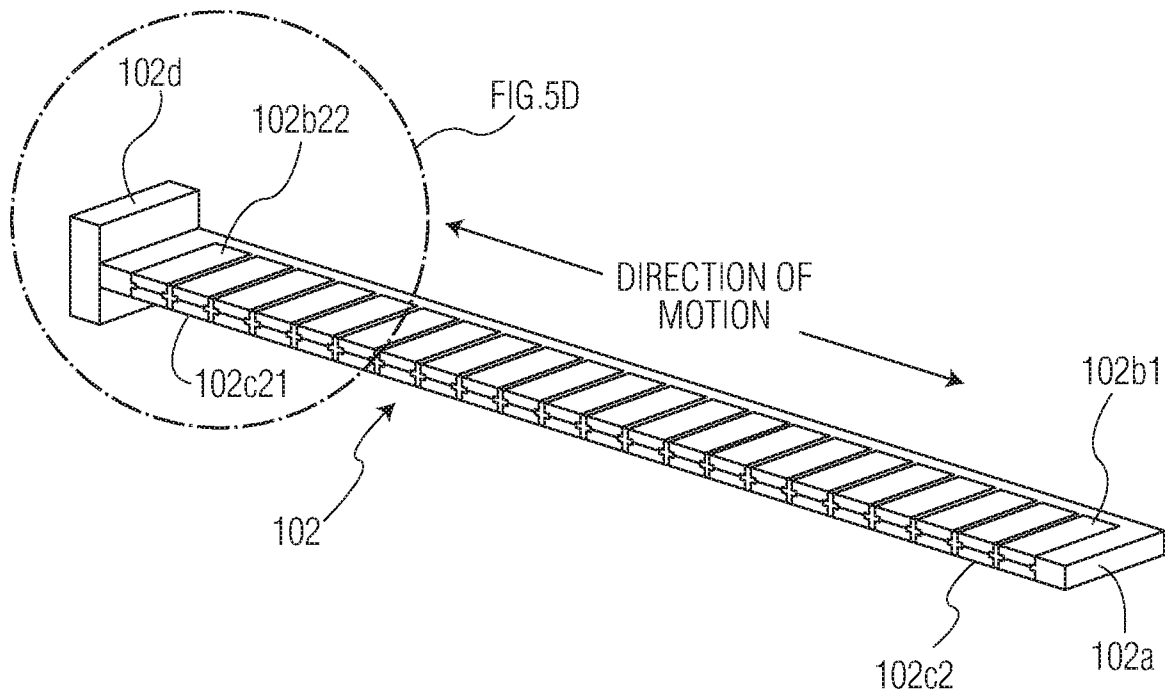


FIG. 5B

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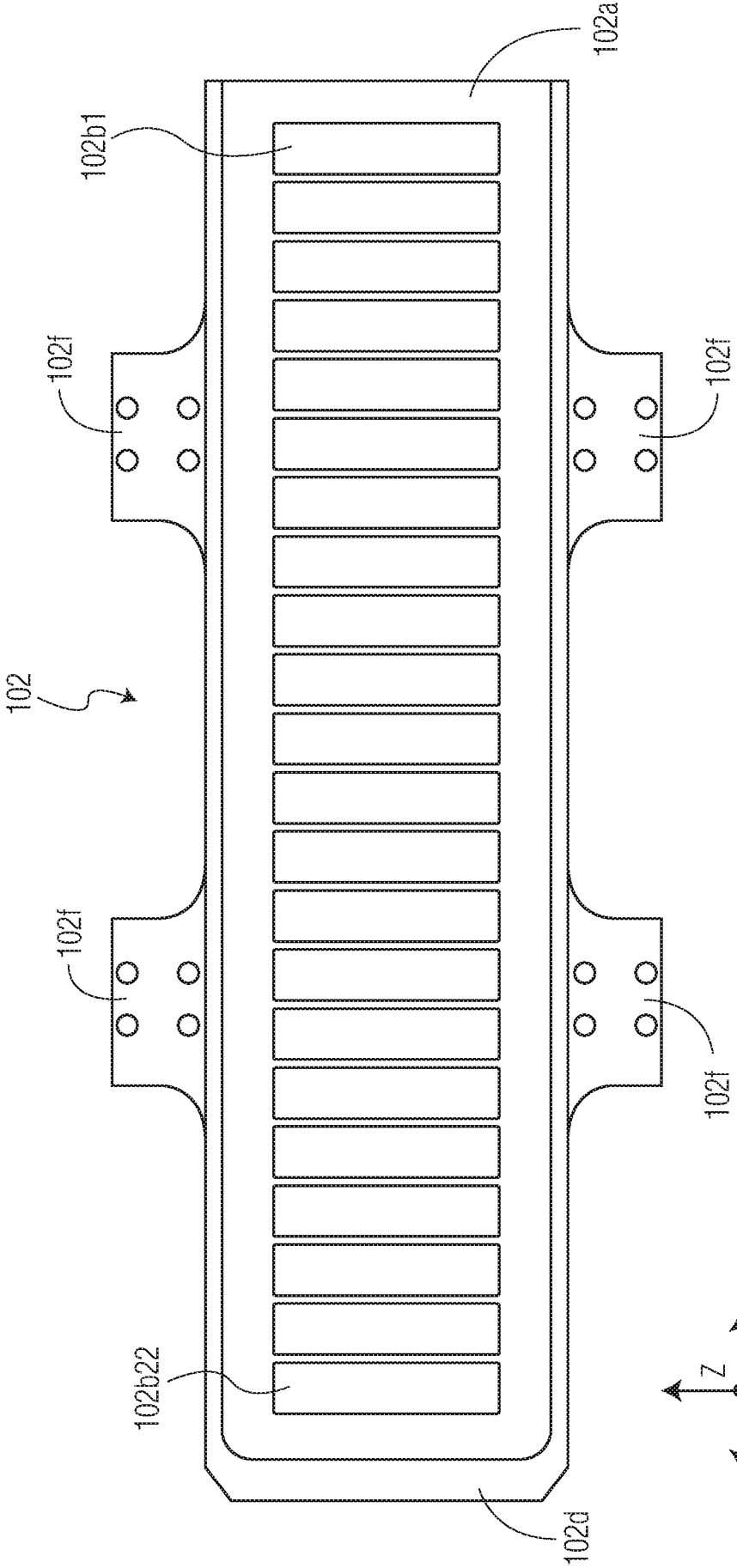


