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(54) Title: RESONANT INERTIAL FORCE GENERATOR HAVING STABLE NATURAL FREQUENCY

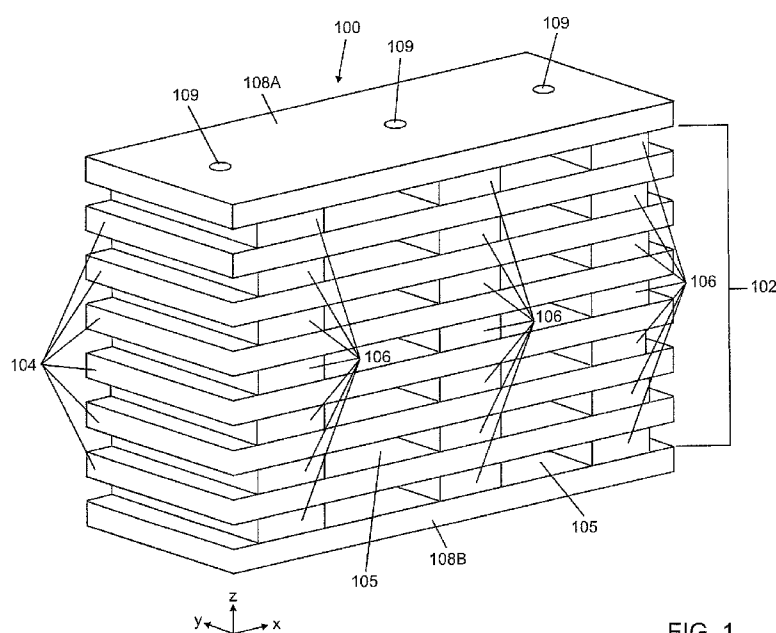


FIG. 1

(57) Abstract: A resonant inertial force generator for controlling vibrations of a structure includes a compliant spring comprising a stack of flexures and elastomeric shims in alternating arrangement, a driven inertial mass coupled to the compliant spring to generate a vibration controlling force.



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RESONANT INERTIAL FORCE GENERATOR HAVING STABLE NATURAL FREQUENCY

CROSS REFERENCE

[0001] This application claims the benefit of, and incorporates by reference, United States Provisional Patent Application Number 61/111,280 filed on November 4, 2008.

FIELD

[0002] The invention relates generally to methods and apparatus for controlling vibrations of structures. More specifically, the invention relates to a resonant inertial force generator for use in controlling vibrations of a structure.

BACKGROUND

[0003] Resonant inertial force generators are used to actively control vibrations of a structure, such as an aircraft fuselage. The inertial force generator is attached to the structure subject to vibrations and controlled to impart a force on the structure that counteracts the vibrations of the structure. Sensors may be attached to the structure to measure vibrations of the structure. The output of the sensors may be used to control the inertial force generator to generate the force required to counteract the vibrations of the structure. The resonant inertial force generator includes an actuated driven inertial mass attached with a compliant spring. Mechanical resonance occurs at a frequency determined by the inertial mass and the compliance of the spring. If the natural frequency of the mass-spring system decays by a large amount, there would be a decrease in the output force of the inertial force generator, which can affect the system performance.

SUMMARY

[0004] In an embodiment the invention includes a resonant inertial force generator for controlling vibrations of a structure which comprises a compliant spring

comprising a stack of flexures and elastomeric shims in alternating arrangement, an inertial mass coupled to the compliant spring, and an actuator for moving the inertial mass.

[0005] In an embodiment the invention includes a resonant inertial force generator which comprises an inertial mass supported by a plurality of flexures and a plurality of intermediate elastomeric shims interleaved with the plurality of flexures.

[0006] In an embodiment the invention includes a compliant spring which comprises a plurality of composite flexure plates layered in a stack and an elastomeric shim disposed between each adjacent pair of the composite flexure plates.

[0007] In an embodiment the invention includes a method of making an inertial force generator which comprises providing an inertial mass, providing n composite flexures, wherein n is an integer and is greater than 1, providing at least $n+1$ elastomeric shims, and interleaving the at least $n+1$ elastomeric shims with the n composite flexures to form a compliant spring comprising an alternating arrangement of flexures and elastomeric shims. The method further includes coupling the inertial mass to the compliant spring and coupling to the inertial mass an actuator capable of moving the inertial mass.

[0008] In an embodiment the invention includes a method of making an inertial force generator which comprises providing an inertial mass, providing a plurality of composite flexures, providing a plurality of elastomeric shims, and stacking the composite flexures and elastomeric shims alternately to form a compliant spring, the elastomeric shims being arranged adjacent to load bearing areas of the composite flexures. The method further includes coupling the inertial mass to the compliant spring and coupling to the inertial mass an actuator capable of moving the inertial mass.

[0009] In an embodiment the invention includes a method of making an inertial force generator spring which comprises providing a plurality of composite flexure plates and providing an intermediate elastomer. The method includes layering the composite flexure plates with the intermediate elastomer between the composite flexure plates to

provide a spring assembly of layered composite flexure plates and intermediate elastomer between adjacent composite flexure plates, with the intermediate elastomer bonded to the composite flexure plates.

[0010] In an embodiment the invention includes a resonant inertial force generator which comprises an inertial mass supported by a plurality of composite flexures arranged in a stack and compliant means for separating said composite flexures.

[0011] In an embodiment the invention includes a resonant inertial force generator for controlling vibrations which comprises an inertial mass on a spring assembly and a motor for moving the inertial mass on the spring assembly. The spring assembly includes at least a first non-elastomeric flexure and at least a first intermediate elastomer, where the first intermediate elastomer is bonded with the first non-elastomeric flexure.

[0012] In an embodiment the invention includes an apparatus for controlling aircraft vibrations which comprises an inertial mass on a spring assembly having a natural frequency NF, an electrically driven motor for moving the inertial mass on the spring assembly, wherein the spring assembly includes at least a first composite flexure and a means for inhibiting a decay in the natural frequency NF.

[0013] In an embodiment the invention includes an apparatus for controlling aircraft vibrations, including a driven inertial mass on a spring assembly having a natural frequency NF with the spring assembly including a plurality of nonhomogeneous composite flexures having first ends and distal second ends with a plurality of elastomeric spacers bonded between the composite flexures proximate the first ends and the distal second ends. Preferably the bonded elastomeric spacers and nonhomogeneous composite flexures inhibit a decay in the natural frequency NF.

It is to be understood that both the foregoing general description and the following detailed description are exemplary of the invention, and are intended to provide an overview or framework for understanding the nature and character of the invention as it

is claimed. The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate various embodiments of the invention, and together with the description serve to explain the principals and operation of the invention.

BRIEF DESCRIPTION OF DRAWINGS

[0014] The accompanying drawings, described below, illustrate typical embodiments of the invention and are not to be considered limiting of the scope of the invention, for the invention may admit to other equally effective embodiments. The figures are not necessarily to scale, and certain features and certain views of the figures may be shown exaggerated in scale or in schematic in the interest of clarity and conciseness.

[0015] FIG. 1 is a perspective view of a compliant spring.

[0016] FIG. 2 is a perspective view of a shaped compliant spring.

[0017] FIG. 3A is a perspective view of a resonant inertial force generator incorporating a plurality of complaint springs.

[0018] FIG. 3B is a vertical cross-section of a resonant inertial force generator incorporating a plurality of complaint springs.

[0019] FIG. 4 illustrates a test setup configuration for investigating endurance of compliant springs when incorporated in inertial force generators.

[0020] FIG. 5 is a comparison of natural frequency decays in a resonant inertial force generator incorporating composite flexures with elastomeric shims as compliant spring and a resonant inertial force generator incorporating composite flexures with metallic shims as compliant spring.

[0021] FIG. 6A-D illustrate compliant springs.

[0022] FIG. 7A-C illustrate a resonant inertial force generator incorporating a plurality of compliant springs.

[0023] FIG. 8A-B are Life Testing Decay plots of resonant inertial force generators such as shown in FIG.7A-C with Hours of Operation along the x-axis and Frequency Decay along the y-axis to show comparisons of natural frequency decays in a resonant inertial force generator such as shown in FIG.7A-C incorporating composite flexures with elastomeric shims as compliant spring as shown in FIG. 6A-D and a comparable resonant inertial force generator incorporating composite flexures with metallic shims as compliant spring.

DETAILED DESCRIPTION

[0024] The invention will now be described in detail with reference to a few preferred embodiments, as illustrated in the accompanying drawings. In describing the preferred embodiments, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be apparent to one skilled in the art that the invention may be practiced without some or all of these specific details. In other instances, well-known features and/or process steps have not been described in detail so as not to unnecessarily obscure the invention. In addition, like or identical reference numerals are used to identify common or similar elements.

[0025] FIG. 1 depicts a compliant spring 100 for use in, for example, a resonant inertial force generator. One or more of the compliant springs 100 may be used to support an inertial mass in the resonant inertial force generator. The compliant spring 100 includes a stack 102 of flexures 104 and elastomeric shims 106 in alternating arrangement. In the illustrated embodiment, the stack 102 includes n flexures 104 and three sets of $n+1$ elastomeric shims 106, where n is an integer. Typically, n is greater than 1 but may also be 1. In the illustrated example, n is 6. In alternate examples, n can be less than 6 or greater than 6, the minimum value being 2. In a preferred example, n is in a range from 2 to 10. In a preferred example, n is about 9 (from 7 to 11, preferably 8 to 10, more preferably $n=9$). In general, the stack 102 can have one or

more flexures 104 and at least one elastomeric shim 106 bonded to the flexure, preferably with the elastomeric shims between each adjacent pair of flexures 104. Each elastomeric shim 106 is preferably bonded or otherwise fixedly attached to adjacent flexures 104. The stack 102 may be sandwiched between end plates 108A, 108B. The elastomeric shims 106 adjacent to the end plates 108A, 108B may be bonded or otherwise fixedly attached to the end plates 108A, 108B. Holes 109 running through the end plates 108A, 108B and stack 102 may be provided for receiving fasteners (not shown), which may be used to fasten the compliant spring 100 to other structures. Alternatively, other means of fastening the compliant spring 100 to other structures, such as clamps, may be used. The layers of the compliant spring 100 may be prepared separately and assembled together, including inserting of bonding material between adjacent layers as necessary. Alternately, techniques such as elastomeric mold bonding in a mold may be used to integrate the different layers of the compliant spring 100.

