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(72) Inventeur/Inventor:
MURISON, BRUCE, CA

(73) Propriétaire/Owner:
OBOTICS INC., CA

(74) Agent: GOWLING WLG (CANADA) LLP

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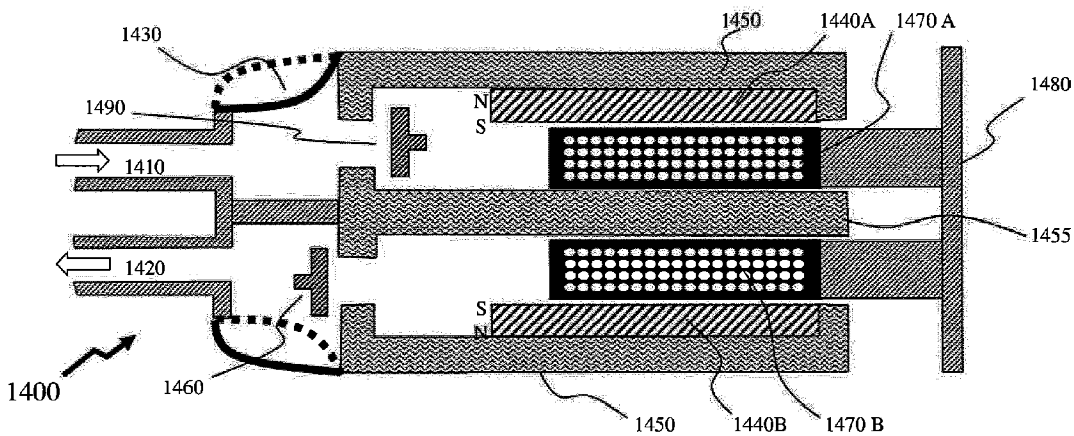

(57) Abrégé/Abstract:
A device for use by an individual for sexual pleasure varying in form, i.e. shape, during its use and allowing for the user to select multiple variations of form either discretely or in combination and for these dynamic variations to be controllable simultaneously and interchangeably while being transparent to the normal use of the device, including the ability to insert, withdraw, rotate, and actuate the variable features manually or remotely. According to embodiments of the invention localized and global variations of devices are implemented using fluidics and electromagnetic pumps/valves wherein a fluid is employed such that controlling the pressure of the fluid results in the movement of an element within the device or the expansion/contraction of an element within the device.

ABSTRACT

A device for use by an individual for sexual pleasure varying in form, i.e. shape, during its use and allowing for the user to select multiple variations of form either discretely or in combination and for these dynamic variations to be controllable simultaneously and interchangeably while being transparent to the normal use of the device, including the ability to insert, withdraw, rotate, and actuate the variable features manually or remotely. According to embodiments of the invention localized and global variations of devices are implemented using fluidics and electromagnetic pumps/valves wherein a fluid is employed such that controlling the pressure of the fluid results in the movement of an element within the device or the expansion/contraction of an element within the device.

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FLUIDIC METHODS AND DEVICES

CROSS-REFERENCE TO RELATED APPLICATIONS

[001] This patent application claims the benefit of priority as a divisional of Canadian Patent Application 2,975,661 entitled "Fluidic Methods and Devices" which itself claims the benefit of priority as a divisional of Canadian Patent Application 2,885,870 entitled "Fluidic Methods and Devices" with a national phase entry date of March 24, 2015; which itself claims the benefit of priority from World Intellectual Property Office Patent Application PCT/CA2013/000809 filed September 26, 2013 entitled "Fluidic Methods and Devices"; which itself claims the benefit of priority from U.S. Provisional Patent Application 61/705,809 filed on September 28, 2012 entitled "Methods and Devices for Fluid Driven Adult Devices."

FIELD OF THE INVENTION

[002] The present invention relates to fluidic devices and more particularly to electromagnetically driven pumps, valves, and switches.

BACKGROUND OF THE INVENTION

[003] The growing acceptance of sexuality and masturbation has resulted in the growth of a market for sexual pleasure devices, also known as sex toys, and then with technology evolution the concepts of "cyber-sex," "phone sex" and "webcam sex." A sex toy is an object or device that is primarily used to facilitate human sexual pleasure and typically are designed to resemble human genitals and may be vibrating or non-vibrating. Prior to this shift there had been a plethora of devices sold for sexual pleasure, although primarily under euphemistic names and a pretense of providing "massage" although their history extends back through ancient Greece to the Upper Paleolithic period before 30,000BC. Modern devices fall broadly into two classes: mechanized and non-mechanized, and in fact the American company Hamilton Beach in 1902 patented the first electric vibrator available for retail sale, making the vibrator the fifth domestic appliance to be electrified. Mechanized devices typically vibrate, although there are examples that rotate, thrust, and even circulate small beads within an elastomeric shell. Non-mechanized devices are made from a solid mass of rigid or semi-rigid material in a variety of shapes.

[004] Vibrators typically operate through the operation of an electric motor wherein a small weight attached off-axis to the motor results in vibration of the motor and hence the body of the portion of the vibrator coupled to the electric motor. They may be powered from connection to an electrical mains socket but typically such vibrators are battery driven which places emphasis on efficiency to derive not only an effective vibration but one over an extended period of time without the user feeling that the vibrator consumes batteries at a high rate. For example, typical vibrators employ 2 or 4 AA batteries, which if of alkaline construction, each have a nominal voltage of 1.5V and a capacity of 1800mAh to 2600mAh under 500mA drain. As such, each battery under such a nominal drain can provide 0.75W of power for 3 to 5 hours such that a vibrator with 2 AA batteries providing such lifetime of use must consume only 1.5W in contrast to less than 3W for one with 4 AA batteries. More batteries consume more space within devices which are generally within a relatively narrow range of physical sizes approximating that of the average penis in penetrative length and have an external portion easily gripped by the user thereby complicating the design. Typically, toys that are large due to power requirements are not as successful as more compact toys.

[005] However, such electric motors with off-axis weights cannot easily operate at low frequencies when seeking to induce excitation to the user in a manner that mimics physical intercourse and stimulation where for example stimulation would be very low or low frequency and high or very high amplitude. Such low frequency, high amplitude vibrations are desirable to users but are not achieved with the vibrators of the prior art. For example providing operation below 40Hz, below 10Hz, below 4Hz, below 1Hz cannot be provided where small DC motors cannot produce much torque at low revolutions per minute (RPM) and therefore cannot move the large heavy weight to produce high amplitude variations. Typically, several thousand RPM is required in this scenario. Accordingly, reducing the weight to reduce torque required leads to reduced vibrations. It is this mode that vibrators operate within through high frequency low amplitude vibrations. It would be beneficial for an alternative drive means to allow low and very low frequency operation discretely or in combination with higher frequency operation and provide user settable high amplitude stimulation as well as offering reduced amplitudes.

[006] Accordingly, today, a wide range of vibrators are offered commercially to users but most of them fall into several broad categories including:

[007] **Clitoral**: The clitoral vibrator is a sex toy used to provide sexual pleasure and to enhance orgasm by stimulating the clitoris. Although most of the vibrators available can be

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used as clitoral vibrators, those designed specifically as clitoral vibrators typically have special designs that do not resemble a vibrator and are generally not phallic shaped. For example, the most common type of clitoral vibrators are small, egg-shaped devices attached to a multi-speed battery pack by a cord. Common variations on the basic design include narrower, bullet-shaped vibrators and those resembling an animal. In other instances, the clitoral vibrator forms part of a vibrator with a second portion to be inserted into the vagina wherein they often have a small animal, such as a rabbit, bear, or dolphin perched near the base of the penetrative vibrator and facing forward to provide clitoral stimulation at the same time with vaginal stimulation. Prior art for clitoral stimulators includes U.S. Patents 7,670,280 and 8,109,869 as well as U.S. Patent Application 2011/0,124,959.

[008] In some instances, such as the We-Vibe™, the clitoral vibrator forms part of a vibrator wherein another section is designed to contact the "G-spot." Prior art for such combined vibrators includes U.S. Patent 7,931,605, U.S. Design Patents 605,779 and 652,942, and U.S. Patent Application 2011/0,124,959.

[009] **Dildo-Shaped:** Typically these devices are approximately penis-shaped and can be made of plastic, silicone, rubber, vinyl, or latex. Dildo is the common name used to define a phallus-like sex toy, which does not, however, provide any type of vibrations. But as vibrators have commonly the shape of a penis, there are many models and designs of vibrating dildos available including those designed for both individual usage, with a partner, for vaginal and anal penetration as well as for oral penetration, and some may be double-ended.

[0010] **Rabbit**: As described above these comprise two vibrators of different sizes. One, a phallus-like shaped vibrator intended to be inserted in the user's vagina, and a second smaller clitoral stimulator placed to engage the clitoris when the first is inserted. The rabbit vibrator was named after the shape of the clitoral stimulator, which resembles a pair of rabbit ears.

[0011] **G-Spot**: These devices are generally curved, often with a soft jelly-like coating intended to make it easier to use to stimulate the g-spot or prostate. These vibrators are typically more curved towards the tip and made of materials such as silicone or acrylic.

[0012] **Egg**: Generally small smooth vibrators designed to be used for stimulation of the clitoris or insertion. They are considered discreet sex toys as they do not measure more than 3 inches in length and approximately ¾ inches to 1¼ inches in width allowing them to be used discretely, essentially at any time.

[0013] Anal: Vibrators designed for anal use typically have either a flared base or a long handle to grip, to prevent them from slipping inside and becoming lodged in the rectum. Anal vibrators come in different shapes but they are commonly butt plugs or phallus-like vibrators. They are recommended to be used with a significant amount of lubricant and to be inserted gently and carefully to prevent any potential damage to the rectal lining.

[0014] Cock Ring: Typically a vibrator inserted in or attached to a cock ring primarily intended to enhance clitoral stimulation during sexual intercourse.

[0015] Pocket Rocket (also known as **Bullet**): Generally cylindrical in shape one of its ends has some vibrating bulges and is primarily intended to stimulate the clitoris or nipples, and not for insertion. Typically, a "pocket rocket" is a mini-vibrator that is typically about three to five inches long and which resembles a small, travel-sized flashlight providing for a discreet sex toy that can be carried around in a purse, pouch, etc. of the user. Due to its small dimension, it is typically powered by a single battery and usually has limited controls; some may have only one speed.

[0016] Butterfly: Generally describing a vibrator with straps for the legs and waist allowing for hands-free clitoral stimulation during sexual intercourse. Typically, these are offered in three variations, traditional, remote control, and with anal and/or vaginal stimulators, and are generally made of flexible materials such as silicone, soft plastic, latex, or jelly.

[0017] In addition to the above general categories there are variants including, but not limited to:

- Dual vibrators which are designed to stimulate two erogenous zones simultaneously or independently, the most common being both clitoral and vaginal stimulators within the same vibrator;
- Triple vibrators which are designed to stimulate three erogenous zones simultaneously or independently;
- Multispeed vibrators which allow users to adjust how fast the vibrator's pulsing or massaging movements occur and generally provide a series of discrete speed settings selectable through a button, slider etc. or pseudo-continuously variable through a rotary control;
- Double ended devices for use by two users together, usually doubled ended dildo or double ended vibrator, for vaginal-vaginal, vaginal-anal, or anal-anal stimulation;

- Nipple stimulators which are designed to stimulate the nipples and/or areola through vibration, suction, and clamping;
- Electrostimulators which are designed to apply electrical stimulation to the nerves of the body, with particular emphasis on the genitals;
- "Flapping" stimulators which have multiple flexible projections upon a "Ferris-wheel" assembly to simulate oral stimulation; and
- Male stimulators which are typically soft silicone sleeves to surround the penis and stimulate it through rhythmic movement by the user.

[0018] The prior art devices described above exploit mechanical actions arising from linear and/or rotary motors in order to achieve the desired physical stimulation. However, motion and pressure may be achieved also through the use of fluidics wherein a fluid is employed such that controlling the pressure of the fluid results in the movement of an element within a structure or the expansion/contraction of an element. However, to date the commercial deployment of sex toys exploiting fluidics has been limited to the provisioning of lubricating oils or gels during use of the device to reduce friction and subsequent pain/irritation either through extended use of the device or from low natural lubrication of the user upon whom the device is used. Examples of prior art for such lubricating devices include, but is not limited to, U.S. Patent 6,749,557 and 7,534,203 and U.S. Patent Applications 2004/0,034,315; and 2004/0,127,766.

[0019] When considering users of the prior art devices described above these present several limitations and drawbacks in terms of providing enhanced functionality, dynamic device adaptability during use, and user specific configuration for example.

[0020] As noted *supra*, the commercial deployment of devices exploiting fluidics has been limited to lubricant release during device use despite several prior art references to using fluidics including, for example,. Stoughton in U.S. Patent 3,910,262 entitled "Therapeutic Apparatus"; Schroeder in U.S. Patent 4,407,275 entitled "Artificial Erection Device"; Kain in U.S. Patents 5,690,603 and 7,998,057 each entitled "Erogenic Stimulator"; Levy in U.S. Patent Application 2003/0,073,881 entitled "Sexual Stimulation"; Regey in U.S. Patent Application 2006/0,041,210 entitled "Portable Sealed Water Jet Female Stimulator"; Gil in U.S. Patent 7,534,203 entitled "Vibrator Device with Inflatable, Alterable Accessories"; and Faulkner in U.S. Patent Application 2005/0,049,453 and 2005/0,234,292, each of which is entitled "Hydraulically Driven Vibrating Massagers,"

[0021] Faulkner teaches devices with means to vibrate and/or rhythmically deform elements within the device. Faulkner teaches a hydraulic actuator to move hydraulic fluid into and out of the device to sequentially and repeatedly inflate and deflate an elastomeric element within the device. Faulkner teaches simple hydraulic drivers, such as cylinders, which are moved by an eccentric gear attached to a rotating shaft, thus injecting and removing hydraulic fluid in a pattern where deformation and flow are sine waves. Also taught, are more complicated hydraulic drivers using cams or computer-controlled drivers wherein cyclic deformations that are not simple sine waves can be created. A preferred embodiment taught by Faulkner is a voice-coil driver, which comprises a solenoid type coil directly coupled to the shaft of a piston which is in turn coupled to a spring, which provides a base level of pressure. Accordingly, a low frequency alternating current is applied to the coil, which in turn drives the shaft, thereby driving the piston such that hydraulic fluid is driven into and out of the piston, thereby moving the elastomeric stimulator. Faulkner further teaches a second fluid immersed driver, such as an electrical coil-driven diaphragm or piezoelectric crystal, which is used to add higher frequency pressure variations to the low frequency cyclic pressure variation from the primary piston based hydraulic oscillator. Accordingly, Faulkner teaches generating a cyclic motion of an element or elements of the device through the cyclic first hydraulic oscillator and applying a vibratory element through a second fluid immersed hydraulic oscillator.

[0022] It is evident therefore to one skilled in the art that the hydraulic driven devices as taught by Faulkner, Gil, Kain, Levy, Schroeder, and Stoughton do not provide devices with the desirable and beneficial features described above which are lacking within known devices of the conventional mechanical activation with electrical motors. Further in considering fluidic pumps that may be employed as part of hydraulic devices then within the prior art there are naturally several designs of pumps. However, to date as discussed *supra* hydraulic devices have not been developed or commercially deployed despite the prior art fluidic concepts identified above in respect of fluidic devices and these prior art pumps. This is likely due to the fact that fluidic pumps are bulky, have low efficiency, and do not operate in the modes required for such devices, such as, for example, low frequency, variable duration, and pulsed for those providing primary pumps for dimensional adjustments or for example high frequency operation for those providing secondary pumps for vibration and other types of motion/excitation. For example, a conventional rotary pump offers poor pressure at low revolutions per minute (rpm), has a complicated motor and separate pump, multiple moving parts, relatively large and expensive even with small impeller, and low effective flow rate from a small impeller.

[0023] Within the prior art there are examples of electromechanical actuators which may provide alternative pumps to those described below in respect of embodiments of the invention in Figures 11 through 17 but with varying limitations and drawbacks. For example so-called voice-coil linear vibrating motors whilst compatible with modification to fluid pumping do not exert a strong force relative to a solenoids closing force but can provide an increased linearity of force over distance. Examples include long coil – short gap with magnetization along axis of motor, short coil motor with magnetization perpendicular to motor axis. Solenoids whilst offering larger force than voice coil motors have a poor ability to exert a steady force on a long stroke piston, typically a few millimeters, and where constant force solenoids are implemented these tend to be short stroke with increased complexity in the design of the coil, body and shape of the cross-section of the plunger. An example of such prior art solenoids based actuators are the FFA and MMA series of actuators from Magnetic Innovations (*www.magneticinnovations.com*). However, such actuators are primarily designed for long stroke, large load displacement, and as replacements for pneumatic cylinders.

[0024] Other prior art moving magnet motor is that described by Astratini-Enache *et al.* in "Moving Magnet Type Actuator with Ring Magnets" (J. Elect. Eng., Vol. 61, pp.144-147) and Leu *et al.* in "Characteristics and Optimal Design of Variable Airgap Linear Force Motors" (IEEE Proc. Pt B, Vol. 135, pp.341-345) but exploit neodymium and samarium-cobalt rare-earth magnets in order to miniaturize the motor dimensions. Petrescu *et al.* in "Study of a Mini-Actuator with Permanent Magnets" (Adv. Elect. & Comp. Eng., Vol. 9, pp.3-6) adds fixed magnets to either end of a moving magnet actuator in order to define the moving magnet position when no activation is provided due to the requirements of robotics and defined zero activation positions for actuators as well as adjusting the force versus displacement characteristic of the actuator. Vladimirescu *et al.* in US Patent 6,870,454 entitled "Linear Switch Actuator" teach to a latching actuator for a microwave switch application wherein the actuator comprises an armature rod with permanent magnets at either end such that as one or other permanent magnet moves outside the coils the structure latches.

[0025] In contrast to moving magnet motors moving iron motors have been reported within the prior art as an alternative, see for example Ibrahim *et al.* in "Design and Optimization of a Moving Iron Linear Permanent Magnet Motor for Reciprocating Compressors using Finite

Element Analysis" (Int. J. Elect. & Comp. Sci. IJECS-IJENS, Vol. 10, pp.84-90). As taught by Ibrahim the design of Evans *et al.* in "Permanent Magnet Linear Actuator for Static and Reciprocating Short Stroke Electromechanical Systems" (IEEE/ASME Trans. Mechatronics, Vol. 6, pp.36-42) which employs rare earth magnets is adapted to employ lower cost magnets which also remove Eddy current issues which required magnet segmentation in prior art moving magnet linear motors. Ibrahim adjusts the resulting reduction in force from the reduced strength magnets by increasing dimensions, magnetic loading and electrical loading whilst optimizing the design for 50Hz electrical mains operation. The resulting motor at 100mm (4 inches) long and 55mm (2.2 inches) diameter, is larger than many of the devices within the prior art and the device dimensions sought for the devices targeted for implementation using these fluidic actuators.

[0026] Likewise, Berling in U.S. Patent 5,833,440 entitled "Linear Motor Arrangement for a Reciprocating Pump System" describes a moving magnet actuator exploiting a pole piece pair magnetically soft material abutting a permanent magnet to conduct the magnetic flux in two different magnetic circuit pathways. In one pathway the armature is attracted to the pole pieces resulting in coil driven motion. However, in the second pathway whilst the armature is not attracted to the pole pieces there is no repulsive force and accordingly a compression spring is used to push the armature away from the pole pieces. Likewise Cedrat Technologies with their Moving Iron Controllable Actuator (MICA) exploit a pair of soft magnetic pole pieces within a magnetic field wherein the magnetic force is intrinsically quadratic meaning that only attraction forces can be produced and accordingly to achieve a return a return spring is added, leading to one fixed position at rest.

[0027] Mokler in U.S. Patent Application 2006/0,210,410 describes a pump comprising a pair of electromagnets disposed around a tubular member wherein associated with each is a magnet. Disposed between the two electromagnets is a pair of permanent magnets as well as permanent magnets at each outer end of the electromagnets. Accordingly, the permanent magnets limit the movement of the magnets under action of the electromagnets. Hertanu *et al.* in "A Novel Minipump Actuated by Magnetic Piston" (J. Elec. Eng., Vol. 61, pp.148-151) similarly exploits permanent magnets at either end to limit the motion of the moving magnet and define the initial position. However, Hertanu also employs ferrofluidic rings at either end of the moving magnet wherein the ferrofluid conforms to the channel shape providing very good seal and can be controlled by external magnetic fields.

[0028] Ibrahim in "Analysis of a Short Stroke, Single Phase Tubular Permanent Magnet Actuator for Reciprocating Compressors" (6th Int. Symposium on Linear Drives for Industrial Applications, LDIA2007, 2007) describes a moving magnet actuator wherein the central moving magnet is formed from a series of radially and axially magnetized trapezoidal ring magnets stacked together with varying magnetic field directions. Accordingly, the resulting magnet is complicated and expensive and whilst Ibrahim in "T. Ibrahim, J. Wang, and D. Howe, "Analysis of a Single-Phase, Quasi-Halbach Magnetised Tubular Permanent Magnet Motor with Non-Ferromagnetic Support Tube" (14th IET Int. Conf. on Power Electronics, Machines and Drives, Vol. 1, pp.762-766) adjusted the magnetized ring magnet design it still requires multiple rings stacked together with different field orientations, they are simply rectangular rather than trapezoidal. Another variant is taught by Lee *et al.* in "Linear Compression for Air Conditioner" (International Compressor Engineering Conference 2004, Paper C047) wherein whilst the magnet again surrounds an inner core and is a single element the compressor exploits a resonant spring assembly and a controller that controls the excitation frequency for maximizing the linear motor efficiency by using system resonance follow-up algorithm.

[0029] Accordingly, it would be desirable to provide pumps and valves that allow for multiple ranges of motion of the device both in terms of overall configuration and dimensions as well as localized variations and multiple moving elements may be implemented using fluidics wherein a fluid is employed such that controlling the pressure and/or flow of the fluid results in the movement of an element(s) within the device or the expansion/contraction of an element(s) within the device. As noted *supra,* the commercial deployment of sexual stimulation devices or devices for sexual pleasure exploiting fluidics has been limited to lubricant release during device use despite several prior art references to using fluidics including, for example, those described below. Accordingly, there remains a need for methods and devices that provide these desirable and beneficial features. It would be particularly beneficial to provide fluidic devices having all of the functions described *supra* in respect of prior art devices but also have the ability to provide these within a deformable device and/or a device having deformable element(s). Further, it would be beneficial to provide devices that employ fluidic actuators, which are essentially non-mechanical and, consequently, are not susceptible to wear-out such as, by stripping drive gears, etc., thereby increasing their reliability and reducing noise. Fluidic devices allow for high efficiency, high power to size ratio, low cost, limited or single moving part(s) and allow for mechanical springless designs as well as functional reduction by providing a piston which is both pump and vibrator.

[0030] Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

SUMMARY OF THE INVENTION

[0031] It is an object of the present invention to mitigate limitations within the prior art relating to fluidic devices and more particularly to electromagnetically driven pumps, valves, and switches.

[0032] In accordance with an embodiment of the invention there is provided a device comprising:

an electromagnetically driven pump for pumping a fluid from an inlet port to an outlet port; and

a fluidic capacitor coupled at one end to the electromagnetically driven pump at other end to a fluidic system; wherein

the fluidic capacitor comprises a first predetermined portion having a first predetermined elasticity and a second predetermined portion having a second predetermined elasticity lower than the first predetermined elasticity wherein the second predetermined portion deforms under activation of the electromagnetically driven pump in a manner such that the electromagnetically driven pump is not at least one of drawing upon or pumping into the complete fluidic system according to whether the fluidic capacitor is on the inlet side or the outlet side port of the electromagnetically driven pump.

[0033] In accordance with an embodiment of the invention there is provided a method comprising:

an electromagnetically driven pump for pumping a fluid upon both forward and backward piston strokes;

first and second valve assemblies coupled to each end of the electromagnetically driven pump, each valve assembly comprising an inlet non-return valve, an outlet non-return valve, and a valve body having a port fluidically coupled to the electromagnetically driven pump, a port coupled to the inlet non-return valve, and a port coupled to the output non-return valve; and

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a first fluidic capacitor disposed at least one of prior to an inlet non-return valve and after an outlet non-return valve; wherein

the first fluidic capacitor comprises a first predetermined portion having a first predetermined elasticity and a second predetermined portion having a second predetermined elasticity lower than the first predetermined elasticity wherein the second predetermined portion deforms under activation of the electromagnetically driven pump in a manner such that the electromagnetically driven pump is not at least one of drawing upon or pumping into s fluidic system to which the electromagnetically driven pump is connected according to whether the fluidic capacitor is on the inlet side or the outlet side port of the electromagnetically driven pump.

[0034] In accordance with an embodiment of the invention there is provided a device comprising:

providing an electrical coil wound upon a bobbin having an inner tubular opening with a minimum diameter determined in dependence upon at least the piston and having a predetermined taper profile at either end of the bobbin providing an increasing diameter towards each end of the bobbin to a predetermined maximum diameter, the predetermined taper profile determined in dependence upon the target performance of an electromagnetically driven device;

providing a pair of thin electrically insulating washers for assembly directly to either side of the coil, each thin electrically insulating washer having an inner diameter at least equal to the predetermined maximum diameter of the bobbin;

providing a pair of inner washers disposed either side of the coil with each adjacent one of the thin electrically insulating washers, each inner washer comprising a disc of predetermined thickness and a projection on the inner edge of the washer matching the predetermined taper profile on the bobbin;

providing a pair of magnets disposed either side of the coil with each adjacent one of the inner washers;

providing a pair of outer washers disposed either side of the coil with each adjacent one of magnets;

assembling the electrical coil, the pair of thin electrically insulating washers, the pair of inner washers, the pair of magnets, and the pair of outer washers in their correct order within a jig, the jig comprising a central circular rod defining a minimum barrel diameter which is less than the minimum diameter of the bobbin by a predetermined amount;

potting the assembled components within the jig; and

disassembling the potted assembly for subsequent insertion of a piston of predetermined dimensions within the barrel formed within the potting material to provide the electromagnetically driven device under appropriate electrical control.

[0035] In accordance with an embodiment of the invention there is provided a method:

providing an electromagnetically driven device comprising at least a piston, the piston having a predetermined outer diameter profile along its length and a predetermined gaps and tolerances with respect to a barrel formed within the electromagnetically driven motor within which the piston moves; wherein

the piston outer diameter profile is determined in dependence upon at least characteristics of the piston stroke within the electromagnetically driven device and a fluid the piston is moving within such that above a predetermined minimum piston speed sufficient hydrodynamic pressure can be generated to generate sufficient lift forces on the piston to offset magnetic attraction forces from off-axis positioning and preventing surface-surface contact between outer surface of the piston and the inner surface of the barrel.

[0036] In accordance with an embodiment of the invention there is provided a method comprising:

simulating the piston dynamics of a piston moving within a fluid within an electromagnetically driven device with at least current induced force as an input, the simulation determining piston position, fluid pressure, and piston velocity as a function of time;

establishing a force signal curve that imparts energy over the entire stroke and permits the piston to traverse the entire desired stroke length;

evolving the force signal curve using a optimization method where the mean current from a particular force curve was minimized;

translating the resulting evolved force signal curve to an applied electrical drive signal curve to provide the signal control current profile for an electrical control circuit to provide to drive the electromagnetically driven device.

[0037] In accordance with an embodiment of the invention there is provided a device comprising:

an electromagnetically driven device comprising:

a piston of predetermined shape with a plurality of slots machined along its axis, the plurality of slots penetrating to a predetermined depth;

a pair of washer-magnet-washer assemblies, each assembly disposed on either side of an electromagnetic coil of the electromagnetically driven device where each washer has a slot cut through its thickness from the inner edge to the other edge; wherein

the slots formed within the piston and washer reduce the formation of radial or circular Eddy currents within the respective one of the piston and washer.

[0038] In accordance with an embodiment of the invention there is provided a device comprising:

an electromagnetically driven device;

a fluidic capacitor which acts as a low pass fluidic filter in combination with other elements of the fluidic system to smooth pressure fluctuations arising from the operation of the electromagnetically driven device over a first predetermined frequency range; and

a control circuit providing a first signal for driving the electromagnetically driven device at a frequency within the first predetermined frequency range and a second signal for driving the electromagnetically driven device with an oscillatory signal above the low pass cut-off frequency of the low pass fluidic filter; wherein

the pulsed fluidic output generated by the second signal is coupled to the fluidic system but the pulsed fluidic output generated by the first signal is filtered to provide a constant fluidic flow from the electromagnetically driven device with predetermined ripple.

[0039] In accordance with an embodiment of the invention there is provided a device comprising:

a pressure valve wherein the pressure valve opens when an applied fluidic pressure exceeds a predetermined value such that a spring force from a spring coupled to a ball bearing seated within a seat sealing the an inlet within the pressure valve cannot keep the ball bearing in position within the seat;

a drive pin operable by an actuator between a first position preventing the ball bearing from moving and a second position allowing the ball bearing to move and having a profile at its end that re-positions the ball bearing back into seat when it transitions to the first position; and

a control circuit for receiving an external control signal and controlling the actuator in dependence therein.

[0040] In accordance with an embodiment of the invention there is provided a method comprising:

a) providing a set-up procedure for an action relating to a functional element of a device to be personalized to an individual;

b) automatically varying an aspect of the action relating to the functional element of the device between a first predetermined value and a second predetermined value in a predetermined number of steps until an input is received from the individual; and

c) terminating step (b) upon receiving the individual's input and storing the value relating to the aspect of the action when the individual provided the input within a profile of a plurality of profiles associated with the device.

[0041] Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0042] Embodiments of the present invention will now be described, by way of example only, with reference to the attached Figures, wherein:

[0043] Figure 1 depicts parallel and serial element actuation exploiting fluidic elements in conjunction with fluidic pump, reservoir and valves according to embodiments of the invention;

[0044] Figure 2 depicts serial element constructions exploiting secondary fluidic pumps and fluidic elements in conjunction with primary fluidic pump, reservoir and valves according to embodiments of the invention;

[0045] Figure 3 depicts a device according to an embodiment of the invention exploiting fluidic elements to adjust aspects of the device during use;

[0046] Figure 4 depicts a device according to an embodiment of the invention exploiting fluidic elements to adjust aspects of primary and secondary elements of the device during use;

[0047] Figure 5 depicts devices according to embodiments of the invention exploiting fluidic elements to provide suction, vibration, or motion sensations;

[0048] Figure 6 depicts an embodiment of the invention relating to the inclusion of fluidic actuated devices within clothing;

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[0049] Figures 7A and 7B depict flow diagrams for process flows relating to setting a device exploiting fluidic elements with single and multiple functions according to embodiments of the invention according to the preference of a user of the device;

[0050] Figure 8 depicts a flow diagram for a process flow relating to establishing a personalization setting for a device exploiting fluidic elements according to embodiments of the invention and its subsequent storage/retrieval from a remote location;

[0051] Figure 9 depicts a flow diagram for a process flow relating to establishing a personalization setting for a device exploiting fluidic elements according to embodiments of the invention and its subsequent storage/retrieval from a remote location to the users device or another device;

[0052] Figure 10 depicts inflation/deflation of an element under fluidic control according to an embodiment of the invention with fluidic pump, reservoirs, non-return valves, and valves;

[0053] Figure 11 depicts an electronically activated valve (EAV) or electronically activated switch for a fluidic system according to an embodiment of the invention;

[0054] Figure 12 depicts an electronically controlled pump for a fluidic system according to an embodiment of the invention;

[0055] Figures 13 and 14 depict electronically controlled pumps for fluidic systems according to embodiments of the invention exploiting fluidic capacitors;

[0056] Figures 15 and 16 depict electronically controlled pumps for fluidic systems according to embodiments of the invention;

[0057] Figure 17 depicts an electronically controlled pump for a fluidic system according to an embodiment of the invention exploiting fluidic capacitors;

[0058] Figures 18 and 19 depict an electronically controlled pump(ECPUMP) according to an embodiment of the invention exploiting full cycle fluidic action;

[0059] Figures 20A through 20C depict an assembly for mounting to an ECPUMP according to an embodiment of the invention to provide inlet and outlet ports with non-return valves;

[0060] Figure 21 to 22D depict compact and mini ECPUMPs according to embodiments of the invention;

[0061] Figures 23A and 23B depict a compact ECPUMP according to an embodiment of the invention with dual inlet and outlet valve assemblies coupling to a fluidic system together with schematic representation of the performance of such ECPUMPs with and without fluidic capacitors;

[0062] Figure 24 depicts a compact ECPUMP according to an embodiment of the invention exploiting the motor depicted in Figures 35 to 36B;

[0063] Figures 25A and 25B depict a compact ECPUMP according to an embodiment of the invention exploiting the motor depicted in Figures 21 to 22B;

[0064] Figure 26 depicts a compact electronically controlled fluidic valve/switch according to an embodiment of the invention;

[0065] Figure 2727 depicts programmable and latching check fluidic valves according to an embodiment of the invention;

[0066] Figure 28 depicts a cross-section and dimensioned compact ECPUMP according to an embodiment of the invention exploiting the motor depicted in Figures 35 to 36B;

[0067] Figures 29 and 30 depict finite element modelling (FEM) results of magnetic flux distributions for compact ECPUMPs obtained during numerical simulation based design analysis;

[0068] Figures 31A depict numerical simulation results for compact ECPUMPs according to embodiments of the invention under parametric variation of piston tooth thickness and washer offset;

[0069] Figures 31B depict numerical simulation results for compact EAVs according to embodiments of the invention under parametric variation of washer offset;

[0070] Figures 32 to 36 depict numerical simulation results for compact ECPUMPs according to embodiments of the invention under parametric variation showing the ability to tune long stroke characteristics;

[0071] Figure 37 and 38 depict parametric space overlap between design parameters for compact ECPUMPs according to embodiments of the invention;

[0072] Figures 39A through 39C depict compact ECPUMP characteristics as a function of frequency according to embodiments of the invention;

[0073] Figure 39D depicts a Y-tube geometry employed in numerical analysis presented in respect of Figures 37 to 39C respectively;

[0074] Figure 39E depicts simulations with respect to generating a current drive profile to provide desired stroke characteristics within the design space for an ECPUMP according to an embodiment of the invention;

[0075] Figures 40 and 41 depict isocontour plots of performance characteristics of a compact ECPUMP system as a function of combining Y-tube design parameters;

[0076] Figures 42 to 44 depict design variations for pump pistons within compact ECPUMPs according to embodiments of the invention;

[0077] Figures 45 and 46 depict piston lubrication pressure profiles in respect of optimizing piston surface profile for reduced friction;

[0078] Figure 47 depicts an exemplary electrical drive circuit for an ECPUMP according to an embodiment of the invention; and

[0079] Figure 48 depicts exemplary current drive performance of the electrical drive circuit of Figure 47.

DETAILED DESCRIPTION

[0080] The present invention is directed to devices for sexual pleasure and more particularly to devices exploiting fluidic control with vibratory and non-vibratory function_and movement.

[0081] The ensuing description provides representative embodiment(s) only, and is not intended to limit the scope, applicability or configuration of the disclosure. Rather, the ensuing description of the embodiment(s) will provide those skilled in the art with an enabling description for implementing an embodiment or embodiments of the invention. It being understood that various changes can be made in the function and arrangement of elements without departing from the spirit and scope as set forth in the appended claims. Accordingly, an embodiment is an example or implementation of the inventions and not the sole implementation. Various appearances of "one embodiment," "an embodiment" or "some embodiments" do not necessarily all refer to the same embodiments. Although various features of the invention may be described in the context of a single embodiment, the features may also be provided separately or in any suitable combination. Conversely, although the invention may be described herein in the context of separate embodiments for clarity, the invention can also be implemented in a single embodiment or any combination of embodiments.

[0082] Reference in the specification to "one embodiment", "an embodiment", "some embodiments" or "other embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least one embodiment, but not necessarily all embodiments, of the inventions. The phraseology and terminology employed herein is not to be construed as limiting but is for descriptive purpose only. It is to be understood that where the claims or specification refer to "a" or "an" element,

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such reference is not to be construed as there being only one of that element. It is to be understood that where the specification states that a component feature, structure, or characteristic "may", "might", "can" or "could" be included, that particular component, feature, structure, or characteristic is not required to be included.

[0083] Reference to terms such as "left", "right", "top", "bottom", "front" and "back" are intended for use in respect to the orientation of the particular feature, structure, or element within the figures depicting embodiments of the invention. It would be evident that such directional terminology with respect to the actual use of a device has no specific meaning as the device can be employed in a multiplicity of orientations by the user or users.

[0084] Reference to terms "including", "comprising", "consisting" and grammatical variants thereof do not preclude the addition of one or more components, features, steps, integers or groups thereof and that the terms are not to be construed as specifying components, features, steps or integers. Likewise the phrase "consisting essentially of", and grammatical variants thereof, when used herein is not to be construed as excluding additional components, steps, features integers or groups thereof but rather that the additional features, integers, steps, components or groups thereof do not materially alter the basic and novel characteristics of the claimed composition, device or method. If the specification or claims refer to "an additional" element, that does not preclude there being more than one of the additional element.

[0085] A "personal electronic device" (PED) as used herein and throughout this disclosure, refers to a wireless device used for communications and/or information transfer that requires a battery or other independent form of energy for power. This includes devices such as, but not limited to, a cellular telephone, smartphone, personal digital assistant (PDA), portable computer, pager, portable multimedia player, remote control, portable gaming console, laptop computer, tablet computer, and an electronic reader.

[0086] A "fixed electronic device" (FED) as used herein and throughout this disclosure, refers to a device that requires interfacing to a wired form of energy for power. However, the device can access one or more networks using wired and/or wireless interfaces. This includes, but is not limited to, a television, computer, laptop computer, gaming console, kiosk, terminal, and interactive display.

[0087] A "server" as used herein, and throughout this disclosure, refers to a physical computer running one or more services as a host to users of other computers, PEDs, FEDs, etc. to serve the client needs of these other users. This includes, but is not limited to, a database server, file server, mail server, print server, web server, gaming server, or virtual environment server.

[0088] A "user" as used herein, and throughout this disclosure, refers to an individual engaging a device according to embodiments of the invention wherein the engagement is a result of their personal use of the device or having another individual using the device upon them.

[0089] A "vibrator" as used herein, and throughout this disclosure, refers to an electronic sexual pleasure device intended for use by an individual or user themselves or in conjunction with activities with another individual or user wherein the vibrator provides a vibratory mechanical function for stimulating nerves or triggering physical sensations.

[0090] A "dildo" as used herein, and throughout this disclosure, refers to a sexual pleasure device intended for use by an individual or user themselves or in conjunction with activities with another individual or user wherein the dildo provides non-vibratory mechanical function for stimulating nerves or triggering physical sensations.

[0091] A "sexual pleasure device" as used herein, and throughout this disclosure, refers to a sexual pleasure device intended for use by an individual or user themselves or in conjunction with activities with another individual or user which can provide one or more functions including, but not limited to, those of a dildo and a vibrator. The sexual pleasure device/toy can be designed to have these functions in combination with design features that are intended to be penetrative or non-penetrative and provide vibratory and non-vibratory mechanical functions. Such sexual pleasure devices can be designed for use with one or more regions of the male and female bodies including but not limited to, the clitoris, the clitoral area (which is the area surrounding and including the clitoris), vagina, rectum, nipples, breasts, penis, testicles, prostate, and "G-spot." In one example a "male sexual pleasure device" is a sexual pleasure device configured to receive a user's penis within a cavity or recess. In another example, a "female sexual pleasure device" is a sexual pleasure device having at least a portion configured to be inserted in a user's vagina or rectum. It should be understood that the user of a female sexual pleasure device can be a male or a female when it is used for insertion in a user's rectum.

[0092] An "ECPUMP" as used herein, and throughout this disclosure, refers to an electrically controlled pump.

[0093] A "profile" as used herein, and throughout this disclosure, refers to a computer and/or microprocessor readable data file comprising data relating to settings and/or limits of a sexual pleasure device. Such profiles may be established by a manufacturer of the sexual pleasure device or established by an individual through a user interface to the sexual pleasure device or a PED/FED in communication with the sexual pleasure device.

[0094] A "balloon" as used herein, and throughout this disclosure, refers to an element intended to adjust its physical geometry upon the injection of a fluid within it. Such balloons can be formed from a variety of elastic and non-elastic materials and be of varying non-inflated and inflated profiles, including for example spherical, elongated, wide, thin, etc. A balloon may also be used to transmit pressure or pressure fluctuations to the sexual pleasure device surface and user where there is an inappreciable, or very low, change in the volume of the balloon.

[0095] When considering users of the prior art sexual pleasure devices described above these present several limitations and drawbacks in terms of providing enhanced functionality, dynamic sexual pleasure device adaptability during use, and user specific configuration for example. For example, it would be desirable for a single sexual pleasure device to support variations in size during use both in length and radial diameter to simulate intercourse even with the sexual pleasure device held static by the user as well as adapting to the user of the sexual pleasure device or the individual upon whom the sexual pleasure device is being used.

[0096] It would be further beneficial for a sexual pleasure device to vary in form, i.e. shape, during its use. It would be yet further desirable for this variation to be integral to the traditional operation of the sexual pleasure device. It would be yet further desirable to provide variable sized and shaped features in an asymmetric fashion on the sexual pleasure device so that the sexual pleasure device provides a further level of sensation control. Such variable sized and shaped features, such as bumps, undulations, knobs, and ridges, may beneficially appear and disappear during use discretely or in conjunction with one or more other motions. In some instances, it may be desirable to provide a radial increase along selected portions of the length of the sexual pleasure device to accommodate specific predilections as well as curvature. In some sexual pleasure device embodiments it would be desirable to have a protrusion at the tip of a sexual pleasure device that extends and retracts while inside the body, providing an internal "tickling"/"stroking" effect, or for use against the clitoris for external "tickling"/"stroking" effect. It would further be desirable to omit radial increase (i.e., provide a constant and unchanging radius) along selected portions of the length of the shaft to accommodate specific predilections whilst the length of the sexual pleasure device changes. In some sexual pleasure device embodiments it would be desirable for the

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outer surface or "skin" of the sexual pleasure device to move within the plane of the skin so that one or more areas of the skin relative to the majority of the outer skin of the sexual pleasure device to provide a capability of friction to the user. Optionally, these regions may also move perpendicular to the plane of the skin surface at the same time. In addition to these various effects it would also be beneficial to separately vary characteristics such as frequency and amplitude over wide ranges as well as being able to control the pulse shape for variable acceleration of initial contact and subsequent physical action as well as being able to simulate/provide more natural physical sensations. For example, a predefined "impact" motion at low frequency may be modified for vibration at the end of the cycle.

[0097] It would be desirable for these dynamic variations to be controllable simultaneously and interchangeably while being transparent to the normal use of the sexual pleasure device, including the ability to insert, withdraw, rotate, and actuate the variable features either with one hand, without readjusting or re-orienting the hand, with two hands, or hands free. In some embodiments of the sexual pleasure device it would be desirable to provide two, perhaps more, independently controllable ranges of shape changes within the same sexual pleasure device, so that in one configuration a first range of overall shapes, vibrations, undulations, motions etc. is available and a second range is available in a second configuration. These configurations may be provided sequentially or in different sessions. Within another embodiment of the invention these configurations may be stored remotely and recalled either by an individual to an existing sexual pleasure device, a new sexual pleasure device, or another sexual pleasure device as part of an encounter with another individual who possesses another sexual pleasure device. Optionally, such profile storage and transfer may also provide for a remote user to control a sexual pleasure device of an individual.

[0098] Accordingly, the desirable multiple ranges of motion of the sexual pleasure device both in terms of overall configuration and dimensions as well as localized variations and movement may be implemented using fluidics wherein a fluid is employed such that controlling the pressure of the fluid results in the movement of an element within the sexual pleasure device or the expansion/contraction of an element within the sexual pleasure device. Embodiments of the invention allow for large amplitude variations of the toy as well as providing operation over a ranges of frequencies from near-DC to frequencies of hundreds of Hertz. Further embodiments of the invention provide for efficient continuous flow/pressure as well as more power hungry pulsed actuations. Further embodiments of the invention provide for designs with no seals or sealing rings on the piston.

[0099] Examples of fluidic actuator systems and sexual pleasure devices exploiting compact, low power fluidic pumps, valves, switches etc. according to embodiments of the invention are described within a co-filed U.S., European and Patent Cooperation Treaty Patent Applications filed September 26, 2013 titled "Methods and Devices for Fluid Driven Adult Devices" which also claim priority from of U.S. Provisional Patent Application 61/705,809 filed on September 26, 2012 entitled "Methods and Devices for Fluid Driven Adult Devices", the entire contents of which are included herein by reference to them.

[00100] FLUIDIC ACTUATOR CONFIGURATIONS

[00101] Now referring to Figure 1 there are depicted parallel and serial element actuation schematics 100A and 100B, respectively, exploiting fluidic elements in conjunction with fluidic pump, reservoir and valves according to embodiments of the invention. Within parallel actuation schematic 100A first to third fluidic actuators 130A through 130C are depicted coupled to first pump 120A on one side via first to third inlet valves 140A through 140C, respectively, and to second pump 120B on the other side via first to third outlet valves 150A through 150C, respectively. First and second pumps 120A and 120B being coupled on their other end to reservoir 110 such that, for example, first pump 120A pumps fluid towards first to third fluidic actuators 130A through 130C respectively and second pump 120B pumps fluid away from them to the reservoir. Accordingly, each of first to third fluidic actuators 130A through 130C, respectively, can be pumped with fluid by opening their respective inlet valve, thereby increasing internal pressure and triggering the motion according to their design. Each of first to third fluidic actuators 130A through 130C, respectively, can be held at increased pressure until their respective outlet valve is opened and second pump 120B removes fluid from the actuator. Accordingly, first to third fluidic actuators 130A through 130C can be individually controlled in pressure profile through the valves and pumps.

[00102] In contrast serial actuation schematic 100B first to third fluidic actuators 180A through 180C are depicted coupled to first pump 170A on one side and to second pump 170B on the other side. First and second pumps 170A and 170B being coupled on their other end to reservoir 160 such that, for example, first pump 170A pumps fluid towards first to third fluidic actuators 180A through 180C, respectively, and second pump 170B pumps fluid away from them to the reservoir. However, in serial actuation schematic 100B first pump 170A is connected only to first reservoir 180A wherein operation of first pump 170A will increase pressure within first reservoir 180A if first valve 190A is closed, second reservoir 180B if first valve 190A is open and second valve 190B closed, or third reservoir 180C if first and

second valves 190A and 190B, respectively, are open and third valve 190C closed. Accordingly, by control of first to third valves 190A through 190C, respectively, the first to third fluidic actuators 180A through 180C, respectively, can be pressurized although some sequences of actuator pressurization and intermediate pressurization available in the parallel actuation schematic 100A are not available although these limitations are counter-balanced by reduced complexity in that fewer valves are required. It would be apparent to one skilled in the art that parallel and serial element actuation schematics 100A and 100B respectively exploiting fluidic elements in conjunction with fluidic pump, reservoir and valves according to embodiments of the invention can be employed together within the same sexual pleasure device either through the use of multiple pump or single pump configurations. In a single pump configuration an additional valve prior to first actuator 180A can be provided to isolate the actuator from the pump when the pump is driving other fluidic actuated elements.

[00103] Now referring to Figure 2 there are depicted first and second serially activated schematics 200A through 200B respectively wherein secondary fluidic pumps and fluidic elements are employed in conjunction with first and second primary fluidic pumps 220A and 220B, reservoir 210 and valves according to embodiments of the invention. In first serially activated schematic 200A first to third fluidic actuators 240A through 240C are disposed in similar configuration as serial actuation schematic 100B in Figure 1. However, a secondary fluidic pump 230 is disposed between the first primary fluidic pump 220A and first fluidic actuator 240A. Accordingly, the secondary fluidic pump 230 can provide additional fluidic motion above and beyond that provided through the pressurization of fluidic actuators by first primary fluidic pump 220A. Such additional fluidic motion can be, for example, the application of a periodic pulse to a linear or sinusoidal pressurization wherein the periodic pulse can be at a higher frequency than the pressurization. For example, the first primary fluidic pump 220A can be programmed to drive sequentially first to third fluidic actuators 240A through 240C to extend the sexual pleasure device length over a period of 1 second before the second primary pump 220B sequentially withdraws fluid over a similar period of 1 second such that the sexual pleasure device has a linear expansion frequency of 0.5Hz. However, the secondary fluidic pump 230 provides a continuous 10Hz sinusoidal pressure atop this overall ramp and reduction thereby acting as a vibration overlap to a piston motion of the sexual pleasure device. According to embodiments of the invention the primary pump can provide operation to a few Hz or tens of Hz, whereas secondary pump can provide operation from similar ranges as primary pump to hundreds of Hz and tens of kHz.

[00104] Second serially activated schematic 200B depicts a variant wherein first and second secondary fluidic pumps 230 and 250 are employed within the fluidic circuit before the first and third fluidic actuators 240A and 240C, respectively such that each of the first and second secondary fluidic pumps 230 and 250 can apply different overlay pressure signals to the overall pressurization of the sexual pleasure device from first primary pump 220A. Accordingly, using the example *supra,* first fluidic pump 230 can apply a 10Hz oscillatory signal to the overall 0.5Hz expansion of the sexual pleasure device but when third fluidic actuator 240C is engaged with the opening of the valve between it and second fluidic actuator 240B the second fluidic pump 250 applies a 2Hz spike to the third fluidic actuator 240C wherein the user senses a "kick" or "sharp push" in addition to the linear expansion and vibration. Second fluidic pump 250 can be activated only when the valve between the second and third fluidic actuators 240B and 240C is open and fluid is being pumped by the first primary pump 220A.

