US 20260150207A1

(19) **United States**

(12) **Patent Application Publication**

Robinson et al.

(10) **Pub. No.: US 2026/0150207 A1**

(43) **Pub. Date: May 28, 2026**

(54) **ROLLER HINGE WITH FRICTION ELEMENTS**

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(21) Appl. No.: **19/364,978**

(22) Filed: **Oct. 21, 2025**

Related U.S. Application Data

(60) Provisional application No. 63/724,826, filed on Nov. 25, 2024, provisional application No. 63/863,769, filed on Aug. 14, 2025.

Publication Classification

(51) **Int. Cl.**

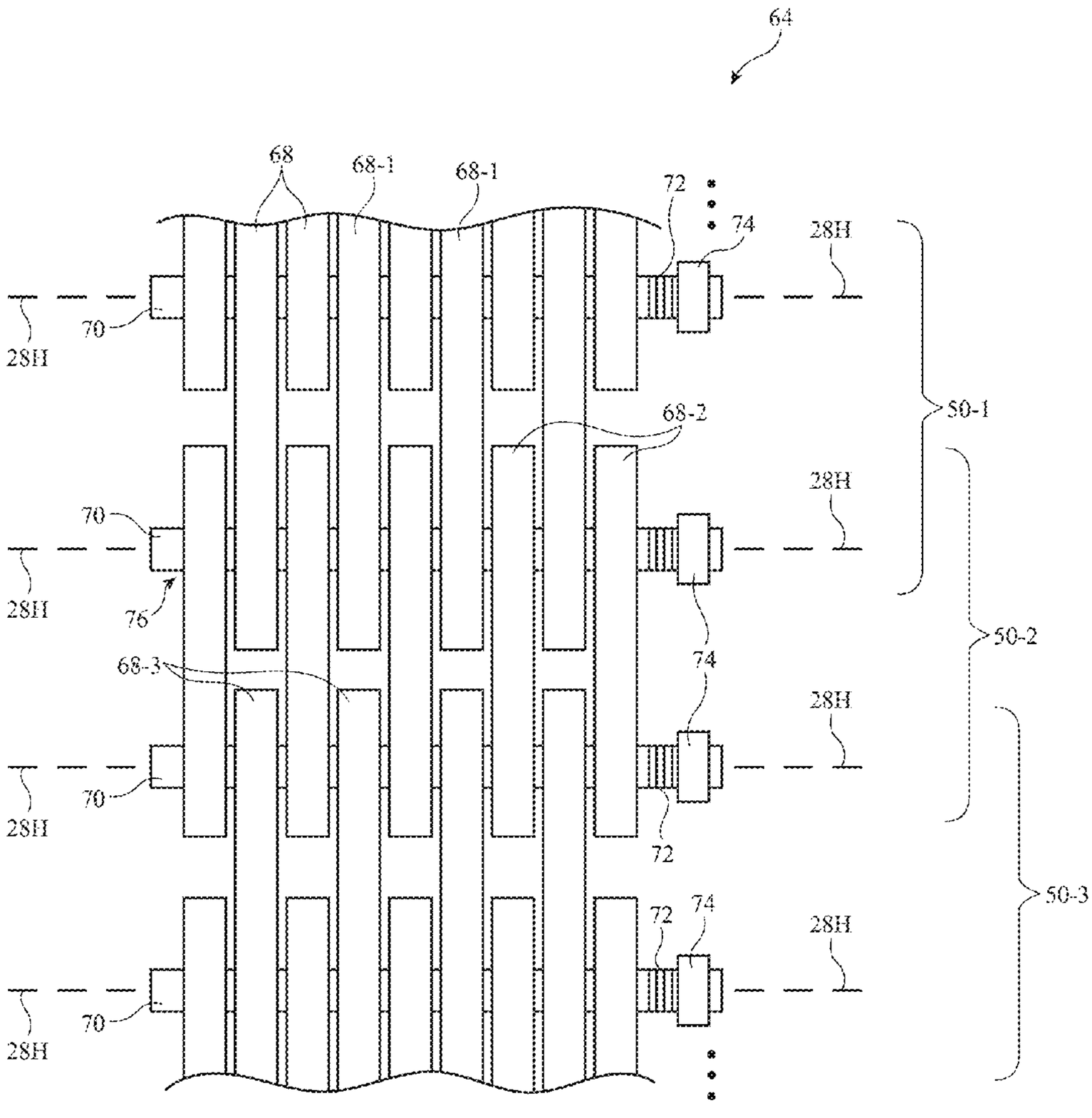
H05K 5/02	(2006.01)
F16C 11/04	(2006.01)
G06F 1/16	(2006.01)

(52) **U.S. Cl.**

CPC ***H05K 5/0226*** (2013.01); ***F16C 11/04*** (2013.01); ***G06F 1/1641*** (2013.01); ***G06F 1/1681*** (2013.01)

(57) **ABSTRACT**

An electronic device may include a flexible display mounted to a foldable housing. The foldable housing may include first and second housing portions coupled by a hinge that is aligned with the bend axis. The hinge may include rollers and interdigitated friction leaves that rotate about multiple axes of rotation. The hinge may include shafts that are received by the leaves and that are each aligned with a respective one of the axes of rotation. Some of the leaves may include gears for imposing synchronous motion of the first and second housing portions, while other leaves may include hard stop structures for imposing an open position hard stop and a closed position hard stop. In some arrangements, the leaves may include a vertical slot that receives a mutual pin and provides both synchronous motion functionality and hard stop functionality.



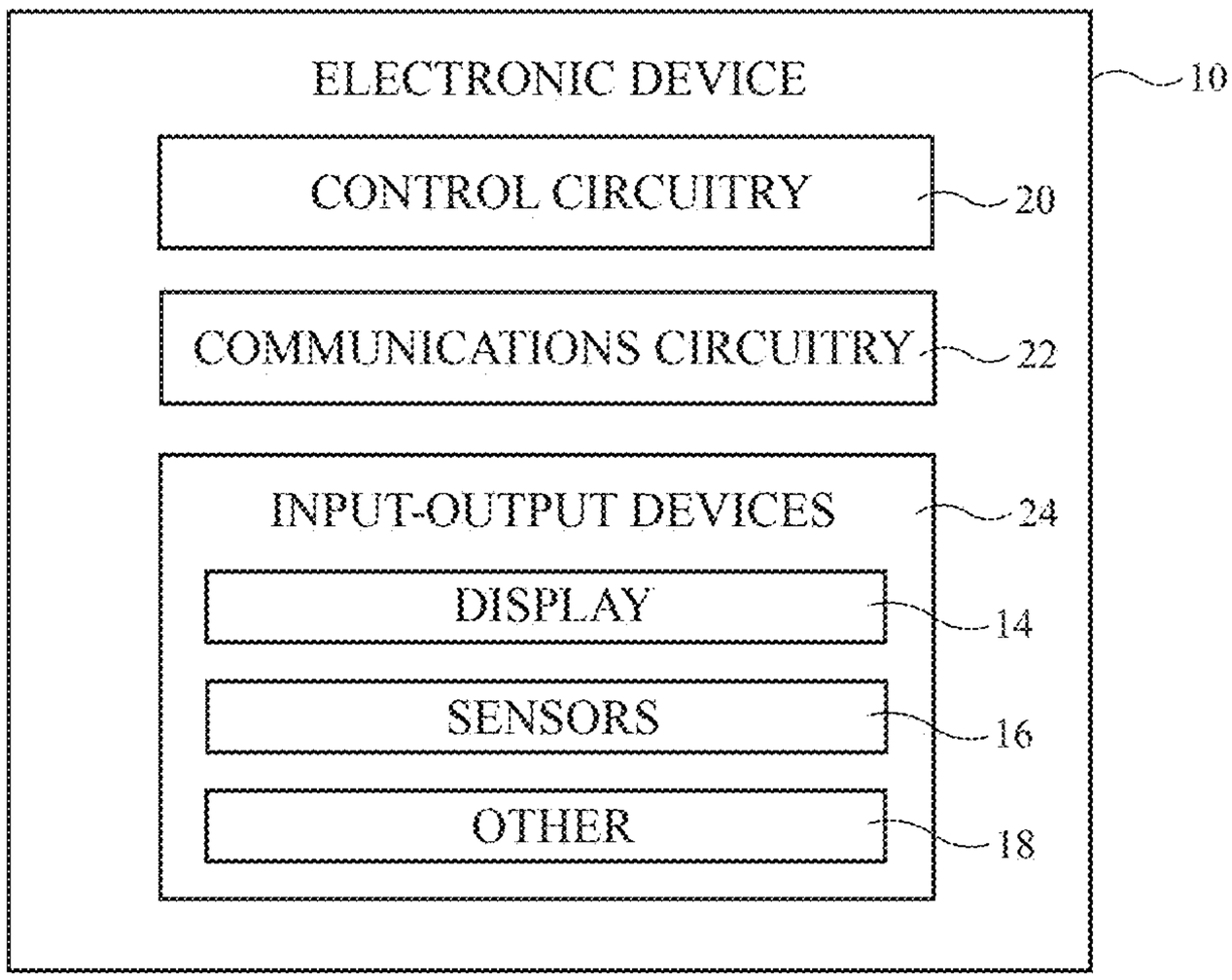

ELECTRONIC DEVICE
10
CONTROL CIRCUITRY
20
COMMUNICATIONS CIRCUITRY
22
INPUT-OUTPUT DEVICES
24
DISPLAY
14
SENSORS
16
OTHER
18

