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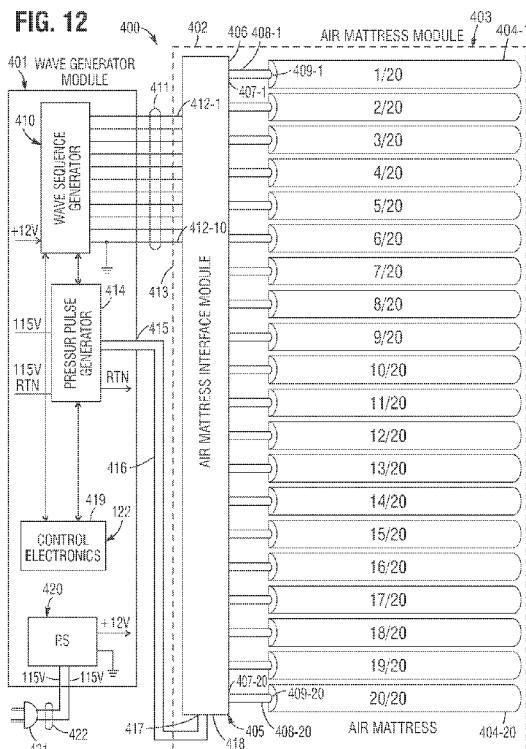
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(54) Title: SOILITON TRAVELING WAVE AIR MATTRESSES



(57) Abstract: A soliton air mattress includes an array of air bladder cells that are individually inflatable to quiescent pressure levels which provide comfortable support for a human body, and a soliton wave generator including an air pressure-pulse generator controlled by a wave sequence generator for introducing into ordered sequences of air bladder cells a wave-like time sequence of air pressure pulses which vary quiescent pressure levels in the cells, the pressure wave resulting in a soliton traveling wave of body support force reduction which traverses surfaces of the air bladder cells, thus reducing normal forces exerted on a body and minimizing the occurrence rate of shear forces exerted on the body, thereby inhibiting formation of bedsores. The soliton wave patterns may optionally simulate water waves and/or rocking motions of a boat to produce relaxing effects.



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**SOLITON TRAVELING WAVE AIR MATTRESSES****BACKGROUND OF THE INVENTION**

This application is a continuation-in-part of U.S. Application No. 14/179,791, filed February 13, 2014, and claims priority of the following patent applications: U.S. 62/038,946, filed August 19, 2014; U.S. 14/179,791, filed February 13, 2014, U.S. 61/771,083, filed March 1, 2013; U.S. 61/764060, filed February 13, 2013.

**A. Field of the Invention**

The present invention relates to mattresses of the type used to support a recumbent human. More particularly, the invention relates to novel air mattresses which have an array of individually inflatable and deflatable air bladder cells that receive air pressure pulses in a timed sequence which results in a soliton traveling wave of body support force variation to traverse the surface of the air bladder cells. The soliton body support forces waves can be programmed to travel longitudinally, laterally or obliquely on the upper support surfaces of the air bladder cells, according to pre-determined patterns which can be used to minimize formation of decubitus sores on a patient's body and alternatively to simulate comforting motions such as floating on a rolling water wave, or rocking in a boat, which simulations may optionally be accompanied by appropriate music and/or environment-simulating sounds.

**B. Description of Background Art**

Pressure sores, which are also known as decubitus ulcers or bed sores occur in the outer tissues of a person's body if parts of the body are subjected to relatively large normal force pressure gradients, and/or tangential or shear forces, for long periods of time. Such sores are caused by reduction in blood circulation caused by surface force pressures which exceed the person's capillary blood pressure. The problems with bed sores forming on the skin of persons with medical conditions which require them to be in relatively immobile positions on a hospital bed or in a wheel chair can be severe, resulting in painful, difficult to treat conditions, loss of limbs, or even death.

For the foregoing reasons, hospitals, nursing homes and other such health care facilities which provide care giving to ailing or elderly people are keenly aware of the necessity for carefully monitoring people under their care to prevent formation of bed sores. A commonly used method to minimize the possibility of bed sore formation is to turn the patient periodically, i.e, to re-adjust the patient's position on a bed mattress or in a wheel chair so that long-term normal force pressure gradients, can be relieved from parts of a patient's body. However, turning invariably results in renewed higher pressures on other parts of the body, so the turning process must be repeated usually at least on a daily basis.

Presumably in response to a perceived need for reducing problems of bed sore formation, a variety of devices and methods have been proposed to reduce long-term, large force or pressure concentrations on a person's body. For example, Cottner et al, in U.S. Patent No. 5,243,723, September 17, 1993, Multi-Chambered Sequentially Pressurized Air Mattress With Four Layers discloses an air mattress which has two lower layers constantly

pressurized at about 1 psi gauge, and two upper layers that each have serpentine shaped, transversely disposed interdigitated membrane areas which are cyclically and alternately pressurized with varying air pressure in a push-pull fashion which creates a standing wave of variation in support force for a patient, with the intended purpose of minimizing formation of decubitus sores. The standing waves produced by alternate inflation and deflation of adjacent interdigitated members shifts support forces up and down, leaving the average maximum reaction support force concentrations on parts of a patient's body unchanged. Moreover, the continuous oscillating motion of the interdigitated members exerts continuous reciprocating tangential or shear forces on parts of a body supported by adjacent interdigitated members, which shear force can collapse blood vessels and thus reduce blood circulation, which can contribute to the formation of shear-force induced decubitus sores.

The present invention was conceived of to provide air mattresses which provide soliton traveling waves of support-forces for the body of a person supported by the mattress, which can reduce maximum force concentrations of the type that can lead to the formation of decubitus bed sores.

#### OBJECTS OF THE INVENTION

An object of the present invention is to provide a soliton traveling wave air mattress apparatus which includes an inflatable air mattress that has a multiplicity of hermetically isolated air bladder cells and a pressure pulse generator which dynamically varies inflation pressures in the cells to thus create a soliton traveling wave of support-force which travels over the upper surface of the mattress.

Another object of the invention is to provide a soliton traveling wave air mattress apparatus which includes a mattress that has a multiplicity of laterally disposed, hermetically isolated air bladder cells, and an air pressure pulse generator which sequentially varies air pressure in the cells to thus create longitudinally traveling soliton body support-force waves on the upper surfaces of the air bladder cells.

Another object of the invention is to provide a soliton traveling wave air mattress comprised of a planar matrix of air bladder cells which are hermetically isolated from one another, and a pressure pulse generator for varying air pressures in the cells by pressure pulses which are applied sequentially to individual cells or groups of cells to create on the upper surfaces of the cells soliton traveling waves of support-force for the body of a person supported by the mattress, the soliton traveling waves being directable longitudinally, laterally, obliquely, or in other directions on the surface of the mattress.

Another object of the invention is to provide a soliton traveling wave air mattress which has a matrix of air bladder cells, each of which has associated therewith a surface reaction force-sensor, the sensors being useable to calculate a gradient vector of surface reaction forces measured by the sensors, and a pressure pulse generator for directing waves of negative pressure pulses to air bladder cells along the path of the gradient

vector to thus create a soliton traveling wave of support force reduction which travels in the direction the gradient vector.

Another object of the invention is to provide a soliton traveling wave air mattress apparatus which has a multiplicity of individually inflatable and deflatable air bladder cells that are hermetically isolated from one another, and a wave generator including a pressure pulse generator and air bladder selector valves which introduces a wave of air pressure pulses into selected sequences of cells to thus create a traveling wave of body support force reduction directed along the gradient path.

Another object of the invention is to provide a soliton traveling wave air mattress apparatus which has a multiplicity of individually inflatable and deflatable air bladder cells that are hermetically isolated from one another, and a wave generator which includes a pressure pulse generator and a selector valve mechanism which introduces pulses of air pressure sequentially into selected air bladder cells in a sequential fashion that produces a soliton traveling pressure wave in the air bladder cells which in turn causes the upper surfaces of the air bladder cells to produce thereon a corresponding soliton traveling wave of support force for a body supported on the upper surface of the air mattress.

Various other objects and advantages of the present invention, and its most novel features, will become apparent to those skilled in the art by perusing the accompanying specification, drawings and claims.

It is to be understood that although the invention disclosed herein is fully capable of achieving the objects and providing the advantages described, the characteristics of the invention described herein are merely illustrative of the preferred embodiments. Accordingly, I do not intend that the scope of my exclusive rights and privileges in the invention be limited to details of the embodiments described. I do intend that equivalents, adaptations and modifications of the invention reasonably inferable from the description contained herein be included within the scope of the invention as defined by the appended claims.

#### SUMMARY OF THE INVENTION

Briefly stated, the present invention comprehends a method and apparatus for alleviating formation of bed sores or decubitus sores on parts of the body of a person such as a medical patient who is supported in a relatively immobile recumbent position on a hospital bed for long periods of time. The apparatus according to the present invention includes an air mattress which is constructed from individually inflatable and deflatable air bladder cells which are arranged in a rectangular array having an upper horizontal patient support surface. The individual air bladder cells are inflated to suitable quiescent pressure levels which provide comfortable support for the body of a recumbent patient. The quiescent or bias pressure levels of the several air bladder cells may be individually adjusted to values which minimize the sum of maximum reaction force concentrations exerted on the body of a patient, as measured by an array of force or pressure sensors which may be associated with the array of air bladder cells.

According to the invention, air pressure in each of the cells is cyclically varied in a manner which causes the support forces afforded by the mattress for a human body to have superimposed on quiescent static or bias values time-varying pressure components to thus produce soliton traveling waves of support force superimposed on the static support forces. Soliton traveling wave components of a quiescent support force are produced by varying in a pre-determined time sequence air pressure in sequences of individual air bladder cells according to pre-determined programs which control pressurized air inlet to and exhausted from individual air bladder cells via electrically controlled valves.

For example, to produce a soliton traveling wave of support force reduction which travels from the head-end towards the foot-end of the mattress, air pressure in a first laterally disposed zone of air bladder cells located at an end of the longitudinal axis of the mattress near the patient's head is momentarily reduced to produce a pressure reduction pulse, followed by a reduction of air pressure in air bladder cells located in longitudinal zones successively closer to the foot-end of the mattress, and so forth, until a pressure reduction pulse occurs in a last longitudinal zone of air bladder cells near the foot-end of the mattress. The soliton traveling pressure wave pulse cycle and resultant soliton traveling support force wave cycle can be activated intermittently, such as once every hour, continuously in groups of several cycles periodically or in response to sensor measurements of reaction forces exerted on a patient.

In one embodiment of the invention, the air bladder cell matrix will have at least two and preferably three parallel longitudinally disposed zones located side-by-side, and preferably have at least 3 and preferably 4 or more laterally disposed zones. For example, a 3 column X 4 row array of 12 air bladder cells which has four longitudinally arranged, laterally disposed zones each three-cells wide enables soliton traveling support force waves to be propagated longitudinally, i.e., head-to-foot, or foot-to-head, laterally, i.e., left-to-right and right-to-left, and obliquely.

Under computer program control, the air pressure in individual air bladder cells, or in groups of cells, such as in all or some of the cells in a row or column, can be temporarily varied from quiescent values of air pressure in a wide variation of time sequences to thus produce a wide variety of soliton waves of patient support forces which travel over the upper surface of the mattress. The traveling soliton support wave patterns can be optimized to alleviate or minimize the formation of decubitus sores which can result from long periods of large static support pressures on parts of a patient's body.

In a simple example, the pressure in all three of the laterally arranged air bladder cells in the first, head-end longitudinal zone of a 3 X 4 matrix air mattress may be reduced from quiescent steady state values by a pulse of negative air pressure input to the cells in that zone for a period of several seconds. At the end of the first air pressure pulse, air pressures in the cells may be restored to their original bias or quiescent values, which have been previously adjusted to provide comfortable support of a patient.

After an initial pressure pulse has been applied to a first air bladder cell or group of cells, similar pressure reduction pulses are applied sequentially to transverse zones 2, 3 and 4. This sequence of air pressure reduction pulses results in a soliton traveling wave of support forces reduction which travels longitudinally from the head-end to the foot-end of the mattress.

The traveling waves of air pressure reduction pulses in the air bladder cells can be performed as a single cycle, at pre-determined times, repeated for several cycles, or performed continuously for pre-determined time periods. Also, the time interval between an air pressure reduction pulse in one zone of air bladder cells and the initiation of an air pressure pulse in a subsequent zone in a pre-selected spatial sequence need not be zero, as it would be in a traveling wave which characterizes water waves, but may, for example, have a finite, selectable, value. In other words, the duty cycle of a pulse generator used to activate air pressure control valves to thus apply a sequence of air pressure pulses to a sequence of air cell bladder zones can be as small as desired. Or, put another way, the time interval between successive pressure pulses applied to successive cells or group of cells, can be as long as desired.

According to the invention, soliton traveling waves of air pressure pulses which decrease for pre-determined time intervals and repetition rate, the maximum reaction force concentrations on parts of a human body can be programmed to travel longitudinally from head-to-foot, as described in the simplified example above, or in the opposite, foot-to-head longitudinal direction on the mattress surface. As stated above, longitudinally traveling soliton body support force waves are produced by varying the air pressure simultaneously in each air bladder cell in a first transverse row of cells, subsequently varying the air pressure in the air bladder cells in a longitudinally adjacent row of cells, and so forth, until the soliton wave of support forces on parts of a patient's body has traversed the entire length or a selected segment of the length of the mattress.

In an exactly analogous fashion, air pressure in laterally adjacent or spaced apart longitudinally disposed columns of adjacent air bladder cells may be sequentially varied to produce laterally traveling waves of body support forces. Also, by sequentially varying air pressure in obliquely located air bladder cells, obliquely soliton traveling waves of body support forces may be generated using the soliton traveling wave air mattress according to the present invention.

According to another aspect of the present invention, an optional force sensor array is optionally provided which has individual surface reaction force sensors associated with individual air bladder cells, in vertical alignment with individual cells. The array of reaction force sensors, which produce electrical signals proportional to reaction forces exerted by the mattress on various parts of a patient's body supported by the individual cells, may be used to create a map of body reaction force concentrations.

The measured values of reaction forces may also be used to create a segmented measured reaction force gradient vector. The reaction force gradient vector may

then be used to calculate a path sequence for producing a soliton traveling wave of air pressure in a sequence of air bladder cells along the reaction force gradient vector.

Since a measured reaction force gradient vector may not necessarily include all of the air bladder cells in an array, and may in some cases be directed between non-adjacent air bladder cells, soliton traveling waves of air pressure may be directed individually to only a small number of the total air bladder cells in an array, some or all of which cells may be non-adjacent. In this way, patient body support reaction forces exerted by the air mattress may be momentarily and periodically reduced in an efficient manner which does not require varying air pressure in all of the air bladder cells in an array.

For example, if reaction force sensors determine that a maximum reaction force is exerted by a first cell, and the force gradient vector from that maximum is directed through three additional cells, some of which may be non-adjacent, an air pressure wave need be directed only to those four air bladder cells to thus create a soliton traveling support force reduction wave which travels over just the four cells. For reasons stated above, the four cells need not necessarily be vertically or horizontally aligned, or adjacent to one another.

According to the invention, a basic embodiment of the soliton traveling wave air mattress, which need not have reaction force sensors, may also be programmed to simulate relaxing motions. Thus, longitudinal traveling soliton support pressure waves in the mattress may be programmed to simulate motions corresponding to floating on a surf wave, and may be accompanied by surf sounds. Also, laterally traveling soliton support force pressure waves can be programmed to simulate gentle rolling or rocking motions of a boat and may be accompanied by water sloshing sounds and/or sounds simulating creaking oarlocks.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a partly schematic, partly perspective view of a traveling wave air mattress apparatus according to the present invention.

Figure 2A is a fragmentary, partly diagrammatic upper plan view of an air mattress component of the air mattress apparatus of Figure 1.

Figure 2B is a fragmentary, partly diagrammatic upper plan view of a first modification of the air mattress of Figure 2A.

Figure 3A is a timing diagram showing relative timing and amplitudes of negative air pressure pulses for producing soliton traveling body support force waves in the apparatus of Figure 1.

Figure 3B is a timing diagram similar to Figure 3A but showing positive pressure pulses and for producing positive soliton traveling body support force waves.

Figure 4 is a view similar to that of Figure 2B, but showing a second modification of the air mattress of Figure 2A having a second arrangement of individual inflatable air cells, in which each transversely disposed row consists of two cells.

Figure 5 is a view similar to Figure 4, showing a third arrangement of air cells in which each row consists of four cells.

Figure 6 is a partly schematic, partly perspective view of a modification of the traveling wave air mattress apparatus of Figure 1, which is suitable for use in health care facilities.

Figure 7A is a partly diagrammatic upper plan view of an air mattress component of the air mattress of Figure 6.

Figure 7B is a timing diagram showing relative timing of pressure pulses and resulting traveling soliton body support force waves of the apparatus of Figure 6.

Figure 8 is a diagrammatic upper plan view of a two-column by six row modification of the air mattress of Figure 7A, showing a hypothetical reaction force gradient vector thereon.

Figure 9 is timing diagram showing a sequence of negative air pressure pulses applied to the mattress of Figure 8 in the direction of the reaction force gradient vector shown in Figure 8.

Figure 10 is a partly diagrammatic view of a soliton wave generator for the apparatus shown in Figure 6, which includes a reciprocating air pulse generator.

Figure 11A is a partly diagrammatic view of another embodiment of a traveling wave air mattress apparatus according to the present invention, which includes a pressure/vacuum pump, showing valves of the apparatus configured for producing negative air pressure in pulses to air bladder cells of an air mattress.

Figure 11B is a view similar to that of Figure 11A, but showing valves configured for producing positive pressure variations in air bladder cells.

Figure 12 is a partly diagrammatic view of a third, modular embodiment of a soliton traveling wave air mattress according to the present invention.

Figure 13 is a partly diagrammatic view of a soliton wave generator and air pressure pulse generator module of the apparatus of Figure 12.

Figure 14 is a partly diagrammatic view of a first type mattress interface module and inflatable air mattress which together with the soliton wave generator and air pressure pulse generator module of Figure 13 comprise a third embodiment of a soliton traveling wave air mattress according to the present invention.

Figure 15 is a partly diagrammatic view of a second type mattress interface module and inflatable air mattress which together with the soliton wave generator and air pressure pulse generator module of Figure 13 comprise a first variation of a third embodiment of a soliton traveling wave air mattress according to the present invention.

Figure 16 is a partly diagrammatic view of a third type of an air mattress interface module and inflatable air mattress which together with the soliton wave generator

and air pressure pulse generator module of Figure 13 comprise a second variation of a third embodiment of a soliton traveling wave air mattress according to the present invention.

Figure 17 is a partly diagrammatic view of a fourth type of air mattress interface module and inflatable air mattress which together with the soliton wave generator and air pressure pulse generator module of Figure 13 comprise a third variation of a third embodiment of a soliton traveling wave air mattress according to the present invention.

Figure 18 is a timing diagram showing a first, active-deflation operating mode of the soliton wave generator of Figure 13.

Figure 19 is a timing diagram showing a second, passive-deflation operating mode of the soliton wave generator module of Figure 13.

Figure 20 is a timing diagram showing relative timing and amplitudes of a sequence of air pulses input sequentially into individual air bladder cells of the air mattress of Figure 17, to thus produce a soliton traveling body support force wave on the upper surface of the air mattress.

Figure 21A is a fragmentary, partly diagrammatic side elevation view of the air mattress of Figure 17, showing the mattress being inflated from an initial deflated state to a fully inflated state by a first sequence of deflating and inflating pulses of the type shown in Figure 20.

Figure 21B is a diagrammatic view similar to that of Figure 21A, showing the progression of a soliton traveling support force-reduction wave traveling in a left-to-right, head-to-foot direction produced on the upper surface of the air bladder cells of the mattress resulting from a sequence of deflating and re-inflating pressure pulses of the type shown in Figure 20 being input to a series of individual laterally disposed air bladder cells of the air mattress beginning at the left, head-end of the mattress and ending at the right, foot-end of the air mattress.

Figure 21C is a partly diagrammatic view showing a body support force-reduction wave produced on the surface of the air mattress of Figure 17 by introducing a sequence of air pressure pulses of the type shown in Figure 20 to a series of pairs of adjacent air bladder cells of the air mattress, beginning at the left, head-end of the air mattress and ending at the right, foot-end of the air mattress.

Figure 21D is a view showing a downward, head-to-foot body support force-production wave produced on the surface of the air mattress of Figure 17 in which odd number air bladder cells 1, 3, . . . through 19 are deflated and re-inflated in a first soliton force-reduction wave, and even number air bladder cells 2, 4, . . . through 20 are deflated and re-inflated in a second soliton body support force-reduction wave.

Figure 21E is a view similar to Figure 21B but showing a soliton body support force wave traveling in a toe-to-head direction produced on the surface of the air mattress by sequentially deflating and re-inflating air bladder cells by pressure pulses beginning at the foot-end of the air mattress, and ending at the head-end of the air mattress.

Figure 21F is a view similar to Figure 21A, showing upwardly and downwardly soliton traveling body support force waves being produced on the surface of the air mattress by simultaneously introducing upwardly and downwardly traveling soliton waves of air pressure deflation/re-inflation pulses into the air bladder cells of the air mattress.

5 Figure 22 is a diagram showing plots of pressure versus time for deflation/re-inflation cycles of a series of air bladder cells of the traveling wave air mattress of Figure 12.

Figure 23 is a diagrammatic view showing deflation pressure versus time curves of an air bladder cell loaded with different body weights.

10 Figure 24 is a timing diagram showing a sequence of negative pressure pulses applied to a sequence of air bladder cells of the air mattress of Figures 12 and 13, in which certain individual air bladder cells that have been determined during a previous soliton traveling wave pulse sequence to have been subjected to weight load forces below a pre-determined minimum value are omitted from the sequence of air bladder cells to which negative air pressure pulses are applied, thus decreasing the time intervals between which  
15 air bladder cells that support pre-determined minimum weight loads are deflated and re-inflated.

Figure 25 is a diagrammatic view of a first modification of the pressure pulse generator component of the apparatus shown in Figure 13.

20 Figure 26 is a diagrammatic view of a second modification of the pressure pulse generator component of the apparatus shown in Figure 13.

Figure 27 is a diagrammatic view of a third modification of the pressure pulse generator component of the apparatus in Figure 13.

Figure 28 is a simplified upper plan view of a modification of the air mattress of Figure 2A, which has concentric oval ring-shaped air bladder cells.

25 Figure 29 is an upper plan view of a modification of the air mattress of Figure 28, in which air bladder cells of the array are segmented into quadrants.

Figure 30 is a simplified upper plan view of another modification of the air mattress of Figure 2A, which has concentric circular ring-shaped air bladder cells.

30 Figure 31 is an upper plan view of a modification of the air mattress of Figure 30, in which air bladder cells of the array are segmented into quadrants.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

35 Figure 1 is a perspective, partly diagrammatic view of a basic embodiment of a soliton traveling wave air mattress apparatus according to the present invention. The apparatus includes an air mattress 20 and a mattress inflation control apparatus 27. As shown in Figure 1, mattress 20 has in upper plan view an outline shape similar to that of a typical hospital mattress, i.e., a longitudinally elongated rectangle having a length of about 80

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inches and a width of about 30 to 36 inches. However, the exact dimensions and shape of mattress 20 are not critical, and may differ from the example given.

As shown in Figure 1, mattress 20 has a generally flat rectangular base panel 21 which may be made of a sheet of a durable flexible plastic material such as polyurethane or polyvinyl. Base panel 21 has protruding upwards therefrom a longitudinally arranged series of laterally elongated, rectangular plan view air bladder cells 22. As shown in Figure 1, each air bladder cell 22 extends from the left-hand longitudinally disposed edge 23 to the right-hand edge 24 of mattress 20. As is also shown in Figure 1, when air bladder cells 22 are inflated, e.g., to a pressure of about 1 psi gauge, the cells have in a vertical longitudinal sectional view generally the shape of a laterally elongated semi-cylinder which has an arcuately curved, convex upper semi-cylindrical surface 25 that extends upwards from base panel 21.

Although the transverse cross-sectional shape and size of air bladder cells 22 is not critical, a typical size and shape for use in a 80 inch X 36 inch mattress having 6 laterally disposed air cells would be a semi-cylinder having a base diameter of about 13 inches and a length of about 36 inches, as shown in Figures 1 and 2A.

Confronting laterally disposed edges 26 of the air bladder cells 22 may contact each other, or as shown in Figures 1 and 2A, edges 26 may optionally be spaced longitudinally apart a short distance, e.g., 1 inch.

Referring to Figure 1, it may be seen that traveling wave air mattress apparatus 10 includes a mattress inflation control apparatus 27 for inflating and deflating air bladder cells 22 to individual pressure levels which provide comfortable support for a person supported by mattress 20. Apparatus 10 also includes a wave generator apparatus 44 for varying air pressure in inflatable air bladder cells 22 in a manner which results in a soliton traveling wave of support-force to propagate on the upper surface 28 of the mattress formed by the upper surfaces 25 of air bladder cells 22. Preferably mattress 20 is enclosed by a soft fabric mattress cover, and an optional thin layer of foam rubber between the upper surface of air bladder cells 22 and an inside surface of the mattress cover.

According to the invention, wave generator apparatus 44 is used to produce a soliton traveling wave of support force for the body of a person supported on the upper surface 28 of mattress 20 by sequentially varying the air pressure in selected paths of individual air bladder cells 22, for example from the head-end to the foot-end of the mattress, in predetermined time sequences.

As shown in Figure 1, mattress inflation level control apparatus 27 includes a source of pressurized air 30, which is preferably an air compressor but may optionally be a tank containing a pressurized gas such as air or nitrogen. Air pressure source 30, which is preferably a compressor driven by an electric motor 55, has an outlet port 31 connected through an outlet tube 32 to the inlet port 33 of a selector manifold 34. Selector manifold 34 has multiple outlet ports 35, e.g., six outlet ports 35-1, 35-2, 35-3, 35-4, 35-5 and 35-6,

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which are individually connected through tubes to the inlet ports 36-1 through 36-6 of a group of cell selector valves 37-1 through 37-6.

Each cell selector valve 37, which may be a simple on/off gate valve, has an outlet port 38 which is connected to a first, e.g., upper inlet tube port 39 of a Y-tube coupler 40. Each Y-tube coupler 40 has a second, lower inlet tube port 41 and an outlet tube port 42 which is connected to an inflation port 43 of an individual air bladder cell 22. Thus for example, outlet tube port 42-1 of Y-tube coupler 40-1 is connected with air pressure-tight fittings to air inlet port 43-1 of the first, head-end air bladder cell 22-1 of traveling wave air mattress 20, and so forth.

As will be explained in further detail below, each cell inflation selector valve 37 is controlled by electrical signals issued by an electronic control module 51 to inflate and deflate individual air bladder cells 22 to quiescent values which provide comfortable support for a person reclining on mattress 20.