FIG. 5E

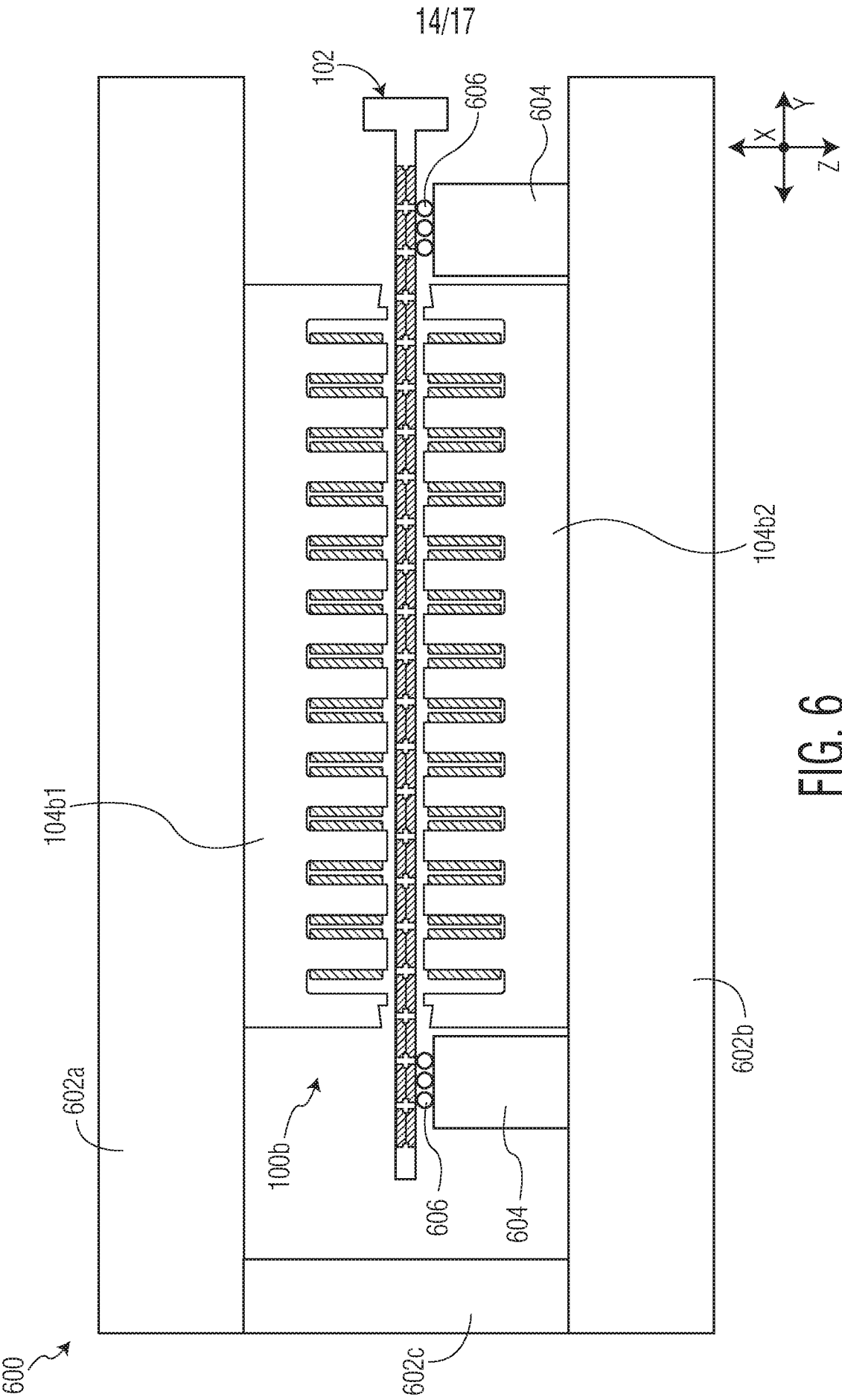