[00105] Also depicted in Figure 2 is parallel activated schematic 200C wherein a circuit similar that of parallel actuation schematic 100A in Figure 1 is shown. However, now a first fluidic pump 230 is disposed prior to the fluidic flow separating to first and second fluidic actuators 240A and 240B respectively and a second fluidic pump 250 is coupled to the third fluidic actuator 240C. Accordingly, using the same example as that of second serially activated schematic 200B *supra* first primary pump 220A provides an overall 0.5Hz pressure increase which drives first and second fluidic actuators 240A and 240B when their valves are opened as well as third fluidic actuator 240C. First fluidic pump 230 provides a 10Hz oscillatory signal to the first and second fluidic actuators 240A and 240B whilst second fluidic pump 5Hz oscillatory signal to third fluidic actuator 240C. As will be evident from discussion of some embodiments of sexual pleasure devices below in respect of Figures 3 through 19 first and second fluidic actuators 240A and 240B can be associated with a penetrative element of the sexual pleasure device whilst the third fluidic actuator 240C is associated with a clitoral stimulator element of the sexual pleasure device. Optionally, first and second fluidic pumps, or one of first and second fluidic pumps, are combined serially in order to provide higher pressure within the fluidic system or they are combined serially such that they provide different fluidic pulse profiles that either can provide individually.

[00106] <u>SEXUAL PLEASURE DEVICES</u>

[00107] Now referring to Figure 3 there is depicted a sexual pleasure device 300 according to an embodiment of the invention exploiting fluidic elements to adjust aspects of the sexual

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pleasure device 300 during use. As depicted in Figure 3, sexual pleasure device 300 comprises extension 320 within which are disposed first to third fluidic actuators 310A through 310C that are coupled to first to third valves 390A through 390C, respectively. As depicted one side of each of first to third valves 390A through 390C respectively are coupled via pump module 370 via second capacitor 395B and on the other side to pump module 370 via first capacitor 395A. Also forming part of the sexual pleasure device is fluidic suction element 380 which is coupled to the pump module 370 via third and fourth capacitors 395C and 395D and fourth valve 390D. First to fourth valves 390A through 390D, respectively, and pump module 370 are coupled to electronic controller 360 that provides the necessary control signals to these elements to sequence the fluidic pumping of the first to third fluidic actuators 310A through 310C and fluidic suction element 380 either in response to a program selected by the user installed within the electronic controller 360 at purchase, a program downloaded by the user to the sexual pleasure device, or a program established by the user.

[00108] Also coupled to the electronic controller 360 are re-chargeable battery 350, charger socket 330, and control selector 340 which provides control inputs to the electronic controller 360. Control selector 340 can for example include at least one of a control knob, a push-button selector, LEDs for setting information to the user, electronic connector for connection to remote electronic sexual pleasure device for program transfer to/from the sexual pleasure device 300 and a wireless interface circuit, such as one operating according to the Bluetooth protocol for example. As depicted, sexual pleasure device 300, therefore, can provide a penetrative vibrator via extension 320 and clitoral stimulator via fluidic suction element 380. Accordingly, first to third fluidic actuators 310A through 310C can for example comprise one or more fluidic actuators such as described above in respect of Figures 1 through 11 as well as a simple radial variant element wherein the pressure expands an element of the sexual pleasure device directly in a radial direction. In other embodiments of the invention a plurality of linear fluidic actuators such as first to third fluidic actuators 310A through 310C can be arranged radially and operated simultaneously, sequentially in order, sequentially in random order, non-sequentially in predetermined order, at fixed rate and/or variable rate.

[00109] Now referring to Figure 4 there is depicted a sexual pleasure device 400 according to an embodiment of the invention exploiting fluidic elements to adjust aspects of primary and secondary elements 460 and 450 respectively of the sexual pleasure device 400 during use. Primary element 460 comprises an expansion element whilst secondary element 450 comprises a flexure element. Each of the primary and secondary elements 460 and 450 are coupled to pump module 440, which is controlled via electronic controller 420 that is interfaced to wireless module 430 and battery 410. Accordingly, sexual pleasure device 400 represents a sexual pleasure device comprising a penetrative element, primary element 460, and vibratory clitoral stimulator element, secondary element 450. Optionally, as described above a second pump can be provided within the pump module 440 or discretely to provide a vibratory function within the penetrative element, primary element 460, as well as the expansion/contraction. Optionally, another pump can be provided within the pump module 440 or discretely to provide a vibratory function in combination with the flexural motion of the secondary element 450.

[00110] Now referring to Figure 5 there are depicted first to third sexual pleasure devices 500A through 500C according to embodiments of the invention exploiting fluidic elements to provide suction and vibration sensations and mimicking an "egg" type vibrator of the prior art. Within each of first to third sexual pleasure devices 500A through 500C there are battery 520, controller 510, pump 530 and reservoir 540. However, in each of first to third sexual pleasure devices 500A through 500C the active element is respectively a suction element 550, a pressure element 1760, and a friction element 1770. Optionally, the pump 530 comprises primary and secondary fluidic pump elements to provide low frequency and high frequency motion to the body part to which the first to third sexual pleasure devices 500A through 500C are engaged upon.

[00111] However, as evident from the subsequent descriptions of ECPUMPs according to embodiments of the invention, in fact, the first and second pumps can be the same ECPUMP with appropriate electrical control signals applied to it. Optionally, a single pump controller can be employed to control both ends of a double-ended sexual pleasure device or dual controllers can be provided. Optionally, a single reservoir can be employed for all pumps whilst in other embodiments fluid from one end of the double-ended sexual pleasure device can be provided to the other sexual pleasure device but some features may not be available simultaneously or may be provided out of phase.

[00112] Within the description *supra* in Figures 1 to 5 in respect of sexual pleasure devices exploiting fluidic actuators discreetly or in combination with other mechanisms, e.g., off-axis weight based vibrators, conventional motors, etc. A variety of other sexual pleasure devices can be implemented without departing from the scope of the invention by combining functions described above in other combinations or exploiting other fluidic actuators. Further, even a specific sexual pleasure device can be designed in multiple variants according to a variety of factors including, but not limited, the intended market demographic and user preferences. For example, a sexual pleasure device initially designed for anal use can be varied according to such demographics, such that, for example, it can be configured for:

- heterosexual and homosexual male users for prostate interactions;
- heterosexual and homosexual female users to be worn during vaginal sex;
- heterosexual and homosexual users to be worn during non-vaginal sex with fixed outside dimensions;
- heterosexual and homosexual users to be worn during non-vaginal sex with expanding outside dimensions.

[00113] Whilst embodiments of the invention are described *supra* in respect of sexual pleasure device/device functions and designs it would be evident that other combination sexual pleasure devices can be provided using these elements and others exploiting the underlying fluidic actuation principles as well as other mechanical functionalities. For example, such combination sexual pleasure devices may include, but not limited to, (vaginal/clitoral), (anal/vaginal), (anal/vaginal/clitoral), (anal/clitoral), (anal/testicle), and (anal/penile). Such combinations can be provided as single user sexual pleasure devices or dual user sexual pleasure devices. It would also be evident that dual user sexual pleasure devices can be male-male, male-female, and female-female with different combinations for each user. Also as discussed below in respect of Figure 20 multiple discrete sexual pleasure devices can be "virtually" combined through a remote controller such that a user can, for example, be presented with different functionality/options when using a sexual pleasure device depending upon the association of the sexual pleasure device with the remote controller and the other sexual pleasure devices or functionality/options can be identical but operation of the sexual pleasure devices are synchronous to each other, plesiochronous, or asynchronous. It would also be evident that male masturbators exploiting actuators can be established for penile stimulation in contrast to prior art manual solutions.

[00114] Within the embodiments of the invention described supra the focus has been to closed loop fluidic systems, sexual pleasure devices and actuators. However, it would be evident that the ability to adjust dimensions of a sexual pleasure device may provide structures with fluidic actuators which suck / compress other chambers or portions of the sexual pleasure device such that a second fluid is manipulated. For example, a small fluidic actuator assembly may allow a chamber on the external surface of the sexual pleasure device to expand / collapse such that, for example, this chamber with a small external opening may provide the sensation of blowing air onto the user's skin. Alternatively, the chamber may provide for the ability for the sexual pleasure device to act upon a second fluid such as water, a lubricant, and a cream for example which is stored within a second reservoir or in the case of water is a fluid surrounding the sexual pleasure device in use within a bath tub for example. Accordingly, the sexual pleasure device may "inhale" water and through the fluidic actuators pumps it up to a higher pressure with or without nozzles to focus the water jet(s). Alternatively, the sexual pleasure device may suck in / blow out from the same end of the toy via non-return valves. In others, the sexual pleasure device may pump lubricant to the surface of the sexual pleasure device or simulate the sensations of ejaculation to a user such that the sexual pleasure device in addition to physically mimic a human action extends this to other sensations.

[00115] Now referring to Figure 6 there is depicted an embodiment of the invention relating to the inclusion of fluidic actuated sexual pleasure devices within clothing scenario 600. Accordingly, as depicted in clothing scenario 600 a user is wearing a corset 605 wherein first to third regions 610 through 630 respectively have been fitted with sexual pleasure devices according to embodiments of the invention exploiting fluidic actuators such as described above and fluidic circuit elements such as described below. As depicted first and second regions 610 and 620, respectively, can be provided with fluidic actuator based suction elements, for example, to provide stimulation to the nipple and areolae of the user and third region 630 can be provided, for example, with a fluidic actuator based pressure element for clitoral stimulation. Based upon the design of the clothing the fluidic system can be distributed over a portion of the clothing such that the overall volume of the sexual pleasure device is not as evident to a third party either for discrete use by the user or such that the visual aesthetics of the clothing are significantly impacted. For example, a fluid reservoir can hold a reasonable volume but be thin and distributed over an area of the item or items of clothing. It would also be evident that combined functions can be provided for each of first to third regions 610 to 630 respectively. For example, first and second regions 610 and 620, respectively, can be a rubbing motion combined with a sucking effect whilst third region 630 can be a sucking, vibration, or friction combination.

[00116] As depicted the clothing, such as depicted by corset 605, can comprise first and second assemblies 600C and 600D, which are in communication with a remote electronic sexual pleasure device 680. As depicted first assembly 600C comprising first and second fluidic actuators 640A and 640B which are coupled to first fluidic assembly 650, such that for example first and second fluidic actuators 640A and 640B are disposed at first and second locations 610 and 620 respectively. Second assembly 600D comprises third fluidic actuator 660 coupled to second fluidic assembly 670 such that third fluidic actuator 660 is associated with third region 630. Alternatively, the first to third fluidic actuators 640A, 640B and 660 respectively can be contained within a single assembly, second assembly 600E, together with a third fluidic assembly 690 which is similarly connected to remote electronic sexual pleasure device 680.

[00117] It would be evident that additional fluidic actuators can be associated with each assembly and item of clothing according to the particular design and functions required. Optionally, remote electronic sexual pleasure device 680 can be, for example, a PED of the user so that adjustments and control of the fluidic driven sexual pleasure devices within their clothing, additional to such clothing, or deployed individually can be performed discretely with their cellphone, PDA, etc. Alternative embodiments of the invention can exploit wired interfaces to controllers rather than wireless interfaces.

[00118] It would be evident to one skilled in the art that the sexual pleasure devices as described above in respect of Figures 1 through 5 can employ solely fluidic actuators to provide the desired characteristics for that particular sexual pleasure device or they can employ mechanical elements including, but not limited to, such as motors with off-axis weights, drive screws, crank shafts, levers, pulleys, cables etc. as well as piezoelectric elements etc. Some can employ additional electrical elements such as to support electrostimulation. For example, a fluidic actuator can be used in conjunction with a pulley assembly to provide motion of a cable which is attached at the other end to the sexual pleasure device such that retraction of the cable deforms the sexual pleasure device to provide variable curvature for example or simulate a finger motion such as exciting the female "G-spot" or male prostate. Most mechanical systems must convert high-speed rotation to low-speed linear motion through eccentric gears and gearboxes whilst fluidic actuators by default provide linear motion in 1, 2, or 3-axes according to the design of the actuator. Other embodiments of the invention may provide for user reconfiguration and/or adjustment. For example, a sexual pleasure device may comprise a base unit comprising pump, batteries, controller etc. and an active unit containing the fluidic actuators alone or in combination with other mechanical and non-mechanical elements. Accordingly, the active unit may be designed to slide relative to the active unit and be fixed at one or more predetermined offsets from an initial reduced state such that for example a user may adjust the length of the toy over, for example, 0, 1, and 2 inches whilst fluidic length adjustments are perhaps an inch maximum so that in combination the same sexual pleasure device provides length variations over 3 inches for example. It would also be evident that in other embodiments of the invention the core of the sexual pleasure device, e.g. a plug, may be manually pumped or expanded mechanically to different widths with subsequent fluidic diameter adjustments. Other variations would be evident combining fluidic actuated sexual pleasure devices with mechanical elements to provide wider variations to accommodate user physiology for example.

[00119] PERSONALIZED CONTROL OF FLUIDIC ACTUATORS

[00120] Referring to Figure 7A there is depicted a flow diagram 700 for a process flow relating to setting a sexual pleasure device exploiting fluidic elements according to embodiments of the invention according to the preference of a user of the sexual pleasure device. As depicted the process begins at step 705 wherein the process starts and proceeds to step 710 wherein the user triggers set-up of the sexual pleasure device. Next in step 715 the user selects the function to be set wherein the process proceeds to step 720 and the sexual pleasure device controller sets the sexual pleasure device to the first setting for that function. Next in step 725 the sexual pleasure device checks for whether the user enters a stop command wherein if not the process proceeds to step 730, increments the function setting, and returns to step 725 for a repeat determination. If the user has entered a stop command the process proceeds to step 735 wherein the setting for that function is stored into memory. Next in step 740 the process determines whether the last function for the sexual pleasure device has been set-up wherein if not the process returns to step 715 otherwise it proceeds to step 745 and stops.

[00121] Accordingly, the process summarized in flow diagram 700 allows a user to adjust the settings of a sexual pleasure device to their individual preferences. For example, such settings can include, but are not be limited to, the maximum radial expansion of the sexual pleasure device, the maximum linear expansion of the sexual pleasure device, frequency of vibration, amplitude of pressure elements, and frequency of expansion. Now referring to Figure 7B there is depicted a flow diagram 7000 for a process flow relating to setting a sexual pleasure device exploiting fluidic elements with multiple functions according to embodiments of the invention according to the preference of a user of the sexual pleasure device. As depicted, the process begins at step 7005 and proceeds to step 7010 wherein the set-up of the first element of the sexual pleasure device, e.g. the penetrative element as described above in respect of primary element 460 of sexual pleasure device 400. Next the process proceeds to step 700A which comprises steps 1615 through 1640 as depicted *supra* in respect of Figure 7A. Upon completion of the first element the process determines in step 7020 whether the last element of the sexual pleasure device has been set-up. If not the process loops back to execute step 700A again for the next element of the sexual pleasure device otherwise the process proceeds to step 7030 and stops.

[00122] For example, considering sexual pleasure device 400 the process might loop back round based upon the user setting performance of the secondary element 450 of sexual pleasure device 400. In other instances, the user can elect to set-up only one of the elements of the sexual pleasure device, some elements or all elements of the sexual pleasure device. Optionally, the user can elect to set only some settings for one sexual pleasure device, and none or all for another sexual pleasure device. It would be evident to one skilled in the art that wherein process flow 7000 is employed with a double-ended sexual pleasure device, that the user making the setting determinations can change once one end of the sexual pleasure device has been set.

[00123] Now referring to Figure 8 there is depicted a flow diagram 800 for a process flow relating to establishing a personalization setting for a sexual pleasure device 805 exploiting fluidic elements according to embodiments of the invention and its subsequent storage/retrieval from a remote location, for example, from a PED 820. The flow diagram 800 begins at step 825 and proceeds to step 700A, which comprises steps 710, 600A, and 720 as described *supra* in respect of process flow 700, wherein the user establishes their preferences for the sexual pleasure device. Upon completion of step 700A the process proceeds to step 830 and transmits the preferences of the user to a remote electronic device, such as a PED, and proceeds to step 835 wherein the user can recall personalization settings on the remote electronic device and select one in step 840. The selected setting is then transferred to the sexual pleasure device in step 845 wherein the process then proceeds to offer the user the option in step 855 to change the setting(s) selected. Based upon the determination in step 855 the process either proceeds to step 875 and stops wherein the setting previously selected is now used by the user or proceeds to step 860 wherein the user is prompted with options on how to adjust the settings of the sexual pleasure device. These being for example changing settings on the sexual pleasure device or the remote wherein the process proceeds to steps 865 and 870 respectively on these determinations and proceeds back to step 835.

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[00124] Accordingly, as depicted in Figure 8 a sexual pleasure device 805 can comprise a wireless interface 810, e.g., Bluetooth, allowing the sexual pleasure device to communicate with a remote electronic device, such as PED 820 of the user. The remote electronic device 820 stores settings of the user or users, for example, three are depicted in Figure 8 entitled "Natasha 1", "Natasha 2", and "John 1." For example "Natasha 1" and "Natasha 2" can differ in speed of penetrative extension motion, radial extension, and length of extension and represent different settings for the user "Natasha", such as, for example solo use and couple use respectively or different moods of solo use.

[00125] In addition to these variations user programming can provide the ability to vary characteristics such as frequency and amplitude over wide ranges as well as being able to control the pulse shape for variable acceleration of initial contact and add other motions to better simulate/provide more natural physical sensations or provide increased sensations. For example, a user can be able to vary pulse width, repetition frequency, and amplitude for a predefined "impact" motion and then modify this to provide vibration over all or a portion of the "impact motion" as well as between "impact" pulses.

[00126] Referring to Figure 9 there is depicted a flow diagram 900 for a process flow relating to establishing a personalization setting for a sexual pleasure device exploiting fluidic elements according to embodiments of the invention and its subsequent storage/retrieval from a remote location to the user's sexual pleasure device or another sexual pleasure device. Accordingly, the process begins at step 910 and proceeds to step 700A, which comprises steps 710, 600A, and 720 as described *supra* in respect of process flow 700, wherein the user establishes their preferences for the sexual pleasure device. Upon completion of step 700A the process proceeds to step 915 and transmits the preferences of the user to a remote electronic device and proceeds to step 920 wherein the user selects whether or not to store the sexual pleasure device settings on a remote web service. A positive selection results in the process proceeding to step 925 and storing the user preferences (settings) on the remote web service before proceeding to step 930 otherwise the process proceeds directly to step 930.

[00127] In step 930 the process is notified as to whether all fluidic sub-assemblies of the device have been set-up. If not, the process proceeds to step 700A, otherwise it proceeds to one of steps 935 through 950 based upon the selection of the user with regard to whether or not to store the user's preferences on the web service. These steps being:

- step 935 – retrieve remote profile for transmission to user's remote electronic device;

- step 940 – retrieve remote profile for transmission to another user's remote electronic device;
- step 945 – allow access for another user to adjust user's remote profile;
- step 950 – user adds purchased device setting profile to user's remote profiles; and
- step 970 – user purchases multimedia content with an associated user profile for a sexual pleasure device or sexual pleasure devices.

[00128] Next in step 955 wherein a process step was selected requiring transmission of the user preferences to a remote electronic device and thence to the sexual pleasure device this is executed at this point prior to the settings of the sexual pleasure device being updated on the sexual pleasure device associated with the selected remote electronic device in step 960 and the process proceeds to step 965 and stops. Accordingly, in step 935 a user can retrieve their own profile and select this for use on their sexual pleasure device, or a new sexual pleasure device they have purchased, whereas in step 940 the user can associate the profile to another user's remote electronic device wherein it is subsequently downloaded to that remote electronic device and transferred to the device associated with that remote electronic device. Hence, a user can load a profile they have established and send it to a friend to use or a partner for loading to their sexual pleasure device either discretely or in combination with another profile associated with the partner. Accordingly a user can load their profile to one end of a double-end sexual pleasure device associated with another user as part of an activity with that other user or to a sexual pleasure device. Alternatively, in step 945 the process allows for another user to control the profile allowing, for example, a remote user to control the sexual pleasure device through updated profiles whilst watching the user of the sexual pleasure device on a webcam whilst in step 950 the process provides for a user to purchase a new profile from a sexual pleasure device manufacturer, a third party, or a friend/another user for their own use. An extension of step 950 is wherein the process proceeds via step 970 and the user purchases an item of multimedia content, such as for example an audio book, song, or video, which has associated with it a profile for a sexual pleasure device according to an embodiment of the invention such that as the user plays the item of multimedia content the profile is provided via a remote electronic device, e.g. the user's PED or Bluetooth enabled TV, to their sexual pleasure device and the profile executed in dependence of the replaying of the multimedia content and the profile set by the provider of the multimedia content. Optionally, the multimedia content can have multiple profiles or multiple modules to the profile such that the single item of multimedia content can be used with a variety of sexual pleasure devices with different functionalities and/or elements.

[00129] Within the process flows described above in respect of Figures 6 through 9 the user can be presented with different actuations patterns relating to different control parameters which can be provided in respect of a single fluidic actuator or multiple fluidic actuators. For example the user can be provided with varying frequency, varying pressure (relating to drive signal amplitude/power), varying pulse profiles, and slew rates. Within the embodiments of the invention described with respect of Figures 8 and 9 the sexual pleasure device communicates with a remote electronic device which can for example be the user's PED. Optionally, the sexual pleasure device can receive data other than a profile to use as part of the user experience including for example music or other audiovisual/multimedia data such that the electronic controller within the sexual pleasure device reproduces the audio portion directly or adjusts aspects of the sexual pleasure device in dependence upon the data received. An ECPUMP can be viewed as acting as a low-mid frequency actuator which can act in combination with a higher frequency actuator or by appropriate ECPUMP and electrical control provide full band coverage. Optionally, where multimedia content is coupled to the sexual pleasure device rather than the sexual pleasure device operating directly in response to the multimedia content the controller can apply the multimedia content raw or processed whilst maintaining the sexual pleasure device's operation within the user set preferences. Similarly, where multimedia content contains a profile which is provided to the sexual pleasure device and executed synchronously to the multimedia content then this profile can define actions which are then established as control profiles by the controller within the user set preferences. For example, an item of multimedia content relating to a woman being sexually stimulated can provide actions that mimic the multimedia content action for some sexual pleasure devices and provide alternate actions for other sexual pleasure devices but these are each synchronous or plesiochronous to the multimedia content.

[00130] Optionally, the user can elect to execute a personalization process, such as that depicted in Figure 8 with respect to process flow 800, upon initial purchase and use of a sexual pleasure device or subsequently upon another use of the sexual pleasure device. However, it would also be evident that the user can perform part or all of the personalization process whilst they are using the sexual pleasure device. For example, a user can be using a rabbit type sexual pleasure device and whilst in use characteristics such as maximum length extension and maximum radial extension of the sexual pleasure device can be limited to

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different values than previously whilst the inserted body and clitoral stimulator are vibrating. Due to the nature of the sensations felt by a user from such sexual pleasure devices it would also be evident that some personalization profile generating process flows can sub-divide the sexual pleasure device such that a sub-set of parameters can be set and adjusted in conjunction with one another prior to adjustment of other aspects. For example, length/diameter variations can be generally linked due to user physiology whilst vibrator amplitude and frequency, for example, can be varied over a wide range for a constant physical sexual pleasure device geometry.

[00131] FLUIDIC ASSEMBLY

[00132] The sexual pleasure devices described herein comprise a fluidic assembly that controls the expansion/reduction of the fluidic chamber(s) within the sexual pleasure devices. The fluidic assembly comprises a combination of fluidic channels, pumps and valves, together with the appropriate control systems. Examples of particular fluidic assemblies are described in detail below, however, it should be understood that alternative assemblies can be incorporated in the present sexual pleasure devices.

[00133] Within the sexual pleasure device embodiments of the invention described *supra* and the fluidic schematics of Figures 1 and 2 fluidic control system incorporating pumps and valves with interconnecting fluidic couplings have been described for providing pressure to a variety of fluidically controlled elements such as described above in respect of Figures 1 through 5. In Figure 3 each of the first to third fluidic actuators 310A through 310C are coupled to the pump module 370 via dual fluidic channels that meet at the associated one of the first to third valves 390A through 390C rather than the configurations depicted in Figures 1 and 2. Referring to Figure 10 this inflation/deflation of an element under fluidic control according to an embodiment of the invention with a single valve is depicted in first and second states 1000A and 1000B respectively. As depicted, a fluidic pump 1010 is coupled to outlet and inlet reservoirs 1040 and 1050 respectively via outlet and inlet fluidic capacitors 1020 and 1030 respectively. Second ports on the outlet and inlet reservoirs 1040 and 1050 respectively are coupled via non-return valves to valve, which is depicted in first and second configurations 1050A and 1050B in first and second stated 1000A and 1000B respectively. In first configuration 1050A the valve couples the outlet of the pump via outlet reservoir 1040 to the fluidic actuator in inflate mode 1060A to increase pressure within the fluidic actuator. In second configuration 1050B the valve couples to the inlet of the pump via inlet reservoir 1050 from the fluidic actuator in deflate mode 1060B to decrease pressure within the fluidic actuator. Accordingly, the fluidic control circuit of Figure 10 provides an alternative control methodology to those described *supra* in respect of Figured 1 and 2. Optionally, the non-return valves can be omitted.

[00134] Now referring to Figure 11 there is depicted an electronically activated valve (EAV) 1100 for a fluidic system according to an embodiment of the invention such as described above in respect of Figure 10, but which can also form the basis of valves for deployment within the fluidic control schematics described *supra* in respect of Figures 1 and 2. Accordingly, as shown a fluidic channel 1120 has an inlet port 1190A and first outlet port 2950B which are disposed on one side of a chamber 1195. On the other side of chamber 1195 are two ports that merge to second output port 1190C. Disposed within chamber 1195 is a magnetic valve core that can move from a first position 1110A blocking inlet port 1190A and associated chamber outlet to second position 1110B blocking first outlet port 1190B and associated chamber outlet. Disposed at one end of the chamber 1195 is first coil 1130 and at the other end second coil 1160. Accordingly in operation the magnetic valve core can be moved from one end of the chamber 1195 to the other end through the selected activation of the first and second coils 1130 and 1160 respectively thereby selectively blocking one or other of the fluidic channel from inlet port 1190A to second outlet port 1190C or first outlet port 1190B to second outlet port 1190C such as depicted and described in respect of Figure 10 to provide selected inflation/deflation of the fluidic actuator through the injection/removal of fluid.

[00135] In operation with the magnetic pole orientation of the magnetic valve core depicted then to establish first position 1110A the North (N) pole is pulled left under operation of the first coil 1130 generating an effective South (S) pole towards the middle of the EAV 1100 and the S pole is pushed left under operation of the second coil 1160 generating an effective S pole towards the middle of the EAV 1100, i.e. the current within second coil 1160 is reversed relative to first coil 1130. Accordingly, to establish the second position 1110B the current within first coil 1130 is reversed relative to the preceding direction thereby generating an effective north pole towards the middle of the EAV 1100 generating a force pushing right and the S pole of the magnetic valve core is pulled right under operation of the second coil 1160 generating an effective N pole towards the middle of the EAV 1100. Optionally, according to the design of the control circuit and available power only one coil can be activated in each instance to generate the force moving the magnetic valve core. Further, it would be evident that in some embodiments of the invention only one electrical coil is provided.

[00136] Optionally, to make EAV 1100 latching and reduce power consumption on the basis that activation of the first or second coils 1130 and 1160 is only required to move the magnetic valve core between the first and second positions 1110Aand 1110B first and second magnets 1140 and 1170 can be disposed at either end of the chamber with pole orientations to provide attraction to the magnetic valve core when at the associated end of the chamber 1195. Each of the first and second magnets 1140 and 1170 providing sufficient force to hold the magnetic valve core at each end once moved there under electromagnetic control of the first and/or second coils 1130 and 1160 respectively. Optionally, which of the piston/washers are magnetic can be inverted in other embodiments of the invention.

[00137] Optionally, these first and second magnets 1140 and 1170 can be pieces formed from a soft magnetic material such that they are magnetized based upon the excitation of the first and second coils 1130 and 1160 respectively. Alternatively first and second magnets 1140 and 1170 can be soft magnetic materials such that they conduct magnetic flux when in contact with the magnetic valve core and are essentially non-magnetised when the magnetic valve core is in the other valve position. It would be evident that variants of the electronically activated valve 1100 can be configured without departing from the scope of the invention including but not limited, non-latching designs, latching designs, single inlet/single outlet designs, single inlet/multiple outlet, multiple inlet/single outlet, as well as variants to the design of the chamber and inlet/outlet fluidic channels and joining to the chamber. Optionally, under no electrical activation the magnetic valve core can be disposed between first and second positions 1110A and 1110B and have a length relative to the valve positions such that multiple ports are "off" such as both of first and second outlet ports 1190B and 1190C respectively in Figure 11.

[00138] Now referring to Figure 12 there is depicted an electronically controlled pump (ECPUMP) 1200 for a fluidic system according to an embodiment of the invention. ECPUMP 1200 is depicted in cross-section view and comprises an outer body 1260 which houses at a first radius away from the axis first and second coils 1280 and 1290 respectively to the left and right hand sides. At a second smaller radius from the axis are first and second permanent magnets 1240 and 1230 respectively which as depicted are poled radially away from axis of the ECPUMP 1200 so that the North (N) pole is disposed towards the first and second coils 1280 and 1290 respectively whilst the South (S) pole is disposed towards the central axis. Disposed within the centre of the ECPUMP 1200 is magnetic piston 1210. Accordingly, alternate activation of the first and second coils 1280 and 1290 results in the magnetic piston 1210 moving along the axis of the ECPUMP 1200. Activation of first coil 1280, with no activation of second coil 1290, results in generation of electromagnetic flux path 1280B, which acts in conjunction with permanent magnet flux path 1280A to pull the magnetic piston 1210 to the left. Subsequently, de-activation of the first coil 1280 and activation of the second coil results in a new electromagnetic flux path being generated from second coil 1290 to magnetic piston 1210, not shown for clarity, and removal of electromagnetic flux paths 1280A and 1280B thereby pulling the magnetic piston 1210 to the right. Accordingly, motion of the magnetic piston 1210 to the left draws fluid from second fluidic channel 1250 past fourth check valve 1270D and subsequent motion to the right pushes fluid past third check valve 1270C. At the same time motion of the magnetic piston 1210 to the left pushes fluid past third check valve 1270A into first fluidic channel 1220 and subsequent motion to the right draws fluid from the first fluidic channel 1220 past second check valve 1270B. Optionally, only a single fluidic channel is provided to the ECPUMP 1200.

[00139] Referring to Figure 13 there is depicted a cross-sectional view X-X of an electronically controlled pump (ECPUMP) 1300 for a fluidic system according to an embodiment of the invention wherein an outer body 1350 has disposed a fluidic assembly 1300A comprising a pair of inlets 1310 with one-way non-return inlet valves 1390 and a pair of outlets 1320 with one-way non-return outlet valves 1360. Each inlet 1310 and outlet 1320 also comprising a fluidic capacitor 1370. For simplicity only one fluidic assembly 1300A is depicted in Figure 13. Internally the outer body 1350 has disposed on the upper side of central body element 1380 within the outer body 1350 a fluidic connection between an inlet valve 1310 at one end of ECPUMP 1300 and outlet valve 1320 at the other end of ECUMP 1300 a first coil 1340A and first magnet 1330A. Disposed to the lower side of central body element 1380 within the outer body 1350 a fluidic connection between an inlet valve 1310 at one end of ECPUMP 1300 and outlet valve 1320 at the other end of ECUMP 1300 second coil 1340B and second magnet 1330B. Accordingly activation of the first and second coils 1330A and 1330B results in the generation of magnetic fields within the regions defined by the outer body 1350 and central body element 1380 which drive the first and second magnets 1340A and 1340B thereby causing them to draw/push fluid within the ECPUMP 1300. It would be evident to one skilled in the art that the one-way non-return inlet valves 1390 and

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one-way non-return outlet valves 1360 facilitate the pumping by removing the return of fluid pumped in one direction when the ECPUMP 1300 cycles in the opposite direction under electromagnetic induced force from activation of the first and second coils 1340A and 1340B. It would also be evident to one skilled in the art that whilst the one-way non-return inlet and outlet valves 1390 and 1360 respectively are depicted in the end-view as being circular that the internal cross-sectional structure of the chambers within the outer body can be of multiple designs including, but not limited to, circular, square, rectangular, arcuate, and polygonal wherein accordingly the magnets and coils are designed to suit. Generally first and second coils 1330A and 1330B are the same coil and/or first and second magnets 1340A and 1340B are the same magnet.

[00140] The fluid drawn by the ECPUMP 1300 and pumped in each cycle can be small compared to the volume of fluid within the fluidic system before and after the ECPUMP 1300. Accordingly, the inventor has found that providing flexible elements between the ECPUMP 1300 and the fluidic systems either end, such as depicted by first and second capacitive elements 1370A and 1370B and as described in respect of previous Figures, provide for sufficient dynamic volume adjustment in the fluid on the inlet and outlet sides to facilitate operation of the ECPUMP 1300 and other pump embodiments described within this specification and act essentially as a fluidic capacitor in terms of providing a reservoir of fluid that can be drained/topped up by the ECPUMP 1300, hence the inventors use of the name to these elements.

[00141] Referring to Figure 14 there is depicted an electronically controlled pump (ECPUMP) 1400 for a fluidic system according to an embodiment of the invention wherein an outer body 1450 has disposed at one end an inlet 1410 with one-way non-return inlet valve 1490 and an outlet 1420 with one-way non-return outlet valve 1460. Each of the inlet 1410 and outlet 1420 also comprising a fluidic capacitor 1430. Internally the outer body 1450 has disposed on its inner surface on the upper side a first magnet 1440A and on the lower side a second magnet 1440B. Centrally disposed within the outer body 1450 is central body element 1455. Disposed between the first magnet 1440A and central body element 1455 is first coil 1470A attached to plunger 1480 and similarly disposed between the second magnet 1440B and central body element 1455 is second coil 1470B similarly attached to plunger 1480. Accordingly activation of the first and second coils 1470A and 1470B results in the generation of magnetic fields within the regions defined by the outer body 1450 and central body element 1455 which in combination with the magnetic fields of the first and second magnets 1440A and 1440B result in the plunger 1480 moving thereby causing fluid to be drawn/pushed within the ECPUMP 1400. It would be evident to one skilled in the art that the one-way non-return inlet valve 1490 and one-way non-return outlet valve 1460 facilitate the pumping by removing the return of fluid pumped in one direction when the ECPUMP 1400 cycles in the opposite direction. Generally first and second magnetics 1440A and 1440B are a single radial magnet or a pair of semi-circular magnets assembled to form a radial design.

[00142] Not depicted within the schematic cross-section of ECPUMP 1400 is the fluidic link between the upper and lower chambers. It would also be evident to one skilled in the art that in a similar manner to ECPUMP 1300 the internal cross-sectional structure of the chambers within the outer body 1450 of ECPUMP 1400 can be of multiple designs including, but not limited to, circular, square, rectangular, arcuate, and polygonal wherein accordingly the magnets and coils are designed to suit. According to another embodiment of the invention the first and second coils 1470A and 1470B can be fixed through plunger 1480 such that the remainder of ECPUMP 1400 moves relative to the plunger. Generally first and second coils 1470A and 1470B are a single coil.

[00143] Now referring to Figure 15 there is depicted an electronically controlled pump (ECPUMP) 1500 for a fluidic system according to an embodiment of the invention. As depicted in the cross-sectional view a central body 1510 has disposed within it a coil 1530 and surrounds piston 1520 comprised of a magnetic material. Disposed at each end of central body 1510 is a magnet 1540 and outer body portion 1550. In this instance each magnet 1540 has its N and S poles aligned along the axis of the ECPUMP 1500 rather than having the N and S poles radially disposed in each ECPUMP described *supra* in respect of Figures 12 through 14 respectively. Accordingly, activation of the coil 1530 in combination with the magnetic field within the piston 1520 and each magnet 1540 results in movement of the piston 1520 within the ECPUMP 1500. Accordingly, ECPUMP 1500 when combined with additional fluidic elements, omitted for clarity but discussed *supra* in respect of Figures 12 through 14 respectively, including but not limited to inlet, outlet, non-return valves, and fluidic capacitors provides for a fluidic pump of low complexity, good efficiency, good performance, lower power requirements and improved manufacturability. One aspect affecting this is the orientation of the magnetic poles relative to the body of magnet 1540 which are now the orientated along the axis of the ECPUMP 1500 rather than radially. The stroke of piston 1520 is related to the thickness of the magnet 1540 and the thickness of the piton tooth.

[00144] Referring to Figure 16 there is depicted a cross-section of an electronically controlled pump (ECPUMP) 1600 for a fluidic system according to an embodiment of the invention. As depicted an outer body 1610 has disposed at each end first and second coils 1620A and 1620B respectively. Disposed within the outer body 1610 there is a pump body 1630 formed of a magnetic material, which is hollow and has disposed at either end non-return valves 1630. The pump body 1640 has its poles at either end along the axis of the ECPUMP 1600. Accordingly, in common with other embodiments of the invention activation of the first and second coils 1620A and 1620B in sequence results in movement of the pump body 1640 relative to the outer body 1610 and accordingly through the action of the non-return valves 1630 pumps fluid from left to right as depicted. ECPUMP 1600 when combined with additional fluidic elements, omitted for clarity but discussed *supra* in respect of Figures 12 through 14 respectively, including but not limited to inlet, outlet and fluidic capacitors provides for a fluidic pump of low complexity and improved manufacturability, particularly in respect of the orientation of the magnetic poles relative to the pump body 1640 formed from the magnetic material. As depicted ECPUMP 1600 has 2 non-return (check) valves 1630 within pump body 1640 and ECPUMP 1600 can be directly integrated into the fluidic system in-line. Additional non-return valves, not depicted for clarity, can be employed within the fluidic system either side of the ECPUMP 1600 to manage overall flow. Optionally, one of the non-return valve 1630 can be removed.

[00145] Now referring to Figure 17 there is depicted an electronically controlled pump (ECPUMP) 1700 for a fluidic system according to an embodiment of the invention. As depicted ECPUMP 1700 comprises first and second fluidic assemblies 1700A and 1700B respectively, which are essentially as described *supra* in respect of Figure 13 and fluidic assemblies 1300, at either end of pump body 1760 which houses within, at either end, first and second coils 1720 and 1730 and disposed axially piston magnet 1710 having its poles disposed axially along the axis of the outer body 1760. Accordingly, activation of the first and second coils 1720 and 1730 results in electromagnetic force being applied to the piston magnet 1710 in a direction determined by the coil activated. Optionally within the first and second fluidic assemblies 1700A and 1700B respectively there are disposed first and second magnets 1740 and 1750 respectively having their poles facing towards the piston magnet 1710 matching to provide repulsive force as the piston magnet 1710 is driven under actuation of first and second coils 1720 and 1730 respectively to the respective ends of the pump body 1760. Alternatively first and second magnets 1740 and 1750 can be orientated in the reverse pole orientations to those shown such that rather than repulsive force as the piston magnet 1710 is driven attractive force is provided. In these optional configurations different electrical activation profiles of the first and second coils 1720 and 1730 respectively. Optionally, these magnets can be pieces of formed from a soft magnetic material such that they are magnetized based upon the excitation of the first and second coils 1720 and 1730 respectively. First and second magnets 1740 and 1750 also result in an increased magnetic flux confinement improving efficiency of the ECPUMP 1700.

[00146] Figures 18 and 19 depict an electronically controlled pump assembly (ECPA) according to an embodiment of the invention exploiting full cycle fluidic action. Referring first to Figure 18 first to third views 1800A to 1800C the ECPA is depicted in assembled, partially exploded end view, and partially exploded side views respectively. As shown ECPA comprises upper clam shell 1810, with inlet port 1815, and lower clam shell 1830 with outlet port 1835 which mount either side of motor frame 1820 upon which electronically controlled fluidic pump assembly (ECFPA) 1840 is mounted. As evident from first to third perspective views 1900A to 1900C in Figure 19 ECFPA 1840 comprises first and second valve assemblies (VALVAS) 1860 and 1870 disposed at either end of electronically controlled magnetically actuated fluid pump (ECPUMP) 1850. Beneficially, the ECPA depicted in Figures 18 and 19 reduce the mass of water being driven by the pump close to a minimum amount as the outlet after the valve opens directly into the body of fluid within the ECPA.

[00147] Optionally, where upper clam shell 1810 and lower clam shell 1830 are implemented to provide elasticity under action of the ECPUMP then these act as fluidic capacitors as described within this specification. In other embodiments such fluidic actuators can have sufficient volume to act as the reservoir for the device rather than requiring the present of a separate reservoir. Alternatively, upper clam shell 1810 and lower clam shell 1830 are rigid such that no fluidic capacitor effect is present in which case these would vibrate at the pump frequency and the fluid leaving / entering the clam shell would be pulsating. Beneficially in both the flexible and stiff shell configurations the upper and lower clam shells 1810 and 1830 can provide directly vibratory excitation to the user. In fact, directly coupling the inlet port 1815 to outlet port 1835 provides a self-contained fluidically actuated device, i.e. a vibrator with flexible upper and lower clam shells 1810 and 1830 which is capable of providing users with vibrations at frequencies not attainable from prior art mechanical off-axis motors. Conversely, a rigid or stiff walled clam shell will not vibrate with much amplitude, but it will provide a pulsating water flow.

[00148] A VALVAS, such as VALVAS 1860 or 1870 in Figure 18 according to an embodiment of the invention provide inlet and outlet ports with non-return valves such as depicted in Figures 20A through 20C for assembly to ECPUMP 1850. Referring initially to Figure 20 an exploded view of the VALVAS 2000, such as providing the first and second VALVAS 1860 and 1870 in Figure 18 is depicted. This comprises inlet manifold 2000A, valve body 2000B, and outlet manifold 2000C. Valve body 2000B is also depicted in perspective view in Figure 20A as well as an end elevation 2010, bottom view 2020, and plan view 2030. Assembling to the valve body 2000B is inlet manifold 2000A as depicted in Figure 20B in perspective view as well as a side elevation 2040, front view 2050, and rear view 2060. Mounted to the inlet manifold 2000A, via first mounting 2090A, is a valve (not shown for clarity), such as half valve 2500E in Figure 25, which is disposed between inlet manifold 2000A and valve body 2000B. Accordingly, the motion of this valve is restrained in one direction by inlet manifold 2000A but unrestrained by valve body 2000B and accordingly fluid motion is towards the valve body 2000B. Also assembled to the valve body 2000B is outlet manifold 2000C as depicted in Figure 20C in perspective view as well as a side elevation 2070, bottom view 2080, and front elevation 2090. Mounted to the valve body 2000B via second mounting 2090B, is a valve (not shown for clarity), such as half valve 3900E in Figure 39, which is therefore disposed between outlet manifold 2000C and valve body 2000B. Accordingly, the motion of this valve is restrained in one direction by valve body 2000B but unrestrained by outlet manifold 2000C. Accordingly, fluid motion is away from valve body 2000B such that the overall combination of inlet manifold 2000A, valve body 2000B, outlet manifold 2000C and the two valves not shown function as inlet/outlet non-return valves coupled to a common port, this being the opening 2025 in the bottom of the valve body 2000B that is adjacent to the piston face.

[00149] Now referring to Figures 21 to 22B there are depicted different views of a compact ECPUMP 2110 according to an embodiment of the invention, which together with inlet and outlet VALVAS 2000 provides ECFPA 2110 with full cycle fluidic action when combined with appropriate external connections. Referring to Figures 21, 22A, and 22B the ECPUMP 2110 is shown schematically exploded inside perspective, exploded in perspective and shown in cross-sectional exploded form. ECPUMP 2110 comprises piston 2130, bobbin core 2140, bobbin case 2150 and isolating washers 2160 together with outer washers 2195, inner washers 2190, magnets 2180 and magnet casings 2170. These are all supported and retained by body sleeve 2120 which can, for example, be injection molded once the remaining elements of ECPUMP 2110 have been assembled within an assembly jig. As depicted in Figure 22C with exploded detail cross-section it can be seen that the inner washers 2190 self-align with the inner profile of the bobbin core 2140 as shown within region 21000. Isolation washers 2160 having been omitted for clarity. Accordingly, with subsequent positioning of magnets 2180 and magnet casings 2170 it would be evident that the resultant magnetic field profiles are appropriately aligned through the washers though the self-alignment from the bobbin core. Piston 2130 is also depicted in end-views 2130A and 2130B which show two different geometries of slots machined or formed within the piston 2130 which disrupt the formation of radial/circular Eddy currents, electrical currents, and/or radial/circular magnetic fields within the piston 2130.

[00150] Dimensions of an embodiment of ECPUMP 2110 are depicted and described below in respect of Figure 44. However, it would be evident that other dimensioned ECPUMPs can be implanted according to the overall requirements of the fluidic system. For example, with a 1.4" (approximately 35.6mm) diameter and 1.175" long (approximately 30mm) ECPUMP with diameter 0.5" (approximately 12.7mm) and 1" (approximately 25.4mm) long piston the pump generates 7 psi at a flow rate of 3l/minute. Accordingly, such a pump occupies approximately 2.7 cubic inches and weighs about 150 grams. Other variants have been built and tested by the inventors for ECPUMP with diameters 1.25" to 1.5" although other sized ECPUMPs can be built.

[00151] The VALVAS can, for example, mount over the ends of the bobbin core 3540. Alternatively, a multi-part bobbin core 2140 can be employed which assembles in stages along with the other elements of the ECPUMP 2110. In each scenario the design of ECPUMP 2110 is towards a low complexity, easily assembled design compatible with low cost manufacturing and assembly for commodity (high volume production) and niche (low volume production) type applications with low cost such as a device. A variant of the ECPUMP is depicted in Figure 22D with Mini-ECPUMP 2200 which similarly comprises coil 2220, outer body 2210, magnet 2230, magnet support 2240, and outer washers 2250 which are all mounted and assembled around body sleeve 2260 within which piston 2270 moves. Embodiments of Mini-ECPUMP 2200 assembled and tested by the inventors have outer diameters between 0.5" (approximately 12.7mm) and 0.625" (approximately 16mm) with length 0.75" (approximately 19mm) using a 0.25" (approximately 6mm) diameter piston of length 0.5" (approximately 12.5mm). Such Mini-ECPUMPs 2200 maintain a pressure of approximately 7 psi with a flow rate proportionally smaller and weigh approximately 20 grams. Optionally, magnetic support 2240 can be omitted.

[00152] Now referring to Figures 23A and 23B there are depicted a compact ECPUMP according to an embodiment of the invention with dual inlet and outlet valve assemblies coupling to a fluidic system together with schematic representation of the performance of such ECPUMPs with and without fluidic capacitors. In Figure 23A first to third views 2300A to 2300C respectively relate to an ECPUMP 2330 according to an embodiment of the invention supporting dual fluidic systems. As depicted in second view 2300B ECPUMP 2330 has to one side first VALVAS 2320 and first ports 2310 whilst at the other side it has second VALVAS 2340 and second ports 2350. As depicted in the perspective view of first view 2300A there are a pair of first ports 2310A/2310B connecting to dual first VALVAS 2320A/2320B on one side of ECPUMP 2330 whilst on the other side there are a pair of second ports 2320A/2320B connecting to dual second VALVAS 2320A/2320B. Accordingly as evident in cross-sectional view 2300C motion of the piston within ECPUMP 2330 towards the right results in fluid being drawn from first port 2310A through first VALVAS 2320 on the left hand side (LHS) and fluid being pushed out through second VALVAS 2340 into second port 2350B. In reverse as the piston moves to the left fluid is drawn from second port 2350A through second VALVAS 2340 whilst fluid is expelled through first VALVAS 2320 into first port 2310B. This cycle when repeated pulls fluid from second Y-port 2365 and pushes it through first Y-port 2360. Connection tubes 2305A and 2305B can in some embodiments of the invention be rigid whilst in others they can be "elastic" such that if the pressure rises above a predetermined value then these expand prior to a check valve, such as depicted in respect of Figure 42, opens. Accordingly, a temporary over-pressuring of the fluidic system can be absorbed prior to the check valve opening. For example, connections tubes 2305A and 2350B can be designed to expand at pressures above 7 psi whilst the check valve triggers at 8 psi.

[00153] In Figure 23B expanded and exploded views 2300D and 2300E depict the VALVAS/port configurations with first and second valve 2370A and 2370B which provide non-return inlet and outlet valves for each end of the assembled ECPUMP assembly. In exploded view 2300E a VALVAS is depicted wherein adjacent to the valve, e.g. second valve 2370B, a fluidic capacitor 2390 is provided formed from capacitor port 2375, expander flange 2380, and cap 2385. Accordingly, design of the cap 2385 through wall thickness, material selection, etc. provides for a flexible portion of the VALVAS acting as a fluidic capacitor or it can be rigid. Such a fluidic capacitor 2390 being a fluidic capacitor such as depicted and described *supra* in respect of Figures 13, 15, and 17 as well as described below in other variants and variations. Referring to first to third graphs 23100 through 23300 there are depicted schematic representations of the fluidic action from a pump under different configurations including, convention single ended action, what the inventors are referring to as full cyclic fluidic action without fluidic capacitors, and full cyclic fluidic action with fluidic capacitors. First graph 23100 depicts the operation of an ECPUMP wherein a single end of the ECPUMP is configured with inlet/outlet non-return valves such as described *supra* in respect of Figures 19 to 22B and 23A. Accordingly, on each cycle the pump pushes fluid on only the second half of the cycle. In second graph 23200 an ECPUMP configuration such as described in Figure 23A is depicted wherein the two ends of an ECPUMP are coupled together via common inlet/outlet ports, such as first and second Y-ports 2360 and 2365 respectively. Accordingly, on each half cycle fluid is pumped to the outlet Y-port such that the fluidic system sees and overall fluidic profile as depicted in second graph 23200 such that the "left" and "right" half cycles are combined. However, in many applications such as devices the resulting physical pulsations can be undesired (or alternatively very desired) as they occur at double the drive frequency of the drive signal to the ECPUMP. Accordingly, the inventors have established that fluidic capacitors disposed in close proximity to the valves act to suppress and smooth the sharp pressure drops within second graph 23200 by essentially making the fluidic time constant of the system longer than the frequency response of the ECPUMP. This results in a smoothed output curve from the ECPUMP providing enhanced performance of the ECPUMPs within the devices and other devices according to embodiments of the invention. According to embodiments of the invention fluidic capacitors can optionally be disposed before and/or after the dual fluidic paths meet and/or split. Further, by design in respect to geometry, wall thickness, material, etc. the properties of these fluidic capacitors can be varied to provide varying absorption/reduction of fluidic variations from the ECPUMPs and/or EAVs according to embodiments of the invention. In other embodiments of the invention the outputs from an ECPUMP, for example, can be coupled to a first set of fluidic actuators before being combined in conjunction with fluidic capacitors to provide the fluid activation of a second set of fluidics actuators. In this manner, a set of first fluidic actuators receive pulsed inputs and vibrate accordingly whilst the second set of fluidic actuators receive a constant input and provide extension/expansion for example. Optionally, prior to the set of first fluidic actuators another set of fluidic capacitors are employed which smooth the pulsed ECPUMP/EAV output to a more sinusoidal profile for the first set of fluidic actuators.