FIG. 1

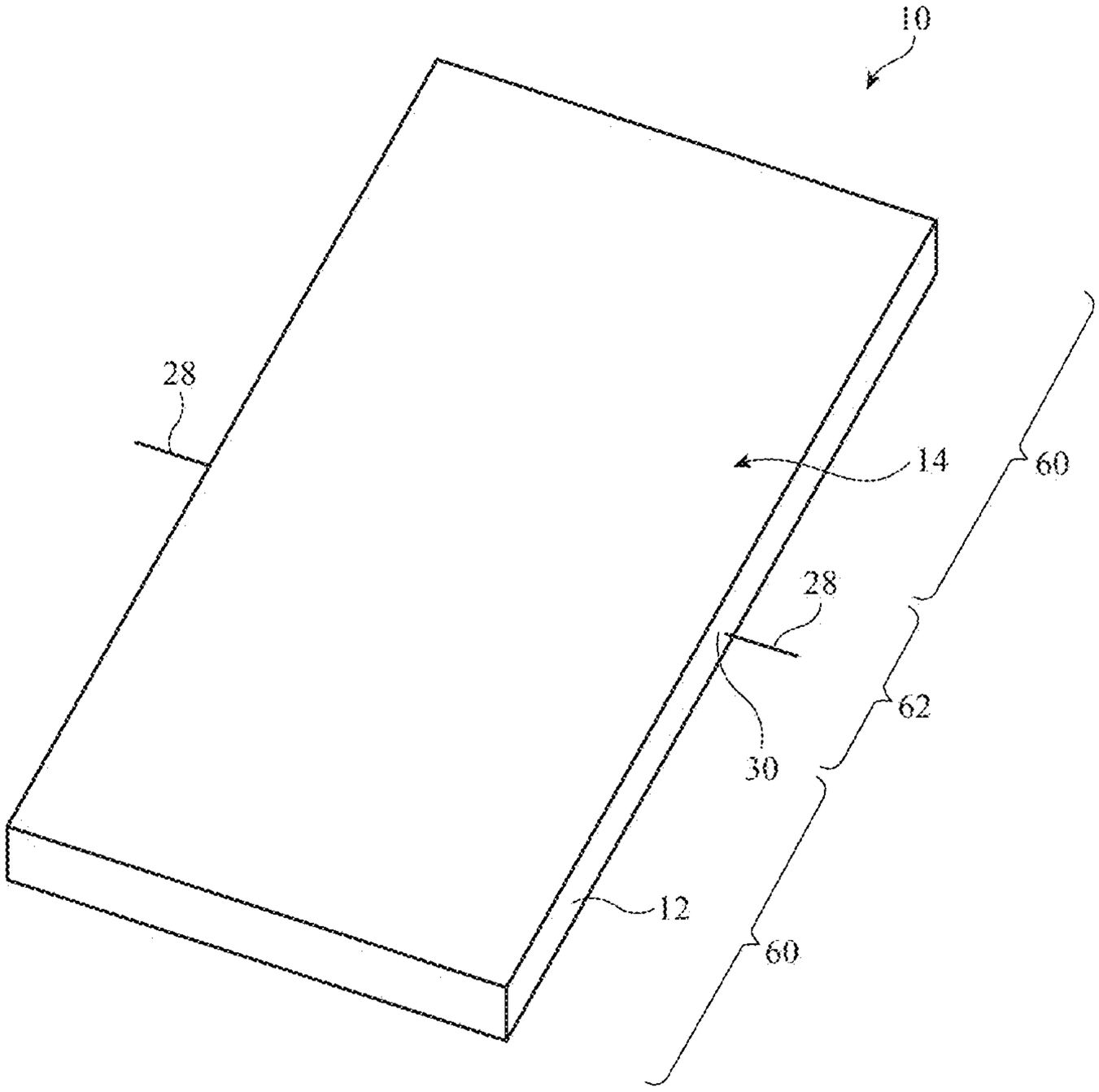


FIG. 2

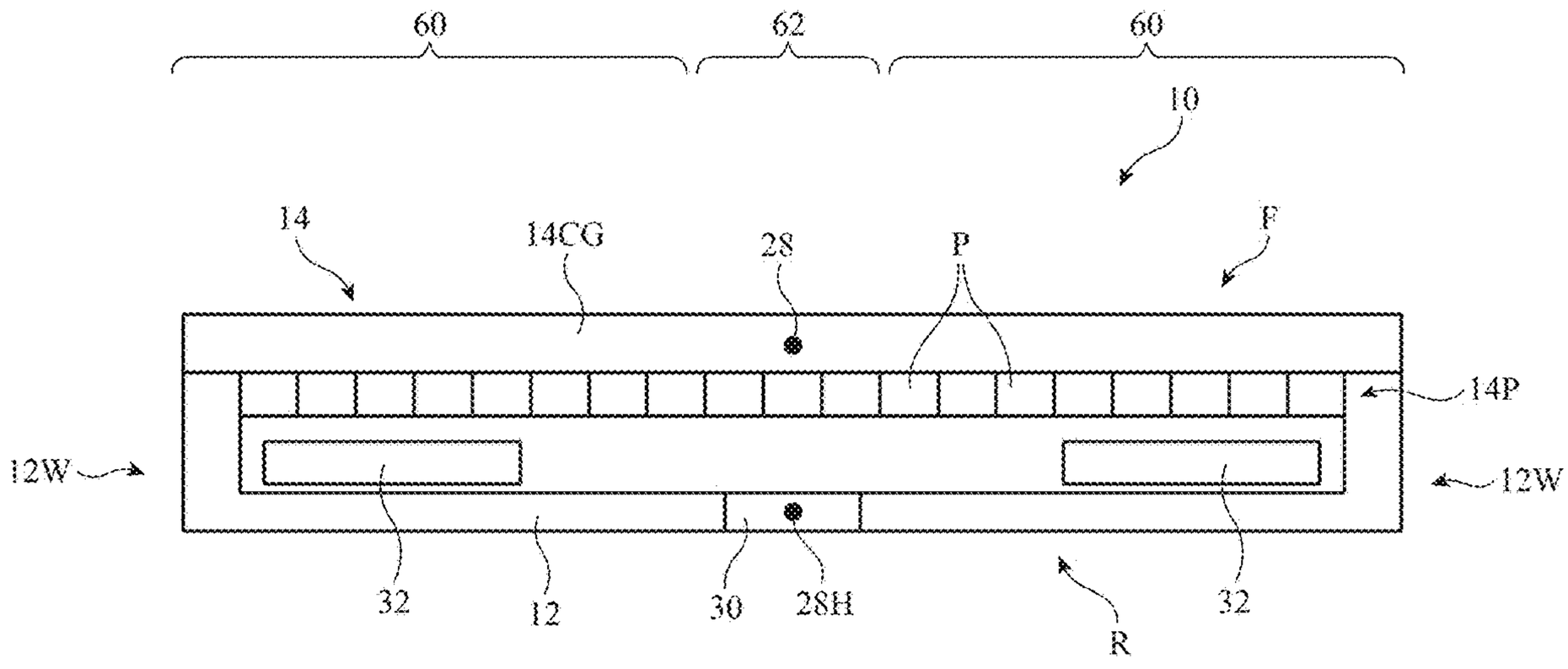


FIG. 3

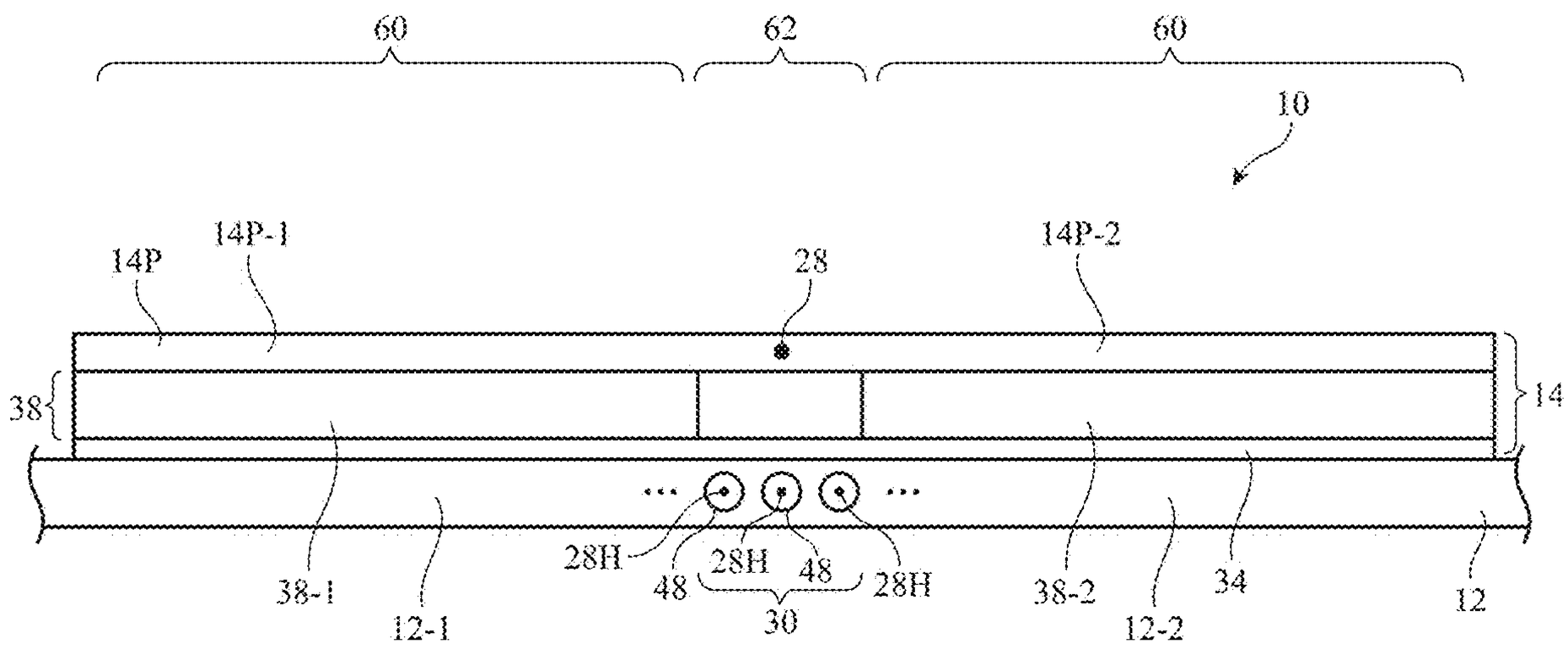

60
62
60
10
14P
14P-1
28
14P-2
38
14
28H
48
28H
48
28H
38-1
12-1
30
38-2
12-2
34
12

FIG. 4

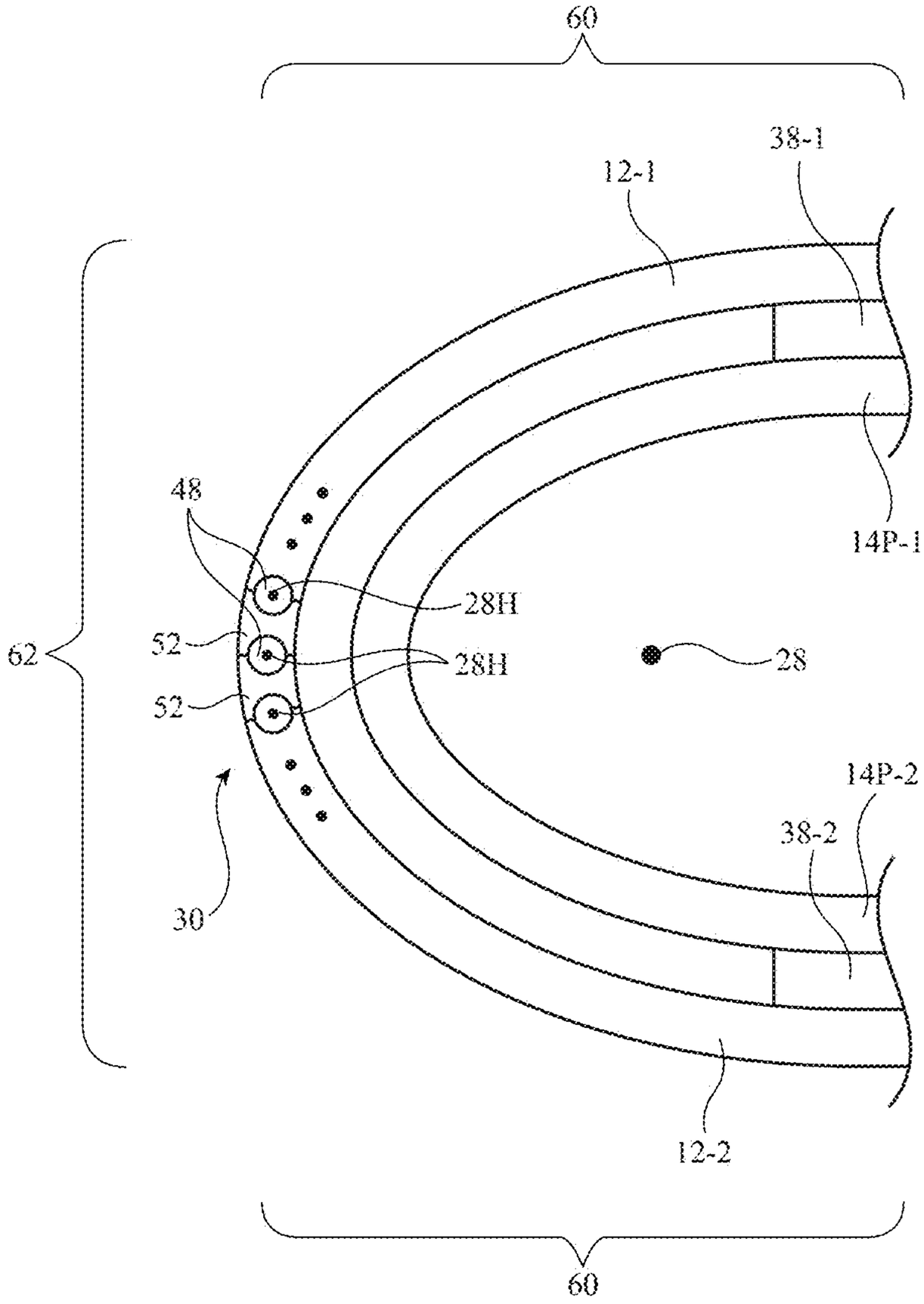


FIG. 5

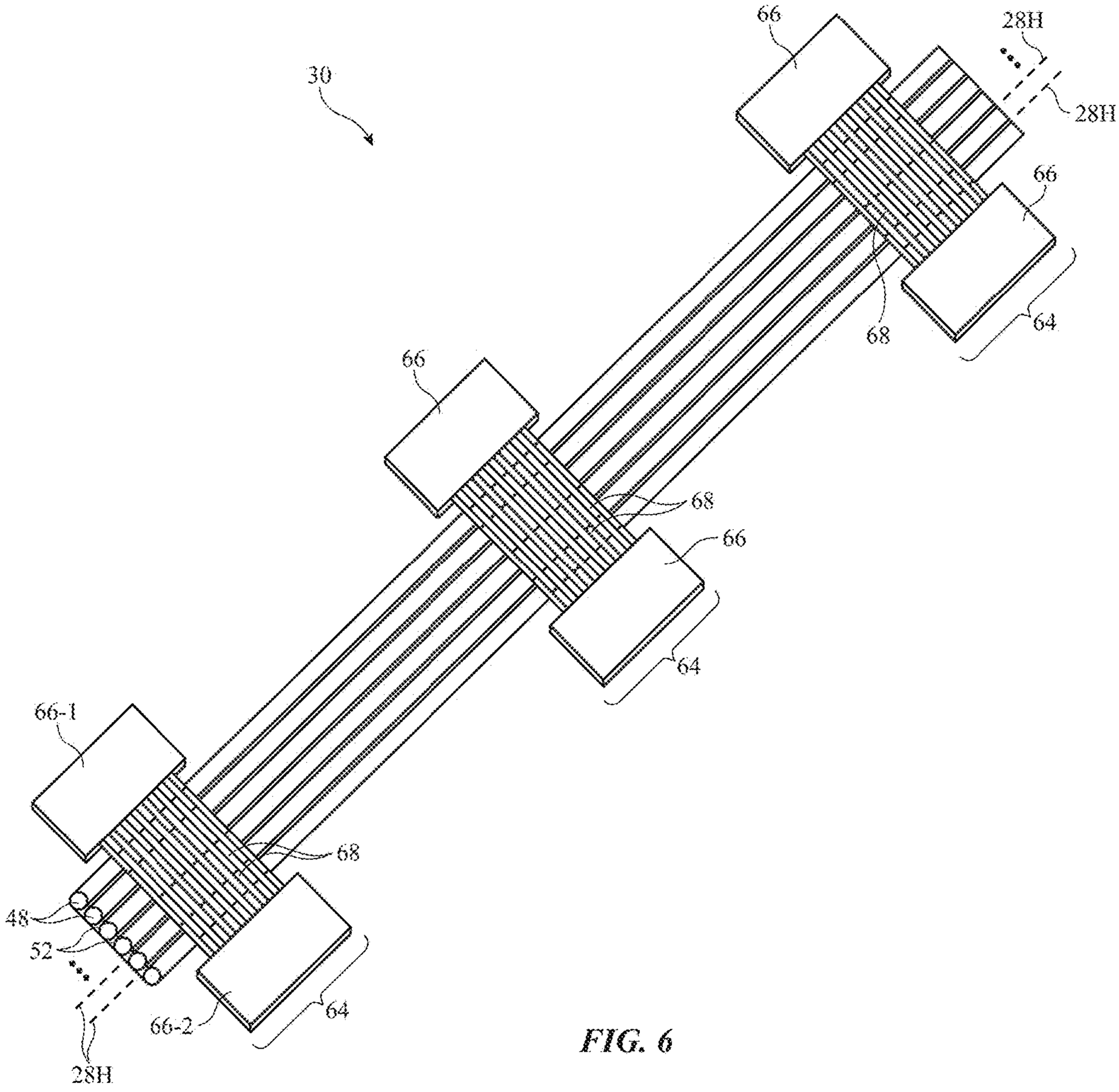


FIG. 6

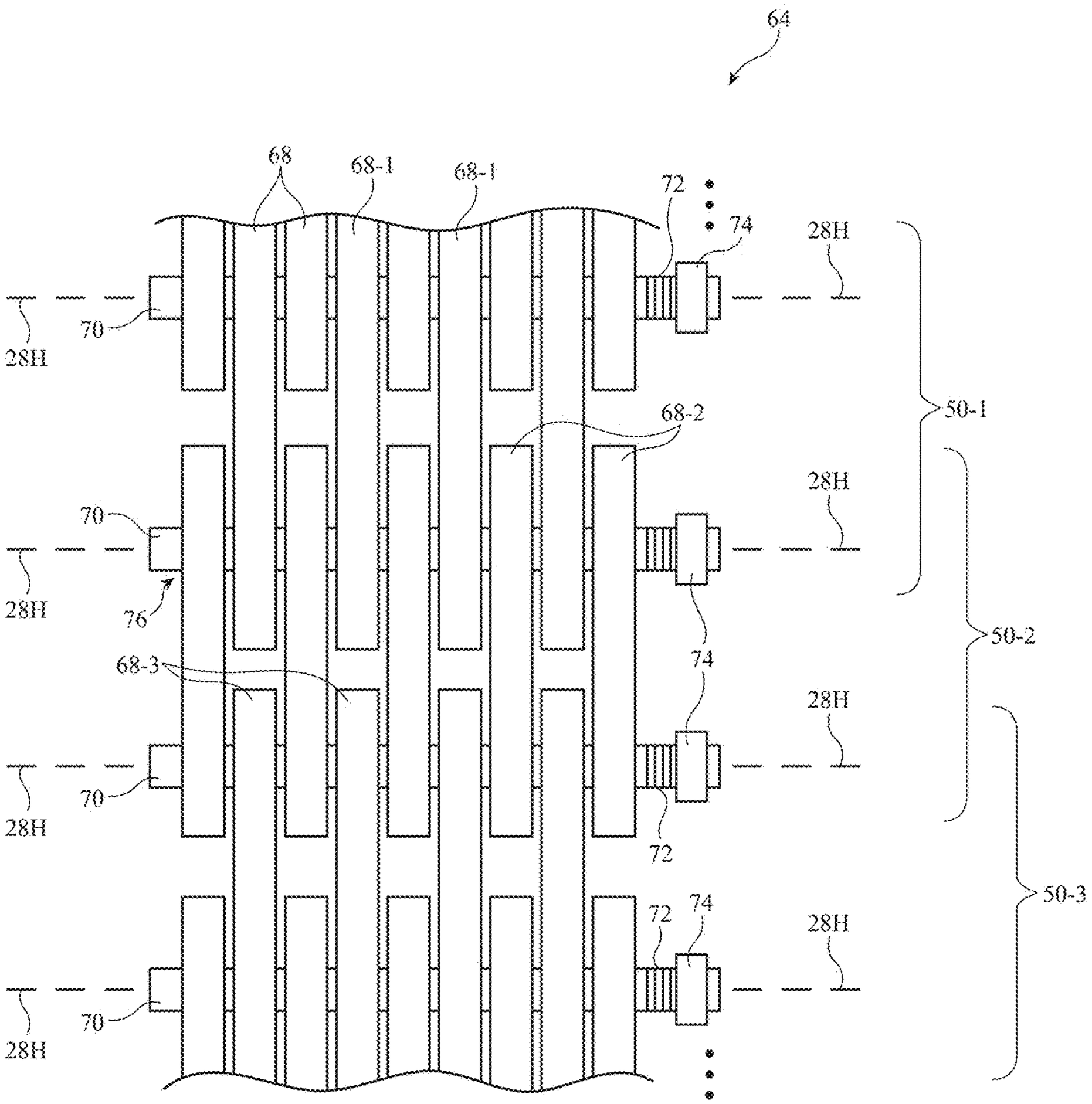

64
68
68-1
68-1
72
74
28H
70
28H
68-2
50-1
70
28H
28H
76
74
68-3
50-2
28H
70
28H
72
50-3
72
74
28H
70
28H

FIG. 7

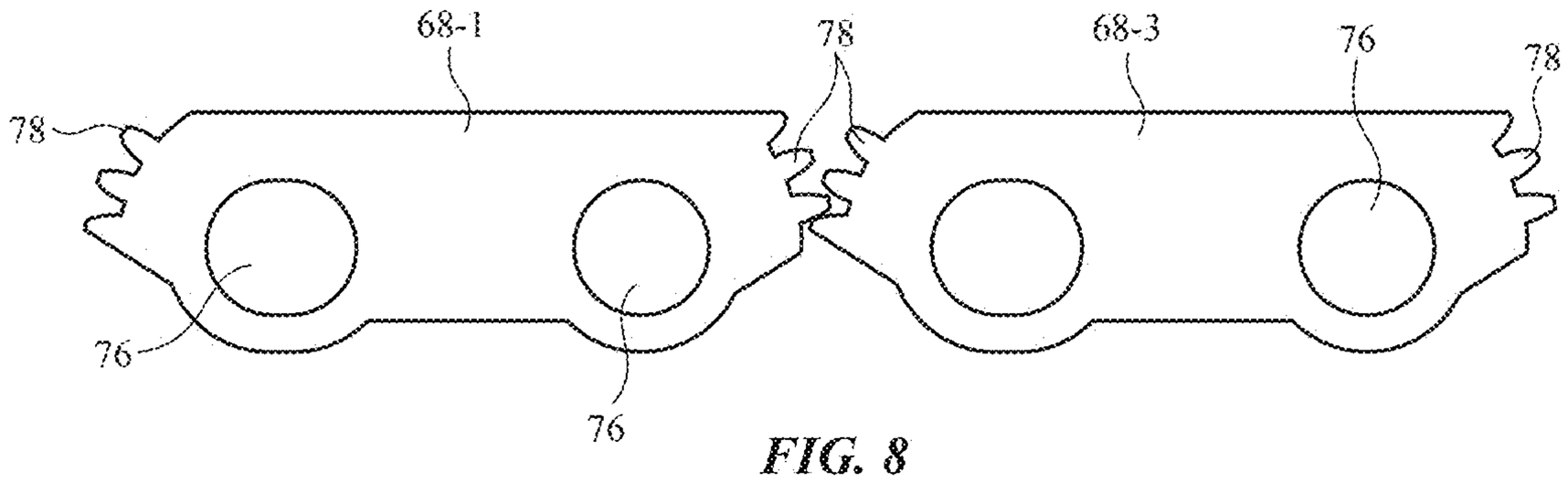


FIG. 8

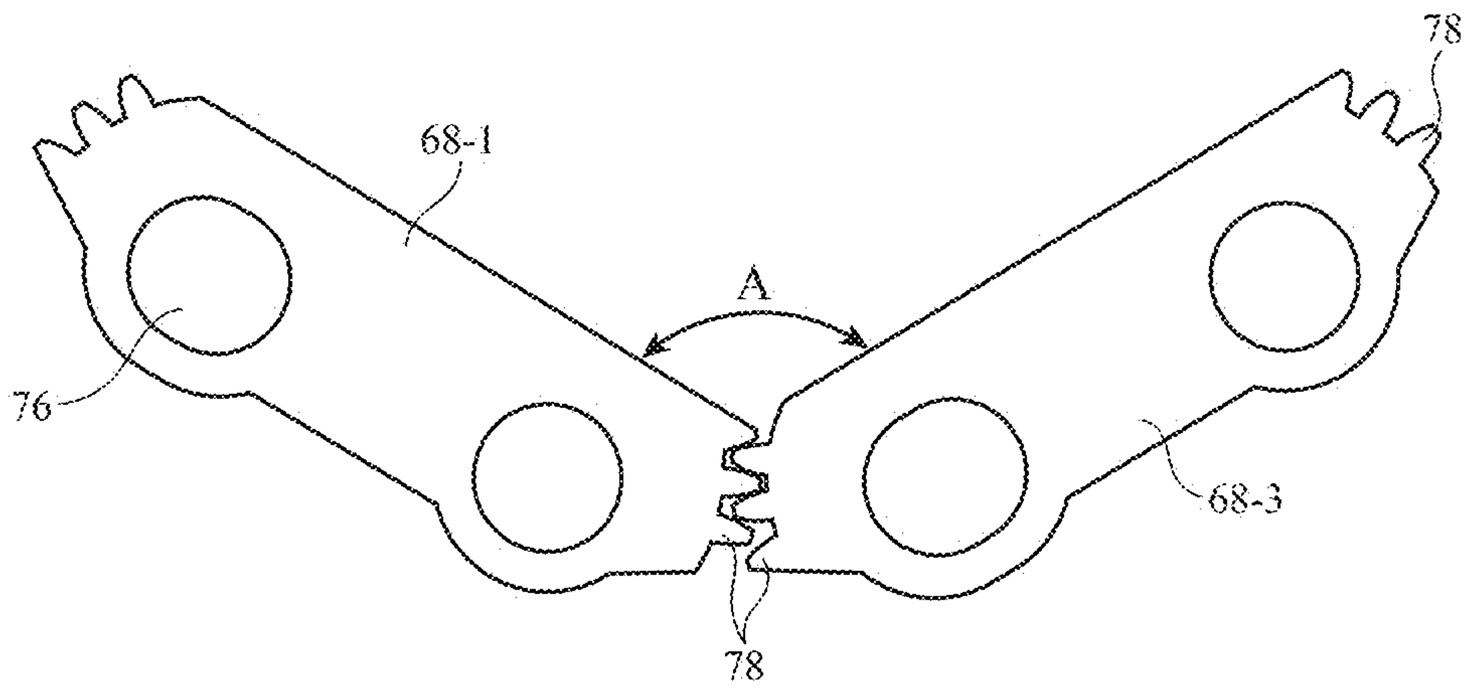


FIG. 9

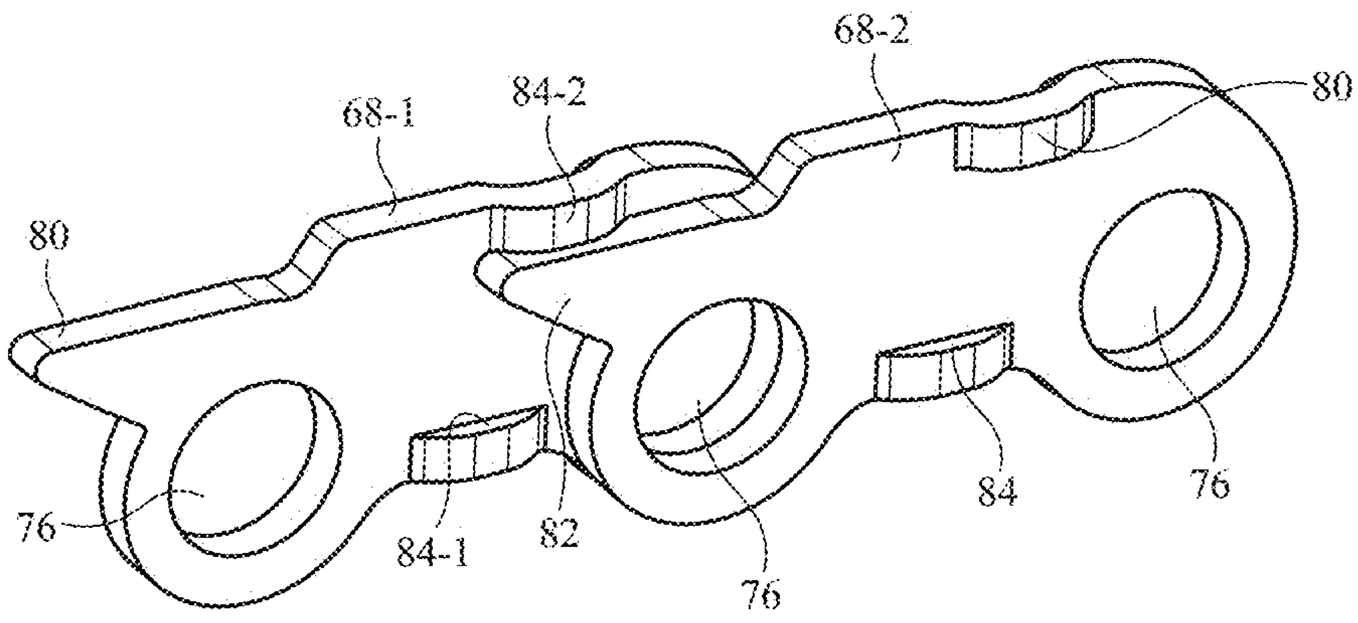


FIG. 10

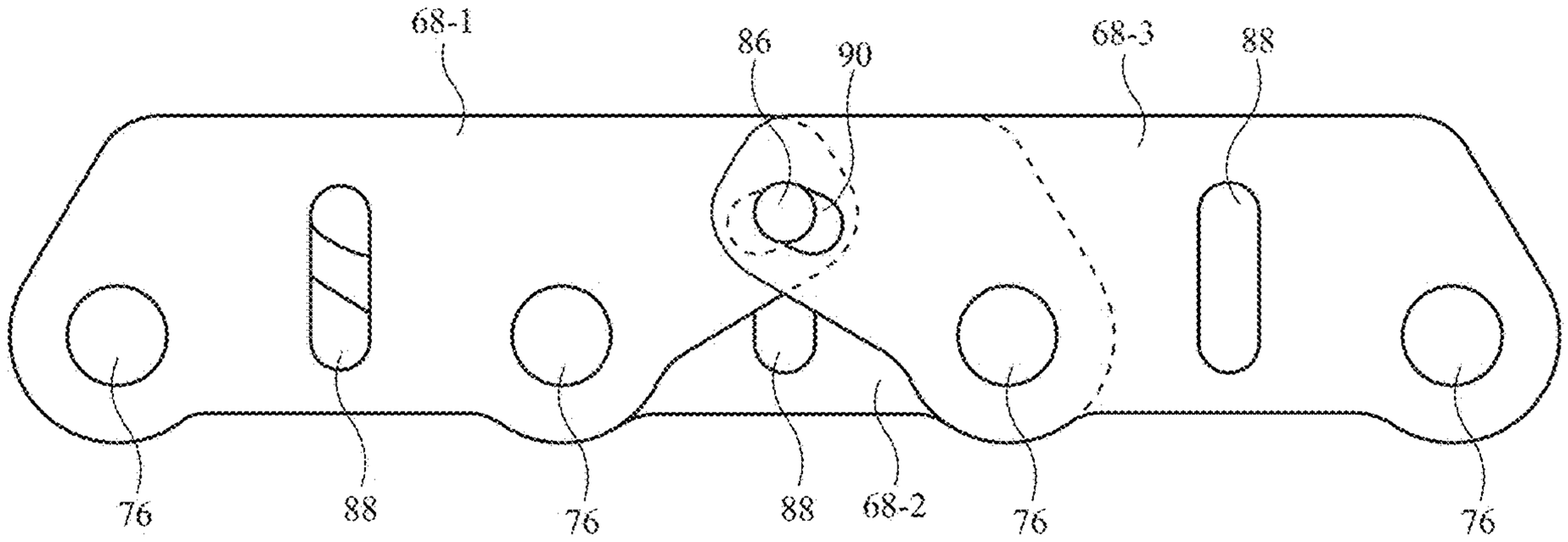

68-1
86
90
68-3
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76