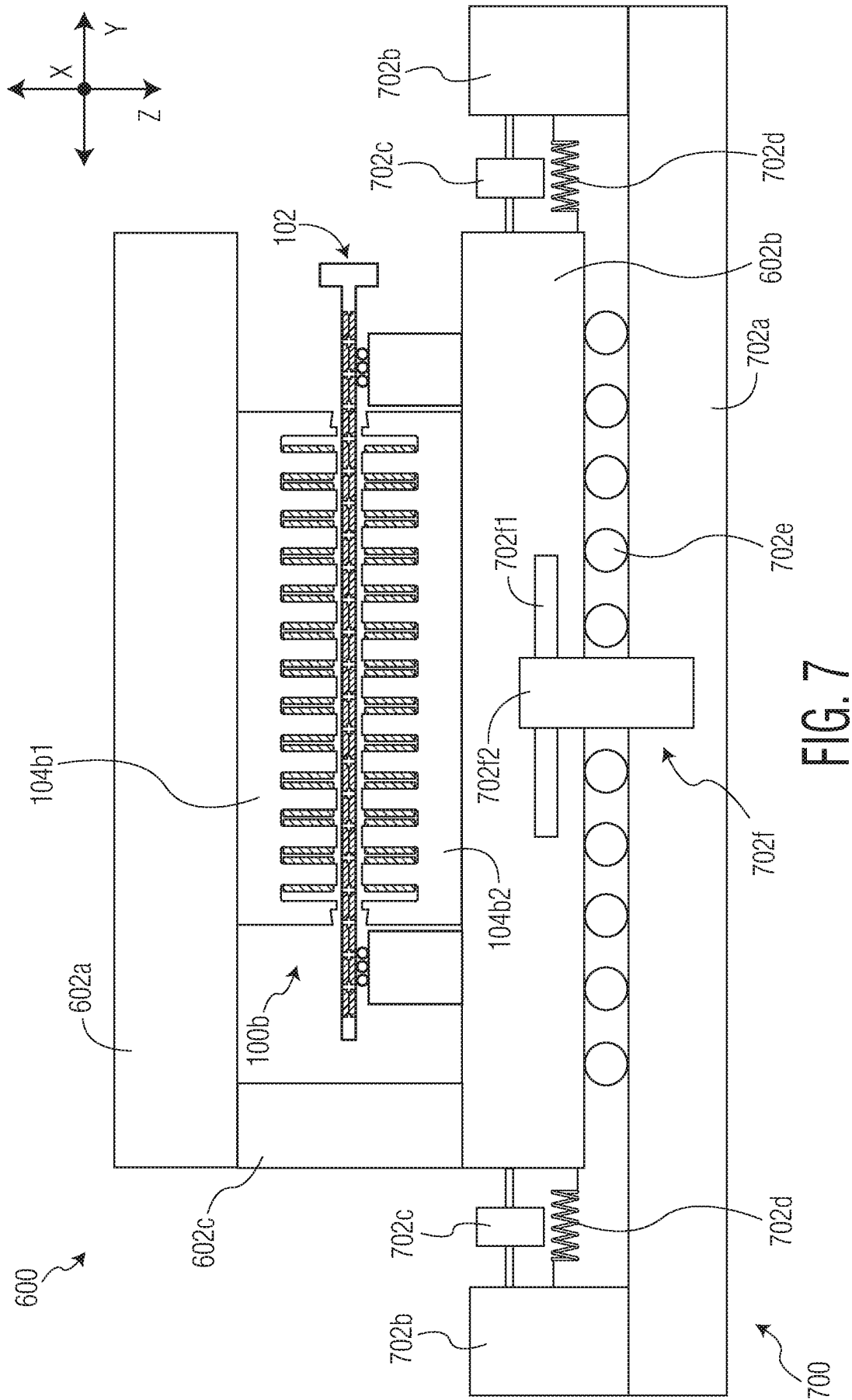