[00154] Now referring to Figure 24 there is depicted a compact ECPFA in first view 2400A according to an embodiment of the invention exploiting an ECPUMP 2480 such as ECPUMP 2100 or ECPUMP 2200 as described and depicted in Figures 21 to 22D. As depicted ECPUMP 2480 is disposed between upper and lower VALVAS which are variants of VALVAS such as described *supra* in respect of Figures 19 to Figure 21. Accordingly upper VALVAS comprises a first body 2425A with first inlet 2440A with first valve 2430A and first outlet 2410A and second valve 2420A whilst lower VALVAS comprises a second body 2425B with second inlet 2440B with third valve 2430B and second outlet 2410B and fourth valve 2420B. The first and second inlets 2440A and 2440B respectively are coupled to Input Y-tube 2460 whilst first and second outlets 2410A and 2410B respectively are coupled to output Y-tube 2470. Second view 2400B depicts in detail the upper VALVAS.

[00155] It is evident that the inner profiles of the first inlet 2450A, first body 2425A, and first outlet 2410A have been profiled. These profiles together with the characteristics of first and second valves 2420A and 2440A are tailored according to the pressure and flow characteristics of the ECPUMP in order to minimize the losses during operation and therefore increasing overall efficiency of the ECPUMP and its associated toy. Additionally, the characteristics of output Y-tube 2470 can be varied in terms of resilience, elasticity, etc. to provide fluidic capacitors by deformation of the output Y-tube 2470 arms rather than the fluidic capacitors as depicted *supra* in respect of Figures 23A and 23B respectively. Optionally, Input Y-tube 2460 can be similarly implemented with predetermined elasticity etc. to provide fluidic capacitors on the input side of the ECPUMP.

[00156] Now referring to Figures 25A there is depicted a compact ECPFA in first and second views 2500A and 2500B respectively exploiting an ECPUMP 2580 according to an embodiment of the invention such as ECPUMP 2100 or ECPUMP 2200 as described and depicted in Figures 21 to 22D. Disposed at either end of the ECPUMP 2580 are first and second VALVAS with inlet valves 2530A/2530B and outlet valves 2550A/2550B coupled to inlets 2520A/2520B and outlets 2560A/2560B respectively. In this ECPFA first and second Y-tubes 2510A and 2510B respectively couple the external physical system to the ECPUMP 2580 to exploit the full cyclic fluidic action principle. In contrast to other ECPUMPs described previously ECPUMP 2580 has first and second springs 2540A and 2540B respectively coupled to the piston from first and second housings 2590A and 2590B, respectively. Accordingly, the electromagnetic motion of the piston within ECPUMP 2580 results in alternating compression/expansion of the first and second springs 2540A and 2540B and accordingly their action to return the piston to central position. Accordingly, the drive signals to ECPUMP 2580 can be different to those in ECPUMPs 2100 and 2200 respectively in that a pulse to induce motion will be arrested through the action of the springs rather than combination of electrical control signals applied to the coil within the ECPUMP together with permanent or soft magnets.

[00157] Figure 25B in first view 2500C depicts outer housing 2590 together with housing 2594 to which first and second springs 2540A and 2540B respectively are coupled. Within the pairs of inlets and outlets within housing 2594 each has a mounting 2592 for supporting insertion of the associated inlet or outlet valves 2530A/2550A respectively. Each inlet/outlet valve 2530A/2550A has a valve seat 2596 and fluidic sealing of outer housing 2590 to ECPUMP 2580 is achieved via O-ring 2505. It would be evident to one skilled in the art that other sealing techniques can be applied without departing from the scope of the invention. Within the housing 2594 there are four valves, two inlet valves 2530A and two outlet valves 2550A. This increases the area of valve presented on the inlet and outlet reducing fluid resistant. Optionally, outer housing 2590 can itself be rigid or flexible. When flexible the outer housing 2590 provides a fluidic capacitor which is very close to the inlet and outlet valves.

[00158] According to the design of the Y-tube combiners/splitters such as Input Y-tube 2470 and output Y-tube 2460 in Figure 24 the behaviour of this element in the fluidic system can be made to resonate with the ECPUMP. Beneficially, a resonant Y-tube provides for a "push"/"suck" at the start of a "forward"/"reverse" stroke to help apply force to the piston near the ends of the stroke. This reduces the required magnetic actuation at the extremes of each stroke. As noted *supra* in respect of third image 2300F in Figure 23B such a fluidic capacitor by providing a resonator with an overall time constant longer than the ECPUMP operation provides for a smooth running of the ECPUMP and fluidic assembly such that energy is not wasted stroking the mass/column of water upstream or downstream of the ECPUMP.

[00159] In addition to all the other design issues identified *supra* and subsequently for ECPUMPs and ECFPAs according to embodiments of the invention thermal expansion is an issue to address during the design phase based upon factors such as recommended ambient operating temperature range and actual temperature of ECPUMP during projected duration of use by the user. For example, the piston must be allowed to expand and the inner and outer washers 2190 and 2195 respectively in Figure 21 are designed for larger inner diameter to allow for expansion during operation as ECPUMP heats up. It would be evident that as elements of ECPUMPs/EAVs according to embodiments of the invention can exploit multiple different materials, e.g. iron for piston and plastic for barrel core, that design analysis should include accommodation for thermal expansion of adjacent elements with close tolerances.

[00160] It would be evident that ECPUMPs such as described *supra* in respect of Figures 18 through 25B respectively and below in respect of Figures 28 to 47 can be implemented without non-return valves on either the input and output ports. It would be further evident that ECPUMPs such as described *supra* in respect of Figures 18 through 25B respectively and below in respect of Figures 28 to 47 can form the basis for variants of other electromagnetically driven fluidic pumps such as described *supra* in respect of Figures 12 through 17.

[00161] Now referring to Figure 26 there are depicted first to fourth views 2600A through 2600D respectively of a compact electronically controlled fluidic valve/switch (ECFVS) according to an embodiment of the invention. As depicted in first and second views 2600A and 2600B respectively the ECFVS comprises first and second bodies 2610 and 2620 respectively. Disposed between these are coupler 2630 for connecting two ports of these elements and an electronically controlled actuator (ECA) comprising magnetic washers 2640 and 2660. Additional aspects of ECA such as coil etc. have been omitted for clarity but would be evident to one of skill in the art. As evident in third and fourth views operation of the coils results in movement of magnet 2670 to either the left or right thereby blocking/opening either of the right and left routes within the second and first bodies 2630 and 2610 respectively. Magnetic washers 2640 and 2660 provide for latching operation of the ECA.

[00162] The ECFVS depicted in Figure 26 can be considered as two valves coupled back to back where the ECFVS requires only one of Port B and Port C active at any one time. This being depicted in third and fourth views 2600C and 2600D respectively. One such implementation of ECFVS is that Port A is coupled to a fluidic actuator, Port B to the outlet of an ECPUMP, and Port C to an inlet of the (or another) ECPUMP. Accordingly, with Port C "closed" fluid is pumped from Port B to Port A driving the fluidic actuator and then with Port C "open" fluid is withdrawn from the fluidic actuator from Port A to Port C. In another configuration fluid input to Port A can be switched to either Port B or Port C and with suitable electronic control to adjust the position of the piston to both Ports B and C. Optionally, with variable pulse width modulation "PWM" of the control signal the ECFVS in the first configuration could be "dithered" so that even when all fluidic actuators are fully expanded a small amount of fluid is continuously inserted/ extracted such that the fluid is always moving within the fluidic system. In the latter configuration variable PWM mode operation can allow to actuators to be simultaneously filled and/or driven with different fill or flow rates. Also depicted is fifth view 2600E of an alternate valve where only one or other of two independent flow paths are to be active. As noted variable pulse operation of the activation coil allows for variable opening ratios such that the valve can also as act a variable fluidic splitter. Embodiments of the invention have open / close times down to 5 milliseconds although typically 10-15ms coil energizing cycles have been employed.

[00163] It would be evident to one skilled in the art that an efficient latching valve has a latching magnetic attraction, which is as small as possible to maintain the piston within the valve against the pressure head it is shutting off. For most devices it is desirable for a valve to be small, fast, have low power operation, and be simple to manufacture. The valve can be one of multiple valves integrated into a manifold. In some valves it can take more power to switch the valve off against a pressure than it is to open it when the pressure is now helping to push the piston. Any of the coil/magnetic driven motors described within this specification can be implemented in alternate designs latch and behave as a valve rather than a pump. A "switching valve" typically would not use one way valves such as a reciprocating pump would likely incorporate. Optionally, a switching valve could be partially powered in DC mode to reduce the latching piston holding force in a controlled manner and allow the closed valve to partially open or conversely the open valve to partially close. Alternatively, switching valves can incorporate closed loop feedback to influence the coil drive signal and therefore the piston's holding force.

[00164] Within an EAV such as depicted in Figure 26 a perfect seal is not always required. In some applications, some leakage of the closed valve, e.g. 1%, can be accommodated as this does not affect materially the operation or the overall efficiency of the system. Consider the design of an EAV depicted in Figure 26, or another valve/switch, then the gate which seals the switching valve can be formed from a softer conforming material to seat well with the piston face or the gate can be made of the same harder plastic as that the rest of the body is made of. Optionally, the piston can be iron and the washers are magnets or the piston can be a magnet and the washers a soft magnetic material. Similarly, single coil, double coil, and a variety of other aspects of the ECPUMP designs can be employed in EAV designs. An EAV can optionally only latch at one end, or there can be alternate designs with gates/ports at one end of the EAV rather than both ends. By appropriate design cascaded EAV elements can form the basis of fluidic switching and regulating circuits.

[00165] Referring to Figure 27 there are depicted programmable and latching check fluidic valves according to embodiments of the invention. First view 2700A depicts a programmable check valve comprising body 2710, threaded valve body 2720, spring 2750, spring retainer 2730, bearing housing 2740, and ball bearing 2760. As threaded valve body 2720 is screwed into body 2710 then spring 2750 is compressed by the action of spring retainer 2730 and bearing housing 2740 such that the pressure required to overcome the spring pressure and open the programmable check valve by moving ball bearing 2760 increases. Second view 2700B depicts the programmable check valve in exploded view. Third view 2700C depicts a latching programmable check valve wherein a check value 2700 such as described *supra* in respect of first and second views 2700A and 2700B respectively has additionally mounted to the threaded valve body a pin 2775 which controlled by electromagnetic drive 2770 which is connected to driver circuit 2780. Accordingly, under direction of driver circuit 2780 the pin 2775 can be engaged behind the ball bearing via the electromagnetic drive 2770. When engaged the pin 2775 prevents the ball bearing moving and accordingly the check valve operating. Accordingly, it would be evident to one skilled in the art that such a latching programmable check valve or latching check valve can resolve hysteresis issues present within prior art pressure relief valves.

[00166] Referring to Figure 28 there are depicted a cross-section view 2800A and dimensioned compact ECPUMP 2800B according to an embodiment of the invention exploiting the concepts described and depicted in respect of Figures 18 to 25A; Cross-section view 2800A provides reference to the dimensions employed by the inventors within simulations and modeling of ECPUMPs according to embodiments of the invention as well as nomenclature of variants in physical experiments and devices. Accordingly, reference to these dimensions is made below in respect to Figures 45 through 57 respectively. Dimensioned compact ECPUMP 2800B represents an embodiment of the invention as described in respect of Figure 18 to 36C and Figures 37 to 25A. Compact ECPUMP 2800B is 1.4″ (approximately 35.6 mm) diameter and 1.175″ long (approximately 30 mm) with a 0.5″ (approximately 12.7mm) by 1″ (approximately 25.4 mm) long piston. Compact ECPUMP

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2800B generates 7 psi at a flow rate of 3 l/minute occupying approximately 2.7 cubic inches and weighing about 150 grams.

[00167] Now referring to Figures 29 and 46 there are depicted FEM modeling results of magnetic flux distributions for compact ECPUMPs obtained during numerical simulation based design analysis simulations run by the inventors. In Figure 29 first FEM 2900 depicts a design, Design 6, according to an initial design with 0.625" outer diameter and length 0.75." The magnet thickness was $Tm = 0.075''$, stator length $Ty = 0.450''$, stator tooth tip $Hst = 0.025''$, slot opening $b = 0.250''$, and piston "tooth" length $Trt = 0.100''$ with an overall linear stroke $Z = 0.140''$. First FEM 2900 depicts the magnetic fluxplot at $I = 1.0A$ for $Z = 0.000''$, i.e. midstroke. With an N42 NdFeB magnet, 192 turns of 28 AWG wire and a force constant of $Kf \approx 1.0lbf / A$ the RMS input power was approximately 0.5W with sinusoidal drive. Second FEM 2950 depicts a subsequent design iteration, Design 21, according to an initial design with 0.625" outer diameter and length 1.025." The magnet thickness was $Tm = 0.100''$, stator length $Ty = 0.675''$, stator tooth tip $Hst = 0.030''$, slot opening $b = 0.425''$, and piston "tooth" length $Trt = 0.125''$ with an overall linear stroke $Z = 0.200''$. Second FEM 2950 depicts the magnetic fluxplot at $I = 1.0A$ for $Z = 0.000''$, i.e. midstroke. With an N42M NdFeB magnet, 170 turns of 22 AWG wire and a force constant of $Kf \approx 3.0lbf / A$ the RMS input power of approximately 2.45W with sinusoidal drive.

[00168] In contrast first to third FEM plots 3000A to 3000C respectively in Figure 30 depict a baseline ECPUMP design in closed circuit and open circuit configurations at midstroke together with open circuit at full stroke. This baseline ECPUMP has a 0.75" outer diameter and length 2.150." The magnet thickness was $Tm = 0.200''$, stator length $Ty = 1.350''$, stator tooth tip $Hst = 0.025''$, slot opening $b = 0.800''$, and piston "tooth" length $Trt = 0.125''$ with an overall linear stroke $Z = 0.200''$. With an N42M NdFeB magnet the overall efficiency was approximately 40% with a force constant of $Kf \approx 4.0lbf / A$ with an RMS input power of approximately 6.9W with sinusoidal drive. Accordingly, it is evident in comparing baseline design depicted in first to third FEM plots 3000A to 3000C with Design 21 in second FEM 2950 in Figure 4 that the inventor have been able to establish substantial improvements in ECPUMP performance in maintaining output pump force whilst reducing the dimensions of the ECPUMP as well as reducing power consumption and improving efficiency.

[00169] Examples of optimizations established by the inventors for fluidic ECPUMPs and fluidic devices are depicted in respect of Figure 31A to 52. Figure 31A depicts the variations in force constant $Kf(lbf/A)$ for varying tooth width, Trt, at either end of the ECPUMP piston for varying stroke position over the range $\pm 0.125''$ as this tooth width is varied from 0.075" to 0.140" showing an increasing offset in peak force constant and lower peak force constant values as the tooth width is increased. In the upper graph the magnet thickness, Tex, is 0.100" whilst in the lower graph the magnet thickness is reduced to 0.075".

[00170] Referring to Figure 31B shows the effects of washer offset for different EAV variations from an initial baseline design. The baseline design at 0V shows an initial rise in force but then linearly decreases with increasing washer offset. However, as evident a 0.015" washer gap whilst reducing the maximum force results in a significant flattening in the force versus washer offset graph. A similar effect is achieved with a reduction in the diameter of the magnet although the replacement of the N42 magnet with a N50 magnet with 0.015" washer gap results in sufficient force for keeping the magnetic valve closed against the fluidic pressure, which in these simulations was based upon design level provisioning of 7 psi and magnets. Accordingly, by modification of the washer, e.g. inner washers 3590/3595 in Figure 35, and adjustment in magnet characteristics the manufacturing tolerances for offsets in assembly/manufacturing efficiency may be increased.

[00171] The force constant in Figure 31B relates to a latching valve and is the holding latching force between the valve washer and latching magnet in the latching valve experienced as it is held closed when latched against an ECPUMP established 7 psi fluidic system pressure. Based upon these simulations a design target for the valve being to hold a pressure of 9 psi was established such that switching the valve requires low power and still maintains latching action.

[00172] Referring to Figures 32 and 33 the force constant, Kf, for an ECPUMP variant similar to that described in dimensioned compact ECPUMP 2800B and Design 21 in respect of second FEM 2950 in Figure 29 is depicted as a function of stroke offset over the range $\pm 0.120''$ under 0A and 2A drive conditions. Accordingly there are curves for parametric variations in respect of air gap, Lg, and length of the inner tooth width of the inner washer, Tti, for constant outer washer thickness, $Tex = 0.075''$. Accordingly, it can be seen that in Figure 33 at 2A the peak reluctance force reduces rapidly with air gap, Lg, but is relatively constant for varying inner tooth width, Tti. It is also evident that these curves are offset relative to the zero piston position and have significantly different behaviour from about $\pm 0..040''$ from this peak position with the force constant becoming negative for positive offsets close to $+0.120''$ with earlier force constant reversal at lower airgaps and yet remains positive for negative offsets to -0.120". Referring to Figure 32 the 0A reluctance force can be seen to approximately constant in magnitude and profile over $\pm 0..040"$ from the zero position for varying air gap and inner tooth width, Tti, and that at higher piston offsets from zero substantial variations in the reluctance magnitude are observed in addition to a cyclic behaviour.

[00173] Accordingly, considering $Lg = 0.005"$ (approximately 0.125mm or 125μm) then the reluctance force exhibits cyclic behaviour with earlier peaks in sequence 1, 2, 3 for inner tooth widths of 0.125", 0.100", and 0.075" respectively. At +0.080" the reluctance varies from -2.5lbf for $/\ Tti = 0.125"$ down to approximately zero at $Lg = 0.020"\ /\ Tti = 0.075"$ which follows the same shifts evident in the 2A current data in Figure 33. Accordingly, the inventors have established ECPUMP designs that exploit large stroke lengths through initial electromagnetic excitation but that have large stroke characteristics determined by the combination of the reluctance force at 0A and the pressure of the fluid. Further as evident from Figure 32 these zero current long stroke characteristics can be established through appropriate design of the ECPUMP.

[00174] Referring to Figures 34 and 51, the effect of different magnetic materials for the magnets is presented for an ECPUMP variant similar to that described in dimensioned compact ECPUMP 2800B and Design 21 in respect of second FEM 2950 in Figure 29 is depicted as a function of stroke offset under a pulsed drive condition. The current profile being represented by the dashed profile in the middle of the two graphs. In Figure 34 the effect of changing from an N30 NdFeB magnet (10,800 Gauss) to an N52 NdFeB magnet (14,300 Gauss) is shown to be minor. More important is the change from standard soft magnetic steel to Hiperco® 50 iron-cobalt-vanadium soft magnetic alloy, which exhibits high magnetic saturation (24 kilogauss), high D.C. maximum permeability, low D.C. coercive force, and low A.C. core loss. Now referring to Figure 35 the variations in force versus position for N52 magnets are depicted for two piston tooth widths, Trt, for three overall piston lengths where it can be seen that whilst the maximum force reduces the opposite piston position values increase as the piston length is varied from short to long. Accordingly, the overall force versus position profile can be modified according to the desired characteristics of the fluidic system such as for example improved overall force magnitude versus piston position.

[00175] Similarly, referring to Figure 36, numerical simulation results for compact ECPUMPs according to an ECPUMP variant similar to that described in dimensioned compact ECPUMP 2800B and Design 21 in respect of second FEM 2950 in Figure 29 are depicted for two different magnetic materials, N30 and N42, at different currents with varying piston position. Accordingly, at zero current each passes through zero force at zero positional offset and has a periodic characteristic with piston position. With increasing current the long stroke characteristics of force change relatively slowly whilst the central short stroke characteristics vary relatively rapidly. Between 0A and 2A at 0" piston position (midstroke) the force goes from $0lbf$ to approximately $8.5lbf$ for either magnet whilst at -0.100" stroke distance the force goes from approximately $1.8lbf$ to approximately $2.3lbf$ for N30 magnet ECPUMPs and approximately $3.3lbf$ to approximately $4.0lbf$ for N30 magnet ECPUMPs.

[00176] As described *supra* linear displacement pumps, such as the ECPUMPs described and depicted in respect of Figures 18 to 23B, result in an area-averaged flow-rate fluctuation downstream from the pumping chamber due to the need for the pumping piston to reverse direction. These fluctuations in flow-rate result in increased instantaneous load on the pump motor with increased flow path length, due to the need to accelerate and decelerate all fluid along the flow-path. As described *supra* the inventors have established that an expandable elastic diaphragm may be employed immediately upstream and downstream from the pumping chamber. Within this section design space analysis against a target ECPUMP/device configuration is presented. The objectives of the inventors in performing the design space analysis were:

- minimize fluctuations of flow rate to an acceptable and/or desirable level based on product requirements;
- some velocity and pressure fluctuations are permissible and in fact desirable, but should be limited to not severely impact efficiency and end-user satisfaction;
- establish fluctuations of flow and/or pressure to maximize water column vibration energy available to the user;
- maximize mechanical energy efficiency by reducing work done on the fluid; and
- minimize or maximize fluid pressure on the pump piston while achieving a flow-rate of Q = 3 L/min, and outlet pressure of 7 psi (gauge) depending upon intended purpose.

[00177] In order to assess the inventor's concept a mathematical model was developed for the dynamic behavior of the elastic capacitor coupled with the fluid response pressure. A sinusoidal piston velocity at a frequency ranging from 0 to 50 Hz was used as an input for the model and piston dynamics were not considered in this analysis. The model, to which the simulation results are presented and described in respect of Figures 37 to 39C respectively, is depicted in Figure 39D and was discretized using an implicit finite volume scheme and solved numerically using a total variation diminishing solution scheme. Numerous simulations were performed where the flow path lengths S_{45} and S_{67}, diaphragm radii R_4, R_5, R_6, and R_7, and elastic coefficients, k, of the different sections were varied independently. The dimensions of the elastic diaphragm and pumping system were selected to vary the damped cut-off frequency of the system, thereby filtering flow-rate and pressure fluctuations downstream from the elastic diaphragm.

The analysis of fluid dynamics is typically performed using the unsteady Euler equation and mass continuity equations, which are integrated along a streamline starting from the cylinder face, and ending downstream from the diaphragm. The elastic diaphragm is modelled as a thin-walled pressure vessel where stress-strain relationships are employed to obtain the diaphragm expansion and compression due to pressure variations. The instantaneous expansion rate of the diaphragm at a particular streamwise location is given by Equation (1) $k = (0.67)/(Et_0)$, and is the elastic stiffness coefficient related to the elastic modulus of silicone, E, and the thickness of the elastic diaphragm, t_0. The coefficient 0.67 is an analytically derived and experimentally verified correction factor to account for thinning of the elastic diaphragm thickness during strain.

$$\frac{d}{dt}(r) = kr^2 \frac{d}{dt}(P) \qquad (1)$$

[00178] From a general viewpoint then varying the geometric parameters k, S, and R has the following effects:

- increasing R and S increases the damping effect of the elastic diaphragm, leading to decreased frictional losses and decreased inertial pressure component;
- increasing R also decreases velocity magnitude minimizing the inertial component of pressure, and viscous losses;
- increasing S however directly increases the inertial pressure component;
- decreasing S decreases the inertial pressure component, but reduces the damping velocity effect at the same time; and

- increasing k increases the damping effect but decreases the critical pressure that the capacitor can operate at.

[00179] The length of the elastic diaphragm, S_{45} and S_{67}, were uniformly scaled from a reference initial value by the ratio S/S_0; the radii of the diaphragm were uniformly scaled by the ratio R/R_0; and the stiffness coefficients, k, were likewise scaled by the ratio k/k_0. Simulations were performed in which S/S_0, R/R_0 and $k/_0$ were independently varied, a 3D parameter space was used to visualize the data as shown in Figures 37 and 38. Figure 37 depicts the parameter space of the simulations wherein 31 different values of k were employed, $0.5 \leq (k/k_0) \leq 2.0$; 51 different values of S were employed, $1 \leq (S/S_0) \leq 4$; and 31 different values of R were employed, $1 \leq (R/R_0) \leq 3$, for a total of 49,011 simulations. Figure 38 depicts the parameter space results of this analysis where isosurfaces of minimum velocity fluctuations, maximum efficiency, and minimum mechanical input power are plotted. Accordingly, each (S/S_0, R/R_0, k/k_0) coordinate corresponds to a different pump configuration and therefore different efficiency characteristics. The isosurfaces show all coordinates where a certain parameter has specific level. For example the mechanical surface indicates all configurations that have a near optimal mechanical efficiency value of 68%. The intersection between the output flow-rate fluctuation isosurface and efficiency isosurface represents the optimum trade-off line between efficiency and velocity fluctuations $\Delta Q/\overline{Q}$. Several points are identified on the surfaces which yield different compromises, which are described in Table 1 below.

	Configuration (k/k_0, S/S_0, R/R_0)	η	$\Delta Q/\overline{Q}$ [%]	P_{IN} [W]	P_{BURST} [psi]	Design Trade-offs
P_0	(1.00, 1.00, 1.00)	0.39	310	3.94	114	Initial configuration
P_1	(1.76 1.02, 2.30)	0.67	1.6	3.03	27	Optimum trade-off between efficiency, input power best flow-rate damping Larger diaphragm size, low critical pressure
P_2	(1.90 0.645, 2.62)	0.69	2.8	2.93	22	Highest efficiency, lowest power required Greater fluctuations, lowest burst pressure
P_3	(1.98, 1.21, 1.69)	0.62	3.0	3.26	34	Smaller Radii and physical dimensions Lower efficiency and higher input power

Table 1: Summary of design configuration points, key parameters, and design trade-offs

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[00180] Figures 39A to 39C respectively show the decreased flow-rate fluctuations, decreased mean cylinder pressure, and correspondingly improved pump efficiency of the optimized configurations compared to the initial reference condition for these different designs. Further refinement is accomplished with more simulations where the radii of the pump are each individually varied and optimized, the flow path from the pump to capacitor is minimized, and losses from the umbrella valves are optimized. These result in further improvements to the theoretical mechanical efficiency of the compact ECPUMPs to 87%. Figures 40 and 41 depict isocontour plots of the velocity fluctuations, efficiency, and mechanical input power in S-R planes for $k/k_0 = 0.5,1.0,1.5,2.0$ from this analysis. Within each graph in Figures 40 and 41 the blank white region represents cases where the pressure within the diaphragm exceeds or is near the critical pressure and the diaphragm expands (balloons out) causing it to rupture. This instability occurs because the elastic diaphragm of the fluidic capacitor has insufficient stiffness rebound causing it to continually accumulate fluid.

[00181] When the bursting pressure (P_{BURST}), approaches the design pressure of 7psi, diaphragm expansion and contraction is greater such that the diaphragm absorbs more energy from the fluid. The expansion and contraction cycles of the diaphragm are nearly $180°$ out of phase with the fluid pressure, and as a result the diaphragm can be used to reduce the pressure load on the pump during the beginning and end of the stroke.

[00182] Another design optimization performed by the inventors relates to addressing the motor force output. As evident from first graph 5500A in Figure 55E the time variation of pressure on the pump piston requires consistently positive force throughout the pump cycle to allow the piston to traverse the entire 0.2" stroke and achieve a sinusoidal velocity profile. Hence, if insufficient force is applied at any time, the piston will decelerate prematurely, preventing the piston from reaching the opposite end and thus decreasing flow rate. However, the characteristics of the magnetic motor prevent or limit the positive force that can be applied at the end of the stroke. Furthermore, at either end of the stroke the motor efficiency is drastically decreased, whereas the motor has the greatest efficiency towards the center of the stroke.

[00183] Accordingly, it was an objective to find a force input signal to allow the piston to achieve its full stroke while meeting the output capabilities of the motor and specify a force signal that takes advantage of the current to force conversion efficiency curve of the electric motor, thus minimizing power requirements and maximizing electrical to mechanical energy

conversion efficiency. In order to do this the piston dynamics were modelled and incorporated into the fluid system simulations, so that force was specified as an input and piston position was solved for in time along with fluid pressure and velocity. An arbitrarily shaped force signal which imparts an energy over the entire stroke that is equal to the energy imparted by the force curve is shown in first graph 3900A in Figure 39E which will permit the piston to traverse the entire length of the stroke. The force signal is defined as an arbitrary curve, which is controlled such that it's integral over the length of the stroke yields an identical energy to the integral of the force curve shown in first graph 3900A of Figure 39E. This force signal curve was then evolved using a cost minimizing optimization method where the mean current calculated from a particular force curve was minimized in simulations.

[00184] Based upon this optimization improved force and piston position curves were determined as shown in second and third graphs 3900B and 3900C in Figure 39. First graph 3900A depicts the force signal optimized to achieve 0.2" stroke and use minimal input current, whilst third graph 3900C depicts the resulting piston position versus time curve. The force curve shown in the second graph 3900B of Figure 39E redistributes energy imparted by the piston towards the center of the stroke, and allows for force to be negative at the end such that the pumping piston is decelerated by fluid pressure imparted by the elastic diaphragm and the zero-current magnetic reluctance force imparted by the motor magnetics. As a result the resulting piston position curve experiences substantially greater acceleration and deceleration towards the middle and end of the stroke cycle period. The corresponding velocity profile suffers from a slight decline in mechanical efficiency, which is more than compensated by the increase in electrical to mechanical energy conversion efficiency. The frequency that the piston oscillates at is determined by the force supplied throughout the stroke. As we wish to apply less current at the ends of the stroke, the zero-current magnetic reluctance force of the piston is tuned to the specific values (± 1.75lbf at 40Hz), which are required to achieve a resonant frequency with minimal current. This force curve can then be converted to the required drive current which is depicted in fourth graph 3900D in Figure 39, which it can be seen requires minimal current to be applied at the beginning and end of the cycle.

[00185] Referring to Figure 47 there is depicted an example of a control circuit for an ECPUMP according to an embodiment of the invention. As depicted digital circuit 4700A comprises high performance digital signal controller, such as for example Microchip dsPIC33FJ128MC302 16-bit digital signal controller which generates output pulse width modulation (PWM) drive signals PWML and PWMH which are coupled to first and second driver circuits 4720 and 4730 which generate the current drive signals applied to the coil within the ECPUMP 3510. An example of the generated drive current applied to the coil of an ECPUMP is depicted in Figure 48. Rather than a continuous signal the generated drive current according to an embodiment of the invention wherein the digital circuit 4710 generates amplitude varying pulses with an 18 kHz frequency. Accordingly, the 450ms drive current signal depicted in Figure 48 is composed of approximately 8000 discrete amplitude weighted cycles of this 18 kHz signal.

[00186] The operation of an ECPUMP using a drive signal such as depicted in Figure 48 provides for continuous operation of the ECPUMP which via fluidic capacitors a constant fluid pressure/flow to the fluidic system and the valves. However, it would be evident that under the direction of a controller exploiting PWM techniques for driving an EAV that the EAV can be turned on and off quickly in order to keep a fluidic actuator, such as a balloon, at a predetermined fill level, e.g. 25%, 50%, and 100%. For example, with an EAV oscillating at 40Hz then pulse width modulating the valve can be within the range 0.1Hz to 40Hz according to fill level desired. In this manner a single ECPUMP can fill and/or maintain the fill level of a plurality of balloons based upon the actuation of the valves, switches, etc. within the overall fluidic system. Similarly, the ECPUMP can be operated at different frequencies e.g. 10Hz to 60Hz. Additional frequency stimulation can be through the timing sequence of a series of valves. It would also be evident that a physical interaction, such as the pressure applied by a finger contacting a user's skin can be mimicked as the PWM based controller technique allows complex actuator expansion or effect profiles to be generated. Hence, a fluidic actuator can be inflated to provide a pressure profile mimicking another individual's finger touching them.

[00187] Figures 42 to 44 depict design variations for pump pistons within compact ECPUMPs according to embodiments of the invention. As evident from the simulations presented *supra* in respect of Figure 29 to 36 and other analysis the performance of an ECPUMP is sensitive to the gap such that lower gap, Lg, result in increased force etc. However, it would also evident that at such low gaps that friction between the piston and the barrel of the ECPUMP, e.g. barrel sleeve 2120 in Figure 21, exists and increases. At the same time a sharp profile to the tooth of the piston results in improved performance but further increases issues of friction at the boundaries between the fluid, piston tooth, and barrel sleeve. Accordingly, first to fourth designs 4200A to 4200D within Figure 42 represent options for design variants to address this issue. In each the ECPUMP 4210 has a design such as described in respect of Figure 21. In first image 4200A the piston 4220 has profiled end caps 4230, for example of a plastic, which provide manipulation of the fluid boundary towards the narrow gap between teeth of the piston 4220 and inner surface of the barrel sleeve, not identified for clarity. Second image 4200B depicts a similar variant but now the piston body between the teeth has been similarly filled with a material, e.g. a plastic. This is further extended in third image 4200C where the outer diameter of the piston teeth has been reduced slightly allowing the piston 4240 to be embedded within the other material 2450, e.g. plastic, such that sharp edges of the piston teeth and manufacturing variations in the pistons are removed from direct contact with the inner surface of the barrel sleeve. Further, in fourth image 4200D the inner surface of the barrel sleeve has been coated with a thin film 4260, or thin layer of material, such that the piston 4240 embedded within the material 4250 runs within the thin film 4260 whose properties are design for low friction rather than mechanical strength etc. in respect of the barrel sleeve where this is molded to the other parts of the ECPUMP 4210.

[00188] First to fourth designs 4300A to 4300D within Figure 43 represent further options for design variants to address the friction issue. In each the ECPUMP 4310 has a design such as described in respect of Figure 35. In first image 4300A the piston 4320 has had the profile of the teeth modified such that rather than a sharp right angle corner there is a smooth tapered gap between the piston 4220 and inner surface of the barrel sleeve. Alternatively in second image 4300B a fluid is injected through the ECPUMP 4310 via lubrication path 4350 into a lubrication groove 4340 within the surface of the piston. Whilst depicted in the central portion of the piton 4340 it would be evident that these can also be implemented at the piston ends directly into lubricant grooves within the teeth of a piston such as 4220 in first image 4200A in Figure 42. Such lubrication can be discretely employed or combined with other techniques described within this specification. The groove 4340 can be optimized to maximize bearing surface area but still provide adequate thick film lubrication to the surface of the piston. Where the lubricant is the same fluid within the overall fluidic system it would be evident that a portion of the fluid pumped by the ECPUMP can be "fed-back" to the lubrication path 4350. Reference is made to lubrication as being thick film as the fluid line between piston and barrel is approximately 0.001" although it would be evident if manufacturing tolerances can be established at desired cost/yield point to refine this then other embodiments of the invention can exploit thin-film lubrication, boundary layer, and or squeeze layer lubrication. It would be evident that in non-inline applications of the ECPUMP concepts that it is not necessary to provide a perfect seal around the piston.

[00189] Third image 4300C depict the scenario wherein the piston 4355 is embedded within a material 4360, e.g. a plastic, which is shaped in what the inventors call a double barrel shape. Fourth image 4300D depicts a variant wherein the piston 4380 is embedded within another material 4390, e.g. a plastic, and a thin film coating 4370 has been deposited upon the inner surface of the barrel sleeve. In other embodiments of the invention ball bearing races can be employed such as depicted for example in first and second images 6000A and 6000B in Figure 60. In first image 6000A a single ball race 6020 is positioned with the slot opening of width. As such ball race 6020 can be the full width of the slot opening or smaller than it depending upon the piston length, slot opening, and piston stroke length in order to allow free longitudinal movement of the piston. In second image 6000B ball bearings 6010 are disposed within grooves within the piston. In this case issues over ball race length are removed as the ball bearings move with the piston. Ball bearings 6010 can, for example, be formed from one or more suitable plastic materials, a ceramic, a mineral, or a glass.

[00190] Also depicted in Figure 43 is third image 4300C in respect of a zone formed between a piston 4340 and barrel end stops 4350 which projects inwardly from barrel inner surface (not marked for clarity). Accordingly, under operation within an embodiment of the invention the piston would move as normal within the barrel of the ECPUMP. However, as the barrel end stops are positioned at slightly longer than the normal operation maximum stroke length then if the piston passes maximum stroke then as it comes closer to the barrel end stops 4350 the fluid between the end of the piston 4340 and barrel end stops 4350 at that end of the ECPUMP begins to compress and apply pressure to the piston in the reverse direction slowing the piston and ultimately the piston 4340 stops before reversing direction. Within another embodiment of the invention the barrel end stops 4350 are placed close to the maximum stroke of the piston 4340 so that on every full length piston stroke this compressed fluid zone between the piston 4340 and barrel end stops 4350 directs fluid into the region between the piston 4340 perimeter and the barrel inner surface. This being beneficial in piston designs with very small clearance between piston 4340 and barrel inner surface with or without profile tapers on the piston teeth.

[00191] In addition to re-designing the piston and piston tooth geometry with hydrodynamic considerations of piston movement through the fluid to reduce friction, as described *supra* in respect of Figures 42 to 43 together with Figures 47 and 48, it would be evident that other factors can also be adjusted in order to seek to reduce the overall coefficient of friction between the moving piston and the stationary body of the ECPUMP. Accordingly, such factors can include, but are not limited to, piston steel selection, plastic selection for barrel, piston surface polish, mold surface polish for forming barrel, manufacturing tolerances for each element, and barrel surface finish. All of these must also additionally be considered in light of the design factors surrounding the ECPUMP itself including, but not limited to, viscosity, magnetic field side loading, non-uniformity of magnetic field generated by coil from assembly/manufacturing considerations, piston design, piston speed, fluid choice, operating temperature range, etc. It is also important to consider that whilst the piston during the stroke can be moving during the mid-stroke at rates of tens of centimeters per second to tens of meters per second that at the ends of each stroke the piston slows, stops and reverses. Accordingly, the fluid lubrication should also be capable of "supporting" the piston so that at rest the piston is surrounded by a film such that thick (or thin) film lubrication can be exploited during this phase of the ECPUMP operation before the piston speed is sufficient for the hydrodynamic effects described *supra* in respect of Figures 47 and 48 are operable, if exploited.

[00192] The ECPUMPs described and depicted according to embodiments of the invention exploit a strong electromagnet that surrounds the magnetic piston. The electromagnets are concentrically located surrounding the piston, and attract the piston in the radial direction as well as the axial direction. If the centroid of the piston is located at the centre of the magnetic flux field, then the piston experiences no net radial force. However, if the piston is displaced slightly from the centroid of the magnetic flux field, then it experiences outward radial force and is pressed against the outer casing side-wall. This contact results in metal-on-metal or metal-on-plastic contact, resulting in substantial frictional losses. Application of wet and/or dry lubrication such as described *supra* in respect of Figures 42 and 43 aim to address the friction by preventing or limiting the abrasive contact due the relatively high radial force applied in conjunction with the relatively small contact area.

[00193] Accordingly, the inventors have exploited hydrodynamic lubrication theory to determine the side-profile of the piston that will generate sufficient lift forces, offsetting the estimated magnetic attraction forces and preventing surface-surface contact. Hydrodynamic lubrication is sought for, typically, 80% of the stroke cycle and simulations exploit 30%-70% propylene glycol as the lubricant/pumping fluid in order to eliminate the need for repeated application of the lubricant. Analysis of curved end-caps fitted to the ends of a flat centre section which includes the piston to provide the necessary side profile to generate lift and prevent the need for further machining of the piston which would impact established magnetic motor configuration by removing magnetic material. Within the hydrodynamic analysis since pressure is directly proportional to velocity a constant velocity approximately 10% of the peak simulated piston velocity was employed to ensure that calculated lift forces are conservative and the piston remains in hydrodynamic lubrication mode.

[00194] A centered piston has a circumferentially uniform clearance, c, from cylinder (barrel) wall, and generates no net pressure profile. As the piston is displaced towards the outer cylinder wall, the difference wall clearance, generates a pressure distribution as illustrated in first and second images 4500A and 4500B in Figure 45. The pressure distribution is symmetric if the piston is parallel to the outer cylinder wall, and generates no lift, but a pitching moment tends to lift the leading edge closest to the wall away from the wall. The pitched up piston now develops a very slight angle relative to the wall, which via the wedge effect causes a pressure field to develop underneath the piston, as shown in third and fourth images 4500C and 4500D in Figure 45. The pressure field causes the piston to lift up, and be repelled from the wall. The forces and moments generated by the hydrodynamic lubrication effects are normalized by Fp, and Mp, which denote the magnetic perturbation force attracting the piston to the side wall, and the corresponding moment applied if the magnetic force is applied through the leading tooth of the magnetic iron.

[00195] A force of $F/F_p > 1$ ensures that the piston is able to be deflect the approximately 2 lbf magnetic side force, and a moment of $M/M_p > 1$ indicates that sufficient moment is generated to tilt the piston upwards to develop the required lift force. While lift force increases when the piston is pitched up, the pitching moment decreases. Thus at a certain angle, the hydrodynamically generated pitching moment will balance the magnetic pitch-down moment, which will govern the maximum lift-force that can be developed. Accordingly, to establish an appropriate configuration pitching moments and forces were calculated at a variety of leading edge inclination heights while independently varying the length, l, and height, h_0, of the end-cap wedge profile. Figure 46 depicts an isosurface showing all configurations where $M/M_p = 1.1$, and which is shaded with grayscale isocontour lines showing the lift-force developed. At zero inclination height, zero lift force is developed for all configurations, so a point must be selected in the light-shaded region of the surface. Lift force, and pitching moment increase linearly with l, but decrease inversely with increased height, h_0. Selecting a small height is increasingly complicated to machine, whereas selecting a longer end-cap length will extend the length of the motor. Thus a compromise is sought between these two factors, such as for example $(l = 0.125", h_0 = 0.003")$.

[00196] It would be evident that the design principles described *supra* in respect of the ECPUMP with respect to the many different factors including, but not limited to, hydrodynamic fluidic effects, design of piston, barrel design, manufacturing, and assembly may also be applied to other electronically controlled magnetically activated devices such as valves and switches for example. Optionally, the piston within any of the embodiments of the invention described *supra* in respect of profiling to support formation of a thick/thin film layer between the piston and the barrel as well as hydrodynamic correction of piston offsets within the barrel may be modified to provide an asymmetric piston that has a different profile at one end to the other either over the entire length and/or over the piston teeth such that during operation the fluid circulates from outside the piston to the region along the piston and out the other end of the piston. In this manner degradation of the fluid locally to the piston due to elevated operating temperatures may be reduced.

[00197] It would be evident to one skilled in the art that the depictions of ECPUMPs and ECFPAs in respect to embodiments of the invention within the descriptions and drawings have not shown or described the construction or presence of the excitation coil. The design and winding of such coils is known within the art and their omission has been for clarity of depiction of the remaining elements of the ECPUMPs and/or ECFPAs. For example, in Figures 21, 22A, and 22B the coil would be wound or formed upon bobbin core 2140 and housed within bobbin case 2150 which includes an opening(s) for feeding the electrical wires in/out for connection to the external electrical drive and control circuit. Examples of such coils include, for example, 170/22, 209/23, 216/24, 320/24, 352/24, 192/28 (e.g. 8 layers of 24 turns per layer), 234/28, 468/32, and 574/33. Each pair of numbers representing the number of windings and American wire gauge (AWG) of the wire employed.

[00198] It would be evident to one skilled in the art that other structures comprising elastic elements, resilient members, and fluidic actuators can be implemented wherein one or more aspects of the motion, dimensions, etc. of elements of the device and the device itself change according to the sequence of actuation of the same subset of fluidic actuators within the element of the device and/or device itself. Further, it would be evident that one or more active elements such as the fluidic pump(s) and fluidic valve(s) can be designed as a single module rather than multiple modules.

[00199] It would be evident to one skilled in the art that by suitable design of the ECPUMPs depicted *supra* in respect of Figures 12 through 17 that in addition to providing pump action, and acting as primary pumps such as described in respect of Figures 1 and 2 that these can also act as second pumps as depicted in these Figures as well as providing vibrator type functionality. Further, within the embodiments of the invention described *supra* in respect of electronically controlled pumps in Figures 12 through 17 it would evident to one skilled in the art that whilst these have been described with the provisioning of fluidic capacitors these can be omitted according to the design of the overall device in terms of aspects including, but not limited to, the tubing employed to connect the various elements of the fluidic system together or those portions of the fluidic system proximate the fluidic pump(s). In some instances the fluidic capacitor removal can result in a cyclic/periodic pressure profile being applied to the overall profile established by the electronic controller wherein the cyclic/periodic pressure profile provides additional stimulation to the user of the device. It would be evident that in other embodiments of the invention a fluidic capacitor can act as a high pass filter dampening low frequency pressure variations but passing higher frequency pressure variations. In other embodiments of the invention an ECPUMP can form the basis of a compact RAM/Hammer pump.

[00200] Within other embodiments of the invention a fluidic actuator can act as a fluidic capacitor and can in some instances be disposed such that any other fluidic actuators are coupled from this fluidic actuator rather than directly from the pump or from the pump via a valve. Within other embodiments of the invention a fluidic capacitor can be provided on one side of the pump such as for example, the inlet.

[00201] Optionally, the inlet fluidic capacitor can be designed to provide minimal impact to the device movement or designed to impact the device movement, such as for example by not adjusting dimensions in response to pump action. In this instance the when the pump piston seeks to draw fluid and one or more fluidic actuators have their control valves open such that there is an active fluidic connection between the pump and fluidic actuator(s) then fluid will be drawn from the fluidic actuator(s) towards the piston. However, if one or more valves is not open or the fluidic actuators are all collapsed, then the "vacuum" at the pump piston inlet would increase and accordingly a pressure relief valve can allow fluid to flow from a high pressure inlet fluidic capacitor or directly from the valve and allow the fluid to circulate when the fluidic actuators are not changing in volume. In this manner the pump can continue to run, such as for example providing, a vibration, even when the device is in a state that there is no adjustment in the volume of the fluidic actuators.

[00202] In some embodiments of the invention the fluidic capacitor function can be removed such that the fluidic system directs all pressure possible, i.e., all that the pump piston can exert, through rigid pipes and control valves to the fluidic actuator such that the motion of the pump piston, is translated into fluid movement into/ out of the fluidic actuator. This can be employed where the distance between fluidic actuator and pump is relatively short and the volume/weight of fluid being driven by the pump piston is not too large. Accordingly, depending upon the fluidic circuit design if more than one valve is open the fluid flow would be shared, and if no valves were open or valves were open but the fluidic actuator cannot expand or contract more, through some pressure/vacuum limits controlled through design of the fluidic actuator and surrounding materials, then the back pressure/vacuum on the pump piston would go up/down until the pressure relief valve opens and allows the fluid to recirculate from the pump outlet to the pump inlet. Accordingly, the pump piston can keep running without the device undergoing any movement. It would be evident that in such embodiments of the invention that the fluidic system with capacitors can contain only a small reservoir or no reservoir.

[00203] Fluidic systems such as described above in respect of embodiments of the invention with reservoirs and/or fluidic capacitors can still employ a pressure relieve valve or optionally have the pressure monitored to shut the pump down under circumstances such as being stalled against closed valves or fluidic actuators that will not move for example or where the pressure exceeds a predetermined threshold. For example, squeezing the device hard can prevent it from expanding when desired thereby leading to stalling the pump but the pressure monitoring can shut the pump down already. Optionally a thermal cut-off can be also employed within the overall control circuit. Optionally, the pump frequency might be adjusted or valves triggered to put the ECPUMP into a closed loop isolated from the actuators for either a predetermined period of time or until pressure has reduced to an acceptable level. It would be evident that more complex decisions could be made such as assessing whether the pressure is periodic/aperiodic and indicative of an intense vaginal orgasm for example rather than an individual squeezing the device. It would be evident that with ECPUMPS we can vary the pump frequency, pump stroke length, pump pulse profile, etc. to vary effective pressure, flow rate, and pulse frequencies of fluid motion within the device and accordingly

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actions from the fluidic actuators to which these fluidic motions are coupled by valves, switches, splitters, etc. In other embodiments of the invention the ECPUMP can be allowed to stall and through appropriate design not overheat.

[00204] Where a pressure sensor is embedded then this can itself establish the desired pressure that the user wishes to experience and then determine the pump drive signals required to achieve this desired result under variations of other pump parameters such as if the user adjusts the frequency at which operating in the user configuration stage the pressure profile is maintained. It would be evident that ECPUMP performance can be monitored. For example, the back electromagnetic field (EMF) generated can be measured to determine the position of the piston within the ECPUMP and compared relative to expected position as well as deriving position - time profile to establish whether adjustments are required to the control signals to achieve the desired device and/or ECPUMP performance. Alternatively capacitive or other sensors can derive piston position, acceleration etc. as well as fluidic flow and pressure at the ECPUMP head could also be monitored to verify performance.

