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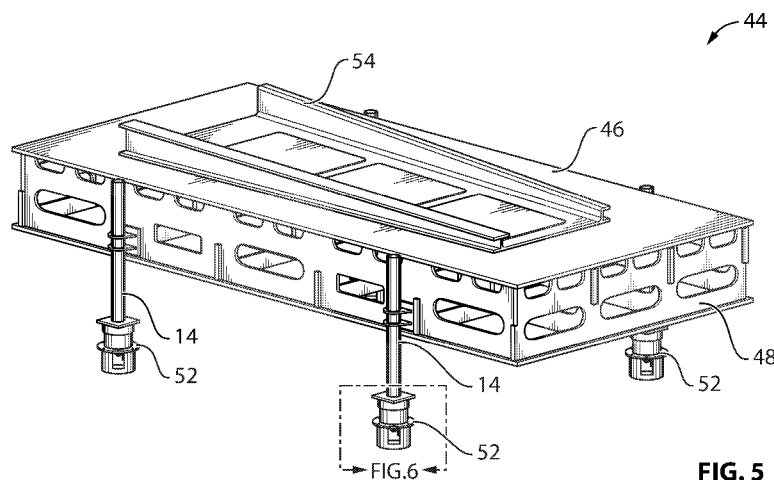
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(54) Title: APPARATUS, SYSTEM, AND METHOD FOR VIBRATION-ASSISTED CONSOLIDATION AND DEGASSING OF COMPOSITE FIBER ELEMENTS

**FIG. 5**

(57) Abstract: An apparatus for assisting in the preparation of a composite fiber element includes a mold (18) having a surface onto which the composite fiber element is positionable, a first vibration generator (16) operatively connected to the mold to impart a first vibration having a first frequency F1 into the mold (18), a second vibration generator (16) operatively connected to the mold to impart a second vibration having a second frequency F2 into the mold, the second frequency being different from the first frequency so as to establish a beating frequency F3, and a controller (38) operatively connected to the first vibration generator (16). The controller (38) is adapted to adjust at least one of the first frequency and an amplitude of the first vibration. A method also is described for consolidating and degassing a composite fiber element. In addition, a damper (52), operable with the apparatus, is described.

**APPARATUS, SYSTEM, AND METHOD FOR
VIBRATION-ASSISTED CONSOLIDATION AND
DEGASSING OF COMPOSITE FIBER ELEMENTS**

Cross-Reference to Related Application(s)

[0001] This International PCT Patent Application relies for priority on U.S. Provisional Patent Application Serial No. 62/006,431, filed on June 2, 2014, the entire content of which is incorporated herein by reference.

Field of the Invention

[0002] The present invention concerns an apparatus and a method for the consolidation of composite fiber elements, such as those used for the construction of composite parts for aircraft and the like. More specifically, the present invention concerns an apparatus and method for the consolidation and degassing of composite fiber elements utilizing controlled vibrations applied to the composite fiber elements.

Background of the Invention

[0003] During the preparation of composite fiber elements, proper degassing and consolidation of the components prior to curing help to improve the overall quality of the composite elements. Existing methods used for degassing and consolidating composite fiber elements have numerous deficiencies.

[0004] In particular, the prior art relies on the application of a single frequency vibration to a composite element to degas the element. Typically, the vibrations are at high frequency, such as ultrasonic vibrations.

[0005] One difficulty with applying high frequency vibrations to composite fiber elements lies in the effect that high frequency vibrations (especially ultrasonic vibrations) have on materials. In particular, high frequency vibrations tend to heat the materials to which they are applied. In the case of uncured composite fiber elements, this is detrimental, because heating may cause the composite fiber element to cure prematurely.

[0006] As such, there remains a need for apparatuses, systems, and methods to improve the debulking and degassing of composite fiber elements while avoiding premature curing thereof.

Summary of the Invention

[0007] The present invention addresses one or more of the deficiencies apparent in the prior art.

[0008] The present invention provides an apparatus for assisting in the preparation of a composite fiber element. The apparatus includes a mold having a surface onto which the composite fiber element is positionable, a first vibration generator operatively connected to the mold to impart a first vibration having a first frequency into the mold, a second vibration generator operatively connected to the mold to impart a second vibration having a second frequency into the mold, the second frequency being different from the first frequency so as to establish a beating frequency, and a controller operatively connected to the first vibration generator. The controller is adapted to adjust at least one of the first frequency and an amplitude of the first vibration.

[0009] In one contemplated embodiment, the controller also may be operatively connected to the second vibration generator.

[0010] In another contemplated embodiment, the controller may sweep through a range encompassing the first frequency.

[0011] It is contemplated that the apparatus may operate such that the beating frequency F_3 is established according to the equation $F_1 - F_2 = F_3$, where F_1 is the first frequency and F_2 is the second frequency.

[0012] In a further embodiment, the apparatus may include a plurality of vibration generators operatively connected to the mold to impart a plurality of vibrations having a plurality of frequencies into the mold. The controller may adjust at least one of the plurality of frequencies and an amplitude of at least one of the plurality of frequencies.

[0013] The apparatus of the present invention also may include a first signal generator operatively connected between the controller and the first vibration generator to receive a first control signal from the controller and generate a first vibration signal for input into the first vibration generator.

[0014] Still further, the apparatus of the present invention may include a second signal generator operatively connected between the controller and the second vibration generator to receive a second control signal from the controller and generate a second vibration signal for input into the second vibration generator.

[0015] In one contemplated embodiment, the controller is a plurality of controllers.

[0016] In another contemplated embodiment, the composite fiber element encompasses fibers immersed in resin and/or fibers are pre-impregnated with the resin.

[0017] It is contemplated that the first frequency F_1 and the second frequency F_2 both are less than about 1 kHz. In another embodiment, the first frequency F_1 and the second frequency F_2 are both less than about 500 Hz.

[0018] The present invention also provides for a method for manufacturing a composite fiber element. The method includes depositing a composite fiber element onto a surface of a mold, applying a first vibration comprising a first frequency F_1 to the mold, applying a second vibration comprising a second frequency F_2 to the mold, establishing a combined waveform with a beating frequency F_3 according to the equation $F_1 - F_2 = F_3$, and sweeping at least the first frequency F_1 of the first vibration.

[0019] It is contemplated that the method also may include applying an n^{th} wave form with an n^{th} frequency F_n to the mold. If so, the beating frequency F_3 also is contemplated to accommodate the n^{th} frequency F_n .

[0020] In one embodiment of the method, the second frequency F_2 is subjected to sweeping.

[0021] In the method of the present invention, the first vibration may be applied to the mold by a first vibration generator and the second vibration may be applied to the mold by a second vibration generator.

[0022] The present invention also provides for a damper that includes a housing, a shaft extending through the housing, a first stack of pistons disposed on the shaft, a second stack of pistons disposed in the housing, and a plurality of elastomeric washers disposed between the first stack of pistons and the second stack of pistons. The first stack of pistons moves together with the shaft when subjected to vibration such that the first stack of pistons moves in relation to the second stack of pistons, thereby deforming the plurality of elastomeric washers.

[0023] In this regard, it is contemplated that the plurality of elastomeric washers are made from silicone rubber.

[0024] The plurality of elastomeric washers alternatively may be made from a high temperature elastomer.

[0025] Regardless of the type of material selected, it is contemplated that the plurality of elastomeric washers deform with a predetermined hysteresis.

[0026] The plurality of elastomeric washers are contemplated to exhibit a first force curve when loaded and a second force curve when unloaded.

[0027] In addition, the damper is contemplated to include a cover adjustably connected to the housing. Adjustment of the cover is contemplated to alter operation of the plurality of elastomeric washers.

[0028] In another embodiment, the damper includes a nut threadedly engaging a bottom end of the shaft. Adjustment of the nut is contemplated to alter a rigidity of the plurality of elastomeric washers.

[0029] Other aspects of the present invention will be made apparent from the discussion that follows.

Brief Description of the Drawings

[0030] One or more embodiments of the present invention are described with reference to the accompanying drawings, in which:

[0031] Fig. 1 is a graphical, top view of one contemplated embodiment of a composite fiber element forming apparatus according to the present invention;

[0032] Fig. 2 is a graphical, top view of another contemplated embodiment of a composite fiber element forming apparatus according to the present invention;

[0033] Fig. 3 is a graphical, top view of a variant of the embodiment of the composite fiber element forming apparatus illustrated in Fig. 1, indicating zones of control for groups of vibration generators connected to the mold portion of the composite fiber element forming apparatus;

[0034] Fig. 4 is a perspective, bottom view of the composite fiber element forming apparatus illustrated in Fig. 3;

[0035] Fig. 5 is a perspective, top view of the composite fiber element forming apparatus illustrated in Fig. 4;

[0036] Fig. 6 is an enlarged detail of the bottom of one of the legs illustrated for the composite fiber element forming apparatus shown in Fig. 5;

[0037] Fig. 7 is a perspective, cross-sectional detail of the interior of a damper incorporated into the bottom of the leg illustrated in Fig. 6;

[0038] Fig. 8 is a cross-sectional side view of the damper illustrated in Fig. 7;

[0039] Fig. 9 is a partial, cross-sectional side view of selected, operative elements of the damper illustrated in Fig. 8, showing the damper in an expanded (or unloaded) condition;

[0040] Fig. 10 is a partial, cross-sectional side view of selected, operative elements of the damper illustrated in Fig. 8, showing the damper in a partially compressed (or partially loaded) condition;

[0041] Fig. 11 is a graph illustrating a hysteresis characteristic of one or more of the plurality of elastomeric washers forming a part of the damper illustrated in Fig. 7;

[0042] Fig. 12 is a perspective illustration of the damper in Fig. 7, with the damper being provided for an embodiment of a leg for the composite fiber element forming apparatus having a caster wheel;

[0043] Fig. 13 is a graphical illustration of one contemplated embodiment of a composite fiber element forming system according to the present invention;

[0044] Fig. 14 is a simplified detail of two vibrational frequencies F_1 , F_2 for first and second wave forms introduced into the composite fiber element forming apparatus according to the invention, the illustration also showing a beating frequency F_3 generated as a result of interference between the first and second wave forms;

[0045] Fig. 15 is a graphical illustration, more detailed than that of Fig. 14, showing two vibrational frequencies F_1 , F_2 (as may be viewed, for example, by an oscilloscope) introduced into the composite fiber element forming apparatus according to the invention and also illustrating the beating frequency generated as a result of interference between the two wave forms;

[0046] Fig. 16 is a graphical illustration of a standing wave that may be generated by four vibration generators according to the present invention;

[0047] Fig. 17 is a graphical illustration of the distorted, randomized wave pattern resulting from introduction of an amplitude sweep of the standing wave shown in Fig. 16;

[0048] Fig. 18 is a perspective illustration of another embodiment of a table on which an aircraft component is placed for curing according to the present invention;

[0049] Fig. 19 is a flow chart illustrating one contemplated method according to the present invention;

[0050] Fig. 20 is a cross-sectional, enlarged detail of a portion of a composite fiber element that has not been created in accordance with the present invention; and

[0051] Fig. 21 is a cross-sectional, enlarged detail of a portion of a composite fiber element that has been created in accordance with the present invention.

Detailed Description of Embodiment(s) of the Invention

[0052] The present invention will now be described in connection with one or more embodiments thereof. Elements from individual embodiments are contemplated to be substitutable for elements in other embodiments. In addition, those skilled in the art will appreciate one or more variations and/or equivalents after appreciating the discussion that follows. Those variations and equivalents are considered to be encompassed by the present invention as if described herein.

[0053] Fig. 1 is a graphical top view of a first embodiment of a composite element forming apparatus 10 according to the present invention. The composite element forming apparatus 10 includes a table 12 supported by a plurality of legs 14. The table 12 includes a number of vibration generators 16 disposed thereon.

[0054] In Fig. 1, the table 12 is illustrated as being rectangular in shape. The table 12, however, need not be rectangular. The table 12 may take any suitable shape without departing from the scope of the present invention. In addition, it is contemplated that the table 12 may be made from any suitable material including, but not limited to steel, alloys of steel, aluminum, alloys of aluminum, metals, metal alloys, plastics, composites, ceramics, plastics, and/or any combination thereof. The material from which the table 12 is constructed is not critical to the operation of the composite element forming apparatus 10 of the present invention.

[0055] As may be apparent from Fig. 1, four legs 14 are provided to support the table 12. Alternative embodiments of the composite element forming apparatus 10 of the present invention

may include a larger or a fewer number of legs 14. In other words, the number of legs 14 is not critical to the construction of the composite element forming apparatus 10 of the present invention. As should be apparent to those skilled in the art, larger tables 12 are contemplated to include a larger number of legs 14.

[0056] As also may be apparent in Fig. 1, the table 12 includes seven (7) vibration generators 16. While seven vibration generators 16 are shown, the present invention is not contemplated to be limited thereto. The composite element forming apparatus 10 may include a larger or a fewer number of vibration generators 16. The vibration generators 16 may be piezoelectric devices, transducers, motors, accelerators, or any other type of generator as should be understood by those skilled in the art.

[0057] As also illustrated in Fig. 1, the composite element forming apparatus 10 includes a mold 18 disposed on the table 12. The mold 18 defines a surface that establishes one or more contoured features for the composite fiber element that is formed thereon. The mold 18 may be made from any suitable material. In one embodiment, it is contemplated that the mold 18 may be affixed to the table 12. In another contemplated embodiment, the mold 18 may be removably connected to the table 12. In yet another contemplated embodiment, the mold 18 may sit freely on table 12 without being directly connected thereto. And in yet another contemplated embodiment, the mold 18 may be large enough to form the table itself, such that the legs 14 are attached directly to the mold 18. Such an embodiment may be applicable for molds for large curved surfaces, such as for an aircraft wing, for example.

[0058] Fig. 2 is a graphical, top view of a composite element forming apparatus 20 according to another embodiment of the present invention. Fig. 2 illustrates that the composite element forming apparatus 20 of the present invention may include a larger number of vibration generators 16 than the composite element forming apparatus 10 illustrated in Fig. 1. In the non-limiting embodiment shown, the composite element forming apparatus 20 comprises thirteen (13) vibration generators 16, however, it is to be understood that any suitable number of vibration generators 16 could be used. In addition, the distribution of the vibration generators 16 differs for the composite element forming apparatus 20 than for the composite element forming apparatus 10.

[0059] Fig. 2 also illustrates a number of molds 22, 24, 26, 28, 30 that are positioned on the table 12. It is contemplated that the table 12 may carry a single mold 18 or a plurality of

molds 22, 24, 26, 28, 30. The exact number and size of the molds, 18, 22, 24, 26, 28, 30 is not critical to the operation of the present invention. In addition, as should be apparent from the foregoing, the surface of the table 12 may form all of or a portion of a mold for formation of the composite element, such that the mold is integrally formed with the surface of the table 12.

[0060] In connection with Figs. 1 and 2, it is noted that the distribution of the vibration generators 16 may be varied without departing from the scope of the present invention. A large number of variables are contemplated to influence the positioning of the vibration generators 16. For example, the shape of the table 12, the shape and thickness of the mold 18, 22, 24, 26, 28, 30, and the frequency of the vibration generators 16, etc., may each play a role in the location and placement of the vibration generators 16 on the table 12. A person of skill in the art would be able to determine the appropriate positioning of the vibration generators 16 on the table 12 depending on the variables present for a given situation.

[0061] Fig. 3 is a graphical illustration of the composite element forming apparatus 10 illustrated in Fig. 1. This illustration of the composite element forming apparatus 10 depicts grouping patterns associated with the vibration generators 16 contemplated for one embodiment of the present invention. In particular, the three vibration generators 16 at the top of the figure form a first zone 32. The vibration generator 16 in the middle of the table 12 defines a second zone 34. The three vibration generators 16 at the bottom of the figure define a third zone 36. The first zone 32 is contemplated to be connected to a first controller 38, the second zone 34 is contemplated to be connected to a second controller 40. The third zone 36 is contemplated to be connected to a third controller 42. It is noted that three controllers 38, 40, 42 are not required for the present invention. To the contrary, only a single controller may be employed for the composite element forming apparatus 10.

[0062] Fig. 4 is a perspective, bottom view of a composite element forming apparatus 44 according to the present invention. The composite element forming apparatus 44 includes a surface 46 that is supported by a plurality of structural ribs 48 and a sub-frame 50. The surface 46 is contemplated to form the table 12 that supports one or more of the molds 18, 22, 24, 26, 28, 30. Several vibration generators 16 are connected to the structural ribs 48 in this contemplated embodiment. As may be apparent, the vibration generators 16 alternatively may be connected to any suitable portion of the composite element forming apparatus 44 to transmit vibrations to the surface 46 thereof.

[0063] As also shown in Fig. 4, the legs 14 may include dampers 52 thereon, which are described in greater detail in connection with Figs. 5-12.