88
76
88
68-2
76
76

FIG. 11

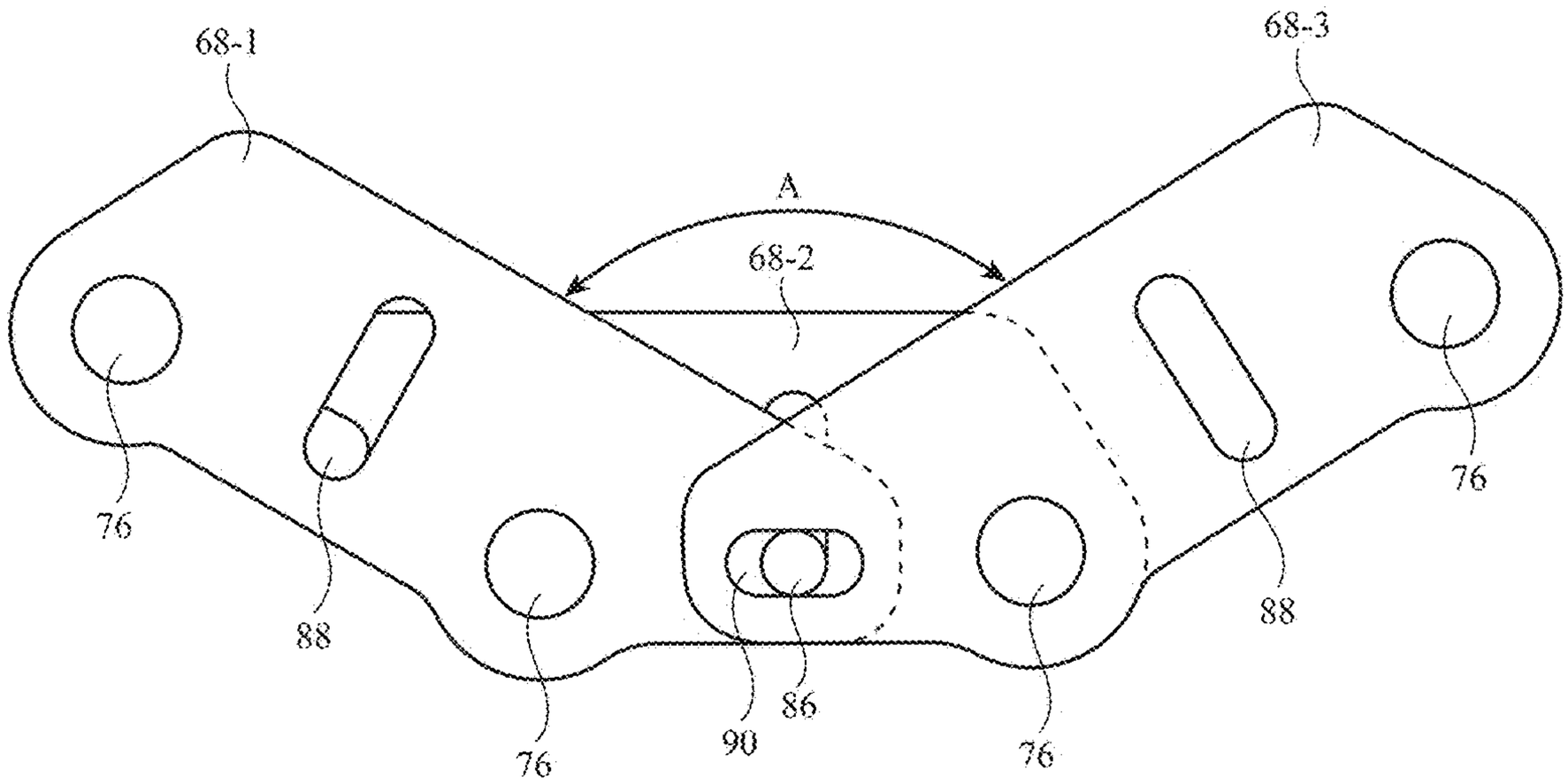

68-1
68-3
A
68-2
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76

FIG. 12

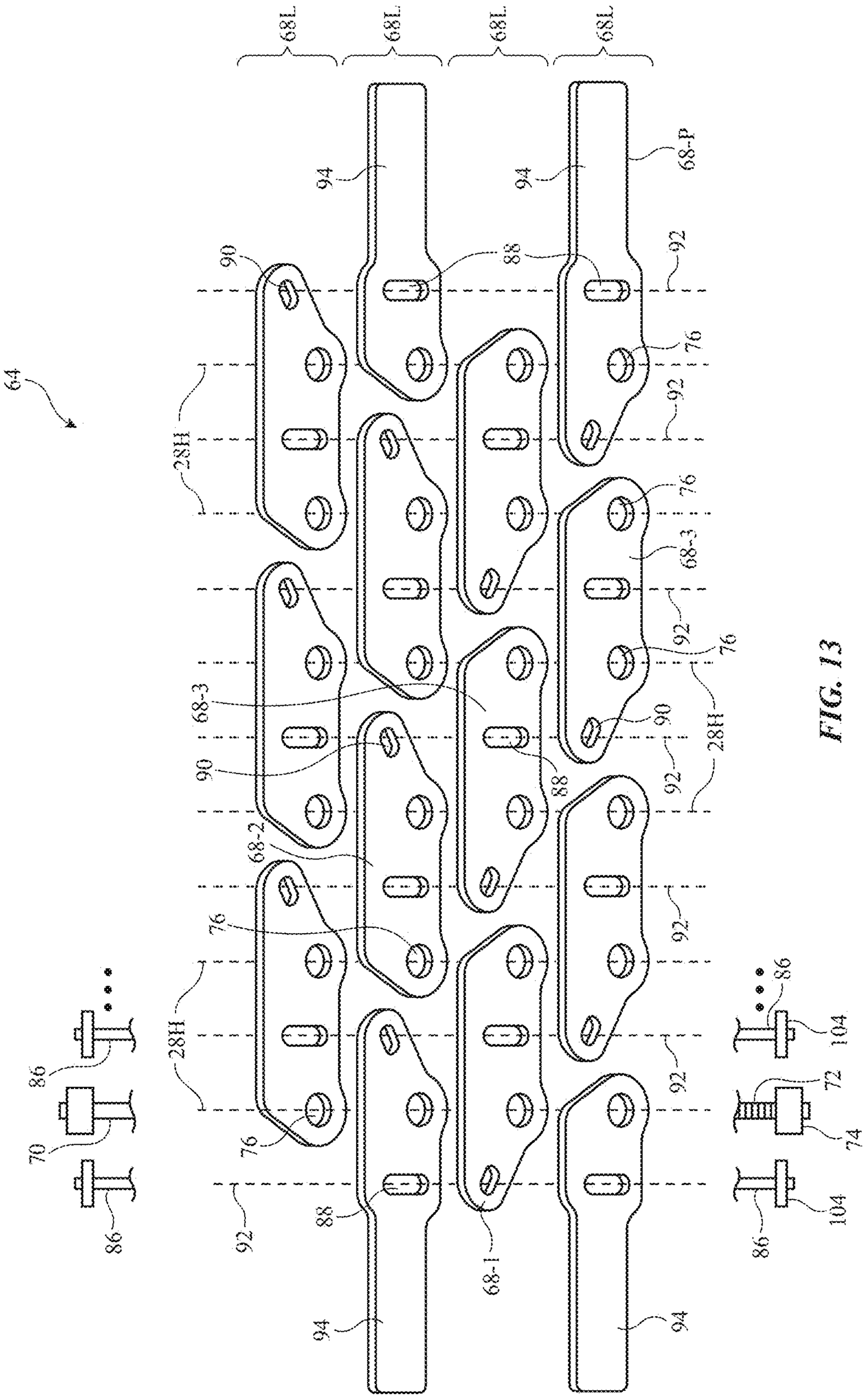

64
68L
68L
68L
68L
94
94
68-P
90
88
92
92
76
28H
68-3
68-2
68-1
86
70
104
72
74

FIG. 13

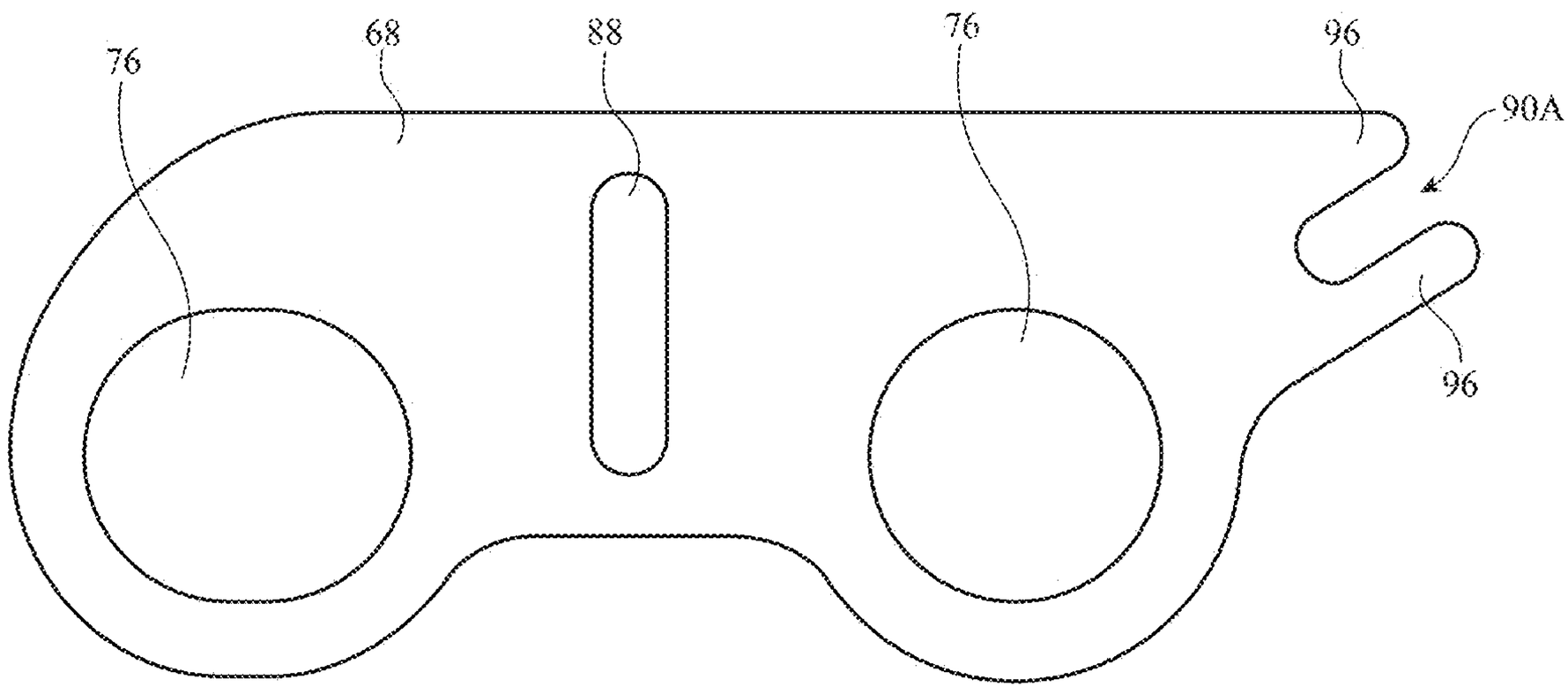


FIG. 14

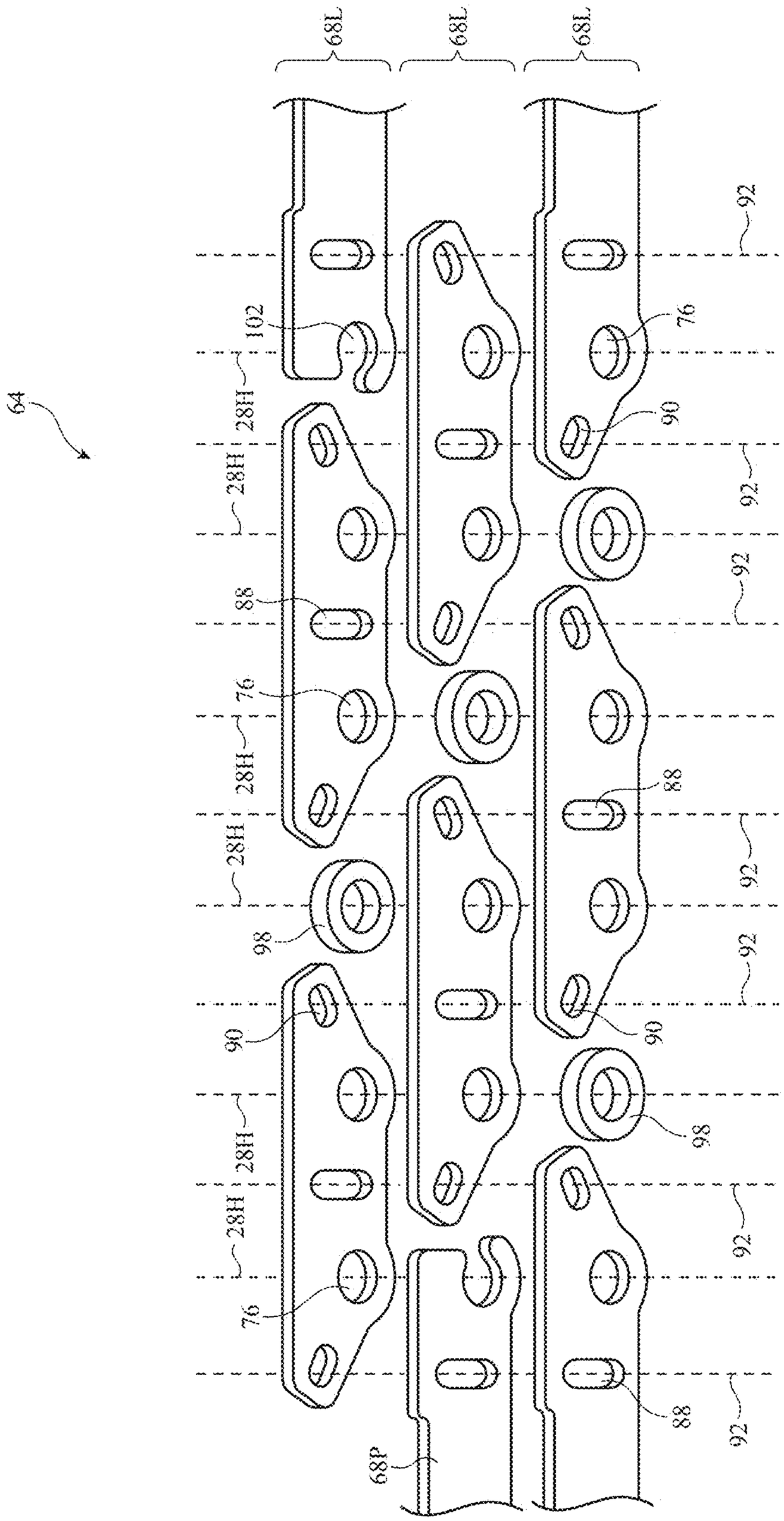

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68L
68L
68L
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102
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28H
28H
28H
28H
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28H
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68P
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FIG. 15