[0026] Flexures 104 in the stack 102 are made of a non-elastomeric material. In a preferred embodiment, flexures 104 are made of a composite material. In a more preferred embodiment, the composite material does not include metal, preferably the flexures are non-metallic flexures, preferably a non-homogenous non-metallic material body. Making flexures 104 of a non-metallic non-homogenous composite material results in a lighter compliant spring 100, i.e., in comparison to one in which the flexures 104 are made of a homogenous metallic material. In one embodiment, the non-homogenous composite material is comprised of reinforcing fibers in cured resin/polymer matrix. In another embodiment, the non-homogenous composite material is comprised of reinforcing fibers in a polymer resin. In yet another embodiment, the non-homogenous composite material is comprised of reinforcing fibers in a resin where the resin is polymerized. In another embodiment, the composite material is a carbon-fiber reinforced composite. In a preferred embodiment, the carbon-fiber reinforced composite is comprised of carbon fibers in a cured polymer matrix. In a more preferred embodiment, the carbon-fiber reinforced composite is comprised of carbon fibers in a cured epoxy matrix. Materials for the elastomeric shims 106 are high-fatigue strength,

broad temperature range elastomers typically used in elastomeric high capacity laminate (HCL) bearings in aerospace vehicle rotary wing rotor head HCL bearings with such elastomer mold bonded between metal shims. In one example, the elastomeric shims 106 are made of post-vulcanized rubber, preferably with the post-vulcanized rubber post-vulcanized bonded to the non-elastomer composite material. The end plates 108A, 108B may be made of a non-elastomeric material. In one or more embodiments of the invention, the end plates 108A, 108B may be metal flexures end plates. In a preferred embodiment, the end plates 108A, 108B are made of a metallic material, such as aluminum.

[0027] In one or more embodiments of the invention, each flexure 104 is in the form of a beam plate, with $L_F \gg W_F \gg t_F$, where L_F is the length of the flexure, W_F is the width of the flexure, and t_F is the thickness of the flexure. In one or more embodiments of the invention, each elastomeric shim 106 is also in the form of a beam plate, with $L*W \gg 2*(L+W)*t$, where L is the length of the shim, W is the width of the shim, t is the thickness of the shim, $L*W$ is the load area of the shim, and $2*(L+W)*t$ is the bulge area of the shim. The shape factor of the shim is defined as the load area divided by the bulge area, i.e., $(L*W)/2*(L+W)*t$. In a preferred embodiment, the elastomeric shims 106 are designed to have a high shape factor to accommodate high loads perpendicular to the face of the elastomeric shim due to preloading the fastener and to minimize bending in the clamp area (load-bearing area) as the stack of flexures is deflected, while allowing for small transverse deflections of one flexure 104 relative to another. As illustrated in the figures the length is oriented along the x-axis, width along the y-axis, and thickness along the z-axis.

[0028] In one or more embodiments of the invention, the elastomeric shims 106 are only located in areas where load will be applied to the stack of flexures 104. In the examples illustrated in FIGS. 1 and 2, these load-bearing areas may be, for example, in the regions including holes 109 which may receive a fastener. In general, the load-bearing areas will depend on the final configuration of the spring 100. In some embodiments, as illustrated in FIGS. 1 and 2, the compliant spring 100 has a cantilever-

cantilever beam structure, which results in a characteristic “S” shape as the flexures 104 are deflected. Where the elastomeric shims 106 are located in only the load bearing areas, the elastomeric shims 106 may create gaps 105 between the flexures 104 in the stack 102 which prevent or minimize inter-flexure rubbing as the stack of flexures 104 deflects into the “S” shape under applied load.

[0029] In one approach, the thickness t of each elastomeric shim 106 is at least a minimum value which would prevent inter-flexure rubbing for a range of loads applied to the compliant spring 100. The preferred thickness of the elastomeric shim 106 should be minimized to maximize shape factor and will typically be in the range of 0.010 in. to 0.025 in. In another approach, for each elastomeric shim 106 arranged between the flexures 104, the shape factor of the elastomeric shim (i.e., load area/bulge area) is selected to be greater than 1, preferably greater than 2, more preferably greater than 5, most preferably greater than 10. In one embodiment, the shape factor of the elastomeric shim 106 is selected from a range including 4, 8, 12, 16, and 20. The shape factor of the elastomeric shims 106 on the same level of the stack 102 would generally be the same. However, the shape factor of the elastomeric shims 106 on different levels of the stack 102 may be different.

[0030] In one or more embodiments of the invention, the lengths of the flexures 104 in the stack 102 are substantially the same. Similarly, the lengths of the elastomeric shims 106 may be substantially the same. The width of the compliant spring 100 may be uniform along the length of the compliant spring 100, where the width of the compliant spring 100 is measured along the y-axis, and the length of the compliant spring 100 is measured along the x-axis. Alternatively, the width of the compliant spring 100 may vary along the length of the compliant spring 100. For example, as shown in FIG. 2, the compliant spring 100 may be tapered to have thinned portions 103, thereby reducing the overall weight of the spring 100.

[0031] FIGS. 3A and 3B show a resonant inertial force generator 140 including an array 141 of compliant springs 100. The springs 100 in FIGS. 3A and 3B have a shape similar to that in FIG. 2. In alternate examples, the springs 100 in FIGS. 3A and

3B may have a shape similar to that in FIG. 1 or other desired shape. In a preferred embodiment the sides of the springs 100 in the array 141 are coupled together so that the springs 100 function as a single unit. As an example, end plates 122, 124 and bolt/nut connections 126, 128 (or other suitable connections) may be used to couple the distal ends of the springs 100 together. The distal ends of the array 141 of springs 100 are coupled to vertical posts 142, 144. The vertical posts 142, 144 may be metallic flexures. The array 141 of springs 100 supports an inertial mass 146. This may be achieved, for example, by coupling the middle portion of the array 141 of springs 100 to the inertial mass 146 through, for example, a plate member 143 and bolt/nut connections 145. The inertial mass 146 in the illustrated example includes a yoke member 147 and a generally cylindrical body 149, where the generally cylindrical body 149 is coupled to the array 141 of springs 100 through the yoke 147. The inertial mass 146 may be made of metallic material as required for use, for example, as required for use in a "voice coil" type linear motor. In an alternative preferred embodiment such as illustrated in FIG. 6-7, the compliant springs 100 are cantilevered from a mounting base 254 to support the inertial mass 146, preferably with the composite springs not arrayed side by side as a unit.

[0032] In an embodiment the inertial force generator 140 includes an actuator 148 (FIG. 3B), which is disposed in a chamber 150 within the generally cylindrical body 149 of the inertial mass 146. The actuator 148 may be operatively coupled to the inertial mass 146 via any suitable means. For example, the actuator 148 may be operatively coupled to the inertial mass 146 via the same bolt/nut connections 145 used to couple the inertial mass 146 to the array 141 of springs 100. In general, a serial coupling is used between the array 141 of springs 100, inertial mass 146, and actuator 148 so that a force applied to the inertial mass 146 by the actuator 148 is transmitted to the array 141 of springs 100, causing the array 141 of springs 100 to move or bend. Motion of the array 141 of springs 100 is transmitted to the vertical posts 142, 144, which are coupled to or mounted on a structure 154 (FIG. 3B). In one example, the structure 154 is part of an aircraft. The structure 154 may be an aircraft fuselage, for example. In one example, the actuator 148 is an electromagnetic actuator or motor. In

one example, the actuator 148 includes a permanent magnet 156 circumscribed by an electromagnetic (EM) coil 158. The permanent magnet 156 is mechanically linked to the inertial mass 146. An electrical drive current supplied to the EM coil 158 is converted to a mechanical force that drives or moves the inertial mass 146. The components of the inertial force generator 140 described above may be shrouded within a casing 160, as shown in FIG. 3B.

[0033] In operation, the inertial force generator 140 generates a force which destructively interferes with and cancels an unwanted vibration force in the structure 154 to which it is attached. The inertial force generator 140 may include a controller system which receives a command signal and in response to the command signal produces the electrical drive current to drive the actuator 148 at an operating frequency. The controller system may additionally receive a feedback signal and based on the feedback signal adjust the electrical drive current provided to the actuator 148. The inertial mass 146 and spring array 141 constitute a mass-spring system having a natural frequency. The natural frequency may be tuned to be close to the operating frequency of the actuator 148 but generally below the operating frequency of the actuator 148. The structure of the compliant springs 100 is such that the natural frequency of the mass-spring system is stable over the operating life of the inertial force generator 140, typically at least 3,000 hours. In particular, the inventors have found that interleaving of elastomeric shims between composite flexures inhibits decay of the natural frequency of the mass-spring system to an acceptable level. In one embodiment, decay of the natural frequency of the mass-spring system is less than 0.4 Hz over at least 3,000 hours of operation of the inertial force generator. In another embodiment, decay of the natural frequency of the mass-spring system is less than 0.2 Hz over at least 3,000 hours of operation of the inertial force generator. In yet another embodiment, decay of the natural frequency of the mass-spring system is less than 0.1 Hz over at least 3,000 hours of operation of the inertial force generator. Preferably the elastomeric means of inhibiting decay, provides a natural frequency decay inhibited inertial force generator as compared with non-elastomeric shimmed flexures, such as metal shims between composite flexures.

[0034] A test was conducted to investigate stability of the natural frequency decay of a mass-spring system incorporating compliant springs such as illustrated in FIG. 1 or FIG. 2. Compliant springs for the test were prepared as follows. Elastomeric shims were cut from molded vulcanized rubber pads with a die. Each elastomeric shim had a thickness of about 10 mils. A spring stack consisting of alternating elastomeric shims and composite flexures were built up with a stainless steel shim on each end of the stack. Post vulcanization bonding of the elastomeric shims to the composite flexures or stainless steel shim was performed to create a bonded assembly. Four of such spring stacks were used to make an array of springs, and the array of springs was installed on an inertial mass as described in FIGS. 3A-3C. For comparison purposes, a similar device was prepared but with metal used as the shim between the composite flexures.