[0064] Fig. 5 is a perspective, top view of the composite element forming apparatus 44 illustrated in Fig. 4. In this view, the mold 54 is illustrated after having been deposited on the surface 46 of the composite element forming apparatus 44. As noted, the surface 46 forms the table 12 onto which one or more molds 18, 22, 24, 26, 28, 30, 54 may be positioned. It is noted that the element designated "54" also may be a composite fiber element that has been formed on the surface 46 using one or more molds 18, 22, 24, 26, 28, 30, 54. In other words, Fig. 5 should not be understood to be limited to the shape of the mold and/or element 54 illustrated thereon.

[0065] Fig. 6 is an enlarged detail of the exterior of the bottom end of one of the legs 14 illustrated in Fig. 5. In particular, Fig. 6 is the portion of the composite element forming apparatus 44 encompassed within the dotted square provided in Fig. 5. As shown, the leg 14 connects to a damper 52. The damper 52, in turn, connects to a footing 56. The footing 56 is contemplated to be connected to a suitable surface, such as a floor or the ground.

[0066] Fig. 7 is a perspective, cross-sectional view of the damper 52 illustrated in Fig. 6. In this view, the damper 52 is positioned between the sub-frame 50 and a ground plane 58, which may or may not be the floor on which the composite element forming apparatus 44 is disposed.

[0067] The damper 52 is provided to isolate the composite element forming apparatus 44 from the ground (or ground plate 58). Being isolated, any vibrations generated by the vibration generators 16 remain isolated to the composite element forming apparatus 44. In addition, the damper 52 isolates the composite element forming apparatus 44 from any vibrations that might be transmitted from the ground plate 58 thereto. In other words, the dampers 52 isolate the composite element forming apparatus 44 so that vibrations produced by the vibration generators 16 may operate without being transmitted (or lost) to the environment and also so that the vibration generators 16 may operate without interference from any external vibration sources.

[0068] The damper 52 includes a housing 60, which is illustrated as being a cylindrical structure. The housing 60 has a removable cover 62 that threadedly engages the top end of the housing 60. An annular flange 64 extends outwardly from the bottom of the housing 60. The annular flange 64 may be attached to suitable substrate, such as the ground plate 58. Holes 66 in the annular flange 64 align with holes 68 in the ground plate 58 so that a suitable fastener may connect the annular flange 64 to the ground plate 58. Alternatively, the annular flange 64 may

be connected to the ground plate 58 via any other suitable means including, but not limited to, adhesives, welding, etc.

[0069] A shaft 70 extends along a central axis of the damper 52. The shaft 70 extends through a hole 72 in the cover 62. The shaft 70 also extends through a hole 74 in the bottom plate 76 of the housing 60. In addition, the shaft 70 passes through a hole 78 in the subframe 50 and a hole 80 in the lowest-most piston 82 within the housing 60. A nut 84 secures the top end of the shaft 70 to the sub-frame 50. A second nut 86 secures the shaft 70 at the bottom end of the damper 52.

[0070] Fig. 8 is a cross-sectional view of the damper 52 arrangement illustrated in Fig. 7. This view provides additional details with respect to the damper 52. In particular, the housing 60 contains a first piston stack 88 and a second piston stack 90. The first piston stack 88 is attached to the shaft 70 and moves with the shaft 70. The second piston stack 90 is connected to, sits upon, and/or is pressed against the bottom plate 76 of the damper 52 and remains stationary with respect to the movement of the shaft 70 due to the tightening pressure provided by the cap 62. The damper 52 is contemplated to include elastomeric washers 92 between the individual pistons forming the piston stacks 88, 90. The elastomeric washers 92 are contemplated to be made from a compressible material that exhibits a suitable hysteresis when compressed. An elastomeric washer 94 is provided on the interior surface of the cover 62 to act as a stop for the top-most piston 96 of the first piston stack 88. Alternatively, the elastomeric washer 96 (also referred to as a spacer) may be any other type of elastic suspension element including, but not limited to, an elastic washer, a flat spring, a coil spring, or the like.

[0071] Figs. 9 – 10 illustrate one contemplated mode of operation of the damper 52. To simplify the discussion of the operation of the damper 52, only relevant portions of the damper 52 are illustrated. It is noted, however, that the construction of the damper 52 is contemplated to be consistent with Figs. 7 and 8 and that omitted portions are merely to simplify the discussion associated with Figs. 9 – 10.

[0072] As shown in Fig. 9, the first piston stack 88 includes five pistons 98 that are equidistantly spaced from one another. The pistons 98 are rigidly separated from one another by spacer bushings 100 (or spacers 100). Similarly, the piston stack 90 includes five pistons 102 separated from one another by spacer rings 104 (or spacers 104).

[0073] In the illustrated embodiment, while five pairs of pistons 98, 102 are illustrated, a larger or a fewer number of pairs may be employed without departing from the scope of the present invention. It is noted that the pistons 98, 102 are contemplated to be employed in pairs, as discussed in connection with the operation of the damper below.

[0074] In Figs. 9 – 10, the pairs of pistons 98, 102 are contemplated to be equidistantly spaced from one another. It is contemplated, however, that the spacing between each pair of pistons 98, 102 may vary, as required or as desired.

[0075] Fig. 9 is a graphical side view of the damper 52 in an unloaded (or fully extended) condition. Fig. 10 illustrates the damper 52 in a partially loaded (or compressed) condition.

[0076] As may be apparent from Fig. 9, the elastomeric washers 92 bias the piston stacks 88, 90 into contact with one another when the damper 52 is in the fully extended position. When the vibration generators 16 are active, it is contemplated that the shaft 70 will move in the direction of the arrows 106. As should be apparent from Fig. 9, the damper 52 operates only after it is in the partially loaded condition. Once partially loaded, the shaft 70 has sufficient clearance to move in the direction of the arrows 106.

[0077] Fig. 10 illustrates the first piston stack 88 in a position where it has moved with respect to the second piston stack 90. In this illustration, the elastomeric washers 92 are compressed and the pistons 98 are at an intermediate position between adjacent ones of the pistons 102. As may be apparent to those skilled in the art, the degree of compression of the elastomeric washers 92 is merely exemplary.

[0078] As noted above, the elastomeric washers 92 are contemplated to be made from a material that exhibits hysteresis when in compression and expansion. Fig. 11 illustrates one example of what is meant by hysteresis.

[0079] As illustrated in Fig. 11, “hysteresis” is defined as a dynamic lag between the compression and expansion of the material used for the elastomeric washers 92. In particular, it is contemplated that the elastomeric washers 92 will compress more rapidly than they expand. This is due, at least in part, to the larger surface area of the elastomeric washers 92 when loaded versus the smaller surface area of the washers 92 when unloaded (or loaded to a lesser degree). As a result, there is a delay between compression (*i.e.*, loading) and expansion (*i.e.*, unloading) that assist with isolation of the composite element forming apparatus 44 from the surrounding environment.

[0080] Materials that exhibit hysteresis include, but are not limited to, high temperature elastomers. One example of a high temperature elastomer is silicone rubber. As should be apparent to those skilled in the art, however, other materials may be employed without departing from the scope of the present invention.

[0081] The hysteresis effect associated with the elastomeric material forming the elastomeric washers 92 is designed to damp a large spectrum of vibrations while permitting passage of only a narrow band of frequencies. In addition, the cover 62, which theadedly engages the housing 60, is contemplated to provide adjustability to the responsiveness of the elastomeric washers 92. In particular, as the cover 62 is tightened onto the housing 60, the cover 62 applies progressively increasing pressure to the elastomeric washers 94. As such, as the cover 62 is screwed more tightly onto the housing, the range of motion for the damper 52 changes. In other words, the responsiveness of the damper 52 is controllable by adjusting the degree to which the cover 62 is screwed onto the housing 60.

[0082] While the damper 52 is illustrated as being reliant on the elastomeric washers 92, 94 as the damping media, it is contemplated that the damper 52 may be a closed device that is filled with a suitable fluid for enhanced damping capacity, as required or as desired. For example, the damper 52 may be filled with air, water, oil, or the like.

[0083] As should be apparent to those skilled in the art, the damper 52 may operate as a low frequency band pass filter, which filters selected frequencies of vibrations. As noted above, the operational range of the damper 52 may be altered by adjusting the degree of tightness of the cover 62. With this construction, it is contemplated that the damper 52 operates at the range of frequencies of vibrations applied by the vibration generators 16, permitting the mold 54 to vibrate freely at a predetermined frequency.

[0084] In connection with the damper 52, it is further noted that the first piston stack 88 is compressed against the second piston stack 90 by the nut 86, making the damper 52 more or less rigid. The more the nut 86 is tightened, the more rigid the damper 52 becomes. As the rigidity of the damper 52 is increased, the range of the damping frequency is decreased (or narrowed). At the same time, the responsiveness of the damper 52 shifts to higher frequencies. In other words, as the nut 86 is tightened, the damper 52 operates within a narrower range and at a higher frequency. Thus, the nut 86 permits the damper 52 to be tuned across a wide range of frequencies in the low frequency domain. The nut 86 is contemplated to adjust the damping

characteristics of the damper 52 while the cover 62 adjusts the frequency pass characteristics of the damper 52.

[0085] Fig. 12 is a perspective illustration of a variant of the leg 14 illustrated in Fig. 6. In this illustration, a caster wheel 108 is illustrated. The caster wheel 108 includes a connection plate 110, a wheel 112, and a damper support 114 attached to the wheel 112 and the connection plate 110. Vertical struts 116 connect the connection plate 110 to the damper support 114 and the wheel 112. The damper support 114 carries the damper 52, which functions in the manner discussed above. The damper 52 is contemplated to replace the spring 118 in this arrangement.

[0086] Fig. 13 is a graphical illustration of a composite element consolidation system 120 according to the present invention. The system 120 includes two vibration generators 16 connected to the table 12. As will be made apparent from the discussion that follows, it is contemplated that the system 120 relies on two or more vibration generators 16. While it is possible for the present invention to be implemented using one vibration generator 16, at least theoretically, the present invention contemplates reliance on two or more vibrations generators 16 as a practical matter.

[0087] As illustrated in Fig. 13, the vibration generators 16 are connected to the table 12 in a manner such as illustrated in Fig. 4. Each vibration generator 16 is connected to a signal generator 122. Each signal generator 122 is, in turn, coupled to a profile generator 124, also referred to herein as a controller 124. The profile generators 124 may be computers or other devices capable of running executable code, such as software. The signal generators 122 interpret the signals generated by the controllers 124 and generate suitable input signals for the vibration generators 16 to operate. While the composite element consolidation system 120 is illustrated as including two signal generators 122 and two profile generators or controllers 124, it is contemplated that one or more of the components may be combined into a single device, as required or as desired.

[0088] The term controller 124, as used in the context of the present invention, is intended to be broadly applicable to any of a number of devices. For example, the controller 124 may include a frequency generator with the capability of generating different waveforms and frequencies, as well as to sweep the frequencies. The controller 124 also may include one or more of a spectrum analyzer, an oscilloscope, and an upper logic controller such as a programmable logic controller, among others. As may be apparent, the programmable logic

controller is contemplated to be the element that controls the operation of the present invention, as the programmable logic controller is contemplated to be able to control multiple frequencies, generators, and complex equipment configurations and combinations that fall within the scope of the present invention.

[0089] With respect to Fig. 13, it is noted that the signal generator 122 may be replaced with an amplifier. In such an arrangement, signal generation is provided, via software, by the controller 124. In this contemplated arrangement, the controller 124 executes software that may provide real time audio spectrum analysis, oscilloscope functionality, and signal generation (among other functions). The signal generated by the controller 124 is transmitted to the vibration generators 16. In the illustrated example, the frequency waveform also is displayed graphically to the user via a display monitor connected to the controller 124.

[0090] Fig. 13 also includes two feedback lines 13. The feedback lines 13 are contemplated to convey signals from accelerometers (*i.e.*, sensors) attached to the table 12. The feedback signals from the accelerometers are provided to the controller 124 so that adjustments in the signals generated by the controller 124 may be adjusted, as required or as desired. It is noted that the application of frequency waveforms and patterns to the table 12 need not be continuous. It is contemplated that the signals may be turned on and off, sequentially, according to a predetermined pattern of operation.

[0091] Fig. 13 also illustrates the wave forms 126, 128 that are generated by the vibration generators 16. In particular, for the illustrated example, a first vibration generator 16 introduces a first vibration onto the table 12 at a first location. The first vibration has a first wave form 126. In the illustrated example, the first wave form 126 is a constant amplitude wave with a frequency of 250 Hz. At the same time, a second vibration generator 16 introduces a second vibration onto the table 12 at a second location. The second vibration has a second wave form 128. In the illustrated example, the second wave form 128 has a constant amplitude with a wave frequency of 255 Hz. In the illustrated example, the amplitudes of the wave forms 126, 128 are equal, but the frequencies differ by 5 Hz. As a result, when the wave forms 126, 128 are applied to the table 12, they interfere with one another to create a combined wave form 130. The combined wave form 130 exhibits a beating frequency, which is 5 Hz in the illustrated example. It is noted that the frequency of the resulting waveform remains at about 250 Hz. It is the amplitude of the resulting waveform that exhibits a beating frequency of 5 Hz.

[0092] As should be apparent, the wave forms 126, 128 are merely exemplary of the infinite number of different wave forms 126, 128 that may be used for the composite element consolidation system 120 of the present invention. The present invention, therefore, is not intended to be limited to the wave forms 126, 128, 130 that are illustrated. As should be apparent, the wave forms 126, 128, 130 may be varied in amplitude and frequency without departing from the scope of the present invention.

[0093] Fig. 14 illustrates a second example of wave forms 132, 134, 136 that may be introduced into the table 12 of the composite fiber consolidation system 120 of the present invention. In this example, the first wave form 132 introduced into the table 12 has a constant amplitude and a frequency of 200 kHz. The second wave form 134 has a constant amplitude and a frequency of 199.990 kHz. When these wave forms 132, 134 are introduced into the table 12, the result is a combined wave form 136 with a cyclic amplitude, having a frequency of 10 Hz (*i.e.*, the beating frequency of the resulting waveform is 10 Hz).

[0094] As illustrated, the combined wave forms 130, 136 establish a beating frequency 138 that is characterized, at least in the illustrated embodiment, by a low frequency beat established by the interference between the first wave form 126, 132 and the second wave form 128, 134. With respect to the present invention, the combined wave forms 130, 136 are understood to assist with consolidation of a composite fiber element that is positioned on composite element forming apparatus 44. The combined wave forms 130, 136 also are contemplated to assist with the reduction in the presence of voids within the resin matrix in which the composite fibers are immersed.

[0095] As may be apparent from the foregoing, low frequency vibrations, introduced as the combined wave forms 130, 136 into the table 12 by the vibration generators 16, assist with consolidation of voids in the resin matrix by encouraging the voids to coalesce. These same vibrations assist with consolidation of the composite fiber element. The beating frequency 138 establishes a high amplitude, low frequency “jostling” of the table 12 to facilitate degassing of the resin and also to help with consolidation of the composite fiber element. The combination of these two actions together results in a composite fiber element with reduced voids, as discussed in greater detail below.

[0096] With renewed reference to Fig. 14, and as dictated by basic physics, the amplitude of the combined wave forms 136 is the sum of the first amplitude A_1 of the first wave form 132

and the second amplitude A_2 of the second wave form 134. When the frequencies F_1 , F_2 of the first wave form 132 and the second wave form 134 are synchronous, the amplitude A_3 of the combined wave form 136 is simply the sum of the first and second amplitudes A_1 and A_2 . The following equation, equation (1), illustrates this principle of physics:

$$A_1 + A_2 = A_3 \dots \dots \dots (1).$$

[0097] As also dictated by the rules of physics, if the first frequency F_1 of the first wave form 132 is not synchronous with the second frequency F_2 of the second wave form 134, the first wave form 132 and the second wave form 134 will interfere with one another either constructively or destructively. In the context of the present invention, interference between the first wave form 132 and the second wave form 134 results in the combined wave form 136 that has a beating frequency 138. This beating frequency also is labeled F_3 .

[0098] The beating frequency F_3 (138) of the combined wave form 136 is the difference between the magnitude of the frequency of the second wave form 134 subtracted from the magnitude of the frequency of the first wave form 132. For the sake of simplicity, it is assumed that the second frequency F_2 is less than or equal to the first frequency F_1 . This expression may be presented in the following equations (2) and (3):

$$F_1 - F_2 = F_3 \dots \dots \dots (2).$$

$$F_1 \geq F_2 \dots \dots \dots (3).$$

[0099] As may be apparent, other wave forms with other frequencies F_n may be introduced into the table 12 in addition to the frequency F_1 of the first wave form 132 and the frequency F_2 of the second wave form 134. The introduction of a third wave form (or additional wave forms) with a frequency F_n will further alter the combined wave form 136 applied to the table 12 in accordance with basic rules of physics.