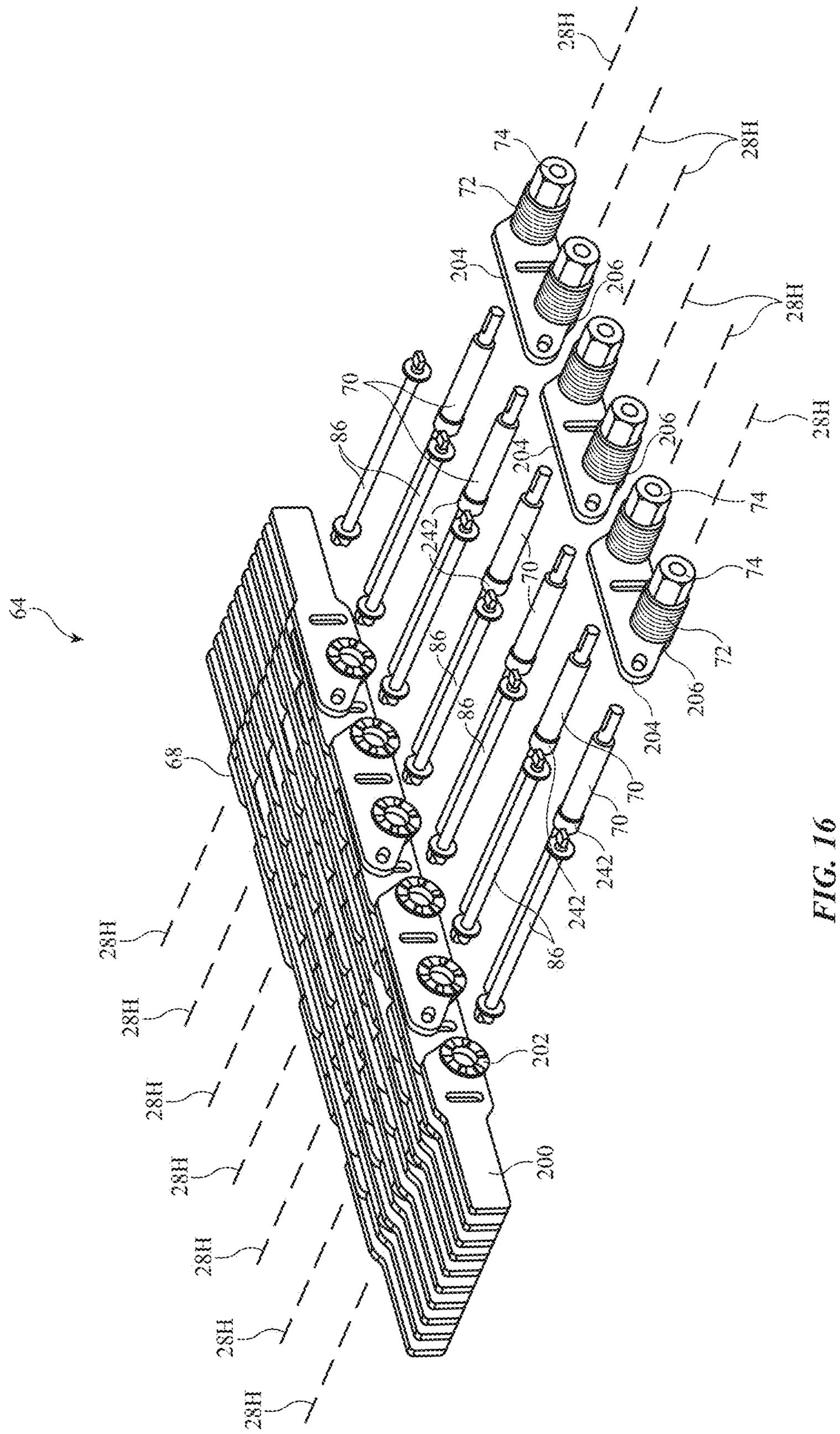


FIG. 16

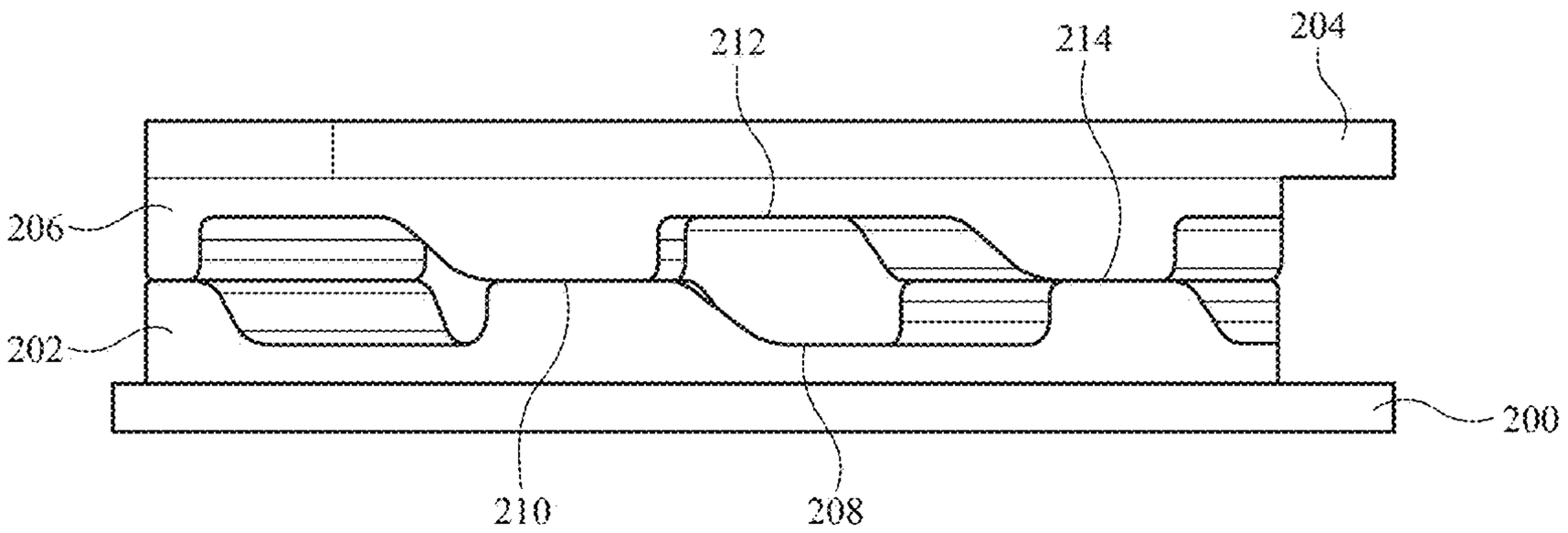


FIG. 17

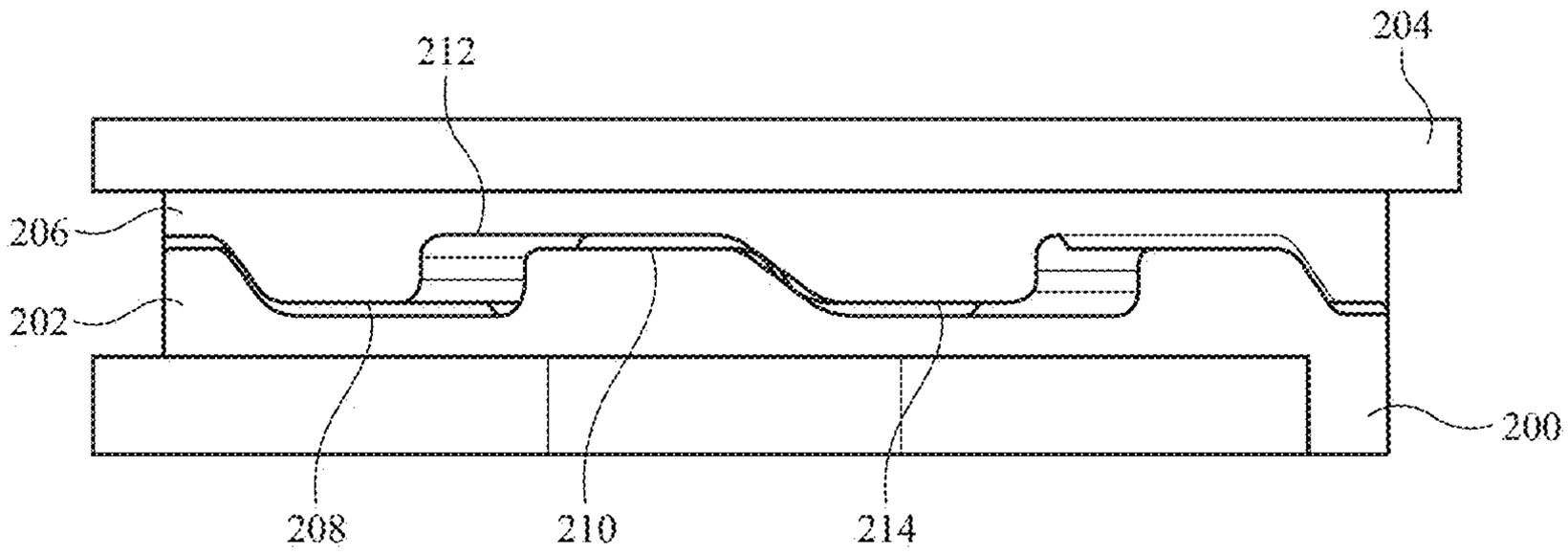


FIG. 18

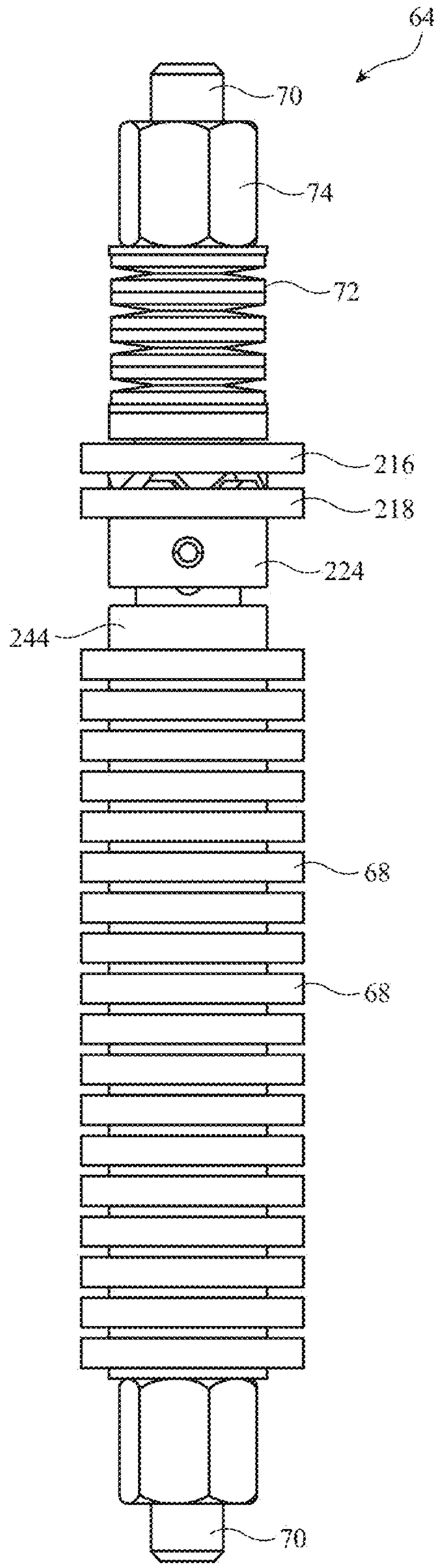


FIG. 19

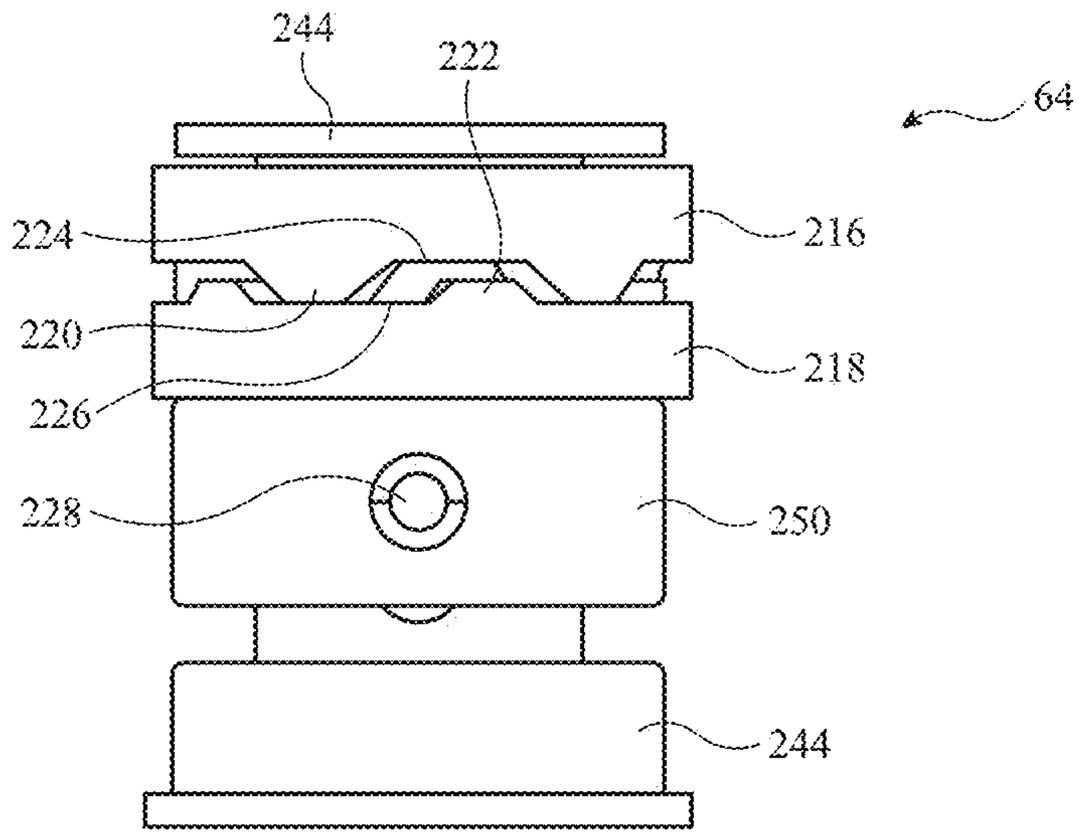

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FIG. 20

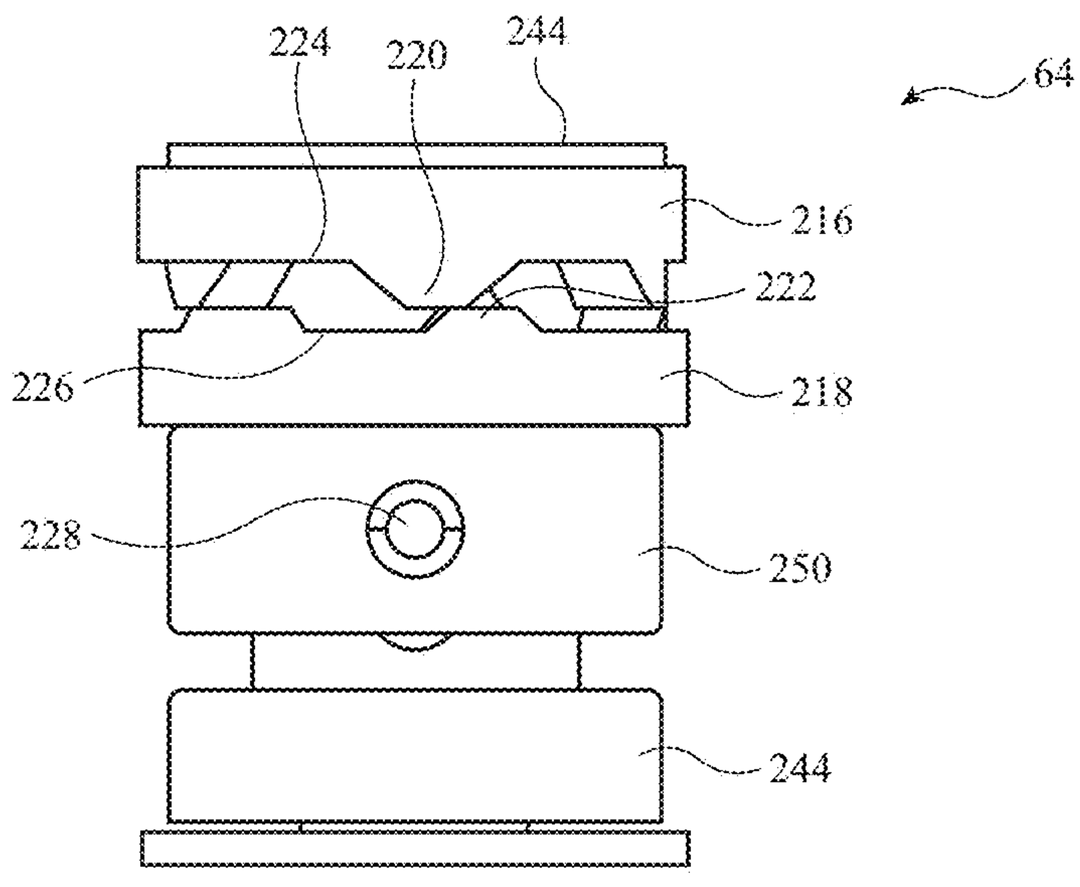

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244

FIG. 21

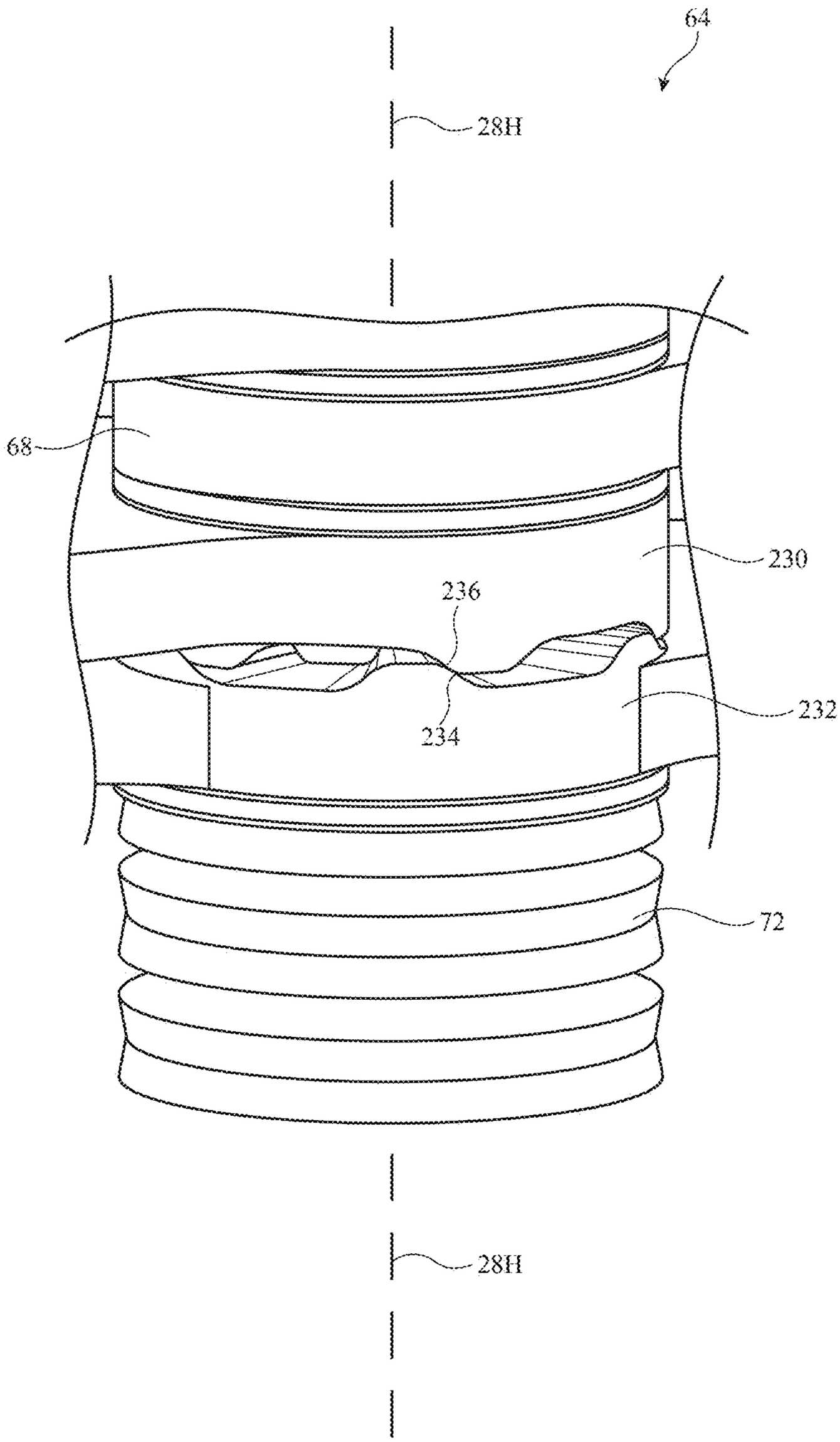


FIG. 22

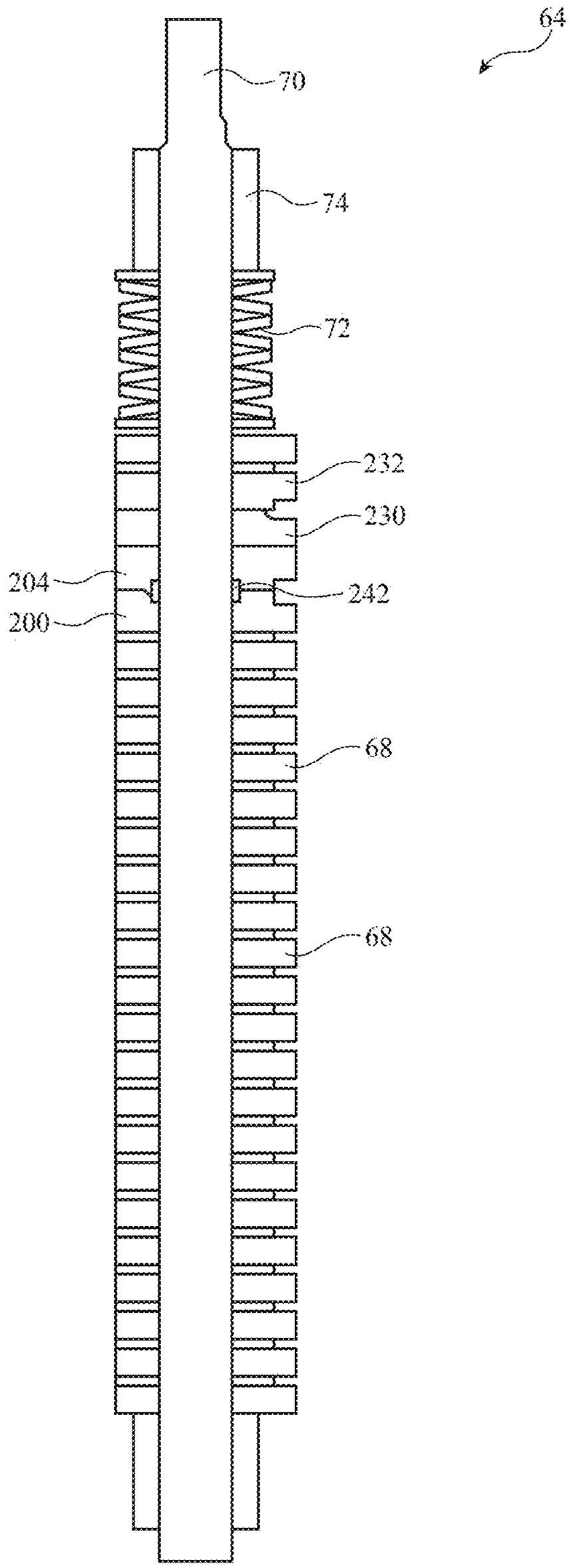


FIG. 23

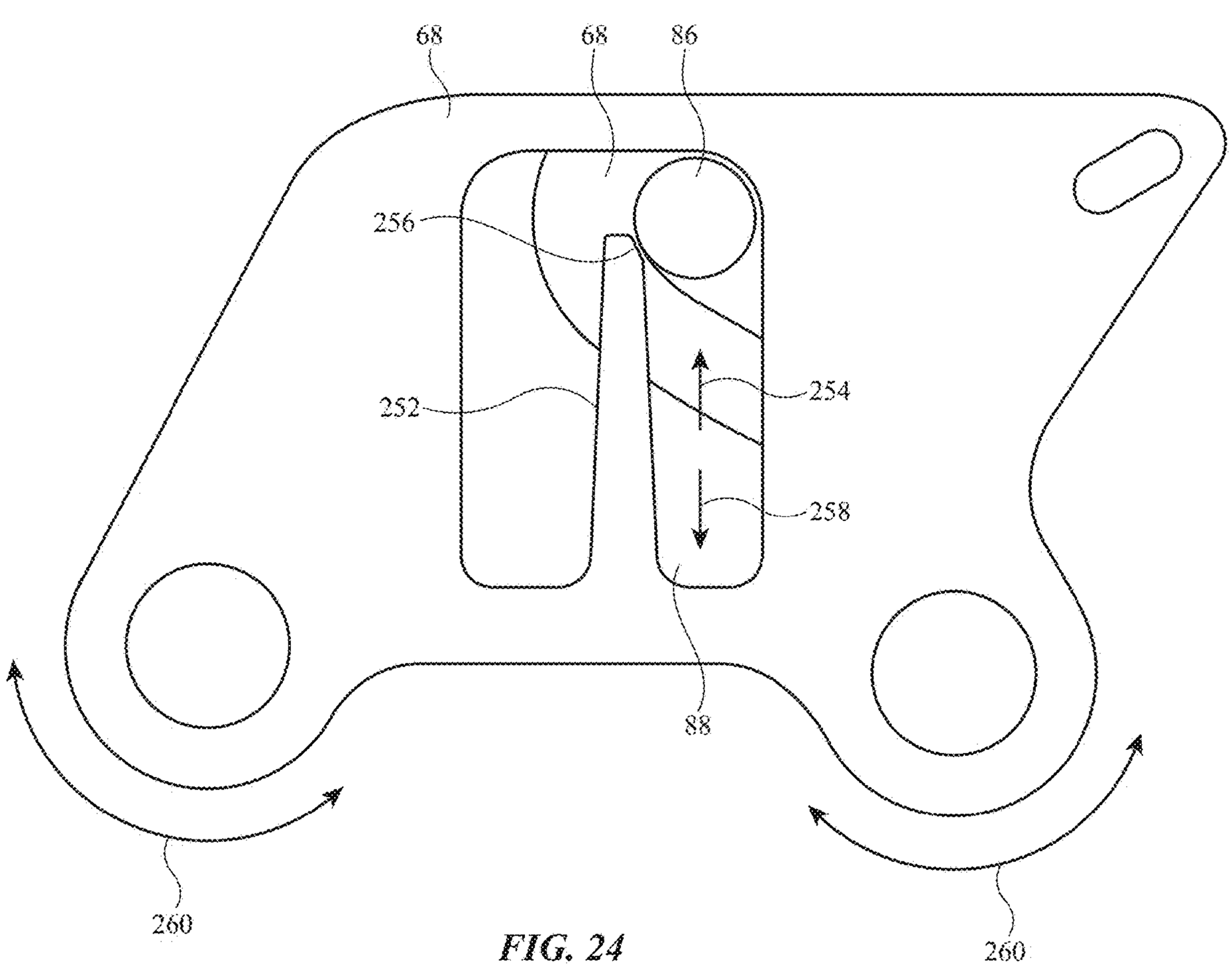


FIG. 24

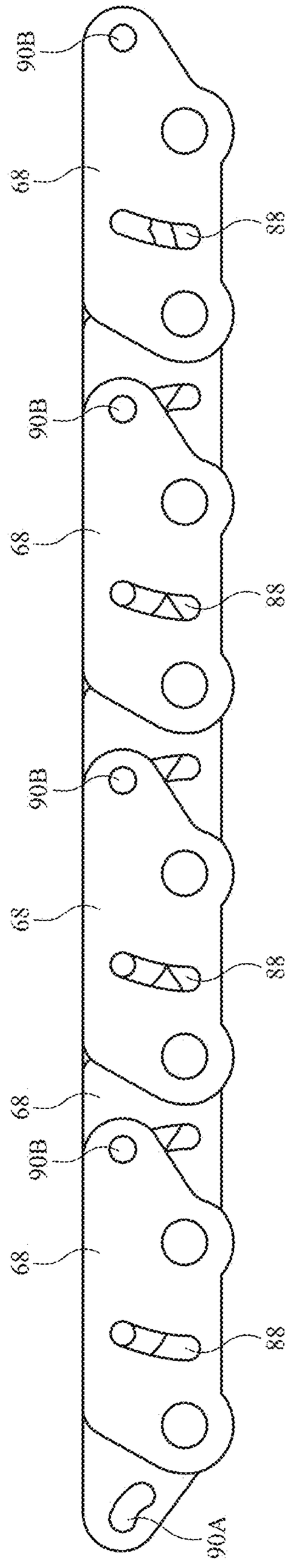


FIG. 25

ROLLER HINGE WITH FRICTION ELEMENTS

[0001] This application claims the benefit of U.S. provisional Ser. No. 63/863,769, filed Aug. 14, 2025, and U.S. provisional Ser. No. 63/724,826, filed Nov. 25, 2024, both of which are hereby incorporated by reference herein in their entireties.

FIELD

[0002] This relates generally to electronic devices and, more particularly, to electronic devices with displays.

BACKGROUND

[0003] Electronic devices often have displays. Portability may be a concern for some devices, which tends to limit available real estate for displays.

SUMMARY

[0004] An electronic device may include a flexible display having first and second display portions that rotate relative to one another about a bend axis. The flexible display may be mounted to a foldable housing having first and second housing portions coupled by a hinge that overlaps the bend axis. The foldable housing may be operable in a flat (e.g., open) state and a folded (e.g., closed) state.

[0005] The hinge may include interdigitated friction leaves that rotate about multiple axes of rotation. The hinge may include shafts that are received by the leaves and that are each aligned with a respective one of the axes of rotation of the hinge. The interdigitated leaves may produce torque through axial friction along the axis of each shaft.

[0006] Some of the leaves may include gears for driving synchronous motion of the first and second housing portions, while other leaves may include hard stop structures for preventing overtravel in the open and closed directions.

[0007] In some arrangements, the leaves may include first and second leaves with an opening and a third leaf with vertical slot aligned with the openings in the first and second leaves. A mutual pin may be inserted through the openings of the first and second leaves and through the vertical slot of the third leaf. The pin and vertical slot may provide both synchronous motion functionality and hard stop functionality.

[0008] If desired, the hinge may include a set of parallel rollers coupled between the first and second housing portions. The interdigitated friction leaves may be located between the rollers and the display.

[0009] The hinge module may include friction reducing cams that help reduce friction in the hinge module as the device approaches a fully open state (e.g., where first and second housing portions are separated by an angle of 180 degrees). Detent cams may be used instead of or in addition to friction reducing cams. Detent cams may be used to produce an opening torque to help force the device into a fully open state. Detent cams may produce opening torque at other angles (e.g., when the device is closed so that the device is easier to open). If desired, friction leaves may include slots with cantilevers that apply a force to timing pins to help push the device into a fully open state. Arrangements in which friction reducing cams and/or detent cams are used to provide friction relief and/or closing torque as the device is being closed may also be used, if desired.

[0010] If desired, detent cams may be configured to generate a torque and to reduce a spring load on the friction leaves to reduce friction in the hinge module. With this type of arrangement, detent cams perform both the function of a friction reducing cam (by reducing friction in the hinge module) and a detent cam (by generating a torque). When detent cams are used in this way, there is still some residual friction in the hinge module due to the residual axial load on the friction leaves.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a schematic diagram of an illustrative electronic device in accordance with some embodiments.