Referring still to Figure 1, it may be seen that wave generator apparatus 44 includes a pressure pulse generator 45 for creating negative and optionally positive pulses of air pressure in an outlet port 46 which are conducted to second, lower inlet port tubes 41 of Y-tube couplers 40. The output port 46 of pressure pulse generator 45 communicates with a source of pressurized air, such as a closed chamber part of a cylinder located on a side of a piston or diaphragm which is longitudinally movable in the cylinder in response to forces exerted on the piston by a linear actuator.

Wave generator apparatus 44 includes a wave generator controller 44A for issuing electrical command signals to pressure pulse generator 45 and other components of the wave generator apparatus. Wave generator controller 44A is preferably a computer, microprocessor, or programmable logic controller (PLC), and preferably communicates with or is optionally replaced by a computer 52 of inflation control apparatus 27.

The magnitude of the negative air pulses need not be any greater than the maximum intended inflation pressure of any air bladder cell 22. For example, if the intended maximum inflation pressure of any of air bladder cells 22-1 through 22-6 is 1 psi, the negative pulse-generating capability of pressure pulse generator 45 should be sufficient to draw all of the air from an air bladder cell 22, e.g., about 1.38 cubic feet, within a pre-determined maximum time limit, e.g., 10 seconds. In actuality, the exhaustion rate of pressure pulse generator 45 may be less, since some modes of operation of the invention envision only a fractional reduction of the pressure in an air bladder cell 22 from a quiescent value, e.g., one-half.

According to the invention, after a negative pressure pulse has been applied to an air bladder cell 22, the air pressure in that cell may be changed to a quiescent or bias value different than pressure at the beginning of the pulse, but is typically restored to the original bias pressure value. In either case, a single pressure pulse generator 45 within wave generator 44 may be used in conjunction with pulse selector valve array 47 to route negative

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or positive pulses of air pressure to selected air bladder cells 22. Thus, as shown in Figures 1 and 2, pressure pulse generator 45 has a single outlet port 46 which is connected through a manifold 48 and pressure pulse selector valves 49 of valve array 47 to second, lower inlet port tubes 41 of selectable Y-tube couplers 40. Each pulse selector valve 49, which may be a simple on/off gate valve, is controlled by electrical signals issued by wave generator controller 44A.

Referring to Figure 1, it may be seen that mattress inflation control apparatus 27 includes an electronic control module 51 for adjusting the static or quiescent inflation pressure levels of air bladder cells 22 to values which provide comfortable support to a person lying on the upper surface 28 of air mattress 20, and for controlling functions of wave generator 44.

As shown in Figure 1, electronic control module 51 preferably includes a computer 52 or a similar programmable electronic component such as a microprocessor or programmable logic controller (PLC) which emits through an interface module 53 command signals for actuating various components of the apparatus 27, such as compressor 30, cell inflation selector valves 37 and optionally pulse selector valves 49. Computer 52 may also receives through interface module 53 various feedback signals such as valve configuration and compressor outlet pressure from a pressure transducer 54, etc.

Depending upon whether mattress system 10 is to be configured as a relatively inexpensive, relaxation-inducing system, or a precision therapeutic system for use in hospitals and similar locations, the system 10 may include less or more complexity and cost-increasing components. For example, while a low-cost soliton traveling wave mattress 20 intended for recreational or relaxation purposes according to the present invention would not require body support-force sensors, embodiments of the invention intended for use in hospital environments would desirably include a force sensor array that used at least one force sensor associated with each air bladder cell of the mattress, to monitor reaction support forces exerted by the air bladder cells on the body of a patient.

Figure 2B illustrates a modification 10B of the traveling wave air mattress 10 according to the present invention. As shown in Figure 2B, each of the air bladder cells 22B of modified air mattress 20B has in addition to inlet port 43 a second inlet port 43B for connection directly to a separate pulse selector valve 49. This construction eliminates a requirement for Y-tube couplers 40, since each cell pulse selector valve 37 may be connected directly to a separate bladder cell inflation port 43B. However, the embodiment which employs Y-couplers as shown in Figures 1 and 2A is preferred, because it minimizes the number of tubes connected to mattress 20.

Figure 3A is a timing diagram showing a typical pattern of variation of air pressure in individual transverse rows of air bladder cells 22 of the basic, relaxational embodiment of soliton traveling wave air mattress system 10 shown in Figures 1 and 2A.

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Referring to Figure 3A, mattress inflation control apparatus 27 is first directed by computer 52 to switch on electrical power to drive motor 55 of air compressor 30. By employing command signals issued from computer 52 through interface module 53 to air bladder cell selector valves 37, individual air bladder cells 22-1, 22-2, 22-3, 22-4, 22-5 and 22-6 may be inflated to pre-determined air pressure values monitored by compressor pressure transducer 54. As shown in Figure 7B, the initial quiescent or bias values of pressure to which individual air bladder cells 22 are inflated need not all be the same.

After the individual air bladder cells 22-1 through 22-6 have been inflated to pre-determined quiescent values, command signals may be initiated by computer 52 and issued through interface module 53 and a wave generator controller 44A to initiate operation of wave generator 44. For example, a first step in the operation of wave generator 44 would be to actuate a first pressure pulse selector valve 49 of pressure pulse generator 45 to thus provide an air flow path between outlet port 46 of pressure pulse generator 45 through lower inlet port tube 41-1 of Y-tube coupler 40-1 to air inlet port 43-1 of first air bladder cell 22-1.

Next, as shown in line 1 of Figure 3A, pressure pulse generator 45 is powered on at a time T1 in response to a command signal from computer 52. As may be understood by referring to Figure 10, applying power to pressure pulse generator 45 causes a solenoid, pneumatic actuator cylinder or stepper motor-driven linear actuator to move a diaphragm or piston 183 in a closed cylinder 180 which has on a first active side 188 of the piston 183 a port 146 connected through a pulse selector valve 215 of pulse selector valve array 47 to the second, lower inlet port tube 41-1 of Y-junction coupler 40-1 connected to inflation port 43-1 of air bladder cell 22-1. Pressure pulse generator 45 may also have located on a second, down-stroke side 181 of piston 183 a second, storage chamber 61, which may be optionally connected through air-tight fittings and an optional valve to a pneumatic accumulator 62.

As shown in Figure 3A, a first air pressure pulse 63-1 emitted by pressure pulse generator 45 and conducted to a first air bladder cell 22-1 has generally an amplitude which varies as a function of time as the negative half of a sine wave. However, the shape of air pressure pulse 63 may optionally be varied under computer control to approximate that of a rectangle, trapezoid, triangle, or other such shape.

The magnitude of air pressure pulse 63 is variable under computer control to a desired value, but typically would be about half or less than the maximum quiescent or bias pressure level in a given air bladder cell or group of air bladder cells. For example, for a quiescent air pressure level of 1 psi in a cell 22 of mattress 20, the amplitude of air pressure pulse 63 would typically be about 0.5 psi or less.

As shown in Figure 3A, first air pressure pulse 63-1 is a negative-going pulse that temporarily reduces the air pressure in air bladder cell 22-1. It is envisioned that for use of mattress 20 in hospital beds or other such therapeutic applications, the pulse of air pressure produced by pressure pulse generator 45 would typically be negative, to thus temporarily reduce the reaction force exerted on a patient's body by a particular air bladder cell 22 or a group of air

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bladder cells 22. However, as shown in Figure 3B, the pulse generator 45 can be configured and commanded to alternatively produce positive-going pressure pulses 64, for applications such as relaxational uses of mattress 20.

The period of pulse 63 may be adjusted to any suitable value under computer control. Thus, the time interval between the beginning, T1 and the end, T2 of pressure pulse 63 shown in line 1 of Figure 3A can be any desired value, e.g., several seconds to several minutes or longer.

Referring now to the graph in line 2 of Figure 3A, it may be seen that pulse generator 45 is used to apply a second air pressure pulse 63-2 in a sequence of air pressure pulses to a second air bladder cell 22-2 at a programable time T3. Beginning time T3 of second pulse 63-2 may be coincident with the end of pulse 63-1, or delayed to occur at any desired programmable time period later than T2, e.g., 1 second, several seconds, or longer. In exactly the same manner, successive air pressure pulses 63-3, 63-4, 63-5, and 63-6 may be applied to air bladder cells 22-3, 22-4, 22-5 and 22-6, which cells are located progressively further towards the foot-end of air mattress 20 from the head-end air bladder cell 22-1.

As shown in graphs in lines 1-6 of Figure 3A, a negative pressure wave is produced in a continuous sequence of air bladder cells 22-1 through 22-6 to thus produce a soliton traveling wave of reduction in support force for the body of a person supported by air mattress 20. However, it should be understood that characteristics of the traveling pressure wave produced by pressure pulse generator 45 of pressure wave generator 44 and hence characteristics of soliton traveling body force support waves may readily be modified in real time by suitably programming computer 52. For example, referring to Figures 2A and 9, the traveling pressure wave may be programmed to skip over selected air bladder cells, such as even cells 22-2, 22-4, by not applying negative pressure pulses to those cells. In fact, apparatus 10 may be programmed to produce sequences of air pressure pulses which travel in any arbitrary path between air bladder cells 22.

As may be readily understood by viewing Figure 3B, the pressure pulses produced by pressure pulse generator 45 may optionally be positive-going (64-1 through 64-6) rather than negative-going, provided the quiescent pressure levels of air bladder cells 22 are initially adjusted to values less than maximum inflation levels.

Also, pressure wave generator 44 may optionally be directed by computer 52 to produce overlapping pressure pulses, parts of which are applied simultaneously to more than two cells or zones of cells to thus produce an overlapping soliton body support-force wave. For example, referring to Figure 3A, the initiation time T3 of a of second air pressure pulse 63-2 may occur between beginning and ending times T1 and T2 of first air pressure pulse 63-1, to thus produce a composite soliton traveling support wave pulse which begins at T1 and ends at T4, and is longer than the individual pulses shown in Figure 3A.

As shown by the dashed lines in Figures 3A and 3B, the pulse generator 45 may be programmed to cause some or all of the air bladder cells 22 that have received a pulse of air

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pressure variation to retain the pressure level in the cell at its maximum changed value, or at a value intermediate between the initial quiescent level and the maximum changed level.

Pressure wave generator 44 may also be directed by computer 52 to produce two or more traveling support force waves which travel simultaneously on the upper surface 28 of mattress 20. Thus, for example, by programming computer 52 to direct wave generator 44 to sequentially apply air pressure pulses to longitudinally descending and ascending pairs of air bladder cells, a first soliton traveling wave of support force may be launched on upper surface 28 an air mattress 20, which travels from the head-end to the foot-end of the mattress, and a second soliton traveling wave of support force launched simultaneously, which travels from the foot-end to the head-end of the mattress. The foregoing pair of simultaneous traveling soliton support waves may be produced by simultaneously applying pulses of air pressure to the following pairs of cells; (22-1 and 22-6), (22-2 and 22-5), (22-3 and 22-4), (22-3 and 22-4), (22-2 and 22-5), and (22-1 and 22-6).

Figure 4 illustrates a second modification 20C of air mattress 20 shown in Figures 1 and 2A, which has a series of six longitudinally arranged, transversely disposed rows, each having 2 side-by-side air bladder cells 22C, for a total of 12 air bladder cells.

Figure 5 illustrates another modification 20D of air mattress 20 shown in Figures 1 and 2A, which has six transversely disposed rows of 4 side-by-side air bladder cells 22D, for a total of 24 air bladder cells.

As discussed above, the soliton traveling wave air mattress apparatus according to the present invention may be programmed to launch pairs of soliton support force waves which travel simultaneously in opposite directions on the upper surface of the air mattress. From this discussion, it will be readily understood that pressure wave generator 44 may be directed by computer 52 to produce laterally moving soliton traveling support force waves on the surface of an air mattress having multiple columns of air bladder cells, such as the mattresses shown in Figures 4 and 5. Moreover, it will be readily understood that according to the present invention, two or more traveling soliton support waves may be simultaneously launched on the mattresses having multiple columns, and these waves can include simultaneously existing pairs of longitudinally traveling waves, laterally traveling waves, or combinations of simultaneous longitudinally and laterally traveling waves.

As shown in Figure 1, wave generator apparatus 44 may be used as an accessory with an existing air mattress apparatus which includes a multi-cell air mattress 20 and an associated inflation control apparatus 27, by interconnecting the wave generator apparatus to the inflation control apparatus using Y-couplers 40. In this accessorized configuration, computer 51 of inflation controls module 51 can provide a signal to wave generator controller 44A indicating when adjustment of quiescent air pressures in air bladder cells 22 has been achieved by the inflation control apparatus 27, whereupon pulse pressure sequences causing soliton traveling wave support force waves may be initiated by pressure pulse generator 45.

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Figures 6 and 7A illustrate an embodiment 110 of a soliton traveling wave air mattress according to the present invention, which is a modification of the basic embodiment 10 and is suitable for use in hospitals, nursing homes and similar facilities.

As shown in Figures 6 and 7A, modified soliton traveling wave apparatus 110 includes a mattress 120 which may be similar in construction to the basic mattress embodiment 20 shown in Figure 1 and described above. For ease of explanation, the mattress shown in Figures 6 and 7 is shown to have 6 transversely disposed, non-subdivided air bladder cells. However, mattress 120 actually includes a rectangular matrix of air bladder cells 122 as shown in Figures 4 and 5, rather than a single column of transversely disposed rows of air bladder cells, which enables air pressure and hence body support forces to vary only in a single, longitudinal head-to-toe direction.

According to the invention, air mattress 120 intended for use in hospitals would have as shown in Figure 4 at least two and preferably three, four, or more separate laterally disposed columnar zones of air bladder cells, as shown in Figure 5.

As shown in Figure 5, 6 and 7A, an example air mattress 120 has six different transversely disposed, longitudinally ordered zones which span the head-to-toe length of the mattress. Each of the six transversely disposed rows of air bladder cells 122 is partitioned into four rectangular air bladder cells, each of which is hermetically isolated from all other air bladder cells.

Thus, in the example embodiment of air mattress 120 shown in Figures 5 and 6, there is a rectangular matrix array of 24 rectangularly-shaped air bladder cells 122-1 through 122-24, each of which is hermetically isolated from all of the other air bladder cells in the array. This construction enables each of the air bladder cells 122-1 through 122-24 to be separately inflated and deflated to individually adjustable bias or quiescent levels.

Apparatus 110 also has an inflation control apparatus 127 and a pressure wave generator 144 that enables air pressure pulses to be applied to individual air bladder cells 122 or groups of cells, in any desired combination and sequence.

Preferably, as shown in Figure 6, traveling wave air mattress 110 includes a force sensor array 170. Force sensor array 170 is comprised of a group of individual flexible surface reaction force sensors 171-1 through 171-24, each of which is fastened in vertical alignment with a separate one of air bladder cells 122-1 through 122-24. Each sensor 171-1 through 171-24 is a two-terminal device which has a first output terminal 172-1 - 172-24 that is connected to an individual lead wire 173-1 through 173-24. Each sensor 171 also has a second output terminal 174-1 - 174-24 which is connected to an individual lead wire 175-1 through 175-24. Alternatively, the sensors 171-1 through 171-24 may be interconnected in an X-Y matrix, using 6 row-connector lead wires 176-1 through 176-6, and 4 column-connector lead wires 177-1 through 177-4. In either arrangement, the lead wires are used to connect sensors 171 to a sensor interface module 176 of inflation control apparatus 127.

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Sensors 171-1 through 171-24 of sensor array 170 are used to monitor reaction support forces exerted on various parts of the body of a person supported by air bladder cells 122-1 through 122-24 of traveling wave air mattress 120.

Monitoring of reaction support forces exerted on a patient's body is performed when a patient first lies down on mattress 120, and the air bladder cells 122-1 through 122-24 are inflated to quiescent or bias values which provide comfortable support to the patient; ideally by reducing reaction support forces which are above a certain desired maximum by reducing air pressure in some cells and increasing air pressure in other cells.

At a pre-determined time after initial adjustment of quiescent air pressure levels in air bladder cells 122-1 through 122-24, computer 152 of inflation control apparatus 127 generates pre-determined patterns of pressure pulses which when applied to the air bladder cells, result in production of soliton traveling waves of patient body-support forces that travel on the upper surface 28 of the mattress.

The magnitude, shape, timing and other characteristics of air pressure pulses generated by pressure pulse generator 145 may in general be similar to those of the pulses described above for the basic embodiment 10 of the traveling wave air mattress. However, since the air bladder cells 122-1 through 122-24 of air mattress 120 have distinct laterally separated as well as longitudinally separated locations, traveling pressure waves and hence traveling soliton body support-force variation waves can be directed laterally and obliquely as well as longitudinally on the surface of the mattress. Moreover, as will be explained in detail below, surface reaction force sensor array 170 of air mattress apparatus 110 may be used to calculate in real time paths for reaction force support waves which can minimize long-term large-magnitude reaction forces which might be exerted on a patient's body, and thus further aid in preventing formation of decubitus sores.

An example of calculating a beneficial path of a traveling pressure support wave in response to reaction force measurements using sensor array 170 may be understood by referring to Figure 8 and Table 1.

Figure 8 is a diagrammatic upper plan view of a two-column by six row modification or part of air mattress 120. As shown in Figure 5, there are twelve air bladder cells 122-1 through 122-12, each of which has attached to and in vertical alignment therewith a separate one of an array of surface reaction force sensors 171-1 through 171-12, which are used to produce a pressure map of surface reaction forces exerted on a patient's body. Hypothetical example values of measured patient body support reaction forces are listed in Table 1. As shown in Figure 8, a surface reaction force gradient vector is constructed using the pressure/force map values of Table 1. The tail end of the gradient vector is located in air bladder cell number 122-1, since the highest surface reaction force, 1.5 kilopascals (kPa) was measured by sensor 171-1 in cell 122-1.

The second highest reaction force of 1.4 kPa was measured in cell number 122-4, so the first segment of the gradient vector V is directed from cell 122-1 to cell 122-4.

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The third highest reaction force of 1.3 kPa was measured in cell number 122-7, so the second segment of gradient vector V is directed from cell 122-4 to cell 122-7.

The fourth highest reaction force of 1.1 kPa was measured in cell number 122-12, so the third segment of gradient force vector V is directed from cell 122-7 to cell 122-12.

According to the invention the segmented gradient force vector V measured and calculated as above is used to direct computer 52 to generate a pressure reduction wave which is applied consecutively to air bladder cells 122-1, 122-4, 122-7 and 122-12, thus producing a soliton traveling surface support reaction force reduction wave which follows the measured reaction force gradient.

TABLE 1

| CELL NUMBER | MAX REACTION FORCE, kPa |
|-------------|-------------------------|
| 1           | 1.5                     |
| 2           | 1.0                     |
| 3           | 0.9                     |
| 4           | 1.4                     |
| 5           | 0.8                     |
| 6           | 0.8                     |
| 7           | 1.3                     |
| 8           | 0.9                     |
| 9           | 0.9                     |
| 10          | 0.9                     |
| 11          | 1.0                     |
| 12          | 1.1                     |

Figure 9 illustrates an example of a pressure pulse wave 163 which is applied by wave generator apparatus 144 to traveling wave air mattress 120 along the path of a gradient vector V calculated by computer 152 from reaction forces exerted on a patient's body and measured by sensors 171.

As shown in Figure 9, traveling pressure pulse wave 163 is created by applying a first pulse 163A of negative pressure created by pressure pulse generator 145 to air bladder cell 122-1 between times T1 and T2. At a time T3 following T1 which optionally precedes T2, a second pulse of negative pressure 163B is applied to air bladder 122-4 and continued until T4. In an exactly analogous fashion, a third negative air pressure pulse 163C is applied to air bladder cell 7 between times T5 and T6, and a fourth and final negative air pressure pulse 163D is applied to air bladder cell 122-12 between times T7 and T8.

As can readily be envisioned by referring to Figures 6-9, the sequence of four negative air pressure pulses 163A, 163B, 163C and 163D applied to air bladder cells 122-1, 122-4,

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122-7 and 122-12, respectively, creates a soliton traveling wave of patient body support-force reduction. As described above, the air bladder cell air pressure reduction soliton traveling wave is directed to follow the patient reaction support force gradient vector. Accordingly, by temporarily reducing the inflation pressure of air bladder cells which are exerting the greatest support force concentrations on a patient's body, these forces, which could cause decubitus sores if left unabated for long periods of time, will be substantially reduced for time periods proportional to the product of the length of pressure reduction pulse 163 and the number of times per day that the traveling pressure pulse wave cycle is repeated.

In general, during the generation of a soliton traveling body support-force variation wave by a sequence of pressure reduction pulses applied to air bladder cells 122, pressures exerted on a patient's body by other air bladder cells, in contrast to total support forces, may increase, since the total support-forces are proportional to the fixed weight of a patient supported by the mattress and hence are constant over time intervals. Moreover, the soliton traveling wave of support-force reduction, or patient movement may shift the distribution of body reaction support-forces at the end of a soliton traveling wave cycle. For the foregoing reasons, sensor array 170 would desirably be used to continuously monitor body support reaction forces over the entire surface of mattress 120, to thus determine whether an initially measured force gradient has shifted location, whereupon successive cycles of soliton traveling support force reduction may be propagated along the paths of newly determined body support -force gradient vectors.

Figure 10 is a partly diagrammatic view of pressure wave generator 144, which may be substantially similar in construction to pressure wave generator 44.

As shown in Figure 10, pressure wave generator 144 includes a pressure pulse generator 145 that has a longitudinally elongated, hollow circular cross-section cylinder 180 which has disposed through its length a coaxial cylindrical inner bore 181. Bore 181 is sealed at a first, head-end of cylinder 180 by a transversely disposed circular disk-shaped cylinder head 182, which has disposed through its thickness dimension an air passageway which comprises an outlet port 146.

As shown in Figure 10, bore 181 of pressure wave generator cylinder 180 has therewithin a circular disk-shaped piston 183. Piston 183 has an outer wall surface 184 which longitudinally slidably contacts in a hermetic seal the inner cylindrical wall surface 185 of cylinder 180.

As shown in Figure 10, that side of cylinder bore 181 located between a head-end transverse surface 186 of piston 183 and the inner surface 187 of cylinder head 182 forms a cylindrically-shaped, head-space active chamber 188 which is positively pressurizable by longitudinal motion of the piston 183 towards the cylinder head 182, and negatively pressurizable by longitudinal motion of the piston towards the transverse base or end wall 189 of cylinder 180.

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As shown in Figure 10, piston 183 of pressure pulse generator 145 has extending longitudinally away from base end surface 190 of the piston a tubular drive shaft 191 which extends longitudinally outwards of lower transverse annular base or end wall 189 of cylinder 180.

Pressure pulse generator 145 includes a force actuator 192 to drive piston drive shaft 191 and piston 183 longitudinally rearward within cylinder 180 to thereby produce within active chamber 188 of the cylinder a negative pressure pulse. Force actuator 192 also has the capability of moving piston drive shaft 191 forward within bore 181 of cylinder 180 to thus restore piston 183 to its original longitudinal location within bore 181 of cylinder 180. Thus, if piston drive shaft 191 is pivotably joined to piston 183, force actuator 192 may consist of a rotary motor coupled to the outer end 193 of piston drive shaft 191 by an eccentric coupler such as a crank. However, in a preferred embodiment of pressure pulse generator 144, force actuator 192 has a different design and construction which provides more control of the characteristics of pressure pulses produced by movement of piston 183 in cylinder 180.

Thus, as shown in Figure 10, piston drive shaft 191 of pressure pulse generator 145 has a hollow tubular construction which includes an elongated circular cross-section bore 194 that extends through the outer, rear transverse annular end wall 195 of the piston drive shaft. The piston drive shaft 191 has fixed within the lower end of bore 194 thereof a cylindrically-shaped follower or jack screw nut 195 which has through its thickness dimension a coaxial threaded bore 196. Bore 196 of follower or jack screw nut 195 receives threadingly therein an elongated threaded lead-screw or jack-screw 197 which is rotatably driven by a stepper motor 198.

Stepper motor 198 receives drive signals from a stepper motor drive electronic module 199 of a wave generator controller 144A which receives command signals from computer 152. This construction of the pressure wave force actuator facilitates repositioning the rest position of piston 183 within cylinder bore 181 to a rearward or retracted position, so that the piston drive shaft 191 and piston 183 can be extended forward to produce positive pressure pulses in outlet port 146, followed at the end of a pulse by retraction to a rearward quiescent position which reduces pressure in an air bladder cell to its quiescent pressure value.

Preferably, as shown in Figure 10, pressure pulse generator 145 includes optional components which enable it to introduce negative or positive air pressure pulses into individually selectable air bladder cells 122 that may be initially inflated to different quiescent pressures, and restore the inflation level to the initial quiescent pressure level at the end of a pressure pulse. Thus, as shown in Figure 10, outlet port 146 of pressure pulse generator 145 is connected through a cylinder isolation valve 200 through a tubular connector fitting 201 to the inlet port 202 of a pulse selector valve array manifold 203. Cylinder isolation valve 200 has a value actuator control input terminal lead 215 which is connected to a command signal output terminal of wave generator controller 144A.

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The pressure pulse generator 145 includes a cell pressure sampling pressure transducer 204 which has a pressure probe 205 that communicates with a hollow cylindrical bore space 206 of tubular fitting 201 that is located between pulse selector valve array manifold 203 and cylinder isolation valve 200. Cell pressure transducer 204 has an output terminal lead 207 which is connected to wave generator controller 144A, which has a command signal output terminal that is connected to stepper motor electronic drive module 199. Wave generator controller 144A is also connected to a signal input interface port of computer 152, to provide coordination between the computer and wave generator controller.

As shown in Figure 10, pressure pulse generator 145 also has a pulse generator cylinder pressure sampling transducer 208 which has a pressure probe 209 that communicates with active chamber head space 188 of bore 181 of cylinder 180. Cylinder pressure sampling transducer 208 has an output terminal lead 210 which is connected to a signal input interface port of wave generator controller 144A.

As is also shown in Figure 10, pressure pulse generator 145 has a cylinder bleed valve 211 which has an inlet port 212 that communicates with active chamber 188 of cylinder 181, an outlet port 213 which communicates with the atmosphere, and an electrical valve actuation control input terminal lead 214 which is connected to a command signal output interface terminal of wave generator controller 144A.

Optionally, as shown in Figure 10, pulse generator may include a manifold isolation valve 216 between tubular fitting 201 and pulse selector manifold 203.

Operation of pressure pulse generator 145 constructed and configured as shown in Figure 10 is as follows.

First, computer 152 issues a command which is transmitted through wave generator controller 144A to open a selected one of pulse selector valves 149 that is connected to a selected air bladder cell 122 which is to receive a pulse of air pressure, and to open optional manifold isolation valve 216.

Second, cell pressure sampling transducer 204 is used to measure the value of quiescent air pressure in the selected air bladder cell 122.

Third, cylinder air pressure sampling transducer 208 is used to measure cylinder air pressure in active chamber 188 of cylinder 180.