[0035] FIG. 4 shows a system for investigating endurance of springs in resonant inertial force generators. During endurance testing of the inertial force generator, frequency sweeps were performed to measure the natural frequency of the inertial force generator. In the configuration shown in FIG. 4, a power supply 171 and a signal generator 170 provide power and command signal, respectively, to an integrated control unit (ICU) 172. The ICU 172 performs amplification and sends control signals to the inertial force generator 176. The inertial force generator 176 represents any inertial force generator under investigation. The ICU 172 was used to set attenuation levels to adjust the drive levels for different channels. The signal analyzer 178 monitors the inertial mass acceleration signals from the inertial force generator 176. The signal conditioner 180 is used to condition the acceleration signals prior to being sent to the signal analyzer 178. During sweep capture, the signal generator 170 was disconnected and the signal analyzer 178 provided the command signal and monitored the command signal, drive current, drive voltage, and inertial mass acceleration. The flexure strain was then calculated using the inertial mass acceleration.

[0036] FIG. 5 is a comparison of the natural frequency decay in an inertial force generator with elastomeric shims interleaved between composite flexures (triangular

markers), as in the present invention, and an inertial force generator with metallic shims interleaved between composite flexures (square markers). All inertial force generators tested were driven at approximately equal frequencies to result in approximately equal strains in the inertial force generators. FIG. 5 shows that the inertial force generator incorporating compliant springs with elastomeric shims has a much lower natural frequency decay than the one incorporating compliant springs with metallic shims. One plausible reason for this is that when using metal shims, the interface between flexure and metal shim has a small amount of slippage that leads to wear between the flexure and the metal shim. On the other hand, when using elastomeric shims, the elastomeric shim allows this motion to be accommodated by shearing of the elastomer, which is why the elastomer is preferably bonded to the flexure. The endurance tests show that the inertial force generator with the elastomeric shims has a very stable natural frequency in which decay is inhibited. For the version using metallic shims, the total decay exceeded 0.3 Hz in 1200 hours. For the inertial force generator with the elastomeric shims, the natural frequency decay over more than 1,100 hours of operation was nearly zero. Temperature testing was performed on the inertial force generator with elastomeric shims, and the inertial force generator with elastomeric shims showed acceptable performance.

[0037] FIG. 6A-D illustrate compliant springs 100 which are preferably used to support an inertial mass such as inertial mass 146 in the electromagnetic actuator resonant inertial force generator 140 illustrated in FIG. 7A-C. The compliant springs 100 include stacks 102 of composite flexures 104 and elastomeric shims 106 in alternating arrangement, with the compliant springs 100 cantilevered from a mounting base 254 to support inertial mass 146 grounded at the opposite ends distal from the mounting base, with the inertial mass 146 disposed in between the compliant springs 100. FIG. 8A-B are Life Testing Decay plots of resonant inertial force generator 140 such as shown in FIG. 7A-C utilizing the bonded elastomeric spacer shims 106 bonded between the composite flexures 104 as shown in FIG. 6A-D, with the bonded elastomeric spacer shim resonant inertial force generator natural frequency shown by the squares in the plots. In the FIG. 8A-B Life Testing Natural Frequency Decay plots

Hours of Operation are along the x-axis and Frequency Decay is along the y-axis. To show comparisons of natural frequency decays in a resonant inertial force generator such as shown in FIG. 7A-C incorporating the composite flexures with elastomeric shims as compliant spring as shown in FIG. 6A-D, a comparable resonant inertial force generator incorporating composite flexures with metallic shims as compliant spring are shown by the triangles in the plots.

[0038] It will be apparent to those skilled in the art that various modifications and variations can be made to the invention without departing from the spirit and scope of the invention. Thus, it is intended that the invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents. It is intended that the scope of differing terms or phrases in the claims may be fulfilled by the same or different structure(s) or step(s).

CLAIMS

What is claimed is:

1. A resonant inertial force generator for controlling vibrations of a structure, comprising:
a compliant spring comprising a stack of flexures and elastomeric shims in alternating arrangement;
an inertial mass coupled to the compliant spring; and
an actuator for moving said inertial mass.
2. The resonant inertial force generator of claim 1, wherein said flexures have flexure surfaces adjacent to said elastomeric shims, said elastomeric shims being bonded to said flexure surfaces.
3. The resonant inertial force generator of claim 1, wherein the number of flexures in the stack is at least 2.
4. The resonant inertial force generator of claim 1, which has a natural frequency with a decay less than 0.1 Hz over 3,000 hours of operation.
5. The resonant inertial force generator of claim 1, wherein the actuator is an electromagnetic actuator.
6. The resonant inertial force generator of claim 1, wherein said flexures are comprised of composite beam plates.
7. The resonant inertial force generator of claim 1, wherein said stack is sandwiched between a pair of end plates.
8. The resonant inertial force generator of claim 7, wherein the elastomeric shims at distal ends of the stack are bonded to the end plates.

9. The resonant inertial actuator of claim 1, wherein at least one of the elastomeric shims in the stack has a shape factor greater than 10.
10. A resonant inertial force generator, comprising:
an inertial mass supported by a plurality of flexures; and
a plurality of intermediate elastomeric shims interleaved with said plurality of flexures.
11. The resonant inertial force generator of claim 10, wherein said flexures are comprised of composite plate members.
12. The resonant inertial force generator of claim 11, wherein said flexures have flexure surfaces adjacent to said intermediate elastomeric shims, said intermediate elastomeric shims being bonded to said flexure surfaces.
13. The resonant inertial force generator of claim 11, wherein each of said intermediate elastomeric shims has a shape factor greater than 10.
14. A compliant spring, comprising:
a plurality of composite flexure plates layered in a stack; and
an elastomeric shim disposed between each adjacent pair of the composite flexure plates.
15. The compliant spring of claim 14, wherein the elastomeric shim is bonded to the adjacent pair of the composite flexure plates.
16. The compliant spring of claim 14, wherein said elastomeric shim has a shape factor greater than 10.

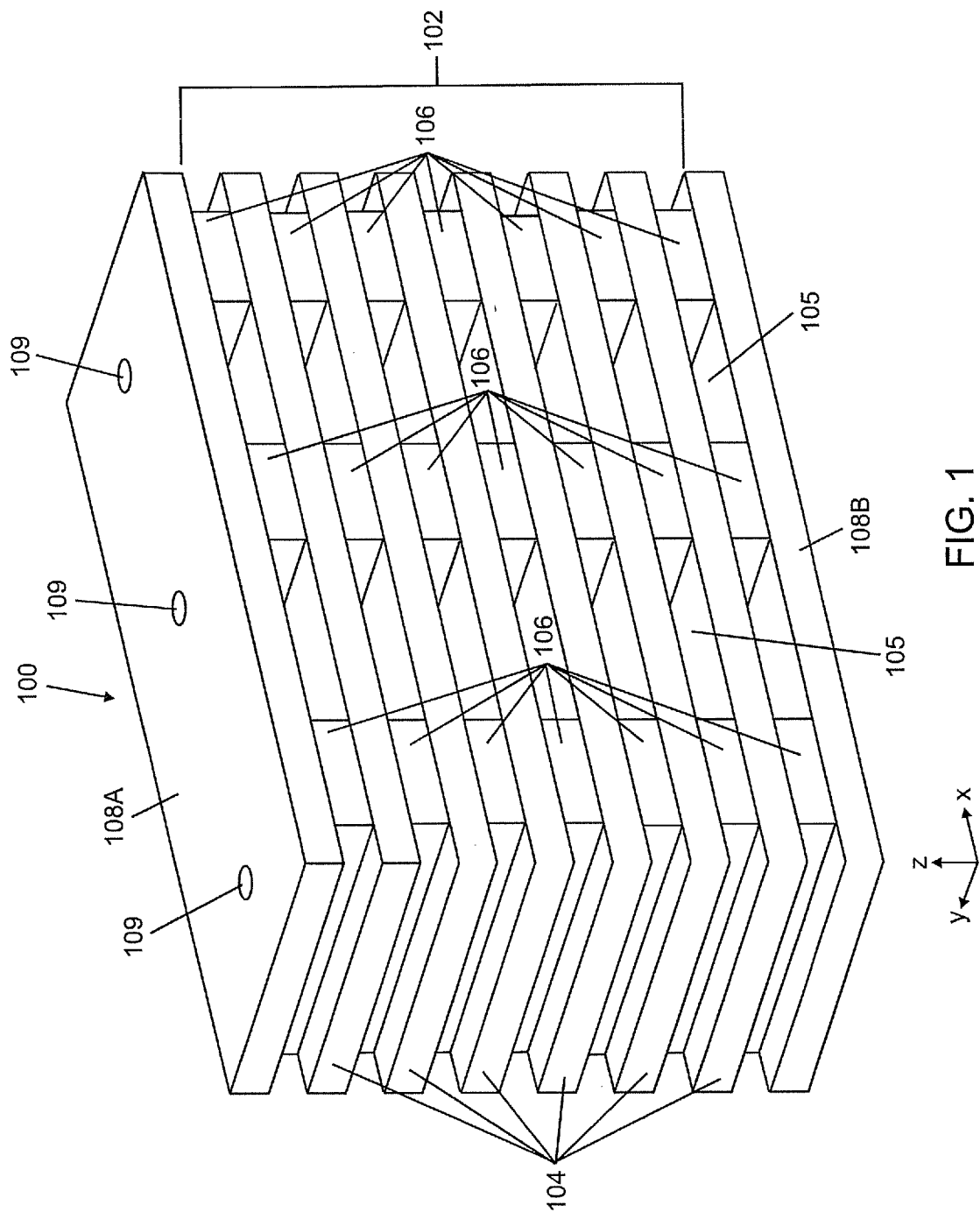
17. A method of making an inertial force generator, comprising:
 - providing an inertial mass;
 - providing n composite flexures, wherein n is an integer and is greater than 1;
 - providing at least $n+1$ elastomeric shims;
 - interleaving the at least $n+1$ elastomeric shims with the n composite flexures to form a compliant spring comprising an alternating arrangement of flexures and elastomeric shims;
 - coupling said inertial mass to the compliant spring; and
 - coupling to the inertial mass an actuator capable of moving the inertial mass.
18. A method of making an inertial force generator, comprising:
 - providing an inertial mass;
 - providing a plurality composite flexures;
 - providing a plurality of elastomeric shims;
 - stacking the composite flexures and elastomeric shims alternately to form a compliant spring, the elastomeric shims being arranged adjacent to load bearing areas of the composite flexures;
 - coupling said inertial mass to said compliant spring; and
 - coupling to the inertial mass an actuator capable of moving the inertial mass.
19. The method of claim 18, wherein stacking the composite flexures and elastomeric shims alternately to form a compliant spring comprises stacking the composite flexures and elastomeric shims to form a plurality of compliant springs.
20. The method of claim 18 wherein stacking the composite flexures and elastomeric shims alternately to form a compliant spring comprises.
21. A method of making an inertial force generator spring, comprising:
 - providing a plurality of composite flexure plates;
 - providing an intermediate elastomer;