FIG. 6



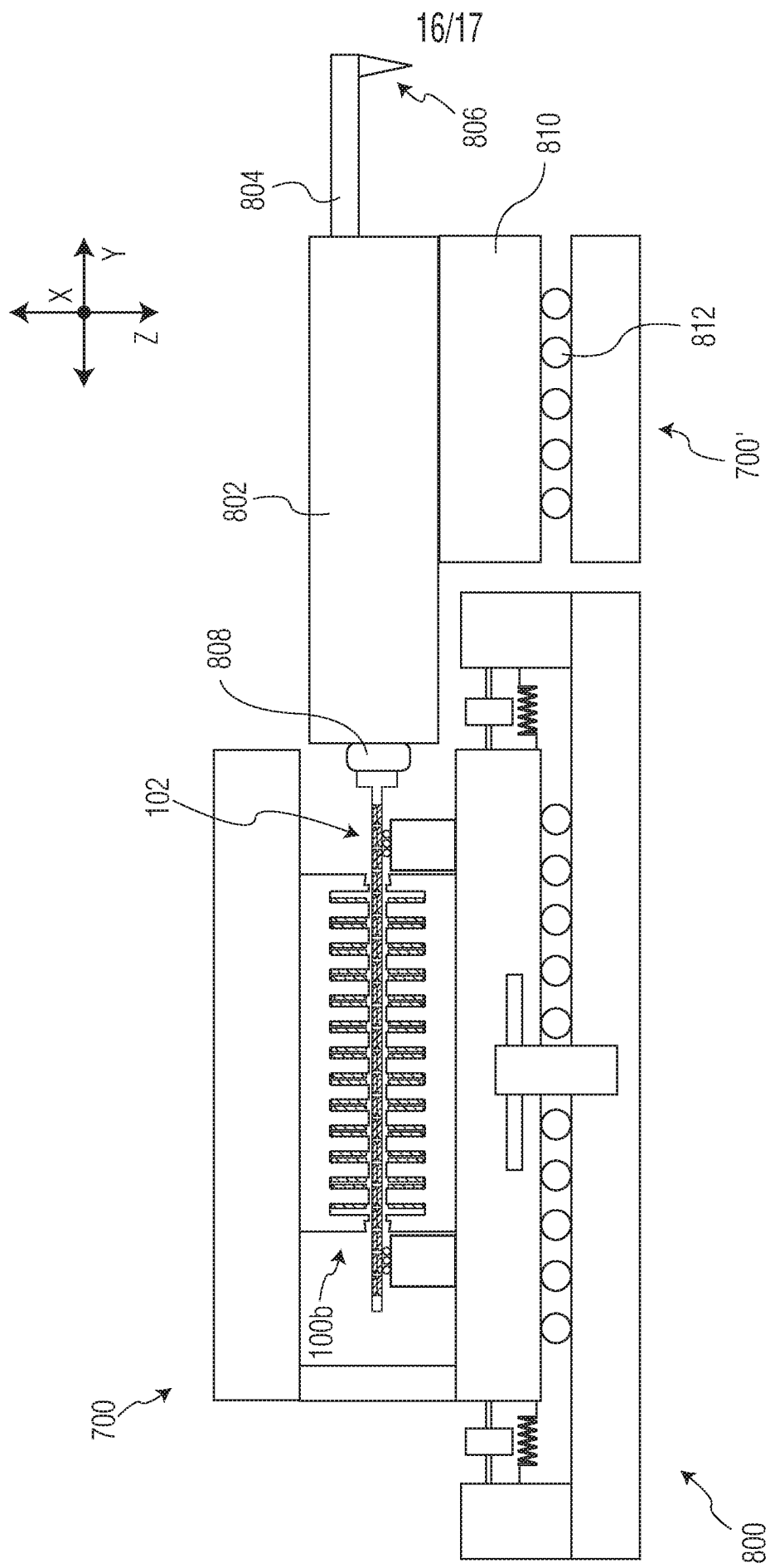