Fourth, the difference in air pressures measured by air bladder cell pressure transducer 204, and cylinder air pressure measured by cylinder air pressure transducer 208 is computed by wave generator controller 144A or computer 152. If the measured air pressure in cylinder active chamber 188 is less than the quiescent air pressure in a selected air bladder cell 122, a command signal is issued to stepper motor controller 199 which causes piston drive shaft 191 and piston 183 to be extended forward within cylinder 180 to increase air pressure in active chamber 188 of the cylinder until it is equal to the quiescent air pressure in the selected air bladder cell 122.

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For example, piston 183 may be extended forward in cylinder bore 181 from position 3 to position 2 in Figure 10. This longitudinal position of piston 183, where the pressures in cylinder 180 and a selected air bladder cell 122 are equalized, is defined as a first home position for the piston, prior to production of a pulse of pressurized by air pressure pulse generator 145, and introduction of the pulse of pressurized air into a selected air bladder cell 122. Cylinder bleed valve 211 may also receive command signals from wave generator controller 144A to enable air flow between cylinder chamber 188 and the atmosphere, to thus facilitate pressure equalization.

Fifth, as shown in Figure 10, cylinder isolation valve 200 is opened in response to a command signal issued through waves generator controller 144A by computer 152, which also causes a command signal to issue to stepper motor driver 199. If the command signal from computer 152 is to reduce air pressure in a selected air bladder cell 122 by producing a negative pressure pulse, piston 183 is retracted to a position such as positions 3, 4 or 5. If the command signal from computer 152 is to increase pressure in a selected air bladder cell 122, piston 183 is extended forward to a longitudinal location such as position 1 in Figure 10. In either case, cylinder isolation valve 200 and optional manifold isolation valve 216 remain open during the initial movement of piston 183.

Sixth, at a predetermined time at which a pulse of air pressure into an air bladder cell is to be terminated, piston 183 is commanded to move in a direction opposite to its direction at the beginning of an air pressure pulse. For example, if the air pressure in a selected air bladder cell is to be restored to the value which it had at the beginning of a pressure pulse, piston 183 would be returned to the initial home position, such as location 2 in Figure 10. However, if it is desired to return the air pressure in a selected air bladder cell 122 to a new quiescent value different from an original quiescent value, piston 183 is moved to a different location at the end of a pressure-pulse cycle.

Seventh, at a predetermined time period after piston 183 has ceased movement at the end of a pressure pulse cycle, pulse selector valve 149, optional manifold isolation valve 216, and cylinder isolation valve 200 are closed in response to command signals received from wave generator controller 144A.

As shown in Figure 10, the output port of each pulse selector valve 149 is coupled to the inlet port 143 of an air bladder cell 122 through the input tube 141 and a Y-coupler 140 which also has an input tube 139 which is coupled to an inflation control apparatus 127 that is used to initially inflate the air bladder cells to initial quiescent pressure values which provide comfortable support to a patient. However, pressure pulse generator 145 may optionally be used to inflate and deflate air bladder cells 122 to initial quiescent pressure values prior to initiation of the seven-step wave generation process described above.

With this optional configuration, pulse selector valves 149 perform a dual function, initially adjusting quiescent pressure levels in individual air bladder cells 122, and subsequently introducing a sequence of pressure pulses into the air bladder cells to create a

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traveling support force wave. Thus, with this optional configuration, the requirement for a separate inflation control apparatus 127 and Y-couplers 140 is eliminated, and each pulse selector valve 149 is connected directly to the port 143 of an air bladder cell 122.

The pressure pulse generator 145 of the pressure wave generator 144 described above requires a piston/cylinder displacement volume at least as large as the maximum volume of air which is intended to be simultaneously input to or removed from one or more air bladder cells 22 or 122. Consequently, pressure pulse generator 145 is ideally suited for use with air mattresses having a relatively large number e.g., 12 to 24 or more, of relatively small air bladder cells. However, for air mattresses which have a relatively small number, e.g., 4 to 6 of relatively large air bladder cells, the displacement requirements for single piston stroke deflation or inflation of one or more air bladder cells may require that the displacement volume and hence size of cylinder 180 of air pulse generator be undesirably large for some applications.

For example, for an air mattresses 20 of the type shown in Figure 1 which has 6 air bladder cells 22 which have a semi-cylindrical shape when inflated to a normal bias pressure of 14.7 lbs./in<sup>2</sup> (101.3 kPascals), i.e., 1 atmosphere, a diameter of 13 inches and a lateral length of 3 feet, the volume of each air bladder cell would be about 1.276 cubic feet. Therefore, the volume of cylinder 180 of air pulse generator 185 shown in Figure 10 would need to be 1.276 cubic feet or larger, if operation of the pulse generator required complete deflation or re-inflation of a single air bladder cell 22 with a single stroke of piston 183 within cylinder 180. An embodiment of a wave generator of the present invention which is useful for creating traveling support force waves in air mattresses having relatively large air bladder cells is shown in Figures 11A and 11B.

As shown in Figures 11A and 11B, an embodiment of wave generator 244 useful for deflating and re-inflating air bladder cells 22 of a relatively large air mattress 20 of the type shown in Figure 1 has an air pulse generator 245 that includes an air pump 280 which has a vacuum inlet port 281 and a pressure output port 282. An example of a suitable type of air pump 280 for use in the present application is a linear air pump which uses a magnet moving in response to time varying electromagnetic force fields produced by an alternating current to drive a piston in a reciprocating motion within a cylinder. Such pumps are described in further detail in "Mechanisms And Mechanical Devices Sourcebook." 5<sup>th</sup> Edition by Neil Sclater, McGraw-Hill, New York 2011, page 374.

As can be envisioned by referring to Figures 11A and 11B, when a piston (not shown) moves inwardly within a cylinder (not shown) of air pump 280 in response to an attractive electromagnetic force, a negative pressure occurs in pump inlet port 281, which may draw air through the inlet port 281 and past an inlet flapper valve 284 into the head-space 285 between the piston 286 and the inlet port. During this first, inlet part of the air pump cycle, negative pressure within head space 285 of air pump 280 also draws an outlet flapper valve

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288 inwardly to a closed position which seals off communication between the pump head-space and outlet port 282.

Conversely, when the piston moves outwardly in response to a repulsive electromagnetic force, a positive pressure pulse is produced in head space 285 of cylinder 283. The positive pressure closes input flapper valve 284 and opens output flapper valve 287, through which a pulse of air at positive pressure is expelled through outlet port 282 of the air pump.

From the foregoing description, it can be readily understood that powering air pump 280 with alternating current at a 60 Hz line frequency results in 60 pulses per second of negative air pressure occurring in inlet port 281 of the pump, and positive pulses of air pressure occurring in outlet port 282 at the same frequency but shifted 180 degrees in phase from the negative air pulses at inlet port 281.

As shown in Figures 11A and 11B, soliton traveling wave generator 244 includes a pressure pulse routing assembly 290 comprised of routing valves and air conduits which are interconnected between linear air pump 280 of air pulse generator 245, and pulse selector valves 249 on pulse selector manifold 246. Pressure-pulse routing assembly 290 connects negative air pressure inlet port 281 of air pump 280 to a selected air bladder cell 22 during the initial, negative-going part of a negative pressure pulse applied to an air bladder cell, and connects the air bladder cell to positive pressure at outlet port 282 of the pump during the final, positive-going part of a negative pressure pulse.

As is also shown in Figures 11A and 11B, pressure-pulse routing assembly 290 includes three 2-way or diverter-type valves which are all similar in construction and function. Thus, as shown in Figures 11A and 11B, wave generator apparatus 244 includes a first, pump inlet router valve 291 which has an output port 292 that is connected to inlet port 281 of pump 280 by a tubular pressure-tight tube 293. Pump inlet router valve 291 has a first, upper selector-manifold inlet port 294 which is connected to a second, selector manifold router valve 311. Selector manifold router valve 311 is connected to inlet port 246 of manifold 248 by a tubular pressure-tight tube 297. Pump inlet router valve 291 also has a second, supply-air inlet port 298.

Also shown in Figures 11A and 11B, pump inlet router valve 291 has an internal valve plate 299 which is pivotably movable by a solenoid actuator 300 in response to an electrical control signal input to an input terminal 301 of the actuator, which is connected by an electrical wire to a first valve control output port 302 of wave generator controller 244A.

Referring still to Figures 11A and 11B, it may be seen that valve plate 299 has a first pivotable position in which the valve plate is pivoted counterclockwise to block air flow to supply-air inlet port 298, and to permit air flow between selector manifold inlet port 294 and outlet port 292 of the valve. In this position, negative air pressure pulses at inlet port 281 of pump 280 are transmitted through pump inlet router valve 291, through selector manifold router valve 311, and through a pulse selector valve 249 of pulse selector manifold 248 to a

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selected air bladder cell 22, thus enabling air to be withdrawn from the air bladder cell through the port 43 of the air bladder cell, which is connected to the selector valve during the first , negative going part of a negative pressure pulse produced by air pump 280.

Since, as pointed out above, the air pump 280 produces a sequence of pressure pulses at a line frequency rate, e.g., 60 Hz, a negative pressure pulse selected by wave generator controller 244A to have a length of 1 second, for example, will actually consist of 1 second long pulse modulated at 60 Hz, i.e., a one-second long train of 60 pulses.

As shown in Figure 11A, air flow from a selected air bladder cell 22 and pulse selector valve 249 is routed through selector manifold router valve 311. Pulse selector manifold router valve 311 has a common outlet port 312 which is connected by a hermetically sealed coupling to input port 246 of pulse selector manifold 248. Pulse selector manifold router valve has a first, upper outlet port 313 which is connected to upper inlet port 294 of pump inlet router valve 201 by a tubular pressure-tight coupler 314. Pulse selector manifold router valve 311 also has a second, lower outlet port 315.

As shown in Figures 11A and 11B, pulse selector manifold router valve 311 has an internal valve plate 319 which is pivotably moveable by a solenoid actuator 320 in response to an electrical control signal input to an input terminal 321 of the actuator which is connected by an electrical wire to a second valve control output port 322 of wave generator controller 244A.

As shown in Figures 11A and 11B, valve plate 319 has a first pivotable position in which the valve plate is pivoted clockwise to block air flow between lower output pulse selector manifold port 246 and lower port 315 of pulse selector manifold router valve 311. As shown in Figure 11A, with valve plate 319 in this position, there is an unobstructed air flow path between manifold output port 246, through valve 311 to input port 294 of pump inlet valve 291, and thence into inlet port 281 of pump 280,

Referring to Figure 11A, it may be seen that pulse routing assembly 290 of wave generator 244 includes a third, pump outlet router valve 331 which has an inlet port 332 that is connected to outlet port 282 of pump 280 by a tubular pressure-tight tube 333. Pump outlet router valve 331 has a first, upper outlet port 334 which is connected by a tubular pressure-tight tube 335 to the lower inlet port 315 of pulse selector manifold router valve 311. Pump outlet router valve 331 also has a second, lower exhaust outlet port 336.

As shown in Figures 11A and 11B, pump outlet router valve 331 has an internal valve plate 339 which is pivotably moveable by a solenoid actuator 340 in response to an electrical control signal input to an input terminal 341 of the actuator, which is connected by an electrical wire to a third valve controller output port 342 of wave generator controller 244A.

As also shown in Figures 11A and 11B, valve plate 339 has a first pivotable position in which the valve plate is pivoted clockwise to block air flow between outlet port 282 of pump 280 and lower input port 315 of pulse selector manifold router valve 311. In this

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position, there is an unobstructed air flow path between pump outlet port 282 and lower outlet port 336 of pump outlet router valve 331.

As indicated by the arrow-headed lines in Figure 11A, with the three router valves 291, 311 and 331 configured as shown in Figure 11A and described above, operation of pump 280 causes air to be withdrawn from a selected air bladder cell 22 into pump inlet 281 and discharged from pump outlet port 282 through output port 336 of pump outlet router valve 331.

Outlet port 336 of pump outlet router valve 331 may optionally open directly to the atmosphere. Preferably, however, as shown in Figures 11A and 11B, outlet port 336 is connected to a first port 341 of a three-way tubular Y-junction or T-junction coupler 340. A second port 342 of coupler 340 is coupled through a tube 344 to lower input port 298 of pump inlet router valve 291. A third port of coupler 340 is coupled through a tube 345 to the inlet port 246 of a pneumatic accumulator or receiver 347. Thus, as shown in Figure 11A, during the initial, negative-going half of a negative air pressure pulse applied to an air bladder cell 22 to withdraw air and reduce the inflation pressure of the cell, withdrawn air is routed into accumulator 347. Optionally, accumulator 347 may consist of one or more separate air bladder cells which are similar in construction to the individual air bladder cells 22 of air mattress 20. The additional air bladder cells which are used as an accumulator may be located remotely from the air mattress or optionally at either or both the foot end and head end of the mattress.

Figure 11B illustrates valve configuration and resulting air flow paths directed by wave generator controller 244A during the second half of a negative pressure pulse, in which a volume of air is re-introduced into an air bladder cell 22 to thus partially or fully re-inflate the cell to a new or original quiescent value of pressure, respectively.

As may be understood by referring to Figure 11B, a positive-going part of a pressure pulse applied to an air bladder cell 22 is created by directing air flow from outlet port 282 of pump 280 to inlet port 246 of pulse selector manifold 248, and thence through a selected valve 249 to a selected air bladder cell 22. Thus, as shown in Figure 11B, valve plate 339 of pump outlet router valve 331 receives a signal from wave generator controller 244A to pivot to a position which allows air flow from pump outlet port 282 and through upper outlet port 334 of valve 331, and thence through inlet port 315 of pulse selector manifold router valve 311, through the port 312 of the manifold router valve, and finally through a selector valve 249 to a selected air bladder cell 22.

As shown in Figure 11B, during the positive-going part of an air pressure pulse to be delivered to an air bladder cell 22, valve plate 319 of pulse selector manifold router valve 311 is positioned by a command signal from wave generator 244A to block air flow through port 313 of valve 311. As is also shown in Figure 11B, during the positive-going part of an air pressure pulse, valve plate 299 of pump inlet routing valve 291 is positioned by a command signal from wave generator 244A to block air flow through port 294 of valve 291. In this

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position, there is created an unobstructed air flow path for air which was pressurized in accumulator 347 during the negative-going part of an air pressure pulse, through pump inlet router valve 291 and thence into inlet port 281 of pump 280.

Referring to Figures 11A and 11B, it may be seen that wave generator 244 preferably includes a pressure transducer 348 which communicates with inlet port 246 of pulse selector manifold 248. With valve plate 319 of selector manifold router valve 311 in a clockwise, closed position as shown in Figure 11A, and valve plate 249 of pump inlet router valve 299 in a clockwise, closed position as shown in Figure 11B, opening a selector valve 249 connected to the port 243 of a selected air bladder cell 222 results in equalization of pressure between the interior volume of the selected air bladder cell and the much smaller volume of a space located between the valve plate 249 and the input port 246 of the pulse selector manifold. Probe 349 of pressure transducer 348 communicates with this space and thus produces at an output terminal 350 of the transducer an electrical signal which is proportional to air pressure within a selected air bladder cell 222, which signal is conducted by an electrical wire 351 to wave generator controller 244A.

Listed below is a typical sequence of operations of wave generator 244 and configurations of router valves 291, 311 and 331 during the various steps of pulse generator 245 in response to electrical control signals issued by wave generator controller 244A to effect pre-programmed sequences of pressure pulse generation which result in soliton traveling support force waves on the surface of air mattress 20. Table 2 following the operational sequence summary lists the configurations of router valves 291, 311 and 331 during the various steps of a pulse generation sequence.

#### WAVE GENERATOR OPERATION SEQUENCE

1. Initialize System.
2. Receive command to begin wave.
3. Open selector valve 249 to select a first air bladder cell 22.
4. Measure pressure in selected cell via pressure transducer 348 connected to inlet port 246 of selector manifold 248.
5. Input pressure measurement value to wave generator controller 244A.
6. Open pump inlet router valve 291.
7. Turn vacuum/pressure pump 280 on to withdraw air from selected cell.
8. Leave pump 280 on until negative pressure-peak measured by transducer 348 and input to controller 244A is achieved.
9. Close pump inlet router valve 291.
10. Shut pump 280 off.
11. Allow time period equal to desired negative peak pressure dwell time period to elapse.
12. Open pump outlet router valve 331.
- 13A. Turn pump on to input air into selected cell 22.

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- 13B. Open selector manifold router valve 311 to input air into selected cell 22.
14. Leave pump on until pressure measured by transducer 348 increases to original or new desired bias level.
- 15A. Close selector manifold router valve 311.
- 5 15B. Close pump outlet router valve 331.
16. Shut pump off.
- Repeat steps 3-16 for additional selected air bladder cells in a sequence required for a desired wave cycle.
- 10 17. Repeat steps 1-16 for each additional wave cycle commanded by wave generator controller 244A.

**TABLE 2**

| <b>SEQUENCE STEPS</b> | <b>VALVE 1, PUMP INLET (291)</b> | <b>VALVE 2, SELECTOR MANIFOLD (311)</b> | <b>VALVE 3, PUMP OUTLET (331)</b> |
|-----------------------|----------------------------------|-----------------------------------------|-----------------------------------|
| 1-5                   | Clockwise (CW), Closed           | <b>CW, Closed</b>                       | <b>CW, Closed</b>                 |
| 6 -8                  | Counterclockwise (CCW) Open      | CW, Closed                              | CW, Closed                        |
| <b>9 -11</b>          | CW, Closed                       | CW, Closed                              | CW, Closed                        |
| <b>12 -14</b>         | CCW, Closed                      | CCW, Open                               | CCW, Open                         |
| <b>15 -16</b>         | CW, Closed                       | CW, Closed                              | CW, Closed                        |

Figures 12-24 illustrate the construction of a third embodiment of a soliton traveling wave air mattress apparatus 400 according to the present invention. As will be explained in detail, soliton traveling wave air mattress 400 has a modular construction which facilitates manufacture and use of a range of traveling wave air mattress apparatuses having different degrees of complexity, cost, and features suitable for use both in preventing the formation of bedsores, and for relaxation purposes.

Referring to Figure 12, modular soliton traveling wave air mattress apparatus 400 may be seen to include a wave generator module 401 and an air mattress module 402. The air mattress module 402 includes an air mattress 403 comprised of an array of generally semi-cylindrically shaped, individually inflatable air bladder cells 404, which are made of air impervious material such as thin vinyl plastic sheeting. An example embodiment of mattress 403, which was found suitable for both health care and relaxational applications, consists of 20 laterally disposed tubes that were arranged in a side-by-side array, each of the tubes having a diameter of about 4 inches and a length of about 34 inches. Thus the mattress 403 had a length of about 80inches and a width of about 34 inches, which is of a suitable size for

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placement on supporting surfaces such as a standard size bed mattress or a portable air mattress.

As shown in Figure 12, air mattress module 402 includes an air mattress interface module 405. Air mattress interface module 405 has on an outlet side 406 thereof a row of twenty individual outlet ports 407-1 through 407-20 for pressurized air, which are connected through flexible tubes 408-1 through 408-20 to inlet ports 409-1 through 409-20 of air bladder cells 404-1 through 404-20.

As is also shown in Figure 12, wave generator module 401 includes a wave sequence generator 410 which is connected through an elongated flexible 15-conductor cable 411 to 15 individual electrical port terminals 412 of an electrical interface port side 413 of air mattress interface module 405.

Referring still to Figure 12, it may be seen that wave generator module 401 includes an air pressure pulse generator 414 which has an outlet port 415. Air pressure outlet port 415 is connected through a single flexible air tube 416 to an inlet port 417 located on a side 418 of air mattress interface module 403.

As shown in Figure 12, wave generator module 401 includes a control electronics module 419 which is connected to wave sequence generator module 410 and air pressure pulse generator 414. Wave generator module 401 also includes a power supply 420 for converting 115-volt A.C. power input to the wave generator module 401 on a power cord 422 terminating in a power plug 421 plugged into a mains power source, into 12-volt D.C. power for operating control electronics module 419, pressure pulse generator 414 and wave sequence generator 410.

In a preferred embodiment of soliton traveling wave apparatus 400, wave generator module 410 may be located some distance from a bed, portable mattress, or other support on which air mattress 403 is placed, and connected to air mattress module 402 by single flexible cable 411 which contains insulated conductors operating at an electrical potential of no more than 12 volts D.C., and by a parallel flexible air tube 416. Desirably, air mattress interface module 405 may be positioned near the foot-end of air mattress 403, and connected to air bladder cells 404-1 through 404-20 of the air mattress by relatively short, flexible electrically insulating air tubes 408-1 through 408-20.

Figure 13 illustrates in more detail the construction of wave generator module 401 of soliton traveling wave air apparatus 400.

As shown in Figure 13, wave sequence generator 410 of wave generator module 401 has 10 electrical output terminals 423-1 through 423-10 and a common ground terminal 424. Wave sequence generator 410 contains electronic circuitry which is powered by 12-volt D.C. power supplied to +12-volt and ground terminals 425, 426, respectively, of the wave generator module from +12-volt and ground output terminals 427, 428 of D.C. power supply 420. Wave sequence generator 410 emits sequentially on output terminals 423-1 through 423-10 thereof 12-volt square-wave like air bladder cell selector pulses 429-1 through 429-10,

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as shown in Figures 18 and 19. As shown in Figure 13, wave sequence generator 410 has an input control port 430 which is connected to an output control port 431 of control electronics module 419. Control electronics module 419 has Mode and Frequency control input ports 432, 433 which may be connected to manually operable switches, or to a data port such as an RS 232 port or a USB port.

In response to Mode and Frequency select control signals input to control electronics module 419 on input terminals 432 and 433 thereof, the frequency and sequencing pattern of bladder selector pulses 429 emitted on terminals 423-1 through 423-10 of the wave sequence generator 410 can be varied by a user of apparatus 400. Thus, for example, a first, basic operating mode of apparatus 400 may consist of a first "downward" (head-to-foot) sequence of bladder selector pulses 429-1 through 429-10 emitted sequentially on terminals 423-1 through 423-10 of wave sequence generator 410, as shown in line 1 of Figure 18.

As indicated by the numbers in parentheses in line 1 of Figure 18, a second operating mode of wave sequence generator 410 may be selected which causes a second, "upward" sequence of bladder selector pulses 429 to be emitted sequentially in terminals 423-10 through 423-1 of wave sequence generator 410. As will be described in detail below, wave sequence generator 410 desirably is controllable to output other sequential patterns of pulses 429.

According to the invention, wave sequence generator 410 is also controllable in response to signals input to frequency control port 433 of control electronics module 419 and conveyed to wave generator control port 430 to vary the repetition rate frequency of bladder selector pulses 429 emitted by the wave sequence generator. As will be explained in detail, a typical range of periods of bladder selector pulses 429-1 through 429-10 on the ten output terminals 423-1 through 423-10 of wave sequence generator 410 of apparatus 400 would be from about one to two seconds to about 1 to 10 minutes. Thus, the total time period for emitting a sequence of 10 equal length pulses 429-1 through 429-10 on terminals 423-1 through 423-10 of wave sequence generator 410 may vary over a typical range of about 10 to 20 seconds to 20 to 100 minutes.

From the foregoing description of functions of wave sequence generator 410 and control electronics module 419, those skilled in the art will recognize that those functions may be readily implemented by a suitably programmed microprocessor, micro controller, programmable logic controller (PLC) or similar programmable electronic controller device. In an example embodiment of the present invention which was tested, wave sequence generator 410 included a PIC model 16C58B Programmable Interrupt Controller, the ten output ports of which were connected to input terminals of ten transistor driver switches. As will be described in detail below, bladder selector pulses 429 on output terminals 423-1 through 423-10 of wave sequence generator 410 are used to actuate individual solenoid valves to an ON configuration for time periods based on the duration of the bladder selector pulses. Thus those skilled in the art will recognize that the current and voltage drive characteristics of wave sequence generator

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410 are dependent on the number and electrical characteristics of the solenoid valves used in apparatus 400. The example embodiment of the invention tested used 12-volt solenoid valves having a coil resistance of about 120 ohms.

As shown in Figure 13, output terminals 423-1 through 423-10 of wave sequence generator 410 are also connected to input ports 435-1 through 435-10 of control electronics module 419. Control electronics module 419 includes electronic circuitry for processing bladder selector pulses 429 emitted from wave sequence generator 410 and input to input terminals 435-1 through 435-10 of the control electronics module, and for emitting valve control signals V1-V7 on output terminals 436-1 through 436-7, and solenoid valve drive signals SV1-SV7 on output terminals 437-1 through 437-7. As shown in Figure 13, control electronics module 419 has a Deflation Pulse Width-adjust input port 438, and an Inflation Pulse Width-adjust input port 439. As is also shown in Figure 13, control electronics module 419 may optionally have a pressure transducer signal input port 440, a rapid-deflate command input port 441, and a rapid-inflate command input port 442.

As may be understood by referring to Figures 13 and 18, control electronics module 419 produces on output ports thereof electrical control signals, in response to command and status signals input to various input ports of the module. As will be clear from the ensuing discussion of other functions of control electronics module 419, the circuitry of that module may be implemented as a micro controller, microprocessor, or PLC. An embodiment of control electronics module 419 which was constructed to test various embodiments of a traveling wave air mattress apparatus 400 according to the present invention employed a combination of separate integrated circuit modules, relays, and semiconductor logic and driver components.

Referring to Figure 13, it may be seen that air pressure pulse generator module 414 of soliton traveling wave air mattress apparatus 400 according to the present invention includes a pressure/vacuum pump 444, which has a vacuum inlet port 445, and a pressure outlet port 446. Vacuum inlet port 445 and pressure outlet port 446 are connected through an arrangement of valves V1-V7 and coupling tubes to pressure/vacuum outlet port 415 of air pressure generator module 414 of wave generator module 401, which is in turn connected through air inlet tube 416 to manifold inlet port 417 of air mattress interface module 405, as shown in Figure 12.

As shown in Figure 13, valves V1-V7 of air pressure pulse generator 414 of wave generator module 401 may be identical, normally OFF (NO), two-way solenoid actuated air valves. Thus, for example, valve V1, reference description number 477-1 in Figure 13, has a solenoid activator SV1 (448) which has a ground return terminal 449-1 and a 12-volt actuation terminal 450-1, which is connected to SV1 drive terminal 437-1 of control electronics module 419. A 12-volt signal level on solenoid valve drive terminal SV1 (437-1) of control electronics module 419 actuates valve SV1 to an ON position, in which air passes freely between first and second opposed ports 451A, 451B of the valve. Conversely, when the 12-

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volt actuating signal is removed from solenoid terminal SV1, valve V1 returns to a closed, OFF position, in which air flow between the ports of the valve is blocked. Table 3 lists the valves V1-V7 shown in Figure 13, and identifies the function of each valve.