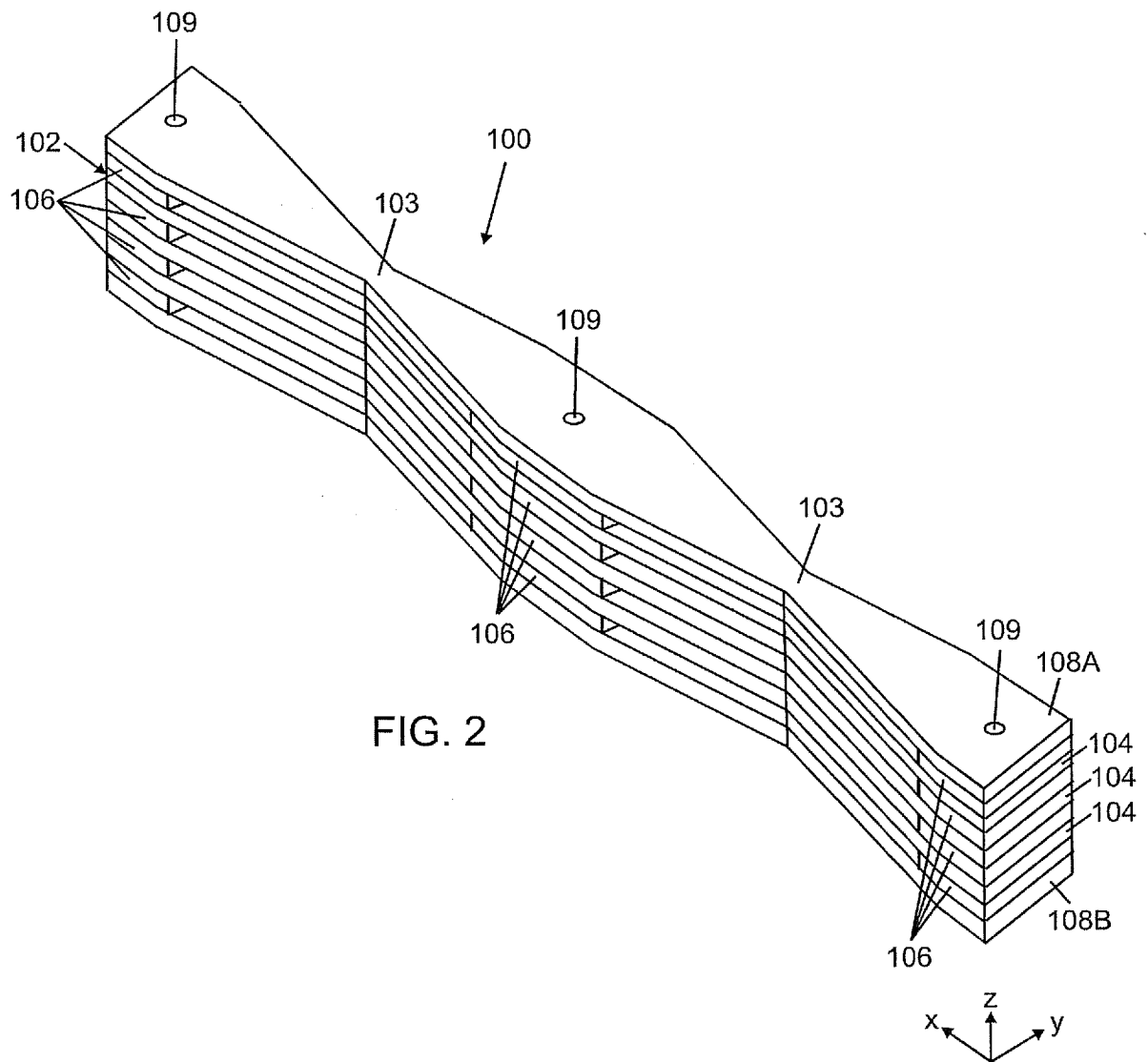
layering said composite flexure plates with said intermediate elastomer between said composite flexure plates to provide a spring assembly of layered composite flexure plates and intermediate elastomer between adjacent composite flexure plates, with said intermediate elastomer bonded to said composite flexure plates.

22. A resonant inertial force generator, comprising:
an inertial mass supported by a plurality of composite flexures arranged in a stack; and
compliant means for separating said composite flexures.
23. A resonant inertial force generator for controlling vibrations, comprising:
an inertial mass on a spring assembly;
a motor for moving said inertial mass on said spring assembly, said spring assembly including at least a first non-elastomeric flexure and at least a first intermediate elastomer, said intermediate elastomer bonded with said first non-elastomeric flexure.
24. The resonant inertial force generator of claim 23, wherein said at least a first intermediate elastomer has a shape factor greater than 10.
25. The resonant inertial force generator of claim 23, wherein said non-elastomeric flexure is a composite non-elastomeric flexure, said composite non-elastomeric flexure being comprised of a plurality of reinforcing fibers in a cured matrix.
26. The resonant inertial force generator of claim 23, wherein said non-elastomeric flexure is a non-metallic composite flexure.
27. An apparatus for controlling aircraft vibrations, comprising:

an inertial mass on a spring assembly having a natural frequency NF, an electrically driven motor for moving said inertial mass on said spring assembly, said spring assembly including at least a first composite flexure and a means for inhibiting a decay in said natural frequency NF.

28. An apparatus for controlling aircraft vibrations, comprising:
a driven inertial mass on a spring assembly having a natural frequency NF with the spring assembly including a plurality of nonhomogeneous composite flexures having first ends and distal second ends with a plurality of elastomeric spacers bonded between the composite flexures proximate the first ends and the distal second ends.