[00100] Fig. 15 illustrates a combined wave form 140 that combines a first wave form with a frequency F_1 of 238.7 Hz and a second waveform with a frequency F_2 of 239.7 Hz. The combined waveform 140 exhibits a beating frequency of 1 Hz.

[00101] As noted in Fig. 15, the frequencies F_1 , F_2 of the first and second waveforms assist with degassing the composite fiber element. The low amplitude regions of the combined waveform 140 assist with coalescing of the bubbles that are degassed from the composite fiber element. The high amplitude regions of the combined waveform 140, when subject to the beating frequency F_3 of 1 Hz, helps to move the plies in the composite fiber element in the radial direction, thereby assisting with consolidation of the plies in the composite fiber element.

[00102] Fig. 16 illustrates one representative pattern of a combined wave form 136, 140 that may be established on the table 12 when vibration generators 16 are positioned at the corners of the table 12. The pattern illustrated in Fig. 16 is a standing wave that has maxima identified by light regions and minima identified by dark regions. As should be apparent from the foregoing, standing waves are not preferred for the combined wave form 136, 140 of the present invention. A standing wave will, by definition, result in an uneven formation of the composite fiber element.

[00103] Fig. 17 is a representative pattern of the combined wave form 136, 140 that is established when a fifth vibration generator 16 is positioned at the center of the table 12 and a sweeping pattern is introduced thereby. As will be described in more detail below, the sweeping pattern is introduced by “sweeping”, or adjusting, the frequency of the waves of one or more of the vibration generators 16 attached to the table 12. The sweeping operation randomizes the pattern established by the combined wave form 136, 140 to prevent the formation of standing waves on the surface of the table 12.

[00104] Fig. 18 illustrates a table 142 that might be employed to create a composite element for a portion of an aircraft. As is apparent, the table 142 defines a curved surface 144 supported by a frame 146. The dampers 52 may be positioned between the curved surface 144 and the frame 146.

[00105] With respect to Fig. 18, it is noted that the table 142 itself functions both as a table 142 and mold. Here, it is contemplated that the composite fiber element will be laid directly onto the curved surface 144. The curved surface 144 is contemplated to include one or more surface features 145 that define aspects of the composite fiber element formed thereon.

[00106] As should be apparent from Fig. 18, the table 142 need not present a flat surface, a horizontal surface, or any other specific angled surface. To the contrary, the table 142 may itself be a mold or a portion of a mold without departing from the scope of the present invention.

[00107] With respect to the present invention, it is noted that beating and sweeping are separate phenomena purposefully applied to the table 12, 142 of the present invention. Beating is described simply as a temporary (*i.e.*, cyclical) increase in the amplitude of the vibration applied to the table 12, 142. "Sweeping" refers to a sweeping of the frequencies F_1 , F_2 of at least one of the first wave form 126, 132 or the second wave form 128, 134 applied to the table 12, 142. Sweeping of one of the frequencies F_1 , F_2 randomizes the combined wave pattern 130, 136 so that standing waves are not established on the surface of the table 12, 142.

[00108] Fig. 19 illustrates one method 150 contemplated by the present invention.

[00109] The method 150 starts at 152.

[00110] From the start at 152, the method 150 proceeds to step 154, where a composite fiber element 148 is deposited on the table 12, 142. The composite fiber element 148 is contemplated to be constructed from one or more layers of composite fiber layers that are stacked on top of one another. Alternatively, the composite fiber layers may be assembled on the table 12, 142, as should be appreciated by those skilled in the art. Accordingly, the term "deposit" is intended to encompass instances where a completed composite fiber element 148 is placed on the table 12, 142 and also instance where the composite fiber element 148 is assembled directly on the table 12, 142, layer by layer.

[00111] Following the step 154, it is contemplated that resin may be injected into or applied to the composite fiber element 148. In other manufacturing circumstances, where the composite fiber element 148 is pre-impregnated with resin, resin may not be provided.

[00112] From step 154, the method proceeds to step 156 where a first vibration is applied according to a first wave form 126, 132 with a first frequency F_1 .

[00113] At step 158, a second vibration is applied according to a second wave form 128, 134 with a second frequency F_2 .

[00114] At step 160, a beating frequency 138 is established according to the equations (2) and (3). The application of the first wave form 126, 132 and the second wave form 128, 134 to the composite fiber element 148 establishes the combined wave form 130, 136, 140, with the beating frequency 138.

[00115] The method 150 then proceeds to step 162 where at least the first frequency F_1 of the first wave form 126, 132 is varied to establish sufficient randomization of the combined wave form 130, 136, 140 on the composite fiber element 148.

[00116] The method 150 ends at step 162.

[00117] As should be apparent, it is contemplated that pressure may be applied to the composite fiber element 148 during the application of the method 150 or afterwards. Pressure may be applied to the composite fiber element 148 during the curing of the resin, following the application of the method 150.

[00118] As may be appreciated, the method 150 may be repeated as often as needed to complete the degassing and consolidation of the composite fiber element 148.

[00119] With respect to the method 150, the composite fiber element 148 is contemplated to be covered by a vacuum bag. The table 12, 142 then may be placed into an autoclave (or oven) so that the composite fiber element 148 is heated to cure the resin.

[00120] As may be apparent from the foregoing, the magnitude of the frequencies F_1 , F_2 , F_n applied by the vibration generators 16 is dependent upon a number of factors. The shape of the table 12, 142, the shape of the mold 18, 22, 24, 26, 28, 30, the thickness of the composite fiber element 148, the vacuum bag, the number and location of the vibration generators 16, and the number and location of the dampers 52 are but some of the variables involved. As such, to determine the resonance frequency to be applied to the composite fiber element 148 is established after the composite fiber element 148 is laid onto the table 12, 142 and the vacuum bag is placed onto the composite fiber element 148.

[00121] It is contemplated that the resonance frequency may be determined by applying a range of frequencies to one of the vibration generators 16 attached to the table 12, 142 and measuring the response. The resonance frequency may be determined by the response from the table 12, 142. Consistent with the discussion above, it is contemplated that the resonance frequency will be selected within a range of 100 – 500 Hz. The beating and sweeping operations may then be tailored to the selected resonance frequency.

[00122] As should be apparent from the foregoing, the resonance frequency for a particular composite fiber element 148 on a table 12, 142 is contemplated to differ for each individual implementation. In other words, it is understood that the resonance frequency will differ each time a new composite fiber element 148 is assembled.

[00123] After the resonance frequency is established, the method 150 may be implemented, as described above.

[00124] Additional details associated with the method 150 are provided below.

[00125] The first frequency F_1 is contemplated to be applied for 15 to 30 min. This is contemplated to assure resin migration into any voids present therein due to what is referred to as the “ratchet effect.”

[00126] After application of the first frequency F_1 , The second frequency F_2 is applied to establish the beating wave with a low frequency, F_1 , as described above.

[00127] As discussed above, the beating wave establishes a low frequency (*i.e.*, 1 – 5 Hz) wave that is contemplated to force the bridges between the voids to brake and, thereby, to connect the voids with the vacuum pathways. In addition, the plies of the composite fiber element 148 are contemplated to move relative to one another, in depth and in plane, thereby reducing bridging in areas of curvature (such as bends or corners in the composite fiber element 148). In other words, the tows settle by moving one relative to another. In addition, pinholes on the mold side surface of the composite fiber element 148 are reduced. It is also contemplated that laminar indications (*i.e.*, large surface interlaminar voids) may be reduced (or eliminated) due to movement of the plies in plane, relative to one another.

[00128] It is noted that beating is contemplated to be limited, because too much beating may break the fibers in the composite fiber element 148 or may fracture the matrix (resin). Therefore, the time of beating vibrations is contemplated not to exceed 15 min. During beating, one of the frequencies F_1 , F_2 may be swept but the sweep range and period is contemplated to be slower than the beating frequency, or the beating may cease to occur.

[00129] The frequency F_1 , F_2 is swept back and forth in the range found on the vibration survey, which is the process whereby the resonance frequency of the mold is determined for a particular cure configuration. The sweep time is contemplated to be kept within a range of between 5 to 10 seconds. The range is contemplated to be maintained between 10 to 20 Hz. The effect of this vibration is to effectuate at least one of the following results, among others: (1) filling voids with resin, (2) consolidating the fiber layers, (3) avoiding excessive resin migration, and (4) avoiding vibration patterns that might result in porosity.

[00130] It is also contemplated that a high single frequency may be applied to the composite fiber element 148 to degas the resin, as discussed in greater detail below. The frequency is contemplated to be selected as high as possible from the harmonics. However, the frequency is contemplated not to exceed 500 Hz – 1,000 Hz. This mode of vibrations is contemplated to be applied as close as possible to the second phase of the cure of the composite

fiber element 148 when volatiles develop in the resin during the curing phase. Vibrations close to the gel point during the curing cycle are to be avoided to avoid resin fracture. A suitable period is the final half hour of the dwell period.

[00131] Effects of this vibration on the composite fiber element 148 include, but are not limited to: (1) microbubbles migrate and impact with one another to form larger bubbles (e.g., macrobubbles) that may be extracted via the vacuum applied to the composite fiber element 148, which may result in improved degassing and (2) the laminate undergoes a detensioning effect, which reduces the spring back phenomenon (deformation of the part due to residual stresses accumulated in the composite fiber element 148), which may improve the consolidation of the fiber layers with the resin. The residual stress accumulated in the composite fiber element 148 is produced by the resin shrinkage during gelling and due to differences in thermal expansion of the composite fiber element 148 versus the mold 18, 22, 24, 26, 28, 30.

[00132] It is noted that the high frequency vibrations, suitable for detensioning the laminate, approach the non-Newtonian behavior of the resin when the resin is liquefying around the fibers, allowing them to come back in the relaxed position.

[00133] Fig. 20 is a cross-sectional view of the composite fiber element 148, illustrating various layers 166 of a composite fiber element 148 without vibrational manipulation according to the present invention. Individual fiber layers 166 are visible, together with a number of voids 168.

[00134] Fig. 21 is a cross-sectional side view of the composite fiber element 148 after having been subject to vibrational manipulation according to the present invention. The number of voids 168 is greatly reduced by comparison with Fig. 20.

[00135] With renewed reference to Fig. 15, there are a number of benefits that results from the establishment of a combined wave form 130, 136, 140 with a beating frequency 138 that is subjected to sweeping.

[00136] It is noted that the present invention is directed to the application of low frequency vibrations to the composite fiber element 148. Low frequency vibrations are, for the purposes of the present invention, vibrations with a frequency of less than about 1 kHz. More specifically, the present invention involves the application of low frequency vibrations of more than 0 Hz but less than about 500 Hz.

[00137] It is noted that the application of high frequency vibrations, especially ultrasonic, high frequency vibrations has a tendency to heat the resin in the composite fiber element 148. As should be apparent to those skilled in the art, when the resin is heated, it begins to cure. As a result, it is desirable to keep the frequencies of the vibrations to a sufficiently low level so that the composite fiber element 148 is able to consolidate and degas prior to curing. The application of low frequency vibrations, as discussed above, assists with this process.

[00138] As discussed above, the present invention provides a system 120 and a method 150 that establishes a beating frequency 138, F_3 , (again, this refers to a beating frequency having a maximum amplitude with a frequency of F_3) by purposefully introducing different vibrational frequencies F_1 , F_2 into the table 12, 142 via two or more vibration generators 46. To ensure adequate degassing and consolidation of the composite fiber element 148, the frequencies F_1 , F_2 are maintained within a low frequency band of vibration. For purposes of the present invention, low frequency vibrations are those below about 1 kHz, preferably less than about 500 Hz and greater than 0 Hz. The beating frequency 138 is contemplated to be lower than the lowest frequency F_1 , F_2 introduced into the composite fiber element 148.

[00139] It is noted that the size of the Table 12, 142 is likely to be a factor that influences the frequency F_1 , F_2 of vibrations generated by the vibration generators 46. In particular, it is contemplated that small tables 12, 142 may require application of frequencies F_1 , F_2 of about 200 Hz, for example. Large tables 12, 142 are contemplated to require smaller frequencies F_1 , F_2 , such as about 25 Hz. As should be apparent, the frequencies F_1 , F_2 applied by the vibration generators 46 is contemplated to be specific to the shape and size of the associated table 12, 142. Moreover, as discussed above, the optimal frequency for a particular table 12, 142 is contemplated to be established, via a vibration survey, after the setup of the composite fiber element on the table 12, 142, but before the table 12, 142 is placed into an autoclave or oven for curing.

[00140] In addition, it is contemplated that the method 150 of the present invention may be applied during the construction of the composite fiber element 148 on the table 12, 142. As such, it is contemplated that the method 150 may be employed as a consolidation method for the stacking up of the plies, and an intermediate step, or as a final step, prior to curing of the composite fiber element 148. This operation is often referred to as “debulking,” and it is currently used by placing the composite fiber element, from time to time, under a vacuum bag,

and applying a vacuum thereto. Thus, as layers are built up, the layers are periodically consolidated at various stages in the buildup operation. It is noted that the plies are quite sticky and do not slide easily relative to one another during this process. This stands in contrast to the curing operation, where the resin is fluid and the plies more readily slide with respect to one another.

[00141] After each layer is deposited, the inertia of the composite fiber element 148 will change as will its resonance frequency. Accordingly, it is contemplated that, for each applied layer, the frequencies F_1 , F_2 of the applied vibrations will differ. In other words, it is contemplated that it may be necessary for the profile controller to change the applied frequencies F_1 , F_2 after each change to the composite fiber element 148, during its assembly.

[00142] It is contemplated that the deviation of the frequency from the beginning to the end of the build-up of the composite fiber element 148 will be within a range of about $\pm 5\%$, $\pm 10\%$, or $\pm 15\%$, depending on the material forming the composite fiber element 148 and the shape of the composite fiber element 148. In other words, it is contemplated that, if the frequency of the vibration is set initially at about 100 Hz, the final frequency, after all of the layers have been deposited on the mold, will be 85 – 115 Hz.

[00143] As may be apparent from the foregoing, the system 120 and the method 150 of the present invention are contemplated to provide the most suitable results when beating and sweeping are employed together to degas and consolidate the composite fiber element 148. As noted, beating involves the creation of a beating frequency 138. Sweeping involves a gradual change in the frequency F_1 , F_2 of the wave forms 126, 128, 132, 134 that are combined to create the beating frequency 138.

[00144] Since ultrasonic frequency vibrations have a tendency to heat the composite fiber element 148, it is contemplated that ultrasonic vibrations may be employed after application of the method 150 described above. As such, the method 150 may be employed to degas and consolidate the composite fiber element 48. Subsequently, high frequency vibrations (*i.e.*, ultrasonic vibrations) may be employed to assist with curing the resin. It is contemplated that ultrasonic heating may be employed together with conventional heating in an autoclave or oven, as required or as desired.

[00145] With respect to the composite fiber element 148, it is contemplated that the composite fiber element 148 combines woven carbon fibers in a resin network. The present

invention, however, is not intended to be limited solely to composite fiber elements 148 made from carbon fibers. To the contrary, any other composite fiber materials, including fiberglass, aramid fibers, are intended to be encompassed by the present invention. In addition, while the present invention contemplates that the composite fibers are woven, non-woven composite materials also are contemplated to fall within the scope of the present invention. Furthermore, the present invention is contemplated to be applicable to composite fiber materials that are pre-impregnated with resin (*i.e.*, pre-preg materials) as well as dry materials (those that are not pre-impregnated with resin).

[00146] The present invention has been described in connection with one or more embodiments. It is contemplated that features from one embodiment may be substituted for features in other embodiments without departing from the scope of the present invention. In addition, as should be apparent to those skilled in the art, there are numerous variations and equivalents of the embodiments that should be apparent to those skilled in the art. The present invention is intended to encompass those variations and equivalents, as if described herein.

What is claimed is:

1. An apparatus for assisting in the preparation of a composite fiber element, the apparatus comprising:
 - a mold having a surface onto which the composite fiber element is positionable;
 - a first vibration generator operatively connected to the mold to impart a first vibration having a first frequency into the mold;
 - a second vibration generator operatively connected to the mold to impart a second vibration having a second frequency into the mold, the second frequency being different from the first frequency so as to establish a beating frequency; and
 - a controller operatively connected to the first vibration generator,wherein the controller is adapted to adjust at least one of the first frequency and an amplitude of the first vibration.
2. The apparatus of claim 1, wherein the controller also is operatively connected to the second vibration generator.
3. The apparatus of claim 1, wherein the controller is adapted to sweep through a range of frequencies encompassing the first frequency.
4. The apparatus of claim 1, wherein the beating frequency F_3 is established according to the equation $F_1 - F_2 = F_3$, F_1 is the first frequency, and F_2 is the second frequency.
5. The apparatus of claim 1, further comprising:
 - a plurality of vibration generators operatively connected to the mold to impart a plurality of vibrations having a plurality of frequencies into the mold,wherein the controller is adapted to adjust at least one of the plurality of frequencies and an amplitude of at least one of the plurality of frequencies.
6. The apparatus of claim 1, further comprising:

a first signal generator operatively connected between the controller and the first vibration generator to receive a first control signal from the controller and generate a first vibration signal for input into the first vibration generator.