[00205] Alternatively, the fluidic system can be designed such that the pump always runs and is varied in revolutions per minute (RPM) according to some desired pattern including the stimulation vibration pattern and the valves are opening and closing so that the device is always moving in one aspect or another and therefore the pump would not need to be shut off in the design scenarios wherein there was no fluidic capacitor or an inadequate fluidic capacitor, reservoir or pressure relief bypass valve.

[00206] Materials

[00207] Within the fluidic assemblies, actuators, devices, fluidic valves and fluidic pumps described above in respect of Figures 1 through 31, the fluid can be a gas or liquid. Such fluids can be non-toxic to the user in the event of physical failure of the device releasing the fluid as well as being non-corrosive to the materials employed within the device for the different elements in contact with the fluid. Within other embodiments of the invention the fluid can be adjusted in temperature, such as heated for example. For example, the fluid can be a 50% propylene glycol and 50% water mixture although other ratios can be employed according to the desired viscosity of the liquid. A range of other materials can be employed based upon desired properties of the fluid, which can include, but are not limited to, it being anti-fungal, a lubricant, a lubricant additive, anti-freeze over storage and/or operating range, anti-bacterial, anti-foaming, inhibiting corrosion, non-toxic, and long lifetime within sealed fluidic systems. Examples of such fluids can include, but are not limited to, vegetable oils, mineral oils, silicones, water, and synthetic oils.

[00208] In terms of materials for the fabrication of the device a variety of materials can be employed in conjunction with the fluidic actuators including for example closed-cell foam, open-celled foam, polystyrene, expanded polystyrene, extruded polystyrene foam, polyurethane foam, phenolic foams, rubber, latex, jelly-rubber, silicone rubber, elastomers, stainless steel, Cyberskin and glass. The fluidic actuator in many embodiments of the invention is designed to expand under an increase in pressure (or injection of fluid) and collapse under a decrease in pressure (or extraction of fluid). Accordingly, the fluidic actuator will typically be formed from an elastic material examples of which include rubber, latex, silicone rubber and an elastomer. In some embodiments of the invention the fluidic connections between the fluidic actuator(s) and the fluidic pump and/or valve can be formed from the same material as the fluidic actuator rather than another material. In such instances the fluidic actuator can be formed by reducing the wall thickness of the material. Examples of manufacturing processes include, but are not limited to, dip-coating, blow molding, vacuum molding, thermoforming and injection molding. It would also be evident that multiple actuators can be formed simultaneously within a single process step as a single piece-part. Alternatively multiple discrete actuators can be coupled together directly or via intermediate tubing through processes such as thermal bonding, ultrasonic bonding, mechanical features, adhesives, etc. Similar processes can then be applied to attach the fluidic actuators to the valves, switches, ECPUMP, ECFPA, EAVs etc.

[00209] DEVICE CONFIGURATION

[00210] Whilst emphasis has been made to self-contained discrete devices it would be evident that according to other embodiments of the invention that the device can be separated into multiple units, such as for example a pump assembly with device coupled to the pump assembly via a flexible tube which can be tens of centimeters, a meter or a few meters long. In other embodiments a very short tube can be employed to isolate the pump assembly from the remainder of the device or as part of a flexible portion of the body allowing user adjustment such as arc of a vaginal penetrative portion of a device. It would also be evident that devices according to embodiments of the invention can be configured to be held during use; fitted to a harness; fitted via an attachment to a part of the user's body or another user's body, e.g., hand, thigh, or foot; or fitted via a suction cup or other mounting means to a physical object such as a wall, floor, or table.

[00211] Within embodiments of the invention with respect to devices and the electronic control the descriptions *supra* in respect of the Figures have described electrical power as being derived from batteries, either standard replaceable (consumable) designs such as alkaline, zinc-carbon, and lithium iron sulphide ($LiFeS_2$) types, or rechargeable designs such as nickel cadmium (NiCd or Nicad), nickel zinc, and nickel-metal hydride (NiMH). Typically, such batteries are AAA or AA although other battery formats including, but not limited to, C, D, and PP3. Accordingly, such devices would be self-contained with electrical power source, controller, pump(s), valve(s) and actuator(s) all formed within the same body. It would be evident that fluidic pumps, electronic controller, and fluidic valves are preferably low power, high efficiency designs when considering battery driven operation although electrical main connections can ease such design limits. For example, considering a device where the operating pressure for fluidic actuators is approximately 2-6 psi with flow rates of approximately for typical geometries and efficiencies then power consumption is approximately 3W. Considering 4 AA rechargeable 1.3V DC batteries then these offer approximately power provisioning such that overall these can provide approximately at approximately for about an hour, i.e. approximately such that multiple pumps can be implemented within the device.

[00212] However, alternate embodiments of devices can be configured in so-called wand type constructions, see for example Hitachi Magic Wand within the prior art for example, wherein increased dimensions are typical but additionally the device includes a power cord and is powered directly from the electrical mains via a transformer. Optionally, a device can be configured with battery and electrical mains connections via a small electrical connector with a cord to a remote transformer and therein a power plug. However, it would also be evident that other embodiments of the invention can be configured to house a predetermined portion of the pump(s), valve(s), power supply, and control electronics within a separate module to that containing the fluidic actuators.

[00213] Within embodiments of the invention to devices and the electronic control the descriptions *supra* in respect of the Figures the electrical control has been described as being within the device. However, optionally the controller can be remote to the device either connected via an electrical cable or communicating via an indirect means such as wireless communications for example. Additionally, the electronic controller has been primarily described as providing control signals to the fluidic pumps and valves, as well as other active elements, of the device. However, in some embodiments of the invention the electronic controller can receive inputs from sensors embedded within the device or external to the device. For example, a sensor can provide an output in dependence upon pressure applied to that portion of the device the user, for example from vaginal contractions, wherein the controller can adjust one or more aspects of the device actions in terms of maximum pressure, speed, slew rate, and extension for example. Optionally, other sensors can be internally deployed within the device to monitor the performance of the device, including for example, linear transducers to monitor length extension, pressure sensors to monitor fluid pressure at predetermined points within the device.

[00214] Within the descriptions supra in respect of fluidic devices exploiting valves, switches, ECPUMP, ECFPA, EAVs etc. according to embodiments of the invention have been described with respect to sexual pleasure devices. However, it would be evident that the fluidic devices, valves, switches, ECPUMP, ECFPA, EAVs etc. as described supra may be exploited in a wide range of other applications benefitting from the provisioning of compact low power fluidic components, sub-assemblies, assemblies, devices, etc. Similarly, the embodiments of the invention may be applied to other valves, switches, ECPUMP, ECFPA, EAVs etc. for a wide range of applications with different flow rates, pressure, fluidic tube diameters etc.

[00215] Specific details are given in the above description to provide a thorough understanding of the embodiments. However, it is understood that the embodiments can be practiced without these specific details. For example, circuits can be shown in block diagrams in order not to obscure the embodiments in unnecessary detail. In other instances, well-known circuits, processes, algorithms, structures, and techniques can be shown without unnecessary detail in order to avoid obscuring the embodiments.

[00216] Implementation of the techniques, blocks, steps and means described above can be done in various ways. For example, these techniques, blocks, steps and means can be implemented in hardware, software, or a combination thereof. For a hardware implementation, the processing units can be implemented within one or more application specific integrated circuits (ASICs), digital signal processors (DSPs), digital signal processing devices (DSPDs), programmable logic devices (PLDs), field programmable gate arrays (FPGAs), processors, controllers, micro-controllers, microprocessors, other electronic units designed to perform the functions described above and/or a combination thereof.

[00217] Also, it is noted that the embodiments can be described as a process, which is depicted as a flowchart, a flow diagram, a data flow diagram, a structure diagram, or a block diagram. Although a flowchart can describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations can be rearranged. A process is terminated when its operations are completed, but could have additional steps not included in the figure. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc. When a process corresponds to a function, its termination corresponds to a return of the function to the calling function or the main function.

[00218] The foregoing disclosure of the embodiments of the present invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many variations and modifications of the embodiments described herein will be apparent to one of ordinary skill in the art in light of the above disclosure. The scope of the invention is to be defined only by the claims appended hereto, and by their equivalents.

[00219] Further, in describing representative embodiments of the present invention, the specification may have presented the method and/or process of the present invention as a particular sequence of steps. However, to the extent that the method or process does not rely on the particular order of steps set forth herein, the method or process should not be limited to the particular sequence of steps described. As one of ordinary skill in the art would appreciate, other sequences of steps may be possible. Therefore, the particular order of the steps set forth in the specification should not be construed as limitations on the claims. In addition, the claims directed to the method and/or process of the present invention should not be limited to the performance of their steps in the order written, and one skilled in the art can readily appreciate that the sequences may be varied.

CLAIMS:

1. An electromagnetic pump comprising:

a piston formed from at least a first magnetic material having a first length and a first predetermined lateral dimension;

a bobbin case formed from a first predetermined material having a second length comprising an inner shell defining a central bore of a second predetermined lateral dimension and having an electrical coil formed from a second predetermined material of predetermined diameter disposed around the inner shell;

first and second assemblies disposed at each end of the bobbin case wherein each assembly comprises an inner washer, a magnet and an outer washer disposed sequentially along an axis defined by the central bore of the bobbin case and in physical contact with each other, wherein

the inner washer being closest to the bobbin case having a first thickness with an inner bore of a third predetermined lateral dimension formed from a third predetermined material that is either ferromagnetic or paramagnetic and having a projection upon a surface towards the bobbin case having a third length with an inner bore of the third predetermined lateral dimension and a predetermined width;

the magnet being between the inner washer and the outer washer and formed from a second magnetic material having a second thickness with an inner bore of a fourth predetermined lateral dimension; and

the outer washer being furthest from the bobbin case having a third thickness with an inner bore of a fifth predetermined lateral dimension and being formed from a fourth predetermined material that is either ferromagnetic or paramagnetic; and

a body sleeve formed from a sixth predetermined material having an inner bore of a sixth predetermined lateral dimension and an outer profile defined centrally by the first predetermined lateral dimension and first length of the central bore of the inner shell of the bobbin case.

2. The electromagnetic pump according to claim 1, wherein a profile on an outer radial surface of the projection of each inner washer aligns with a corresponding profile on each end of the central bore of the inner shell.

3. The electromagnetic pump according to claim 1, wherein the body sleeve further comprises a stop at each end having a fourth thickness, an inner bore of the sixth predetermined lateral dimension and a body against an outer surface of the outer washer in order to retain the first and second assemblies and the bobbin case in physical contact with one another.

4. The electromagnetic pump according to claim 1, further comprising

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at least one of:

an isolation washer disposed between each inner washer and the bobbin case formed from a non-conductive material; and

an outer shell forming part of the bobbin case such that the electrical coil is between the inner shell and outer shell.

5. The electromagnetic pump according to claim 1, wherein at least one of the inner washer, the outer washer, an outer body disposed around the electrical coil and the piston at least one of disrupts at least one of radial Eddy currents, circular Eddy currents, electrical currents, radial magnetic fields, and circular magnetic fields.

6. The electromagnetic pump according to claim 1, wherein

at least one of:

the body sleeve is electrically and magnetically non-conductive; the electromagnetic pump further comprises a magnet casing formed from a fifth

predetermined material having the second thickness and an inner bore to allow the magnet to fit within the magnet casing; and

the electromagnetic pump further comprises a magnet casing formed from a fifth predetermined material which is at least one of paramagnetic and ferromagnetic having the second thickness and an inner bore to allow the magnet to fit within the magnet casing.

7. The electromagnetic pump according to claim 3, further comprising a valve assembly disposed on one end comprising a housing attached to at least one of the stop of the body sleeve and the outer washer, an inlet non-return valve, and an outlet non-return valve such that the electromagnetic pump can pump on both strokes of the piston.

8. The electromagnetic pump according to claim 1, further comprising an outer body disposed around outside of the electrical coil and having a length along the electromagnetic pump to have a first end in proximity to the inner washer of first assembly and a second distal end in proximity with the inner washer of the second assembly to magnetically couple the first assembly and second assembly.

9. The electromagnetic pump according to claim 1, wherein at least one of:

the electromagnetic pump has a maximum diameter between 0.5 inches (12.7 mm) and 2.0 inches (50.8 mm); and

the electromagnetic pump has a maximum length between 0.75 inches (19 mm) and 2.0 inches (50.8 mm).

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10. The electromagnetic pump according to claim 1, wherein

at least one of:

the piston has a central portion having reduced diameter relative ends which have the first predetermined lateral dimension and a first predetermined length larger than the third thickness; and

a gap between the outer periphery of the piston and the inner bore of the magnet is below a predetermined value such that for small stroke lengths of the piston a zero-current reluctance force versus piston displacement is approximately linear but for large stroke lengths the zero-current reluctance force outside the small stroke region oscillates and increases substantially in magnitude such that the piston is magnetically pulled back towards the center of the electromagnetic pump.

11. The electromagnetic pump according to claim 1, wherein the coil is activated with a predetermined current profile to generate a force versus position curve that redistributes energy imparted by or onto the piston to the centre of the stroke and allows the force to be negative at the ends of the stroke such that the piston is decelerated by a fluid pressure and a zero-current reluctance force imparted by the magnetics of the electromagnetic pump.

12. The electromagnetic pump according to claim 11, wherein a frequency of oscillation of the electromagnetic pump is determined by the force supplied throughout the piston stroke; and

the zero-current reluctance force is tuned to a specific value in order to achieve a desired resonant frequency of operation with minimum current.

13. The electromagnetic pump according to claim 1, wherein the piston is magnetically sprung away from each end of the electromagnetic pump by establishing that a zero-current reluctance force versus piston displacement is initially approximately linear for a predetermined stroke length but then for increasing stroke lengths beyond the small stroke length the zero-current reluctance force initially oscillates and reverses sign but then increases substantially in magnitude such that the piston is magnetically pushed back towards the center of the electromagnetic pump.

14. The electromagnetic pump according to claim 1, wherein the piston further comprises at least one of:

profiled end caps of a sixth predetermined material;

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a central portion having reduced diameter relative to its ends at the first predetermined lateral dimension and a filler of a seventh predetermined material disposed around this central portion to the one of a diameter equal to and greater than the diameter as the ends; and

wherein the central portion and the piston are embedded within an eighth predetermined material having the first predetermined lateral dimension.

15. The electromagnetic pump according to claim 1, wherein the inner bore of the body sleeve is coated with a low friction material.

16. The electromagnetic pump according to claim 1, wherein

the piston further comprises a lubrication channel; and

the bobbin case and body sleeve further comprise a lubrication path allowing a lubricant to be fed via the lubrication path to the external surface of the piston inner bore of the body sleeve.

17. The electromagnetic pump according to claim 1, wherein at least one of:

the piston and body sleeve have disposed between them at a predetermined position a ball race of predetermined length established in dependence upon a stroke length of the piston when the electromagnetic pump is operated;

the piston and body sleeve have disposed between them at a predetermined position a predetermined number of ball bearings which are formed from a material selected from group comprising a metal, an alloy, a plastic, a ceramic, a mineral and a glass;

the inner bore of the body sleeve comprises barrel stops at each end disposed with respect to the maximum stroke of the piston such that upon each full length piston stroke a fluid being pumped is compressed between the piston and barrel end stop to direct fluid between the outer surface of the piston and the inner surface of the body sleeve; and

the piston is hydrodynamically lubricated such that in motion the piston generates sufficient lift force to overcome magnetic attraction and prevent surface-surface contact.

18. The electromagnetic pump according to claim 1, wherein the second magnetic material is at least one a neodymium rare-earth material, a samarium-cobalt rare-earth material, sintered neodymium iron boron and bonded neodymium iron boron.

19. An electromagnetic pump comprising:

a piston formed from at least a first magnetic material having a predetermined length and a first predetermined lateral dimension;

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a bobbin case formed from a first predetermined material having an inner shell of a first length and defining a central bore with a second predetermined lateral dimension, and a predetermined thickness upon which is wound an electrical coil formed from a second predetermined material of predetermined diameter;

first and second assemblies disposed at each end of the bobbin case wherein each assembly comprises a magnet and an outer washer disposed in sequence away from the bobbin case along an axis defined by the central bore and in physical contact with each other:

the magnet being closest to the bobbin case and formed from a second magnetic material having a first thickness with an inner bore of a third predetermined lateral dimension equal to or larger than the second predetermined lateral dimension;

the outer washer being furthest from the bobbin case and formed from a third predetermined material having an inner bore of a fourth predetermined lateral dimension, a second length along the inner bore; and

a body sleeve formed from a fourth predetermined material having an inner bore of a sixth predetermined lateral dimension and an outer profile defined centrally by the second predetermined lateral dimension and first length of the central bore of the bobbin case and then sequentially away in either direction along an axis defined by the inner bore by the first thickness of the magnet, and the second length and the fourth predetermined lateral dimension of the inner bore of the outer washer such that these elements are aligned axially along the body sleeve; wherein

the magnet is supported by a magnet support disposed between the magnet and the body sleeve, wherein the magnet support is formed from a fifth predetermined material and has an outer dimension of the third predetermined lateral dimension.

20. The electromagnetic pump according to claim 1, wherein

the outer profile of the body sleeve is further defined axially away from the bobbin case in either direction by at least one of:

the third predetermined lateral dimension together with the first thickness and the second length of the inner bore of the inner washer, the second thickness of the magnet, the third thickness and fifth predetermined lateral dimension of the inner bore of the outer washer such that these elements are aligned axially along the body sleeve; and

the third predetermined lateral dimension together with the first thickness and the second length of the inner bore of the inner washer, the second thickness and fourth predetermined lateral dimension of the inner bore of the magnet, the third thickness and fifth predetermined lateral dimension of the inner bore of the outer washer such that these elements are aligned axially along the body sleeve.

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21. The electromagnetic pump according to claim 19, wherein the body sleeve further comprises a stop at each end having a fourth thickness, an inner bore of the sixth predetermined lateral dimension and a body against an outer surface of the outer washer in order to retain the elements of the first and second assemblies and the bobbin case in physical contact with one another.

22. The electromagnetic pump according to claim 19, wherein at least one of the outer washer, an outer body disposed around the electrical coil and the piston at least one of disrupts at least one of radial Eddy currents, circular Eddy currents, electrical currents, radial magnetic fields, and circular magnetic fields.

23. The electromagnetic pump according to claim 19, further comprising at least one of:

an isolation washer disposed between each magnet and the bobbin case formed from a non-conductive material; and

an outer shell forming part of the bobbin case such that the electrical coil is between the inner shell and outer shell and the outer shell forms part of a magnetic circuit with the magnets in the first and second assemblies.

24. The electromagnetic pump according to claim 19, further comprising a valve assembly disposed on one end comprising a housing attached to at least one of the stop of the body sleeve and the outer washer, an inlet non-return valve, and an outlet non-return valve such that the electromagnetic pump can pump on both strokes of the piston.

25. The electromagnetic pump according to claim 19, wherein at least one of:

the body sleeve is electrically and magnetically non-conductive; and

the outer washer is at least one of paramagnetic and ferromagnetic.

26. The electromagnetic pump according to claim 19, wherein the first magnetic material is at least one of a neodymium rare-earth material, a samarium-cobalt rare-earth material, sintered neodymium iron boron and bonded neodymium iron boron.

27. The electromagnetic pump according to claim 19, wherein at least one of:

the electromagnetic pump has a maximum diameter between 0.5 inches (12.7 mm) and 2.0 inches (50.8 mm); and

the electromagnetic pump has a maximum length between 0.75 inches (19 mm) and 2.0 inches (50.8 mm).

28. The electromagnetic pump according to claim 19, wherein at least one of;

the piston has:

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a central portion having reduced diameter relative to ends which have the first predetermined lateral dimension and a first predetermined length larger than the third thickness; and

its predetermined length such that respective ends of the piston are past an inner surface of each of the magnets disposed towards the bobbin case when the position is centrally positioned within the electromagnetic pump; and

a gap between an outer periphery of the piston and the inner bore of the magnet is below a predetermined value such that for small stroke lengths of the piston a zero-current reluctance force versus piston displacement is approximately linear but for large stroke lengths the reluctance outside the small stroke region oscillates and increases substantially in magnitude such that the piston is magnetically pulled back towards the center of the electromagnetic pump.

29. The electromagnetic pump according to claim 19, wherein the coil is activated with a predetermined current profile to generate a force versus position curve that redistributes energy imparted by the piston to the centre of the stroke and allows the force to be negative at the ends of the stroke such that the piston is decelerated by a fluid pressure and a zero-current reluctance force imparted by the magnetics of the electromagnetic pump.

30. The electromagnetic pump according to claim 19,

wherein at least one of:

a frequency of oscillation of the electromagnetic pump is determined by force supplied throughout the piston stroke; and

a zero-current reluctance force is tuned to a specific value in order to achieve a desired resonant frequency with minimum current.

31. The electromagnetic pump according to claim 19, wherein

the piston further comprises at least one of:

profiled end caps of a fifth predetermined material;

a central portion having reduced diameter relative to its ends and a filler of a sixth predetermined material disposed around this central portion;

wherein the central portion and the piston are embedded within a seventh predetermined material having the predetermined lateral dimension.

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32. The electromagnetic pump according to claim 19, wherein the inner bore of the body sleeve is coated with a material to reduce a coefficient of friction of the piston to the inner bore of the body sleeve and the piston from that between the piston and the inner bore of the body sleeve within the material.

33. The electromagnetic pump according to claim 19, wherein

the piston further comprises a lubrication channel; and

the bobbin case and body sleeve further comprise a lubrication path allowing a lubricant to be fed via the lubrication path to the external surface of the piston.

34. The electromagnetic pump according to claim 19, wherein at least one of:

the piston and body sleeve have disposed between them at a predetermined position a ball race of predetermined length established in dependence upon a stroke length of the piston when the electromagnetic pump is operated;

the piston and body sleeve have disposed between them at a predetermined position a predetermined number of ball bearings which are formed from a material selected from group comprising a metal, an alloy, a plastic, a ceramic, a mineral and a glass;

the inner bore of the body sleeve comprises barrel stops at each end disposed with respect to the maximum stroke of the piston such that upon each full length piston stroke a fluid being pumped is compressed between the piston and barrel end stop to direct fluid between the outer surface of the piston and the inner surface of the body sleeve; and

the piston is hydrodynamically lubricated such that in motion the piston generates sufficient lift force to overcome magnetic attraction and prevent surface-surface contact.

35. The electromagnetic pump according to claim 19, wherein the second magnetic material is at least one a neodymium rare-earth material, a samarium-cobalt rare-earth material, sintered neodymium iron boron and bonded neodymium iron boron.

36. The electromagnetic pump according to claim 19, wherein the outer profile of the body sleeve is further defined axially away from the bobbin case in either direction by the first thickness of the magnet, and the second length and the fourth predetermined lateral dimension of the inner bore of the outer washer such that these elements are aligned axially along the body sleeve.

37. An electromagnetic pump comprising:

a piston formed from at least a first magnetic material having a predetermined length and a first predetermined lateral dimension;

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a bobbin case formed from a first predetermined material having an inner shell of a first length and defining a central bore with a second predetermined lateral dimension, and a predetermined thickness upon which is wound an electrical coil formed from a second predetermined material of predetermined diameter;

first and second assemblies disposed at each end ❑f the bobbin case wherein each assembly comprises a magnet and an outer washer disposed in sequence away from the bobbin case along an axis defined by the central bore and in physical contact with each other:

the magnet being closest to the bobbin case and formed from a second magnetic material having a first thickness with an inner bore of a third predetermined lateral dimension equal to or larger than the second predetermined lateral dimension;

the outer washer being furthest from the bobbin case and formed from a third predetermined material having an inner bore of a fourth predetermined lateral dimension, a second length along the inner bore; and

a body sleeve formed from a fourth predetermined material having an inner bore of a sixth predetermined lateral dimension and an outer profile defined centrally by the second predetermined lateral dimension and first length of the central bore of the bobbin case and then sequentially away in either direction along an axis defined by the inner bore by the first thickness of the magnet, and the second length and the fourth predetermined lateral dimension of the inner bore of the outer washer such that these elements are aligned axially along the body sleeve; and

at least one of:

an isolation washer disposed between each magnet and the bobbin case formed from a non-conductive material; and

an outer shell forming part of the bobbin case such that the electrical coil is between the inner shell and outer shell and the outer shell forms part of a magnetic circuit with the magnets in the first and second assemblies.

38. An electromagnetic pump comprising:

a piston formed from at least a first magnetic material having a predetermined length and a first predetermined lateral dimension;

a bobbin case formed from a first predetermined material having an inner shell of a first length and defining a central bore with a second predetermined lateral dimension, and a predetermined thickness upon which is wound an electrical coil formed from a second predetermined material of predetermined diameter;

first and second assemblies disposed at each end of the bobbin case wherein each assembly comprises a magnet and an outer washer disposed in sequence away from the bobbin case along an axis defined by the central bore and in physical contact with each other:

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the magnet being closest to the bobbin case and formed from a second magnetic material having a first thickness with an inner bore of a third predetermined lateral dimension equal to or larger than the second predetermined lateral dimension;

the outer washer being furthest from the bobbin case and formed from a third predetermined material having an inner bore of a fourth predetermined lateral dimension, a second length along the inner bore; and

a body sleeve formed from a fourth predetermined material having an inner bore of a sixth predetermined lateral dimension and an outer profile defined centrally by the second predetermined lateral dimension and first length of the central bore of the bobbin case and then sequentially away in either direction along an axis defined by the inner bore by the first thickness of the magnet, and the second length and the fourth predetermined lateral dimension of the inner bore of the outer washer such that these elements are aligned axially along the body sleeve; wherein

at least one of:

the piston has:

a central portion having reduced diameter relative to the ends which have the first predetermined lateral dimension and a first predetermined length larger than the third thickness; and

its predetermined length such that the ends of the piston are past an inner surface of each of the magnets disposed towards the bobbin case when the position is centrally positioned within the electromagnetic pump; and

a gap between an outer periphery of the piston and the inner bore of the magnet is below a predetermined value such that for small stroke lengths of the piston a zero-current reluctance force versus piston displacement is approximately linear but for large stroke lengths the reluctance outside the small stroke region oscillates and increases substantially in magnitude such that the piston is magnetically pulled back towards the center of the electromagnetic pump.

39. An electromagnetic pump comprising:

a piston formed from at least a first magnetic material having a predetermined length and a first predetermined lateral dimension;

a bobbin case formed from a first predetermined material having an inner shell of a first length and defining a central bore with a second predetermined lateral dimension, and a predetermined thickness upon which is wound an electrical coil formed from a second predetermined material of predetermined diameter;

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first and second assemblies disposed at each end of the bobbin case wherein each assembly comprises a magnet and an outer washer disposed in sequence away from the bobbin case along an axis defined by the central bore and in physical contact with each other:

the magnet being closest to the bobbin case and formed from a second magnetic material having a first thickness with an inner bore of a third predetermined lateral dimension equal to or larger than the second predetermined lateral dimension;

the outer washer being furthest from the bobbin case and formed from a third predetermined material having an inner bore of a fourth predetermined lateral dimension, a second length along the inner bore; and

a body sleeve formed from a fourth predetermined material having an inner bore of a sixth predetermined lateral dimension and an outer profile defined centrally by the second predetermined lateral dimension and first length of the central bore of the bobbin case and then sequentially away in either direction along an axis defined by the inner bore by the first thickness of the magnet, and the second length and the fourth predetermined lateral dimension of the inner bore of the outer washer such that these elements are aligned axially along the body sleeve; wherein

the piston further comprises at least one of:

profiled end caps of a fifth predetermined material;

a central portion having reduced diameter relative to its ends and a filler of a sixth predetermined material disposed around this central portion;

wherein the central portion and the piston are embedded within a seventh predetermined material having the predetermined lateral dimension.

40. An electromagnetic pump comprising:

a piston formed from at least a first magnetic material having a predetermined length and a first predetermined lateral dimension;

a bobbin case formed from a first predetermined material having an inner shell of a first length and defining a central bore with a second predetermined lateral dimension, and a predetermined thickness upon which is wound an electrical coil formed from a second predetermined material of predetermined diameter;

first and second assemblies disposed at each end of the bobbin case wherein each assembly comprises a magnet and an outer washer disposed in sequence away from the bobbin case along an axis defined by the central bore and in physical contact with each other:

the magnet being closest to the bobbin case and formed from a second magnetic material having a first thickness with an inner bore of a third predetermined lateral dimension equal to or larger than the second predetermined lateral dimension;

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the outer washer being furthest from the bobbin case and formed from a third predetermined material having an inner bore of a fourth predetermined lateral dimension, a second length along the inner bore; and

a body sleeve formed from a fourth predetermined material having an inner bore of a sixth predetermined lateral dimension and an outer profile defined centrally by the second predetermined lateral dimension and first length of the central bore of the bobbin case and then sequentially away in either direction along an axis defined by the inner bore by the first thickness of the magnet, and the second length and the fourth predetermined lateral dimension of the inner bore of the outer washer such that these elements are aligned axially along the body sleeve; wherein

at least one of

the piston and body sleeve have disposed between them at a predetermined position a ball race of predetermined length established in dependence upon a stroke length of the piston when the electromagnetic pump is operated;

the piston and body sleeve have disposed between them at a predetermined position a predetermined number of ball bearings which are formed from a material selected from group comprising a metal, an alloy, a plastic, a ceramic, a mineral and a glass;

the inner bore of the body sleeve comprises barrel stops at each end disposed with respect to the maximum stroke of the piston such that upon each full length piston stroke a fluid being pumped is compressed between the piston and barrel end stop to direct fluid between the outer surface of the piston and the inner surface of the body sleeve; and

the piston is hydrodynamically lubricated such that in motion the piston generates sufficient lift force to overcome magnetic attraction and prevent surface-surface contact.

41. An electromagnetic pump comprising:

a piston formed from at least a first magnetic material having a first length and a first predetermined lateral dimension;

a bobbin case formed from a first predetermined material having a second length comprising an inner shell defining a central bore of a second predetermined lateral dimension and having an electrical coil formed from a second predetermined material of predetermined diameter disposed around the inner shell;

first and second assemblies disposed at each end of the bobbin case wherein each assembly comprises a magnet formed from a second magnetic material having a first thickness with an inner bore of a third predetermined lateral dimension; and

a body sleeve formed from a fourth predetermined material having:

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an inner bore having a predetermined tolerance with respect to the first predetermined lateral dimension of the piston and an outer profile defined centrally by the first predetermined lateral dimension and first length of the central bore of the bobbin case and then axially away in either direction by the second length, the first thickness and third predetermined lateral dimension of the inner bore of the magnet such that these elements are aligned.

42. The electromagnetic pump according to claim 41, further comprising

an inner washer having a second thickness with an inner bore of a fourth predetermined lateral dimension formed from a fourth predetermined material that is either ferromagnetic or paramagnetic.

43. The electromagnetic pump according to claim 42, wherein each inner washer has a projection upon the surface towards the bobbin case having a third length with an inner bore of the third predetermined lateral dimension and a predetermined width.

44. The electromagnetic pump according to claim 42, wherein each inner washer has a projection upon the surface towards the bobbin case having a third length with an inner bore of the third predetermined lateral dimension and a predetermined width wherein a profile on the outer radial surface of the projection of each inner washer aligns with a corresponding profile on each end of the central bore of the inner shell such that the magnetic field profiles within the electromagnetic pump from each of the first and second assemblies are aligned through the pair of inner washers and their self-alignment with respect to the central core of the bobbin case.

45. The electromagnetic pump according to claim 42, further comprising an isolation washer disposed between each inner washer and the bobbin case formed from a non-conductive material with an inner periphery defined by the inner bore of the third predetermined lateral dimension and width of the inner washer.

46. The electromagnetic pump according to claim 41, further comprising at least one of:

a magnet casing formed from a fourth predetermined material having the first thickness and an inner bore to allow the magnet to fit within the magnet casing; and

a magnet casing formed from a fourth predetermined material which is at least one of paramagnetic and ferromagnetic having the first thickness and an inner bore to allow the magnet to fit within the magnet casing.

47. The electromagnetic pump according to claim 41, further comprising

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an outer washer having a second thickness with an inner bore of a fourth predetermined lateral dimension and being formed from a fourth predetermined material.

48. The electromagnetic pump according to claim 41, further comprising an outer washer having a second thickness with an inner bore of a fourth predetermined lateral dimension and being formed from a fourth predetermined material which is at least one of paramagnetic and ferromagnetic.

49. The electromagnetic pump according to claim 41, further comprising a stop at each end having a second thickness, an inner bore of a fourth predetermined lateral dimension and a body against an outer surface of the one of the first assembly and the second assembly at the respective end of the electromagnetic pump in order to retain the elements of the first and second assemblies and the bobbin case in physical contact with one another.

50. The electromagnetic pump according to claim 41, wherein

at least one of:

the body sleeve is electrically and magnetically non-conductive; and

the body sleeve is formed by an injection molding process and is formed once the bobbin case, and the first and second assemblies have been assembled together within an assembly tool.

51. The electromagnetic pump according to claim 41, wherein the piston has one or more slots formed around the perimeter of the piston in predetermined locations to disrupt at least one of radial Eddy currents, circular Eddy currents, electrical currents, radial magnetic fields, and circular magnetic fields.

52. The electromagnetic pump according to claim 41, further comprising a valve assembly disposed on one end comprising a housing attached to at least one of the stop of the body sleeve and the outer washer, an inlet non-return valve, and an outlet non-return valve such that the electromagnetic pump can pump on both strokes of the piston.

53. The electromagnetic pump according to claim 41, wherein

the piston has:

a central portion having reduced diameter relative to the ends which have the predetermined lateral dimension and a first predetermined length larger than the third thickness; and

has its predetermined length such that the ends of the piston are past the outer surfaces of the magnets when the piston is centrally positioned relative to the bobbin case; and

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the gap between the outer periphery of the piston and the inner bore of the magnet is below a predetermined value such that for small stroke lengths of the piston a zero-current reluctance force versus piston displacement is approximately linear but for large stroke lengths the zero-current reluctance force outside the small stroke region oscillates and increases substantially in magnitude such that the piston is magnetically pulled back towards the center of the electromagnetic pump.

54. The electromagnetic pump according to claim 41, wherein the coil is activated with a predetermined current profile to generate a force versus position curve that redistributes energy imparted by the piston to the centre of the stroke and allows the force to be negative at the ends of the stroke such that the piston is decelerated by the fluid pressure and the zero-current reluctance force imparted by the magnetics of the electromagnetic pump.

55. The electromagnetic pump according to claim 41, wherein a frequency of oscillation of the electromagnetic pump is determined by the force supplied throughout the piston stroke; and

the zero-current reluctance force is tuned to a specific value in order to achieve a desired resonant frequency of operation with minimum current.

56. The electromagnetic pump according to claim 41, wherein the piston is magnetically sprung away from each end of the electromagnetic pump by establishing that the zero-current reluctance force versus piston displacement is initially approximately linear for a predetermined stroke length but then for increasing stroke lengths beyond the small stroke length the zero-current reluctance force initially oscillates and reverses sign but then increases substantially in magnitude such that the piston is magnetically pushed back towards the center of the electromagnetic pump.

57. The electromagnetic pump according to claim 41, wherein
the piston further comprises at least one of:
profiled end caps of a fifth predetermined material;
a central portion having reduced diameter relative to its ends at the first predetermined lateral dimension and a filler of a sixth predetermined material disposed around this central portion to the same diameter as the ends;
a central portion having reduced diameter relative to its ends and the piston is embedded within a seventh predetermined material having the first predetermined lateral dimension.

58. The electromagnetic pump according to claim 41, wherein
at least one of:

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the inner bore of the body sleeve is coated with a low friction material; and

the piston further comprises a lubrication channel and the bobbin case and body sleeve provide a lubrication path allowing a lubricant to be fed via the lubrication path to the external surface of the piston inner bore of the body sleeve is coated with a low friction material.

59. The electromagnetic pump according to claim 41, wherein
at least one of:

the piston and body sleeve have disposed between them at a predetermined position a ball race of predetermined length established in dependence upon a stroke length of the piston when the electromagnetic pump is operated;

the piston and body sleeve have disposed between them at a predetermined position a predetermined number of ball bearings which are formed from a material selected from group comprising a metal, an alloy, a plastic, a ceramic, a mineral and a glass;

the inner bore of the body sleeve comprises barrel stops at each end disposed with respect to the maximum stroke of the piston such that upon each full length piston stroke a fluid being pumped is compressed between the piston and barrel end stop to direct fluid between the outer surface of the piston and the inner surface of the body sleeve; and

the piston is hydrodynamically lubricated such that in motion the piston generates sufficient lift force to overcome magnetic attraction and prevent surface-surface contact.

60. The electromagnetic pump according to claim 41, wherein
each of the first and second assemblies further comprises:

an inner washer an inner washer having a second thickness with an inner bore of a fourth predetermined lateral dimension formed from a fourth predetermined material that is either ferromagnetic or paramagnetic;

an outer washer having a third thickness with an inner bore of a fifth predetermined lateral dimension and being formed from a fifth predetermined material which is at least one of ferromagnetic or paramagnetic; and

a magnet casing having the second thickness with an inner bore of a sixth predetermined lateral dimension formed from a sixth predetermined material; and

each magnet has an outer dimension of the sixth predetermined lateral dimension.

61. The electromagnetic pump according to claim 41, wherein

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each of the first and second assemblies further comprises a magnet casing having the second thickness with an inner bore of a sixth predetermined lateral dimension formed from a sixth predetermined material; and

each magnet has an outer dimension of the sixth predetermined lateral dimension.

62. The electromagnetic pump according to claim 41, wherein

each of the first and second assemblies further comprises:

an outer washer having a second thickness with an inner bore of a fourth predetermined lateral dimension and being formed from a fourth predetermined material; and

a magnet casing having the second thickness with an inner bore of a fifth predetermined lateral dimension formed from a fifth predetermined material; and

each magnet has an outer dimension of the fifth predetermined lateral dimension.

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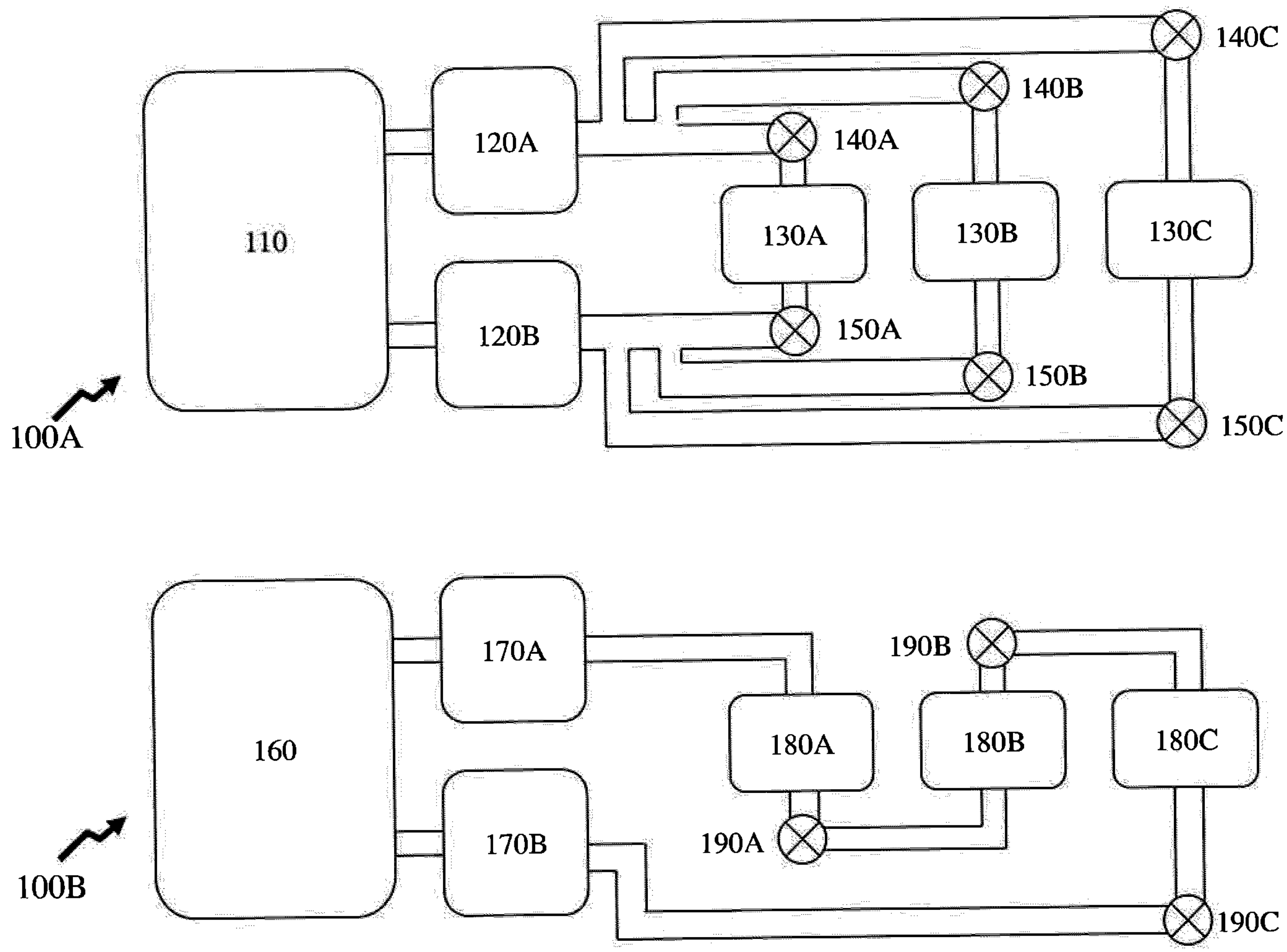
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190C
100B

Figure 1

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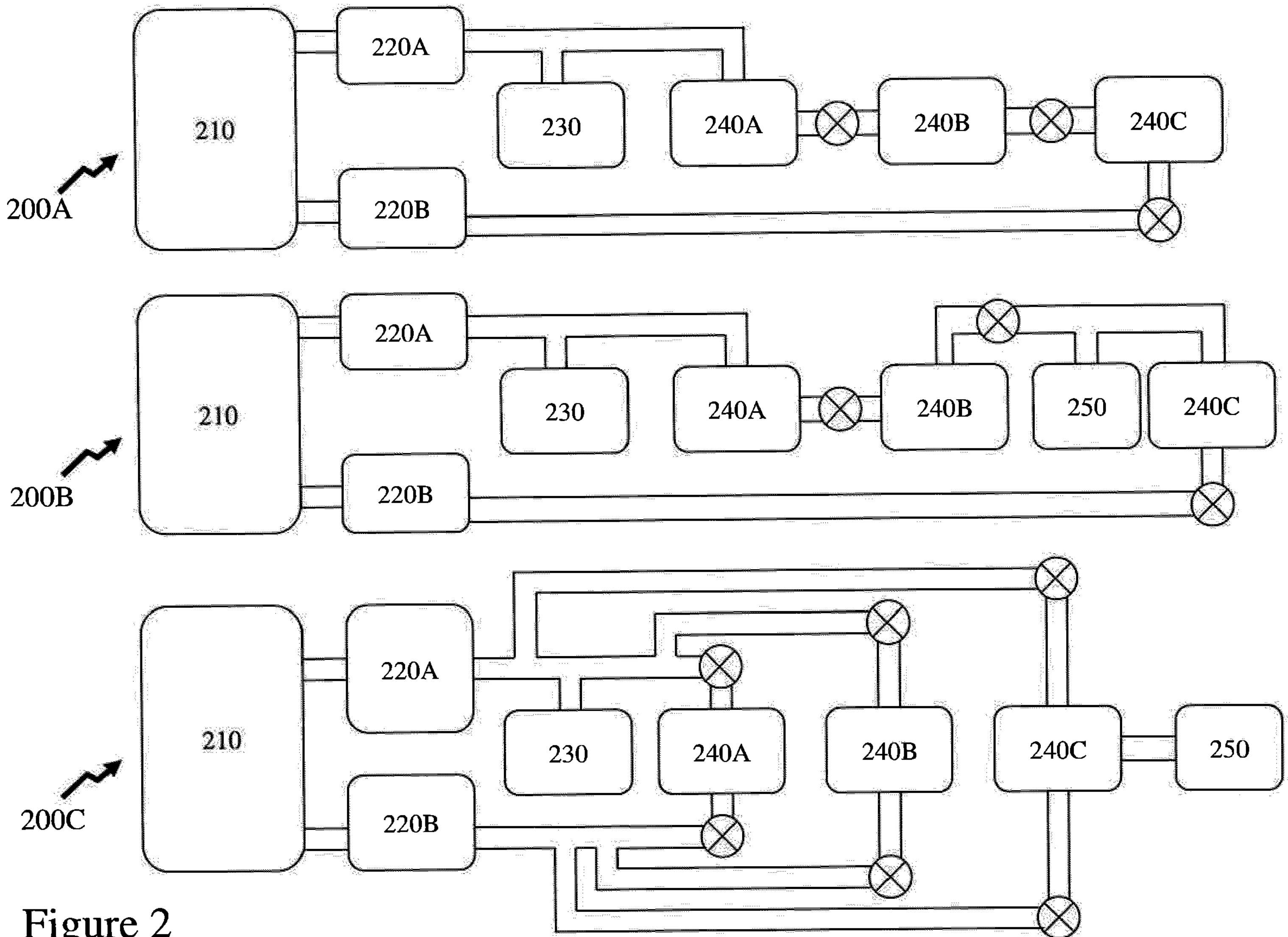
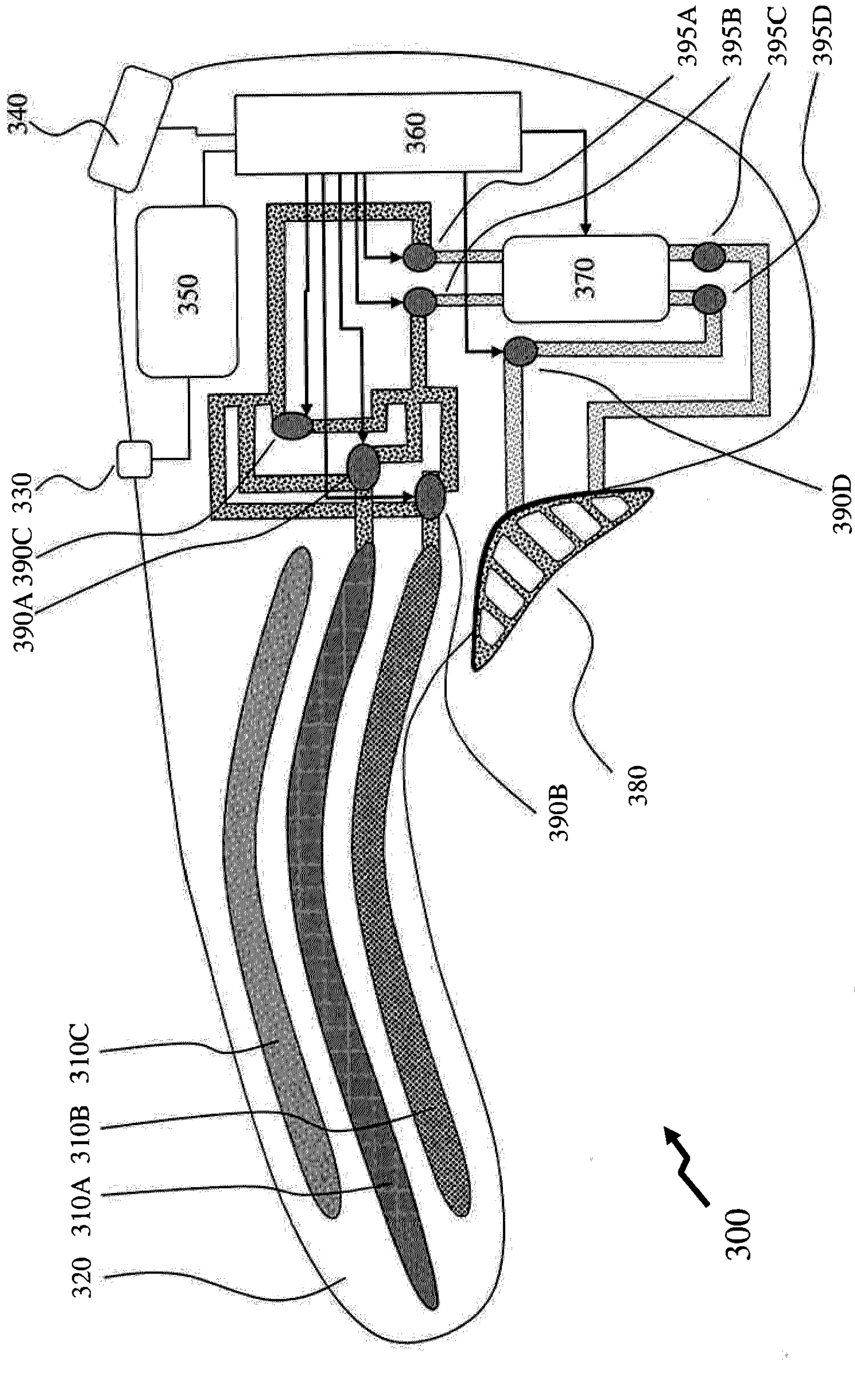


Figure 2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310A
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300