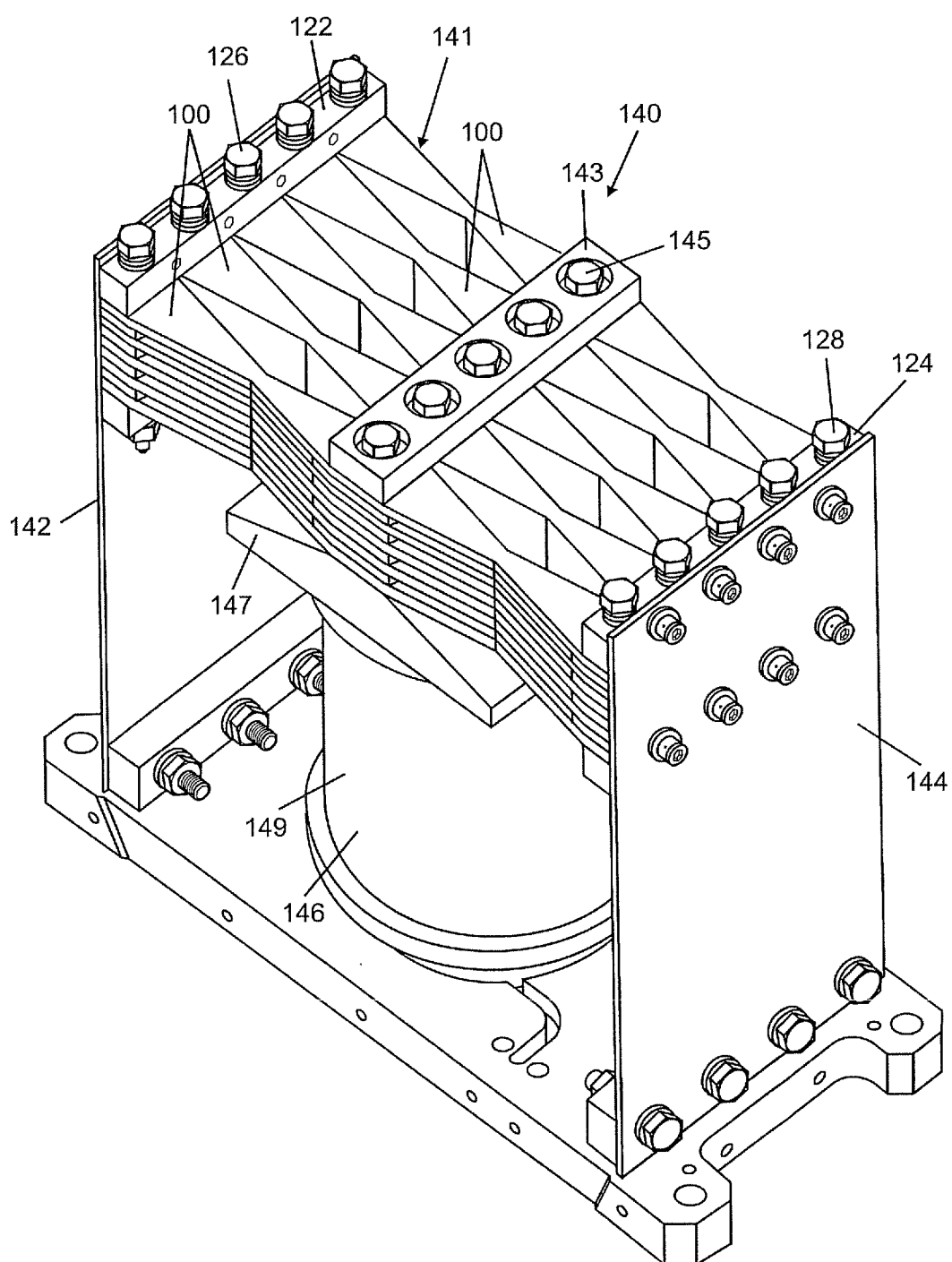


FIG. 3A

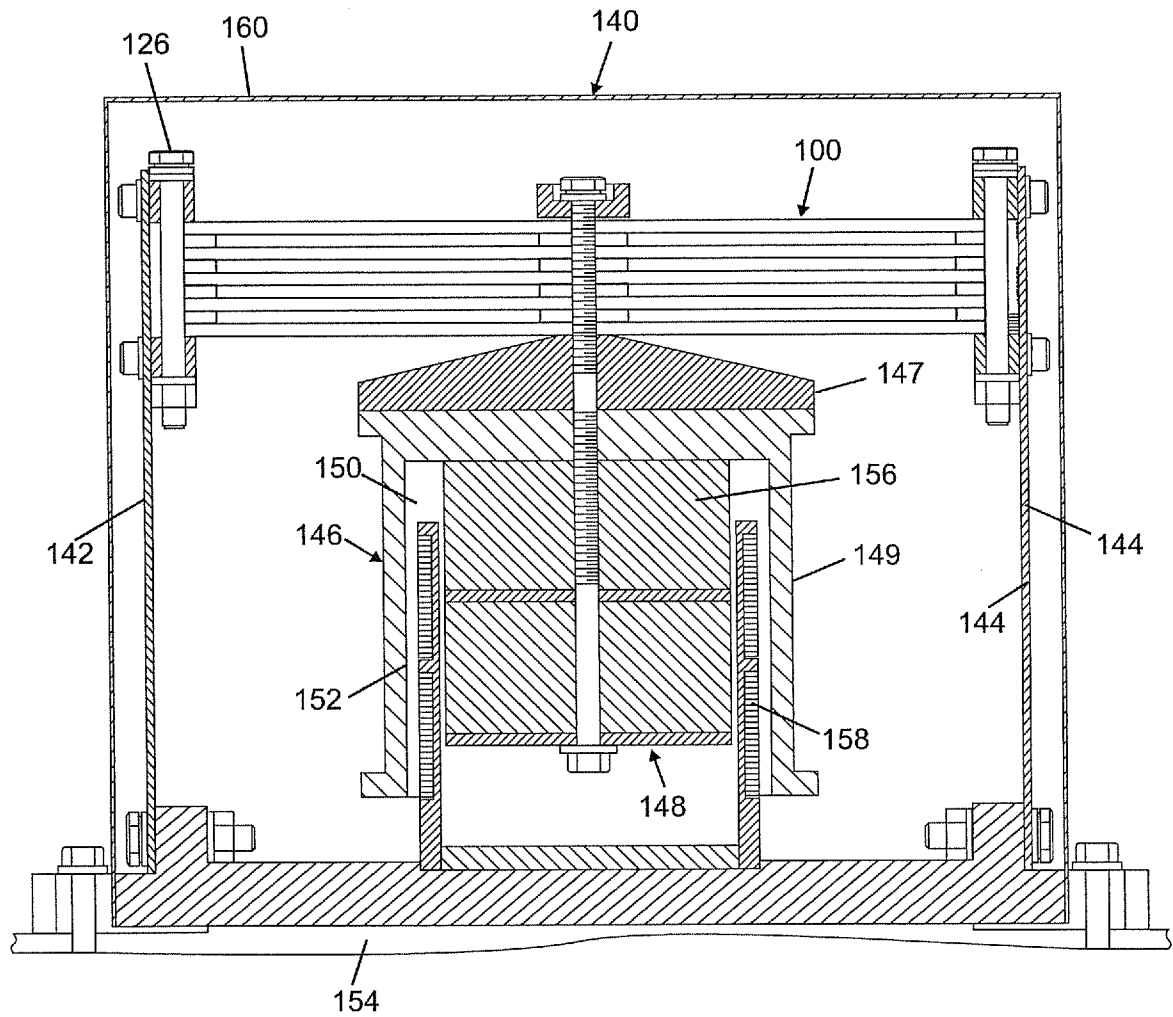
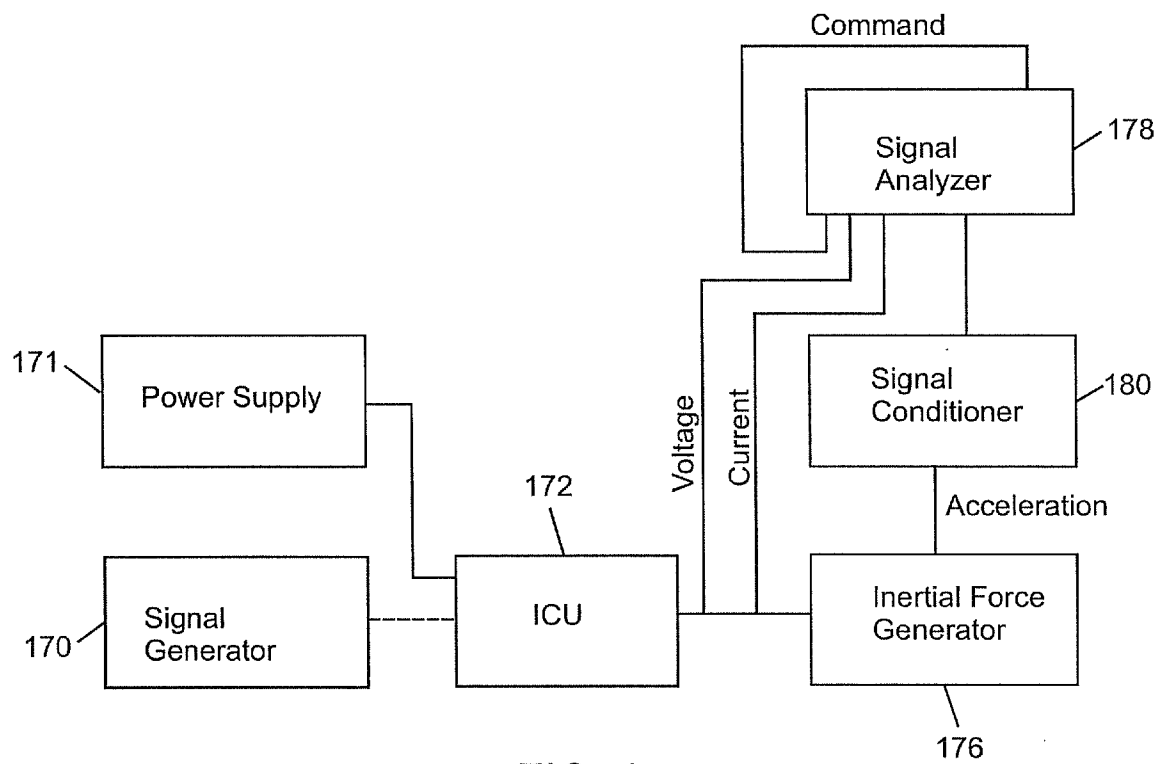