7. The apparatus of claim 6, further comprising:

a second signal generator operatively connected between the controller and the second vibration generator to receive a second control signal from the controller and generate a second vibration signal for input into the second vibration generator.

8. The apparatus of claim 1, wherein the controller comprises a plurality of controllers.

9. The apparatus of claim 1, wherein the composite fiber element comprises a fiber immersed in resin.

10. The apparatus of claim 1, wherein the composite fiber element is pre-impregnated with resin.

11. The apparatus of claim 1, wherein the first frequency F_1 and the second frequency F_2 are both less than about 1 kHz.

12. The apparatus of claim 11, wherein the first frequency F_1 and the second frequency F_2 are both less than about 500 Hz.

13. A method for manufacturing a composite fiber element, comprising:

depositing a composite fiber element onto a surface of a mold;

applying a first vibration comprising a first frequency F_1 to the mold;

applying a second vibration comprising a second frequency F_2 to the mold;

establishing a combined waveform with a beating frequency F_3 according to the equation

$F_1 - F_2 = F_3$; and

sweeping at least the first frequency F_1 of the first vibration.

14. The method of claim 13, further comprising:
applying an n^{th} wave form with an n^{th} frequency F_n to the mold.
15. The method of claim 14, wherein the beating frequency F_3 also accommodates the n^{th} frequency F_n .
16. The method of claim 13, further comprising:
sweeping the second frequency F_2 .
17. The method of claim 13, wherein the first vibration is applied to the mold by a first vibration generator and the second vibration is applied to the mold by a second vibration generator.
18. A damper, comprising:
a housing;
a shaft extending through the housing;
a first stack of pistons disposed on the shaft;
a second stack of pistons disposed in the housing; and
a plurality of elastomeric washers disposed between the first stack of pistons and the second stack of pistons;
wherein the first stack of pistons moves together with the shaft when subjected to vibration such that the first stack of pistons moves in relation to the second stack of pistons, thereby deforming the plurality of elastomeric washers.
19. The damper of claim 18, wherein the plurality of elastomeric washers comprise silicone rubber.
20. The damper of claim 18, wherein the plurality of elastomeric washers comprise a high temperature elastomer.

21. The damper of claim 18, wherein the plurality of elastomeric washers deform with a predetermined hysteresis.
22. The damper of claim 21, wherein the plurality of elastomeric washers exhibit a first force curve when loaded and a second force curve when unloaded.
23. The damper of claim 18, further comprising:
a cover adjustably connected to the housing, wherein adjustment of the cover alters operation of the plurality of elastomeric washers.
24. The damper of claim 18, further comprising:
a nut threadedly engaging a bottom end of the shaft, wherein adjustment of the nut alters a rigidity of the plurality of elastomeric washers.

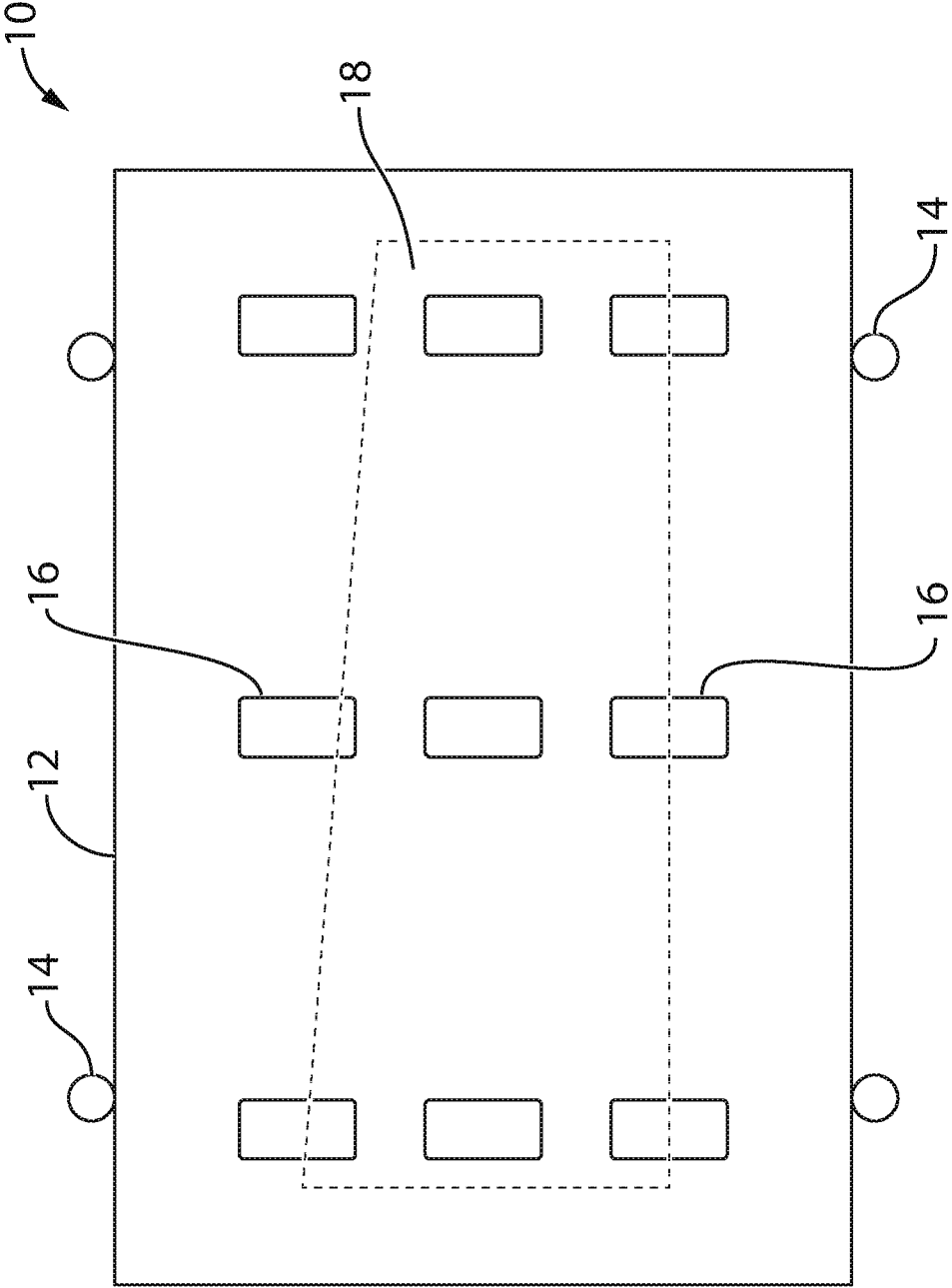


FIG. 1

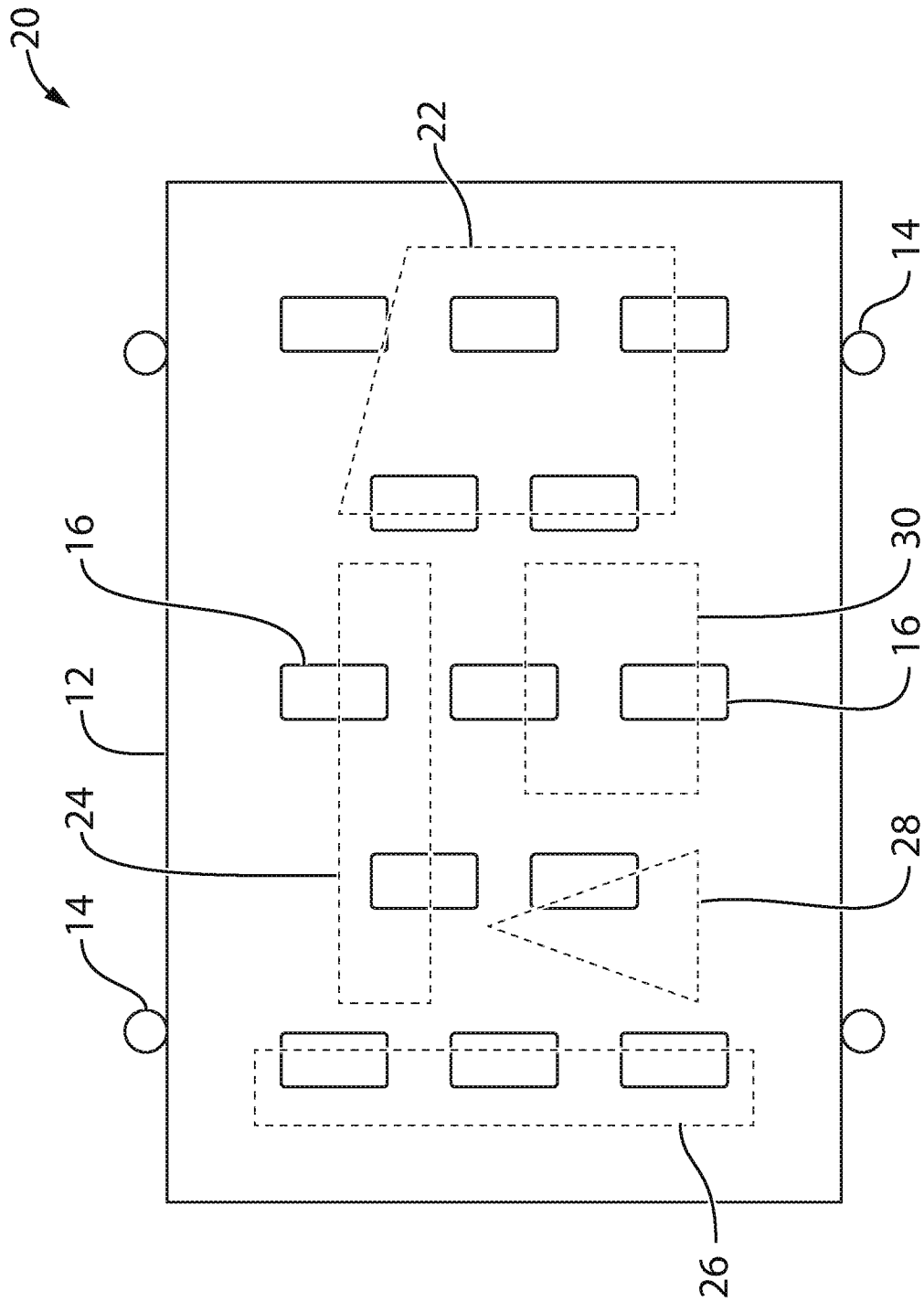


FIG. 2

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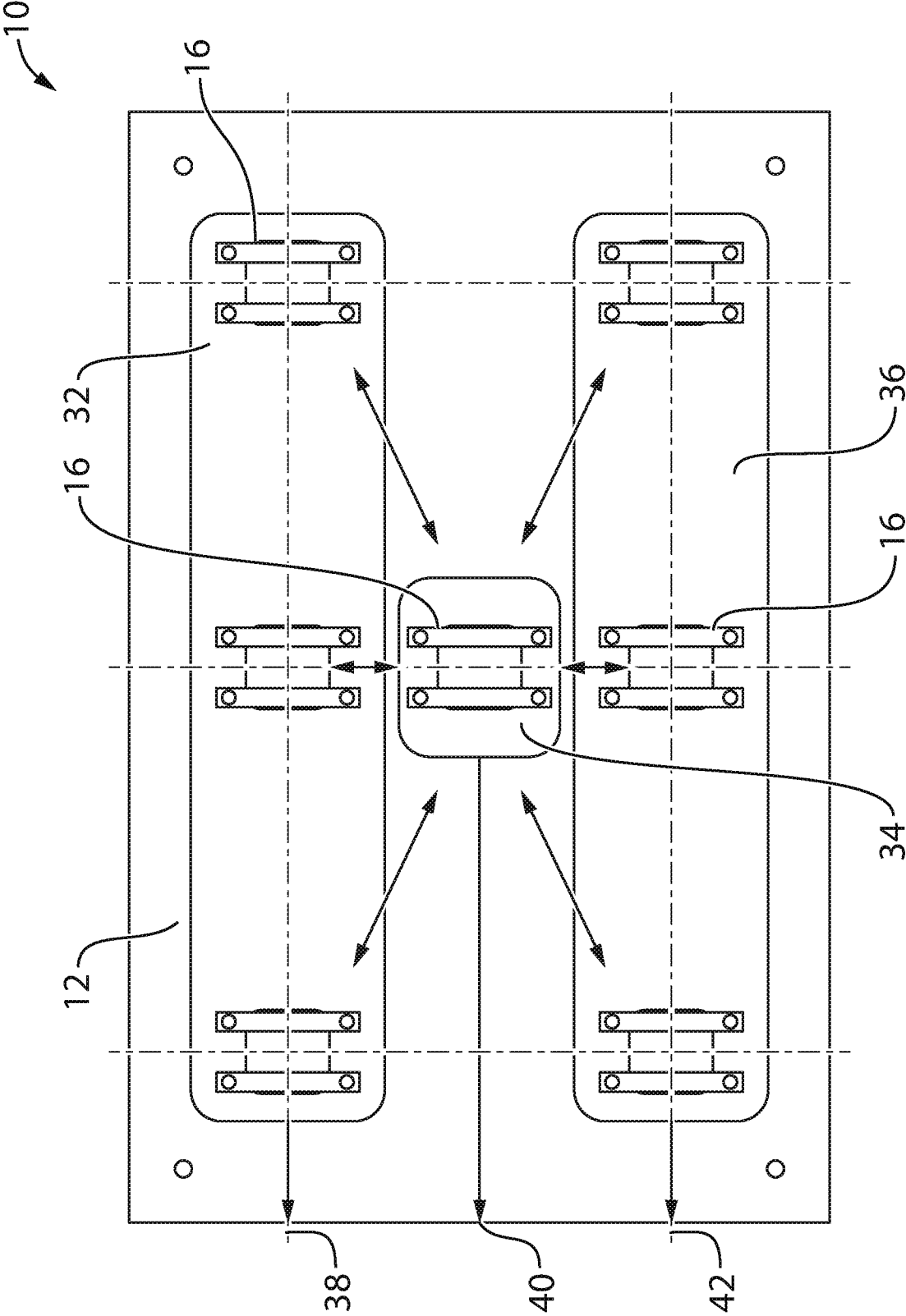


FIG. 3

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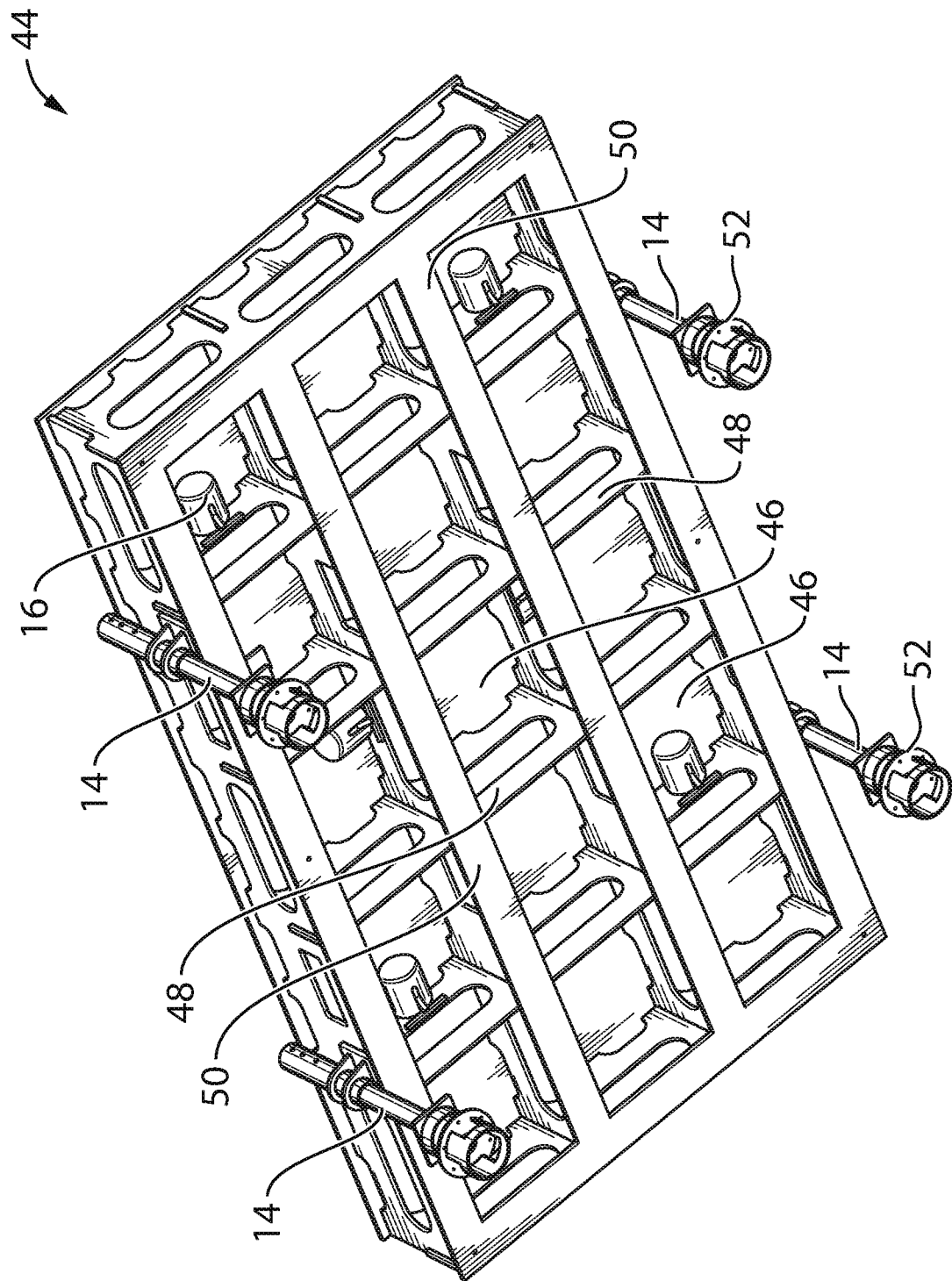