Figure 3

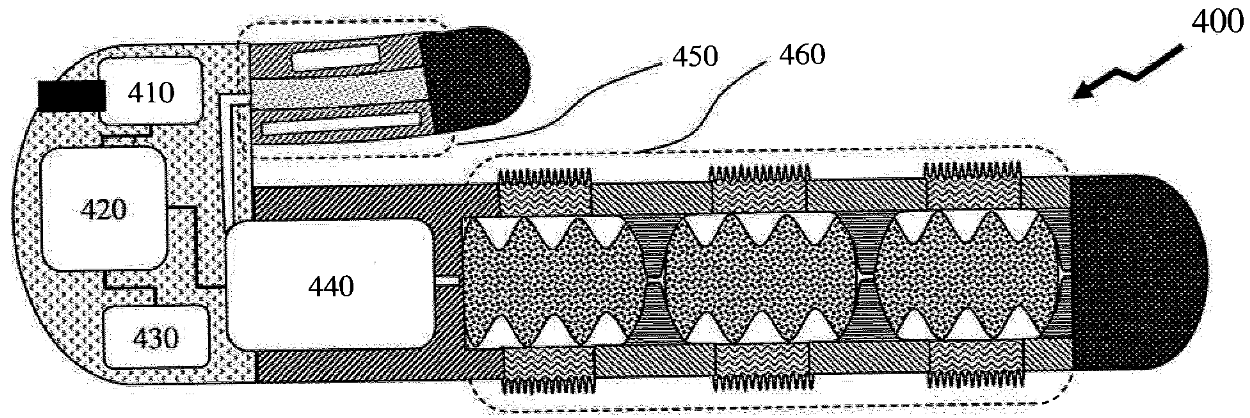


Figure 4

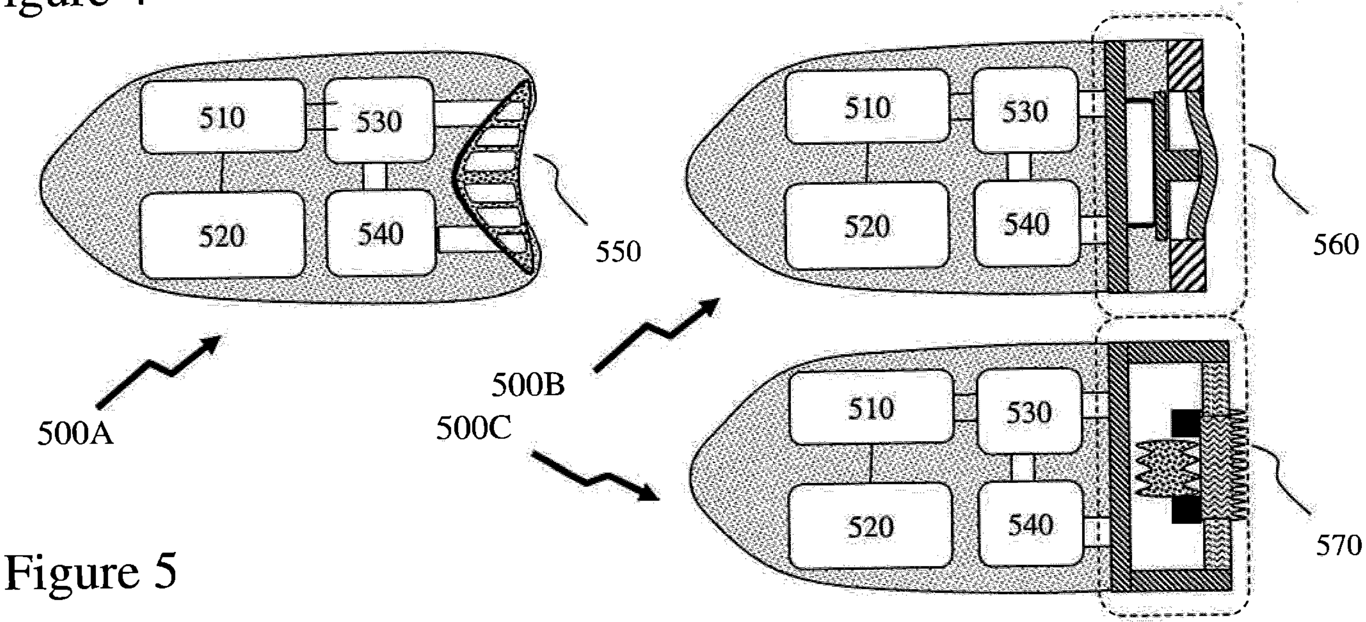
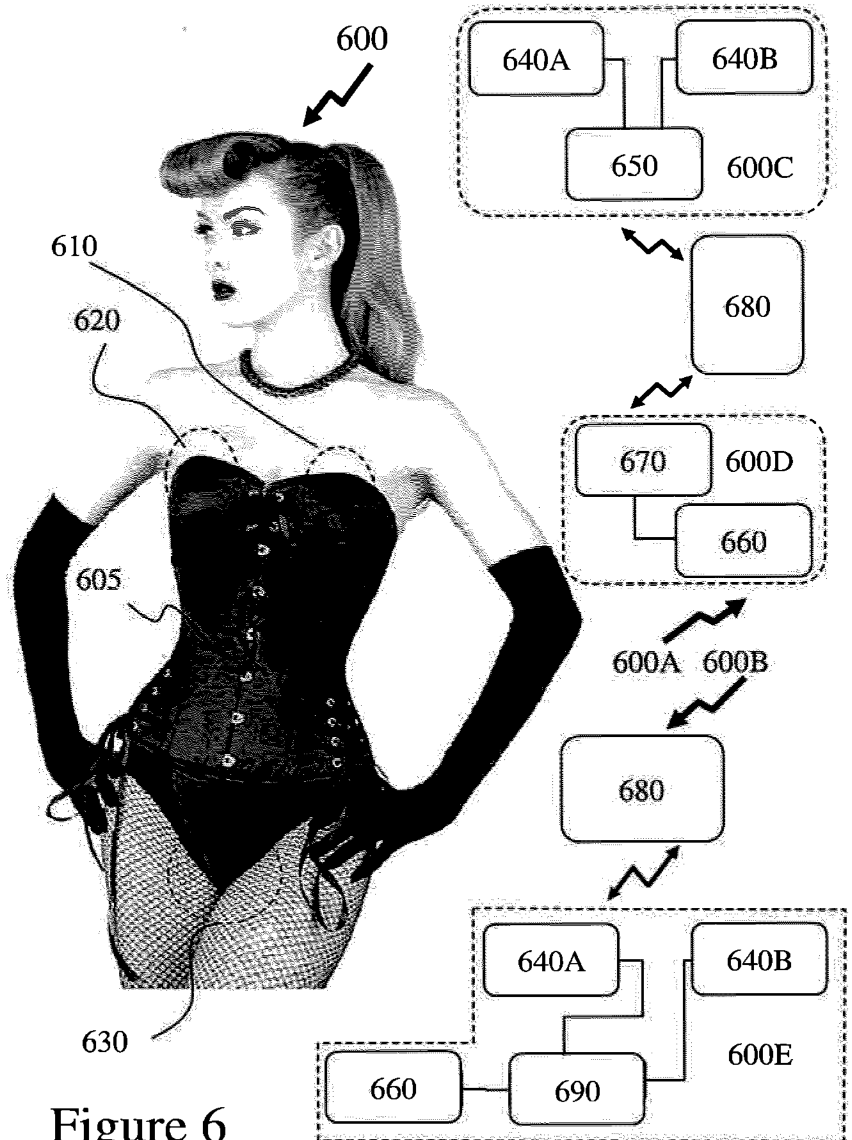


Figure 5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600E
660
690

Figure 6

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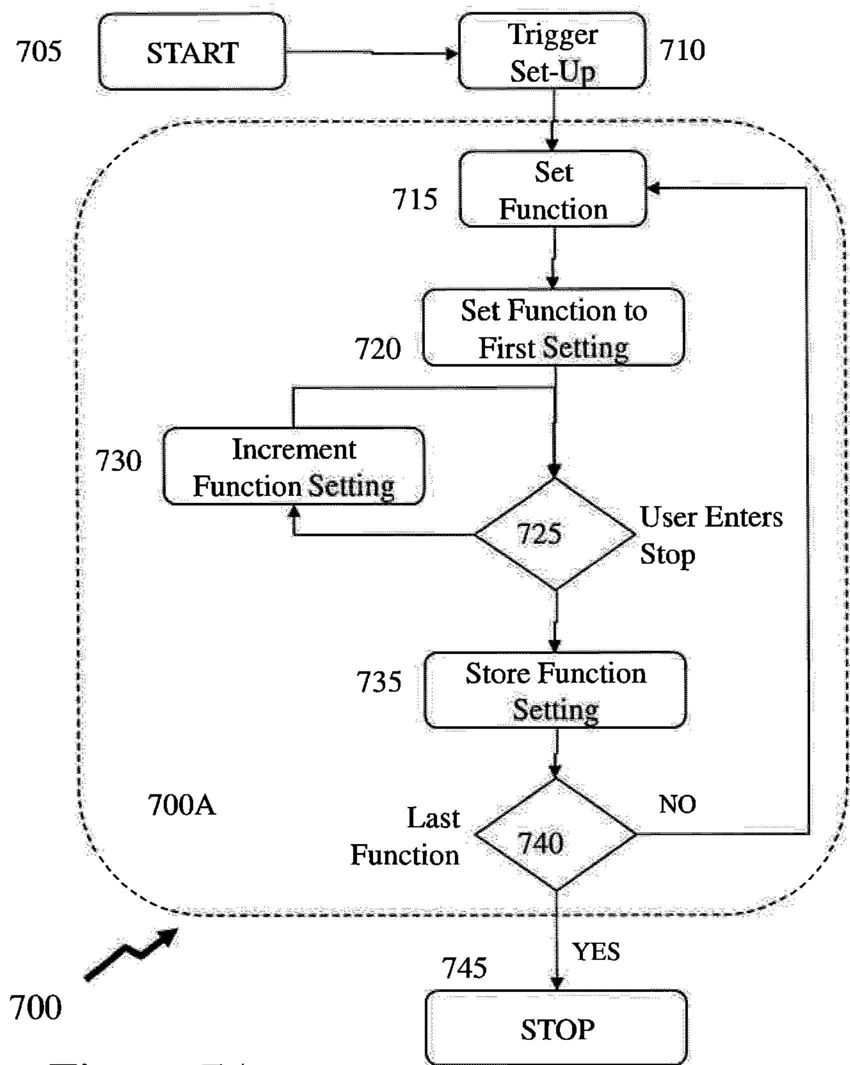


Figure 7A

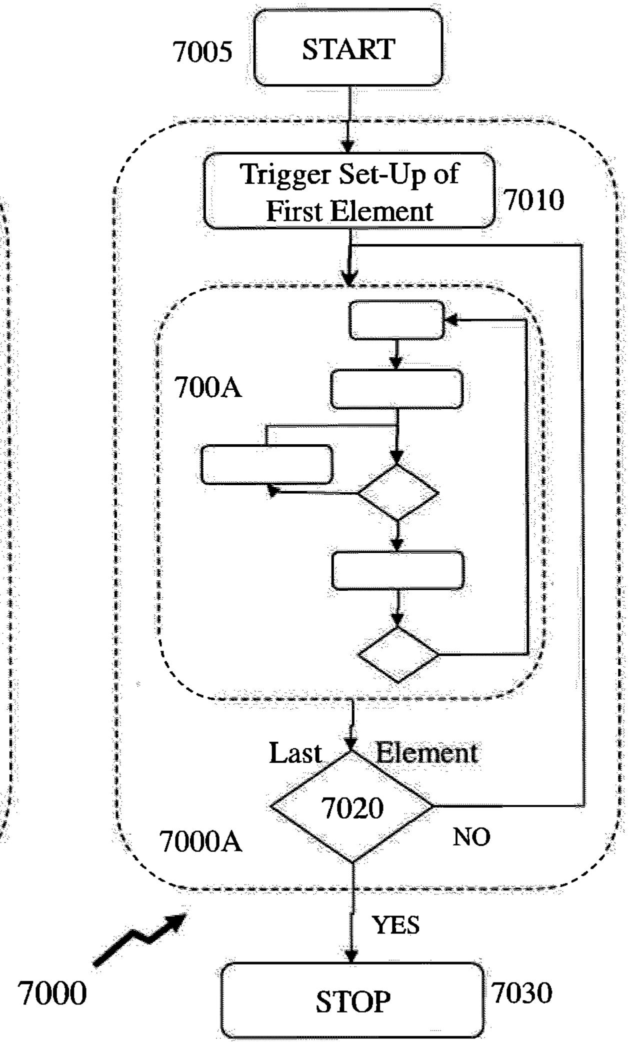
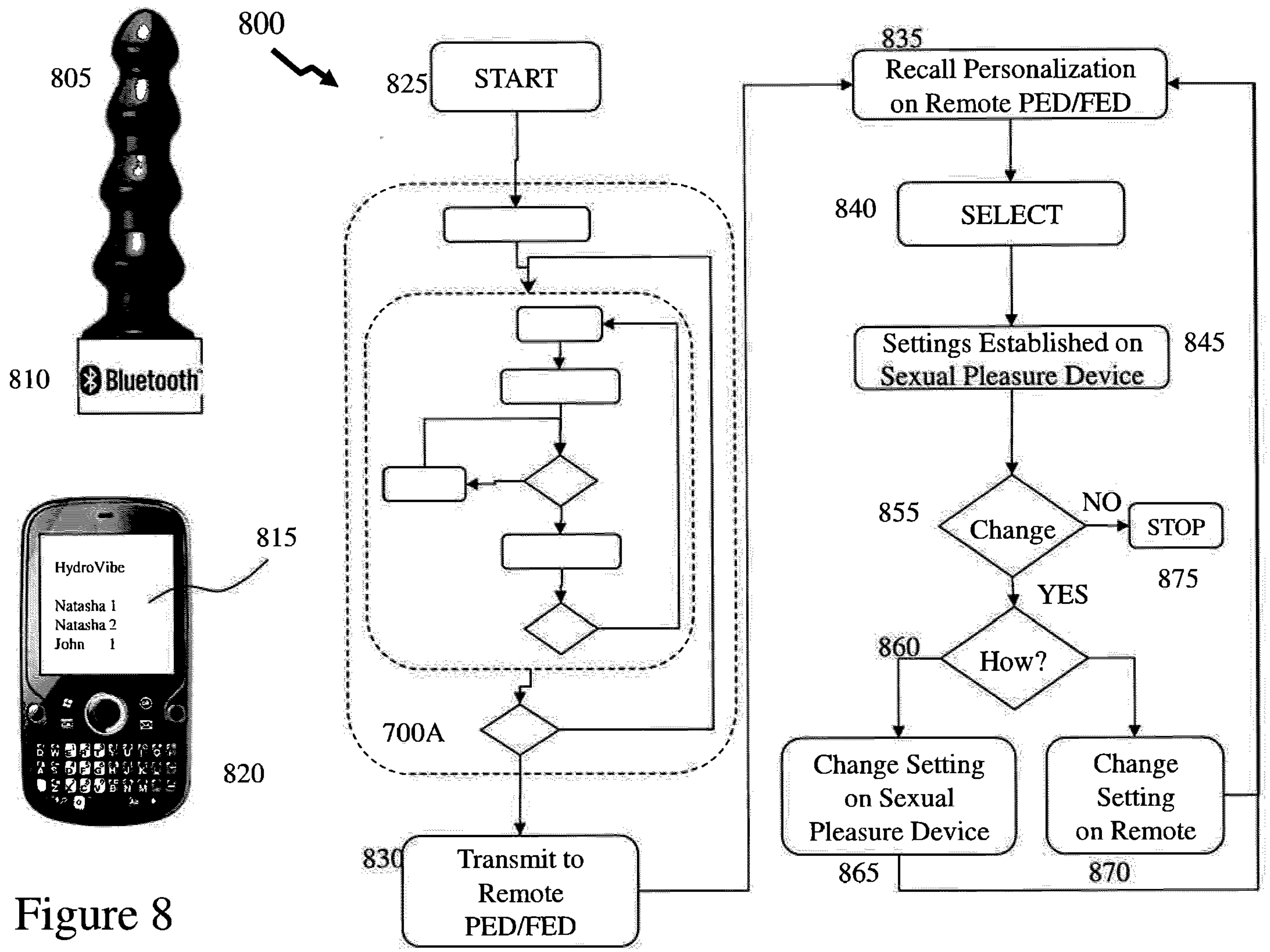


Figure 7B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810
Bluetooth
HydroVibe
Natasha 1
Natasha 2
John 1
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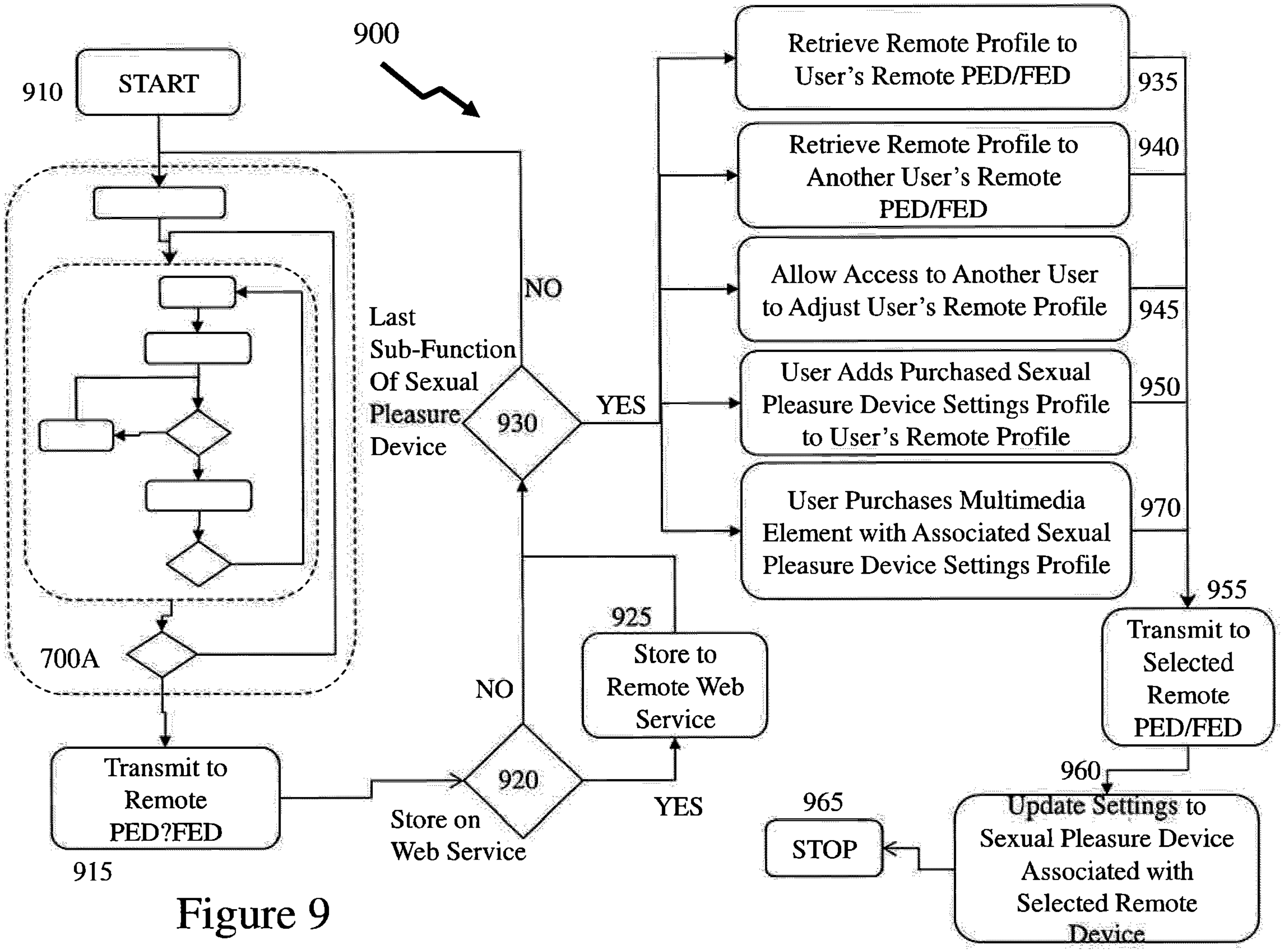
820
800
825
START
700A
830
Transmit to Remote PED/FED
835
Recall Personalization on Remote PED/FED
840
SELECT
Settings Established on Sexual Pleasure Device
845
855
Change
NO
STOP
875
YES
860
How?
Change Setting on Sexual Pleasure Device
865
Change Setting on Remote
870

Figure 8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910
START
700A
Last
Sub-Function
Of Sexual
Pleasure
Device
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NO
YES
Transmit to
Remote
PED?FED
915
Store on
Web Service
920
NO
YES
925
Store to
Remote Web
Service
Retrieve Remote Profile to
User's Remote PED/FED
935
Retrieve Remote Profile to
Another User's Remote
PED/FED
940
Allow Access to Another User
to Adjust User's Remote Profile
945
User Adds Purchased Sexual
Pleasure Device Settings Profile
to User's Remote Profile
950
User Purchases Multimedia
Element with Associated Sexual
Pleasure Device Settings Profile
970
955
Transmit to
Selected
Remote
PED/FED
960
Update Settings to
Sexual Pleasure Device
Associated with
Selected Remote
Device
965
STOP

Figure 9

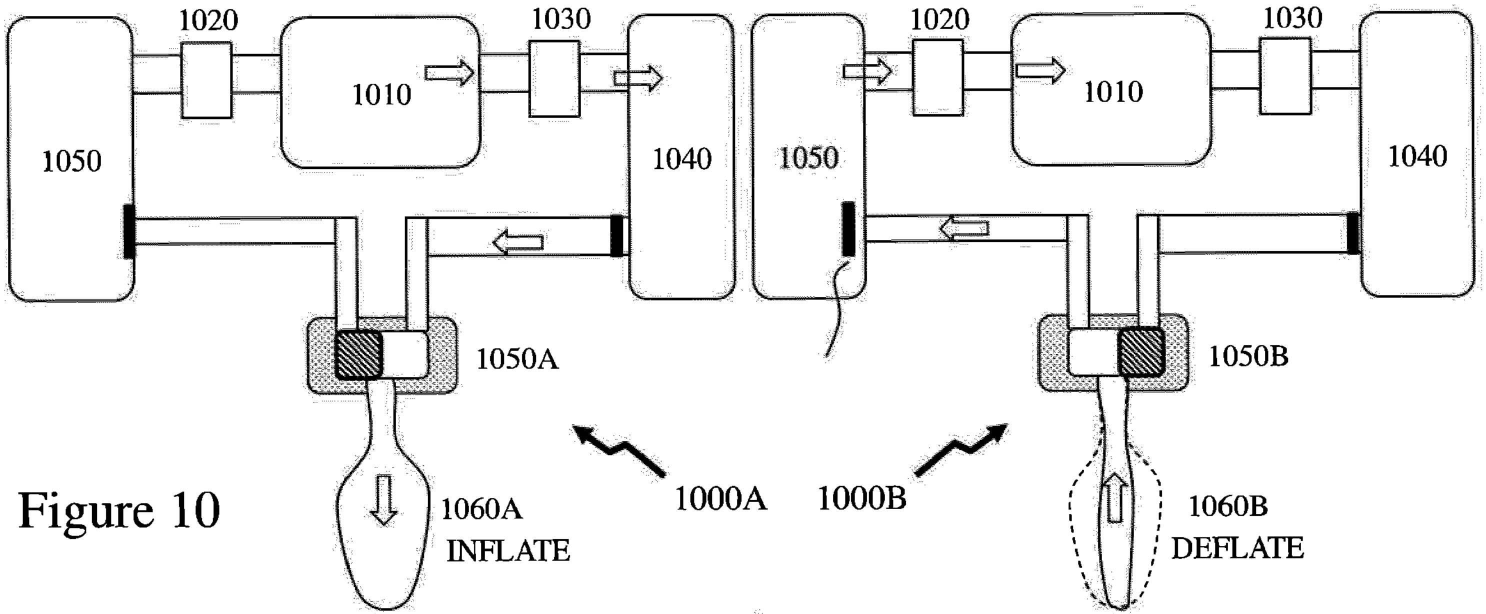

Figure 10

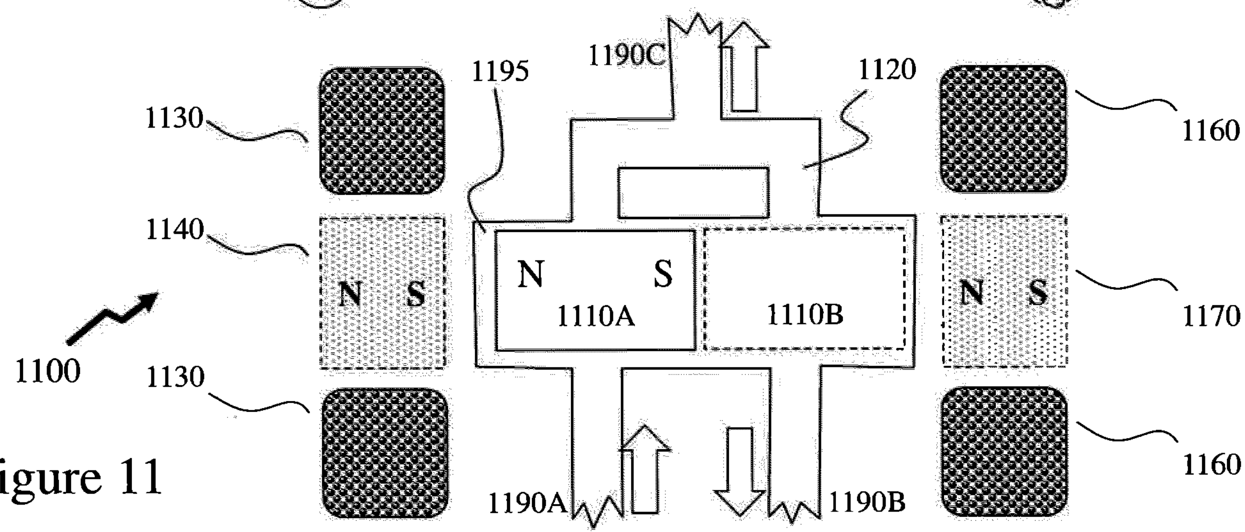

Figure 11

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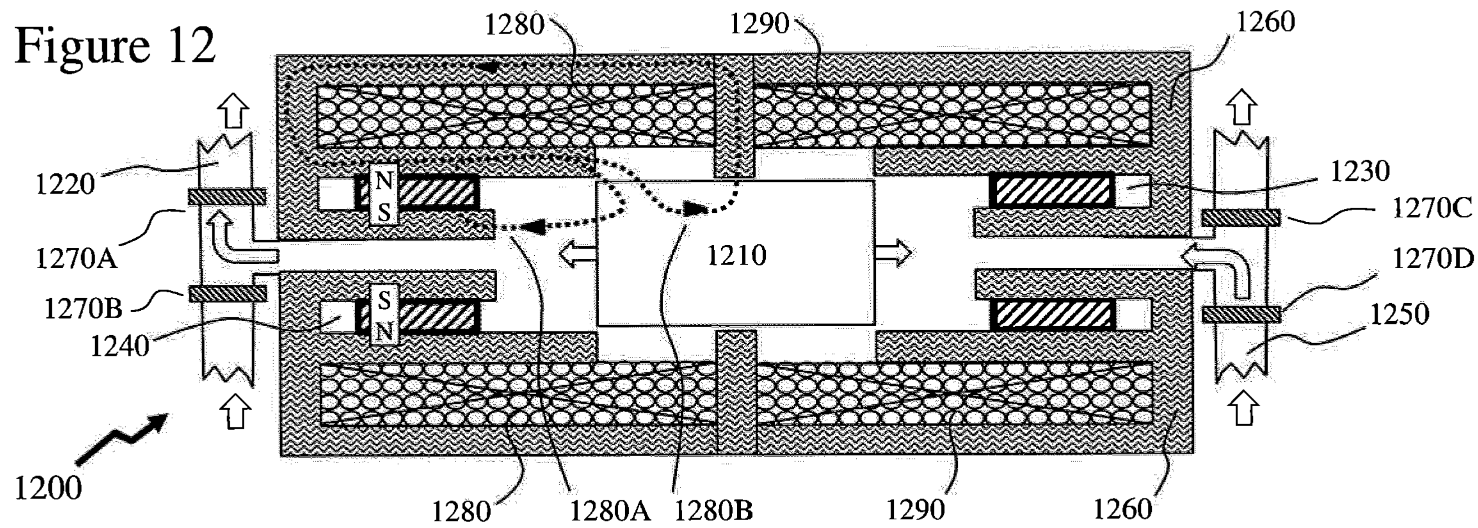
Figure 12



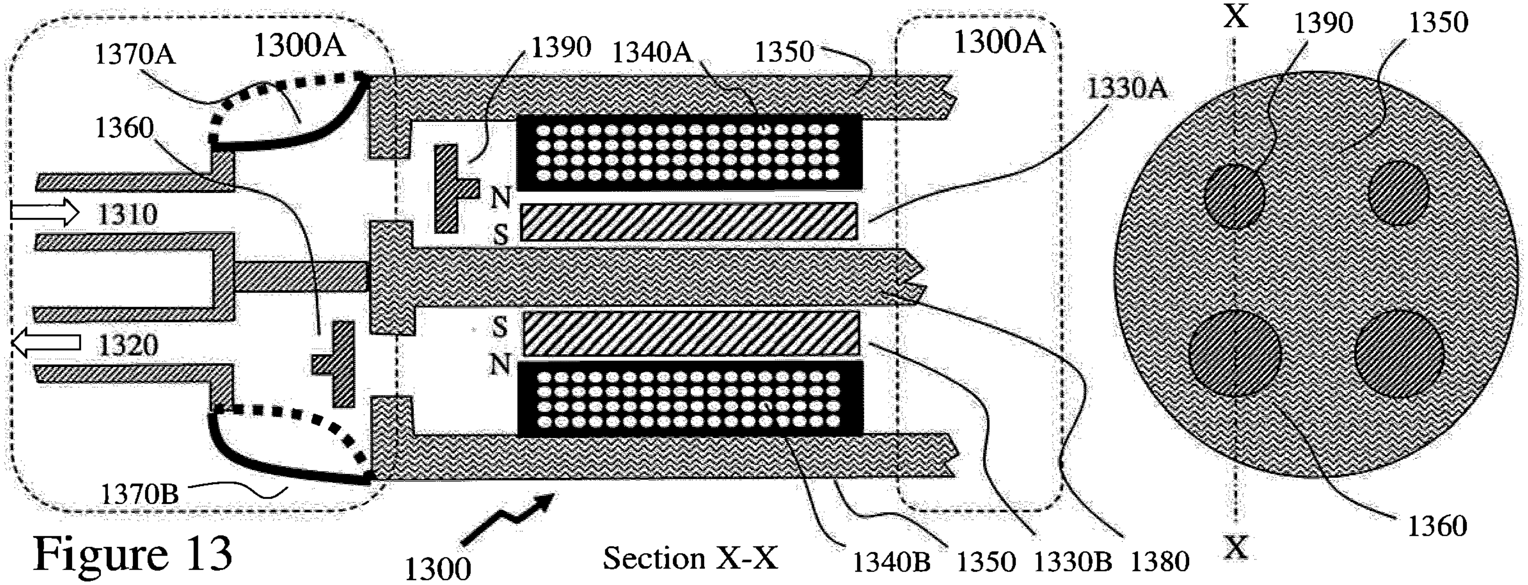


Figure 13

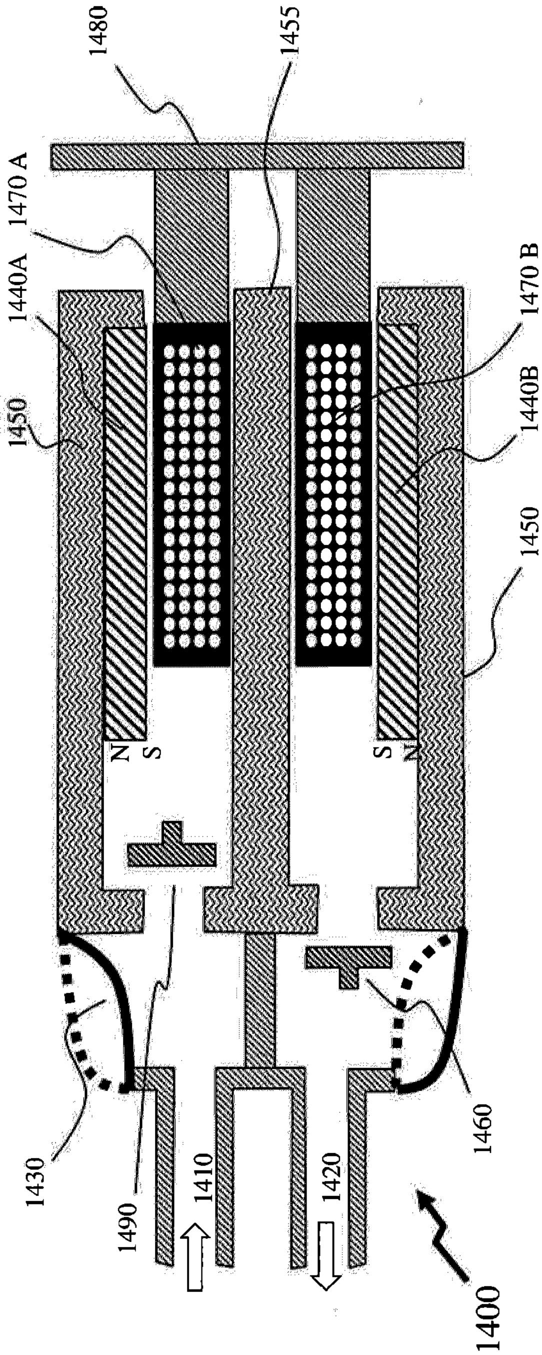


Figure 14

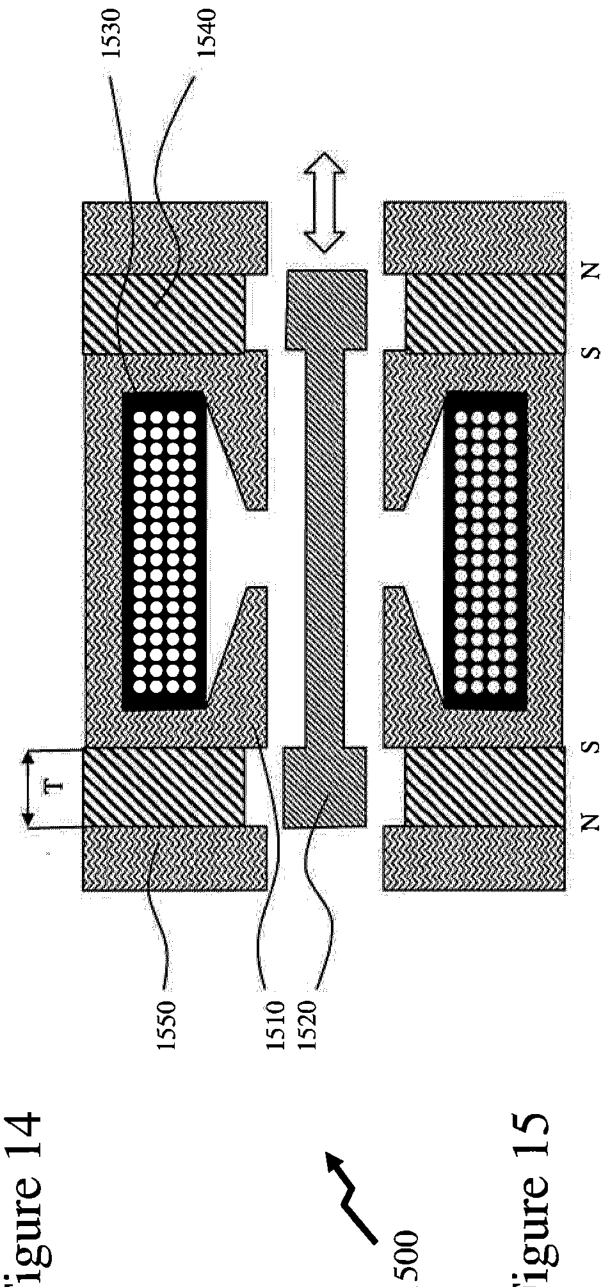


Figure 15

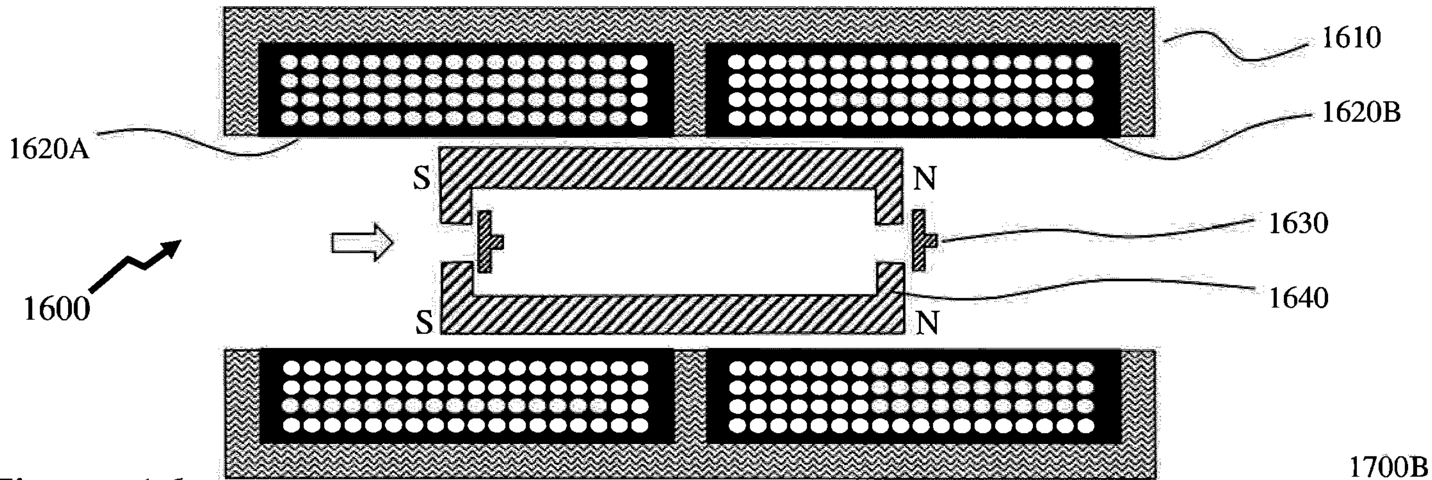


Figure 16

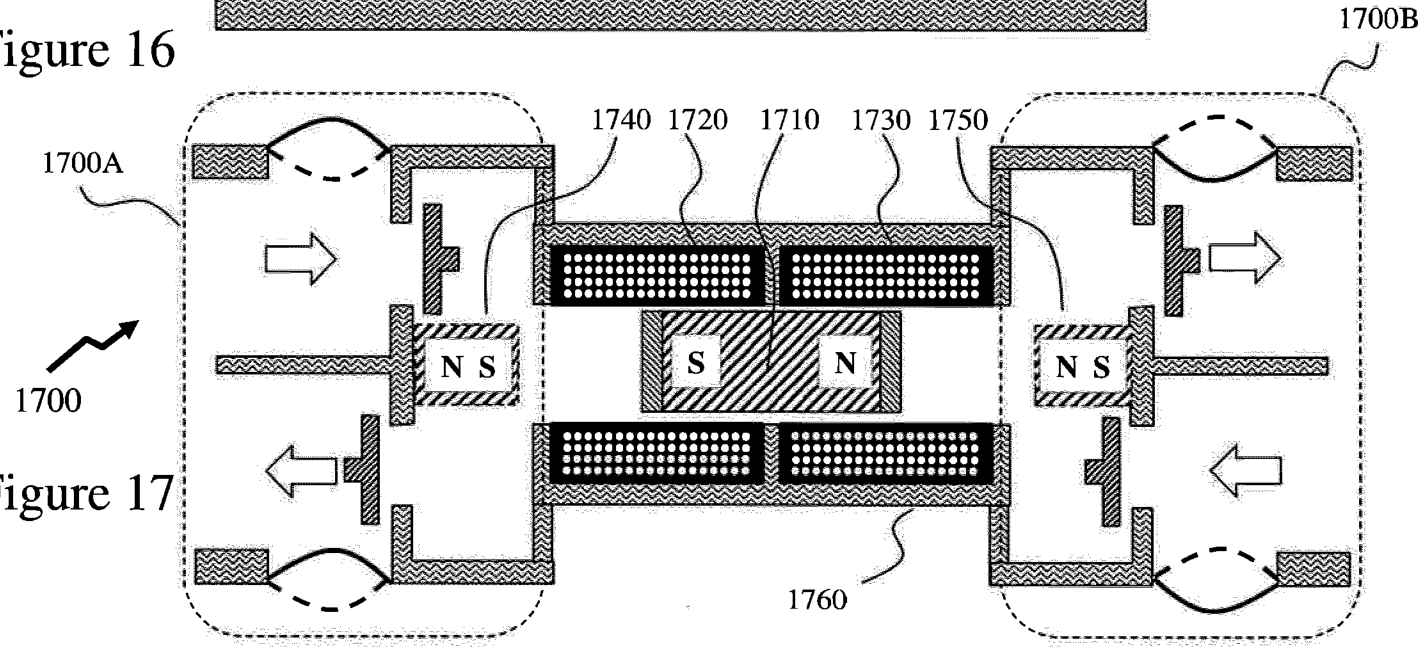
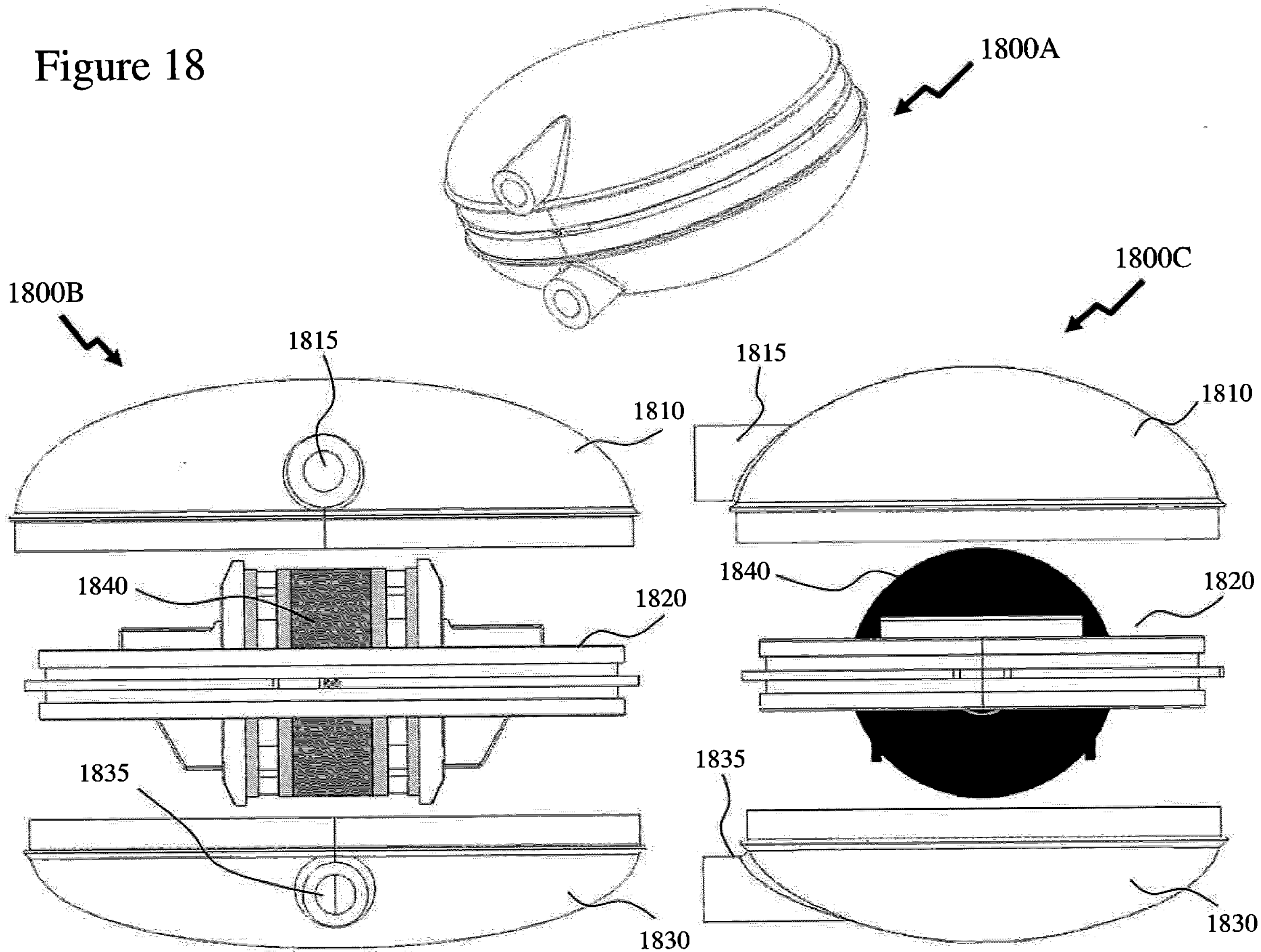


Figure 17

Figure 18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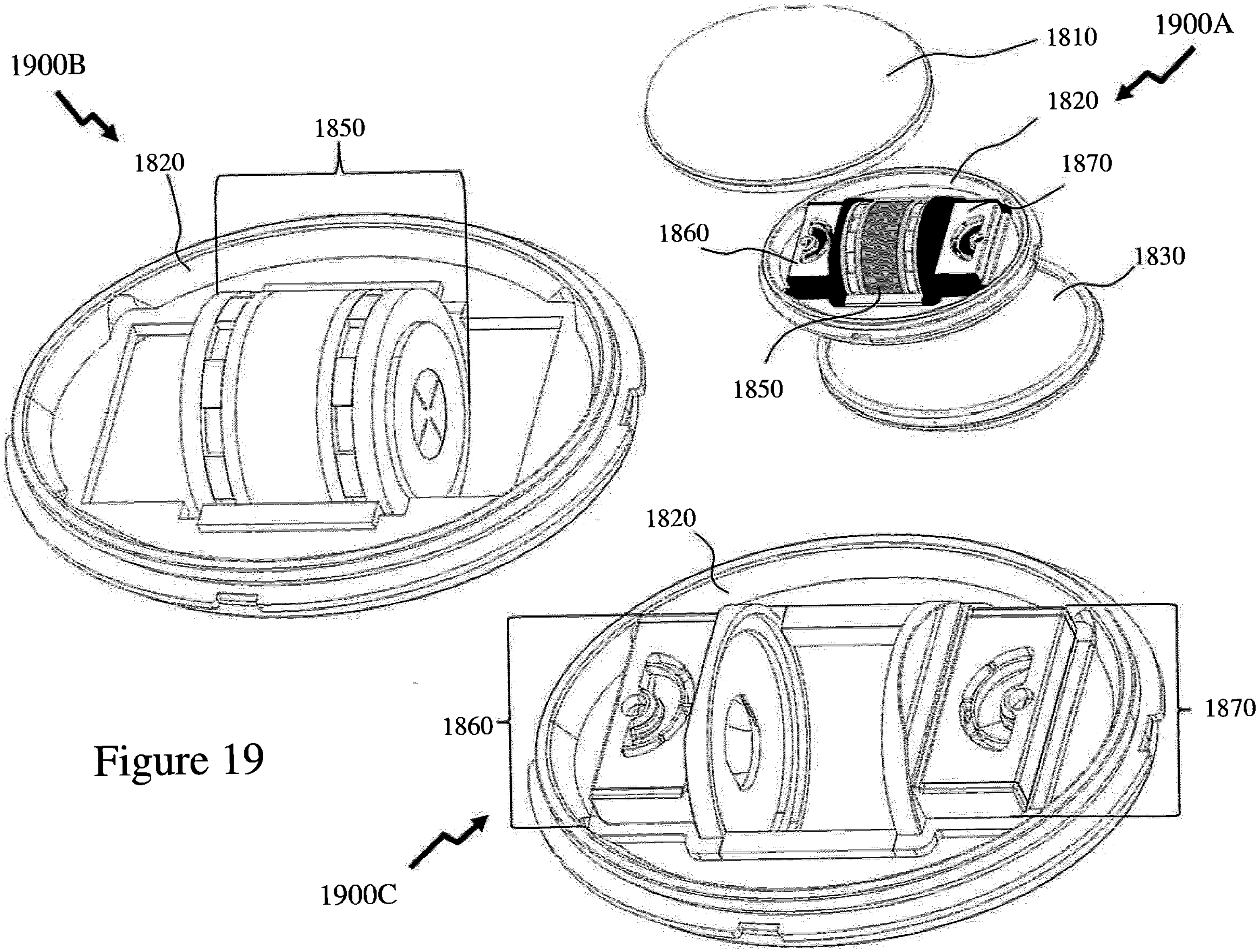
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Figure 19