FIG. 3B



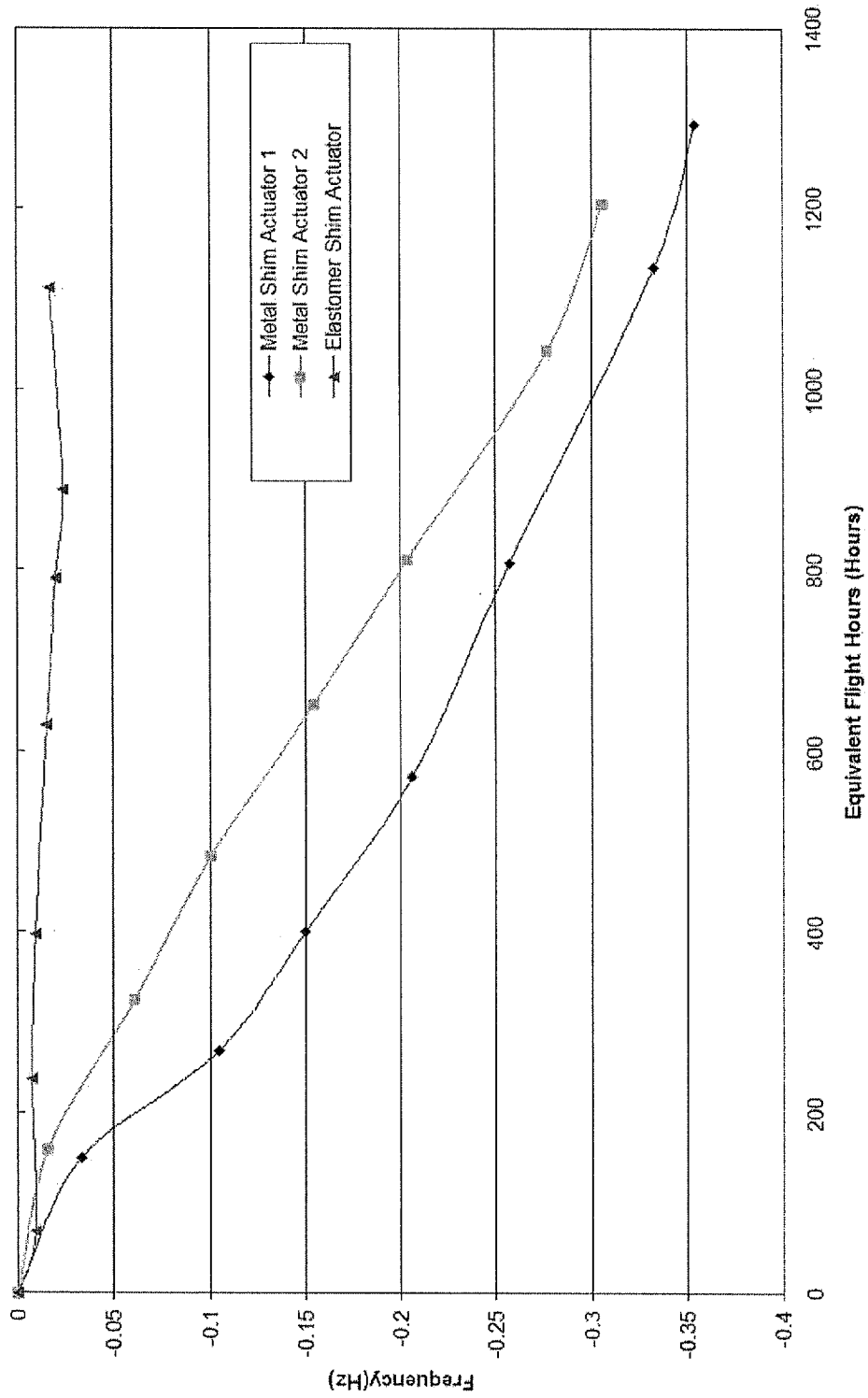


FIG. 5

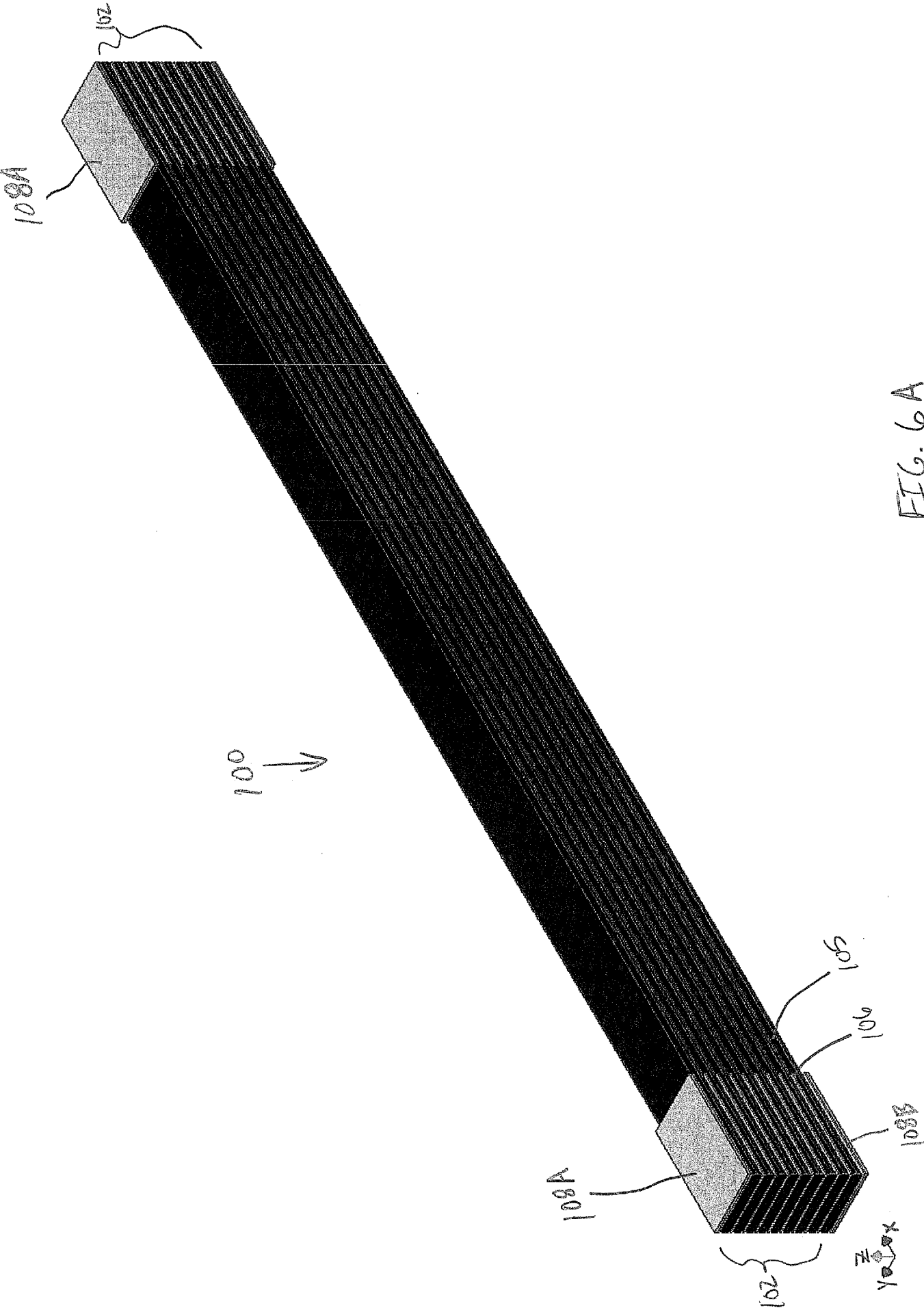


FIG. 6B

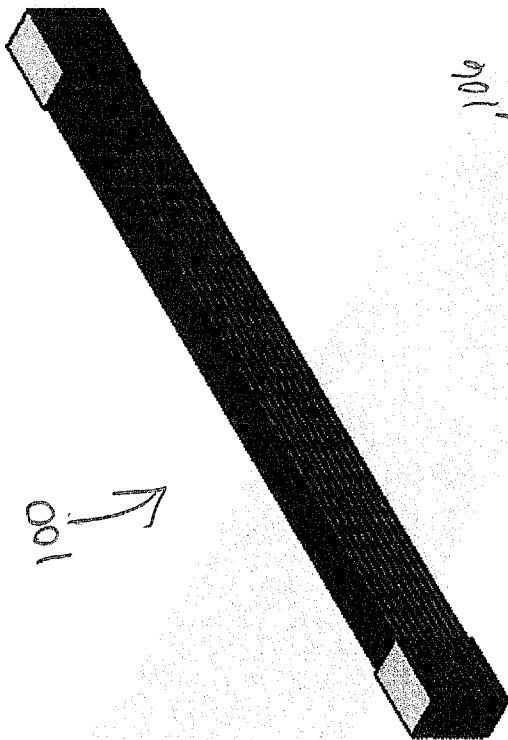