FIG. 4

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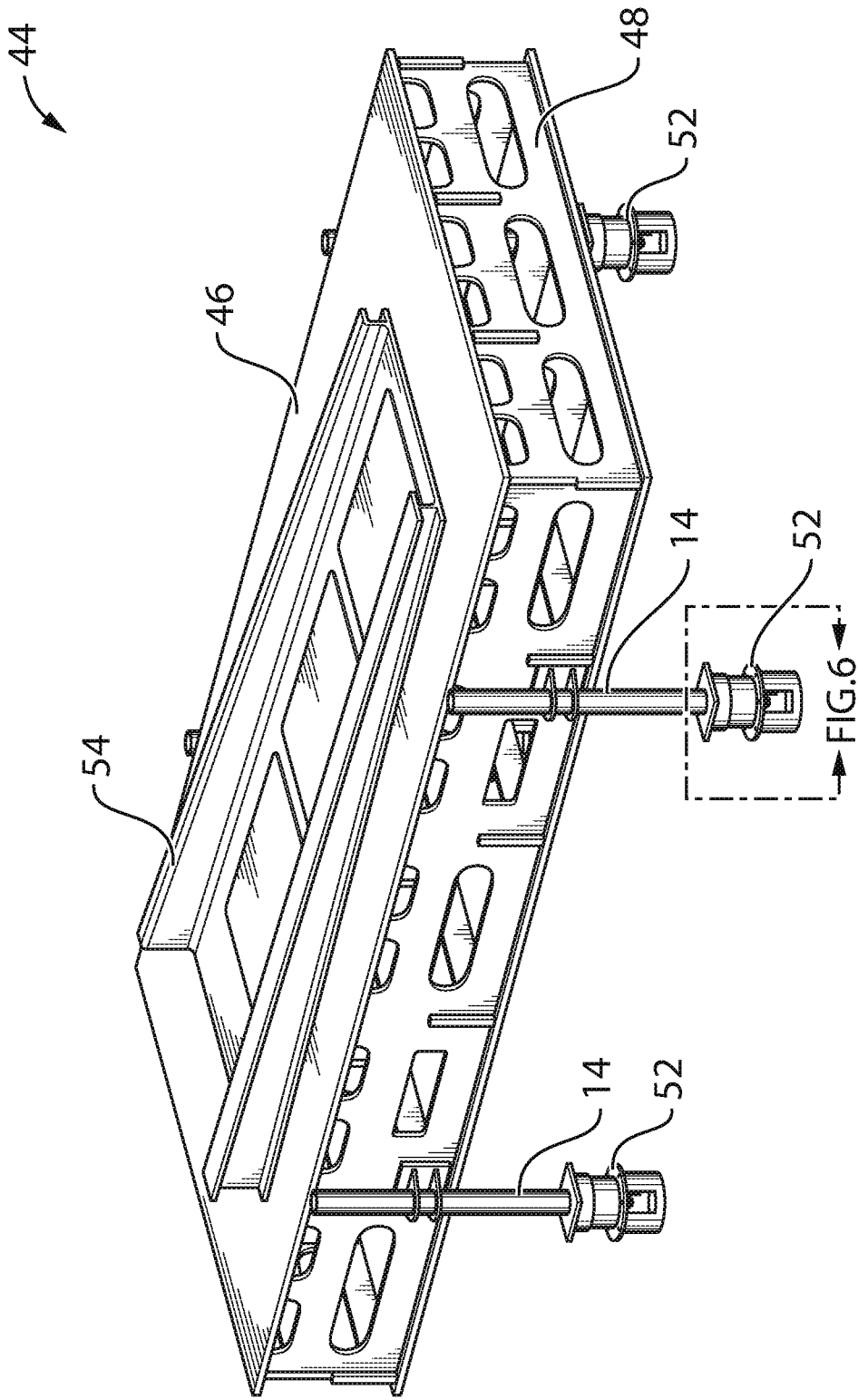


FIG. 5

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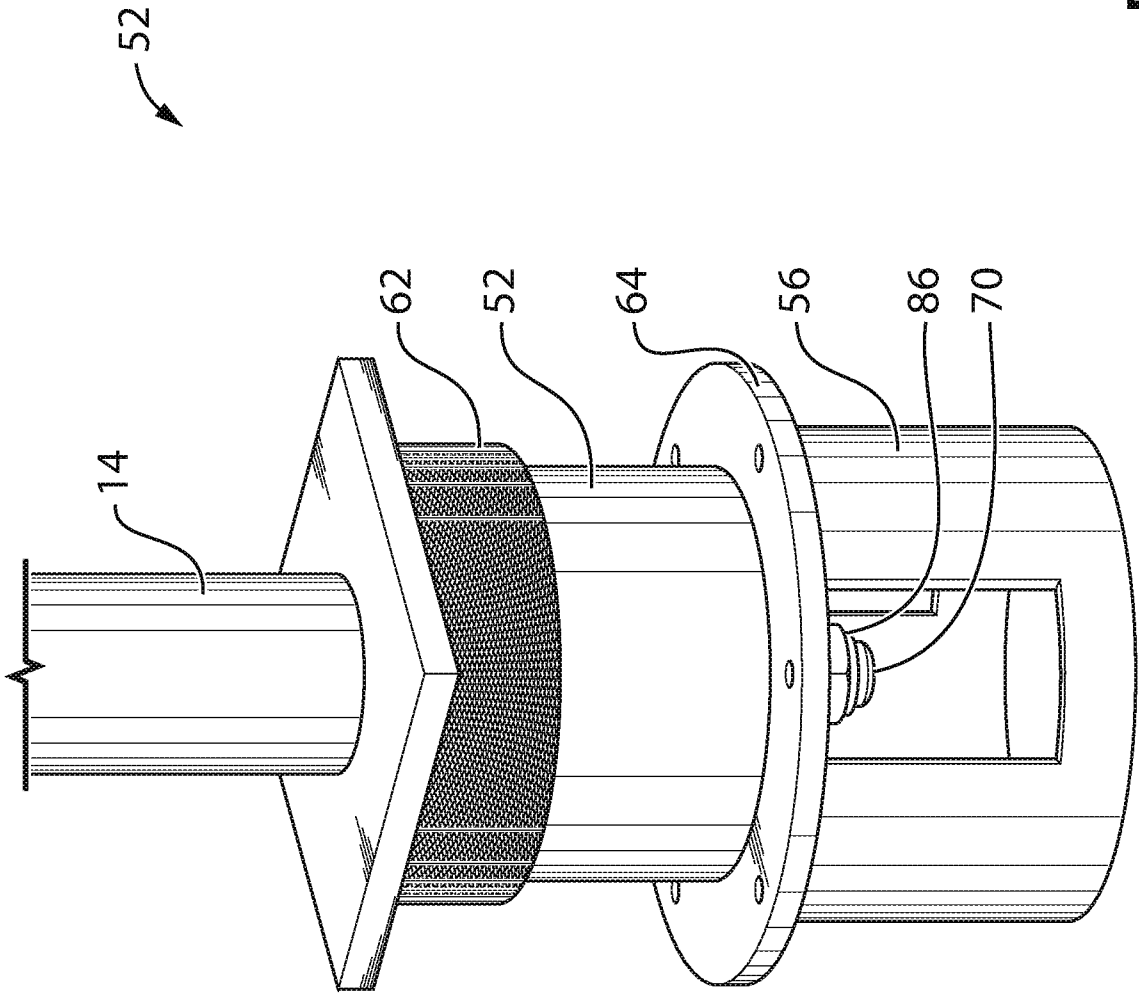
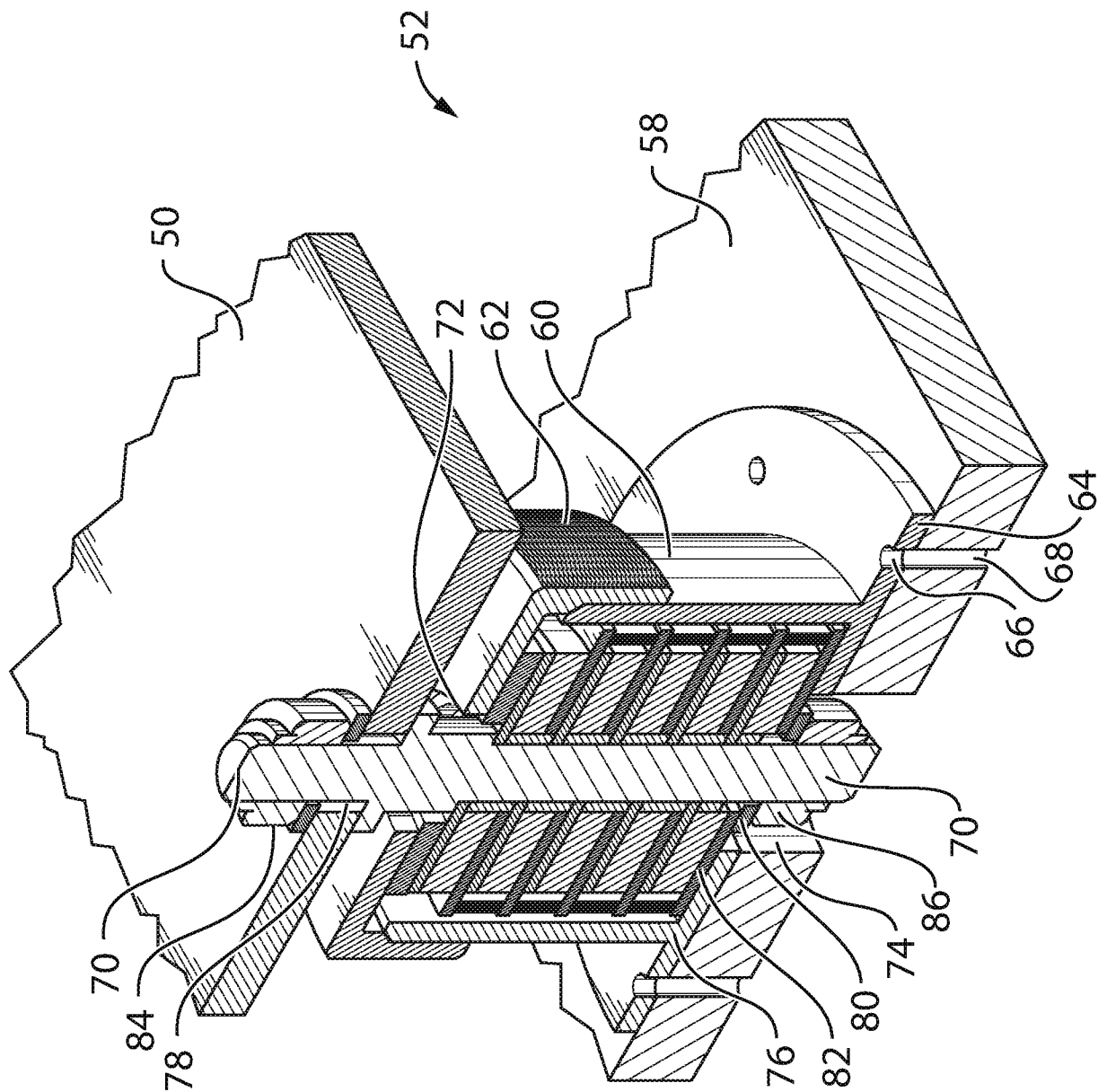


FIG. 6

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FIG. 7



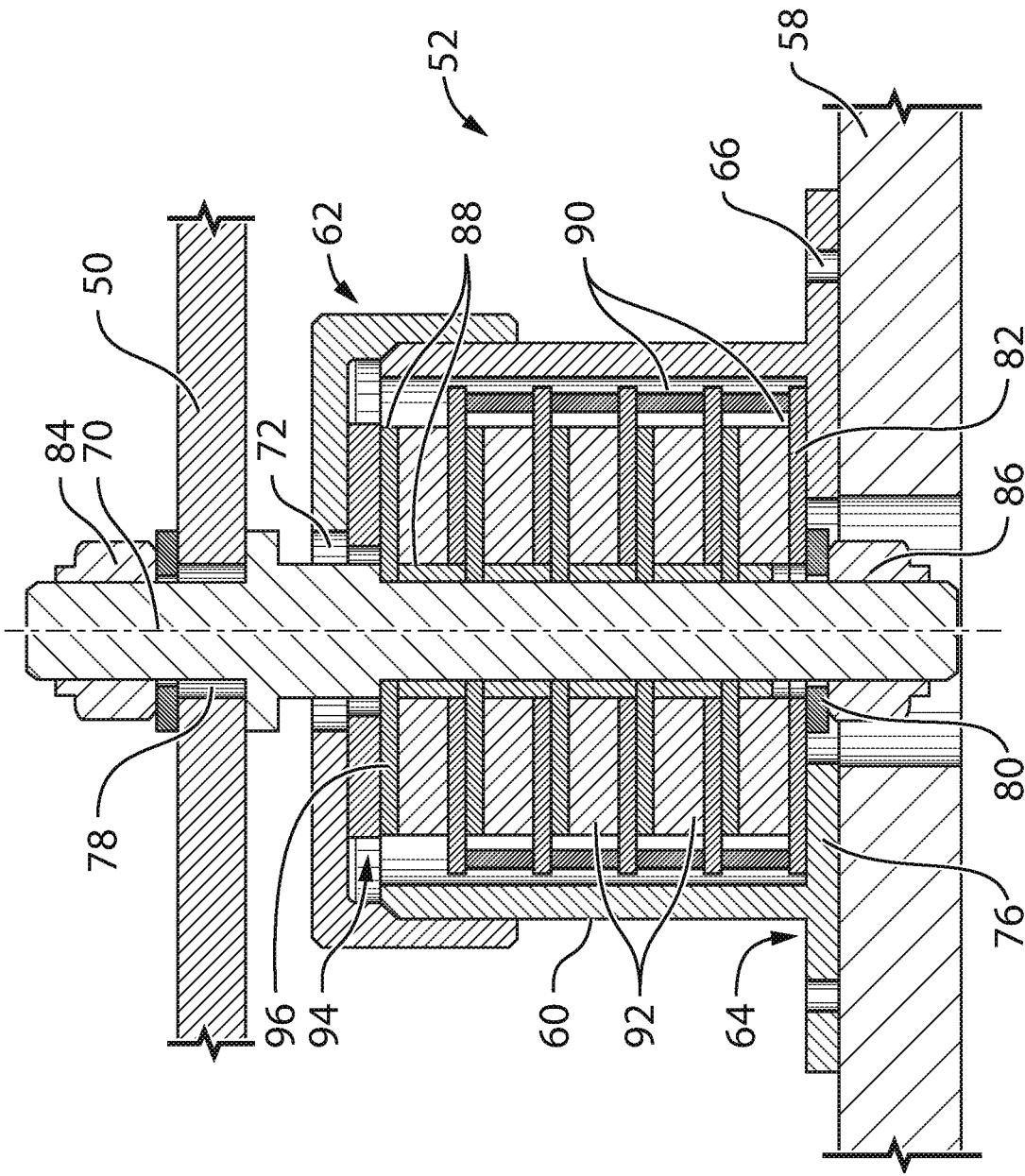
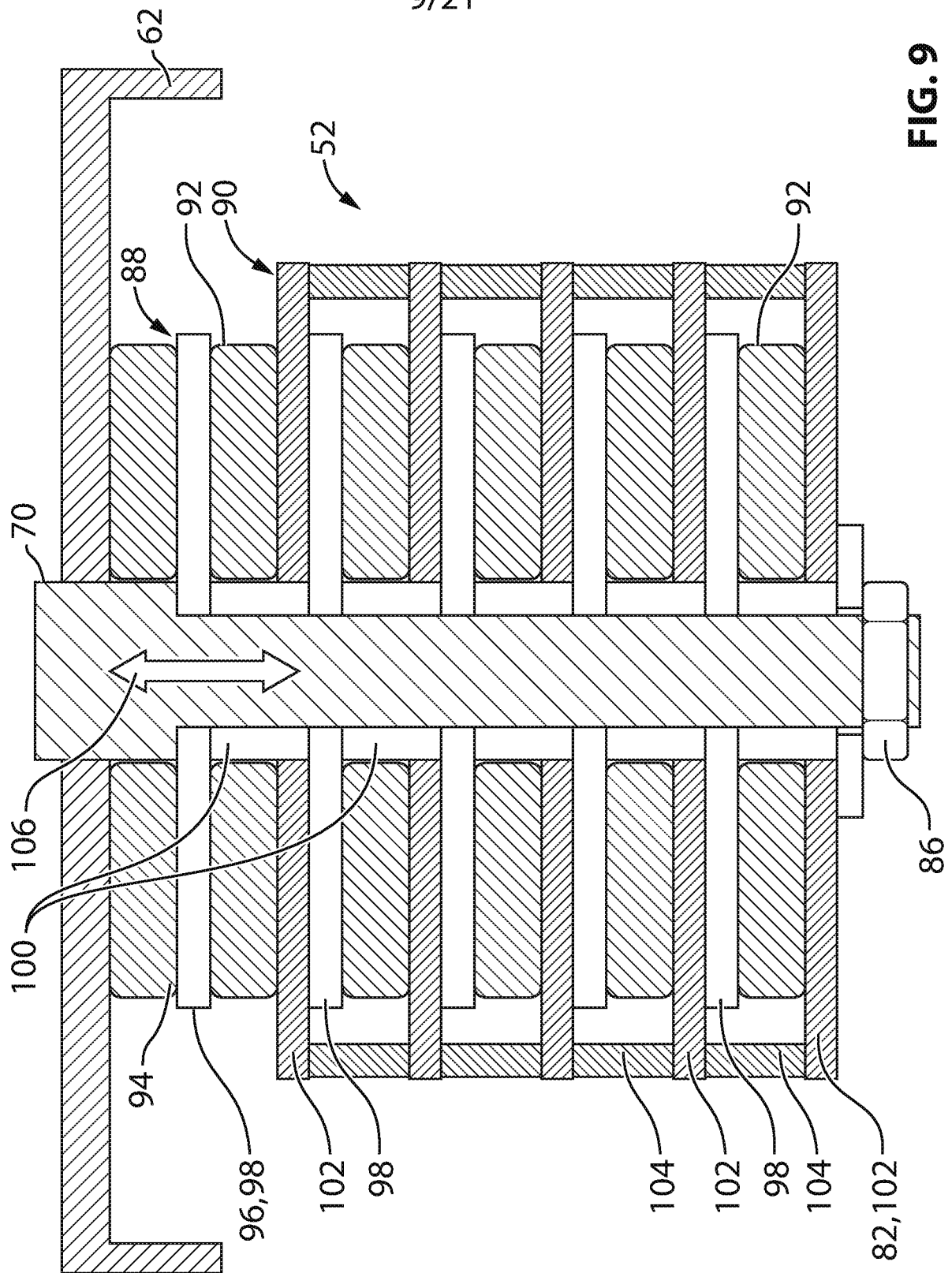