[0012] FIG. **2** is a perspective view of an illustrative electronic device with a display in accordance with some embodiments.

[0013] FIG. **3** is a side view of an illustrative electronic device in accordance with some embodiments.

[0014] FIG. **4** is a side view of an illustrative electronic device having a foldable housing and a foldable display in a flat state in accordance with some embodiments.

[0015] FIG. **5** is a side view of the electronic device of FIG. **4** in a folded state in accordance with some embodiments.

[0016] FIG. **6** is a perspective view of an illustrative hinge assembly that includes parallel rollers coupled to hinge modules with interdigitated friction leaves in accordance with some embodiments.

[0017] FIG. **7** is a top view of an illustrative hinge module that may be used in the hinge assembly of FIG. **6** in accordance with some embodiments.

[0018] FIGS. **8** and **9** are front views of an illustrative pair of friction leaves that may be used in the hinge modules of FIGS. **6** and **7** with gears for driving synchronous motion of first and second housing portions in accordance with some embodiments.

[0019] FIG. **10** is a perspective view of an illustrative pair of friction leaves that may be used in the hinge modules of FIGS. **6** and **7** with hard stop structures for providing an open hard stop position and a closed hard stop position in accordance with some embodiments.

[0020] FIGS. **11** and **12** are front views of an illustrative set of friction leaves that may be used in the hinge modules of FIGS. **6** and **7** with openings and vertical slots that receive pins for driving synchronous motion of first and second housing portions and for providing hard stops in the open and closed positions in accordance with some embodiments.

[0021] FIG. **13** is an exploded perspective view of a hinge module that includes friction leaves of the type shown in FIGS. **11** and **12** in accordance with some embodiments.

[0022] FIG. **14** is a front view of an illustrative friction leaf having an opening formed from one or more cantilevered arms and configured to receive a pin in accordance with some embodiments.

[0023] FIG. **15** is an exploded perspective view of a hinge module that includes double-headed friction leaves for receiving shafts and pins as discussed in connection with FIGS. **11** and **12** in accordance with some embodiments.

[0024] FIG. **16** is an exploded perspective view of an illustrative hinge module having friction reducing cams that load and unload friction leaves as the electronic device moves between folded and unfolded states in accordance with some embodiments.

[0025] FIG. **17** is a side view of illustrative friction reducing cams of the type shown in FIG. **16** showing how the friction reducing cams are positioned when the electronic device is in a folded, fully closed state in accordance with some embodiments.

[0026] FIG. **18** is a side view of illustrative friction reducing cams of the type shown in FIG. **16** showing how the friction reducing cams are positioned when the electronic device is in an unfolded, fully open state in accordance with some embodiments.

[0027] FIG. **19** is a side view of a portion of an illustrative hinge module having friction reducing cams and a movable sleeve that is used to load and unload friction leaves as the electronic device moves between folded and unfolded states in accordance with some embodiments.

[0028] FIG. **20** is a side view of illustrative friction reducing cams of the type shown in FIG. **19** showing how the friction reducing cams are positioned when the electronic device is in a folded, fully closed state in accordance with some embodiments.