**TABLE 3**

| VALVE | ELEMENT<br>NUMBER | FUNCTION                                |
|-------|-------------------|-----------------------------------------|
| V1    | 447               | Manifold vacuum                         |
| V2    | 453               | Manifold pressure                       |
| V3    | 459               | Pump recirculate/bypass                 |
| V4    | 465               | Pump vacuum inlet                       |
| V5    | 471               | Pump exhaust to atmosphere              |
| V6    | 477               | Vacuum inlet from/exhaust to atmosphere |
| V7    | 483               | Pressure regulator bypass               |

As shown in Figure 13, valves V1-V7 (reference designation numbers 477-1, 453, 459, 465, 471, 477, 483) are interconnected through an arrangement of Tee-couplers and tubes between pressure/vacuum pump 444 and pressure/vacuum outlet port 415 of air pressure pulse generator 414. The Tee-couplers include five couplers 489, 490, 491, 492, 493. When an optional pressure transducer 494 is included in apparatus 400, it is connected to pressure/vacuum outlet port 415 of wave generator module 401 through a sixth Tee-coupler 495.

Air pressure pulse generator 414 of wave generator module 401 is used to introduce pulses of air into individually selectable air bladder cells 404 of air mattress 403 (see Figure 12) in a manner which is described in detail below. The construction and functions of apparatus 400 which enable transmission of air pressure pulses to selected air bladder cells 404 may be best understood by referring to Figure 14 in addition to Figures 12, 13, and 18.

As shown in Figure 14, air mattress interface module 405 includes a distributor manifold 496 what has an inlet port 417 for pressurized air which is connected through a single flexible air tube 416 to air pressure pulse generator 414 of wave generator module 401, as shown in Figure 12 and previously described. Distributor manifold 496 has a series, e.g., ten, of air outlet ports 497-1 through 497-10. Each air outlet port 497 is connected through a flexible air tube to a first port 498 of a solenoid air bladder cell valve 499. Each solenoid air bladder cell valve 499 is a normally OFF valve that permits passage of air between first port 498 and a second port 500 thereof, only when solenoid actuator 501 of the valve is actuated by a 12-volt signal impressed on input terminal 502, and return terminal 503 of the solenoid is connected to a ground return through ground return conductor RTN1 (504).

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As may be understood by referring to Figures 12 and 13 in addition to Figure 14, each solenoid drive terminal 502-1 through 502-10 of the solenoid valves 499-1 through 499-10 is connected through a separate insulated conductor 505-1 through 505-10 of interface cable 411 to a separate output terminal 423-1 through 423-10 of wave sequence generator module 410. Also, common ground conductor line 504 of air mattress interface module 405 is connected through a separate conductor of cable 411 to ground return output terminal 424 of wave sequence generator 410.

From the foregoing description, it will be understood that when a 12-volt D.C. actuating signal is emitted from an output terminal, e.g., 423-1 of wave sequence generator 410, a corresponding air bladder cell valve, e.g., 499-1 of air mattress interface module 405, will be actuated to an ON configuration. In this ON configuration, there is pneumatic communication between second port 500 of the valve 499 and pressure/vacuum outlet port 415 of air pressure pulse generator 414 of wave generator module 401. Thus, as shown in Figure 14, air pressure pulses in pressure/vacuum outlet port 415 of air pressure pulse generator 414 are conducted to outlet port 501-1 of valve 499-1, which may be connected to inlet port 409 of an individual air bladder cell 404.

Optionally, as shown in Figure 14, the second port of an air bladder cell inflation valve 499 may be coupled to a pair of air bladder cells through a Tee-coupler 506. Thus, as shown in Figure 14, a first Tee-coupler 506-1 enables air pulses to be conveyed simultaneously to a pair of adjacent air bladder cells 404-1, 404-2. With this arrangement, a 10-outlet port distributor manifold 490 and ten air bladder cell inflation valves 499 may be used to convey air pressure pulses to all 20 of the air bladder cells of a 20-cell air mattress.

As may be understood by referring to Figures 12, 13, and 14, in response to electrical control signals input to air pressure pulse generator 414 from wave sequence generator 410 and control electronics module 419, the air pressure pulse generator produces in pressure/vacuum outlet port 415 air pulses which are conveyed through air mattress interface module 405 to selected air bladder cells 404-1 through 404-20. As shown in Figure 20, each air pulse 510 consists of a negative differential pressure component beginning at time T1 and ending at time T2 of the pulse. The negative differential pressure component T1-T2 here refers to a reduction of pressure at the inlet port 409 of an air bladder cell 404 that causes the air bladder cell to partially or fully deflate.

In a first, active deflation mode of operation of pressure pulse generator 414, pressure reduction component T1-T2 of air pulse 510 is produced by actuating valves of apparatus 400 in a manner which connects the inlet port 409 of an air bladder cell 404 through valves and tubes to the vacuum or suction inlet port 445 of pressure/vacuum pump 444. In a second, passive deflation mode of operation of air pressure pulse generator 414, the deflation component T1-T2 of air pulse 510 is produced by actuating valves of the apparatus 400 in a manner which creates a path for air under pressure in an air bladder to be exhausted to the atmosphere.

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As shown in Figure 20, air pressure pulse 510 includes a second, re-inflation component during the time interval T2-T3. The re-inflation component T2-T3 is produced by actuating valves of apparatus 400 in a manner which creates a pathway for pressurized air discharged from pressure outlet port 446 of pressure/vacuum pump 444 to the inlet port 409 of an air bladder cell 404.

Details of the operation of air pressure pulse generator 414 which are effective in producing a sequence of air-pressure pulses 510 of the type shown in Figure 20, and conveying the pulses to an air mattress 403, of the type shown in Figure 14 may be best understood by referring to Figures 13 and 18.

As may be understood by referring to Figures 13 and 18, control electronics 419 contains circuitry which produces a sequence of control signals SV1-SV7 for valves V1-V7 upon receiving a bladder selector pulse 429 from any one of the ten output ports 423-1 through 423-10 of wave sequence generator 410, which ports are connected to input ports 435-1 through 435-10 of control electronics module 419. For example, as shown in Figure 18, control electronics module 419 produces in response to the leading, positive-going edge of a first bladder selector pulse 429-1 on output in terminal 423-1 of wave sequence generator 410 the leading edge of a positive-going, Deflate pulse P1. As shown in Figure 18, the duration (t12-t11) of Deflate pulse P1 is adjustable as indicated by the variable time location of the trailing edge of the pulse at t12. The duration of Deflate pulse P1 may be adjusted by a signal on input control terminal 432 of control electronics module, for example, by varying the time constant of a monostable multivibrator, or ONE SHOT, triggered by the leading edge of a bladder selector pulse 429-1 at time t11.

As shown in Figures 13 and 18, pulse V1 is output on solenoid valve drive terminal SV1 (437-1) to thus turn valve V1 ON. As shown in Figure 18, valve V4 is also ON at the same time as valve V1, thus providing an air path between vacuum inlet port 445 of pump 444, pressure/vacuum outlet port 415 of air pressure pulse generator 414, pressure/vacuum inlet port 417 of the distributor manifold, air bladder cell valve 493-1, and selected air bladder cell 404-1. At the same time valve actuator drive signal SV5 is also positive, thus enabling pressurized air discharged from pressure outlet port 446 of pressure/vacuum port to pass through pressure regulator 512 and exhausted into the atmosphere.

Referring still to Figures 13, 18, and 20, it may be seen that the negative-going, trailing edge of Deflate pulse P1 triggers the leading edge of an Inflate pulse P2. As shown in Figure 18, the time location of the trailing edge of inflate pulse P2 is also adjustable to thus adjust the duration of deflate pulse P2. As will be readily understood by those skilled in the art, P2 may be generated by a second one-shot triggered by the trailing edge of deflate pulse P1.

Referring to Figure 13, it may be seen that when manifold vacuum valve V1 is turned OFF at the end of Deflate pulse P1, manifold pressure valve V2 is turned ON, thus

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providing an air path from pressure outlet port 446 of pressure/vacuum pump 444 to an air bladder cell, such as a selected air bladder cell 404-1. As may also be understood by referring to Figures 13 and 18, during Inflate pulse P2, pump vacuum inlet valve V4 and vacuum atmosphere vent valve V6 are ON, providing inlet air to vacuum inlet port 445 of pressure/vacuum pump 444.

Optionally, an accumulator of the type shown as element 347 in Figure 11B may be used in a hermetically sealed modification of air pulse generator 414 shown in Figure 13. In this modification, the exhaust port outlet of pump exhaust vent valve V5 (471) would be connected through an optional check valve to a first port of an accumulator, and the inlet/exhaust port of vacuum inlet valve V6 (477) would be connected to a second port of the accumulator.

Referring to Figure 18, it may be seen that after the last pulse in a sequence of bladder selector wave pulses 429 has been emitted from wave sequence generator 410, e.g., after a sequence of 10 or 20 pulses, apparatus 400 may selectably continue to cyclically output sequences of control pulse signals, or enter into a rest mode. As indicated by the solid lines at the right-hand side of Figure 18, during a rest period of apparatus 400, pump recirculate/bypass valve V3 (459) may be turned on. Alternatively, as shown in dashed lines, a resting mode may be selected in which valves V4(465), V5 (471) and V6(477) are turned on to provide venting to the atmosphere of both vacuum inlet port 445 and pressure outlet port 446 of pressure/vacuum pump 444. Using either of the foregoing rest modes eliminates the necessity for switching pressure/vacuum pump 444 on and off during operation of apparatus 400. Figure 19 illustrates a second, passive deflation mode of operation of apparatus 400.

In the passive deflation mode, V4 is closed and valves V1 and V6 are opened during the deflation component of an air pressure pulse, allowing pressurized air from an air bladder cell 404 to escape to the atmosphere through an open port of valve V6, rather than being connected to vacuum inlet port 445 of pressure/vacuum pump 444. As will be explained below, the slower deflation rate of an air bladder cell in a passive deflation mode facilitates a novel and advantageous mode of operation of apparatus 400.

Table 4 summarizes the configuration of valves V1-V6 for the above-described operational modes of wave generator module 401.

**TABLE 4**

|              | <b>ACTIVE<br/>DEFLATE</b> | <b>PASSIVE<br/>DEFLATE</b> | <b>INFLATE</b> | <b>REST<br/>(RECIRCULATING PUMP)</b> | <b>REST<br/>(VENTING PUMP)</b> |
|--------------|---------------------------|----------------------------|----------------|--------------------------------------|--------------------------------|
| <b>VALVE</b> | <b>STATE</b>              | <b>STATE</b>               | <b>STATE</b>   | <b>STATE</b>                         | <b>STATE</b>                   |
| V1           | ON                        | ON                         | OFF            | OFF                                  | OFF                            |
| V2           | OFF                       | OFF                        | ON             | OFF                                  | OFF                            |

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|    |     |     |     |     |     |
|----|-----|-----|-----|-----|-----|
| V3 | OFF | ON  | OFF | ON  | OFF |
| V4 | ON  | OFF | ON  | OFF | ON  |
| V5 | ON  | ON  | OFF | OFF | ON  |
| V6 | OFF | ON  | ON  | ON  | ON  |

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Figures 20, 21A, and 21B illustrate how soliton traveling wave air mattress apparatus 400 produces soliton traveling waves of body support forces on the surface of air mattress 403.

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As shown in line 1 of Figure 21A, before apparatus 400 is powered on, an air mattress 403 of the type shown in Figure 12 having, for example, 20 air bladder cells 404 (only the first 10 are shown) may be in a deflated state. At time T1, a first pulse of air 510 (see Figure 20) is input to first air bladder cell 404-1 of the air mattress 403.

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As shown in Figure 20 and has been described above, air pulse 510-1 has a first, deflation component beginning at time T1 and ending at time T2. Since all of the air bladder cells 404 of air mattress 404 were presumed to be deflated, there will be no change in the contour of air bladder cell 404 during the period T1-T2. However, if any air bladder cell were partially deflated, it will be fully deflated by the deflation component of air pulse 510 during the period T1 to T2.

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At time T2, the inflation component of air pulse 510-1 begins to inflate first air bladder cell 404-1. The inflation component of air pulse 510-1 continues until time T3. The duration of inflation pulse component T3-T2 of air pulse 510, and the maximum inflation pressure, which is adjusted by adjusting pressure regulator 511, are selected to inflate air bladder cell 404-1 to a pre-determined steady-state pressure PS, which causes the upper body support surface 512 of the air bladder cell to assume the generally semi-cylindrically shaped contour shown in line 2 of Figure 21A

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Referring to lines 3 through 10 of Figure 21A, it may be seen that successive air bladder cells 404-2 through 404-20 are sequentially selected and inflated by wave generator module 401, resulting in a fully inflated air mattress 403 as shown in the last line of Figure 21A.

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Figure 21B illustrates how apparatus 400 produces a soliton traveling wave of body support force reduction on the upper surface 512 of air mattress 403.

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As shown in Figure 21B, after a first cycle of 10 or 20 pulses emitted by wave sequence generator 410 to initialize an air mattress 403 to a fully inflated state as shown in the last line of Figure 21B, a second and successive cycles of wave sequence pulses are effective in producing a soliton traveling body support force reduction wave on the upper surface 512 of air mattress 403. Thus, as shown in line 2 of Figure 21B, during the deflation period T1-T2 of a first, head-end air bladder cell 404-1, that air bladder cell is deflated to thus reduce the support force exerted by the air bladder cell on a body part. The duration of this deflation

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component T1-T2 of the air pulse 510 may be adjusted to any suitable value, such as 1 to 5 minutes or longer.

At time T2 of a first deflation pulse, air bladder cell 404-1 is re-inflated to a pre-determined quiescent pressure, during the time interval T2 to T3. The minimum duration of inflation component T2 to T3 of air pulse 510 is typically determined by how long it takes to inflate an individual air bladder cell 404 to a desired pressure, which for a relatively small pressure/vacuum pump having an outlet pressure of 36 PSI and an air flow rate of 5.5 lpm would be about 30 seconds to one minute.

As shown in lines 3-11 of Figure 21B, sequentially deflating and re-inflating the remaining air bladder cells 404-2 through 404-10 or 404-20 of a 10 or 20 bladder mattress causes a soliton traveling wave of body support force reduction to progress from one end to the other end of air mattress 403. For example, if the first air bladder cell 404-1 is located at the head-end of a bed, a traveling wave of body support force reduction 513 will be propagated from left to right as shown in Figure 21B, i.e., from the head-end to the foot-end of air mattress 403.

As may be understood by referring to Figure 21B, deflation of each air bladder cell 404 is initiated at the times T1, - - T10 coinciding with the beginning of a sequence of air bladder selector pulses 429-1 through 429-10, as shown in Figure 18. At the end of each bladder selector pulse, the selected air bladder cell is left in a fully inflated state. Thus, at the time T1, coincident with a first bladder selector pulse 429-1, air bladder cell 404-1 becomes deflated, and at the end of pulse 429-1, is fully re-inflated.

In a basic embodiment of the apparatus 400 according to the present invention shown in Figures 12, 13, and 14, a wave sequence generator 410 having ten output ports, and a distributor manifold having ten outlet air ports in a simplified, low-cost configuration, are used to control a 20-air bladder cell air mattress. This configuration also utilizes only ten air bladder cell valves 499 to minimize cost and complexity.

As shown in Figure 14, the ten-port wave sequence generator 410, ten-port distributor manifold 490, and ten air bladder cell valves 499 are enabled to control an air mattress 403 which has 20 air bladder cells 404-1 through 404-20, by driving a pair of air bladder cells 404 from each distributor outlet port using a single air bladder cell valve 499 connected to each port. Figure 21C illustrates generation of a soliton traveling body support force reduction wave in which adjacent pairs of air bladder cells 404 are sequentially deflated and re-inflated to produce a head-to-foot traveling body force support wave on an air mattress 403 having 20 air bladder cells 404.

Figures 13, 15, and 21D illustrate a modification of apparatus 400 which uses a 10-output port wave sequence generator 410, a 10-outlet port distributor manifold 490, and 20 air bladder cell valves 499 to individually inflate and deflate 20 air bladder cells. As shown in Figure 15, each of the 10 output ports 497-1 through 497-10 of ten-output port distributor manifold 490 is coupled through a Tee coupler 515-1 through 515-10 to a pair of air bladder

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cell valves 517A-517B to a pair of air bladder cells 404-1, 404-2 through 404-19, 404-20. Each air bladder cell valve 517A has a solenoid actuator which has a 12-volt input terminal 519A and a first ground return input terminal 520A. Similarly, each second bank air bladder cell valve 517B has a solenoid actuator which has a 12-volt input terminal 519B and a second ground return input terminal 520B.

As shown in Figures 13 and 15, the 12-volt solenoid actuator input terminals 519A, 519B of each pair of air bladder cell valves 517A, 517B are connected to a single output terminal 423 of wave sequence generator 410 through a single insulated conductor 521 of cable 411. The first ground return terminal 520A of the solenoid actuator of each air bladder cell valve 517A is connected to a first common return conductor RTN1 (522). Also, the second ground return terminal 520B of each air bladder cell valve 517B is connected to a second common return conductor RNT2 (523).

As shown in Figure 13 and 15, RTN1 and RTN2 conductors are deployed from air mattress module 402 to control electronics module 419 of wave generator module 401. As shown in Figure 13, RTN1 conductor 522 and RTN2 conductor 523 are connected to the B and C contacts of a SPDT relay 525. Relay 525 is driven by a toggle flip-flop FF2 (not shown) in control electronics module 419. As may be understood by referring to Figure 18, toggle FF2 is triggered alternately between SET and RESET states at the end of each 10 inflation pulses P2. With this arrangement, it will be understood that when power is first applied to control electronics module 419, either RTN1 line or RTN2 line will be connected to ground through contacts of relay 525. In this first position of relay 525, a sequence of 10 pulses 429-1 through 429-10 will actuate air bladder cells valves 517A-1 through 517-10, or 517B-1 through 517B-10. After the 10th pulse 429-10 is input to control electronics module 419, flip-flop FF2 will be toggled to a different state as shown in the last line of Figure 18. With the foregoing arrangement, a sequence of deflating and re-inflating only the 10 odd-number air bladder cells 404 of an air mattress 403 alternating with a sequence of deflating and re-inflating only even-number air bladder cells 404, results in the generation of alternating odd and even head-to-toe body support force waves, as shown in Figure 21D.

Figure 16 illustrates another variation of the soliton traveling wave air mattress 400 according to the present invention. This variation employs a router manifold interposed between the distributor manifold and air bladder cells shown in Figure 15 and enables creating a non-alternating, consecutive sequence of air bladder cell deflation and re-inflation cycles in an air mattress 403 having 20 air bladder cells 404 using a ten-output port distributor manifold.

Figure 17 illustrates another variation of the apparatus 400 which uses a pair of 10 output port distributor manifold 490A, 490B, 20 air bladder cell valves, and a ten-output terminal wave sequence generator to produce soliton traveling body support force variation waves on an air mattress 403 having 20 air bladder cells, using the toggle flip-flop FF2 as described above.

Figure 21E illustrates the formation of a backward, foot-end towards head-end traveling body support force wave which may be generated using the traveling wave apparatus of Figures 12-17.

Figure 21F illustrates another type of soliton body support force reduction wave which can be produced by the apparatus 400 according to the present invention, in which the operating mode of the wave sequence generator is selected to produce simultaneous up and down soliton traveling waves of pulses 429. It should be noted that wave sequence generator 410 may be programmed to enable production of a virtually unlimited variety of wave sequences. Also, as shown in Figure 13, control electronics module 419 optionally includes Rapid Inflate and Rapid Deflate input ports, which would be used to command wave generator module 410 to output inflate only or deflate only signals 429 simultaneously on all 10 output ports 423 of the wave generator module, and a command signal turn on pressure regulator bypass valve V7 (483).

Figures 22-24 illustrate a modification of traveling wave air mattress 400. As may be understood by referring to Figures 20 and 22, the bladder selector pulses 429 output sequentially from wave sequence generator 410 are typically used to generate a pattern of deflation and re-inflation pulses 510 which travel sequentially from each air bladder cell 404 to the next adjacent cell, each pair of air bladder cells to the next adjacent pair, each odd air bladder cell to the next odd air bladder cell, and each even air bladder cell to the next even air bladder cell. However, it should be recognized that it may in some cases be desired to omit certain air bladder cells from the deflation/re-inflation sequence. For example, if certain bladder cells 404 of the air mattress are very lightly loaded, or simply not loaded at all because a short person is lying on the air mattress, it may be desired to skip the lightly loaded or unloaded air bladder cells, affording the possibility of decreasing the times between which loaded air bladder cells are pulsed.

Therefore, apparatus 400 according to the present invention optionally includes elements which provide a novel and efficient means of monitoring average loading of individual air bladder cells, and utilizing that information to provide command signals to wave sequence generator module 410 to omit inputting air-pulse command signals 429 to air bladder cells 404 which are subjected to average weight load forces below a predetermined threshold value.

The novel structure and method of periodically sensing minimum weight loads of individual air bladder cells 404, and responding to the sensing of minimum loading by periodically omitting application of force-reducing deflation/inflation pulses to such cells may be best understood by referring to Figures 13, 18, 19, 22, 23, and 24.

As shown in Figure 23, when an air pressure pulse 510 is applied to an air bladder cell 404 that is subjected to a significant weight load of, for example, 5 to 10 pounds, that air bladder cell will deflate relatively rapidly to a pre-determined pressure  $P_T$  at a time  $T.L.$ , as indicated by the solid line in Figure 23.

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On the other hand, an unloaded or lightly loaded air bladder cell will take longer until time TU to deflate, as indicated by the dashed line in Figure 23. Consequently, by measuring the air pressure in pressure/vacuum outlet port 415 of air pulse generator by pressure transducer PT (485) at a time TL after the initiation of the deflation component of air pulse 510, and determining that it has not yet been reduced below the threshold pressure PT, it can be concluded that there is little or no load on that particular air bladder cell. Accordingly, the wave sequence generator 410 may in this case be commanded by a signal from control electronics module 419 to skip issuing a square wave bladder selector pulse 424 signal to deflate that air bladder cell, during the next sequence of bladder selector pulses 429 emitted by the wave sequence generator.

The time difference between loaded and unloaded reduction of inflation pressure crossing the PT threshold may be enhanced by utilizing the passive deflation mode described previously. Thus, as shown in Figures 18 and 19, flip-flop FF2 may be toggled at the end of each 10 or 20 pulses 429 to thus switch between active and passive deflation modes as desired to thereby increase resolution in determination of the differences in weight loading of the air bladder cells 404.

Figure 24 illustrates a sequence of air bladder cell deflation/re-inflation pulses 510, in which pulses to air bladder cells 2, 3, 5, and 6 have been omitted because they have been determined in a previous sequence of deflation/inflation pulses to have been subjected to a time-average weight load below a predetermined value which is insufficient to result in those cells deflating to or below a threshold pressure PT on or before time TL.

Those skilled in the art will recognize that the time sequences of air pressure pulses 63 shown in Figures 3A and 3B, considered collectively, have a characteristic of soliton traveling waves, i.e., each sequence consists of a solitary traveling pressure wave having a constant amplitude. As has been described above, the sequence of air pressure pulses depicted in plots 1-6 of Figure 3A, when input into a series of air bladder cells, such as the one shown in Figure 7A, result in a traveling soliton wave of pressure variation in the air bladder cells, which in turn produces a soliton traveling wave of body support force variation, i.e., reduction, as depicted in Figure 21B.

Another characteristic of a soliton traveling wave is that it maintains its amplitude and shape in spite of collisions with other soliton traveling waves. The lines labeled T9-T2 of Figure 21F illustrates that the soliton traveling waves of body support force in air mattresses according to the present invention also have this characteristic. Thus as shown in lines T9-T2 of Figure 21F, a first soliton wave of traveling body support force traveling from left to right, e.g., from the head-end to the foot-end of an air mattress, collides with a second soliton wave of traveling body support force traveling from right to left, e.g., from the foot-end of a mattress towards the head-end, at time T10. At time T1, the downward and upward soliton ~~pulses~~ traveling waves have passed through each other without change.

Figure 25 illustrates a first modification 614 of the air pressure pulse generator component or module shown in Figure 13 and described above, which requires only five valves rather than the seven shown in Figure 13.

In modified air pressure pulse generator module 614, air bladder cells 404 (see Figure 12) are initially inflated *en masse*, as follows. With valves V1 (477-1), V3 (459), and V5 (471) in closed, OFF, positions, and valves V6 (477) and V2 (453) in open, ON positions, pressure/vacuum pump 444 is powered on. This action enables air to be drawn from the atmosphere through valve V6 (477), vacuum inlet port 445 of pressure/vacuum pump 444, expelled from outlet port 446 of the pressure/vacuum pump, and passed through valve V2 (453) to air bladder cells 404, e.g., the twenty air bladder cells 404-1 through 404-20 shown in Figure 12. After a time period sufficient to inflate all twenty air bladder cells 404-1 through 404-20 to a desired quiescent air pressure valves V6 (477) and V2 (453) are actuated to an OFF position, and valve V3 (459) is actuated to an ON position, enabling air to be circulated through V3 and pressure/vacuum pump 444 during a rest interval. During this rest interval, pump 444 may be powered off or remain on.

Following an initial rest interval after inflation of all air bladder cells 404-1 through 404-20, a soliton traveling wave of air pressure and resulting traveling soliton body support force wave in air mattress module 403 may be initiated. A first step in initiating a traveling air pressure pulse wave consists of issuing a manifold selector valve opening signal 429 to a selected air bladder cell selector valve or valves, e.g., valve 499-1 connected to air bladder cells 404-1 and 401-2, as shown in Figure 18. Next, in response to control signals issued from control electronics module 419, valve V3 (459) is closed, and valves V1 (477-1) and V5 (471) are opened. As may be understood by referring to Figure 25, this valve configuration enables air to be withdrawn from a selected air bladder cell or cells 404 through valve V1 (477-1), vacuum inlet port 445 of pressure/vacuum pump 444, through outlet port 446 of the pressure/vacuum pump, and through valve V5 (471) to the atmosphere.

The foregoing valve configuration in the initial, deflation part of an air bladder cell pressure pulse is maintained for a time interval sufficient to reduce air pressure in a selected air bladder cell or cells to a pre-determined value.

At the end of a deflation period, valves V1, V2, V3, V5, and V6 are actuated to the initial *en masse* inflation configuration described above. Since pressure/vacuum pump 444 need only have a capacity to fully deflate or re-inflate one or two air bladder cells in a period of, for example, one-half to two minutes, the time period for inflating a single air bladder cell with pressure/vacuum pump operating at full capacity would be about one-twentieth that required to fully inflate a fully-deflated air mattress 403 having twenty air bladder cells. Thus, the time required to re-inflate a single fully-deflated air bladder cell 404 would typically be about one-half to one minute versus ten to twenty minutes to fully inflate all twenty air bladder cells.

At the end of an initial deflation/re-inflation air pulse cycle as described above, the apparatus may be programmed to enter a rest period of a selectable duration, such as the

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time interval between T13 and T21 shown in lines 1 and 2 of Figure 20. During the rest period, valves V1, V2, V3, V5, and V6 are configured as described above for the initial rest interval.