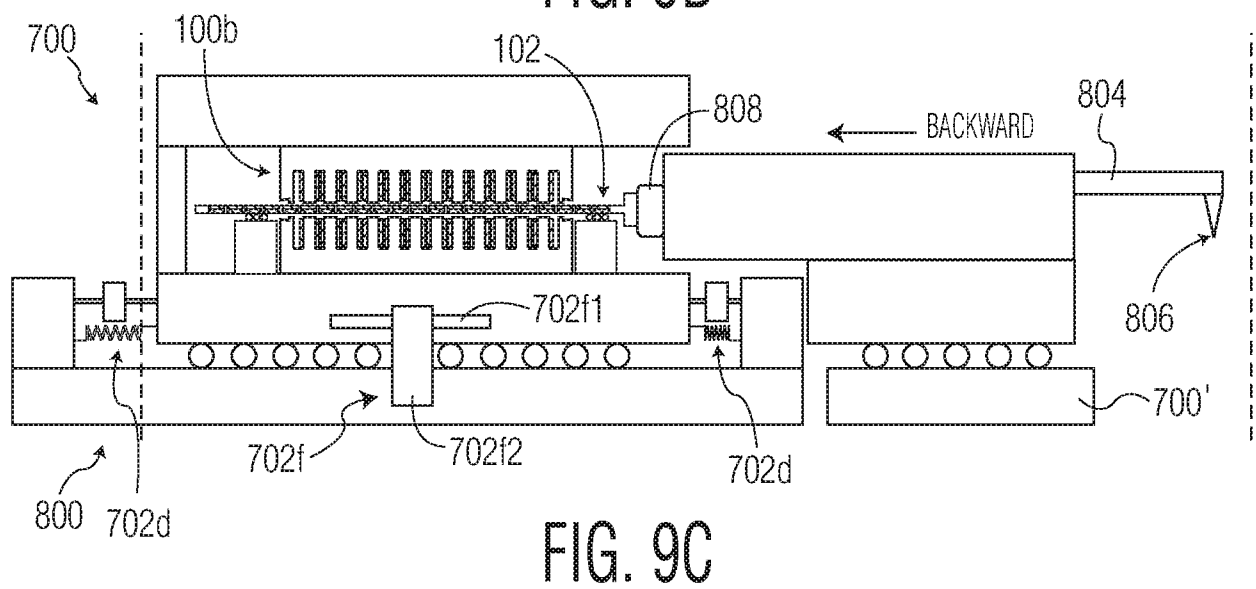
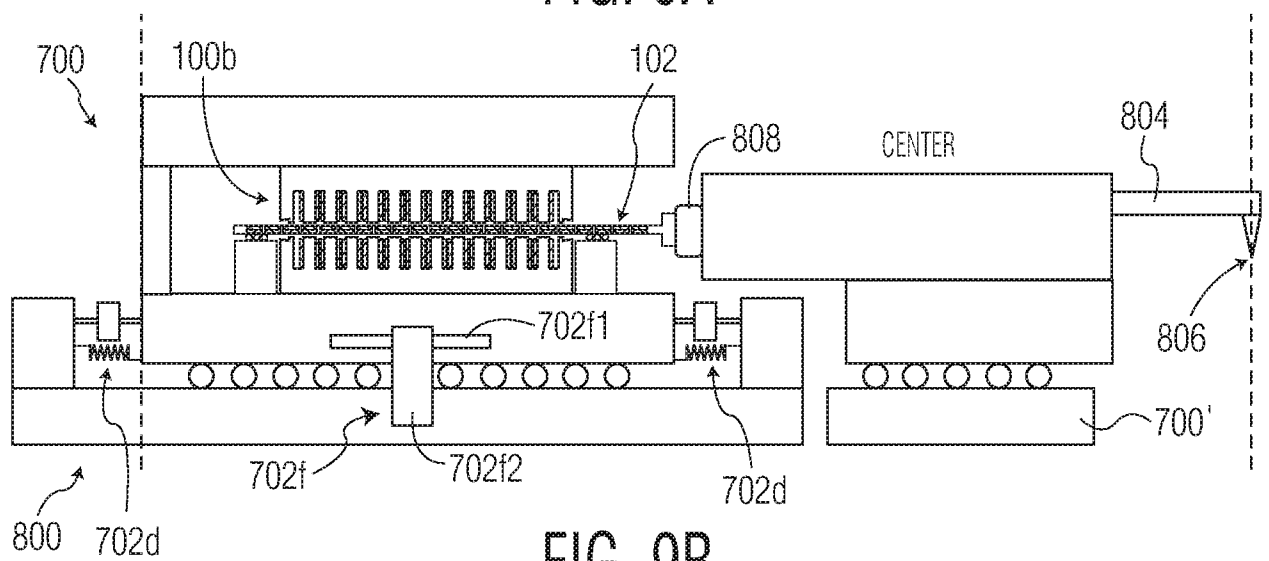