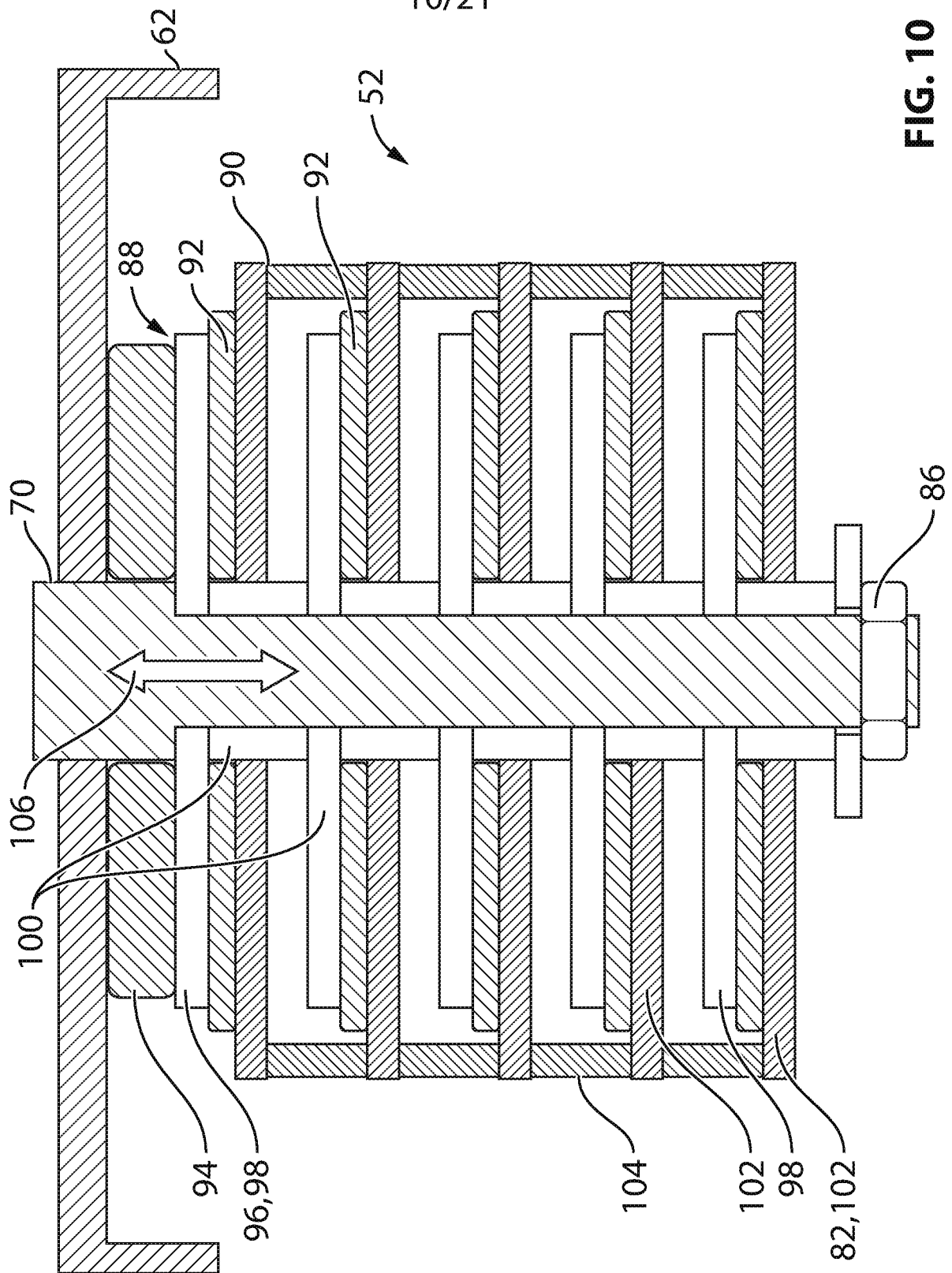
FIG. 8

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**FIG. 10**

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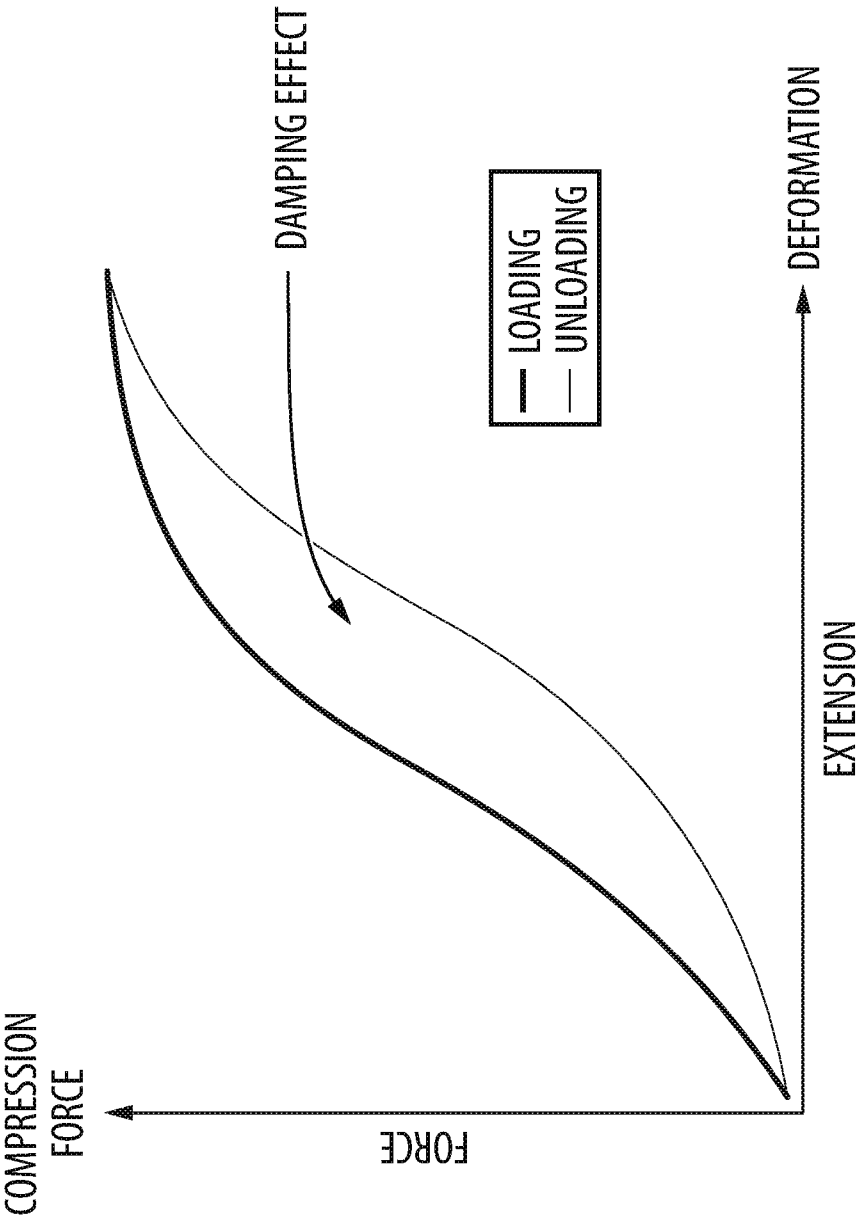


FIG. 11

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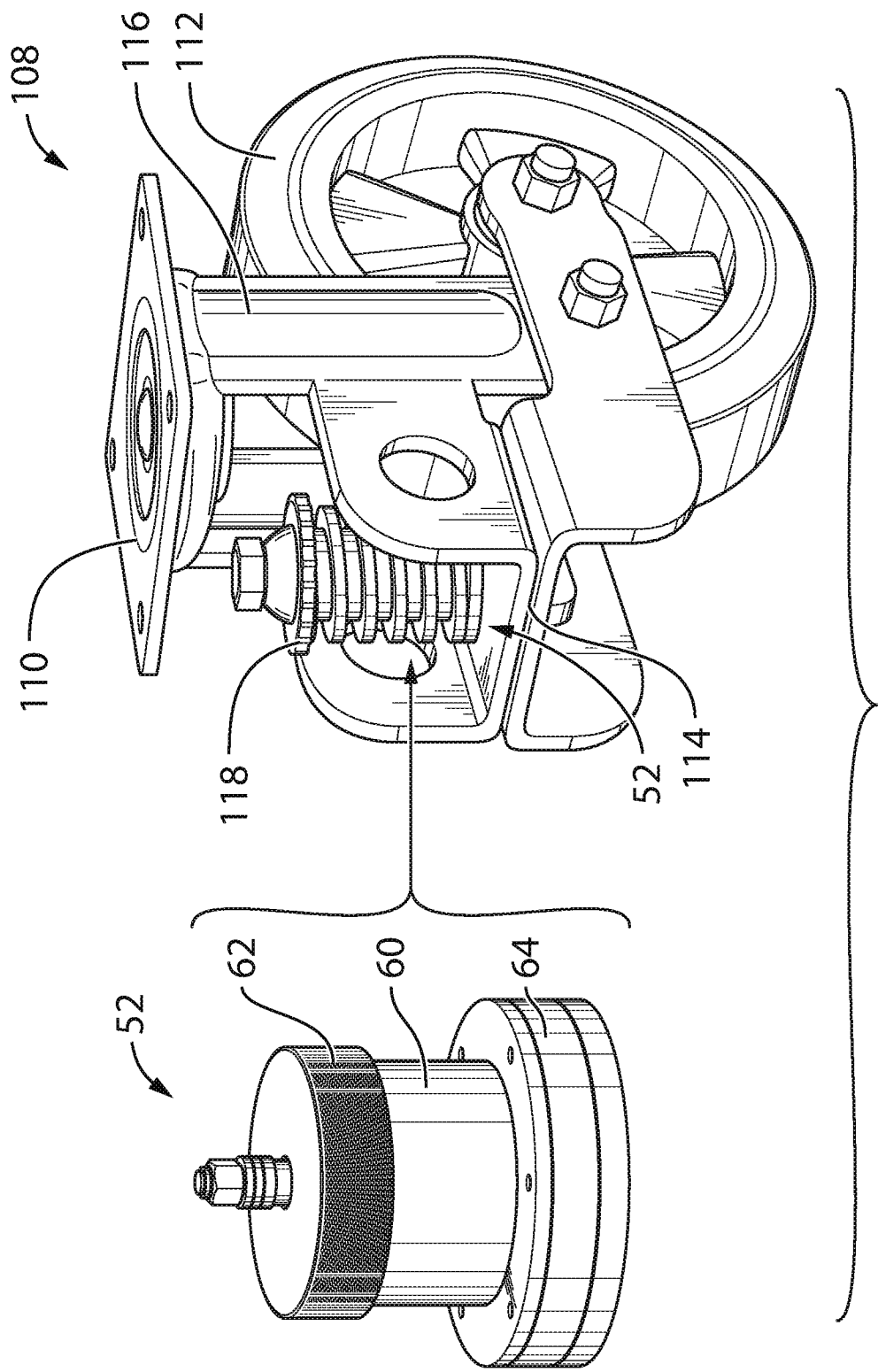
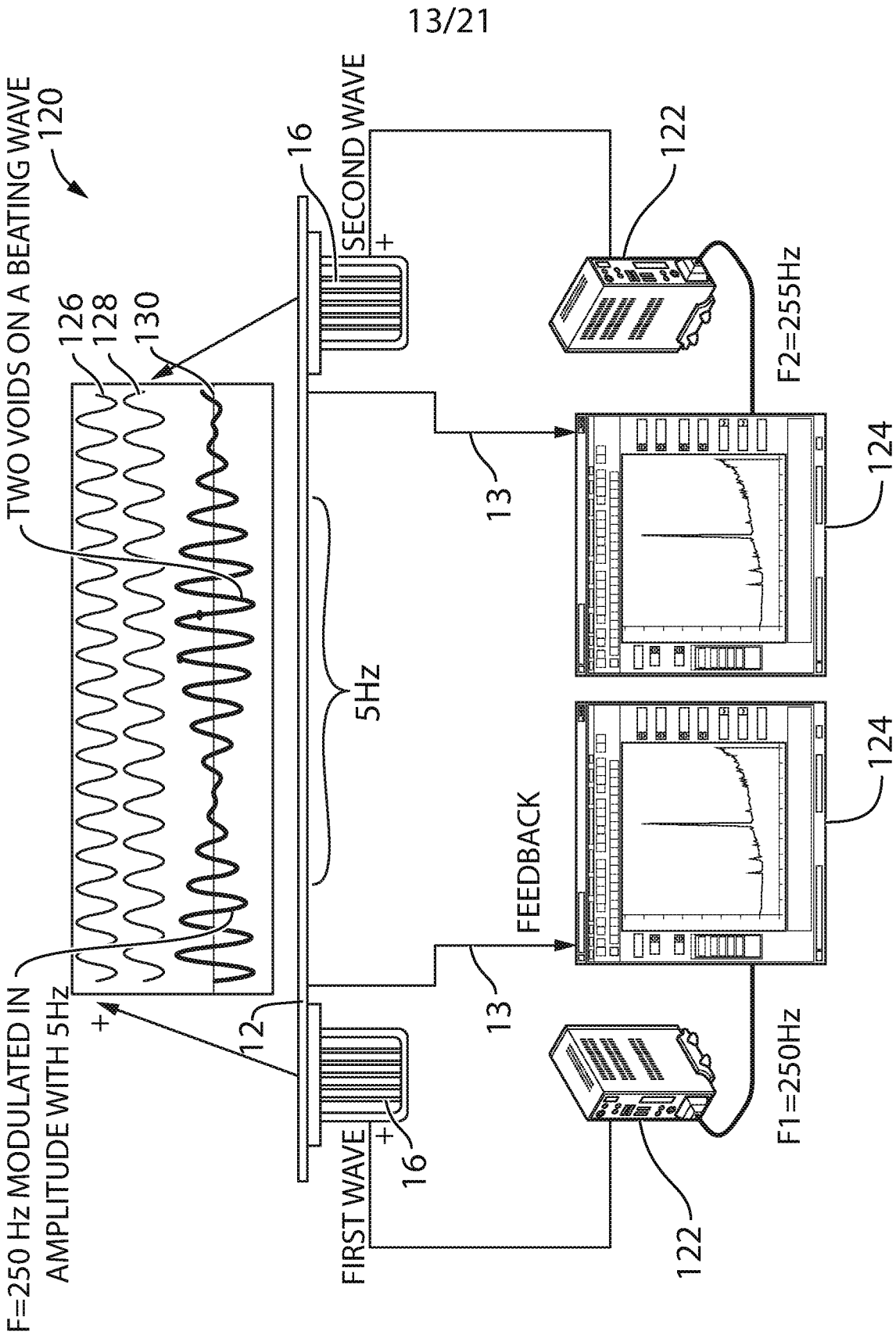