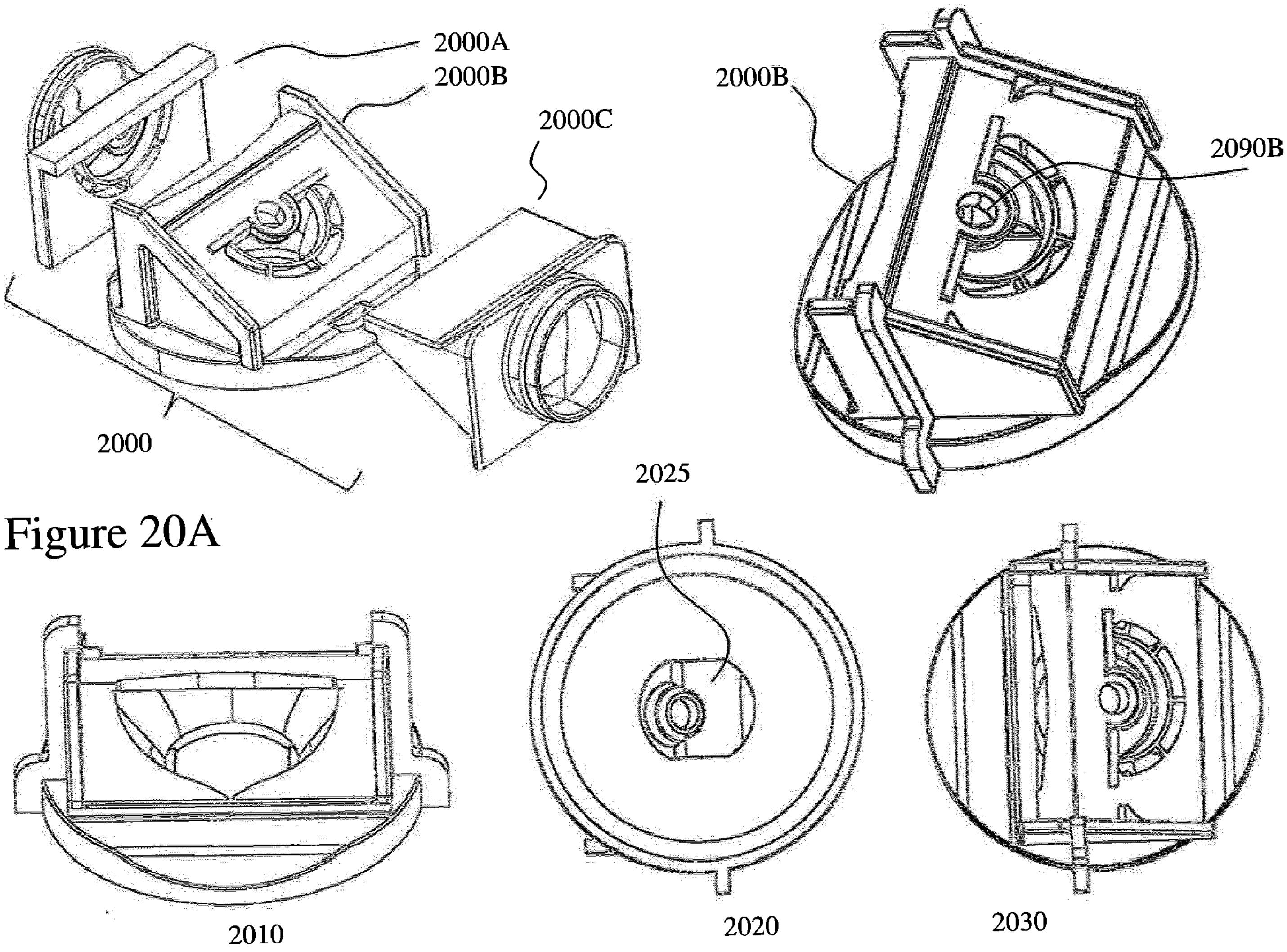

Figure 20A

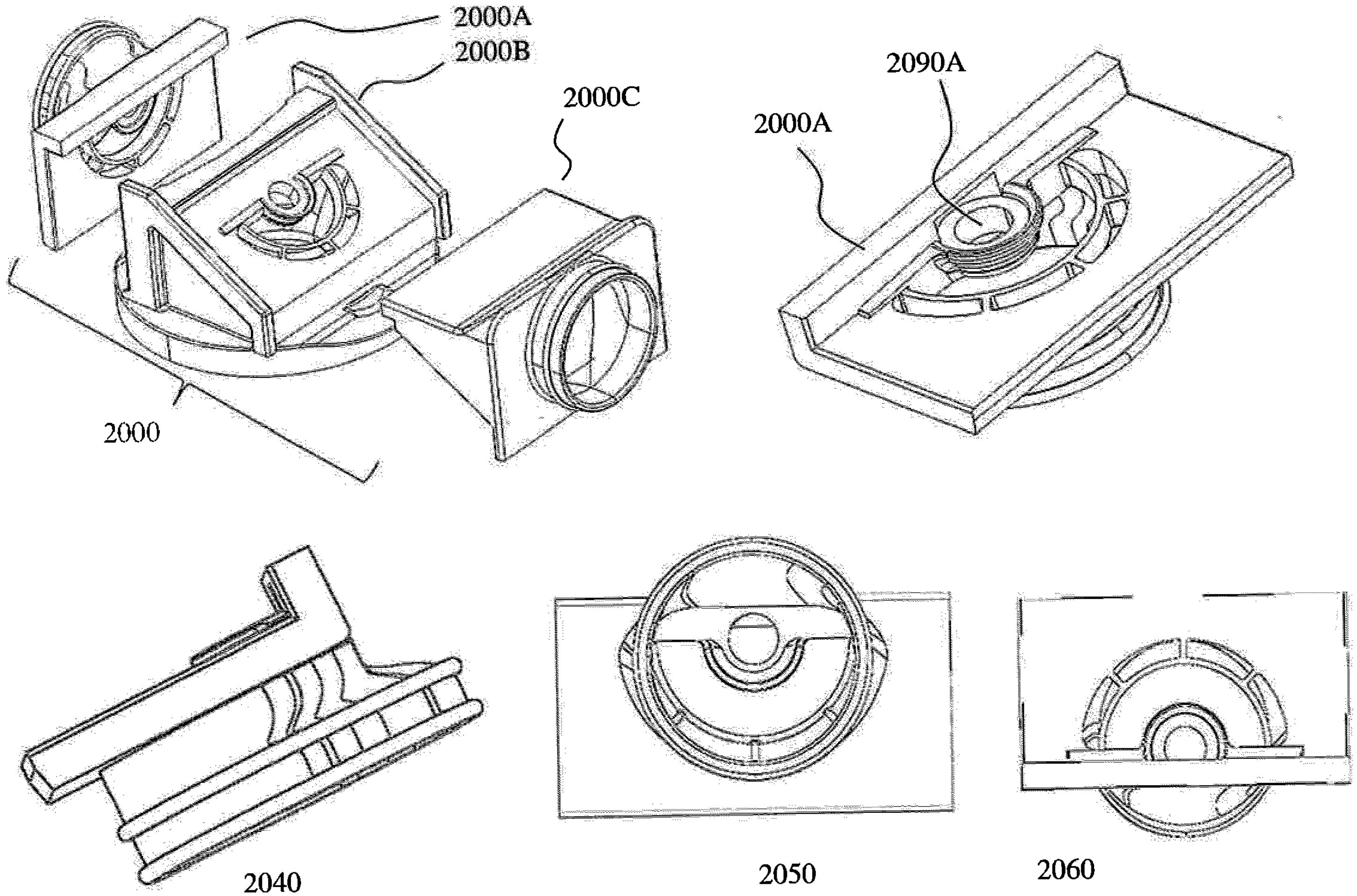

Figure 20B

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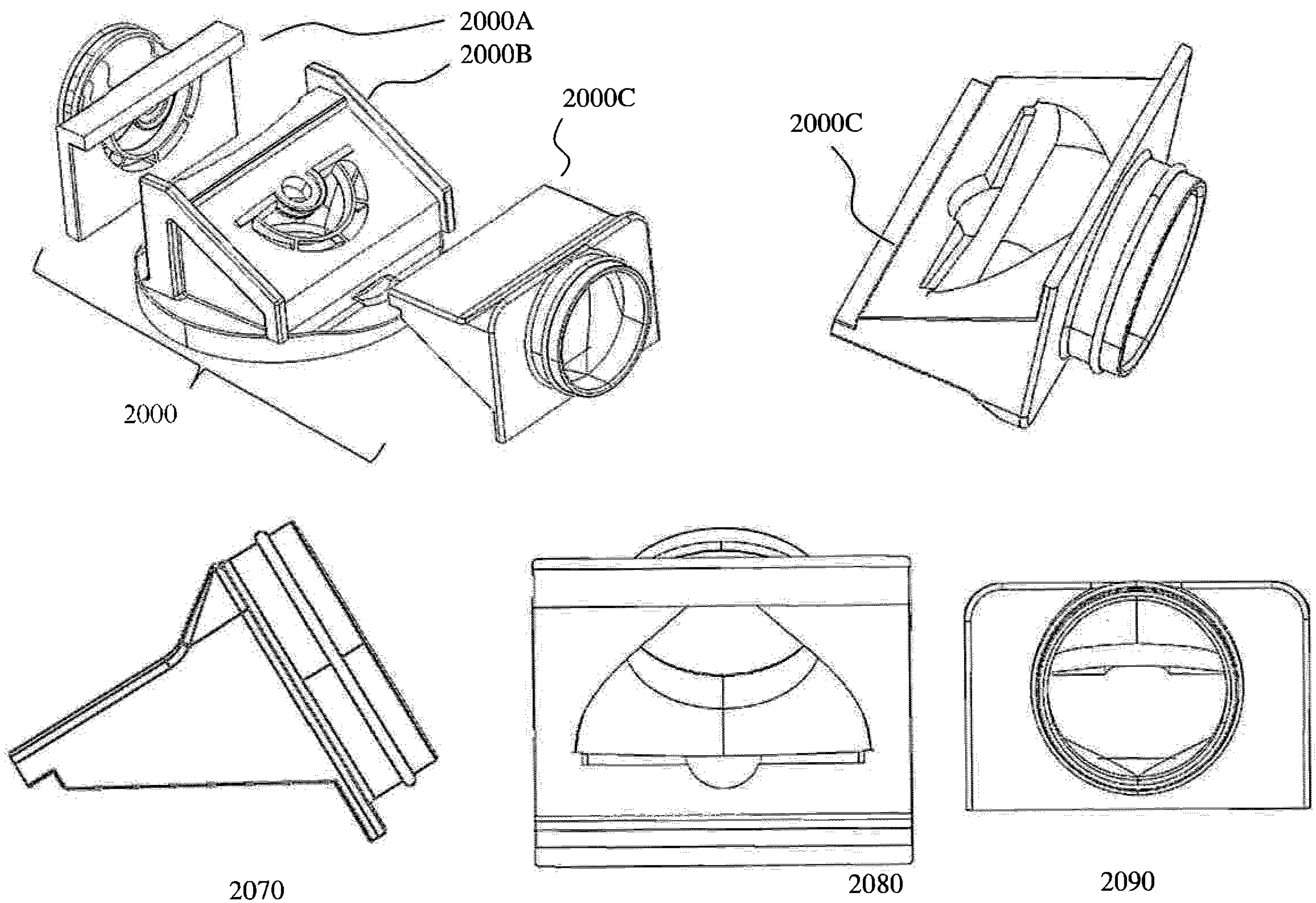
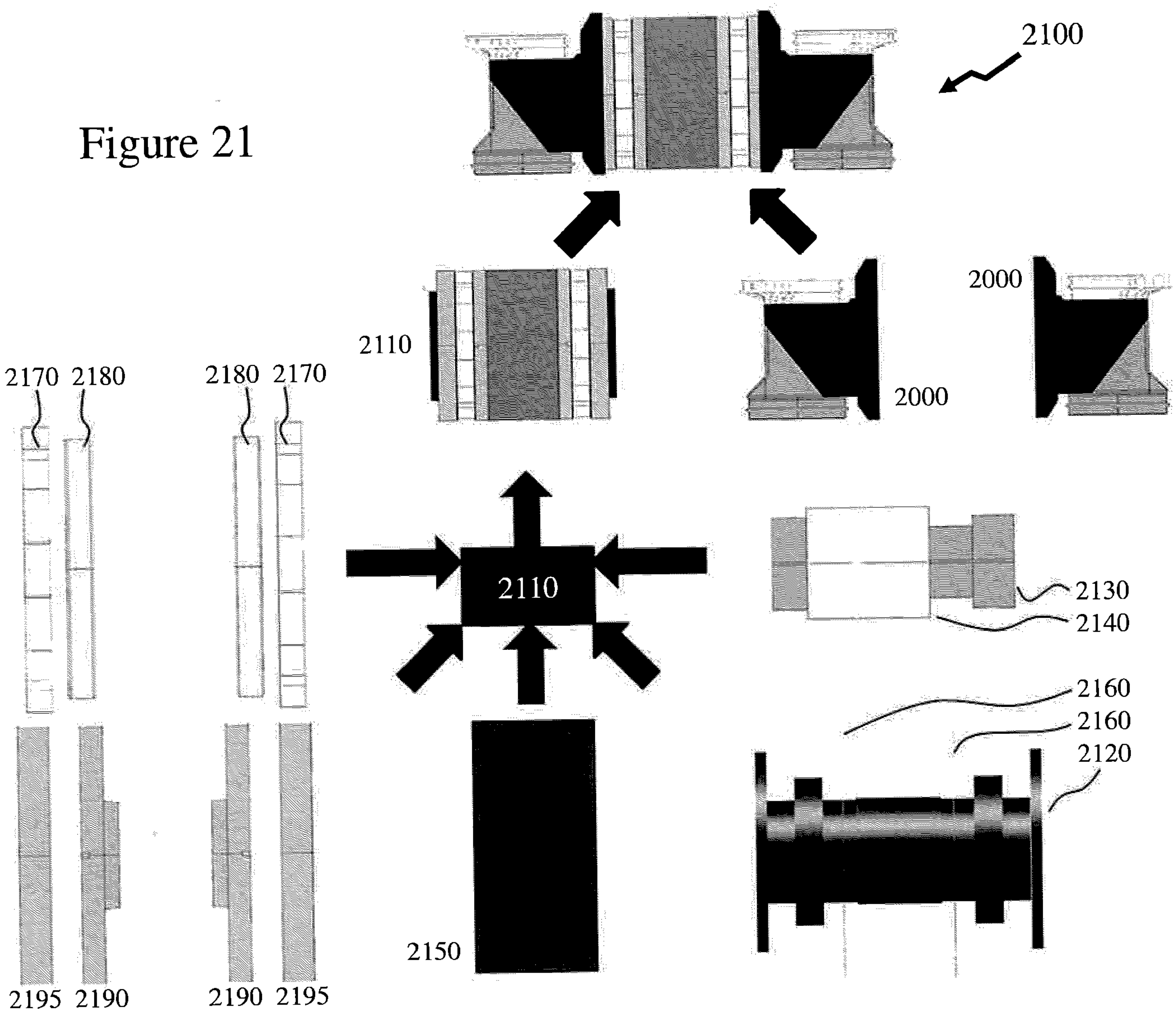


Figure 20C

Figure 21



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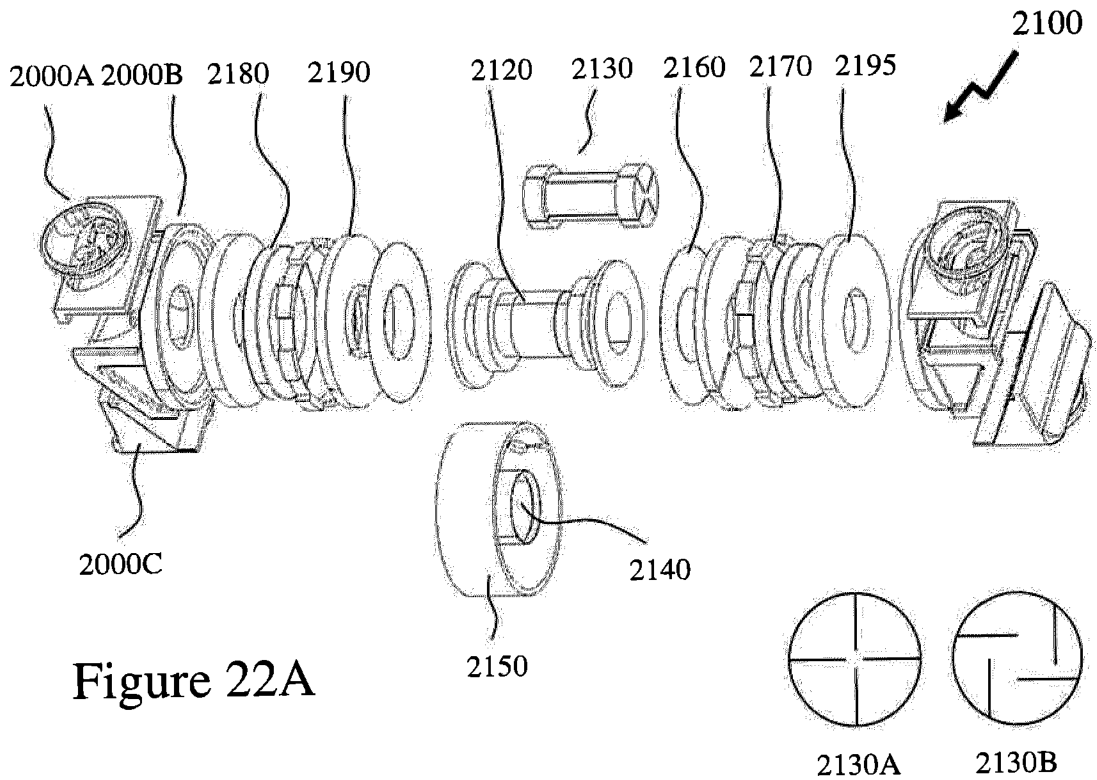


Figure 22A

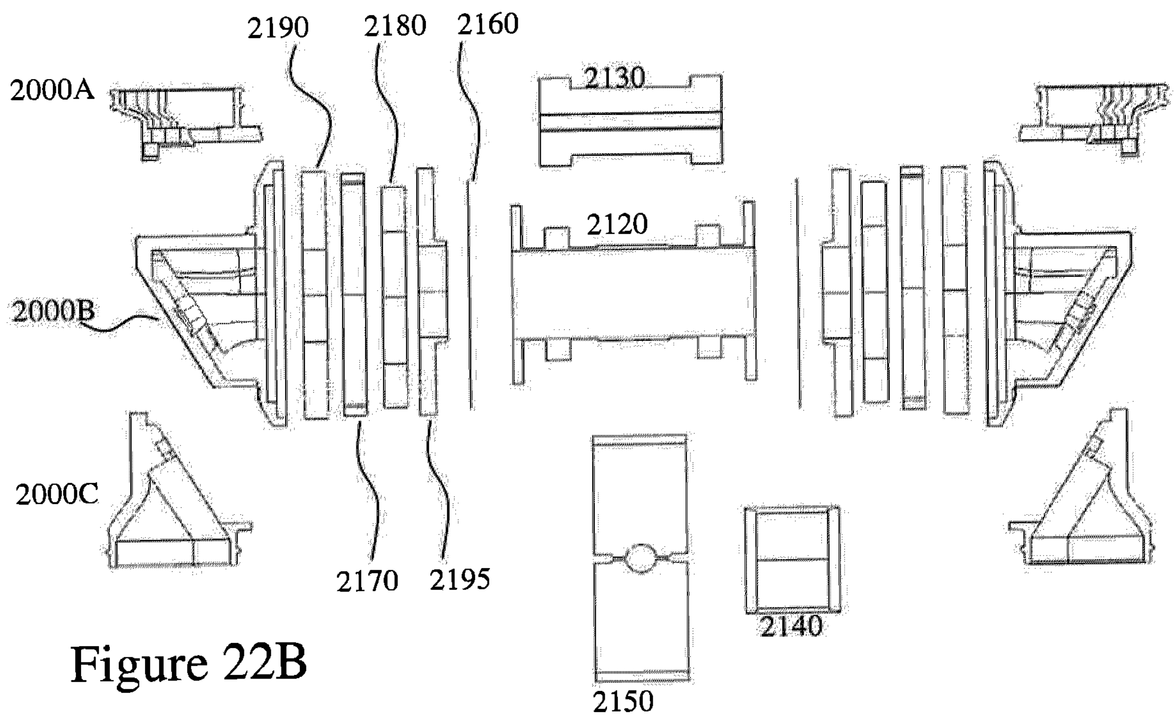


Figure 22B

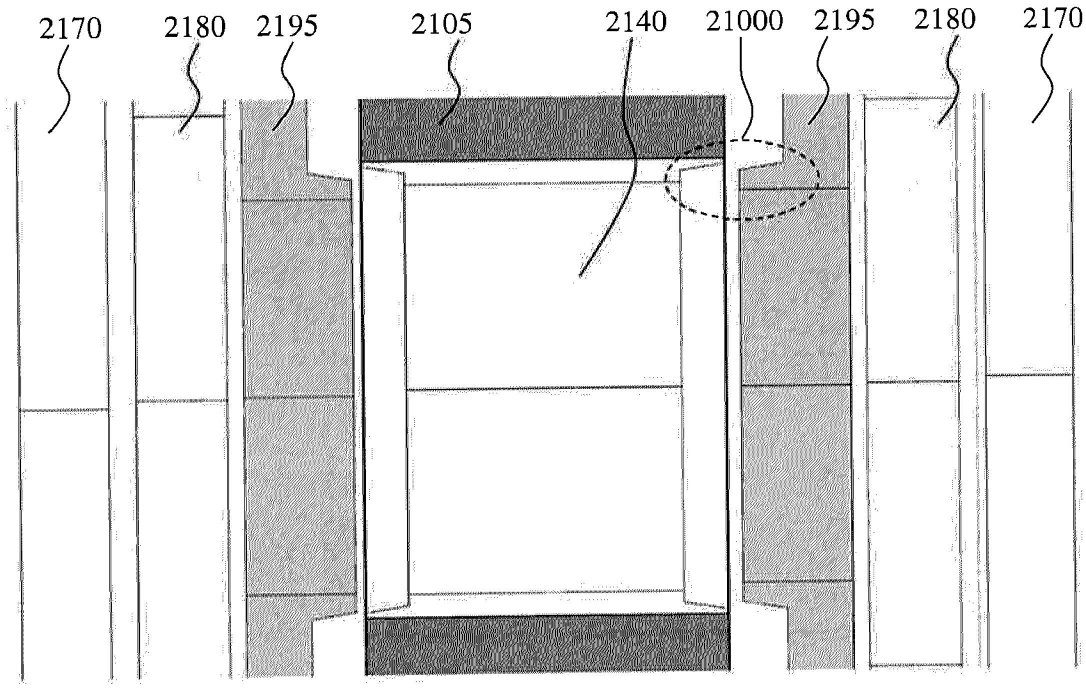


Figure 22C

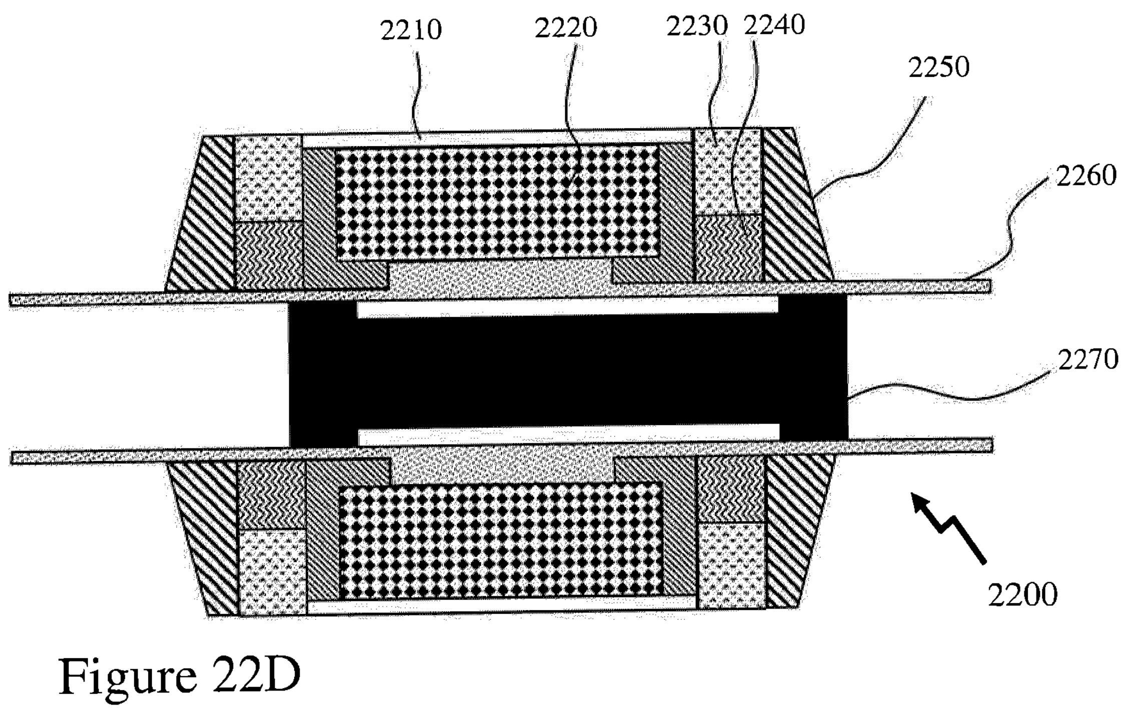
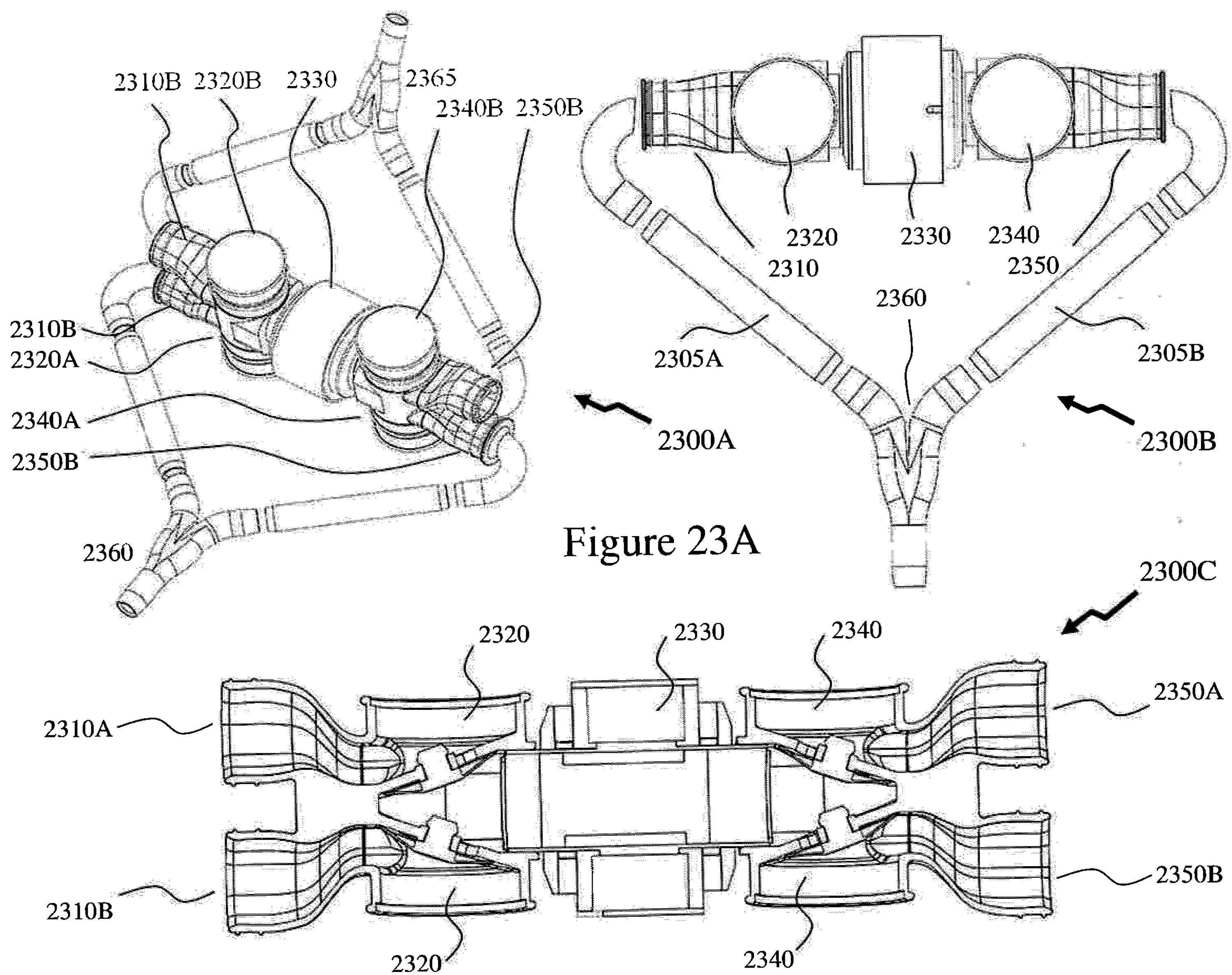


Figure 22D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2340
2310
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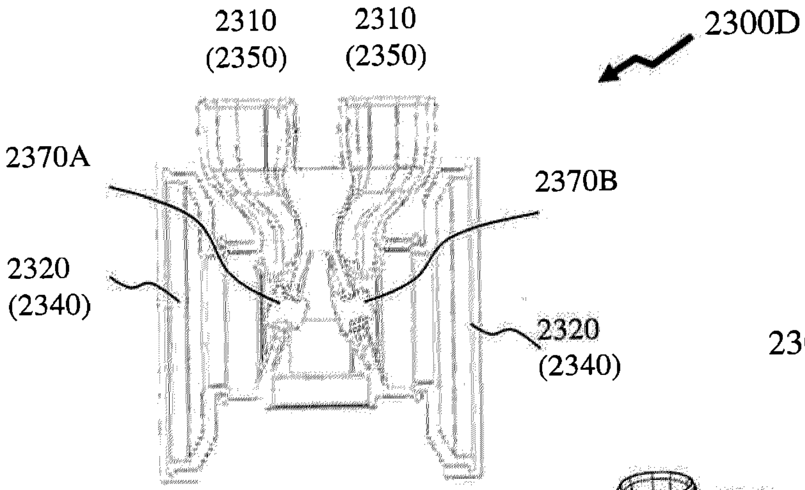
Figure 23A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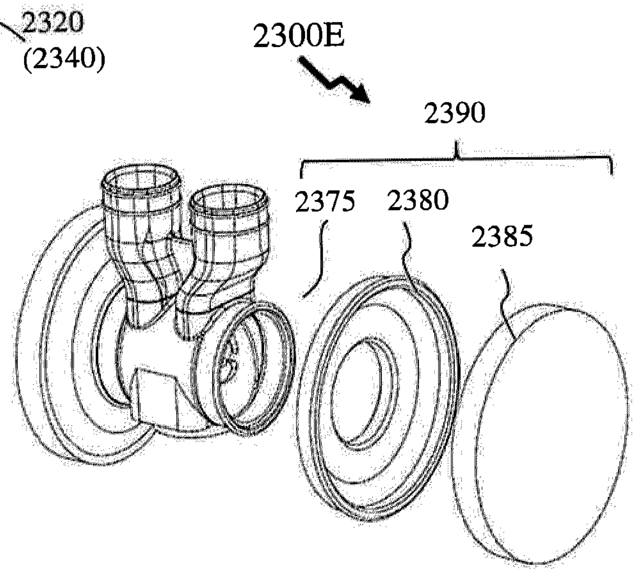
(2340)
2320
(2340)

Figure 23B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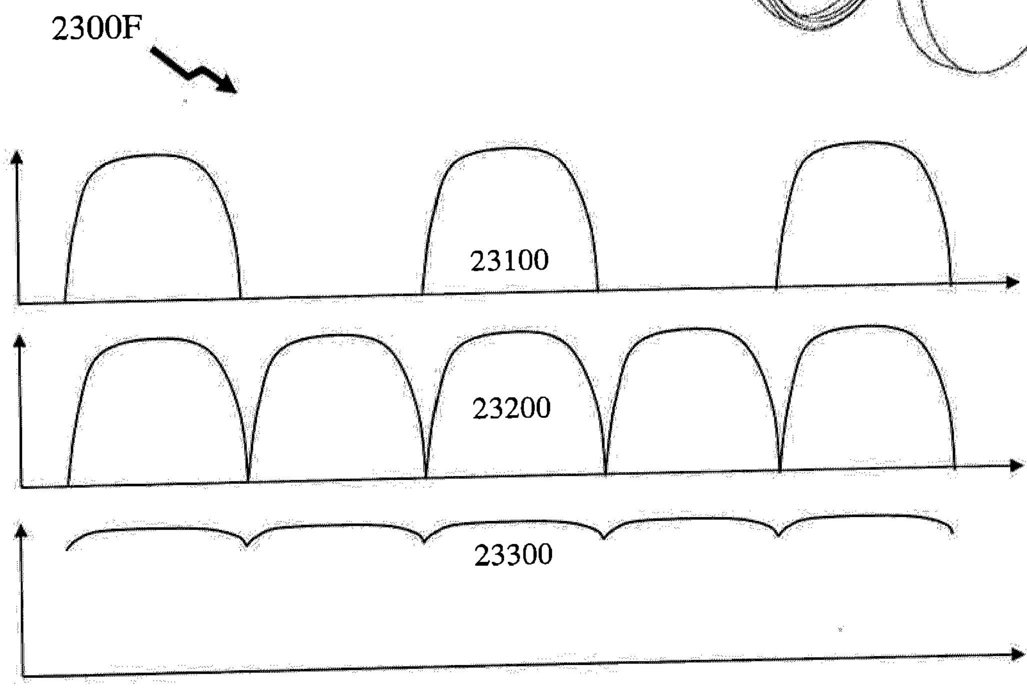
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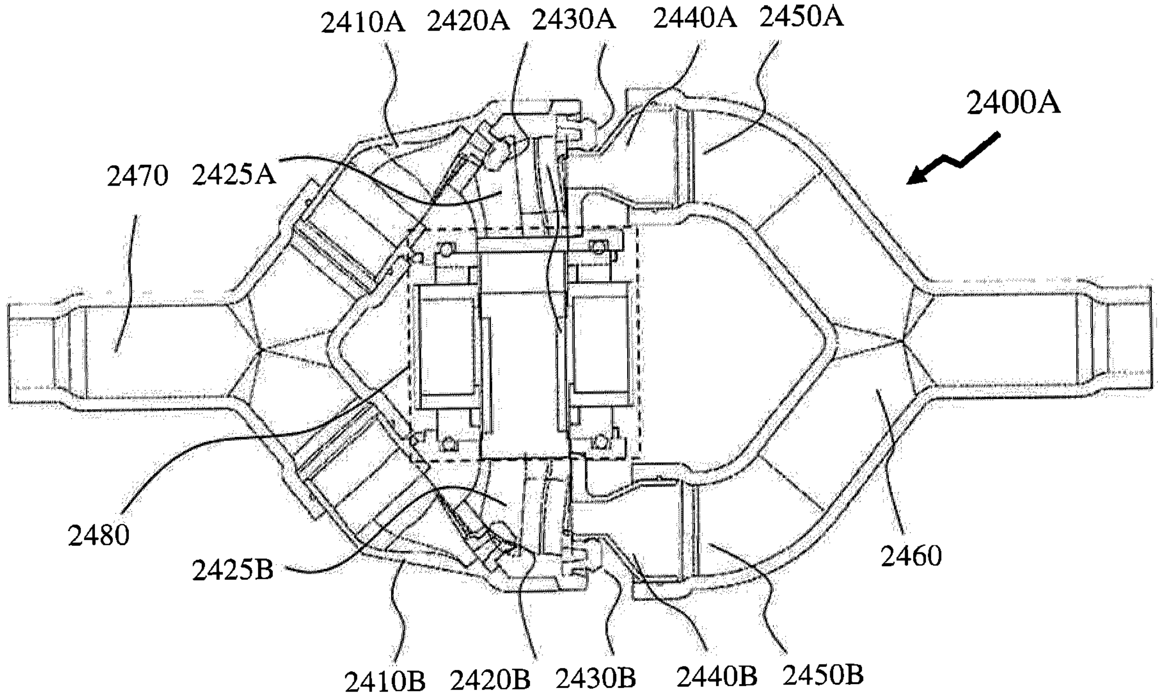

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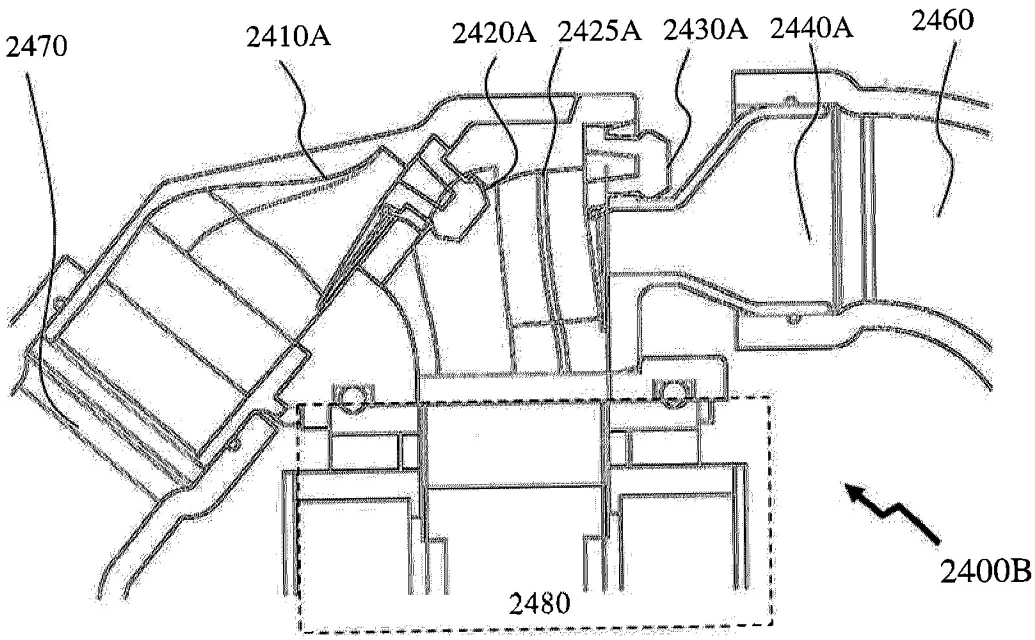
2450B

Figure 24



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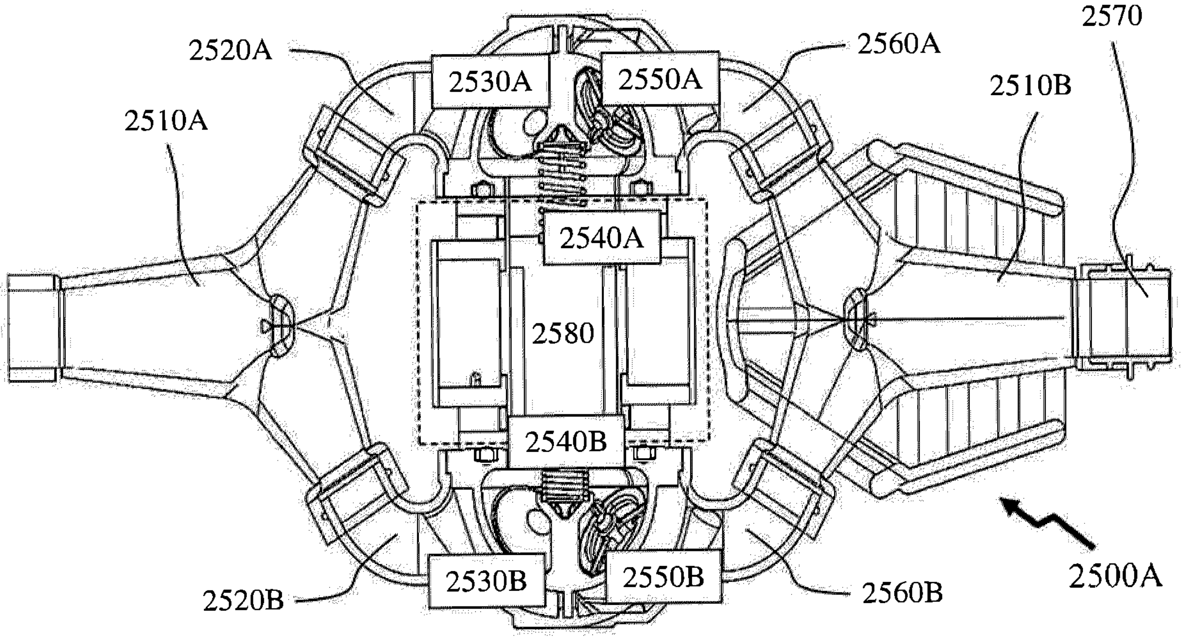
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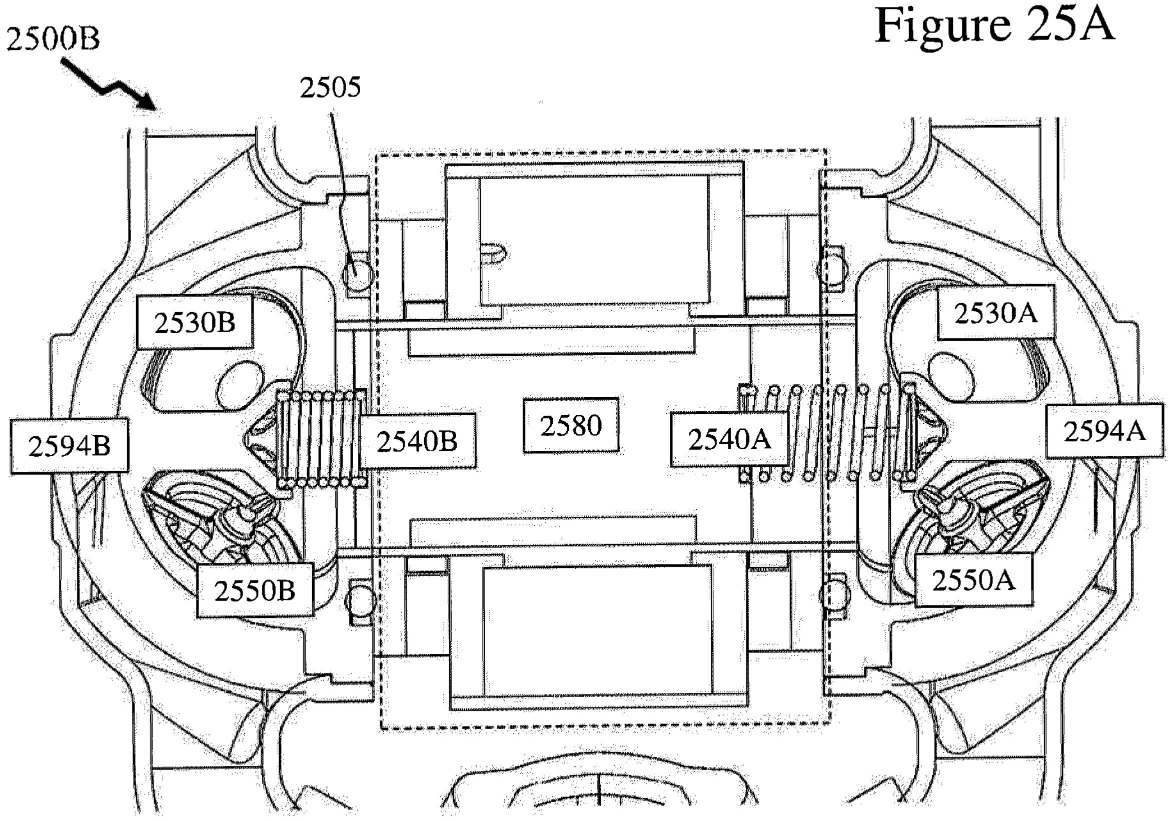
2560B

Figure 25A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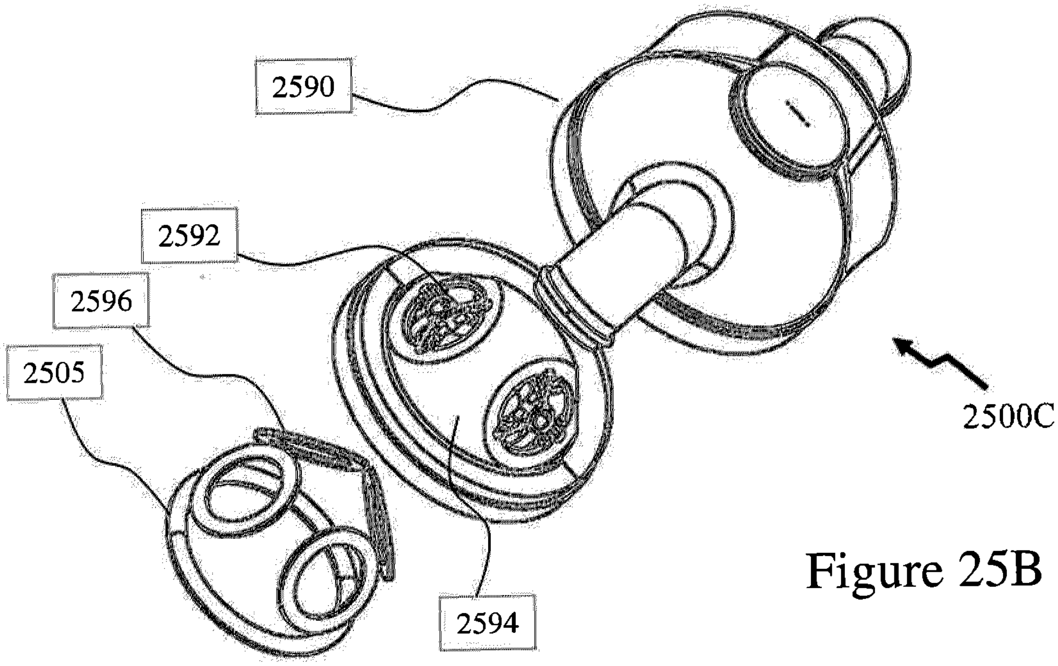
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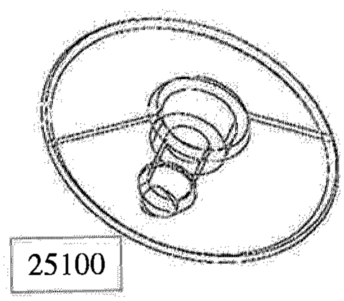
Figure 25B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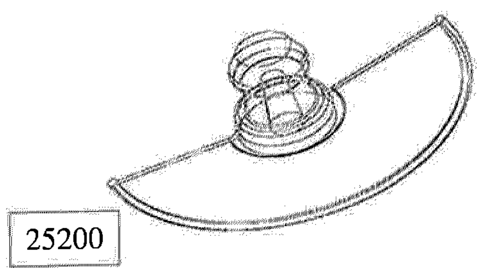
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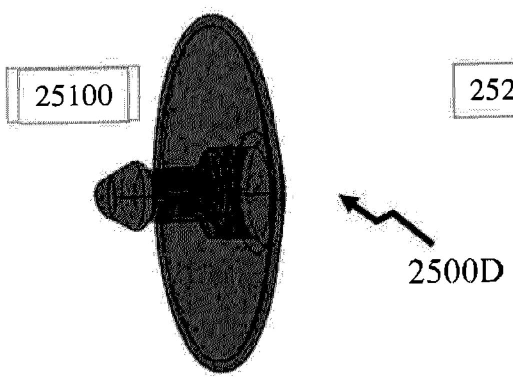
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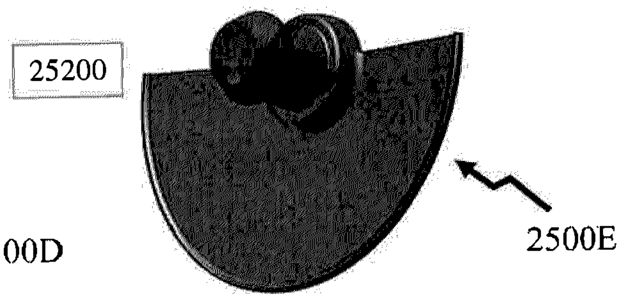

25200
2500E

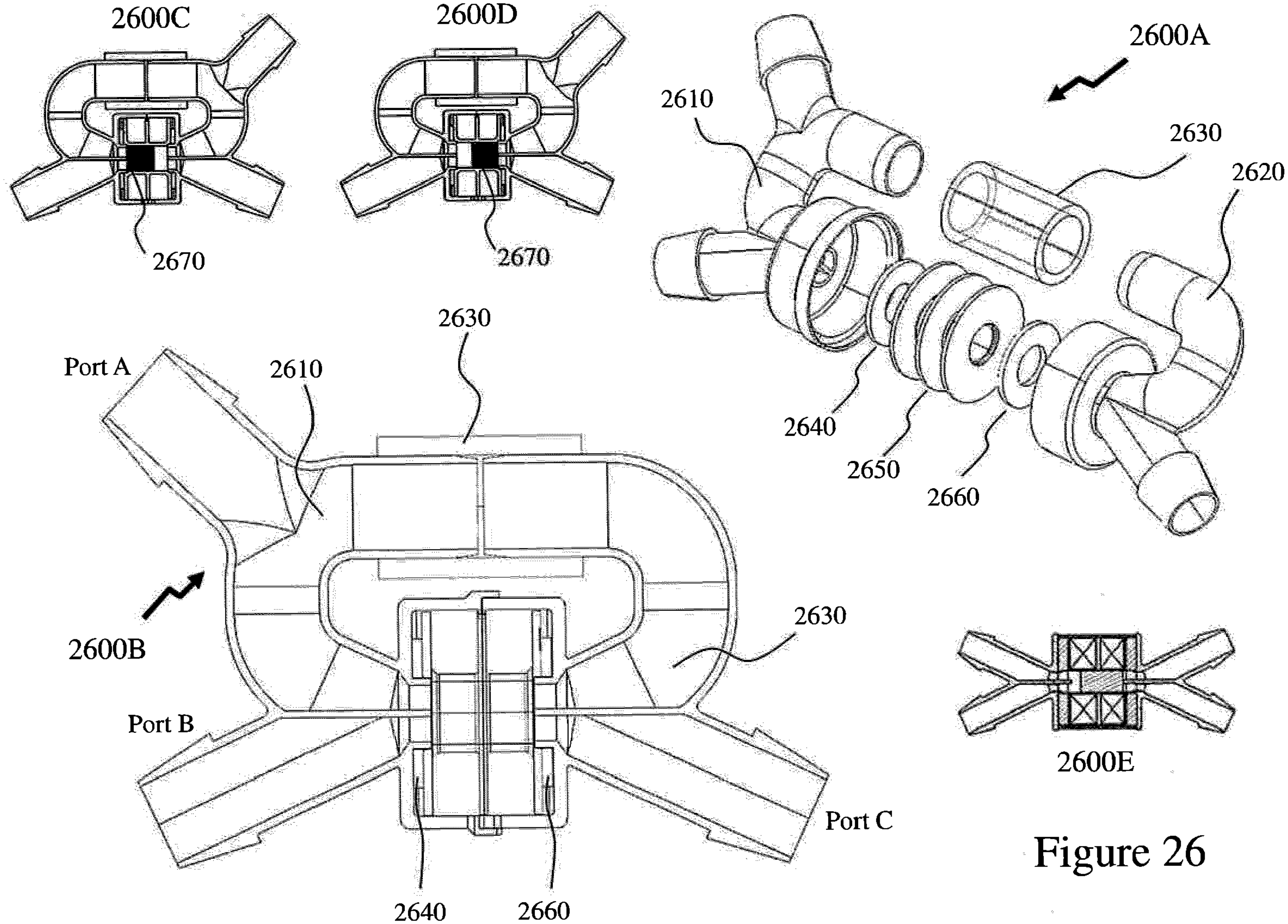

2600C
2670
2600D
2670
2600A
2610
2630
2620
2640
2650
2660
2630
Port A
2610
2630
2600B
Port B
Port C
2640
2660
2600E