[0029] FIG. **21** is a side view of illustrative friction reducing cams of the type shown in FIG. **19** showing how the friction reducing cams are positioned when the electronic device is in an unfolded, fully open state in accordance with some embodiments.

[0030] FIG. **22** is a side view of illustrative detent cams configured to produce an opening torque as the electronic device moves into an unfolded state in accordance with some embodiments.

[0031] FIG. **23** is a side view of a portion of an illustrative hinge module having detent cams that produce opening torque and friction reducing cams that reduce a load on friction leaves as the device approaches an unfolded state in accordance with some embodiments.

[0032] FIG. **24** is a side view of an illustrative friction leaf having a detent feature that produces an opening torque in accordance with some embodiments.

[0033] FIG. **25** is a side view of illustrative friction leaves that include press fit holes for receiving timing pins in accordance with some embodiments.

DETAILED DESCRIPTION

[0034] Electronic devices may be provided with displays. Displays may be used for displaying images for users. Displays may be formed from arrays of light-emitting diode pixels or other pixels. For example, a device may have an organic light-emitting diode display or a display formed from an array of micro-light-emitting diodes (e.g., diodes formed from crystalline semiconductor dies).

[0035] A schematic diagram of an illustrative electronic device having a display is shown in FIG. **1**. Device **10** may be a cellular telephone, tablet computer, laptop computer, wristwatch device or other wearable device, a television, a stand-alone computer display or other monitor, a computer display with an embedded computer (e.g., a desktop computer), a system embedded in a vehicle, kiosk, or other embedded electronic device, a media player, or other electronic equipment. Configurations in which device **10** is a cellular telephone, tablet computer, or other portable electronic device may sometimes be described herein as an example. This is illustrative. Device **10** may, in general, be any suitable electronic device with a display.

[0036] Device **10** may include control circuitry **20**. Control circuitry **20** may include storage and processing circuitry for supporting the operation of device **10**. The storage and processing circuitry may include storage such as non-volatile memory (e.g., flash memory or other electrically-programmable-read-only memory configured to form a solid state drive), volatile memory (e.g., static or dynamic random-access-memory), etc. Processing circuitry in control circuitry **20** may be used to gather input from sensors and other input devices and may be used to control output devices. The processing circuitry may be based on one or more microprocessors, microcontrollers, digital signal processors, baseband processors and other wireless communications circuits, power management units, audio chips, application specific integrated circuits, etc. During operation, control circuitry **20** may use a display and other output devices in providing a user with visual output and other output.

[0037] To support communications between device **10** and external equipment, control circuitry **20** may communicate using communications circuitry **22**. Circuitry **22** may include antennas, radio-frequency transceiver circuitry (wireless transceiver circuitry), and other wireless communications circuitry and/or wired communications circuitry. Circuitry **22**, which may sometimes be referred to as control circuitry and/or control and communications circuitry, may support bidirectional wireless communications between device **10** and external equipment over a wireless link (e.g., circuitry **22** may include radio-frequency transceiver circuitry such as wireless local area network transceiver circuitry configured to support communications over a wireless local area network link, near-field communications transceiver circuitry configured to support communications over a near-field communications link, cellular telephone transceiver circuitry configured to support communications over a cellular telephone link, or transceiver circuitry configured to support communications over any other suitable wired or wireless communications link). Wireless communications may, for example, be supported over a Bluetooth® link, a WiFi® link, a wireless link operating at a frequency between 6 GHz and 300 GHz, a 60 GHz link, or other millimeter wave link, cellular telephone link, wireless local area network link, personal area network communications link, or other wireless communications link. Device **10** may, if desired, include power circuits for transmitting and/or receiving wired and/or wireless power and may include batteries or other energy storage devices. For example, device **10** may include a coil and rectifier to receive wireless power that is provided to circuitry in device **10**.

[0038] Device **10** may include input-output devices such as devices **24**. Input-output devices **24** may be used in gathering user input, in gathering information on the environment surrounding the user, and/or in providing a user with output. Devices **24** may include one or more displays such as display **14**. Display **14** may be an organic light-emitting diode display, a liquid crystal display, an electrophoretic display, an electrowetting display, a plasma display, a microelectromechanical systems display, a display having a pixel array formed from crystalline semiconductor light-emitting diode dies (sometimes referred to as microLEDs), and/or other display. Configurations in which display **14** is an organic light-emitting diode display or microLED display are sometimes described herein as an example.

[0039] Display **14** may have an array of pixels configured to display images for a user. The pixels may be formed as part of a display panel that is bendable. This allows device

10 to be folded and unfolded about a bend axis. For example, a flexible (bendable) display in device **10** may be folded so that device **10** may be placed in a compact shape for storage and may be unfolded when it is desired to view images on the display.

[0040] Sensors **16** in input-output devices **24** may include force sensors (e.g., strain gauges, capacitive force sensors, resistive force sensors, etc.), audio sensors such as microphones, touch and/or proximity sensors such as capacitive sensors (e.g., a two-dimensional capacitive touch sensor integrated into display **14**, a two-dimensional capacitive touch sensor overlapping display **14**, and/or a touch sensor that forms a button, trackpad, or other input device not associated with a display), and other sensors. If desired, sensors **16** may include optical sensors such as optical sensors that emit and detect light, ultrasonic sensors, optical touch sensors, optical proximity sensors, and/or other touch sensors and/or proximity sensors, monochromatic and color ambient light sensors, image sensors, fingerprint sensors, temperature sensors, sensors for measuring three-dimensional non-contact gestures ("air gestures"), pressure sensors, sensors for detecting position, orientation, and/or motion (e.g., accelerometers, magnetic sensors such as compass sensors, gyroscopes, and/or inertial measurement units that contain some or all of these sensors), health sensors, radio-frequency sensors, depth sensors (e.g., structured light sensors and/or depth sensors based on stereo imaging devices that capture three-dimensional images), optical sensors such as self-mixing sensors and light detection and ranging (lidar) sensors that gather time-of-flight measurements, humidity sensors, moisture sensors, gaze tracking sensors, and/or other sensors. In some arrangements, device **10** may use sensors **16** and/or other input-output devices to gather user input. For example, buttons may be used to gather button press input, touch sensors overlapping displays can be used for gathering user touch screen input, touch pads may be used in gathering touch input, microphones may be used for gathering audio input, accelerometers may be used in monitoring when a finger contacts an input surface and may therefore be used to gather finger press input, etc.

[0041] If desired, electronic device **10** may include additional components (see, e.g., other devices **18** in input-output devices **24**). The additional components may include haptic output devices, audio output devices such as speakers, light-emitting diodes for status indicators, light sources such as light-emitting diodes that illuminate portions of a housing and/or display structure, other optical output devices, and/or other circuitry for gathering input and/or providing output. Device **10** may also include a battery or other energy storage device, connector ports for supporting wired communication with ancillary equipment and for receiving wired power, and other circuitry.

[0042] FIG. **2** is a perspective view of electronic device **10** in an illustrative configuration in which device **10** is a portable electronic device such as a cellular telephone or tablet computer. As shown in FIG. **2**, device **10** may have a display such as display **14**. Display **14** may cover some or all of the front face of device **10**. Touch sensor circuitry such as two-dimensional capacitive touch sensor circuitry may be incorporated into display **14**.

[0043] Display **14** may be mounted in housing **12**. Housing **12** may form front and rear housing walls, sidewall structures, and/or internal supporting structures (e.g., a frame, an optional midplate member, etc.) for device **10**. Glass structures, transparent polymer structures, and/or other transparent structures that cover display **14** and other portions of device **10** may provide structural support for device **10** and may sometimes be referred to as housing structures. For example, a transparent housing portion such as a glass or polymer housing structure that covers and protects a pixel array in display **14** may serve as a display cover layer for the pixel array while also serving as a housing wall on the front face of device **10**. In configurations in which a display cover layer is formed from glass, the display cover layer may sometimes be referred to as a display cover glass or display cover glass layer. The portions of housing **12** on the sidewalls and rear wall of device **10** may be formed from glass or other transparent structures and/or opaque structures. Sidewalls and rear wall structures may be formed as extensions to the front portion of housing **12** (e.g., as integral portions of the display cover layer) and/or may include separate housing wall structures.

[0044] Device **10** may be a foldable electronic device that folds along one or more bend axes such as bend axis **28**. In the example of FIG. **2**, device **10** includes first and second portions **60** joined by bendable portion **62**. Portions **60** of device **10** (e.g., portions **60** of display **14** and housing **12**, sometimes referred to as the non-bending regions of device **10**) may rotate relative to one another about axis **28**. As one portion **60** rotates relative to another portion **60** (e.g., during folding and unfolding of device **10**), bendable portion **62** of display **14** may bend and flex (e.g., while portions **60** remain flat).

[0045] Housing **12** may have flexible structures (e.g., bendable housing wall structures) and/or hinge structures such as hinge **30**. Hinge **30** may have a hinge axis aligned with or offset relative to display bend axis **28**, depending on the type of hinge used. Bend axis **28** may, for example, be the bend axis around which display **14** bends, whereas hinge **30** may bend about a hinge bend axis. In some arrangements such as teardrop hinge arrangements, the hinge bend axis of hinge **30** may be aligned with display bend axis **28** of display **14**. In other arrangements such as constant length hinge arrangements (e.g., a roller hinge), the hinge bend axis may be offset from display bend axis **28**. Device **10** may include one or more translation modules that facilitate translation of display **14** relative to housing **12** that may be needed to accommodate the offset between display bend axis **28** and the hinge bend axis.

[0046] Hinge **30** and/or flexible housing structures that overlap bend axis **28** may allow housing **12** to bend about the hinge bend axis. For example, portion **60** of housing **12** may be located on one side of hinge **30** and another portion **60** of housing **12** may be located on the opposing side of bend hinge **30**. Portions **60** of housing **12** may be configured to rotate relative to one another about hinge **30**. Hinge **30** may be a roller hinge including one or more rollers each having a longitudinal axis that extends parallel to bend axis **28**. This is merely illustrative. If desired, hinge **30** may include other types of hinge structures.

[0047] As housing **12** is bent about hinge **30**, the flexibility of display **14** allows display **14** to bend about axis **28**. In an illustrative configuration, housing **12** and display **14** may bend by 180°. This allows display **14** to be folded back on itself (e.g., such that first and second portions **60** of display **14** face each other). The ability to place device **10** in a folded configuration in this way may help make device **10** compact

so that device **10** can be stored efficiently. When it is desired to view images on display **14**, device **10** may be unfolded about axis **28** to place device **10** in the unfolded (e.g., flat) configuration of FIG. **2**. This allows display **14** to lie flat and allows a user to view flat images on display **14**. The ability to fold display **14** onto itself allows device **10** to exhibit an inwardly folding behavior. Display **14** may be sufficiently flexible to allow device **10** to be folded outwardly and/or inwardly, if desired.

[0048] Device **10** of FIG. **2** has a rectangular outline (rectangular periphery) with four corners. As shown in FIG. **2**, a first pair of parallel edges (e.g., the left and right edges of device **10** in the example of FIG. **2**) may be longer than a second pair of parallel edges (e.g., the upper and lower edges of device **10** of FIG. **2**) that are oriented at right angles to the first pair of parallel edges. In this type of configuration, housing **12** is elongated along a longitudinal axis that is perpendicular to bend axis **28**. Housing **12** may have other shapes, if desired (e.g., shapes in which housing **12** has a longitudinal axis that extends parallel to bend axis **28**). With an arrangement of the type shown in FIG. **2**, the length of device **10** along its longitudinal axis may be reduced by folding device **10** about axis **28**.

[0049] FIG. **3** is a cross-sectional side view of an illustrative foldable electronic device. Device **10** of FIG. **3** may bend about bend axis **28**. Bend axis **28** may be aligned with display cover layer **14**CG or other structures in device **10**. For example, bend axis **28** may pass through a portion of display cover layer **14**CG or may be located above or below layer **14**CG.

[0050] Hinge **30** may bend about one or more hinge axes such as hinge bend axis **28**H (sometimes referred to as a hinge axis, a rotational axis, etc.). In arrangements where hinge **30** is a teardrop hinge, hinge bend axis **28**H of hinge **30** may be aligned with display bend axis **28** of display **14**. In arrangements where hinge **30** is a constant length hinge such as a roller hinge, hinge bend axis **28**H may be offset from display bend axis **28**. Device **10** may include one or more translation modules that help slide display **14** relative to housing **12** during opening and closing of device **10** to accommodate the offset between display bend axis **28** and hinge bend axis **28**H.

[0051] As shown in FIG. **3**, display **14** includes an array of pixels P forming display panel **14**P under an inwardly facing surface of display cover layer **14**CG. Display panel **14**P may be, for example, a flexible organic light-emitting diode display or a microLED display in which light-emitting pixels are formed on a flexible substrate layer (e.g., a flexible layer of polyimide or a sheet of other flexible polymer). Flexible support layer(s) for display **14** may also be formed from flexible glass, flexible metal, and/or other flexible structures.

[0052] Display cover layer **14**CG may be formed from polymer, glass, crystalline materials such as sapphire, other materials, and/or combinations of these materials. To enhance flexibility, a portion of layer **14**CG that overlaps bend axis **28** may be locally thinned (e.g., this portion may be thinned relative to portions of layer **14**CG that do not overlap bend axis **28**). The thickness of layer **14**CG (e.g., the non-thinned portions of layer **14**CG) may be 50-200 microns, 70-150 microns, 100-200 microns, 100-600 microns, at least 100 microns, at least 200 microns, less than 600 microns, less than 400 microns, less than 250 microns, less than 150 microns, less than 100 microns, at least 50 microns, or other suitable thickness.

[0053] In the example of FIG. **3**, housing **12** has portions that form a rear housing wall on rear face R of device **10** and has portions forming sidewalls **12**W of device **10**. The rear housing wall of housing **12** may form a support layer for components in device **10**. Housing **12** may also have one or more interior supporting layers (e.g., frame structures such as an optional midplate, etc.). These interior supporting layers and the rear housing wall may have first and second portions that are coupled to opposing sides of hinge **30** or may be sufficiently flexible to bend around bend axis **28**.

[0054] Electrical components **32** may be mounted in the interior of device **10** (e.g., between display **14** and the rear of housing **12**. Components **32** may include circuitry of the type shown in FIG. **1** (e.g., control circuitry **20**, communications circuitry **22**, input-output devices **24**, batteries, etc.). Display **14** may be mounted on front face F of device **10**. When device **10** is folded about axis **28**, display cover layer **14**CG, display panel **14**P, and the other structures of device **10** that overlap bend axis **28** may flex and bend to accommodate folding.

[0055] FIG. **4** is a side view of device **10** in a flat state (sometimes referred to as an open state or unfolded state). As shown in FIG. **4**, device **10** may include foldable display **14** mounted to a housing such as foldable housing **12**. Housing **12** may have first housing portion **12-1** and second housing portion **12-2**. Hinge **30** may be located between housing portions **12-1** and **12-2** and may allow housing portions **12-1** and **12-2** to rotate relative to one another about one or more hinge bend axes **28**H. Housing portions **12-1** and **12-2** may form rear housing walls on the rear face R of device **10** (FIG. **3**).

[0056] Display **14** may include a display panel such as display panel **14**P mounted to a display plate such as display plate **38** (sometimes referred to as a support structure, a midplate, a backplate, etc.). Display plate **38** may include first portion **38-1** that supports a first portion **14**P-**1** of display panel **14**P on one side of bend axis **28** and a second portion **38-2** that supports a second portion **14**P-**2** of display panel **14**P on an opposing side of bend axis **28**. Display plates **38-1** and **38-2** may rotate relative to one another about bend axis **28** as device **10** is opened and closed. Display plate **38-1** may overlap portion **12-1** of housing **12** and display plate **38-2** may overlap portion **12-2** of housing **12**.

[0057] Display panel portion **14**P-**1** may be fixed relative to display plate **38-1**, while display plate **38-1** may be movable relative to housing portion **12-1** (e.g., display plate **38-1** may be permitted to shear and slide relative to housing **12-1** during opening and closing of device **10**). Similarly, display panel portion **14**P-**2** may be fixed relative to display plate **38-2**, while display plate **38-2** may be movable relative to housing portion **12-2** (e.g., display plate **38-2** may be permitted to shear and slide relative to housing **12-2** during opening and closing of device **10**). If desired, an optional shearing layer **34** may be interposed between housing **12** and display plate **38** to allow display **14** to slide relative to housing **12**. Layer **34** may include one or more flexible polymers, coatings of lubricant, and/or other suitable slippery materials (e.g., polytetrafluoroethylene).

[0058] The ability of display **14** to move (e.g., slide) relative to housing **12** may permit housing **12** to use different types of hinge structures such as a roller hinge. In particular, hinge **30** may be a roller hinge having one or more parallel

rollers such as rollers **48**. Rollers **48** may have longitudinal axes that extend parallel to bend axis **28**. Hinges of this type (sometimes referred to as constant-length hinges) may span a distance between housing portions **12-1** and **12-2** that remains constant as device **10** is folded and unfolded. This is merely illustrative, however. If desired, hinge **30** may be any other suitable type of hinge (e.g., a four-bar linkage, a teardrop hinge, a flexible housing member, etc.). In some hinge arrangements (such as a teardrop hinge), translation of display **14** relative to housing **12** may be used to absorb tolerances (e.g., during manufacturing or during operation of device **10** by a user over time). Arrangements in which display **14** slides relative to housing **12** during opening and closing of device **10** are sometimes described herein as an illustrative example.

[0059] Hinge **30** (sometimes referred to as a hinge assembly) may have a multilink design that allows hinge **30** to bend about multiple hinge axes **28**H. As shown in FIG. **5**, for example, hinge **30** may have multiple interconnected portions such as links **52** coupled between rollers **48**. Links **52** may have an hourglass shape with first and second recesses for receiving respective first and second rollers **48**. Links **52** may be coupled to each other for rotational motion and may extend in a linked series between housing portions **12-1** and **12-2**. As device **10** moves from the flat state of FIG. **4** to the folded (e.g., closed) state of FIG. **5**, a first pair of links **52** of hinge **30** may bend about a first hinge axis **28**H, a second pair of links **52** of hinge **30** may bend about a second hinge axis **28**H, a third pair of links of hinge **30** may bend about a third hinge axis **28**H, etc. Hinge **30** may bend about two, three, four, five, six, or more than six hinge axes **28**H. Arrangements in which hinge **30** has six parallel axes **28**H of rotation are sometimes described herein as an illustrative example.