FIG. 12



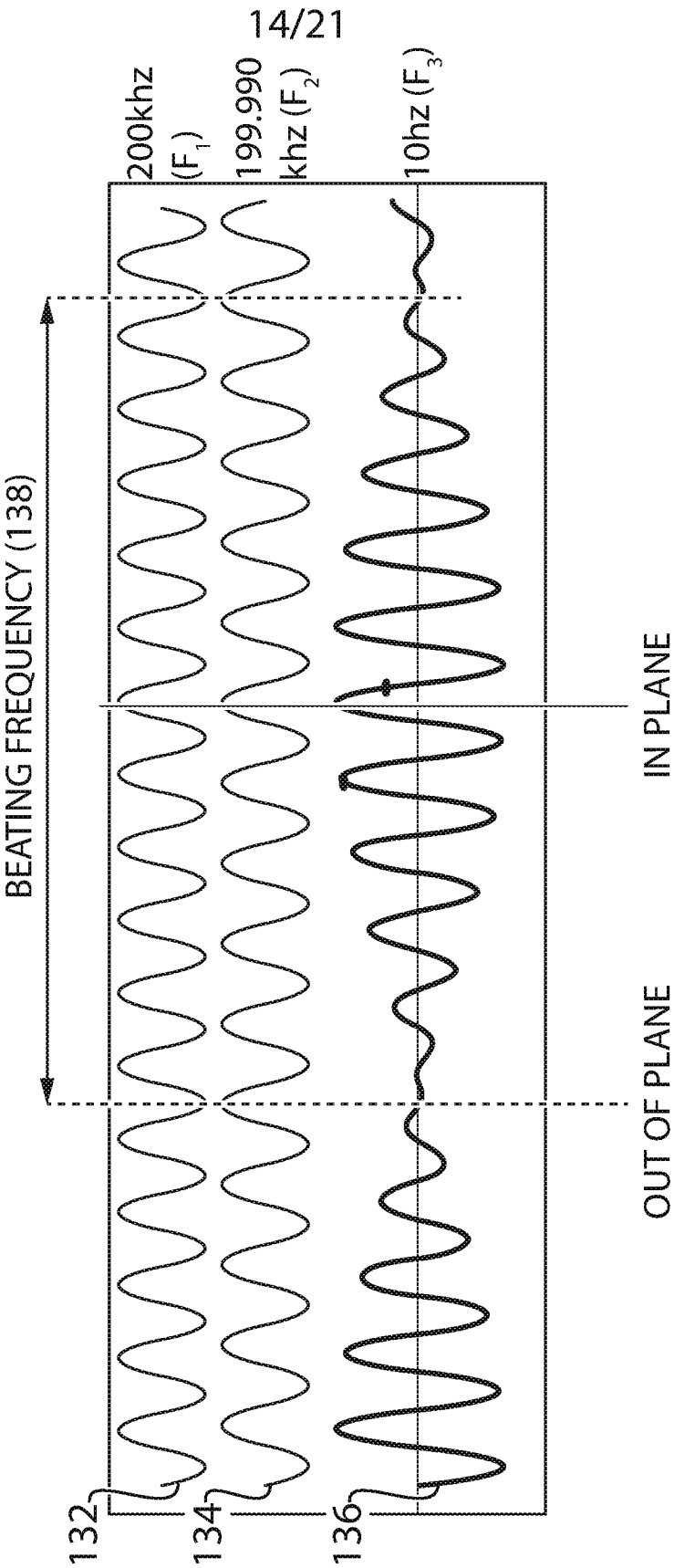


FIG. 14

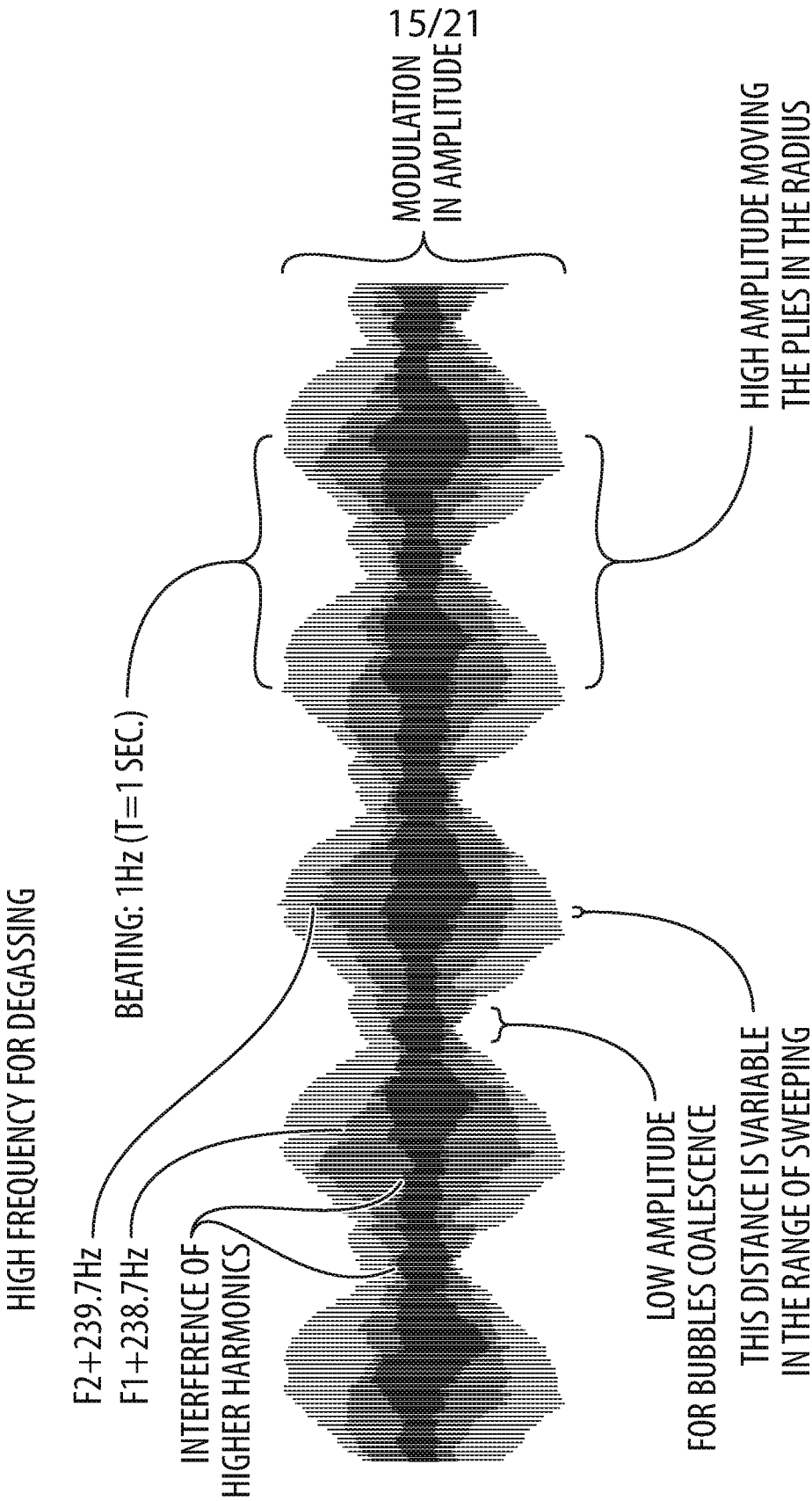


FIG. 15

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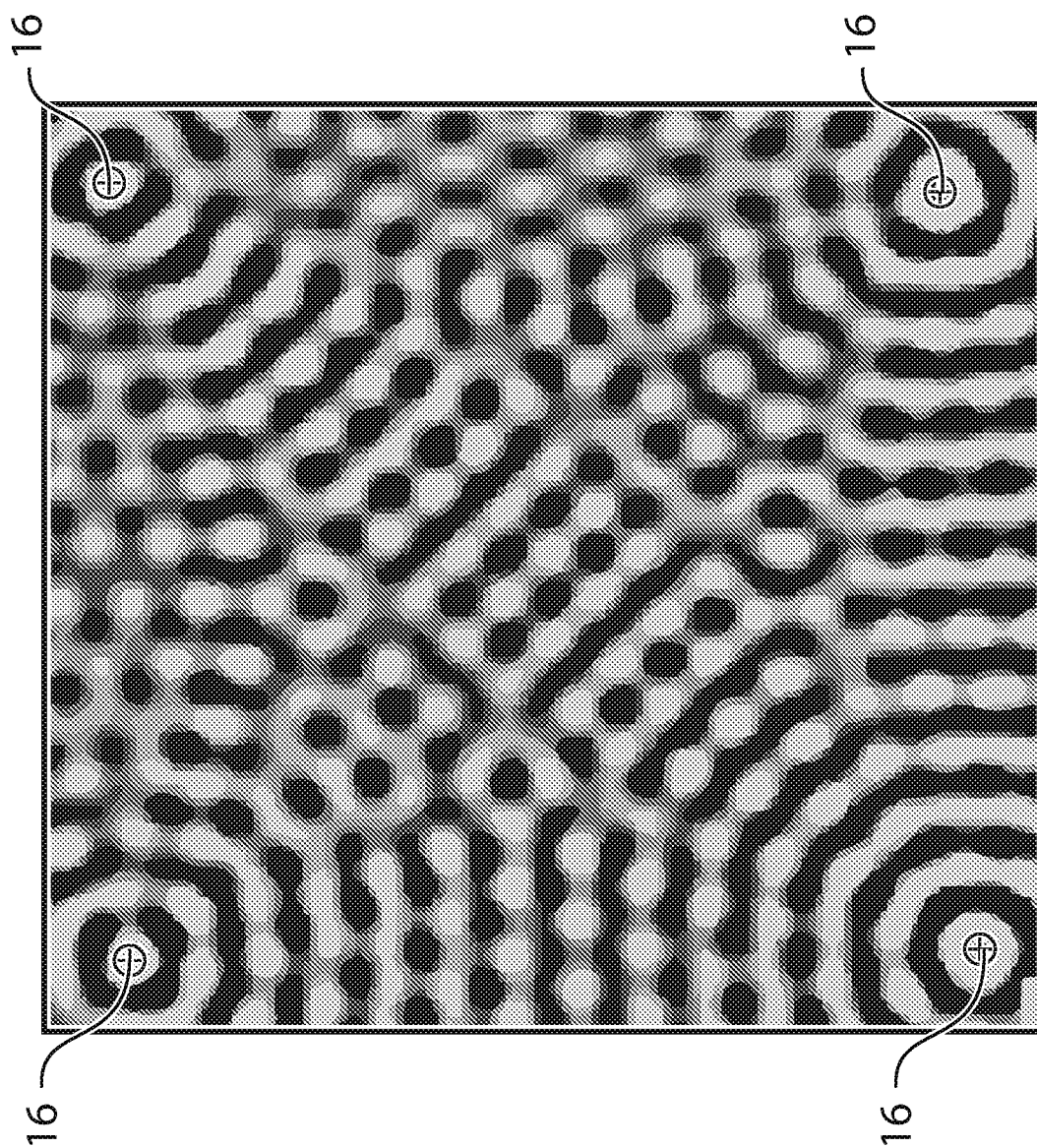