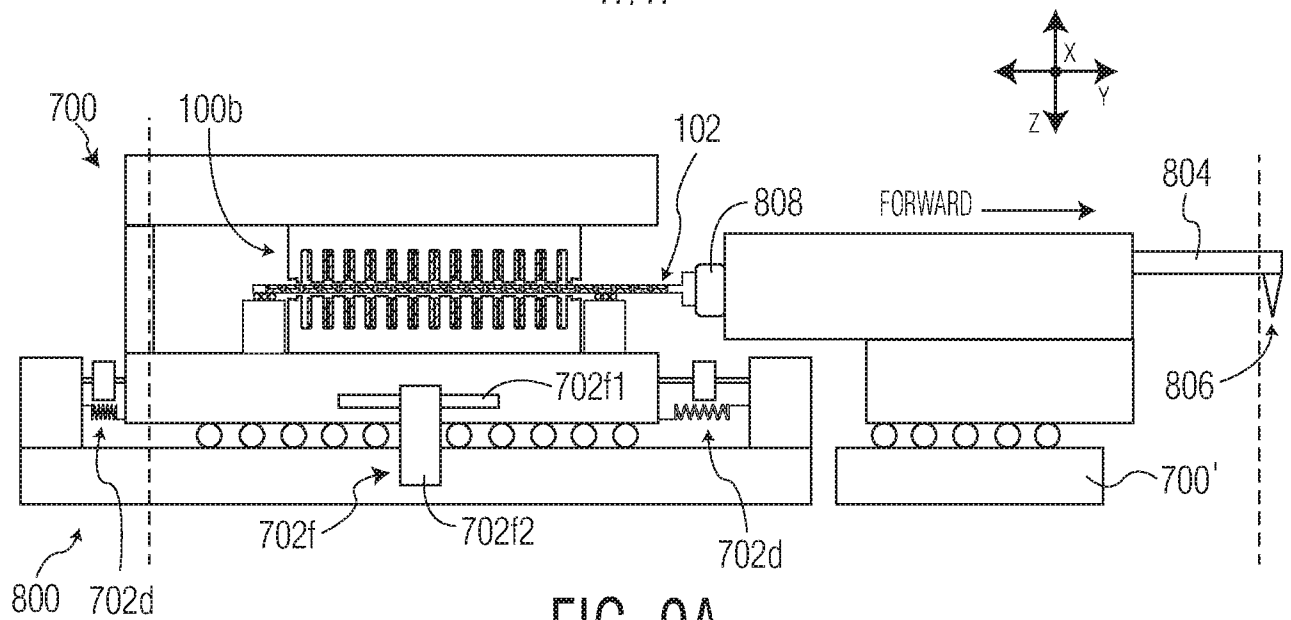