[0060] Each pair of adjacent hinge links **52** may be restricted in its amount of overall rotation. For example, links **52** may be configured so that no two adjacent links **52** are allowed to rotate more than a maximum rotation angle (e.g., a maximum rotation angle that is less than 180°, less than 90°, less than 45°, less than 25°, 5-50°, or within any other suitable range. With this arrangement, links **52** collectively allow hinge **30** to rotate by a desired amount (e.g., 180°) without creating an excessively small bend radius for display **14** about bend axis **28**. The maximum rotation angle may be the same for all pairs of adjacent links **52** or different pairs of adjacent links **52** may have different maximum rotation angles. As an example, the maximum rotation angle may be 30° for the link pairs that are adjacent to housing **12**, whereas the maximum rotation angle may be 60° for the link pairs in the middle of hinge **30**. Arrangements where each link rotates by the same maximum rotation angle with respect to its neighboring links and/or in which the middle links **52** in hinge **30** have maximum rotation angles than the links **52** immediately adjacent to housing **12** may also be used, if desired.

[0061] To maintain satisfactory friction between rotating parts of device **10**, hinge **30** may be provided with friction clutch structures. As an example, in addition to rollers **48** and links **52**, hinge **30** may be provided with interdigitated sets of fingers that are pressed together to create rotational friction when rotating with respect to each other. These friction-producing structures, which may sometimes be referred to as leaves, friction clutch structures, a friction clutch, hinge friction structures, rotational friction structures, etc., may be integrated into links **52**, may be attached to links **52** so that the friction-producing structures produce rotational friction for the attached links **52**, and/or may otherwise be coupled between portions of housing **12** that rotate with respect to each other. The friction produced by the friction clutch structures allows a first portion of housing **12** to be maintained in a desired rotational orientation with respect to a second portion of housing **12** (e.g., housing halves **12-1** and **12-2** may be placed perpendicular or nearly perpendicular to each other, may be closed onto each other, may be placed in an open planar configuration, and/or may otherwise be positioned as desired by rotating these portions with respect to each other about bend axes **28**H of hinge **30**).

[0062] Hinge **30** may include friction leaves with intermeshed gears (e.g., teeth) for driving synchronous motion of housing portions **12-1** and **12-2**, may include friction leaves with protruding elements that form a hard stop (e.g., a travel limit) in the open position and/or the closed position, and/or may include friction leaves with overlapping slots and mating pins that provide both synchronous motion of housing portions **12-1** and **12-2** as well as hard stops in the open and closed positions.

[0063] FIG. **6** is a perspective view of an illustrative hinge **30**. Hinge **30** (sometimes referred to as a hinge assembly) may include rollers **48** (e.g., elongated cylinders) coupled by links **52**. Links **52** may be hourglass-shaped structures with recesses for receiving respective rollers **48**. Hinge rollers **48** may serve as a flexible outer housing layer that bridges the gap between housing portions **12-1** and **12-2** of housing **12**. Hinge rollers **48** may be exposed on an outer surface (e.g., an outer spine) of device **10**, or hinge rollers **48** may be concealed from view by a separate outer housing layer over hinge **30**. Each link **52** may be configured to rotate relative to an adjacent link **52** about a respective hinge axis **28**H that is aligned with the longitudinal axis of a given roller **48**.

[0064] Hinge **30** may include one or more hinge modules **64** coupled to rollers **48**. Hinge modules **64** may overlap rollers **48** and may be interposed between rollers **48** and display **14**. While rollers **48** may permit rotation of housing portions **12-1** and **12-2** about hinge axes **28**H, synchronous motion of housing portion **12-1** and housing portion **12-2** may be driven by hinge modules **64**. In the example of FIG. **6**, hinge **30** includes three hinge modules **64**, with two hinge modules **64** located at the outer edges of hinge **30** and one hinge module **64** located at the center of hinge **30**. If desired, hinge **30** may include greater than three or fewer than three hinge modules **64**.

[0065] Each hinge module **64** may include first and second plates such as hinge plates **66** that attach to a respective one of housing portions **12-1** and **12-2**. For example, hinge plate **66-1** may be fixed to housing portion **12-1** on one side of hinge **30**, and hinge plate **66-2** may be fixed to housing portion **12-2** on an opposing side of hinge **30**. Screws or other attachment structures may be used to attach each hinge plate **66** to a respective one of housing portions **12-1** and **12-2**.

[0066] A series of interdigitated hinge leaves such as hinge leaves **68** may extend between plates **66**. Each leaf **68** (sometimes referred to as a hinge finger, a finger, a friction element, a friction leaf, a friction clutch member, etc.) may be formed from a thin metal plate with one or more openings for receiving shafts and/or pins, gears that form teeth for driving synchronous motion, protrusions for forming hard stops in the open and closed positions, and/or other features.

Leaves **68** may be pressed together to create rotational friction when rotating with respect to each other. The friction produced by leaves **68** allows housing portion **12-1** to be maintained in a desired rotational orientation with respect to housing portion **12-2** (e.g., housing portions **12-1** and **12-2** may be placed perpendicular or nearly perpendicular to each other, may be closed onto each other, may be placed in an open planar configuration, and/or may otherwise be positioned as desired by rotating these portions with respect to each other about bend axes **28**H of hinge **30**).

[0067] FIG. **7** is a top view of an illustrative hinge module **64** formed from interdigitated leaves **68**. In the example of FIG. **7**, hinge module **64** has a first set **50-1** of leaves **68-1** and a second set **50-2** of leaves **68-2**. Fingers **68-1** in the first set **50-1** are interdigitated with fingers **68-2** in the second set **50-2**. A shaft such as shaft **70** may pass through a respective opening **76** in each leaf **68**. A respective one of hinge axes **28**H may be aligned with the longitudinal axis of shaft **70** (which is also aligned with the longitudinal axis of a given roller **48**). Fingers **68-1** of first set **50-1** and fingers **68-2** of second set **50-2** rotate relative to each other about hinge axis **28**H. Some leaves **68** may include first and second openings **76** for respectively receiving first and second shafts **70**. For example, leaves **68-2** may include a first opening **76** for a first shaft **70** that links leaves **68-2** with leaves **68-1** of set **50-1** and may include a second opening **76** for a second shaft **70** that links leaves **68-2** with leaves **68-3** of set **50-3**.

[0068] A spring such as spring **72** (e.g., disc-shaped springs, a stack of washers that form a spring, etc.) may be inserted onto shaft **70** and may be configured to press fingers **68** towards each other along shaft **70**. Fingers **68** may be relatively thin (e.g., fingers **68** may have a relatively small dimension along the axis of shaft **70**) and may have relatively larger surface areas where fingers **68** contact each other (e.g., fingers **68** may be thin plates). This allows satisfactory friction to be created without requiring an overly bulky clutch. A nut such as nut **74** that is threaded onto shaft **70** may be used to adjust the amount by which spring **72** presses fingers **68** together along shaft **70** to impart a desired amount of friction (e.g., sufficient friction to hold first and second housing portions **12-1** and **12-2** at a desired angle relative to each to each other when the first portion is resting on a surface).

[0069] The structures of FIG. **7** may be repeated depending on the number of rotational axes in hinge **30**. For example, if there are six hinge axes **28**H in hinge **30**, there may be six shafts **70** that each pass through a respective pair of sets of interdigitated leaves **68**.

[0070] To help ensure that leaves **68** rotate evenly throughout hinge **30**, device **10** may have intermeshed gears that extend between rotating portions of housing **12** (e.g., in parallel with hinge **30**). The gears and/or other rotation synchronization structures may help ensure that movement of housing portion **12-1** will produce equal and opposite movement of opposing housing portion **12-2**. An illustrative rotation synchronization mechanism with gears of the type that may be used for rotational (angular movement) synchronization in hinge **30** are shown in FIGS. **8** and **9**.

[0071] As shown in FIG. **8**, leaf **68-1** and leaf **68-3** may include mating gears such as gears **78**. During operation, housing portions **12-1** and **12-2** can rotate with respect to each other about axes **28**H. Angular movement synchronization gears **78**, which are formed from teeth on the opposing edges of leaves **68**, are coupled in series between housing portions **12-1** and **12-2**. This arrangement causes rotation of one side of device **10** to cause equal and opposite rotation of the other side of device **10**.

[0072] As shown in FIG. **9**, clockwise rotation of gear **78** of leaf **68-1** causes gear **78** of leaf **68-3** to rotate counterclockwise. A series of gears **78** coupled in this way between housing portions **12-1** and **12-2** may be used to drive synchronous motion of housing portions **12-1** and **12-2**. If desired, each adjacent pair of gears **78** may provide synchronous motion across a given range A of angles (e.g., where angle A is equal to 30.5°, equal to 30°, between 30° and 35°, between 25° and 40°, between 15° and 60°, less than 35°, greater than 35°, etc.).

[0073] FIG. **10** shows an illustrative leaf **68** that may be used to provide a hard stop in the open position and/or the closed position. As shown in FIG. **10**, leaf **68-1** and leaf **68-2** may include hard stop structures **80**. Hard stop structures **80** may include protrusions **82** and surfaces **84**. Protrusions **82** may travel back and forth between hard stop surfaces **84** as device **10** is opened and closed. When protrusion **82** reaches hard stop surface **84-2**, device **10** may be prevented from being opened further. When protrusion **82** reaches hard stop surface **84-1**, device **10** may be prevented from being closed further.

[0074] In some arrangements, hinge module **64** of FIGS. **6** and **7** may include a first group of leaves **68** having the structure of FIGS. **8** and **9** and a second group of leaves **68** having the structure of FIG. **10**. The first group of leaves **68** may be used to drive synchronous motion of housing portions **12-1** and **12-2**, whereas the second group of leaves **68** may be used to prevent overtravel in the open and closed directions. For example, each set **50** of leaves **68** may include some leaves **68** with gears **78** of FIGS. **8** and **9** and some leaves **68** with hard stop structures **80** of FIG. **10**.

[0075] In some arrangements, the same set of leaves **68** may be configured to drive synchronous motion of housing portions **12-1** and **12-2** and to prevent overtravel of housing portions **12-1** and **12-2** in the open and/or closed positions. FIGS. **11** and **12** show illustrative leaves **68** that may be used to both drive synchronous motion as well as provide a hard stop in the open and closed positions.

[0076] As shown in FIG. **11**, leaf **68-1** and leaf **68-3** may be mirror images of each other. Each leaf **68** may include a pair of openings **76** for receiving a respective pair of shafts **70**, as discussed in connection with FIG. **7**. Additionally, leaves **68-1** and **68-3** may each include a smaller opening **90** (sometimes referred to as a pin opening or mutual pin opening) for receiving a pin such as pin **86** (sometimes referred to as a mutual pin or a timing pin). Leaf **68-2** may overlap leaves **68-1** and **68-3** and may include a vertical slot **88** that overlaps openings **90** of leaves **68-1** and **68-3**. Pin **86** may be received within opening **90** of leaf **68-1**, opening **90** of leaf **68-3**, and slot **88** of leaf **68-2**.

[0077] As leaf **68-1** rotates relative to leaf **68-3** during opening and closing of device **10**, slot **88** of leaf **68-2** may ensure that pin **86** stays an equal distance from the two adjacent hinge axes **28**H on either side of pin **86**. Each hinge axis **28**H may each pass through a respective one of shaft openings **76** where shaft **70** is received. This provides synchronous motion of housing portion **12-1** relative to housing portion **12-2** over angle range A of FIG. **12**. Angle A may be equal to 30.5°, equal to 30°, between 30° and 35°, between 25° and 40°, between 15° and 60°, less than 35°, greater than 35°, or any other suitable angle.

[0078] Additionally, the top and bottom edges of vertical slot **88** provide hard stop surfaces that limit travel in both the open direction and the closed direction. When pin **86** reaches the top of slot **88**, as shown in the flat state of FIG. **11**, pin **86** may be prevented from traveling further in that direction and housing portions **12-1** and **12-2** may be prevented from opening further. When pin **86** reaches the bottom of slot **88**, as shown in the folded state of FIG. **12**, pin **86** may be prevented from traveling further in that direction and housing portions **12-1** and **12-2** may be prevented from closing further.

[0079] FIG. **13** is an exploded perspective view of an illustrative hinge module **64** that uses leaves **68** of the type shown in FIGS. **11** and **12**. In the example of FIG. **13**, hinge module **64** may include four layers **68**L of leaves **68**. This is merely illustrative. If desired, hinge module **64** may include more than four layers **68**L of leaves **68**. Leaves **68** at the outer ends of hinge module **64** may include protruding portions **68**P for attaching to hinge plates **66** (FIG. **6**) and/or for attaching directly to housing **12**.

[0080] As shown in FIG. **13**, leaves **68** include openings **90** and vertical slots **88** for receiving pins **86**. Each pin **86** may be inserted through openings **90** and slots **88** along a respective mutual pin axis **92** of FIG. **13**. Each shaft **70** may be inserted through shaft openings **76** along a respective hinge axis **28**H of FIG. **13**. Each hinge axis **28**H may be located between a pair of pin axes **92**. In the example of FIG. **13**, hinge module **64** includes six shafts **70** that permit rotation of leaves **68** about six parallel hinge axes **28**H. Seven pins **86** oriented along seven parallel pin axes **92** are used to impose synchronous motion of housing portions **12-1** and **12-2**, while the upper and lower surfaces of vertical slot **88** form hard stops for preventing overtravel in the open and closed directions.

[0081] One of the benefits of using pins **86** is that the torque of each hinge axis **28**H can be tuned individually to ensure even torque, even wear, and consistent performance. For example, before pins **86** are installed in hinge module **64**, nuts **74** on respective shafts **70** may be tightened or loosened to achieve the desired amount of torque through axial friction between leaves **68** along each shaft **70**. Once the desired amount of torque is achieved on each shaft **70**, pins **86** may be installed along pin axes **92**. A nut **104** or other fastener may be attached to the end of each pin **86** to fix pin **86** within openings **90** and slots **88**.

[0082] FIG. **14** shows another illustrative configuration for leaf **68** that may be used with a mutual pin gear setup of the type described in connection with FIGS. **11**, **12**, and **13**. As shown in FIG. **14**, opening **90** may include one or more cantilevered arms **96** (e.g., teeth that form a gear). Pin **86** may be received between the two cantilevered arms **96**. The open arm arrangement of FIG. **14** may provide less strength than the closed opening **90** of FIGS. **11**, **12**, and **13**, but additional strength can be provided by increasing the thickness of arms **96** (if needed).

[0083] FIG. **15** shows another illustrative arrangement for hinge module **64** that includes a mutual pin gear of the type described in connection with FIGS. **11**, **12**, and **13**. In the example of FIG. **15**, leaves **68** each include first and second openings **76** for receiving respective shafts **70**, first and second openings **90** for receiving respective pins **86**, and slot **88** for receiving an additional pin **86**. Washers **98** that receive shafts **70** may be used as spacer elements between certain pairs of leaves **68**. This type of "double header" leaf **68** (e.g., in which both ends of leaf **68** include a respective opening **90** for receiving pin **86**, as opposed to just one end in the example of FIG. **13**) may reduce the minimum number of layers **68**L that are needed to achieve synchronous motion functionality and hard stop functionality. For example, three layers **68**L of leaves **68** that have openings **90** on both ends may be sufficient to achieve synchronous motion and hard stop functionality. If desired, hinge module **64** may include more than three layers **68**L of leaves **68**.

[0084] As in the example of FIG. **13**, hinge module **64** of FIG. **15** includes six shafts **70** that permit rotation of leaves **68** about six parallel hinge axes **28**H. Seven pins **86** oriented along seven parallel pin axes **92** are used to impose synchronous motion of housing portions **12-1** and **12-2**, with the upper and lower edges of vertical slot **88** forming hard stops for preventing overtravel in the open and closed directions.

[0085] If desired, torque on each individual axis **28**H may be tuned individually by adjusting nuts **74** on respective shafts **70** before pins **86** are installed. Once the desired amount of torque is achieved on each shaft **70**, pins **86** may be installed along pin axes **92**.

[0086] Electronic device **10** may be used in multiple "open" states. In a laptop-type state, device **10** is open in a laptop shape and housing portions **12-1** and **12-2** may be separated by an angle of 90°, 100°, 110°, or some other angle between 45° and 135°. The torque produced by hinge module **64** is sufficiently high that electronic device **10** can remain in this laptop position without snapping closed or snapping open. In a fully open state (e.g., when device **10** is unfolded and flat), housing portions **12-1** and **12-2** are separated by an angle of 180°. If hinge module **64** continues to apply high torque as device **10** moves towards this fully open state, device **10** may tend to spring back on itself, if care is not taken. It may be desirable to reduce the friction in hinge module **64** as electronic device **10** approaches this fully open state. FIG. **16** is an exploded perspective view of an illustrative hinge module **64** that may exhibit a reduction in friction (and therefore torque) as device **10** approaches a fully open, flat state.

[0087] As shown in FIG. **16**, hinge module **64** may include six shafts **70** that permit rotation of leaves **68** about six parallel hinge axes **28**H. Seven pins **86** oriented along seven parallel pin axes are used to impose synchronous motion of housing portions **12-1** and **12-2**. This is merely illustrative. If desired, hinge module **64** may have less than six or more than six hinge axes **28**H.

[0088] Along each hinge axis **28**H, spring **72** on shaft **70** may apply a force onto a set of friction leaves **68** that are located on that shaft **70**. A set of cams such as cam **200** and cam **204** may be located on shaft **70** (e.g., may have openings that receive shaft **70**) between leaves **68** and springs **72**. Cams **200** and **204** may be friction reducing cams that are used to adjust the load that is applied by springs **72** on friction leaves **68**. Cam **200** may have cam surfaces **202** that engage and disengage with cam surfaces **206** of cam **204** as device opens and closes. Each cam **200** and **204** may bridge two hinge axes **28**H (e.g., similar to friction leaves **68**).

[0089] When device **10** is folded closed (and housing portions **12-1** and **12-2** are separated by an angle of 0°), cam surfaces **202** and **206** may engage and expand apart from each other, which causes cams **200** and **204** to transfer the load from springs **72** onto friction leaves **68**. Cam surfaces **202** and **206** may be designed to remain engaged until device

10 approaches a nearly open state (e.g., when housing portions **12-1** and **12-2** are separated by a threshold angle of 160° or more, 170° or more, 150° or more, or some other threshold angle between 110° and 180°), which ensures that sufficient torque is applied by hinge module **64** until device **10** reaches the nearly open state. When device **10** is opened past the given threshold angle, cam surfaces **202** and **206** may disengage, which causes cams **200** and **204** to remove the spring load from friction leaves **68**. When friction leaves **68** are no longer loaded by springs **72**, the friction in hinge module **64** is reduced and the user may find it easier to move device **10** into the fully open position.

[0090] If desired, some or all of shafts **70** may have a shoulder such as shoulder **242**. Shoulder **242** may be used to support a load from springs **72** when cams **200** and **204** are disengaged. This may be useful in arrangements where the stroke of cams **200** and **204** is relatively short. Rather than requiring cams **200** and **204** to fully unload springs **72** from friction leaves **68**, cams **200** and **204** only partially unload springs **72** until springs **72** are supported by shoulder **242**.