FIG. 16

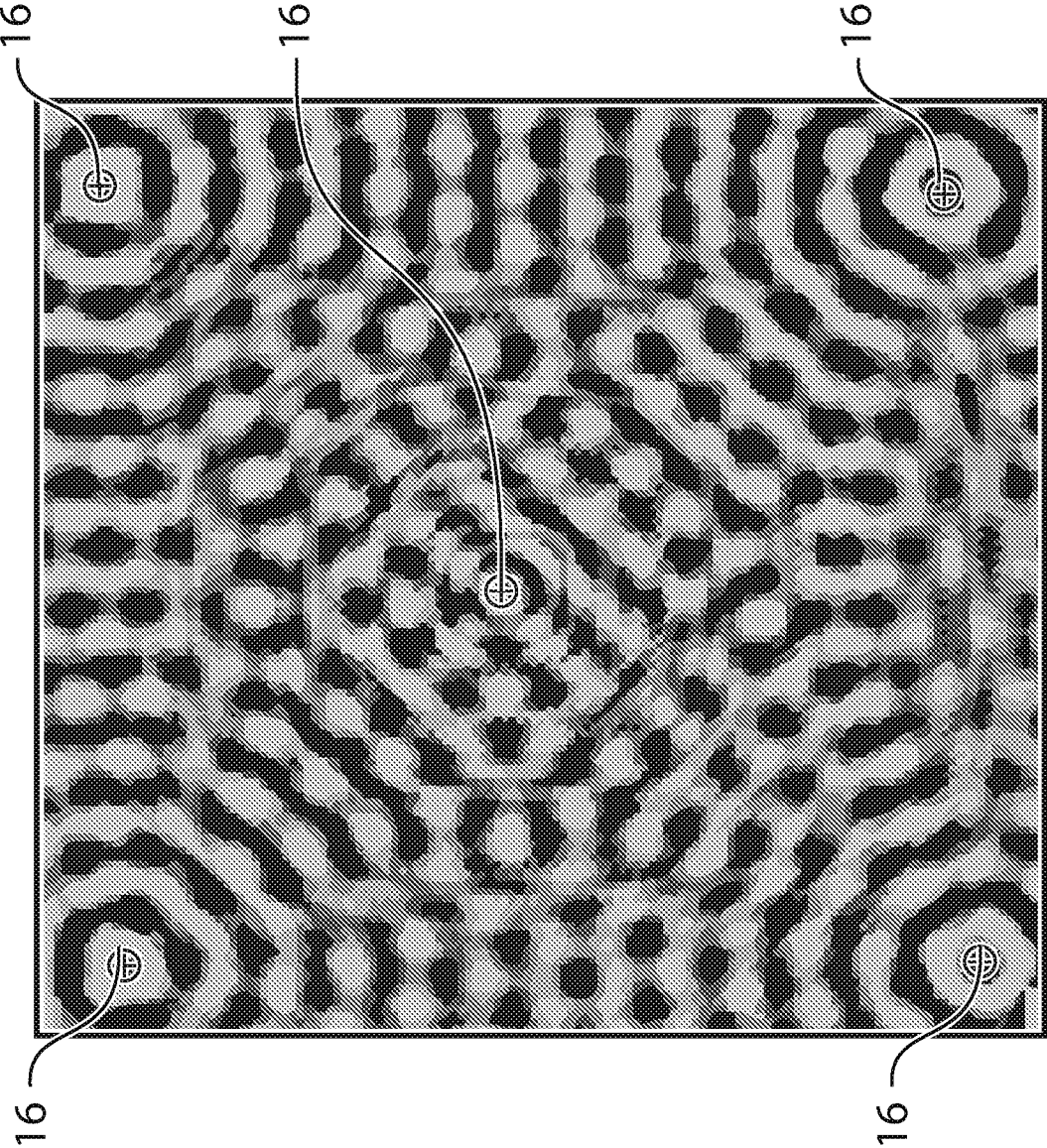


FIG. 17

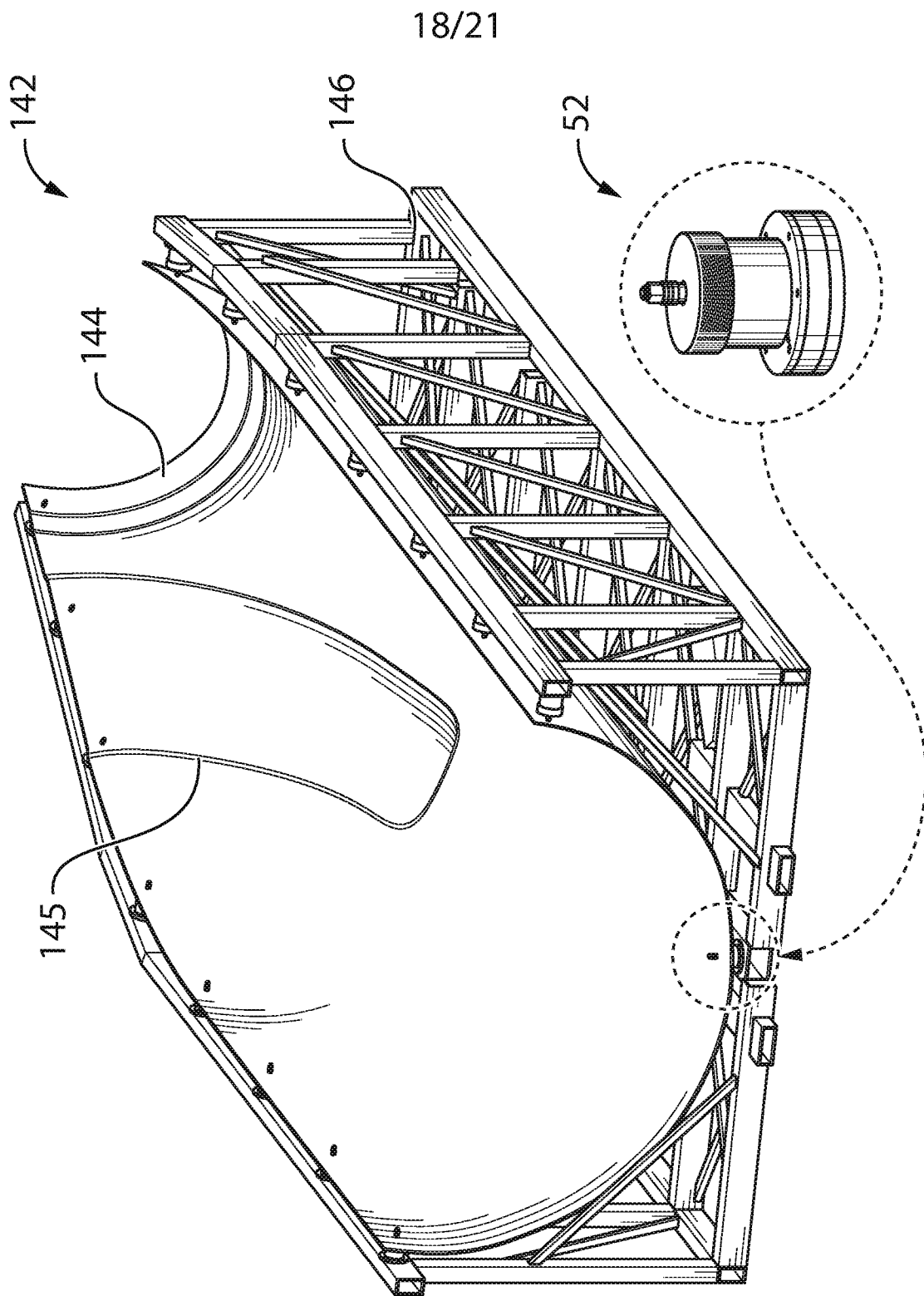


FIG. 18

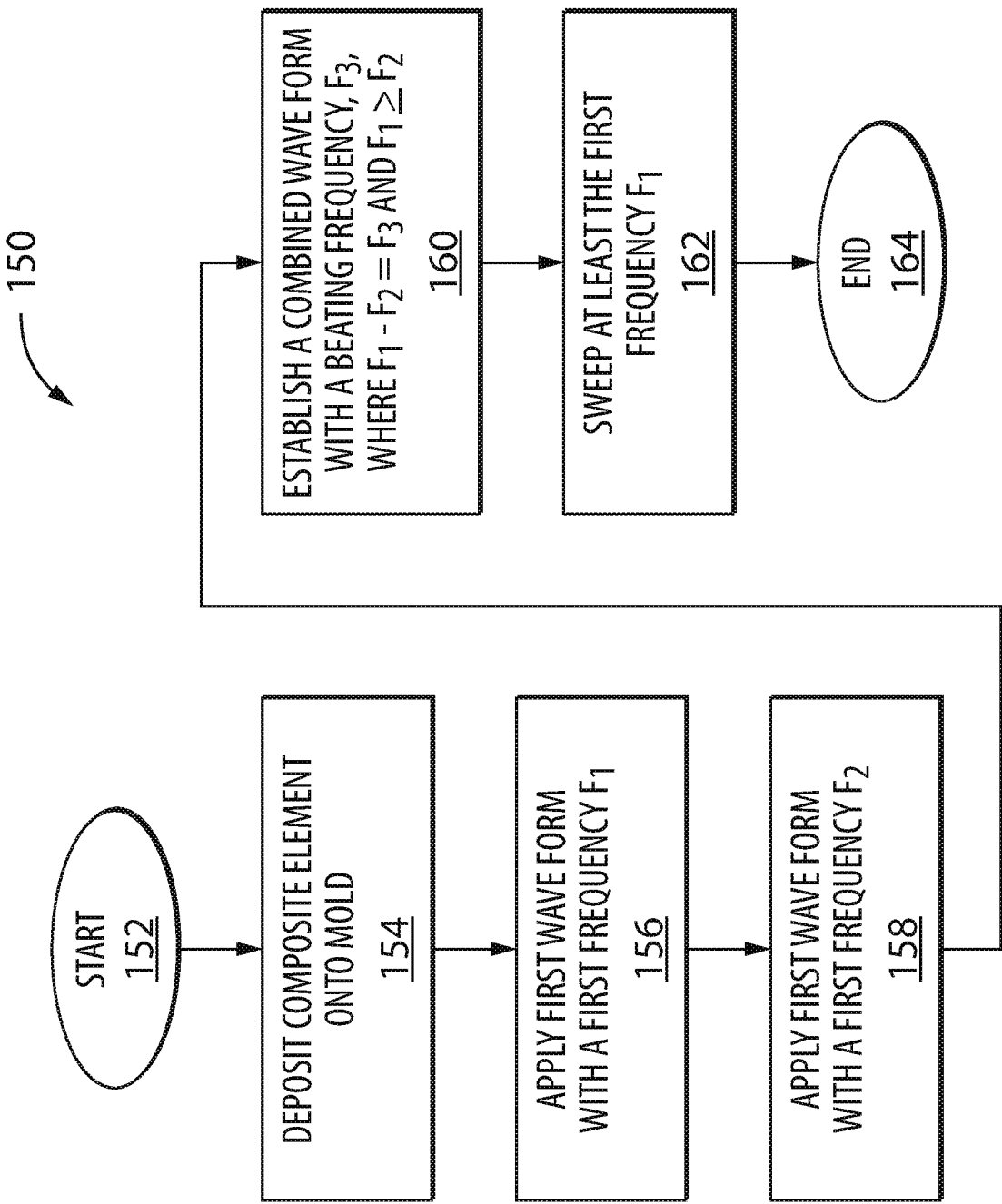


FIG. 19

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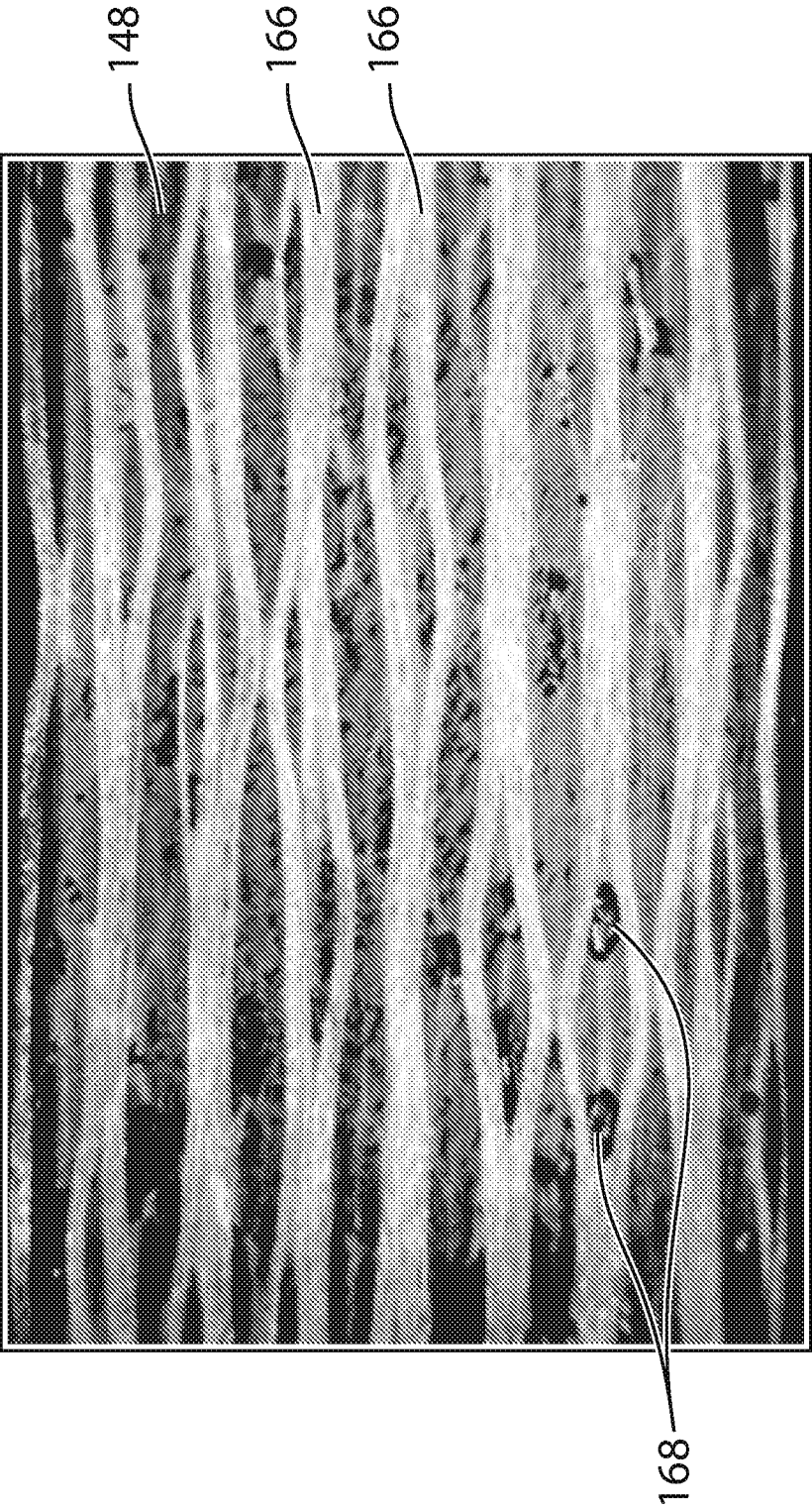


FIG. 20

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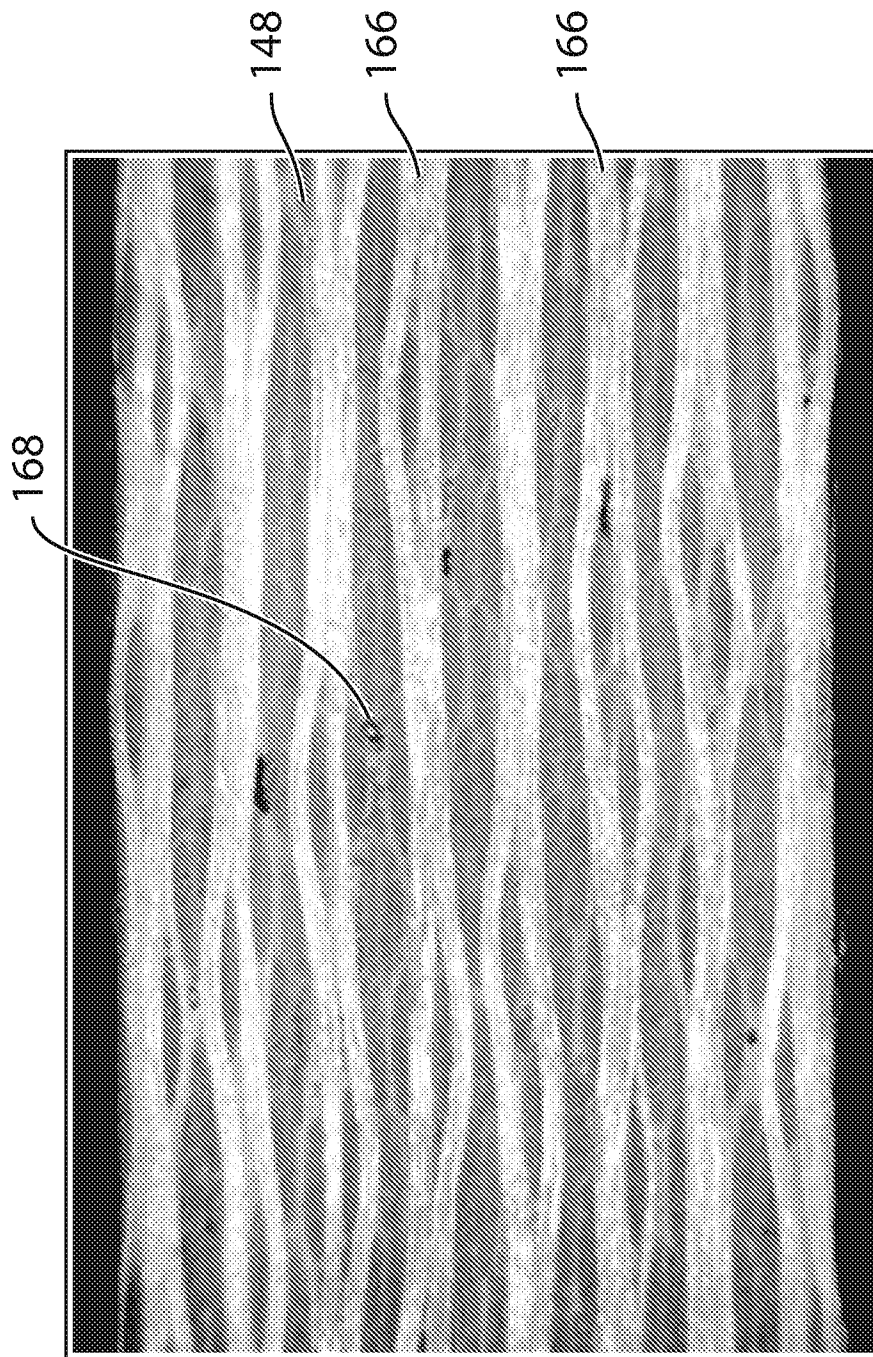


FIG. 21

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/054038

A. CLASSIFICATION OF SUBJECT MATTER INV. B06B1/16 F16F3/087 B29C70/54 B28B1/087 B28B17/00 ADD. B29C70/44		
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) B06B F16F B29C B28B		
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) EP0-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/040106 A1 (SIMMERER STEFAN [DE] ET AL) 16 February 2012 (2012-02-16) paragraphs [0041], [0043], [0052], [0054], [0056]; figures 5,6,9 -----	1-7,9-17
X	DE 100 48 281 A1 (IFF WEIMAR [DE]) 11 April 2002 (2002-04-11) paragraph [0042]; claims 1-4; figures -----	1-5,11,12
A	EP 2 100 711 A1 (AIRBUS ESPANA SL [ES]) 16 September 2009 (2009-09-16) paragraph [0026]; claims 1,2,5,6; figures 1,2 -----	1,9,10
A	US 6 684 681 B1 (ZOMBO PAUL [US]) 3 February 2004 (2004-02-03) column 4, line 17 - line 26 column 5, line 31 - line 50; figures ----- -/--	1
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents :		
"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "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) "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 "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	Date of mailing of the international search report	
26 August 2015	11/11/2015	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Bibollet-Ruche, D	

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/054038

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 43 01 367 A1 (BALD HUBERT [DE]) 5 January 1994 (1994-01-05) column 3, line 45 - line 53; claims 1,6; figures -----	1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2015/054038

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search 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 No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

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

see additional 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 fees, this Authority did not invite payment of additional fees.
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.:

1-7, 9-17

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-7, 9-17

A signal generator operatively is connected between a controller and a vibration generator to receive a control signal from the controller and generate a vibration signal for input into the vibration generator.

2. claims: 1, 8

A controller comprising a plurality of controllers.

3. claims: 18-24

A damper

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2015/054038

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 2012040106	A1	16-02-2012	CN 102371688 A	14-03-2012
			DE 102011052664 A1	16-02-2012
			US 2012040106 A1	16-02-2012

DE 10048281	A1	11-04-2002	NONE	

EP 2100711	A1	16-09-2009	EP 2100711 A1	16-09-2009
			US 2008181980 A1	31-07-2008
			WO 2008065212 A1	05-06-2008

US 6684681	B1	03-02-2004	NONE	

DE 4301367	A1	05-01-1994	NONE	