After a pre-determined rest period, second and successive air pressure pulses may be applied to second and successive air bladder cells 404, in the same manner as described above.

It should be noted that modified pressure pulse generator 614 shown in Figure 25 draws in air from the atmosphere through the inlet port of valve V6 (459) and exhausts air to the atmosphere through the outlet port of valve V5 (471).

Figure 26 illustrates another modification of air pressure pulse generator 414 shown in Figure 13, in which air cyclically exhausted from and inlet to air bladder cells is transmitted to and from one or more accumulators rather than to the atmosphere. In this modified, closed system, after an initial supply of air such as filtered air from the atmosphere is input to the apparatus to inflate all air bladder cells 404 and one or more accumulators, the air pressure pulse generator 714 may be isolated from external air inlet sources and exhaust locations.

As shown in Figure 26, second modified pressure generator module 714 has, in addition to the five valves of first modified pressure pulse generator 614, two additional valves, V4 (477-2) and V7 (477-3).

As may be understood from the description above of the initial *en masse* inflation of all air bladder cells of an air mattress, valve V4 (477-2) may be actuated to an ON position to enable an initial volume of air to be drawn in from the atmosphere or other source to inflate all air bladder cells 404, in a "rapid inflate" or *en masse* inflation mode.

Similarly, it will be understood that valve V7 (477-3) may be actuated to an ON position to exhaust air from all air bladder cells 404 to the atmosphere in a "rapid deflate" mode. However, cyclical deflation and re-inflation of selected air bladder cells by air pressure pulse generator 714 after all of the air bladder cells 404 of an air mattress have been inflated is performed in isolation from the atmosphere, as will now be described.

Referring to Figure 26, it may be seen that second modified pressure pulse generator 714 has in the lower, vacuum inlet arm thereof a valve V4 (465) used to provide air from an external source such as the atmosphere to initially inflate all of the air bladder cells 404 of an air mattress 403. As shown in Figure 26, air pressure pulse generator 714 has in addition to external air inlet control valve V4 (465), an additional air inlet valve V6 (478).

Air inlet valve V6 (478) has an inlet port connected to a sealed interior space of a first accumulator, Accumulator 1. According to the invention, Accumulator 1 may consist of one and preferably two additional air bladder cells 404-21, 404-22, as may be understood by referring to Figure 27. When two air bladder cells are used, they are connected in parallel by a tee-coupler. The foregoing air bladder cells may be positioned at the foot end of air mattress 403. Optionally, since the length of air mattress 403 would typically be greater than

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that required for a patient, the two foot-end air bladder cells 404-19 and 404-20 could be used as Accumulator 1 air bladder cells.

Referring still to Figure 26, it may be seen that second modified air pressure pulse generator 714 has in the upper, pressure output arm thereof a valve V7 (483) which is used to exhaust air withdrawn from all air bladder cells 404 of an air mattress 403 to the atmosphere, in a rapid deflation mode.

As shown in Figure 26, air pressure pulse generator 714 has in addition to external air exhaust valve V7 (483), and additional air outlet valve V5 (498). Air outlet valve V5 (498) has an outlet port connected to the sealed interior space of a second accumulator, Accumulator 2. According to the invention, Accumulator 2 may consist of one and preferably two air bladder cells 404 connected in parallel by a tee-coupler as has been described above for Accumulator 1.

Figure 27 illustrates a third embodiment 814 of an air pressure pulse generator according to the present invention. As shown in Figure 27, air pressure pulse generator 814 includes an accumulator interconnect Tee 499 which has a first port thereof connected to the outlet port of outlet valve V5 (498), a second port connected to the inlet port of inlet valve V6 (478), and a third, accumulator port. The third, accumulator port is connected to a single accumulator of the type described above, which consists of one and preferably two air bladder cells 404-21, 404-22 connected in parallel and located at the foot end of air mattress 403, or in a separate location such as below a support surface for air mattress 403.

The novel configuration of air pressure pulse generator modules 714, 814 shown in Figures 26 and 27 facilitates a novel Body Support Force Equalization Mode of operation of the air mattress inflation control apparatus shown in those figures, as will now be described.

Referring to Figure 27, after all air bladder cells 404 have been inflated to configure air mattress 403 for use, and after a person has lain down on the air mattress, a Body Support Force Equalization Mode may be entered before initiation of cyclical generation of soliton traveling air pressure waves as described above. The purpose of the Body Support Force Equalization Mode is to decrease large body support force concentration and imbalances to distribute body support force more equally. In other words, the result of utilizing the Body Support Force Equalization Mode according to the present invention is to adjust the air pressure in individual air bladder cells 404 to average bias levels which are more nearly equal to one another, before superimposing a soliton traveling force reducing pressure wave in a sequence of air bladder cells 404.

In the Body Support Force Equalization Mode according to the present invention, all air bladder cells 404 of an air mattress 403 are first inflated *en masse* to a pre-determined pressure level.

Next, pressure/vacuum pump 444 is preferably turned off, and pump bypass valve V3 (459) is turned on. Valves V1 (477-1), V2 (453), V5 and V6 (477) are also actuated to ON positions at this time.

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Next, sequence generator 410 receives a signal to output a sequence of selector valve control signals 429-1 through 429-10 or 429-20 to manifold selector valves 499.

When each individual manifold selector valve 499 is actuated to an ON position, air in a selected air bladder cell 404 that is pressurized above the pressure in control accumulators 1 and 2, air flows into the accumulators, thus reducing body support force on a particular air bladder cell that is heavily loaded, as by a body protuberance.

Conversely, if the air pressure in a selected air bladder cell is less than that in control accumulators 1 and 2, air flows from the accumulators to that air bladder cell. This results in re-distribution of body support forces to more nearly equal values as the manifold valves are actuated sequentially to ON positions.

After one or more repetitions of the manifold selector valve actuating sequence described above, cyclical traveling pressure waves are initiated by control electronics module 419. In a preferred mode of operation, these pressure waves would have a smaller amplitude than that used without prior equalization of the different bias pressure levels in the air bladder cells by utilization of the Body Support Force Equalization Mode. The amplitude of the traveling pressure waves imposed on quiescent bias pressures in the air bladder cells is conveniently reduced by decreasing the duration of both deflation and re-inflation periods of a traveling air pressure pulse wave. Thus the traveling pressure wave may be speeded up without requiring an increase in the volumetric flow rate of pressure/vacuum pump 444.

The Body Support Force Equalization Mode described above may be initiated periodically, e.g., hourly, or optionally in response to sensed body weight redistributions above a pre-determined threshold value, which may be measured by an optional pressure or force sensor.

Figure 28 illustrates a modification of a basic embodiment of an air mattress according to the present invention shown in 2A. Modified air mattress 503 shown in Figure 28 includes oval plan-view, annular ring-shaped parallel tubular air bladder cells 50 which are arranged in a concentric array. Each of air bladder cells 504 has an air inlet port 509 which protrudes downwardly from a lower surface of the air bladder cell. In this arrangement, air bladder cells 504-1 through 504-10 may receive sequential pulses of air pressure variation to thus produce on the upper surfaces of the air bladder cells a soliton traveling wave of body support force variation. This soliton traveling wave has an elliptical ring-shaped wave front that travels radially outwardly from the center of mattress 503 to the outer perimeter of the air mattress, which is coincident with the outer perimeter of outermost air bladder cell 504-10 when air pressure pulses are introduced to air bladder cells 504-1 through 504-10 in ascending order, and radially inwardly when the pulses are introduced into its air bladder cells in reverse order, i.e., 504-10 through 504-1.

Figure 29 illustrates a modification 523 of air mattress 503 shown in Figure 28, in which oval ring-shaped air bladder cells 524 are segmented into four contiguous quadrant arc-shaped segments, 524-A, 524-B, 524-C, and 524-D. In this embodiment, soliton traveling

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waves of body support force may be caused to travel in circumferential directions on the surfaces of the air bladder cells, as well as in radial directions as have been described above for the air mattress 503 shown in Figure 28. Thus, for example, pulses of air pressure variation may be sequentially applied first to one or more air bladder cells 524A-1 through 524A-10 in a first quadrant, e.g., the upper right-hand quadrant of air bladder cells shown in Figure 29. Following introduction of first air pressure or pulses into air bladder cells 524-A in the first quadrant of air mattress 523, subsequent air pressure variation pulses may be introduced sequentially into air bladder cells located into quadrants B, C, and D, to thus produce a soliton traveling wave of body support force variation which travels in a clockwise sense on the upper surface of air mattress 523.

In an exactly analogous fashion, counterclockwise soliton traveling waves of body support force may be produced on the upper surface of air mattress 523 by introducing pulses of air pressure variation sequentially into air bladder cells 524 located in quadrants A, D, C, and B, respectively.

Figures 30 and 31 illustrate circular air mattresses 603 and 623 which are exactly analogous in construction and function to oval air mattresses 503 and 523 described above, with the following single difference. Mattresses 603 and 623 are comprised of air bladder cells 604, 624 which have annular ring shapes that have a circular plan view rather than being oval-shaped. Thus air mattresses 603, 623 have an aspect ratio which is more suitable for matching the shape of a chair or wheel chair.

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What is claimed is:

1. A traveling wave air mattress apparatus comprising in combination;

5 a. an air mattress which includes an array of N flexible individually inflatable and deflatable air bladder cells, where N is at least three, said air bladder cells spanning a first area dimension of said air mattress and being arranged in a series which spans a second area dimension of said air mattress, said air bladder cells having upper surfaces which in combination comprise a body support surface for a human body, and

10 b. a soliton wave generator apparatus including an air pressure pulse generator for cyclically introducing timed sequences of pulses of air pressure variation into a predetermined series of said air bladder cells, each said sequence comprising at least a first train of pulses in which a first pulse is introduced into at least a first selected first-end air bladder cell proximate a first end of said array, and subsequent pulses of air pressure variation introduced into successive air bladder cells of said series, said sequence of pulses of air pressure variation producing a soliton traveling wave of body support force variation which traverses  
15 said body support surface of said air mattress in a direction parallel to the second dimension of said air mattress, said soliton traveling wave having a wave-front width which spans the first dimension of said air mattress and a length less than one half the second dimension of said air mattress spanned by said air bladder cells.

20 2. The traveling wave air mattress apparatus of Claim 1 wherein said air mattress is further defined as including a base panel which supports said array of air bladder cells.

3. The traveling wave air mattress apparatus of Claim 1 wherein said array of air bladder cells includes at least three air bladder cells disposed laterally between opposite longitudinal sides of said mattress at different longitudinal locations of said array.

25 4. The traveling wave air mattress apparatus of Claim 1 wherein said array of air bladder cells includes at least three air bladder cells which are disposed longitudinally between opposite lateral ends of said array at different lateral locations of said array.

30 5. The traveling wave air mattress apparatus of Claim 1 wherein said array of air bladder cells is further defined as comprising a matrix of at least  $P \times Q$  individual air bladder cells consisting of P rows of laterally disposed air bladder cells, each consisting of Q individual air bladder cells where both P and Q are at least three.

6. The traveling wave air mattress of Claim 1 wherein said array of air bladder cells includes at least three concentric air bladder cells that have in plan view the shape of an annular ring.

7. The traveling wave air mattress of Claim 6 wherein said annular ring shape is further defined as being oval.

35 8. The traveling wave air mattress of Claim 6 wherein said annular ring shape is further defined as being circular.

9. The traveling wave air mattress of Claim 6 wherein said air bladder cells are segmented into at least two circumferentially separated individually inflatable and deflatable arc-shaped segments.

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10. The traveling wave air mattress of Claim 6 wherein said air bladder cells are segmented into at least four circumferentially separated individually inflatable and deflatable arc-shaped quadrant segments.

11. The traveling wave air mattress of Claim 10 wherein said annular ring shape is further defined as being oval.

12. The traveling wave air mattress of Claim 10 wherein said annular ring shape is further defined as being circular.

13. The traveling wave air mattress apparatus of Claim 1 further including a mattress inflation level control apparatus for inflating and deflating said air bladder cells to selectable quiescent air pressure levels.

14. The traveling wave air mattress apparatus of Claim 13 wherein said inflation control apparatus includes said wave generator apparatus.

15. The traveling wave air mattress apparatus of Claim 1 wherein said air pressure pulse generator of said wave generator apparatus has an output port which is selectably coupleable to selected individual air bladder cells of said array of air bladder cells.

16. A traveling wave air mattress apparatus comprising;

a. an array of flexible air bladder cells having upper surfaces for supporting a human body, said air bladder cells being hermetically isolated from one another and individually inflatable and deflatable, and

b. a wave generator apparatus including an air pressure pulse generator for sequentially introducing pulses of air pressure into a selectable sequence of said air bladder cells to thereby introduce a traveling wave of air pressure variation in said cells from static pressure values and hence cause a traveling wave of variation in support force for a body to traverse upper surfaces of at least some of said air bladder cells. said air pressure pulse generator including;

i. a hermetically sealable pressure chamber which communicates with said outlet port of said air pressure pulse generator and a movable member within said chamber which is movable away from said outlet port in a first retracted direction from a first, rest position to a second, active position to withdraw air from a selected air bladder cell through said outlet port and into said chamber, to thus decrease air pressure within the selected cell from an initial quiescent pressure, and movable in a second, extended direction towards said outlet port to expel air through said output port and back into said selected air bladder cell to increase pressure in said selected air bladder cell, and

ii. an actuator responsive to an actuator driver signal to thus move said movable member.

17. The traveling wave air mattress apparatus of Claim 16 wherein said movable member is one of a diaphragm and a piston.

18. The traveling wave air mattress apparatus of Claim 17 wherein said air pressure pulse generator is further defined as including a force actuator for moving said movable member.

19. A traveling wave air mattress apparatus for decreasing the magnitude and duration of reaction force concentrations exerted on the body of a patient, said apparatus comprising;

5 a. an inflatable air mattress including a base panel having protruding upwards therefrom a multiplicity of flexible individually inflatable and deflatable air bladder cells which are hermetically isolated from one another, said air bladder cells being disposed in a direction which spans a first area dimension of the base panel and being arranged in a series which spans a second area dimension of the bases panel, each of said air bladder cells having at least a first hermetically sealable port through which pressurized air may be introduced to and removed from a hollow interior space of said air bladder cell,

10 b. an inflation control apparatus for introducing and removing air into said air bladder cells to thus inflate and deflate each air bladder cell to adjustable quiescent air pressure levels, and

15 c. a soliton wave generator apparatus including an air pressure pulse generator for cyclically introducing timed sequences of pulses of air pressure variation into a predetermined series of said air bladder cells, each said sequence comprising at least a first train of pulses in which a first pulse is introduced into at least a first selected first-end air bladder cell proximate a first end of said array, and subsequent pulses of air pressure variation into successive air bladder cells of said series, said sequence of pulses of air pressure variation producing a soliton traveling wave of body support force variation which traverses said body support surface of said air mattress in a direction parallel to the second dimension of the base panel, said soliton traveling wave having a wave-front width which spans the first dimension of said air mattress and a length less than one half the second dimension of said air mattress spanned by said air bladder cells.

20 20. The traveling wave air mattress apparatus of Claim 19 further including an array of surface reaction force sensors, each being associated with individual ones of said air bladder cells, each of said sensors producing a sensor output signal which is proportional to a surface reaction support force exerted on a patient's body by said air bladder cells associated with said sensors.

25 21. The traveling wave air mattress apparatus of Claim 20 further including an electronic memory for storing measured values of reaction force concentrations measured by said surface reaction force sensors, an electronic computer for creating a list of air bladder cells ordered from larger to smaller of said reaction force values measured by said sensors to thereby produce a force gradient vector, and an electronic controller for directing said pressure pulse generator to apply air pressure pulses sequentially to at least some of said air bladder cells along said force gradient vector.

30 35 22. The traveling wave air mattress apparatus of Claim 19 wherein said wave generator apparatus is further defined as including a wave generator controller for issuing command signals to said air pressure pulse generator which controls at least one of air bladder cell selection, pressure-pulse magnitude, sign, shape, duration and relative sequencing.

23. The traveling wave air mattress apparatus of Claim 1 wherein said soliton wave generator apparatus includes a wave generator controller for issuing command signals to said air pressure pulse generator which cause said air pressure pulse generator to introduce pulses of air pressure into selected air bladder cells in a sequence that causes a wave of inflation pressure variation to travel over selectable paths of said air bladder cells and a corresponding traveling wave of body support force variations to travel over said paths.

24. The traveling wave air mattress apparatus of Claim 23 further including individual surface reaction force sensors associated with at least some of said air bladder cells, each of said sensors producing a sensor output signal which is proportional to a surface reaction force exerted on a patient's body by an associated air bladder cell.

25. The traveling wave air mattress apparatus of Claim 24 further including an electronic memory for storing measured values of reaction force concentrations measured by said surface reaction force sensors, an electronic computer for creating a list of air bladder cells ordered from larger to smaller of said reaction force values measured by said sensors to thereby produce a force gradient vector, and an electronic controller for directing said pressure pulse generator to apply air pressure-pulses sequentially to a first air bladder cell of said list on which a larger reaction force was measured, and sequentially to air bladder cells of said list on which successively smaller reaction forces were measured along said force gradient vector.

26. The traveling wave air mattress apparatus of Claim 23 wherein said soliton wave generator apparatus is further defined as including a wave generator controller for issuing command signals to said air pressure-pulse generator which controls at least one of air bladder cell selection, pressure-pulse magnitude, sign shape, duration and relative sequencing.

27. A method for decreasing the magnitude and duration of reaction support force concentrations exerted on a body by individually inflatable and deflatable air bladder cells of an air mattress, said method comprising introducing pulses of air into selected ones of bladder cells of an inflatable air mattress in sequences which cause waves of inflation pressure variation to travel over selectable paths of said air bladder cells and corresponding soliton traveling waves of body support force variations to travel over said paths.

28. The method of Claim 27 further including storing measured values of reaction support forces exerted on a body supported by an inflatable air mattress, calculating a reaction force gradient vector based upon said measured values of reaction support forces, and directing said sequences of air pulses sequentially to at least some of said air bladder cells along said force gradient vector.

29. The traveling wave air mattress apparatus of Claim 1 wherein said soliton wave generator apparatus includes;

a. a pulse polarity router assembly for selectably conducting positive or negative pressure air pulses produced by said air pressure pulse generator to a pulse bladder selector-manifold,

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b, a pulse selector manifold for receiving said positive or negative pressure air pulses and conducting said pulses to one of a selected air bladder cell and a group of air bladder cells, and

5 c. a wave generator controller responsive to programmed commands in causing said air pulse generator to emit air pressure pulses, controlling said pulse polarity router assembly, and controlling said selector manifold to thereby select air bladder cells which are to receive air pressure pulses.

10 30. The apparatus of Claim 29 wherein said pressure pulse generator is further defined as being an air pump having an inlet port for providing negative pressure pulses of air and an outlet port for producing positive pressure pulses of air.

31. The apparatus of Claim 30 wherein said router assembly includes a multiplicity of valves and air conduits for alternately and selectably connecting said inlet and outlet ports of said air pump to an inlet port of said pulse bladder selector manifold.

15 32. The apparatus of Claim 31 wherein said multiplicity of valves includes a pump inlet router valve which has an output port connected by a pump inlet conduit to said to pump inlet port, a first inlet port for communication with said inlet port of said pulse selector manifold, and a pump inlet valve element actuatable between a first, open position to enable air flow from said inlet port of said pulse selector manifold to said pump inlet port, and a second, closed position to block air flow from said inlet of said pulse selector manifold to said pump inlet port.

20 33. The apparatus of Claim 32 wherein said pump inlet router valve is further defined as having a second inlet port which communicates with said outlet port of said pump inlet router valve when said pump inlet valve element is actuated to a second, closed position.

34. The apparatus of Claim 32 wherein said second inlet port of said pump inlet router valve communicates with an air supply.

25 35. The apparatus of Claim 34 wherein said air supply is the atmosphere.

36. The apparatus of Claim 34 wherein said air supply is a pneumatic supply accumulator.

37. The apparatus of Claim 36 wherein said pneumatic supply accumulator is further defined as least one additional air bladder cell.

30 38. The apparatus of Claim 34 further including a selector manifold router valve which has an output port connected by an air conduit to said inlet port of said pump inlet router valve, a first inlet port connected to said inlet port of said pulse bladder selector manifold, and a selector manifold valve element actuatable between a first open position to enable air flow from said first input port of said pulse selector manifold to said first inlet port of said pump inlet router valve, and a second, closed position to block air flow from said pulse selector manifold to said first inlet port of said pump inlet router valve.

35 39. The apparatus of Claim 38 wherein said selector manifold router valve is further defined as having a second inlet port which communicates with said outlet port of said selector manifold router valve when said selector manifold valve element is actuated to said closed position.

40. The apparatus of Claim 34 further including a pump outlet router valve which has an input port connected by a pump outlet conduit to said pump outlet port, a first outlet port connected by an air conduit to said second outlet port of said pulse selector router valve, and a pump outlet valve element actuatable between a first open position to enable air flow from said inlet port of said pump outlet router valve to said first outlet port of said pump outlet router valve, and a second, closed position to block air flow from said inlet port of said inlet port to said first outlet port of said pump inlet router valve.

41. The apparatus of Claim 40 wherein said pump output router valve is further defined as having a second outlet port which communicates with said inlet port of said pump outlet router valve when said pump output valve element is actuated to a second, closed position.

42. The apparatus of Claim 41 wherein said second outlet port of said pump outlet router valve communicates with an air exhaust space.

43. The apparatus of Claim 42 wherein said air exhaust space is the atmosphere.

44. The apparatus of Claim 42 wherein said exhaust space is an internal volume of a pneumatic exhaust accumulator which is connected to said second outlet port of said pump outlet router valve by a first outlet conduit.

45. The apparatus of Claim 44 wherein said air exhaust accumulator is coextensive with said air-supply accumulator.

46. The apparatus of Claim 45 wherein said accumulator is further defined as least one additional air bladder cell. .

47. The apparatus of Claim 44 further including a second output conduit which connects said second outlet port of said pump outlet router valve to said second input port of said pump inlet router valve.

48. The apparatus of Claim 29 further including an exhaust rate sensor device for monitoring exhaust rate of air from a deflating air bladder cell and varying at least one of occurrence time, duration, and magnitude of a subsequent deflation and re-inflation cycle of that air bladder cell if the exhaust rate is below a predetermined threshold value.

49. The traveling wave air mattress of Claim 1 wherein said successive air bladder cells of said series are spaced successively further from said first selected first-end air bladder cell.

50. The traveling wave air mattress apparatus of Claim 49 wherein said sequence of pulses of air pressure variation includes a second train of pulses in which a first pulse is introduced into at least a first selected second-end air bladder cell proximate a second end of said array and subsequent pulses of air pressure variation into successive air bladder cells of said series, said sequence of pulses of air pressure variation producing a soliton wave of body support force variation which traverses said body support surface of said air mattress in a direction parallel to the second dimension of said air mattress, said soliton wave having a wave-front width which spans the first dimension of said air mattress and a length less than one half the second dimension of said air mattress spanned by said air bladder cells.

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51. The traveling wave air mattress of Claim 50 wherein said successive air bladder cells of said series are spaced successively further from said first selected second-end air bladder cell.

52. The traveling wave air mattress of Claim 51 wherein said second train of pulses of air pressure variation is initiated after the end of a time interval in which said first train of pulses of air pressure variation occurred.

53. The traveling wave air mattress of Claim 52 wherein said second train of pulses of air pressure variation is initiated during a time interval in which said first train of air pulses occurs.

54. The traveling wave air mattress of Claim 19 wherein said successive air bladder cells of said series are spaced progressively further from said first selected first-end air bladder cell.

55. The traveling wave air mattress of Claim 54 wherein said sequence of pulses of air pressure variation includes a second train of pulses in which a first pulse is introduced into at least a first selected second-end air bladder cell proximate a second end of said array and subsequent pulses of air pressure variation into successive air bladder cells of said series, said sequence of pulses of air pressure variation producing a soliton wave of body support force variation which traverses said body support surface of said air mattress in a direction perpendicular to said air bladder cells, said soliton wave having a wave-front width which spans the first dimension of said air mattress and a length less than one half the second dimension of said air mattress spanned by said air bladder cells.

56. The traveling wave air mattress of Claim 55 wherein said successive air bladder cells of said series are spaced successively further from said first selected second-end air bladder cell.

57. The traveling wave air mattress of Claim 56 wherein said second train of pulses of air pressure variation is initiated after the end of a time interval in which said first train of pulses of air pressure variation occurred.

58. The traveling wave air mattress of Claim 56 wherein said second train of pulses of air pressure variation is initiated during a time interval in which said first train of air pulses occurs.

59. In an air mattress which includes an array of N flexible individually inflatable and deflatable air bladder cells, having surfaces which provide a body support force, the improvement comprising a soliton wave generator operably interconnected to said air mattress, said soliton wave generator apparatus comprising an air pressure pulse generator for cyclically introducing timed sequences of pulses of air pressure variation into a predetermined series of said air bladder cells, each said sequence comprising at least a first train of pulses in which a first pulse is introduced into at least a first first-end selected air bladder cell proximate a first end of said array, and subsequent pulses of air pressure variation into successive air bladder cells of said series, said sequence of pulses of air pressure variation producing a soliton traveling wave of body support force variation which traverses said surfaces of said air bladder cells in a direction parallel to a second area dimension of said array, said soliton traveling wave having a wave-front width which spans a first dimension of said air mattress and a length less than one half a second dimension of said air mattress spanned by said air bladder cells.

60. The improvement of Claim 59 wherein said wave generator apparatus includes a wave generator controller for issuing command signals to said air pressure pulse generator which cause said air pressure pulse generator to introduce pulses of air pressure into selected air bladder cells in a sequence that causes a wave of inflation pressure variation to travel over selectable paths of said air bladder cells and a corresponding traveling wave of body support force variations to travel over said paths.

61. The improvement of Claim 59 wherein said sequence of pulses of air pressure variation includes a second train of pulses in which a first pulse is introduced into at least a first selected second-end air bladder cell proximate a second end of said array and subsequent pulses of air pressure variation into successive air bladder cells of said series, said sequence of pulses of air pressure variation producing a soliton traveling wave of body support force variation which traverses said body support surface of said air mattress in a direction parallel to a second area dimension of said array, said soliton traveling wave having a wave-front width which spans a first dimension of said air mattress and a length less than one half the second dimension of said air mattress spanned by said air bladder cells.

62. The improvement of Claim 61 wherein said second train of pulses of air pressure variation is initiated after the end of a time interval in which said first train of pulses of air pressure variation occurred.

63. The improvement of Claim 61 wherein said second train of pulses of air pressure variation is initiated during a time interval in which said first train of air pulses occurs.

64. The apparatus of Claim 48 wherein said exhaust rate sensor device comprises in combination a pressure sensor for pneumatically communicating with a said deflating air bladder cell, a pressure sensor, and a timed threshold device for interrogating said pressure sensor at a predetermined time to assess whether or not pressure in said air bladder cell is below a predetermined threshold value at said predetermined time.