Figure 26

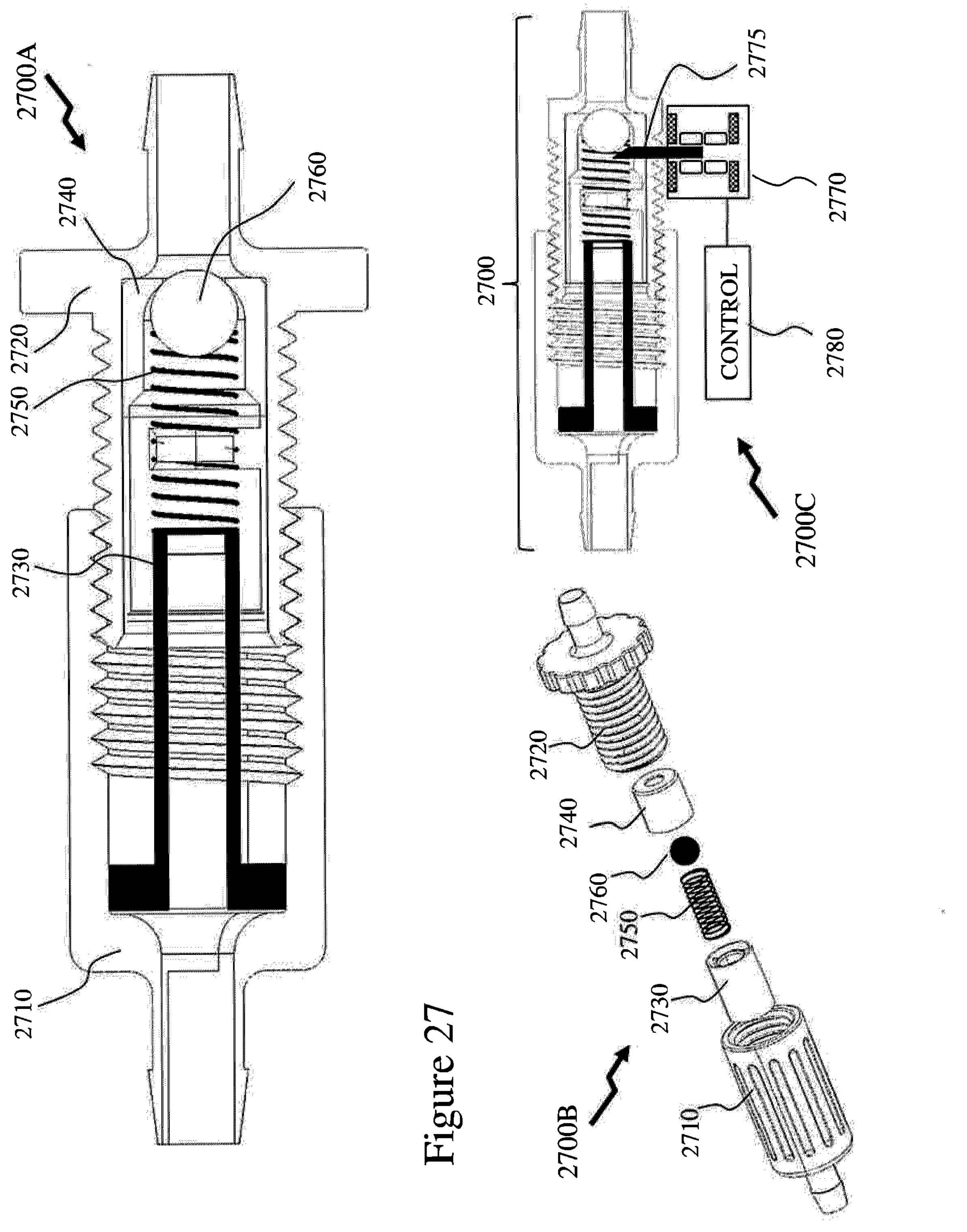

2700A
2740
2760
2720
2750
2730
2710
2700B
2720
2740
2760
2750
2730
2710
2700
2775
2770
CONTROL
2780
2700C

Figure 27

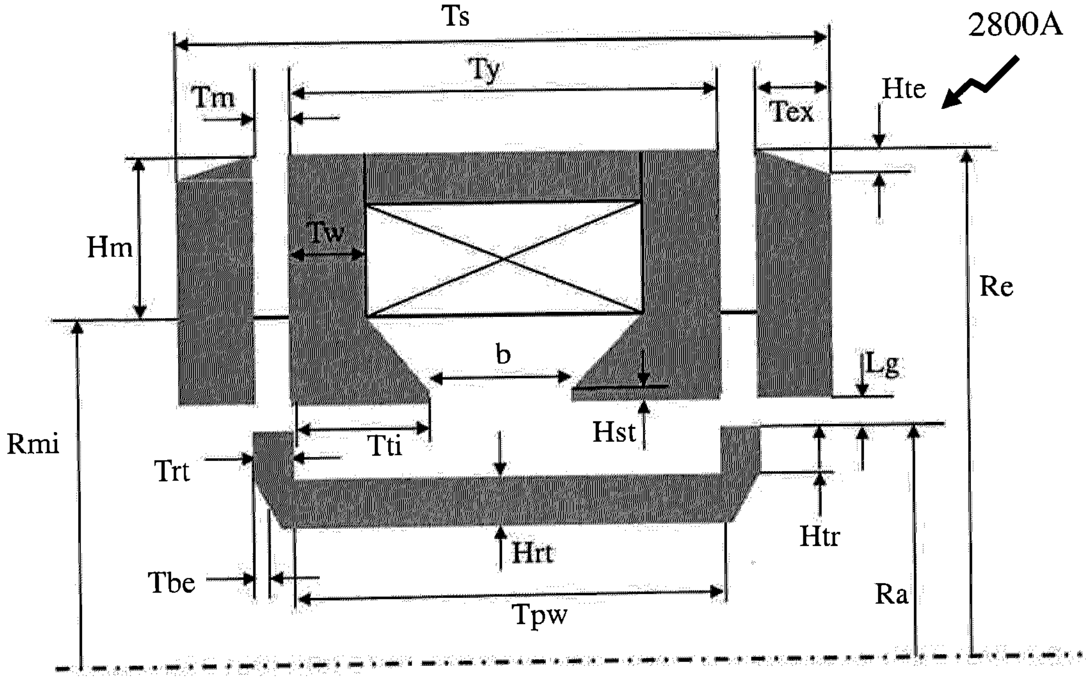
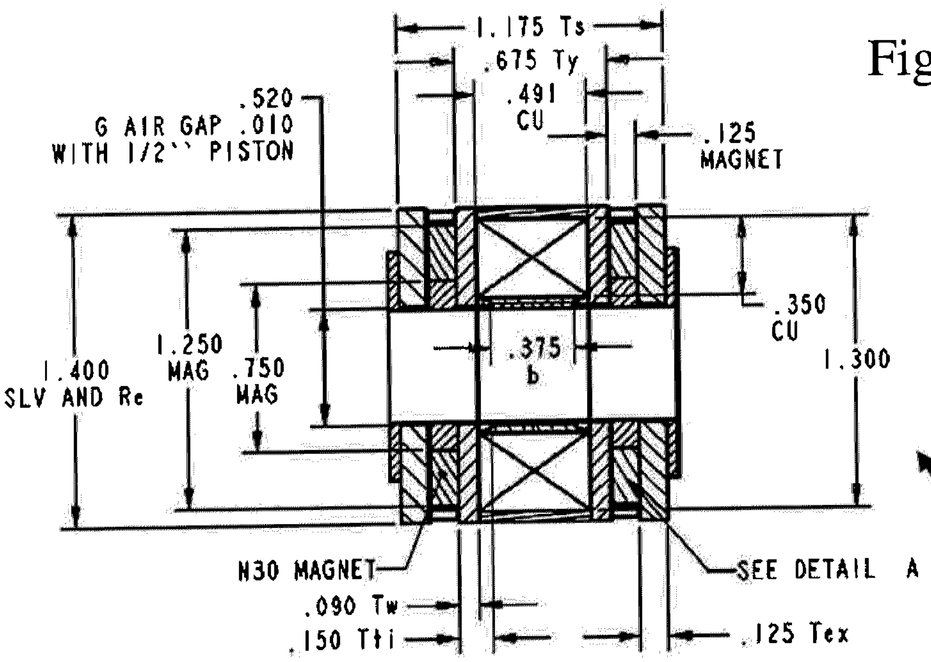

Ts
2800A
Ty
Tm
Tex
Hte
Hm
Tw
Re
b
Lg
Rmi
Hst
Tti
Trt
Htr
Hrt
Tbe
Ra
Tpw

Figure 28


1.175 Ts
.675 Ty
.520
G AIR GAP .010
WITH 1/2`` PISTON
.491
CU
.125
MAGNET
.350
CU
1.250
MAG
.375
b
1.300
1.400
SLV AND Re
.750
MAG
N30 MAGNET
SEE DETAIL A
2800B
.090 Tw
.150 Tti
.125 Tex

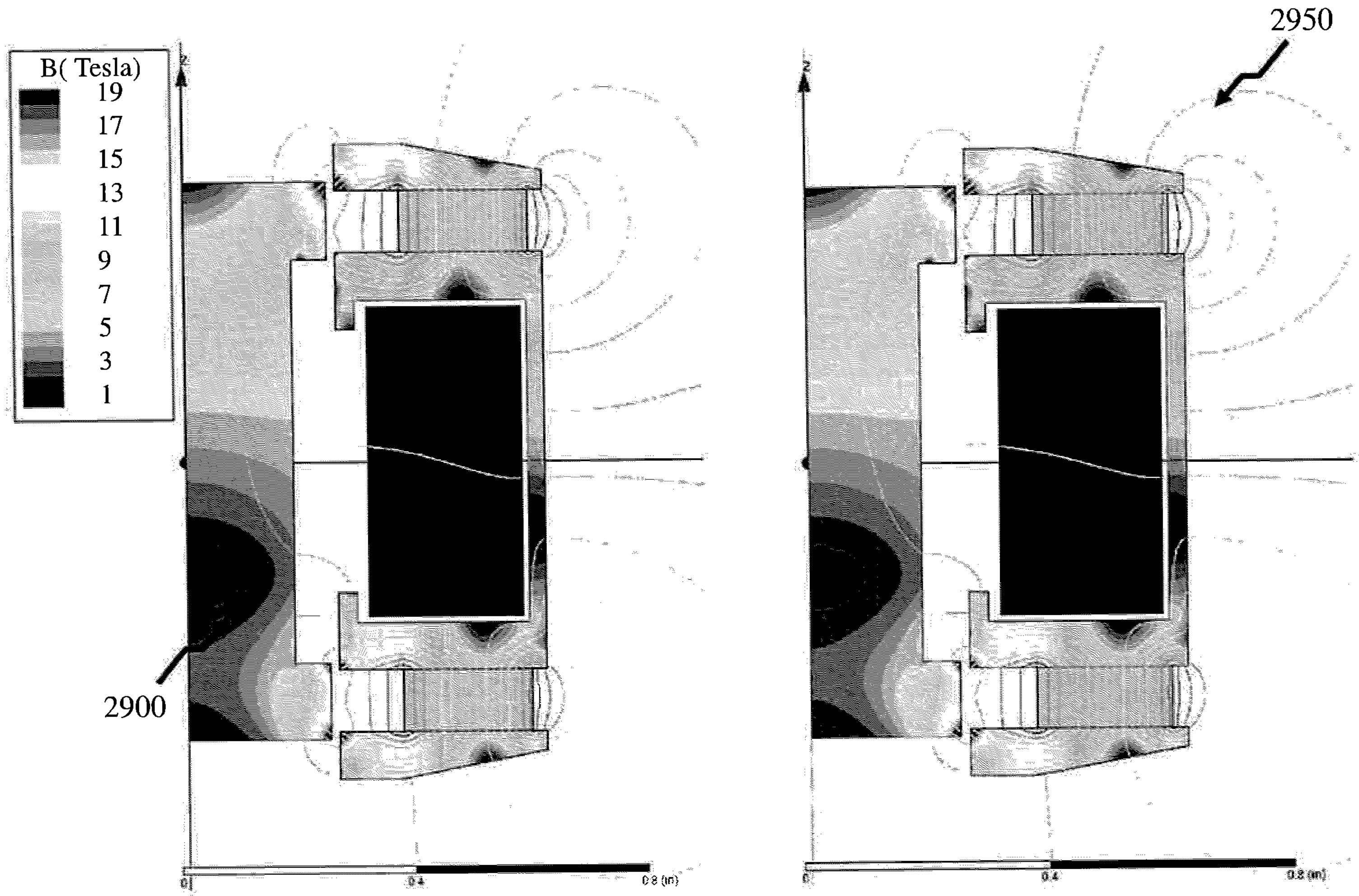
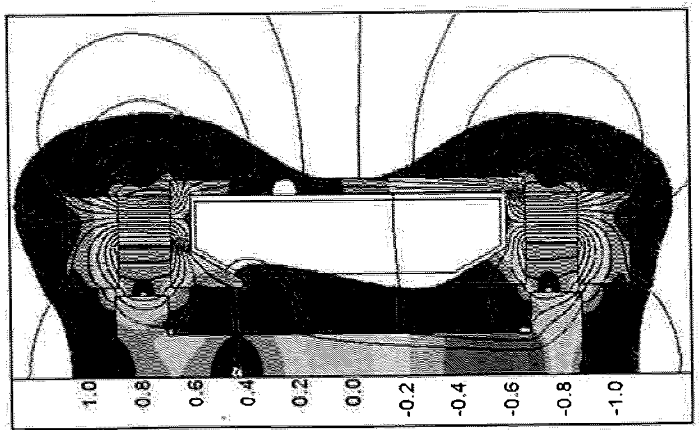
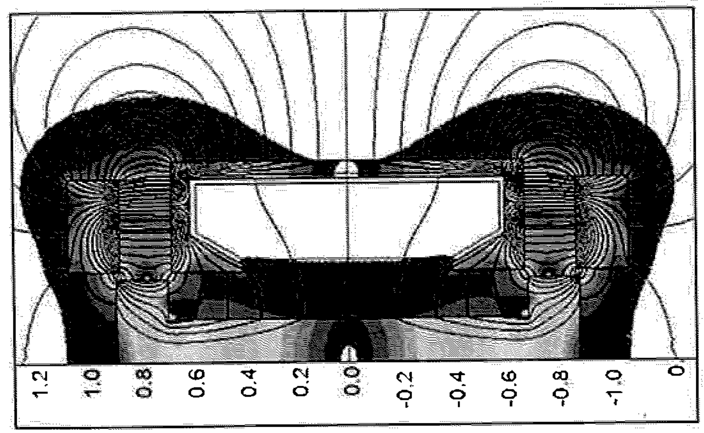


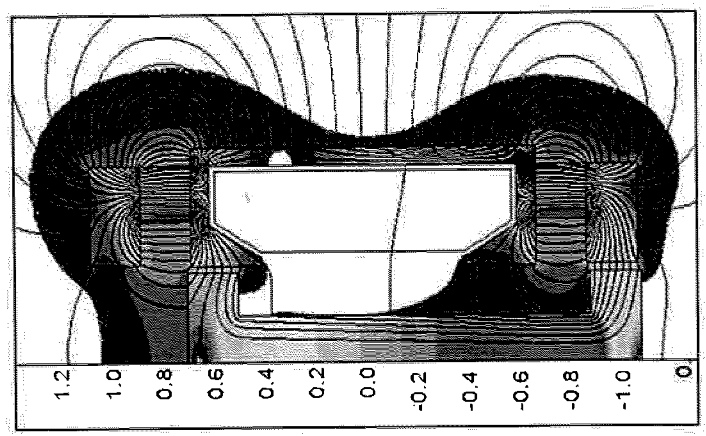
Figure 29



3000A
Closed Circuit
at Midstroke



3000B
Open Circuit
at Midstroke



3000C
Open Circuit
at Full Stroke

Figure 30

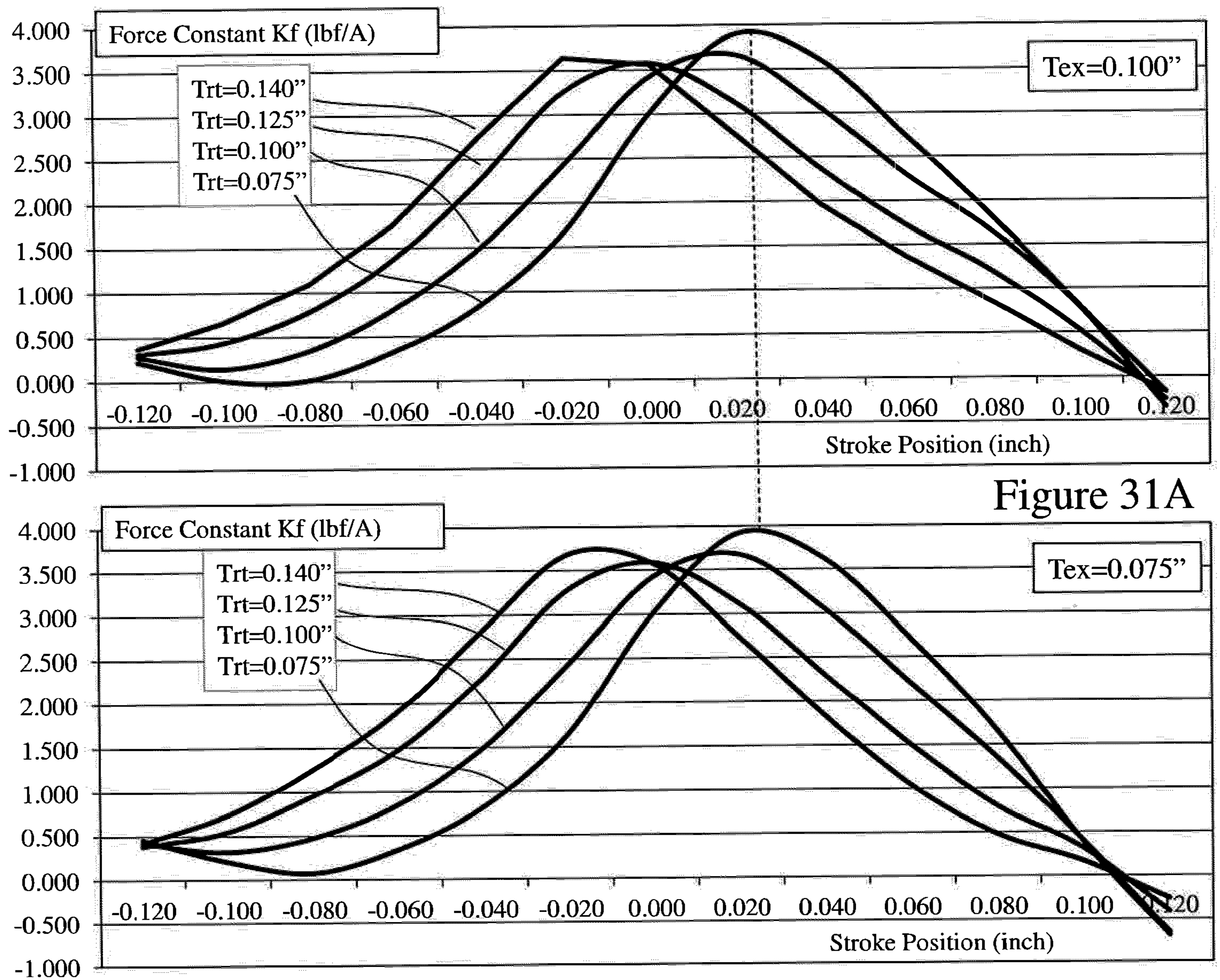

Force Constant Kf (lbf/A)
Tex=0.100"
Trt=0.140"
Trt=0.125"
Trt=0.100"
Trt=0.075"
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-0.120 -0.100 -0.080 -0.060 -0.040 -0.020 0.000 0.020 0.040 0.060 0.080 0.100 0.120
Stroke Position (inch)
Force Constant Kf (lbf/A)
Tex=0.075"
Trt=0.140"
Trt=0.125"
Trt=0.100"
Trt=0.075"
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-0.120 -0.100 -0.080 -0.060 -0.040 -0.020 0.000 0.020 0.040 0.060 0.080 0.100 0.120
Stroke Position (inch)

Figure 31A

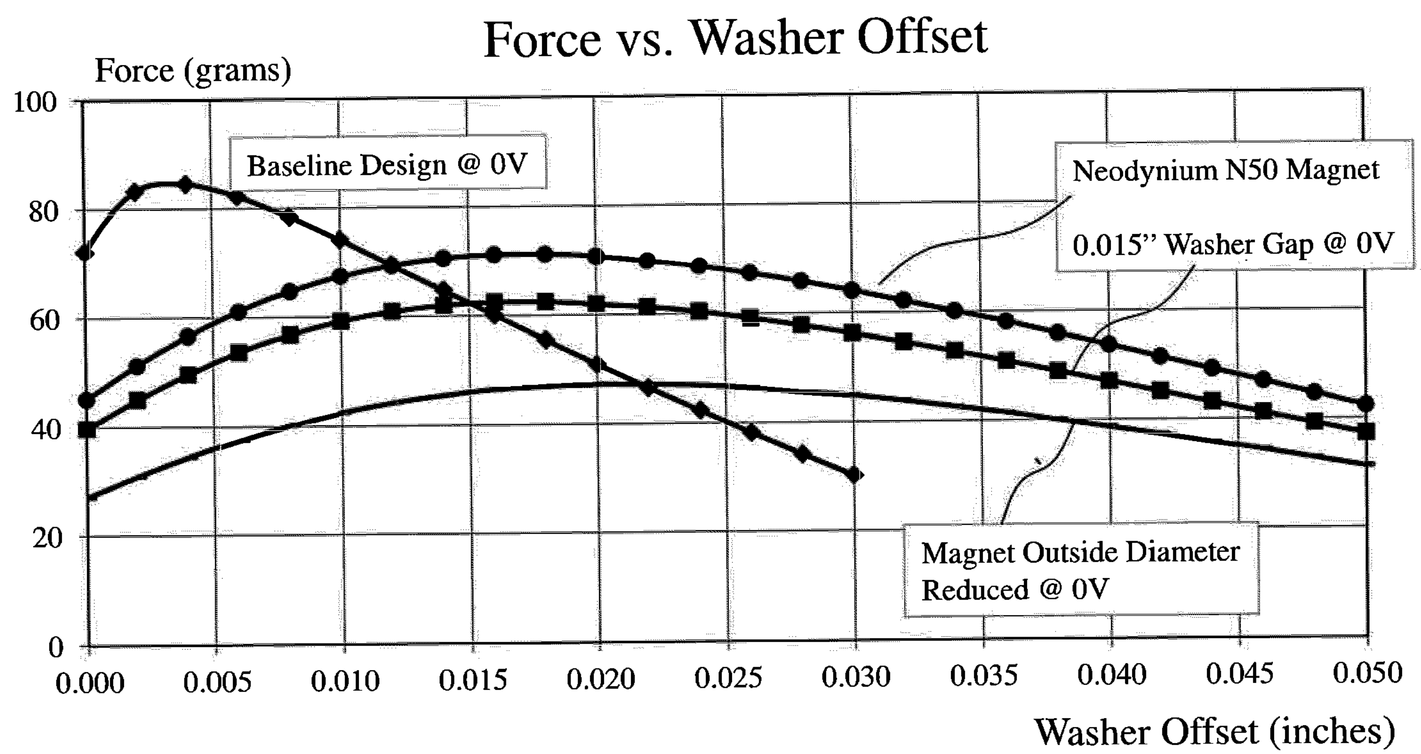


Figure 31B

CA 3069476 2020-01-24

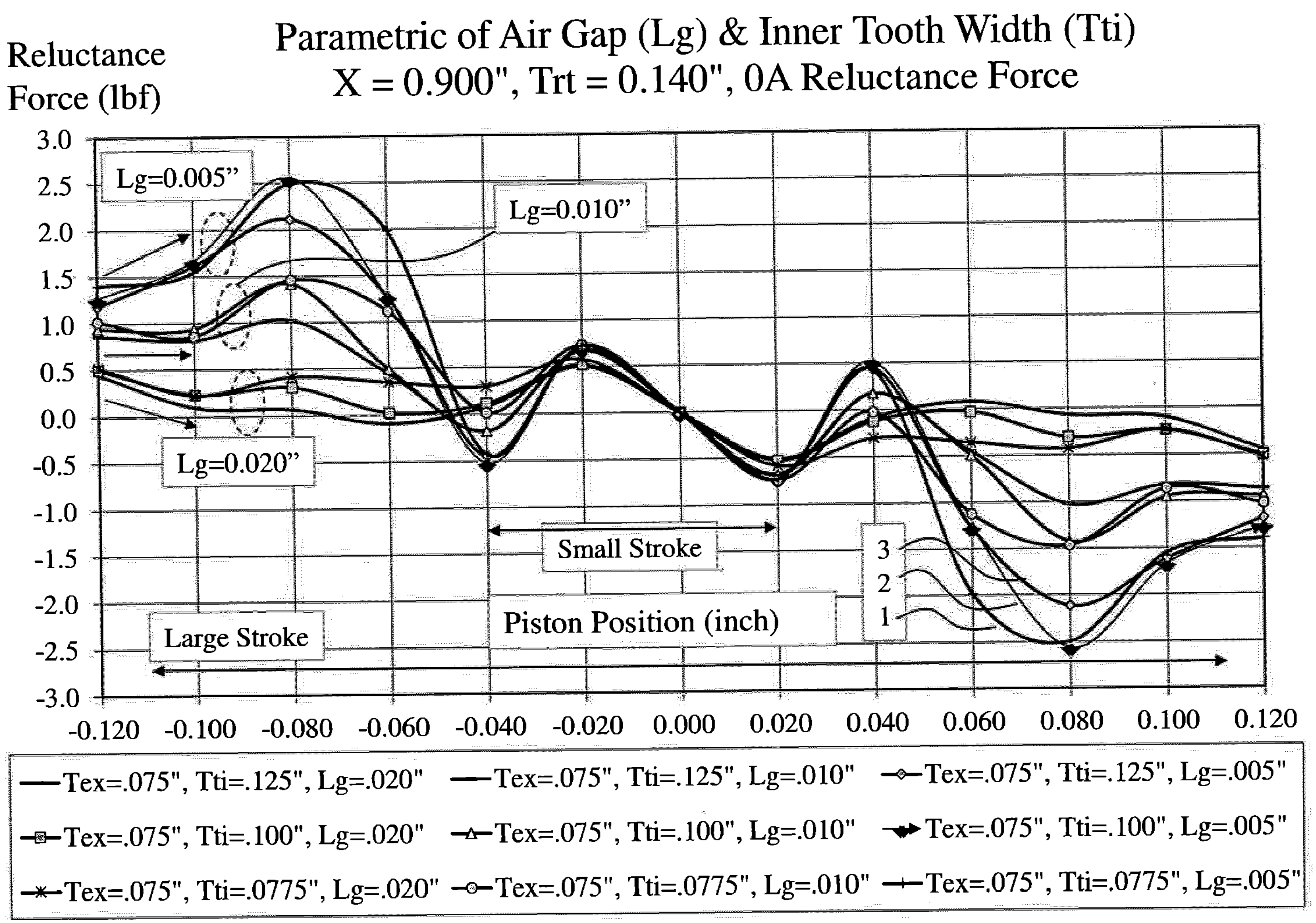
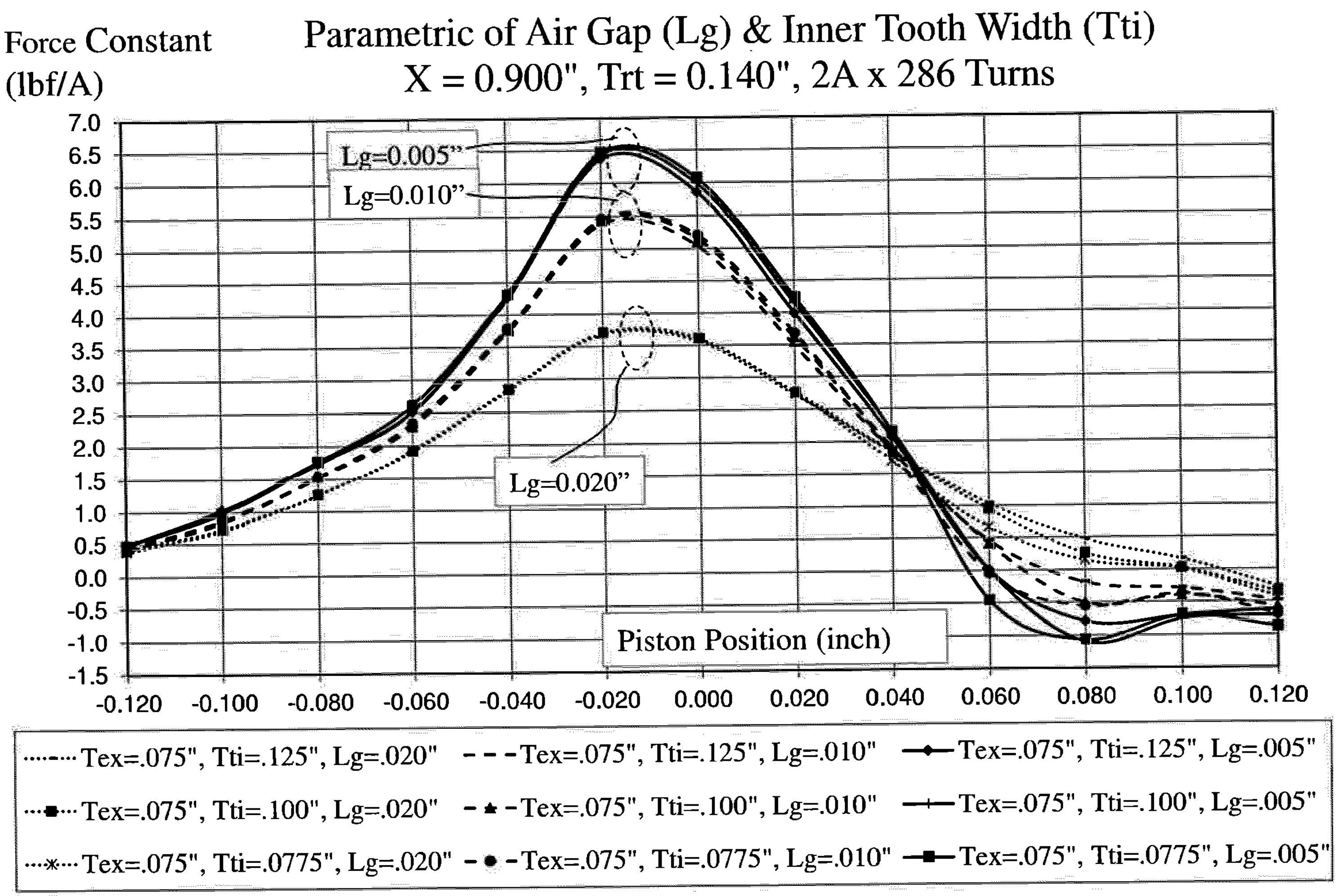

Parametric of Air Gap (Lg) & Inner Tooth Width (Tti)
X = 0.900", Trt = 0.140", 0A Reluctance Force
Reluctance Force (lbf)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
Lg=0.005”
Lg=0.010”
Lg=0.020”
Small Stroke
Large Stroke
Piston Position (inch)
3
2
1
-0.120
-0.100
-0.080
-0.060
-0.040
-0.020
0.000
0.020
0.040
0.060
0.080
0.100
0.120
Tex=.075", Tti=.125", Lg=.020"
Tex=.075", Tti=.125", Lg=.010"
Tex=.075", Tti=.125", Lg=.005"
Tex=.075", Tti=.100", Lg=.020"
Tex=.075", Tti=.100", Lg=.010"
Tex=.075", Tti=.100", Lg=.005"
Tex=.075", Tti=.0775", Lg=.020"
Tex=.075", Tti=.0775", Lg=.010"
Tex=.075", Tti=.0775", Lg=.005"

Figure 32



Force Constant
(lbf/A)
Parametric of Air Gap (Lg) & Inner Tooth Width (Tti)
X = 0.900", Trt = 0.140", 2A x 286 Turns
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Lg=0.005”
Lg=0.010”
Lg=0.020”
Piston Position (inch)
-0.120
-0.100
-0.080
-0.060
-0.040
-0.020
0.000
0.020
0.040
0.060
0.080
0.100
0.120
Tex=.075", Tti=.125", Lg=.020"
Tex=.075", Tti=.125", Lg=.010"
Tex=.075", Tti=.125", Lg=.005"
Tex=.075", Tti=.100", Lg=.020"
Tex=.075", Tti=.100", Lg=.010"
Tex=.075", Tti=.100", Lg=.005"
Tex=.075", Tti=.0775", Lg=.020"
Tex=.075", Tti=.0775", Lg=.010"
Tex=.075", Tti=.0775", Lg=.005"

Figure 33

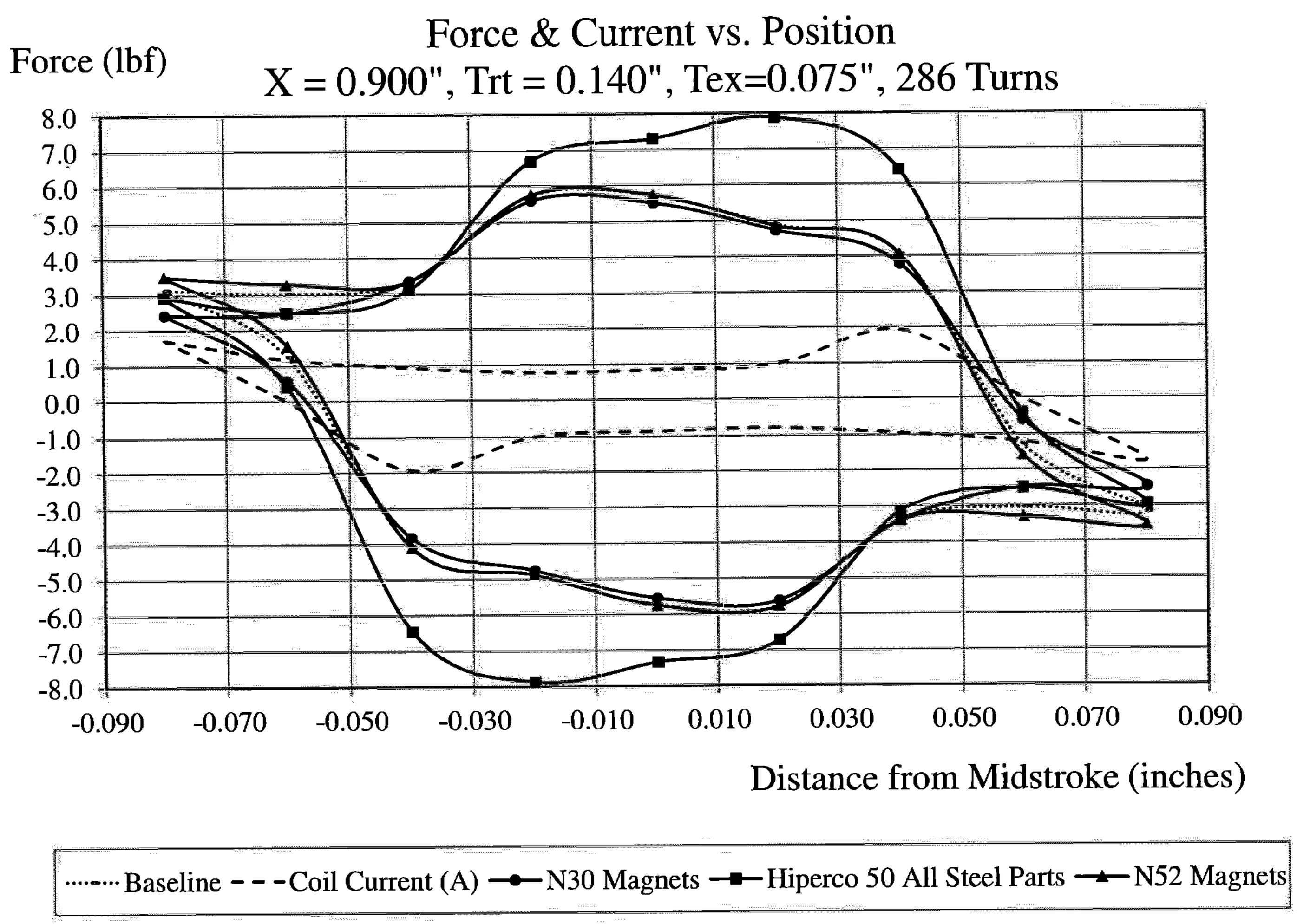

Force & Current vs. Position
X = 0.900", Trt = 0.140", Tex=0.075", 286 Turns
Force (lbf)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-0.090
-0.070
-0.050
-0.030
-0.010
0.010
0.030
0.050
0.070
0.090
Distance from Midstroke (inches)
Baseline
Coil Current (A)
N30 Magnets
Hiperco 50 All Steel Parts
N52 Magnets

Figure 34

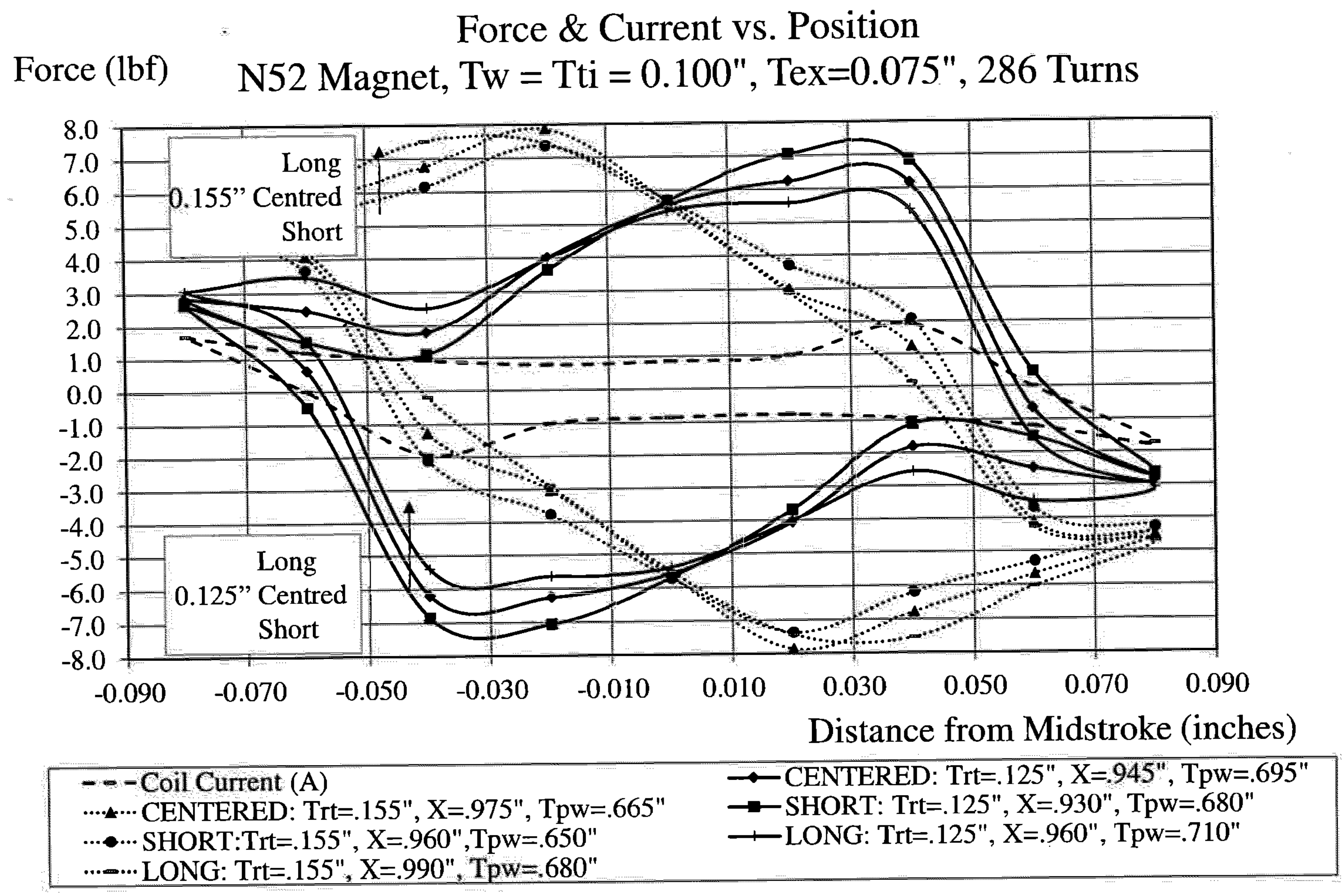

Force & Current vs. Position
N52 Magnet, Tw = Tti = 0.100", Tex=0.075", 286 Turns
Force (lbf)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-0.090
-0.070
-0.050
-0.030
-0.010
0.010
0.030
0.050
0.070
0.090
Distance from Midstroke (inches)
Long
0.155" Centred
Short
Long
0.125" Centred
Short
Coil Current (A)
CENTERED: Trt=.155", X=.975", Tpw=.665"
SHORT:Trt=.155", X=.960",Tpw=.650"
LONG: Trt=.155", X=.990", Tpw=.680"
CENTERED: Trt=.125", X=.945", Tpw=.695"
SHORT: Trt=.125", X=.930", Tpw=.680"
LONG: Trt=.125", X=.960", Tpw=.710"

Figure 35

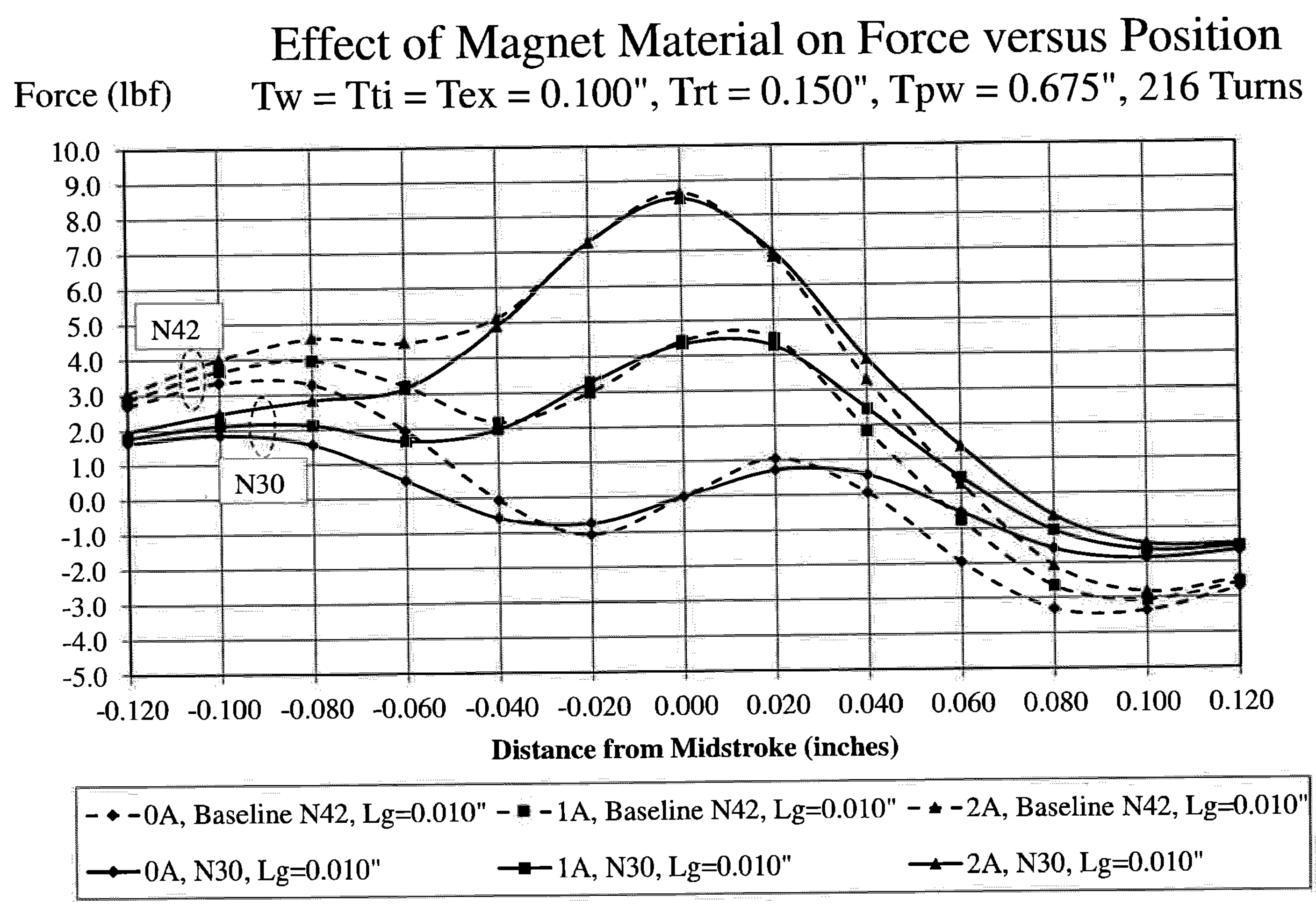

Effect of Magnet Material on Force versus Position
Force (lbf)
Tw = Tti = Tex = 0.100", Trt = 0.150", Tpw = 0.675", 216 Turns
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
N42
N30
-0.120 -0.100 -0.080 -0.060 -0.040 -0.020 0.000 0.020 0.040 0.060 0.080 0.100 0.120
Distance from Midstroke (inches)
0A, Baseline N42, Lg=0.010"
1A, Baseline N42, Lg=0.010"
2A, Baseline N42, Lg=0.010"
0A, N30, Lg=0.010"
1A, N30, Lg=0.010"
2A, N30, Lg=0.010"