FIG. 8

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A. CLASSIFICATION OF SUBJECT MATTER**H02K 41/03(2006.01)i, H02K 35/02(2006.01)i, H02K 1/27(2006.01)i, H02K 3/48(2006.01)i**

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)

H02K 41/03; B66B 013/14; H02K 41/00; H02K 35/02; H02K 1/27; H02K 3/48

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: liner motor, moving magnet assembly, coil assembly, teeth, encoder

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2006-0012251 A1 (KOJI MIYARA et al.) 19 January 2006 See paragraphs [0008], [0046]-[0047], [0049]-[0051], [0068]; and figures 4, 6, 10.	1-19
Y	US 2010-0225179 A1 (XIAOPENG WANG) 09 September 2010 See paragraphs [0020]-[0021], [0045], [0047]; and figure 1.	1-19
Y	US 2007-0096567 A1 (YASUHIRO MIYAMOTO et al.) 03 May 2007 See paragraph [0047]; and figure 4A.	12
Y	US 2006-0232141 A1 (AKIHIRO TERAMACHI et al.) 19 October 2006 See paragraph [0044]; and figures 2, 6.	13-16
Y	US 2002-0050426 A1 (KOUKI YAMAMOTO et al.) 02 May 2002 See claim 3; and figures 2-4.	19



Further documents are listed in the continuation of Box C.



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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

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"&" document member of the same patent family

Date of the actual completion of the international search

27 July 2020 (27.07.2020)

Date of mailing of the international search report

28 July 2020 (28.07.2020)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2020/028479

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2006-0012251 A1	19/01/2006	EP 1617546 A2 EP 1617546 A3 JP 2006-034017 A	18/01/2006 05/04/2006 02/02/2006
US 2010-0225179 A1	09/09/2010	TW 200838098 A TW I405389 B US 7825549 B2 WO 2008-079144 A1	16/09/2008 11/08/2013 02/11/2010 03/07/2008
US 2007-0096567 A1	03/05/2007	CN 100553085 C CN 1965460 A JP 4702629 B2 KR 10-1066357 B1 KR 10-2007-0021184 A TW I362162 B US 7659641 B2 WO 2005-122369 A1	21/10/2009 16/05/2007 15/06/2011 20/09/2011 22/02/2007 11/04/2012 09/02/2010 22/12/2005
US 2006-0232141 A1	19/10/2006	CN 1765046 A CN 1765046 B EP 1615322 A1 EP 1615322 A4 EP 1615322 B1 JP 2004-312983 A JP 4259978 B2 KR 10-1023564 B1 KR 10-2005-0115924 A TW 200427186 A TW I233249 B US 7456526 B2 WO 2004-086597 A1	26/04/2006 14/04/2010 11/01/2006 26/05/2010 08/05/2013 04/11/2004 30/04/2009 21/03/2011 08/12/2005 01/12/2004 21/05/2005 25/11/2008 07/10/2004
US 2002-0050426 A1	02/05/2002	CN 1217080 C CN 1473235 A EP 1330585 A1 JP 2002-138754 A JP 3972575 B2 KR 10-0775423 B1 KR 10-2003-0040568 A KR 10-2007-0039138 A TW 561130 B US 2003-0037996 A1 US 6467584 B2 US 6675938 B2 WO 02-36917 A1	31/08/2005 04/02/2004 30/07/2003 17/05/2002 05/09/2007 12/11/2007 22/05/2003 11/04/2007 11/11/2003 27/02/2003 22/10/2002 13/01/2004 10/05/2002