65. In an air mattress which includes an array of N flexible individually inflatable and deflatable air bladder cells having surfaces which provide a body support force, the improvement comprising an apparatus for selectably exhausting air individually from an air bladder cell of the array, monitoring the rate of exhaust to determine whether a weight load on said cell is below a predetermined value, and varying at least one of occurrence time, duration, and magnitude of re-inflation of said air bladder cell if said exhaust rate is below a predetermined value.

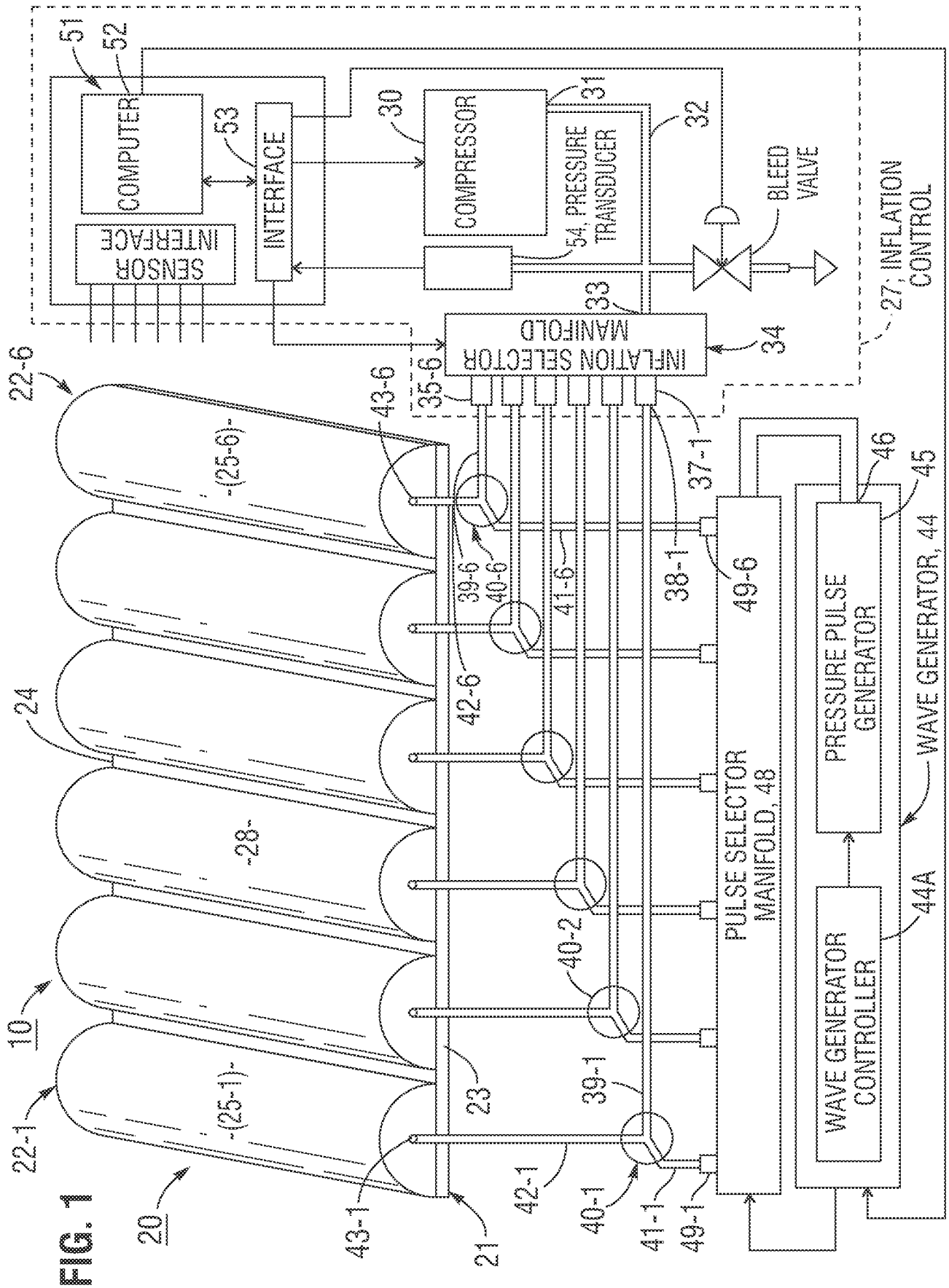
66. The improved air mattress of Claim 64 wherein said exhaust rate sensor device comprises in combination a pressure sensor for pneumatically communicating with a said deflating air bladder cell, a pressure sensor, and a timed threshold device for interrogating said pressure sensor at a predetermined time to assess whether or not pressure in said air bladder cell is below a predetermined threshold value at said predetermined time.

67. In an air mattress which includes an array of N flexible individually inflatable and deflatable air bladder cells having surfaces which provide a body support force, the improvement comprising; an apparatus including an electronic memory for storing measured values of

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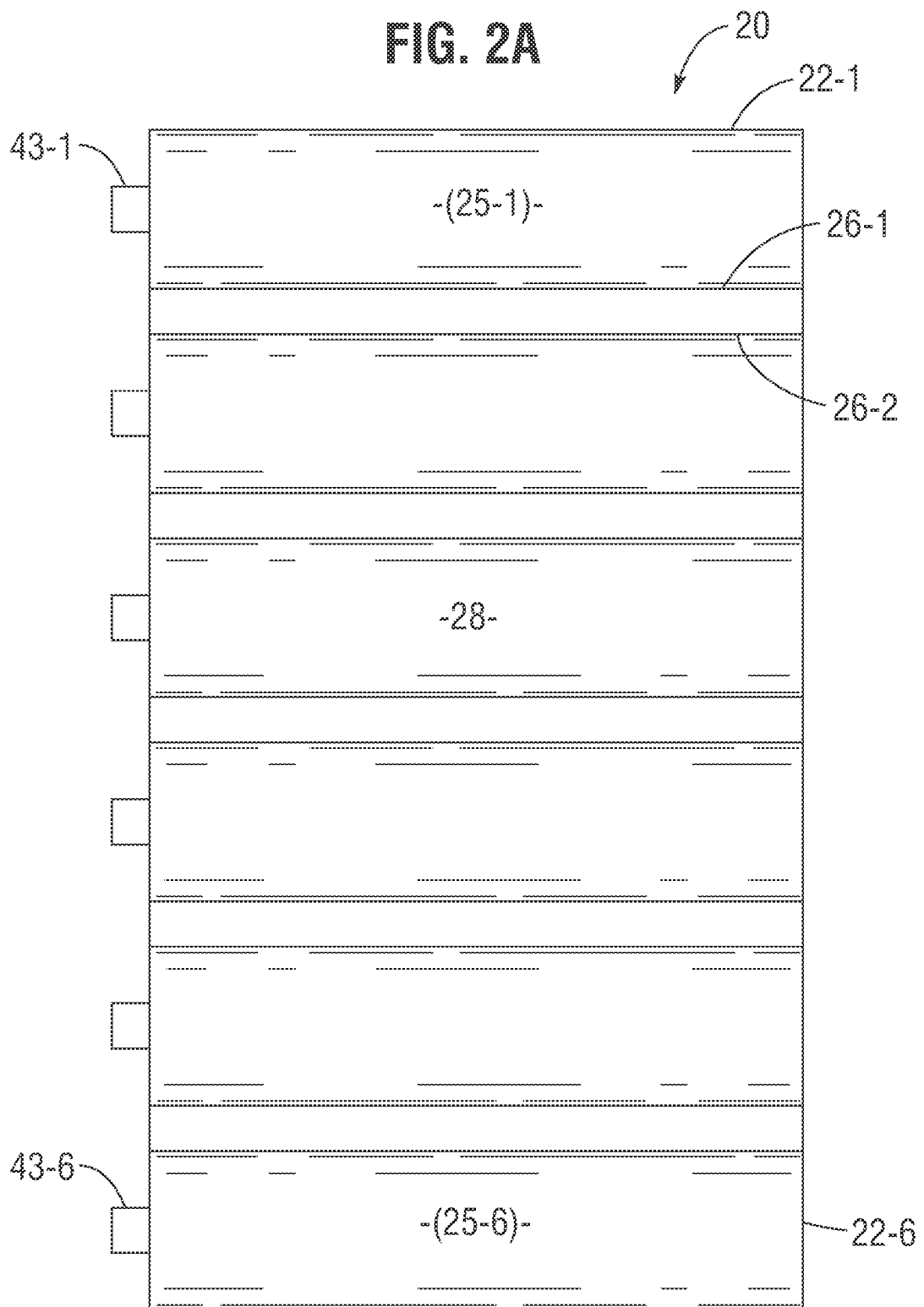
reaction force concentrations measured by surface reaction force sensors associated with individual air bladder cells, an electronic computer for creating a list of air bladder cells ordered from larger to smaller of said reaction force values measured by said sensors to thereby produce a force-gradient vector, and an electronic controller for directing said pressure pulse generator to apply air pressure-pulses sequentially to a first air bladder cell of said list on which a larger reaction force was measured, and sequentially to air bladder cells of said list on which successively smaller reaction forces were measured along said force gradient vector.

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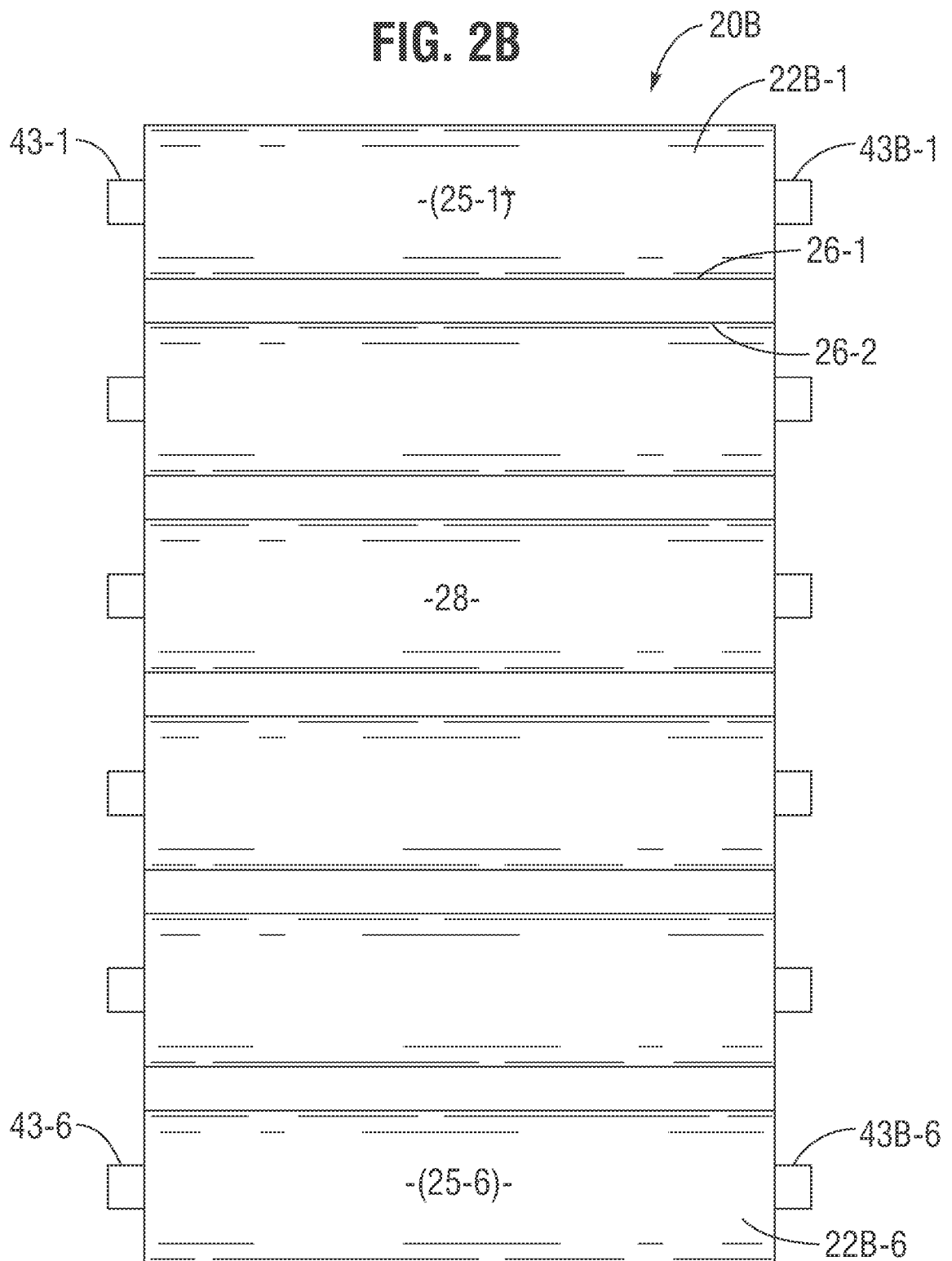


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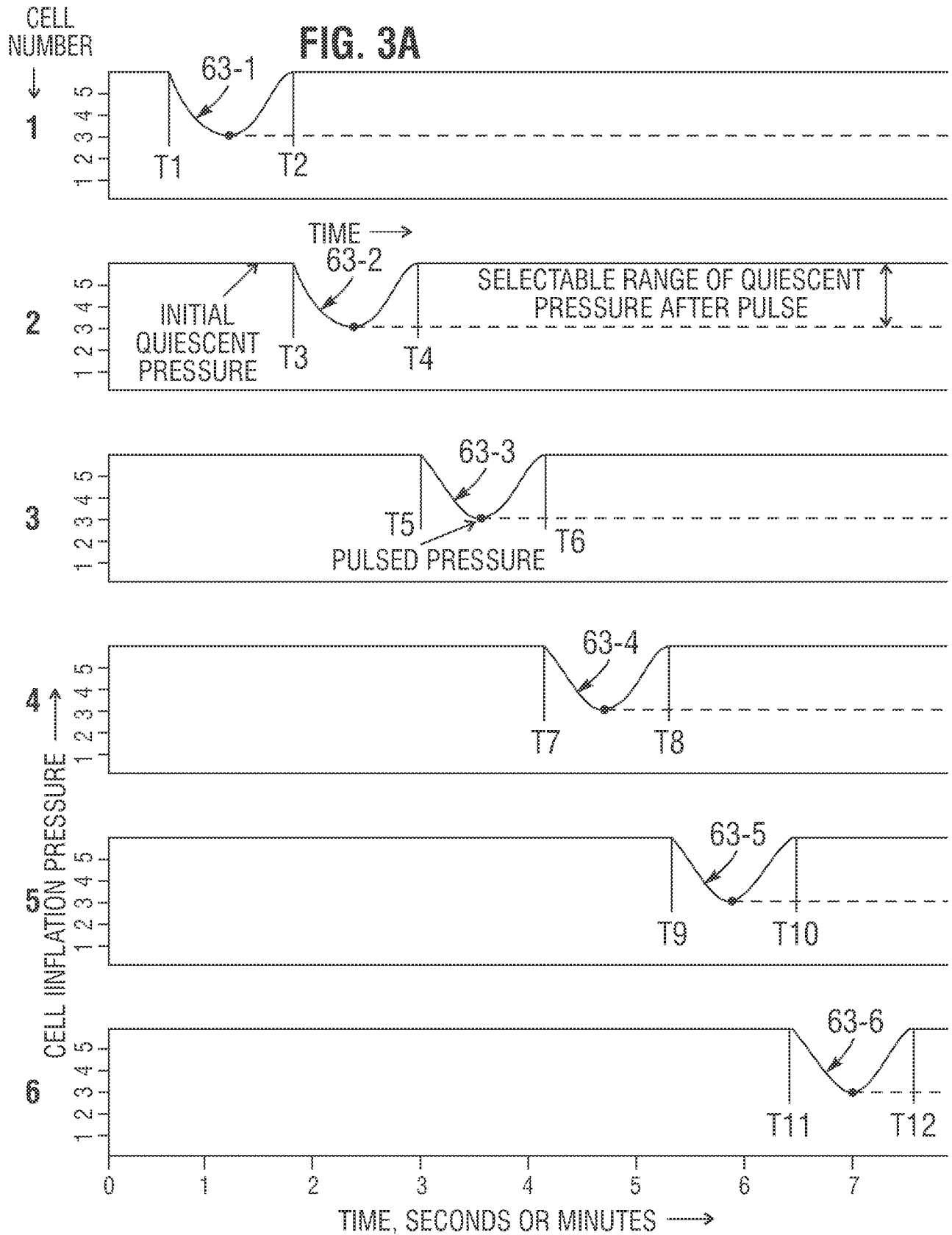
**FIG. 2A**



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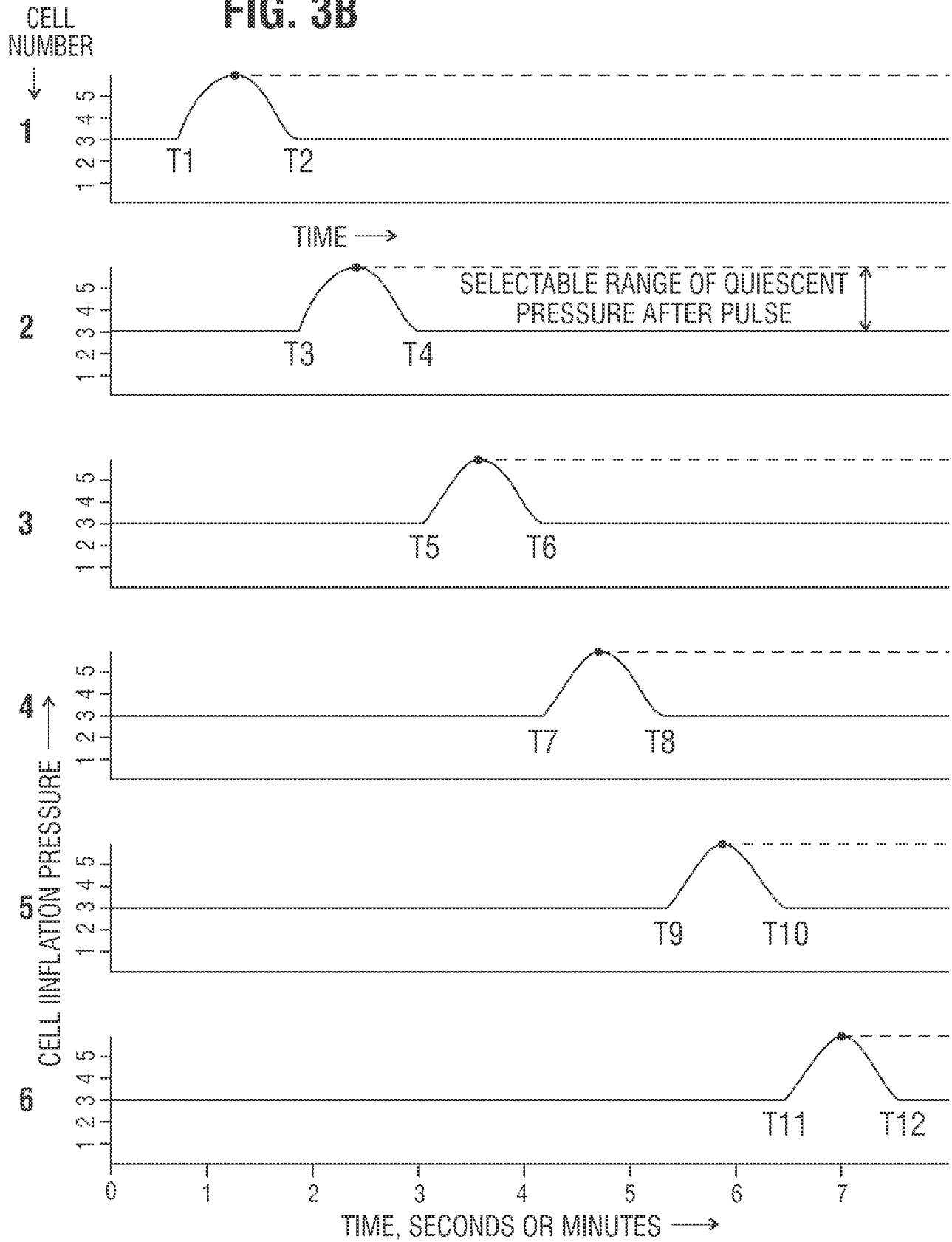
**FIG. 2B**

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FIG. 3B



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**FIG. 4**

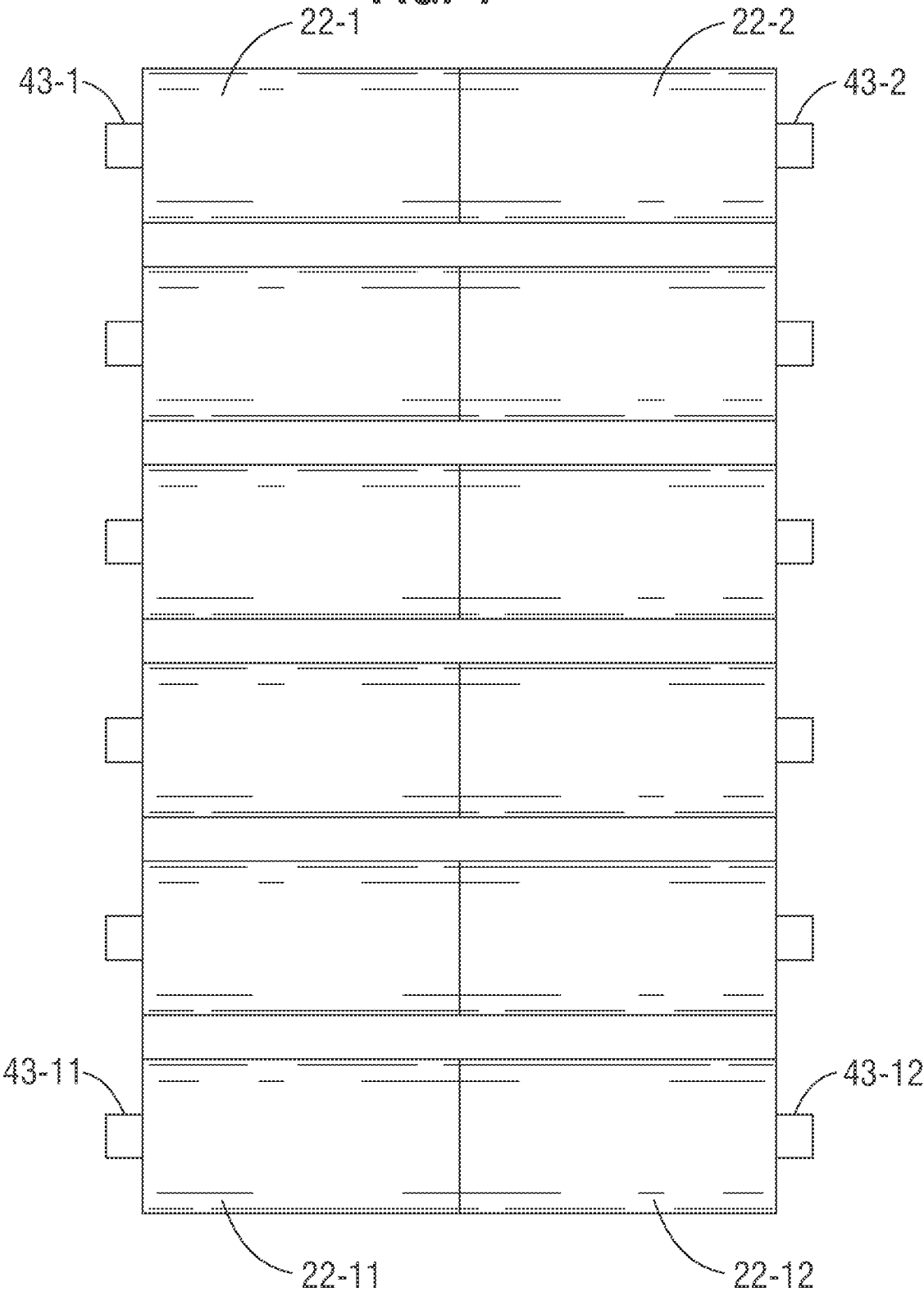
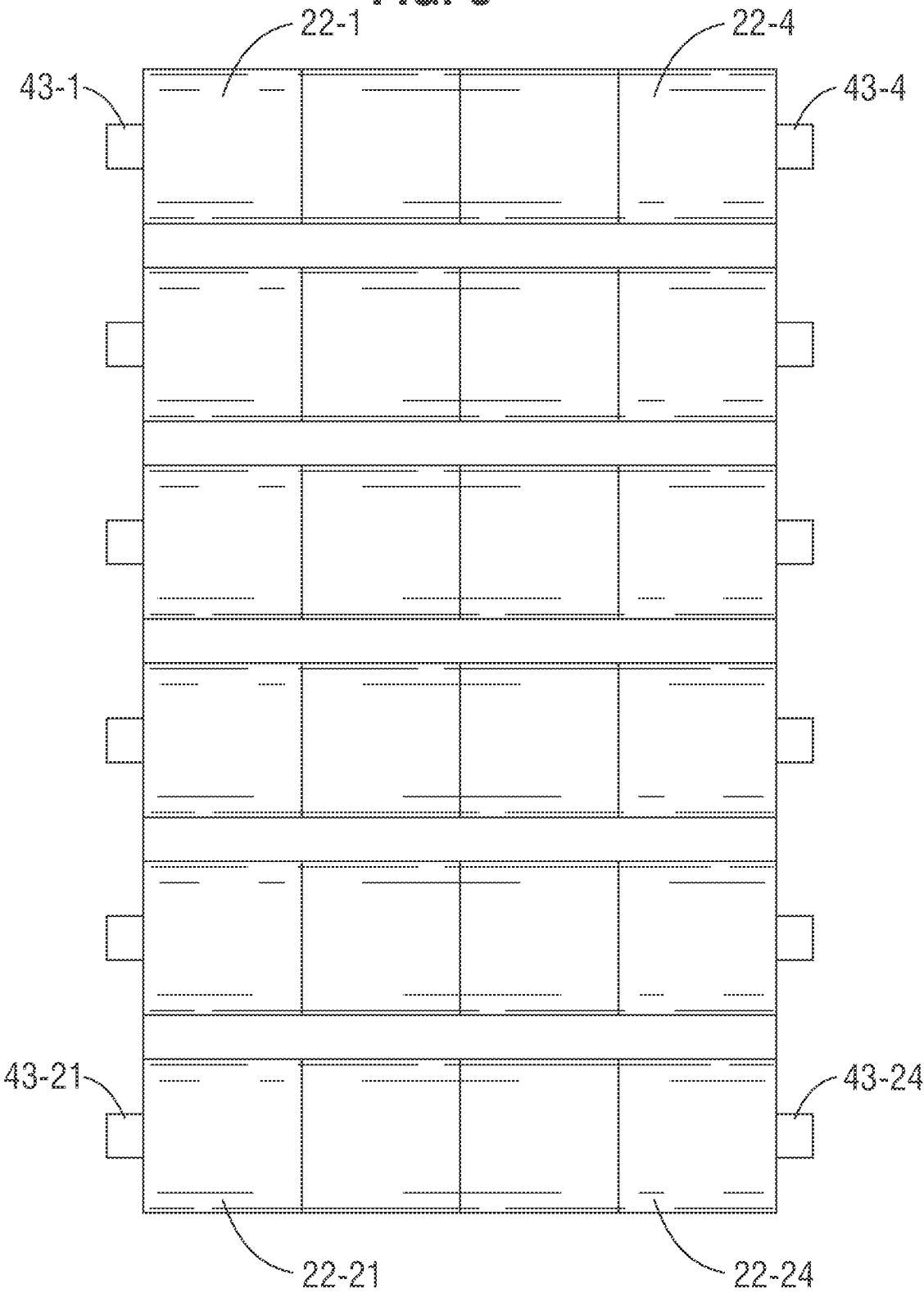
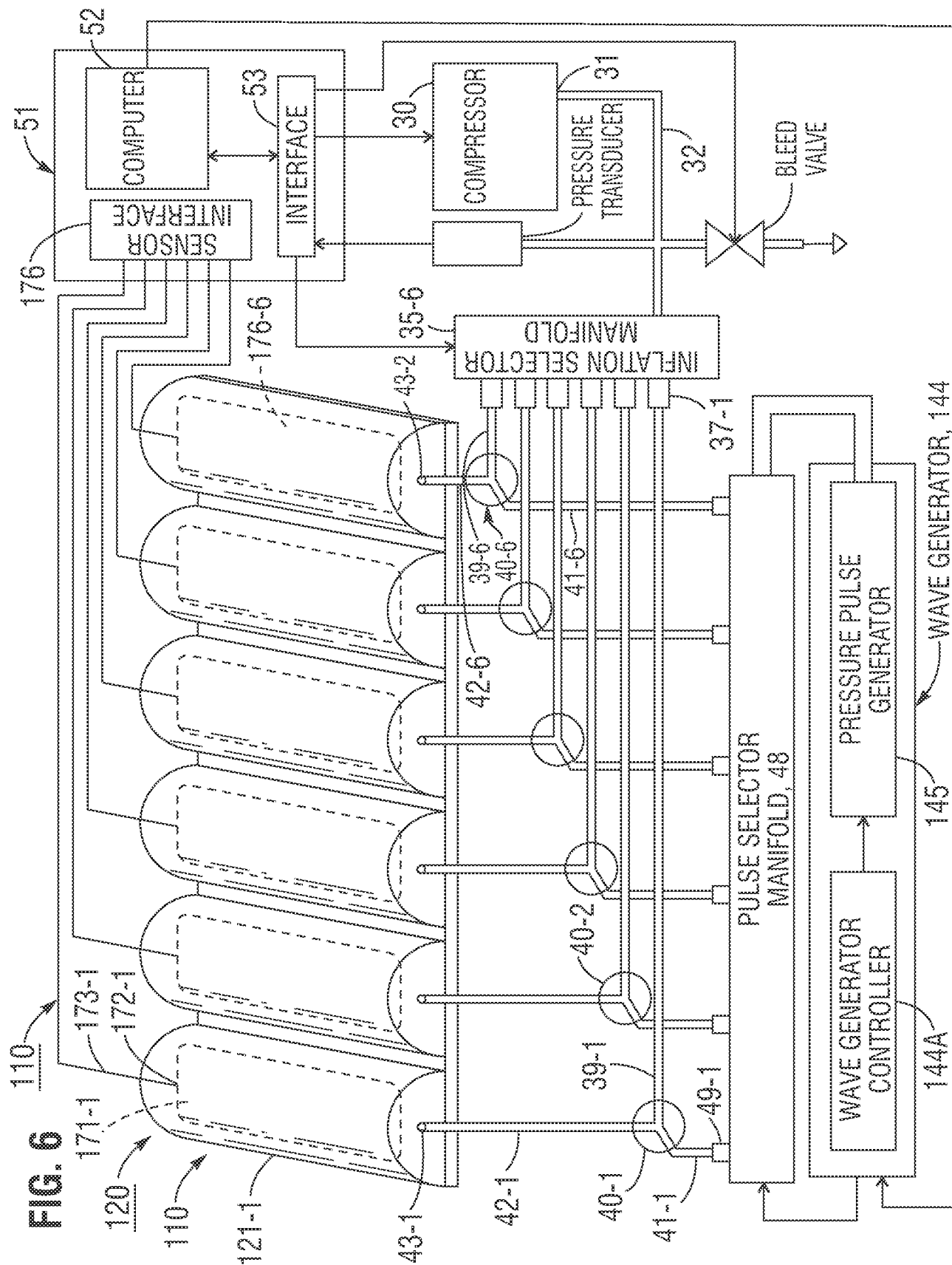