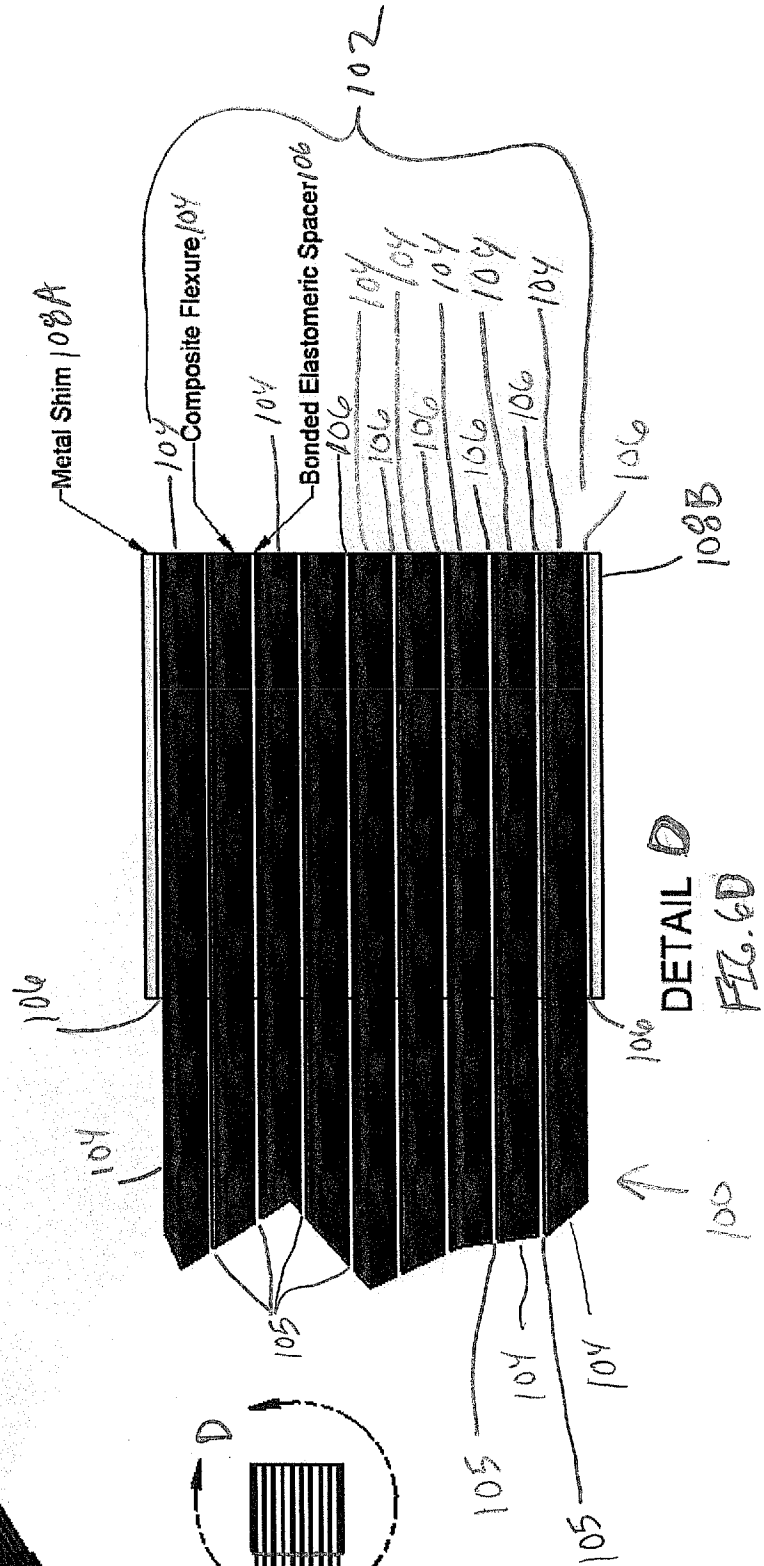
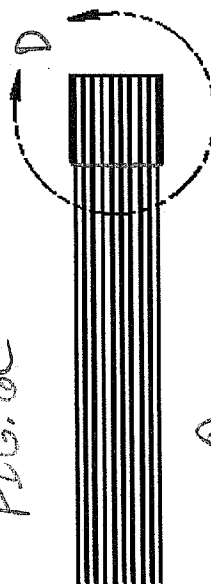
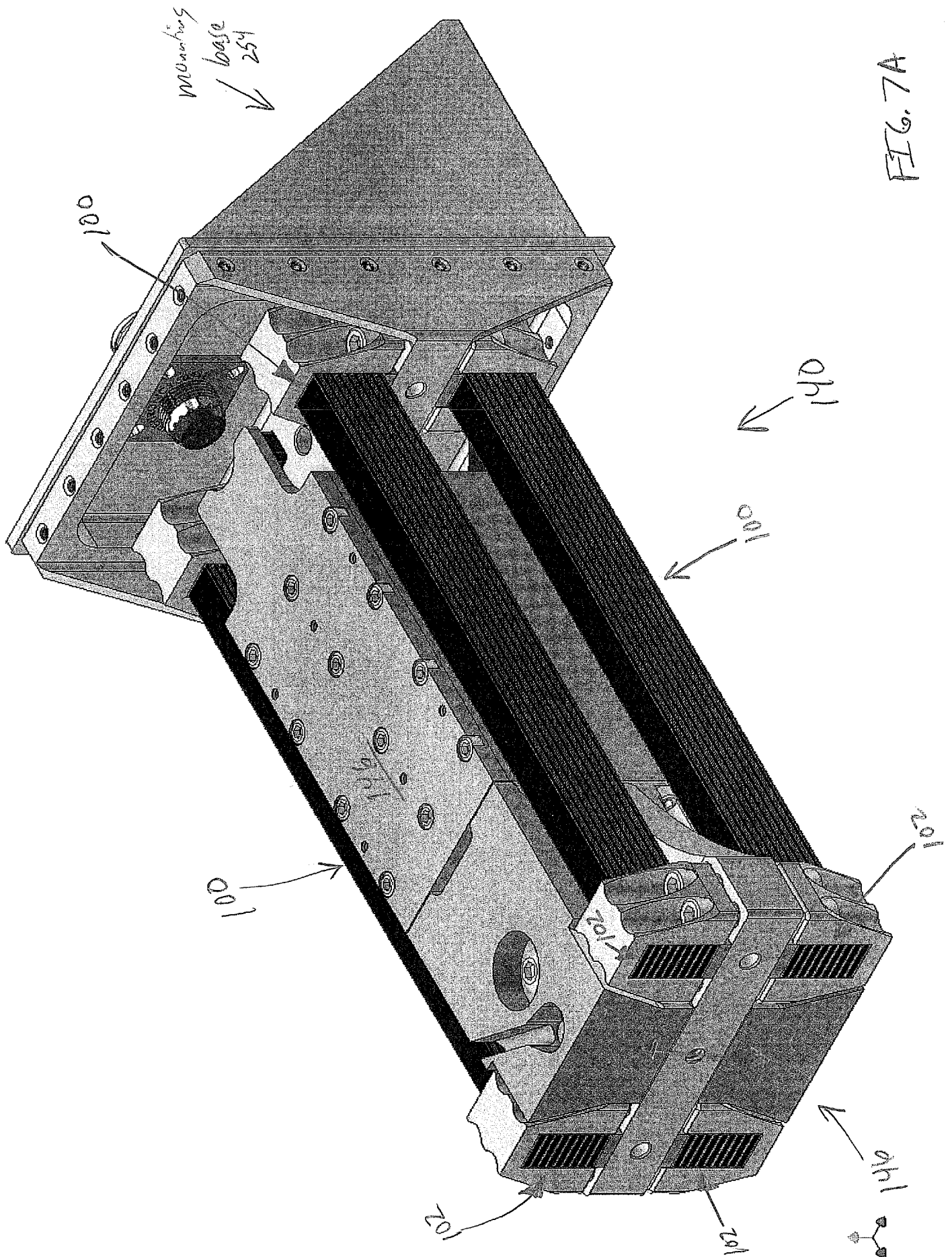