Figure 36

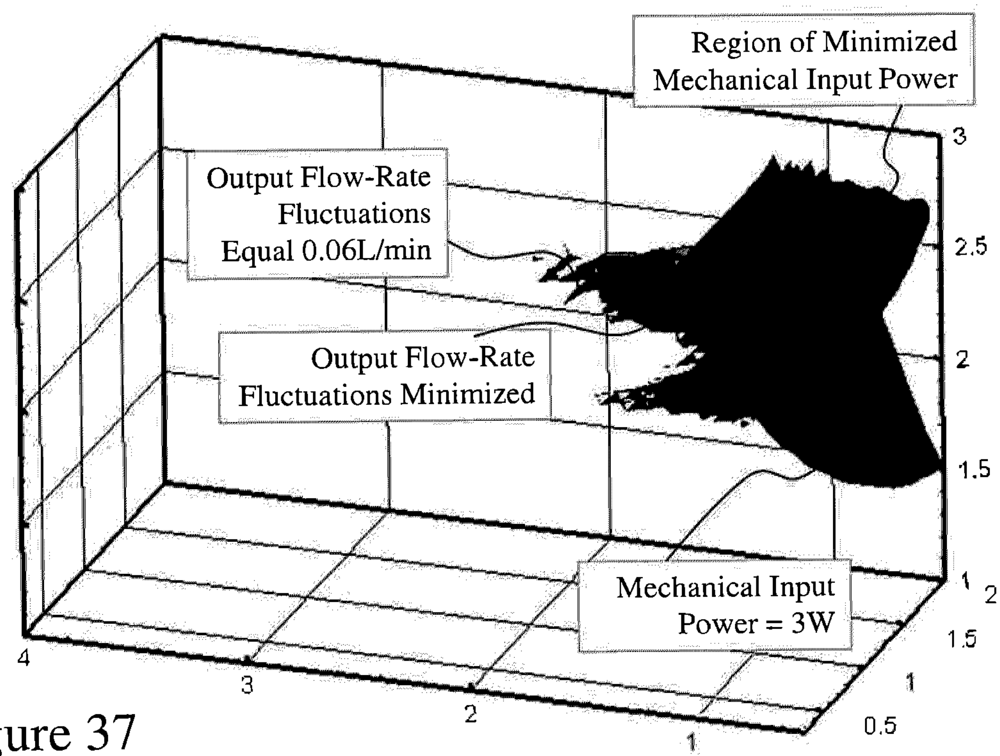


Figure 37

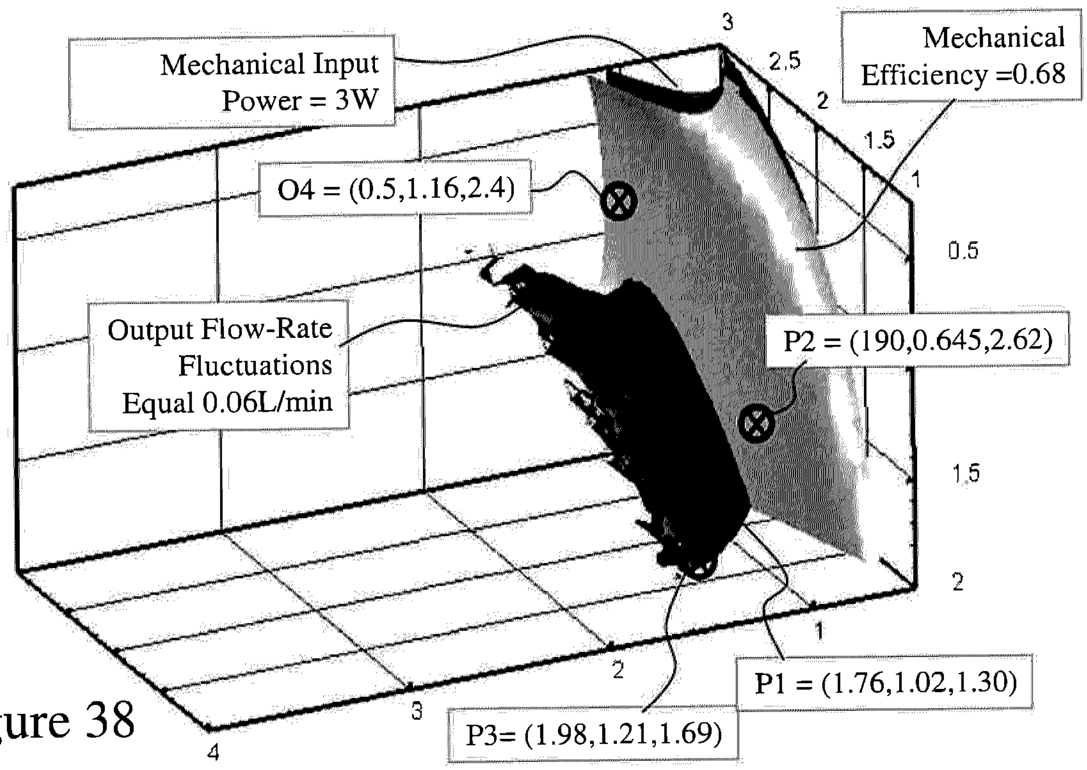
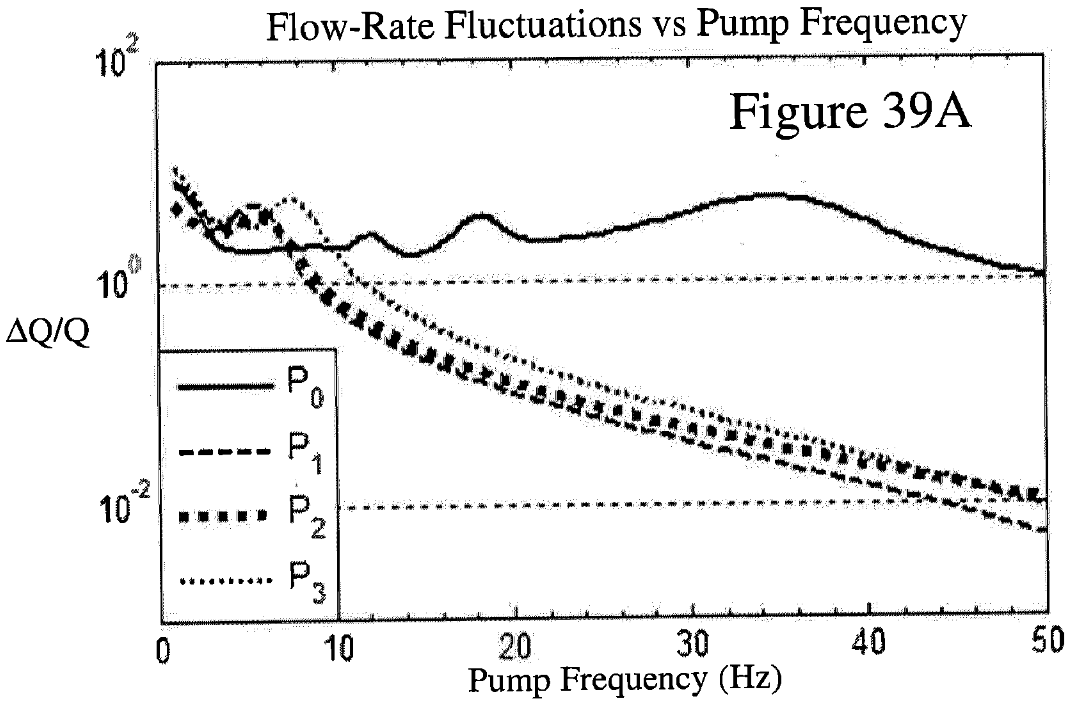
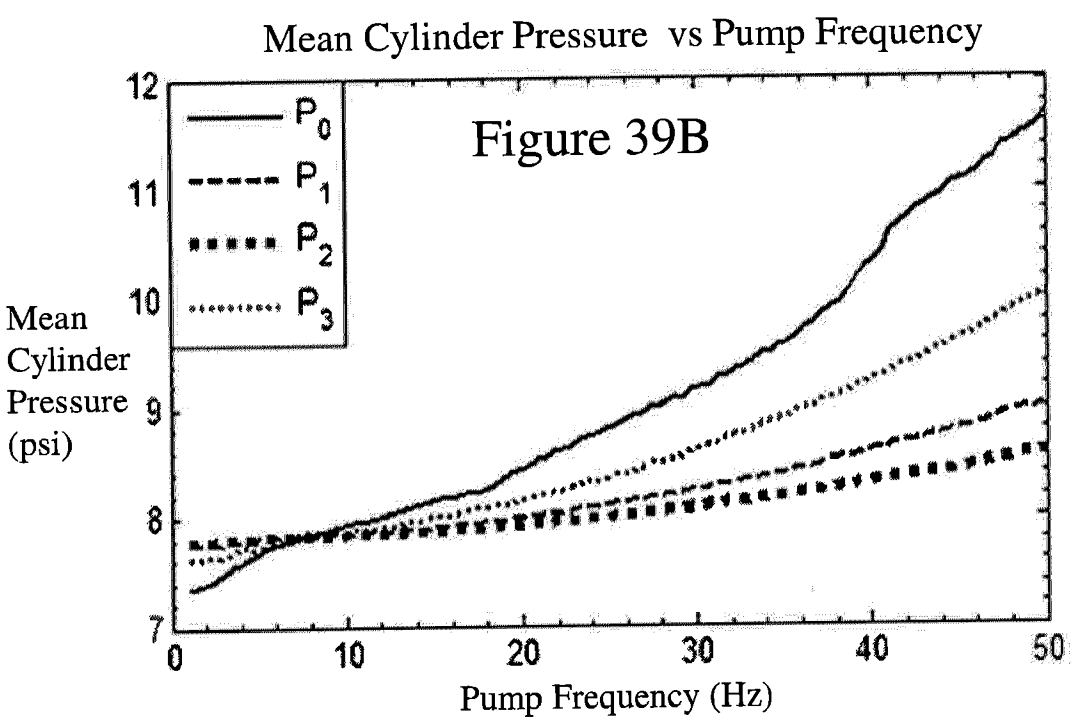


Figure 38


Flow-Rate Fluctuations vs Pump Frequency
Figure 39A
10^2
10^0
10^-2
ΔQ/Q
P0
P1
P2
P3
0
10
20
30
40
50
Pump Frequency (Hz)


Mean Cylinder Pressure vs Pump Frequency
Figure 39B
12
11
10
9
8
7
Mean Cylinder Pressure (psi)
P0
P1
P2
P3
0
10
20
30
40
50
Pump Frequency (Hz)

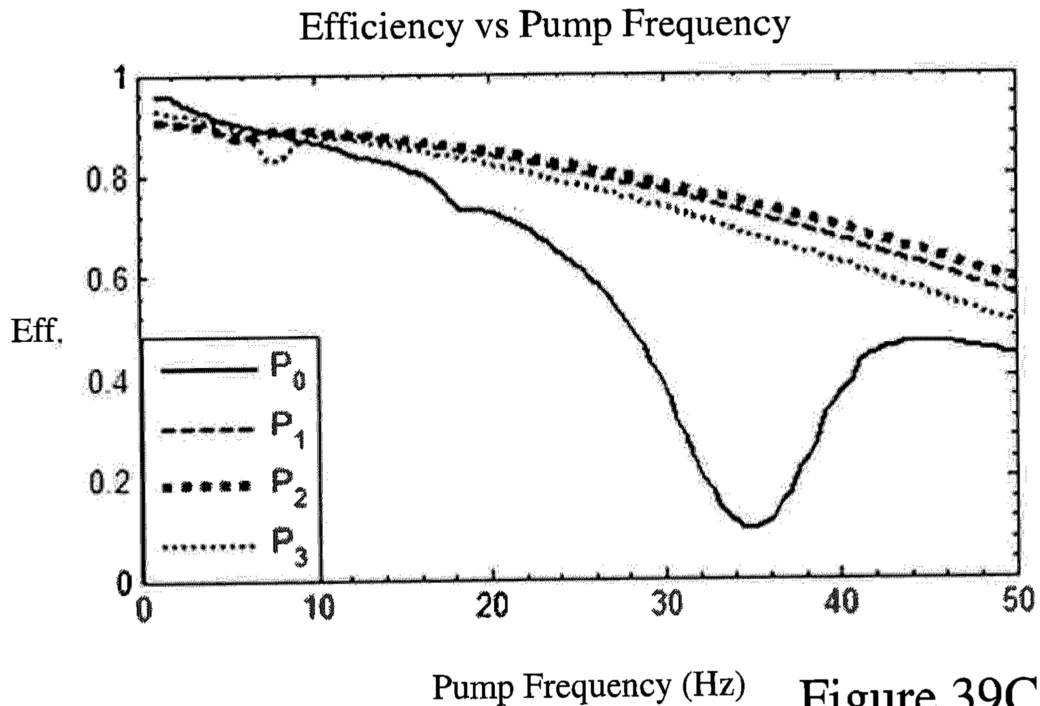


Figure 39C

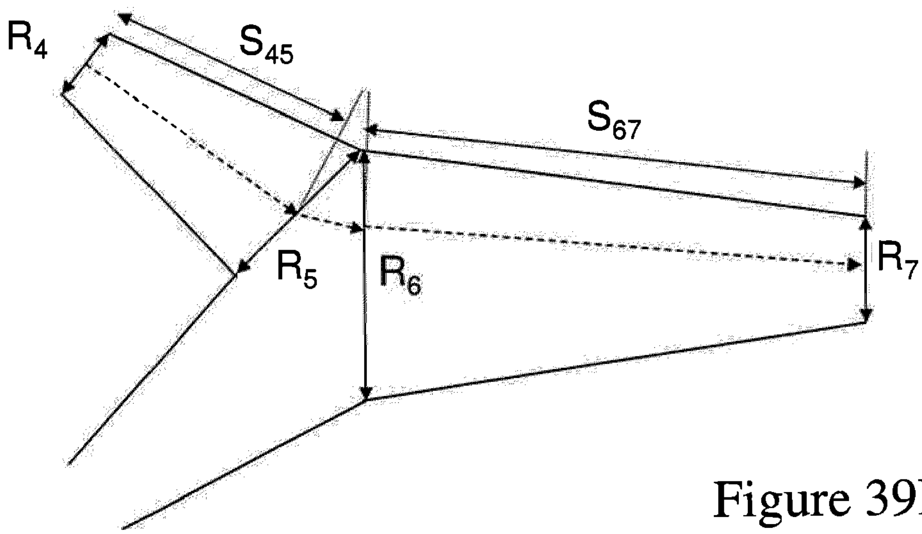


Figure 39D

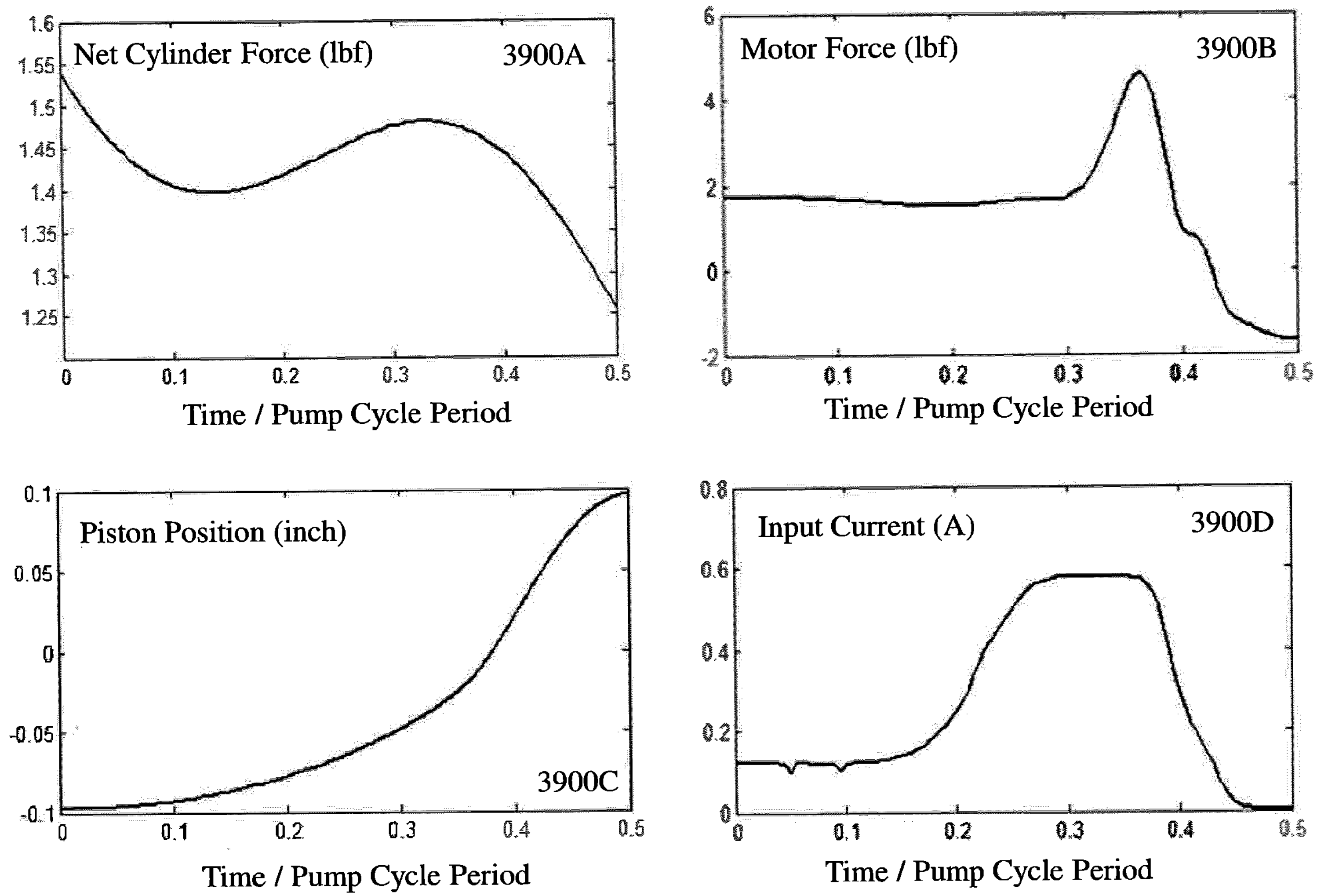

Net Cylinder Force (lbf)
3900A
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
0
0.1
0.2
0.3
0.4
0.5
Time / Pump Cycle Period
Motor Force (lbf)
3900B
6
4
2
0
-2
Time / Pump Cycle Period
Piston Position (inch)
3900C
0.1
0.05
0
-0.05
-0.1
Time / Pump Cycle Period
Input Current (A)
3900D
0.8
0.6
0.4
0.2
0
Time / Pump Cycle Period

Figure 39E

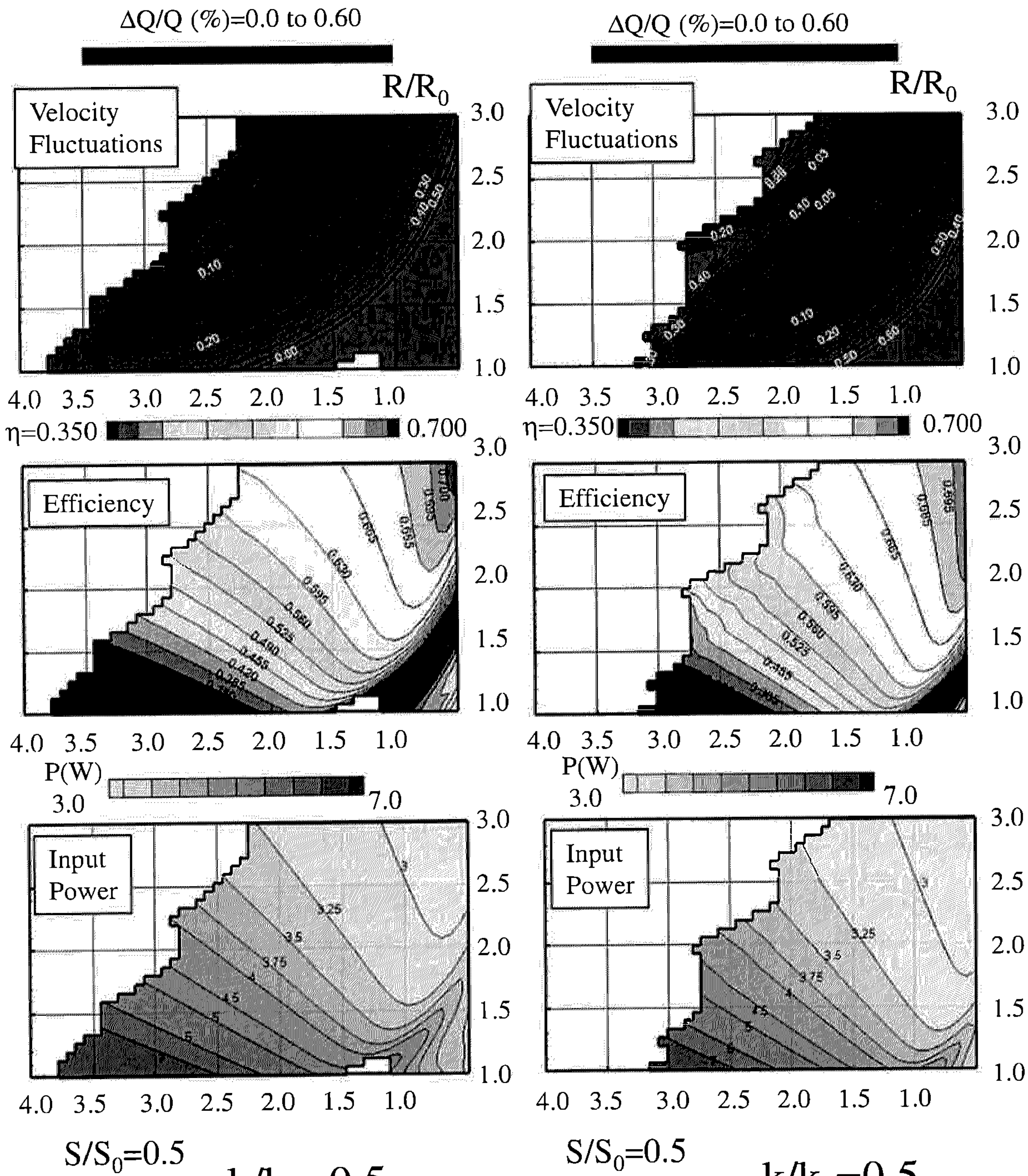

ΔQ/Q (%)=0.0 to 0.60
Velocity Fluctuations
R/R0
3.0
2.5
2.0
1.5
1.0
4.0 3.5 3.0 2.5 2.0 1.5 1.0
η=0.350
0.700
Efficiency
P(W)
3.0
7.0
Input Power
S/S0=0.5
k/k0=0.5

Figure 40

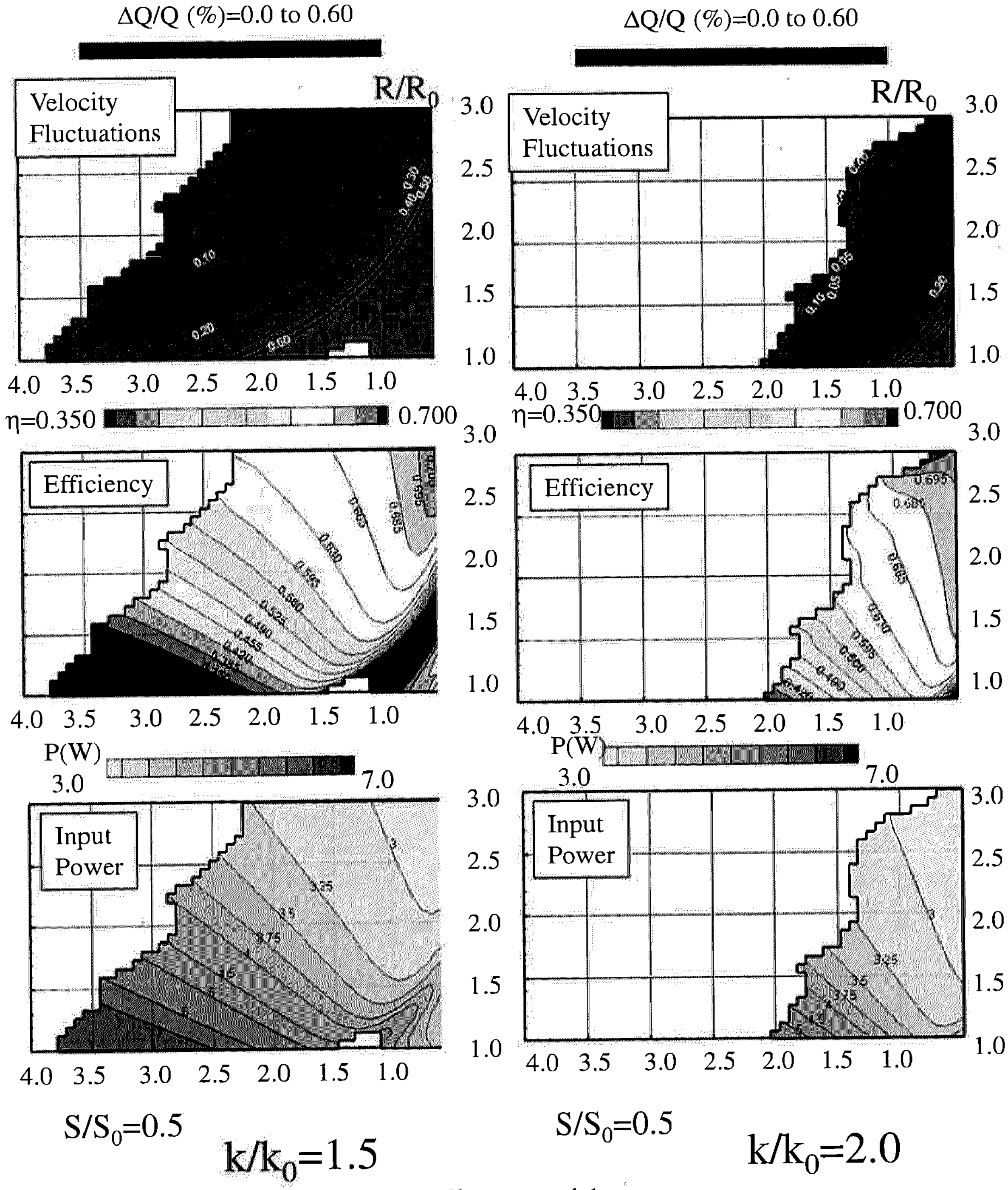

ΔQ/Q (%)=0.0 to 0.60
ΔQ/Q (%)=0.0 to 0.60
Velocity Fluctuations
Velocity Fluctuations
R/R0
R/R0
3.0
2.5
2.0
1.5
1.0
4.0 3.5 3.0 2.5 2.0 1.5 1.0
η=0.350
0.700
Efficiency
Efficiency
P(W)
3.0
7.0
Input Power
Input Power
S/S0=0.5
k/k0=1.5
S/S0=0.5
k/k0=2.0

Figure 41

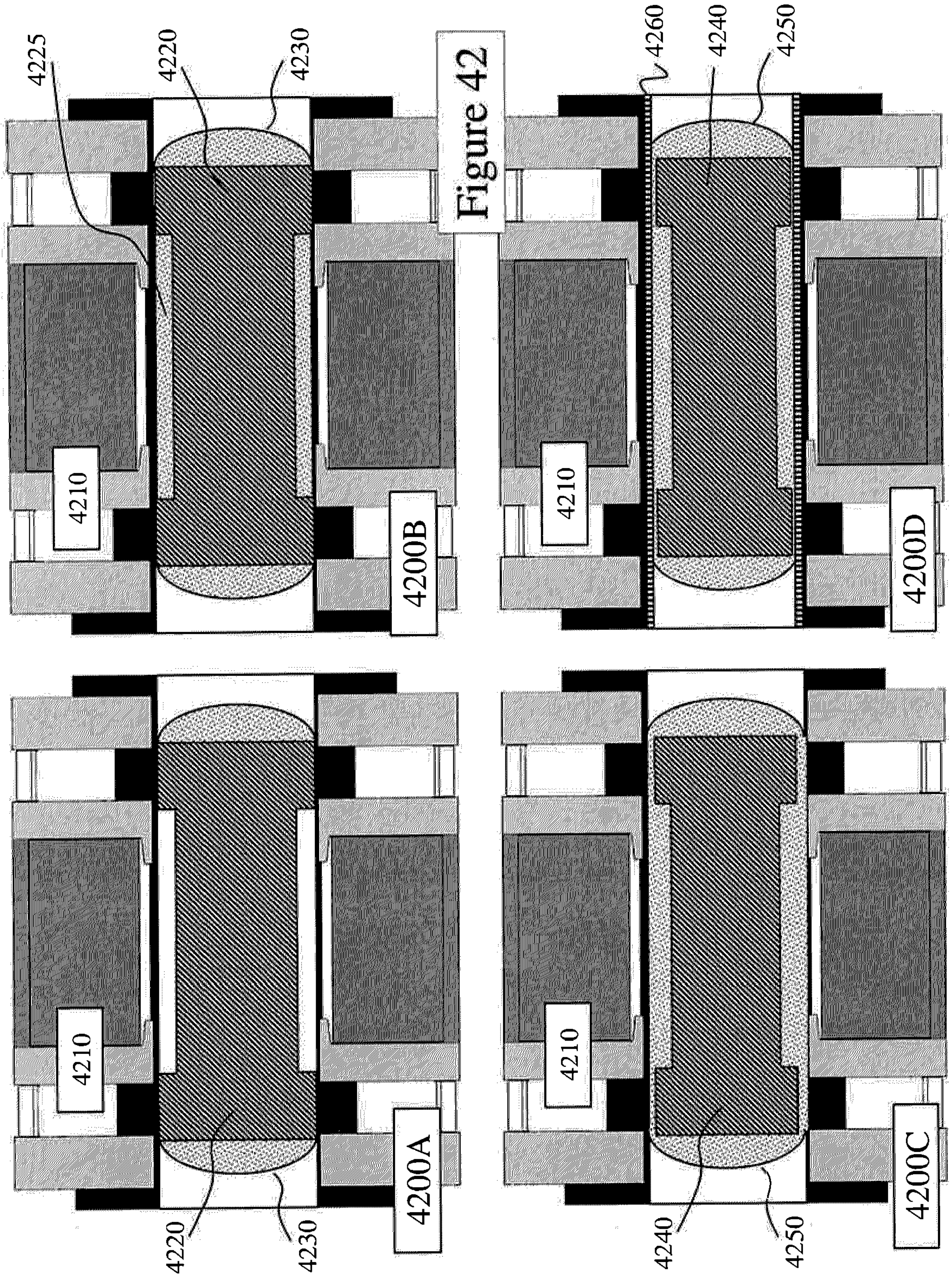


Figure 42

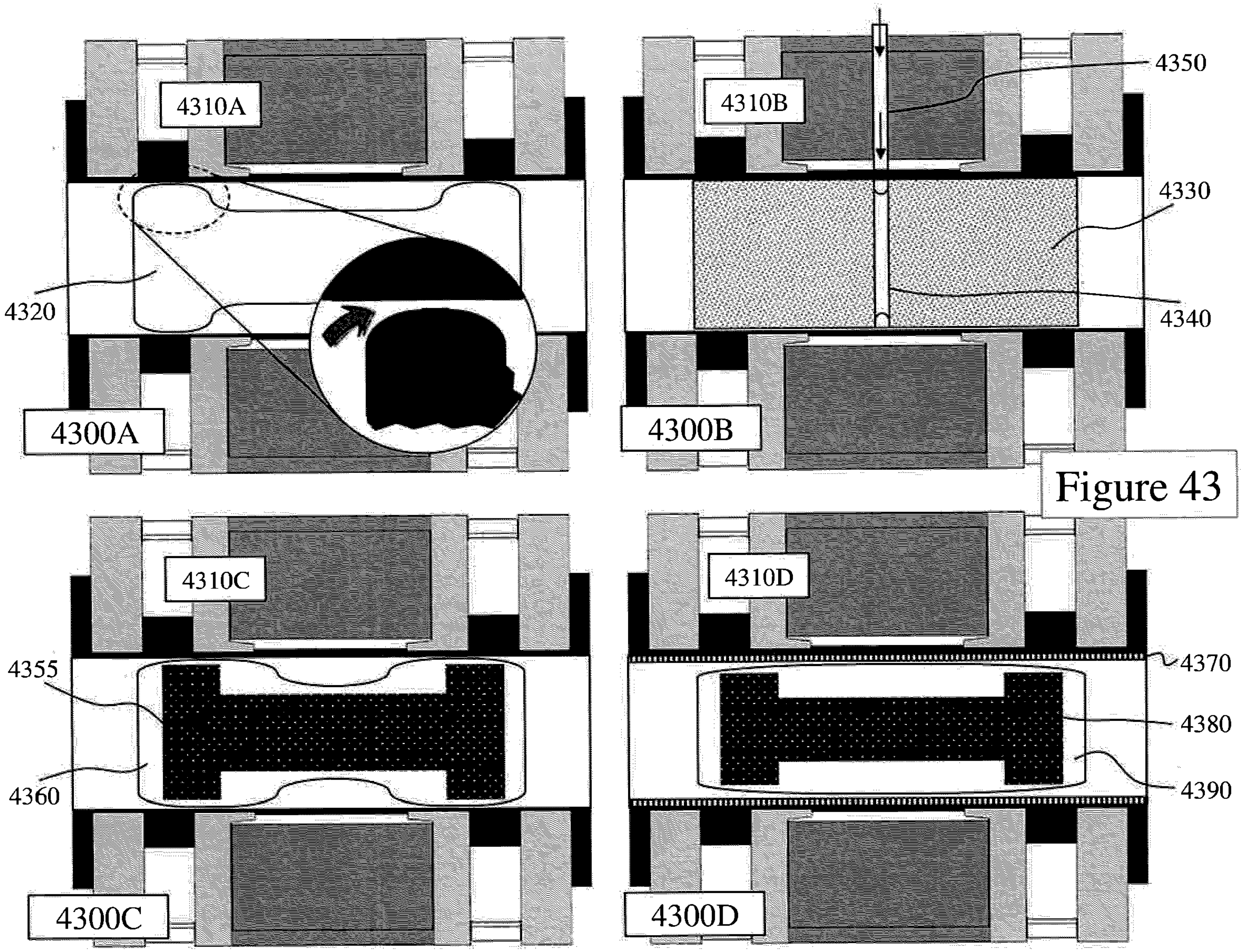
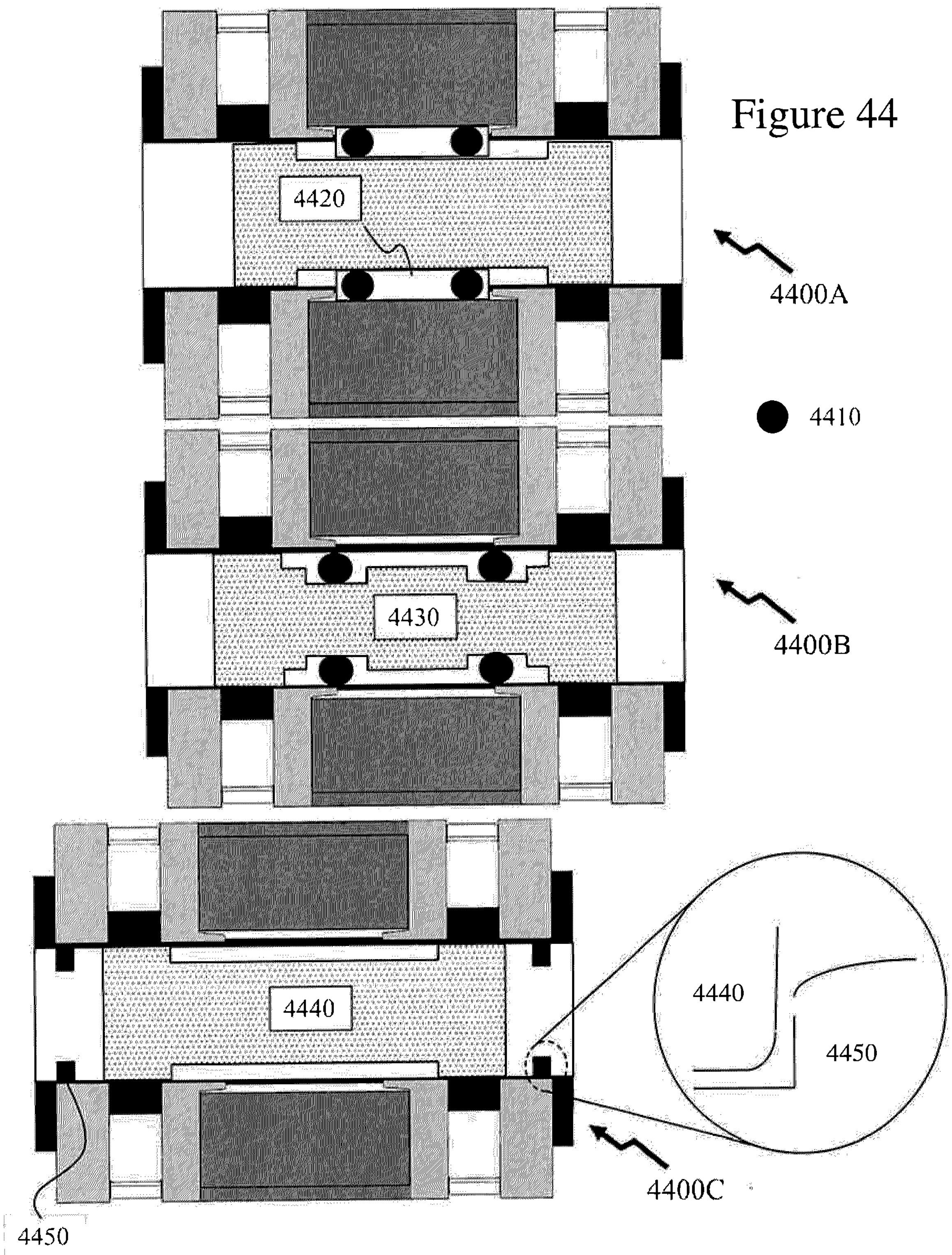

4310A
4320
4300A
4310B
4350
4330
4340
4300B
4310C
4355
4360
4300C
4310D
4370
4380
4390
4300D

Figure 43

Figure 44



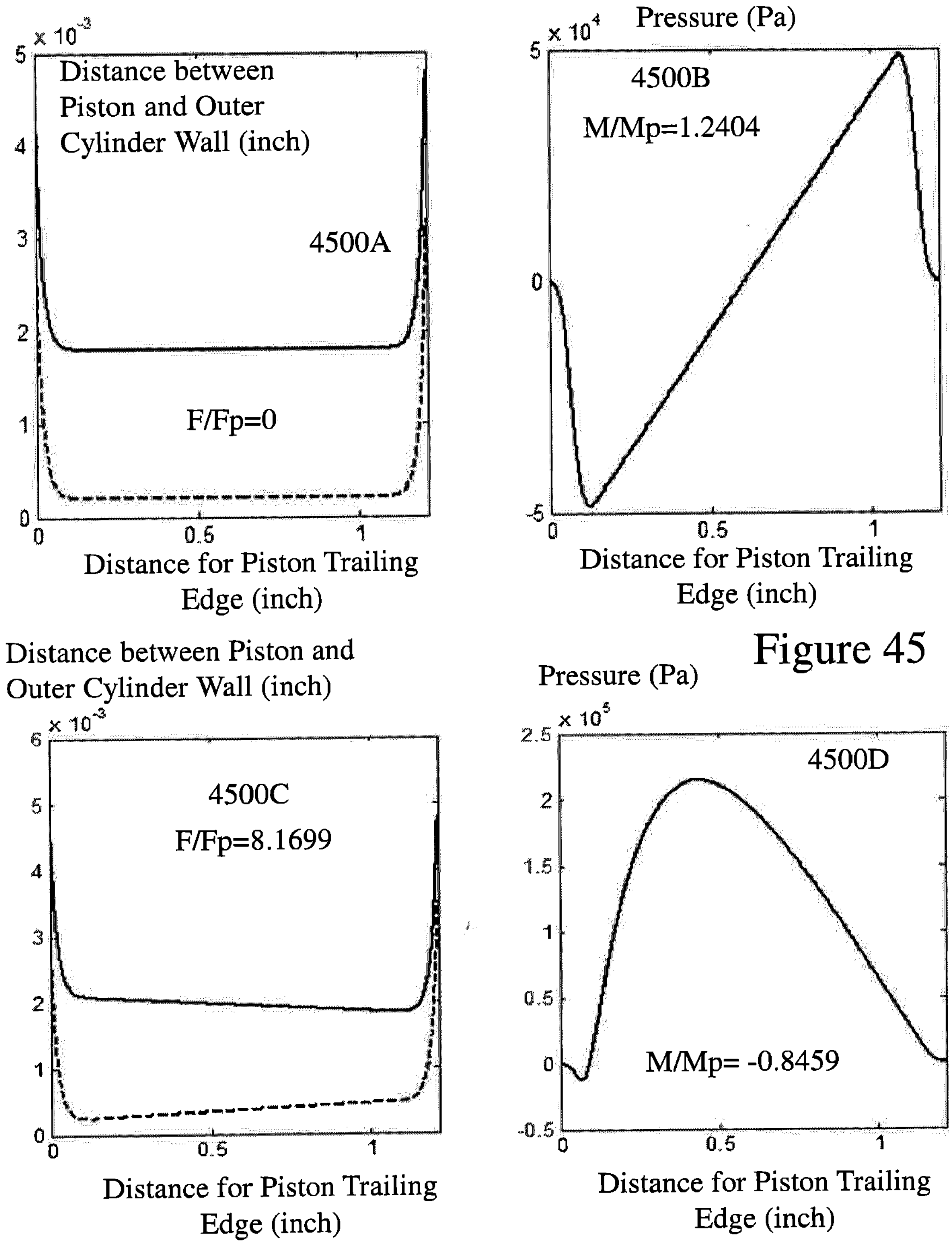

Distance between Piston and Outer Cylinder Wall (inch)
x 10^-3
4500A
F/Fp=0
Distance for Piston Trailing Edge (inch)
Pressure (Pa)
x 10^4
4500B
M/Mp=1.2404
Distance for Piston Trailing Edge (inch)
Distance between Piston and Outer Cylinder Wall (inch)
x 10^-3
4500C
F/Fp=8.1699
Distance for Piston Trailing Edge (inch)
Pressure (Pa)
x 10^5
4500D
M/Mp= -0.8459
Distance for Piston Trailing Edge (inch)

Figure 45

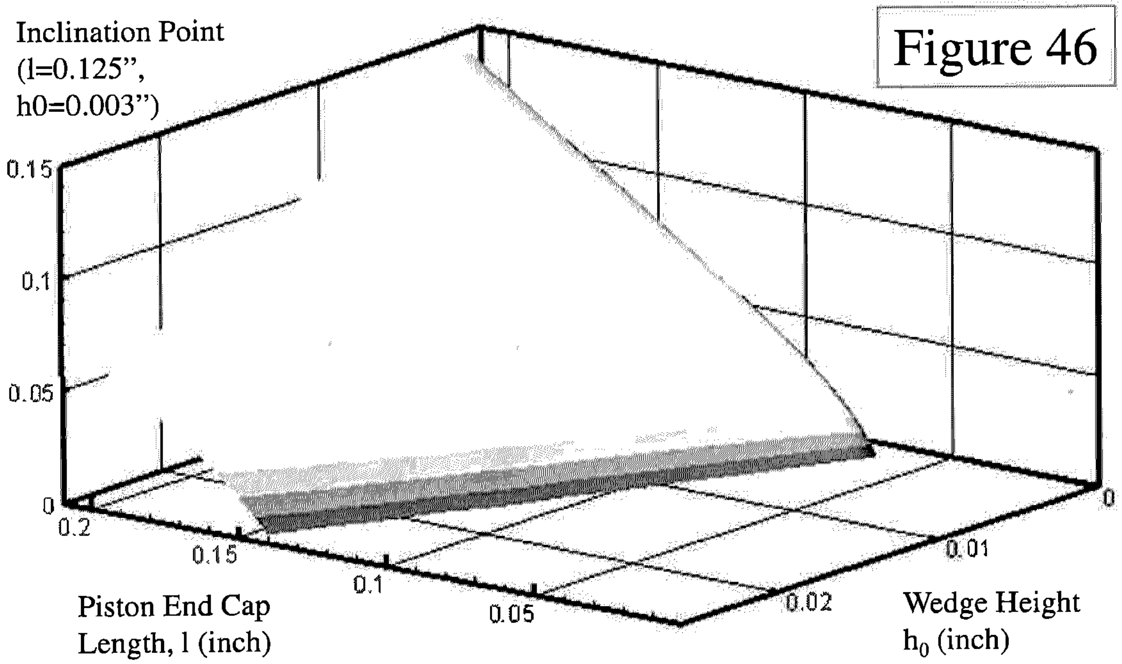


Figure 46

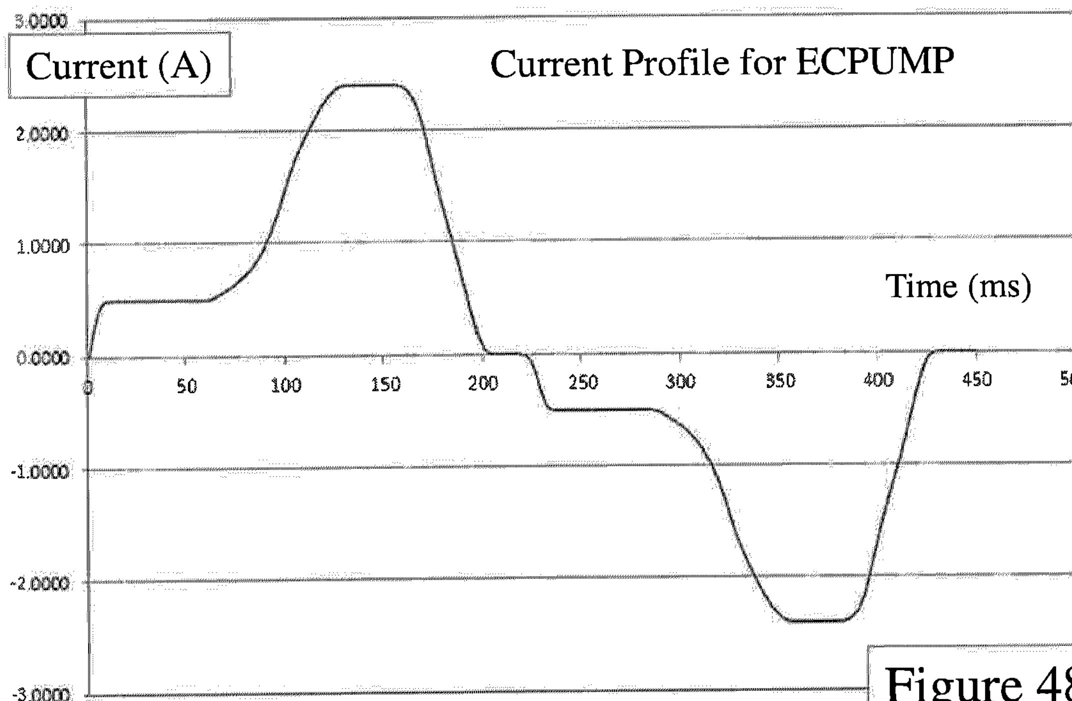


Figure 48

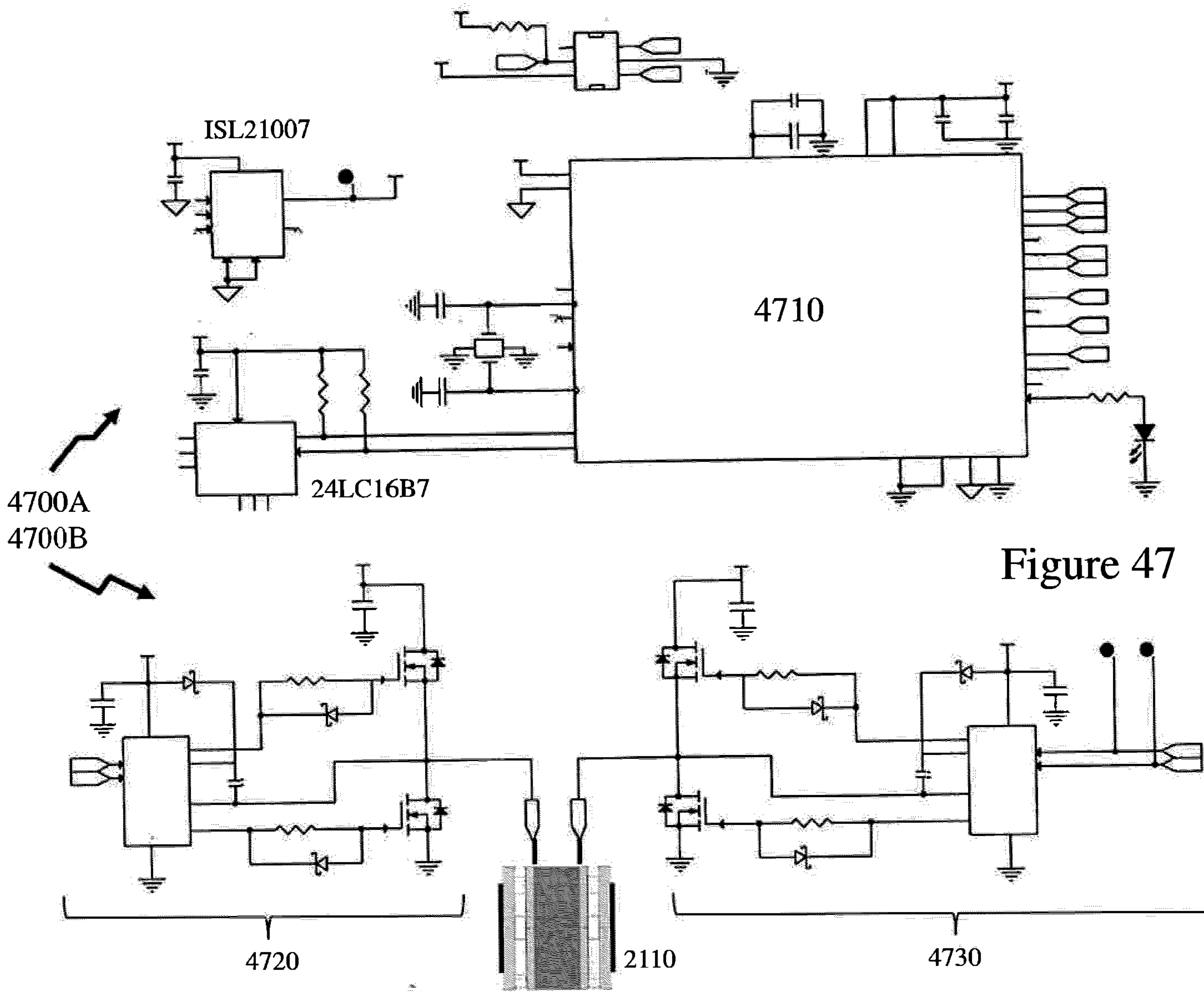
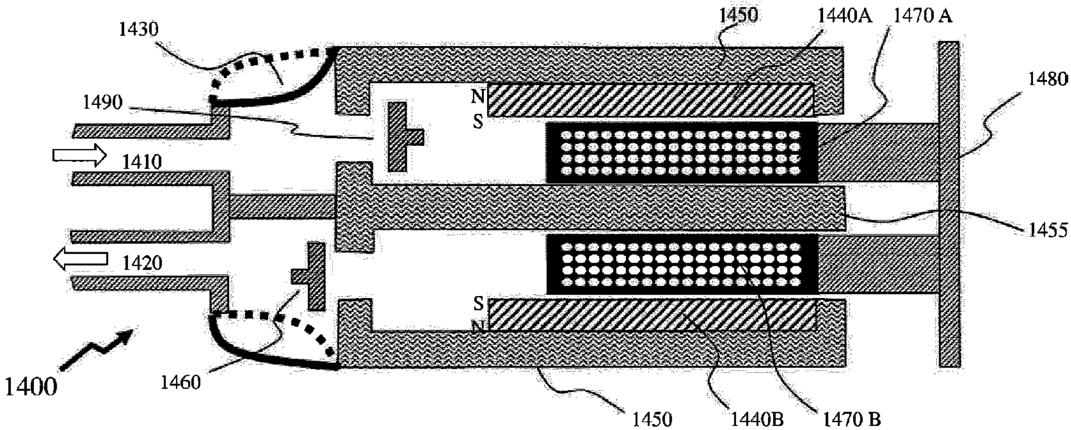


Figure 47


1450
1440A
1470 A
1430
1480
1490
N
S
1410
1455
1420
S
N
1460
1400
1450
1440B
1470 B