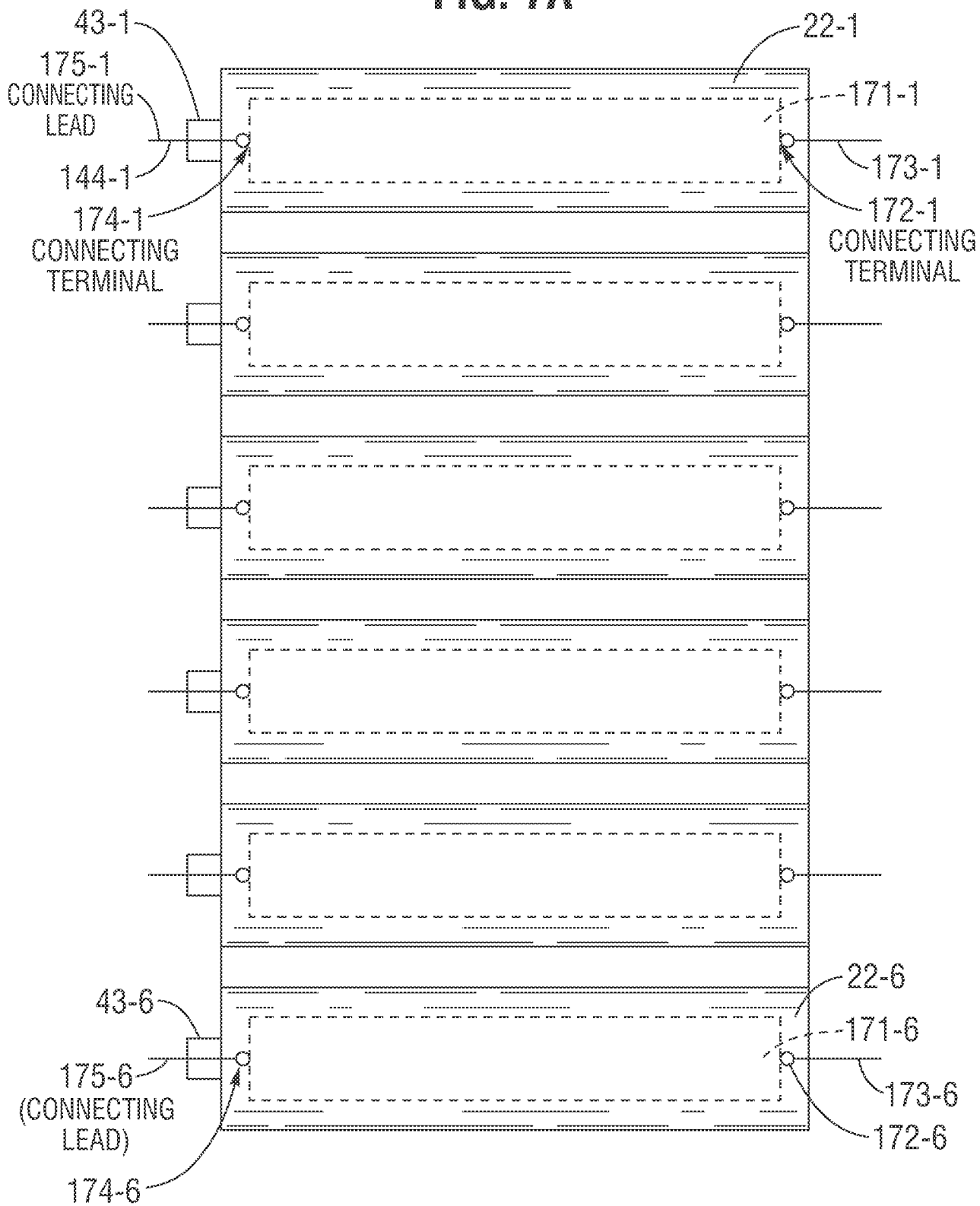
FIG. 5



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**FIG. 7A**

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**FIG. 7B**

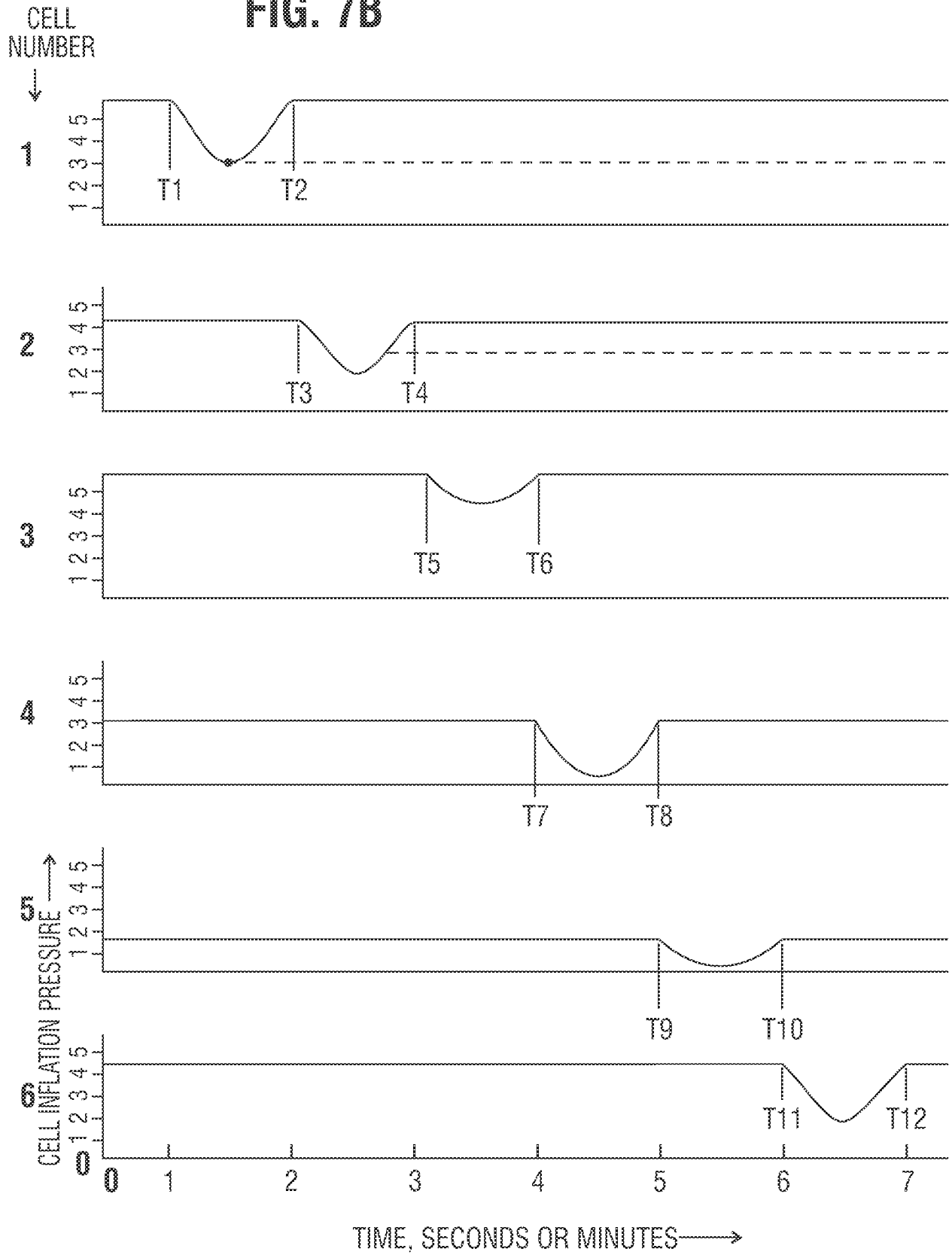
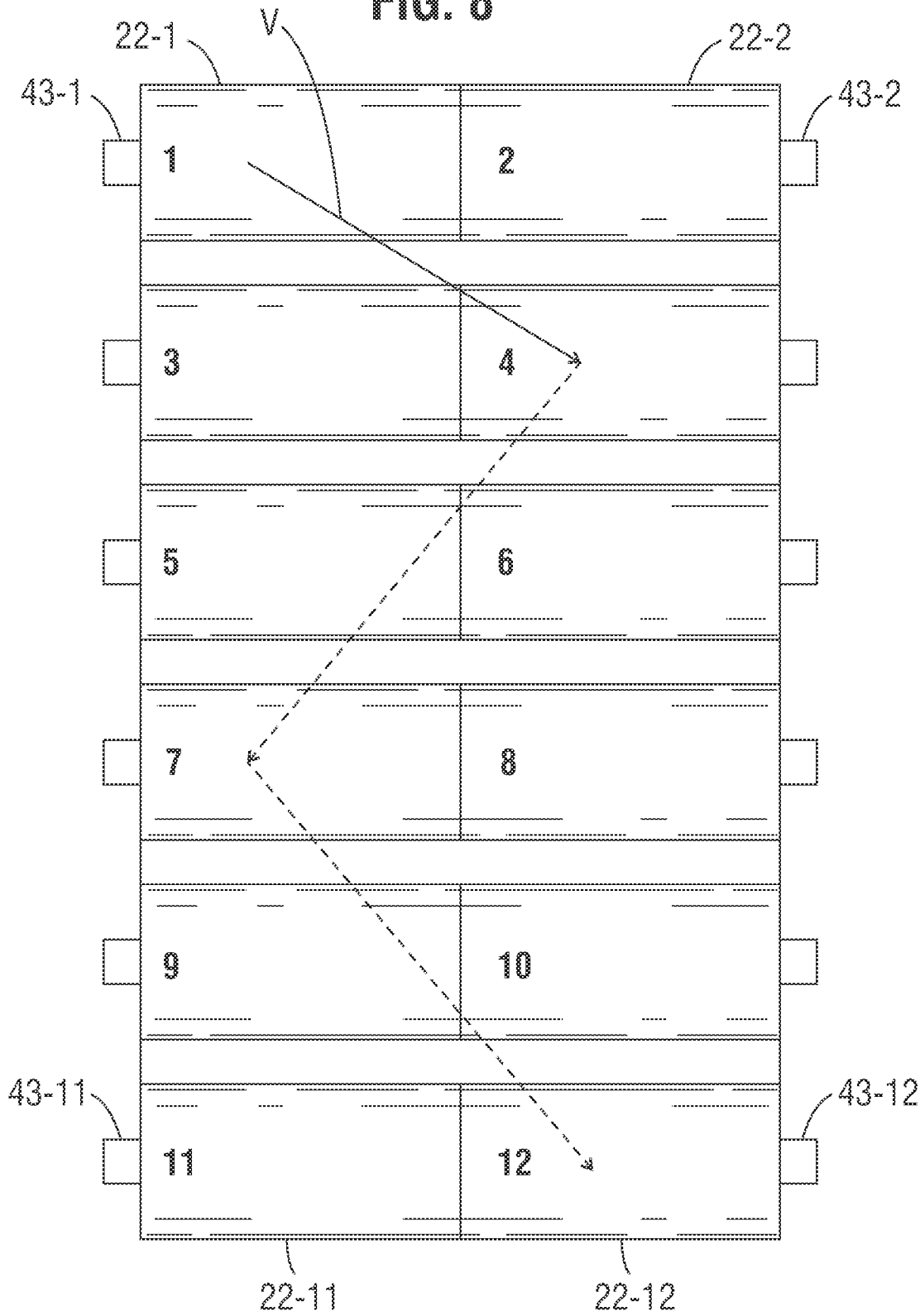


FIG. 8



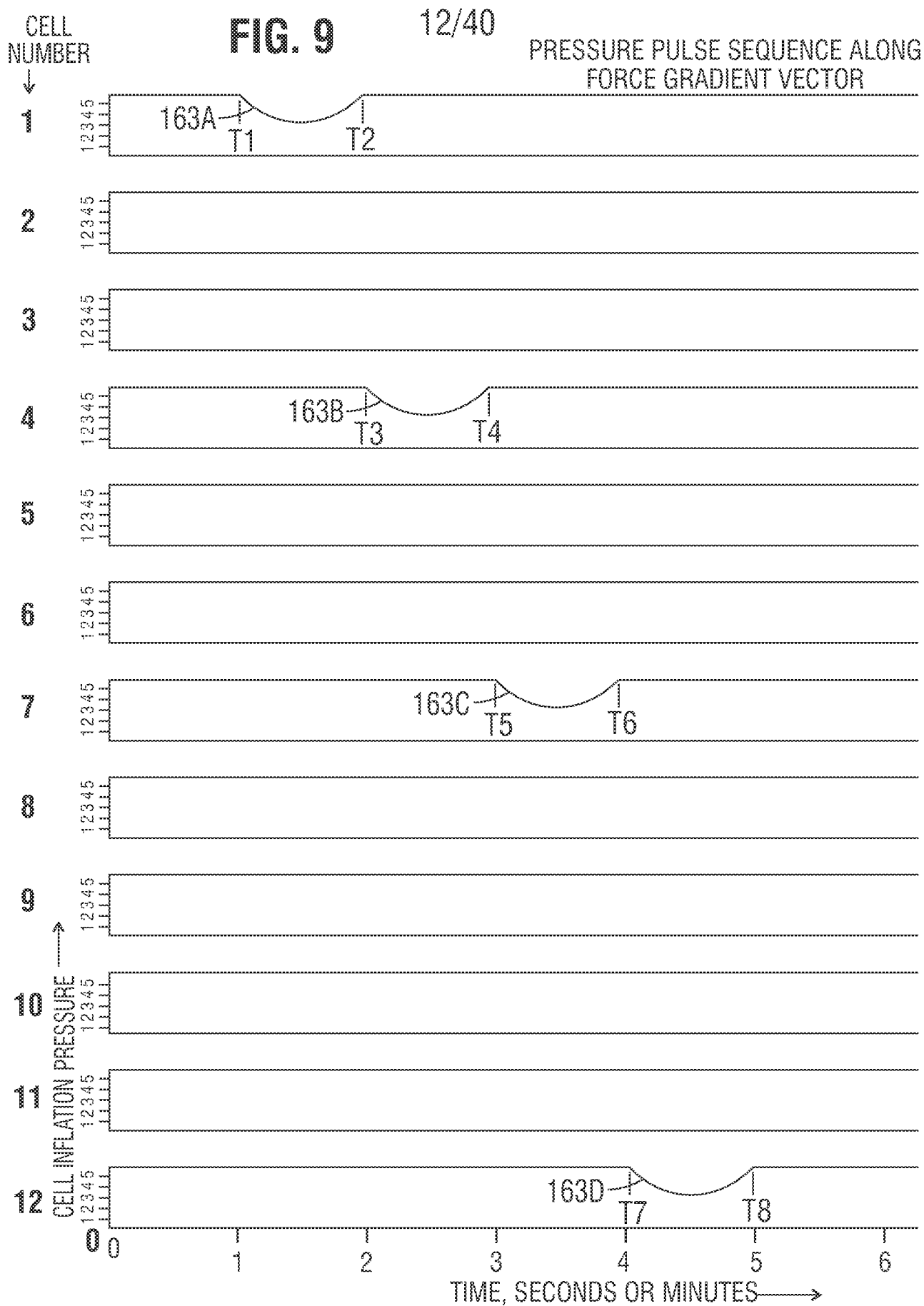
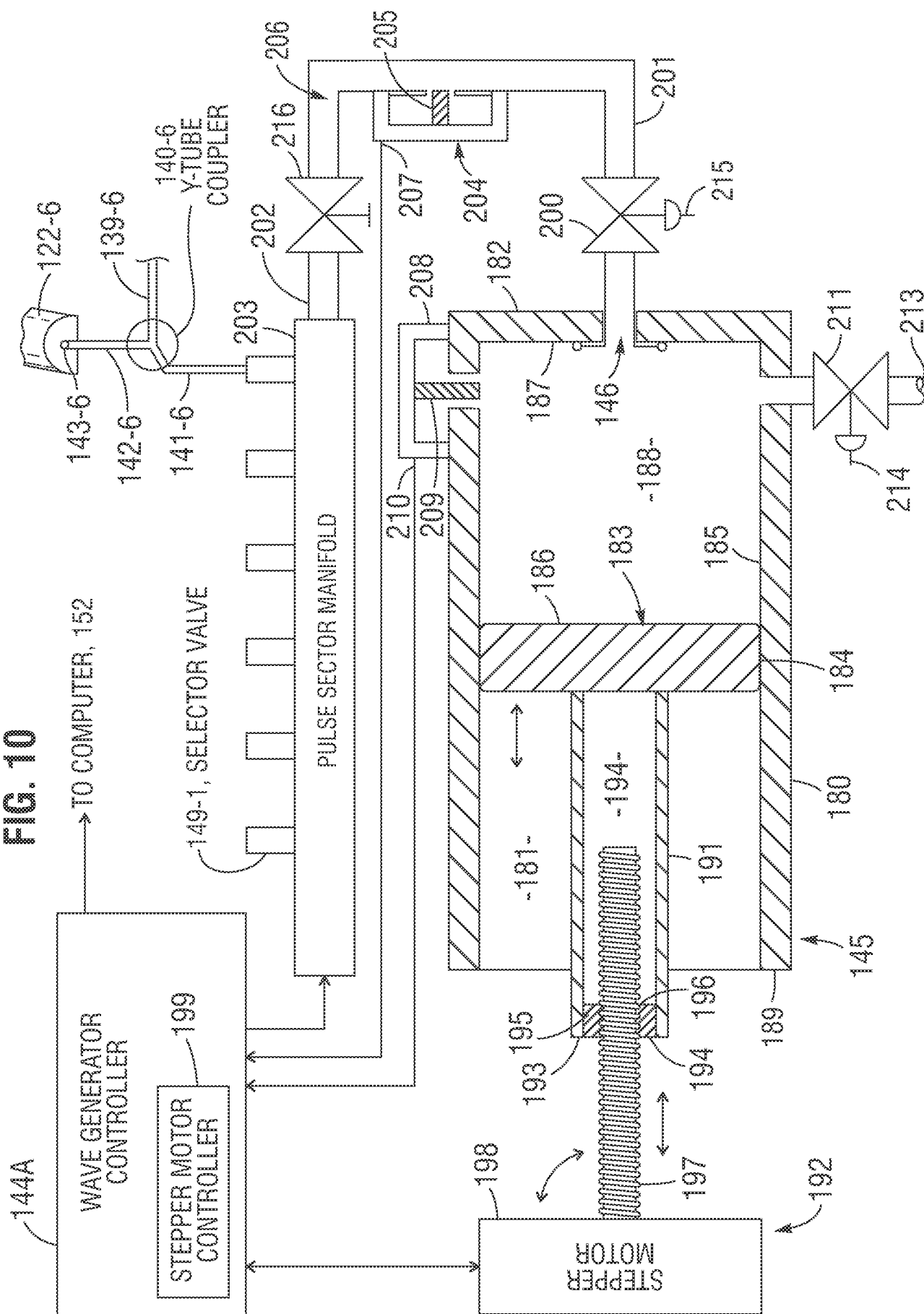
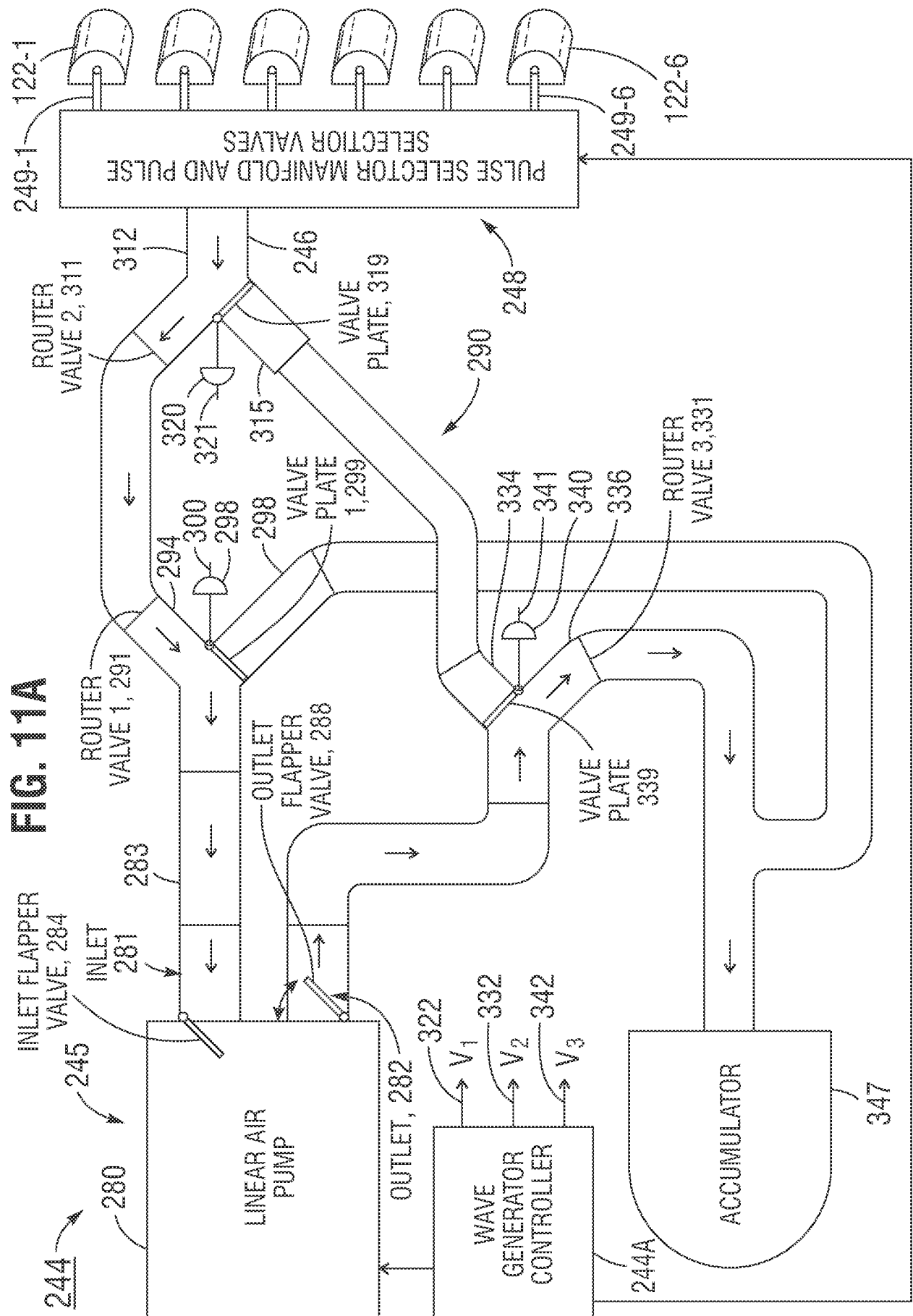