[0091] If desired, cams **200** and **204** on each hinge axis **28**H may disengage (and thereby reduce friction in hinge module **64**) at the same threshold angle (e.g., 160° or other suitable angle), or some cams **200** and **204** may disengage at different angles compared to other cams **202** and **204**. Friction reduction using cams **200** and **204** can be configured to disengage at any suitable range of angles depending on the desired functionality of device **10**.

[0092] FIGS. **17** and **18** are side views of cams **200** and **204** showing how cam surfaces **202** and **206** may engage and disengage as device **10** moves between folded and flat states.

[0093] FIG. **17** shows the positions of cams **200** and **204** when device **10** is in a folded, fully closed state (e.g., when housing portions **12-1** and **12-2** are separated by an angle of 0°). In this closed state, cam surfaces **202** and **206** are engaged. In particular, peaks **210** of cam **200** are aligned with and contacting peaks **214** of cam **204**, and the valleys **208** of cam **200** are aligned with the valleys **212** of cam **204**. In this position, the load from springs **72** is transferred onto friction leaves **68** and the torque produced by hinge module **64** is relatively high. As device **10** moves from the folded closed position of FIG. **17** to a nearly fully open position, peaks **210** and **214** may remain in contact (and thus cams **200** and **204** may remain engaged) until a threshold angle is reached (e.g., 160° or other suitable threshold angle). At this angle, peaks **214** begin to fall into valleys **208**, and peaks **210** begin to fall into valleys **212**, until cams **200** and **204** reach the disengaged state of FIG. **18**.

[0094] In the disengaged state of FIG. **18**, peaks **210** of cam **200** are aligned with and received within valleys **212** of cam **204**, and the peaks **214** of cam **204** are aligned with and received within valleys **208** of cam **200**. In this disengaged position, the load from springs **72** is not transferred onto friction leaves **68** due to a gap that is produced between cam **200** and friction leaves **68**. This reduces the torque produced by hinge module **64** when device **10** is in the fully open state compared to the torque produced by hinge module **64** when cams **200** and **204** are engaged and device **10** is in the closed state. If desired, some of the load from springs **72** may be supported by a shoulder on shaft **70** such as shoulder **242** of FIG. **16**.

[0095] FIG. **19** shows another illustrative example of cams that are used to reduce friction in hinge module **64** as device **10** approaches a fully open state. Cams **216** and **218** may located on shaft **70** and may be interposed between spring **72** and a stack of friction leaves **68**. Similar to cams **200** and **204** of FIG. **16**, friction reducing cams **216** and **218** may bridge across two hinge axes **28**H and may be used to adjust the load that is applied by springs **72** onto friction leaves **68**. The movement of cams **216** and **218** of FIG. **19** is reversed relative to that of cams **200** and **204** of FIG. **16**. In particular, cams **216** and **218** may be disengaged in the folded state to transfer load from springs **72** onto friction leaves **68**. Cams **216** and **218** may engage as the device approaches the fully open state to remove the load applied by springs **72** from friction leaves **68** and thereby reduce friction in hinge module **64**. This reversed motion of cams **216** and **218** in the opening direction (e.g., in which cams **216** and **218** engage in the opening direction) tends to force hinge axes **28**H into synchronization, which in turn helps prevent a premature drop in torque in hinge module **64**. The synchronization is driven by the resistance torque to engaging cams **216** and **218**, so any backlash is absorbed by an out-of-sync hinge axis **28**H before cams **216** and **218** begin to engage.

[0096] To accommodate the reverse motion of cams **216** and **218**, cams **216** and **218** use a movable sleeve **244** that slides along shaft **70** to load and unload friction leaves **68**. When cams **216** and **218** are disengaged, cams **216** and **218** do not load sleeve **244**, which in turn allows springs **72** to bypass cams **216** and **218** and apply a load to friction leaves **68** via sleeve **244**. When cams **216** and **218** are engaged, cams **216** and **218** expand away from each other and lift sleeve **244** up onto a collar such as collar **250**, which is fixed relative to shaft **70** using pin **228**. This transfers the load from springs **72** away from friction leaves **68** and onto collar **250** to reduce friction in hinge module **64** as device **10** approaches a fully open state.

[0097] FIGS. **20** and **21** are side views of cams **216** and **218** showing how cams **216** and **218** may disengage and engage as device **10** moves between folded and flat states.

[0098] FIG. **20** shows the positions of cams **216** and **218** when device **10** is in a folded closed state (e.g., when housing portions **12-1** and **12-2** are separated by an angle of 0°). In this closed state, cams **216** and **218** are disengaged. In particular, peaks **220** of cam **216** are aligned with valleys **226** of cam **218**, and the peaks **222** of cam **218** are aligned with the valleys **224** of cam **216**. In this position, the load from springs **72** is transferred onto friction leaves **68** through sleeve **244** and the torque produced by hinge module **64** is relatively high. As device **10** moves from the folded closed position to a nearly fully open position, cams **216** and **218** may remain disengaged until a threshold angle is reached (e.g., 160° or other suitable threshold angle). At this angle, peaks **220** begin to align with peaks **222**, and valleys **224** begin to align with valleys **226**, until cams **216** and **218** reach the engaged state of FIG. **21**.

[0099] In the engaged state of FIG. **21**, peaks **220** of cam **216** are aligned with and contacting peaks **222** of cam **218**, and valleys **224** of cam **216** are aligned with valleys **226** of cam **218**. In this engaged position, the load from springs **72** is not transferred onto friction leaves **68** and is instead transferred onto collar **250**, thereby reducing the torque produced by hinge module **64** compared to the torque produced by hinge module **64** when cams **216** and **218** are disengaged.

[0100] In some arrangements, it may be desirable to apply an opening torque that helps push device **10** into an open position. This can be achieved using detent cams on each

hinge axis, as shown in FIG. **22**. Detent cams may be used instead of or in addition to friction reducing cams.

[0101] FIG. **22** is a side view of an illustrative pair of detent cams that may be used to apply an opening torque as the device approaches a fully open position. As shown in FIG. **22**, detent cams **230** and **232** may be mounted on shaft **70** between friction leaves **68** and spring **72**. Similar to the friction reducing cams of FIGS. **16-21**, detent cams **230** and **232** may bridge across two hinge axes **28**H and may be used to adjust the load that is applied by springs **72** onto friction leaves **68**. Unlike the friction reducing cams, which remove the spring load from leaves **68** entirely as device **10** approaches a fully open position, detent cams **230** and **232** may apply a torque that helps push device **10** into the fully open state when a given threshold angle is reached. In particular, when device **10** reaches a given threshold angle (e.g., when housing portions **12-1** and **12-2** are separated by a threshold angle of 160° or more, 170° or more, 150° or more, or some other angle between 110°and 180°), ramp **236** of cam **230** may be aligned with and contacting ramp **234** of cam **232**, as shown in FIG. **22**. Ramps **234** and **236** each have an angle that generates a reacting torque to help force hinge module **64** into the open state when this threshold angle is reached.

[0102] In the example of FIG. **22**, the peaks on cams **230** and **232** have flat surfaces, which allows for constant friction across a certain range of angles during opening and closing. If desired, these flat surfaces may instead be sloped so that torque is gradually increased across that range of angles during opening and closing. This allows the torque to reach its peak within a smaller range of the hinge's motion (e.g., right before cams **230** and **232** engage). Additionally, as device **10** approaches a closed position, sloped surfaces at the peaks of cams **230** and **232** may help reduce hinge torque, which in turn helps reduce the force needed from closing magnets, latches, or other systems to help close device **10**.

[0103] If desired, detent cams **230** and **232** may be configured to generate a torque and to reduce a spring load on the friction leaves to reduce friction in the hinge module. With this type of arrangement, detent cams perform both the function of a friction reducing cam (by reducing friction in hinge module **46**) and a detent cam (by generating a torque). When detent cams are used in this way, there is still some residual friction in the hinge module due to the residual axial load on friction leaves **68**.

[0104] If desired, hinge module **64** may include a combination of friction reducing cams of the type described in connection with FIGS. **16-21** and detent cams of the type described in connection with FIG. **22**. FIG. **23** is a side view of a portion of a hinge module that includes both friction reducing cams and detent cams.

[0105] As shown in FIG. **23**, hinge module **64** may include detent cams **230** and **232** and friction reducing cams **204** and **200**. Detent cams **230** and **232** may be mounted on shaft **70** between shoulder **242** and springs **72**. Friction reducing cams **204** and **200** may be mounted on shaft **70** between shoulder **242** and friction leaves **68**. As device **10** approaches a fully open state, friction reducing cams **200** and **204** may disengage and the spring load may be transferred onto shoulder **242**. Meanwhile, detent cams **230** and **232** may remain engaged at all times and may generate an opening torque due to the angles of the ramps that are contacting each other (e.g., ramps **234** and **236** of FIG. **22**).

[0106] If desired, hinge module **64** may include more than one set of detent cams on each hinge axis **28**H to achieve a greater amount of opening torque. Additionally, detent cams may be configured to apply opening torque at different ranges of angles. For example, detent cams may be configured to apply an opening torque when device **10** is in a folded closed position to make device **10** easier to open. Different layers of detent cams may apply opening torque at different angles (e.g., some may apply opening torque at a folded closed state and others may apply opening torque at the fully open state). Cams such as friction reducing cams and detent cams may have cam surfaces that are molded (e.g., metal injection molded) or may have cam surfaces that are stamped, embossed, or otherwise forged into the cam. If desired, friction reducing cams and/or detent cams may be integrated into some or all of friction leaves **68**.

[0107] Although the friction reducing cams of FIGS. **16-21** and the detent cams of FIGS. **22** and **23** are being used to reduce friction and/or provide an opening torque in the opening direction, it should be understood that friction reducing cams and/or detent cams may also or instead be used to reduce friction and/or provide a closing torque in the closing direction. For example, as device **10** moves from an open position to a nearly fully closed position (e.g., when the angle between housing portions **12-1** and **12-2** reaches a threshold angle close to 0° such as 3°, 5°, 10°, or some other threshold angle), friction reducing cams of the type described in connection with FIGS. **16-21** may be used to reduce load on friction leaves **68** and/or detent cams of the type described in connection with FIGS. **22** and **23** may be used to apply a closing torque in the closing direction. This may help reduce the need for closing magnets or other systems to help close device **10**.

[0108] FIG. **24** is a side view of an illustrative friction leaf that may be used in hinge module **64** to help push hinge module **64** into the open state as device **10** approaches a fully flat position. In the example of FIG. **24**, vertical slot **88** of friction leaf **68** includes a cantilever such as cantilever **252** that protrudes into slot **88** and that applies a spring force onto pin **86**. As devices **10** opens and closes, pin **86** may slide linearly up and down within slot **88** while leaf **68** rotates in directions **260**. When device **10** moves into a folded closed position, pin **86** moves downward within slot **88** in direction **258**. When device **10** moves into an unfolded open position, pin **86** moves upward within slot **88** in direction **254**. Cantilever **252** may have an angled surface **256** at the top that creates a bump on the side of cantilever **252**. When pin **86** moves past this bump created by angled surface **256**, angled surface **256** may force pin **86** into the open state.

[0109] Device **10** may be operated in a system that uses personally identifiable information. It is well understood that the use of personally identifiable information should follow privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining the privacy of users. In particular, personally identifiable information data should be managed and handled so as to minimize risks of unintentional or unauthorized access or use, and the nature of authorized use should be clearly indicated to users.

[0110] FIG. **25** is a side view of an illustrative set of friction leaves that may be used in hinge module **64** to help reduce backlash. As discussed in connection with FIGS. **11** and **12**, hinge module **64** may include timing pins **86** for

ensuring synchronous motion across hinge axes **28**H (FIG. **13**). In some arrangements, each timing pin **86** passes through three different types of slots in friction leaves **68**. If desired, one or more of these three slots may instead be a press fit connection to reduce backlash from those openings. As shown in FIG. **25**, for example, openings **90**B in leaves **68** may be press fit holes that receive and form press fit connections with respective timing pins **86**. Openings **90**B may be tri-lobular shaped in order to create an interference with timing pin **86** on three sides of timing pin **86**.

[0111] In addition to passing through openings **90**B in a first leaf **68**, each timing pin **86** may also pass through a respective opening **90**A on a second leaf **68** and a respective slot **88** on a third leaf **68**. Because timing pin **86** is fixed to the first leaf **68** via a press fit connection in opening **90**B, timing pin **86** rotates with that first leaf **68**. To accommodate this rotation, opening **90**A in the second leaf may be curved and slot **88** in the third leaf may be slightly curved. The example of FIG. **25** only shows four layers of leaves **68**. If desired, hinge module **64** may include more than four layers of leaves **68** and each timing pin **86** may pass through and form press fit connections with multiple leaves **68**.

[0112] The foregoing is merely illustrative and various modifications can be made to the described embodiments. The foregoing embodiments may be implemented individually or in any combination.

What is claimed is:

1. An electronic device, comprising:

a foldable housing having first and second housing portions that rotate relative to one another;

a hinge coupled between the first and second housing portions, wherein the hinge has multiple axes of rotation and comprises:

interdigitated leaves that each include an opening;

a shaft that passes through the opening and that aligns with a respective one of the axes of rotation; and

rollers coupled between the first and second housing portions; and

a foldable display that overlaps the first and second housing portions and the hinge.

2. The electronic device defined in claim **1** wherein the interdigitated leaves comprise a first group of leaves that each include a gear configured to drive synchronous motion of the first housing portion and the second housing portion.

3. The electronic device defined in claim **2** wherein the interdigitated leaves comprise a second group of leaves that each include hard stop structures configured to impose an open position hard stop and a closed position hard stop.

4. The electronic device defined in claim **1** wherein the interdigitated leaves include:

first and second leaves each having an additional opening; and

a third leaf having a vertical slot aligned with the additional openings of the first and second leaves, the hinge further comprising a pin that passes through the vertical slot and the additional openings of the first and second leaves.

5. The electronic device defined in claim **4** wherein the vertical slot is configured to maintain the pin at an equal distance from the adjacent axes of rotation that are located on opposing sides of the pin.

6. The electronic device defined in claim **4** wherein the vertical slot has top and bottom surfaces that respectively impose an open position hard stop and a closed position hard stop.

7. The electronic device defined in claim **4** wherein the interdigitated leaves are interposed between the display and the rollers.

8. The electronic device defined in claim **4** wherein the additional opening is formed from first and second cantilevered arms.

9. The electronic device defined in claim **4** wherein the third leaf comprises first and second openings formed on opposing ends of the third leaf, the hinge further comprising first and second additional pins that are respectively received within the first and second openings.

10. The electronic device defined in claim **4** wherein:

the additional opening in the first leaf is tri-lobular shaped and forms a press fit connection with the pin;

the additional opening in the second leaf is curved; and

the vertical slot in the third leaf is curved.

11. A hinge assembly having multiple axes of rotation and configured to drive synchronous motion of a foldable housing, the hinge assembly comprising:

elongated cylinders that extend parallel to the axes of rotation; and

a hinge module coupled to the elongated cylinders, wherein the hinge module comprises a friction hinge with interdigitated leaves that rotate relative to one another about the multiple axes of rotation.

12. The hinge assembly defined in claim **11** wherein the interdigitated leaves comprise:

first and second leaves with intermeshed gears for driving the synchronous motion of the foldable housing.

13. The hinge assembly defined in claim **12** wherein the interdigitated leaves comprise:

third and fourth leaves with hard stop structures for preventing overtravel of the foldable housing.

14. The hinge assembly defined in claim **11** wherein the interdigitated leaves comprise:

first and second leaves each having an opening; and

a third leaf having a vertical slot aligned with the openings of the first and second leaves, the hinge assembly further comprising a pin that passes through the vertical slot and the openings of the first and second leaves.

15. The hinge assembly defined in claim **11** further comprising:

shafts that pass through respective sets of the interdigitated leaves, wherein each of the shafts is aligned with a respective one of the axes of rotation; and

hourglass-shaped links that are each interposed between a respective pair of the elongated cylinders.

16. An electronic device, comprising:

a housing having first and second housing portions that fold relative to one another;

a hinge coupled between the first and second housing portions and configured to rotate about multiple axes of rotation, wherein the hinge comprises:

shafts that each extend along a respective one of the axes of rotation;

pins that extend parallel to the shafts, wherein each of the shafts is interposed between a respective pair of the pins; and

interdigitated friction fingers that respectively receive the shafts and the pins, wherein the interdigitated friction fingers produce torque through axial friction along the shafts.

17. The electronic device defined in claim **16** wherein the interdigitated friction fingers comprise:

first and second friction fingers each having an opening; and

a third friction finger having a vertical slot aligned with the openings of the first and second friction fingers, wherein a respective one of the pins passes through the openings of the first and second friction fingers and the vertical slot of the third friction finger.

18. The electronic device defined in claim **17** wherein the vertical slot is configured to maintain the respective one of the pins at an equal distance from the adjacent axes of rotation that are located on opposing sides of the respective one of the pins.

19. The electronic device defined in claim **17** wherein the vertical slot has top and bottom surfaces that respectively impose an open position hard stop and a closed position hard stop.

20. The electronic device defined in claim **16** further comprising:

a foldable display coupled to the housing; and

rollers coupled between the first and second housing portions and extending parallel to the axes of rotation, wherein the interdigitated friction fingers are interposed between the foldable display and the rollers.

21. The electronic device defined in claim **16** further comprising:

a spring on each of the shafts that is configured to apply a load to the interdigitated friction fingers; and

friction reducing cams on each of the shafts that transfer the load away from the interdigitated friction fingers as the electronic device approaches an open state in which the first and second housing portions are separated by an angle of 180 degrees.

22. The electronic device defined in claim **21** wherein each of the shafts has a shoulder and wherein the friction reducing cams transfer the load onto the shoulder as the electronic device approaches the open state.

23. The electronic device defined in claim **21** further comprising a sleeve and a collar on each of the shafts, wherein the sleeve is movable relative to the shaft and the collar is fixed relative to the shaft, and wherein the friction reducing cams move the sleeve onto the collar to transfer the load onto the collar as the electronic device approaches the open state.

24. The electronic device defined in claim **16** further comprising:

detent cams on each of the shafts that are configured to generate a torque that pushes the electronic device into an open state in which the first and second housing portions are separated by an angle of 180 degrees.

25. The electronic device defined in claim **16** wherein at least some of the interdigitated friction fingers include a slot and a cantilever that protrudes into the slot, wherein the cantilever has an angled surface that applies a force to the pin to push the electronic device into an open state in which the first and second housing portions are separated by an angle of 180 degrees.

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