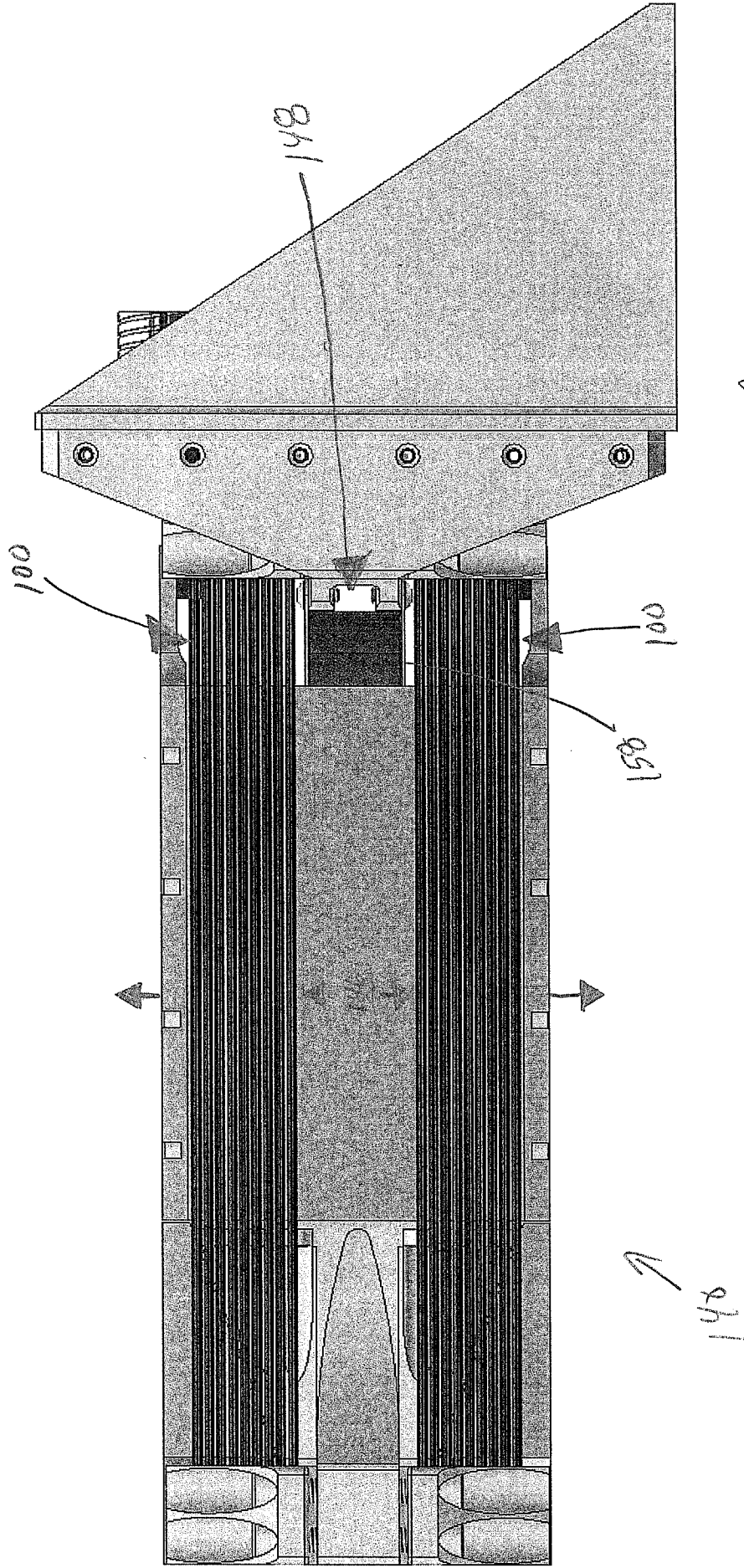
FIG. 6C



DETAIL D

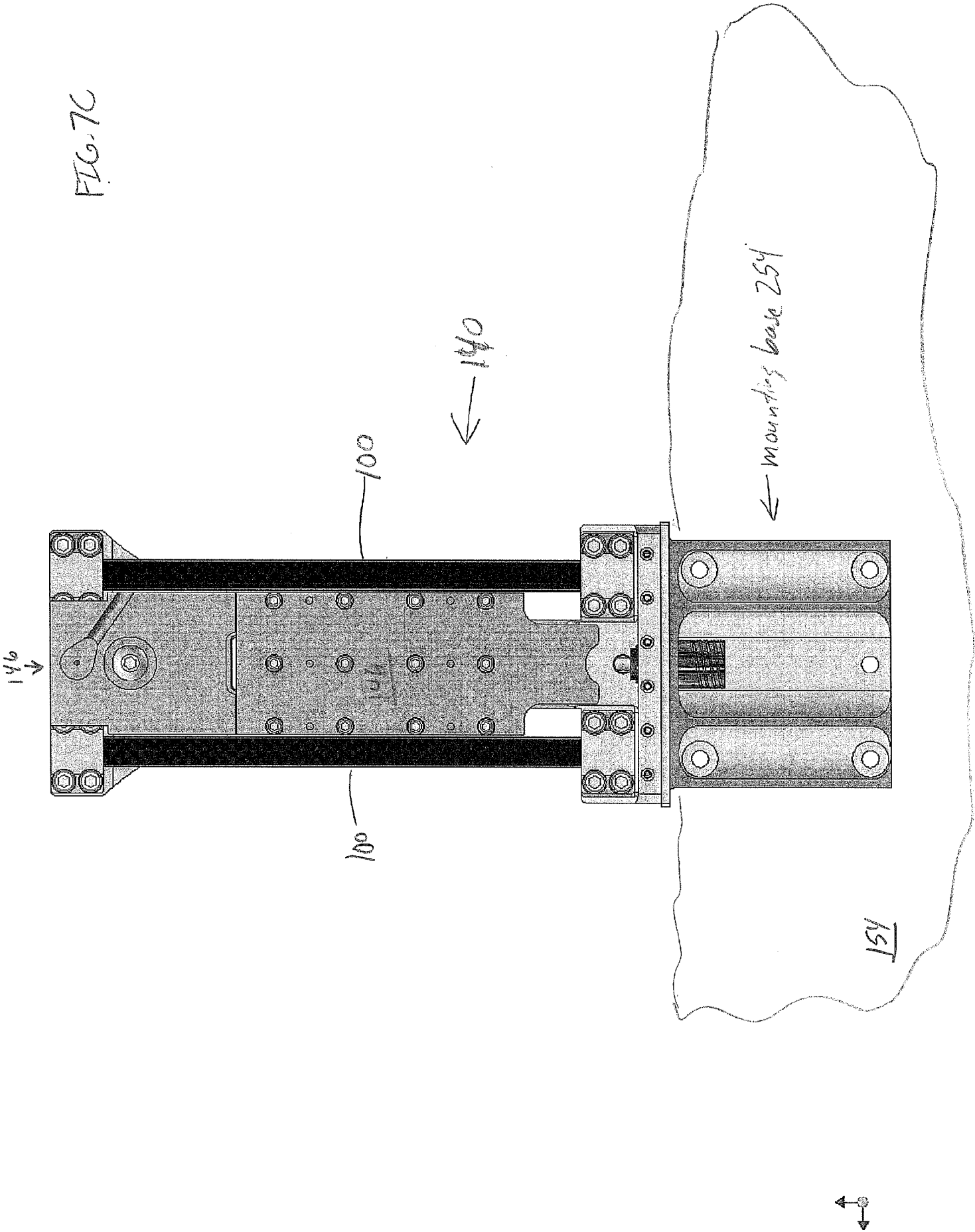
FIG. 6D





↑
mounting base 254

FIG. 7B



Life Testing - Decay of NF

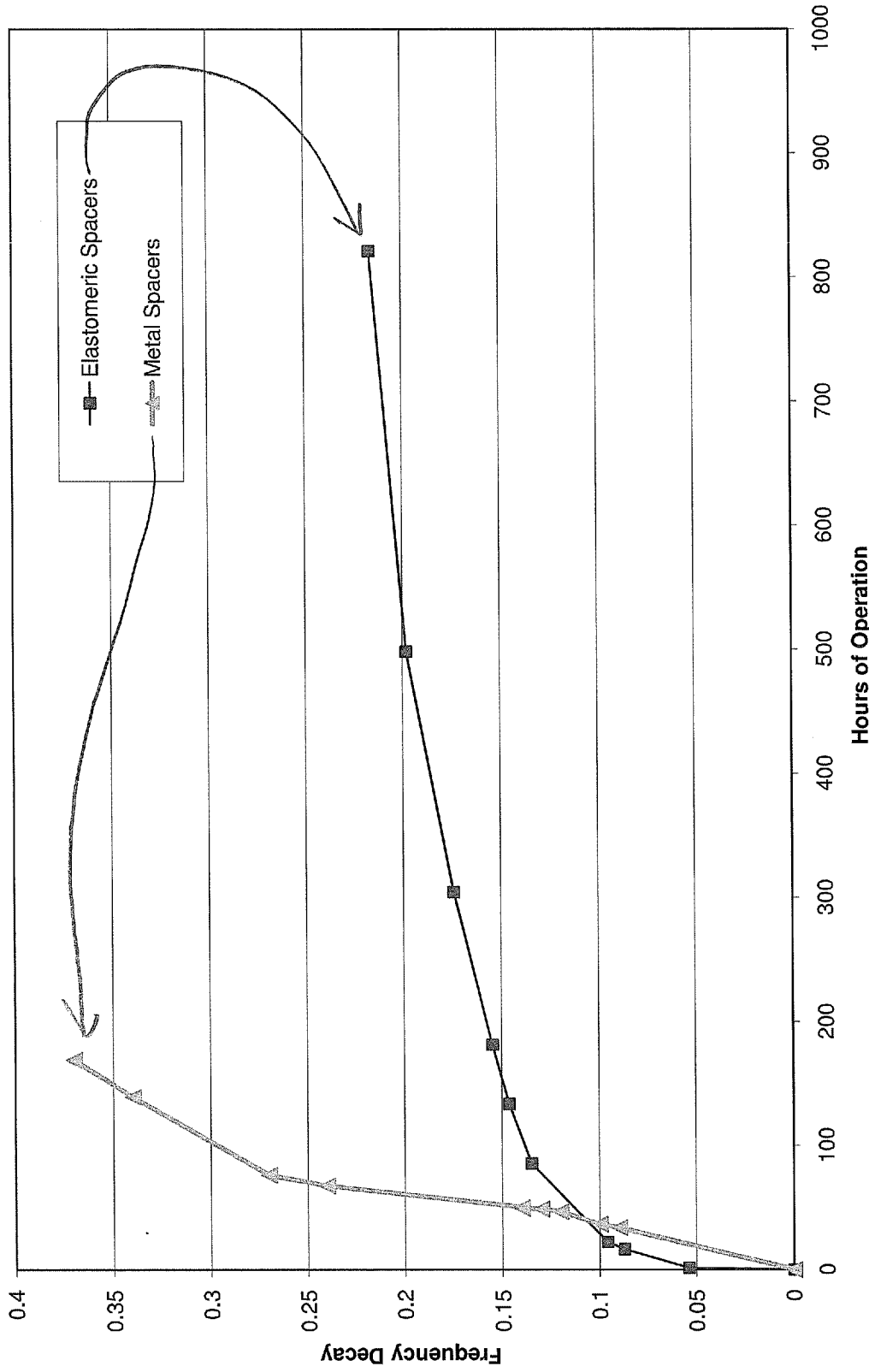


FIG. 8A

Life Testing Decay Log of NF

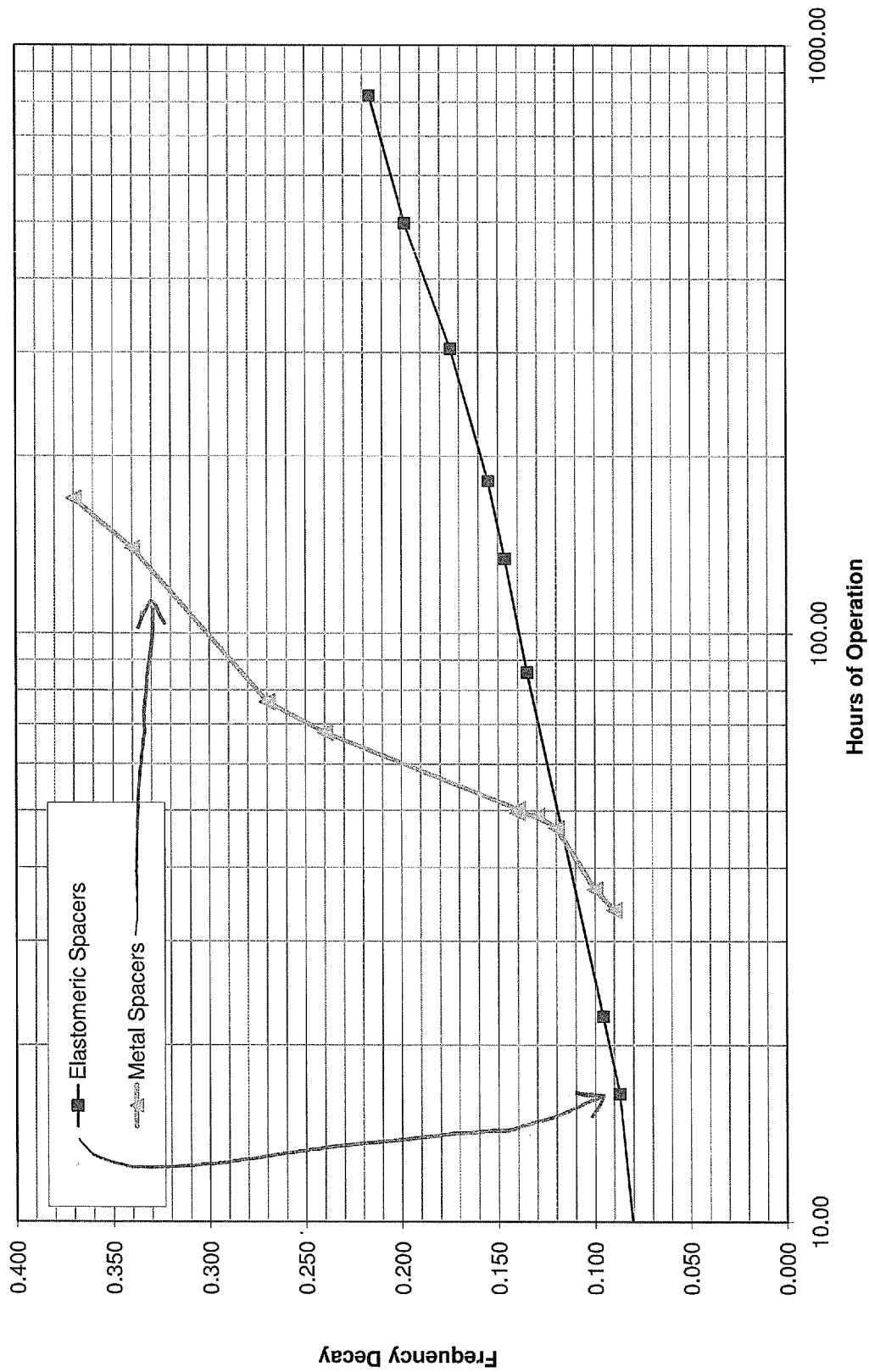


FIG. 8B

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2009/063193

A. CLASSIFICATION OF SUBJECT MATTER

INV. F16F7/10 F16F7/116 F16F1/20 F16F1/22

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)

F16F

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2006/054738 A1 (BADRE-ALAM ASKARI [US] ET AL) 16 March 2006 (2006-03-16) figures	1-9, 17-20, 23-28
Y	DE 198 23 716 A1 (BTR AVS TECHNICAL CENTRE GMBH [DE]) 2 December 1999 (1999-12-02) figures	1-9, 17-20, 23-26
X	EP 1 780 440 A1 (SHARP KK [JP]) 2 May 2007 (2007-05-02)	10-13
Y	figures 11-12	1-9, 17-20, 23-26
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

18 March 2010

Date of mailing of the international search report

25/03/2010

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Pirog, Pawel

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2009/063193

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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