FIG. 10





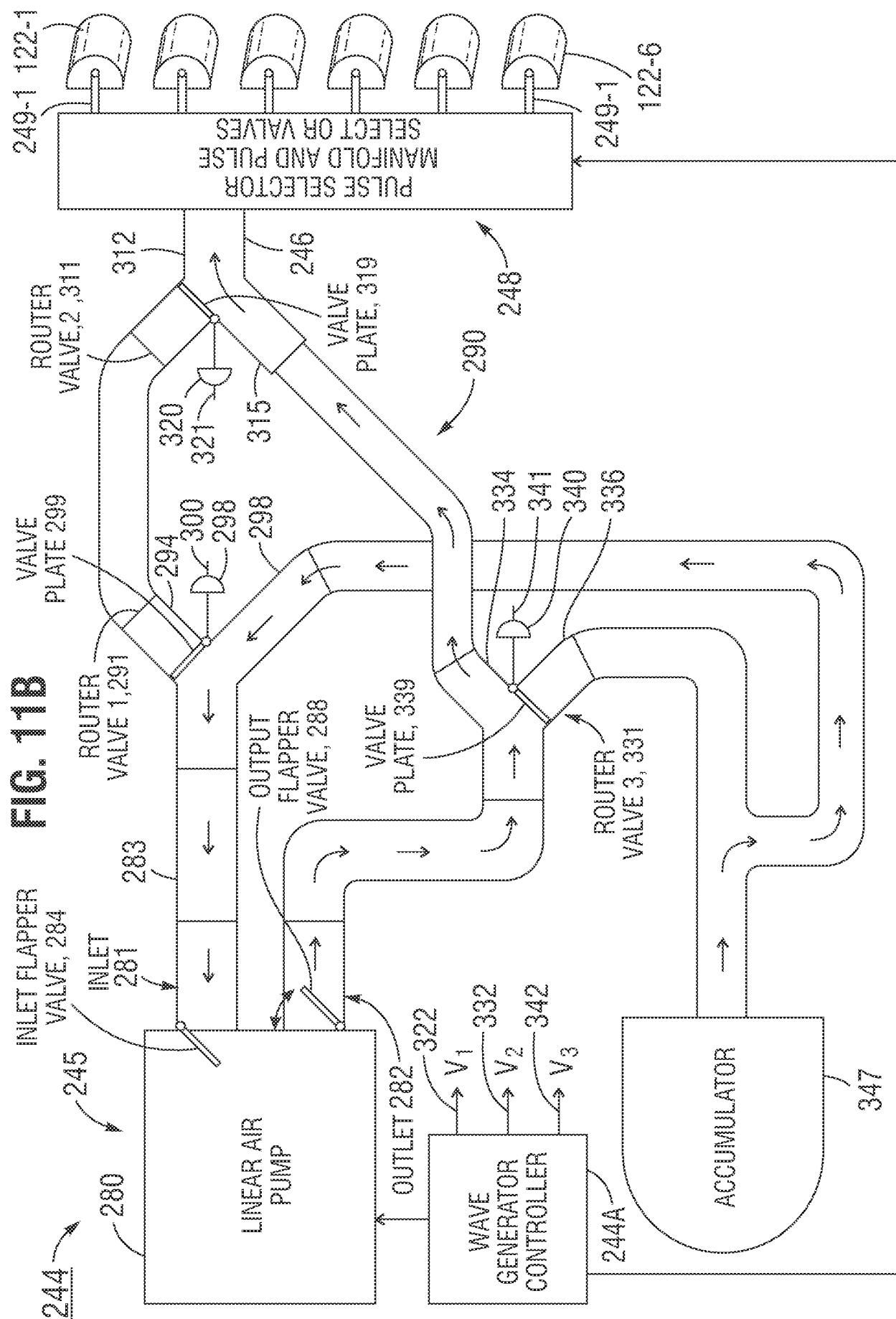
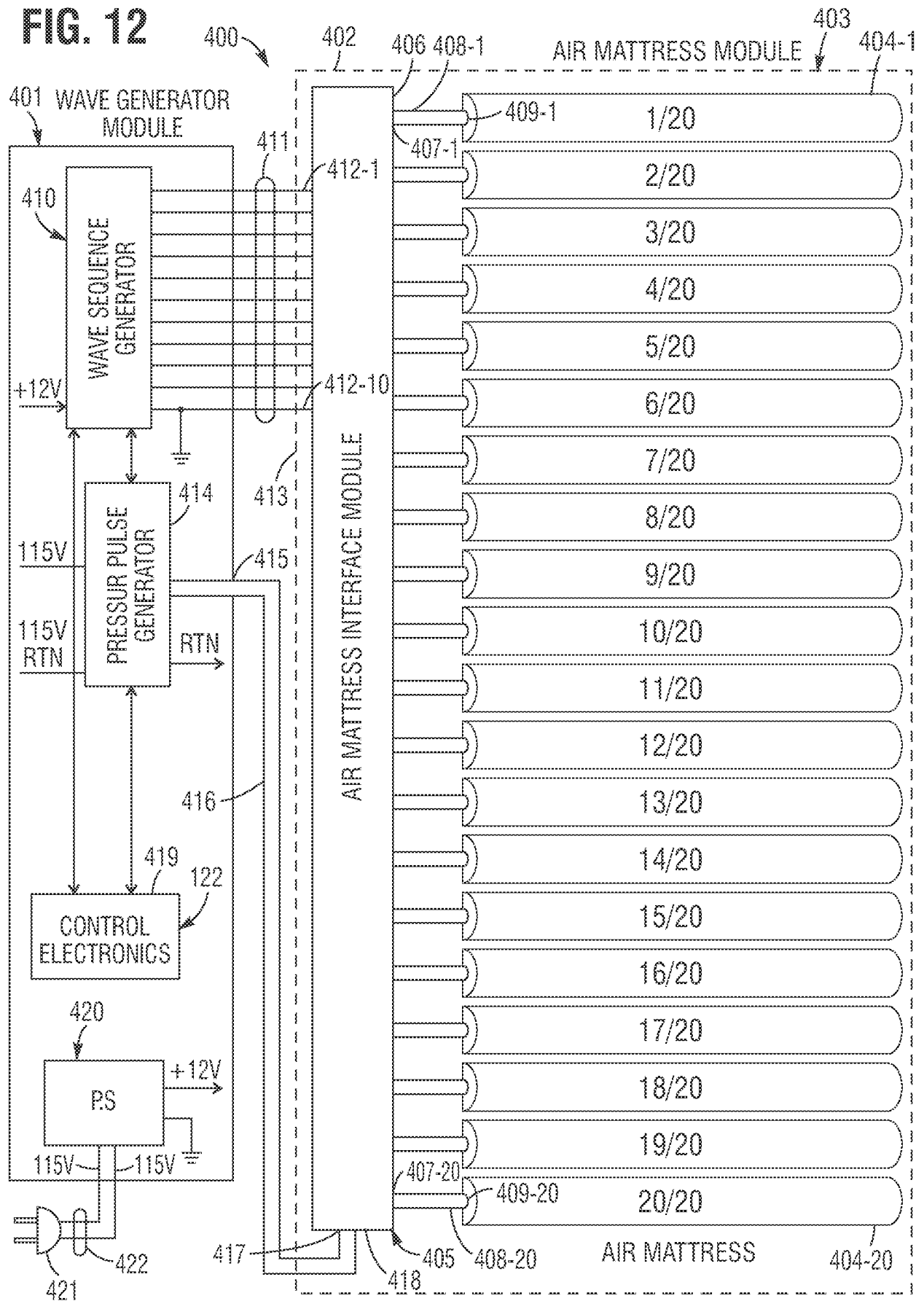
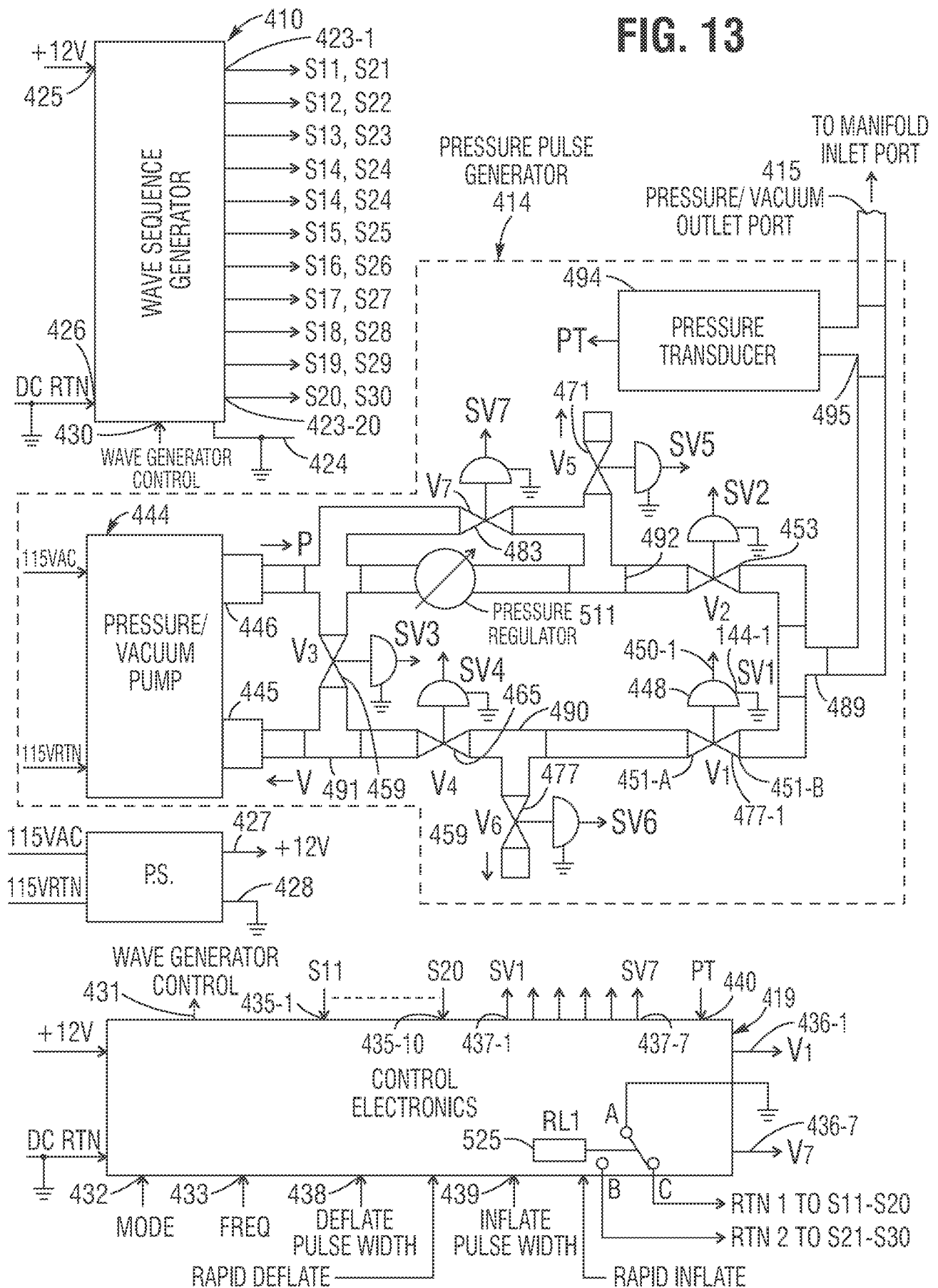


FIG. 12



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FIG. 13



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**FIG. 14**

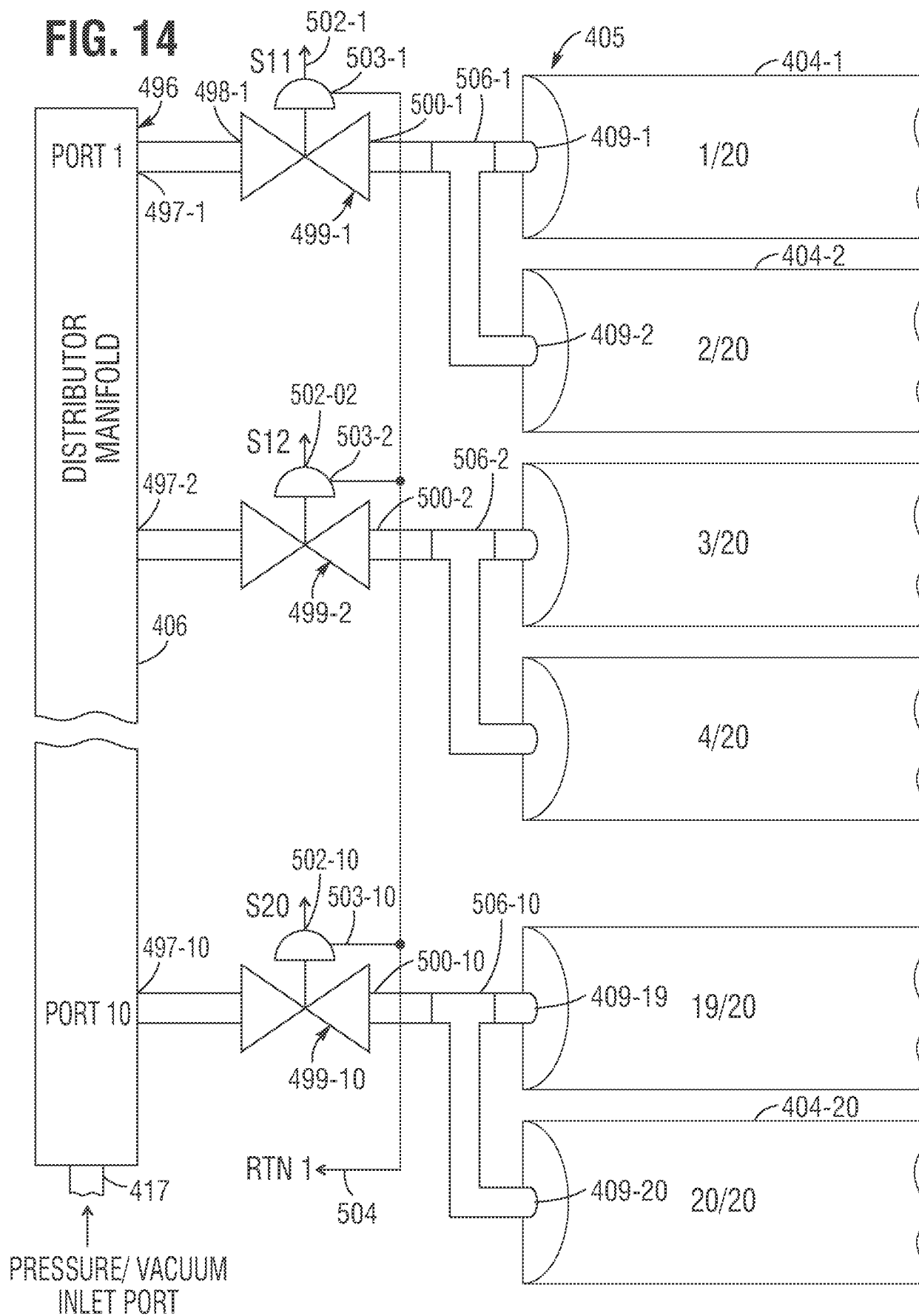
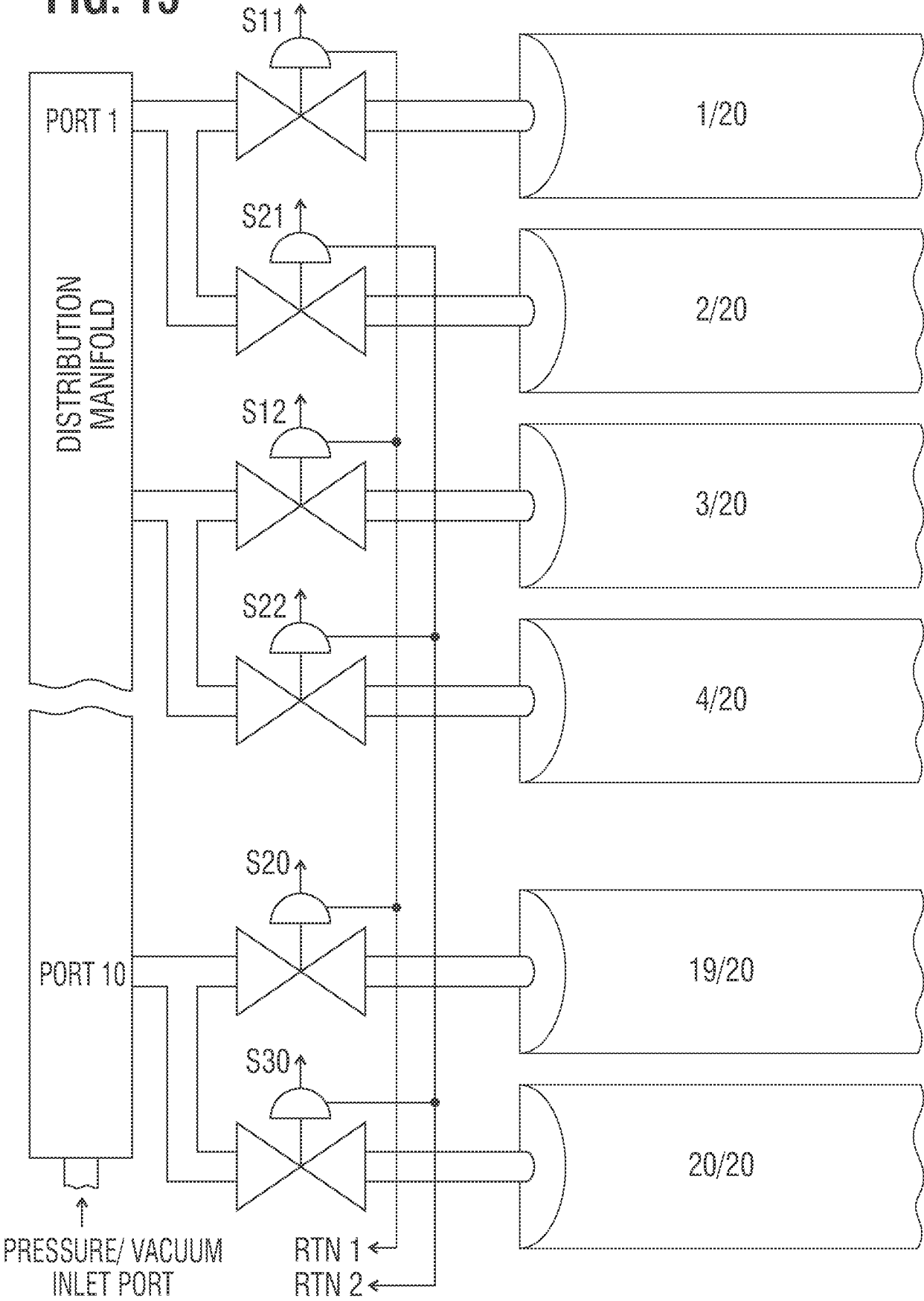


FIG. 15



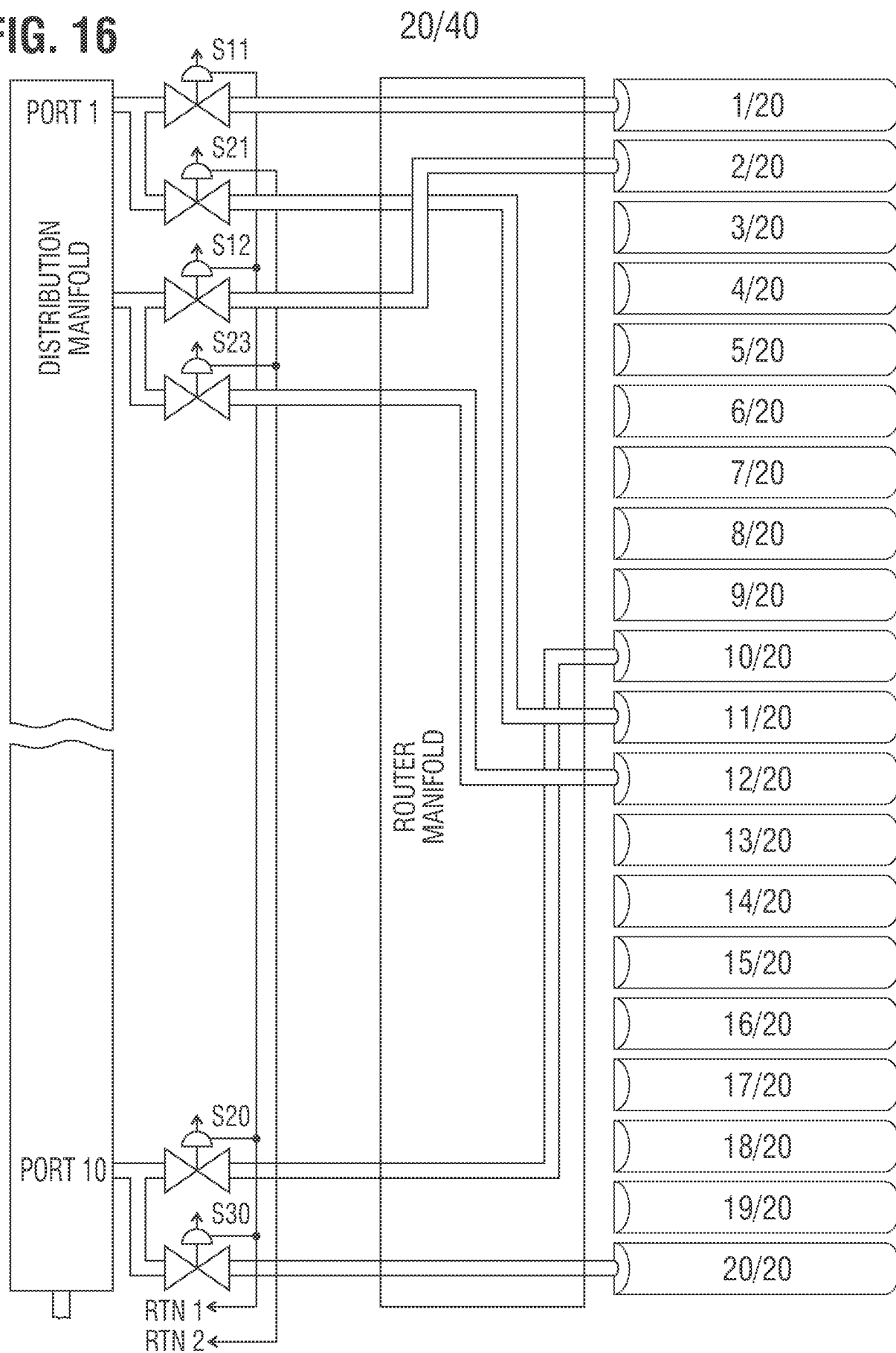
**FIG. 16**

FIG. 17, Part 1 of 2

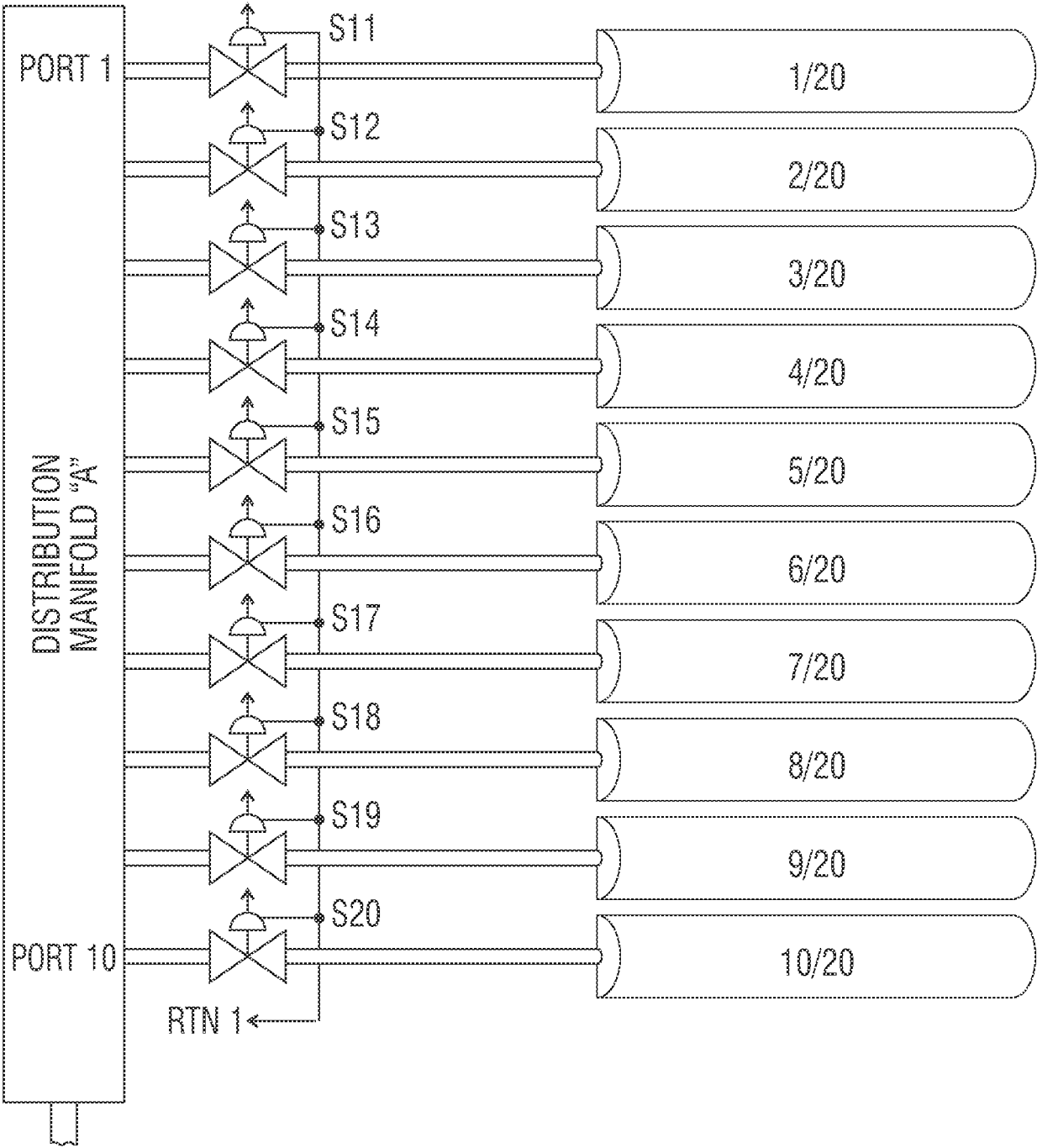


FIG. 17, Part 2 of 2

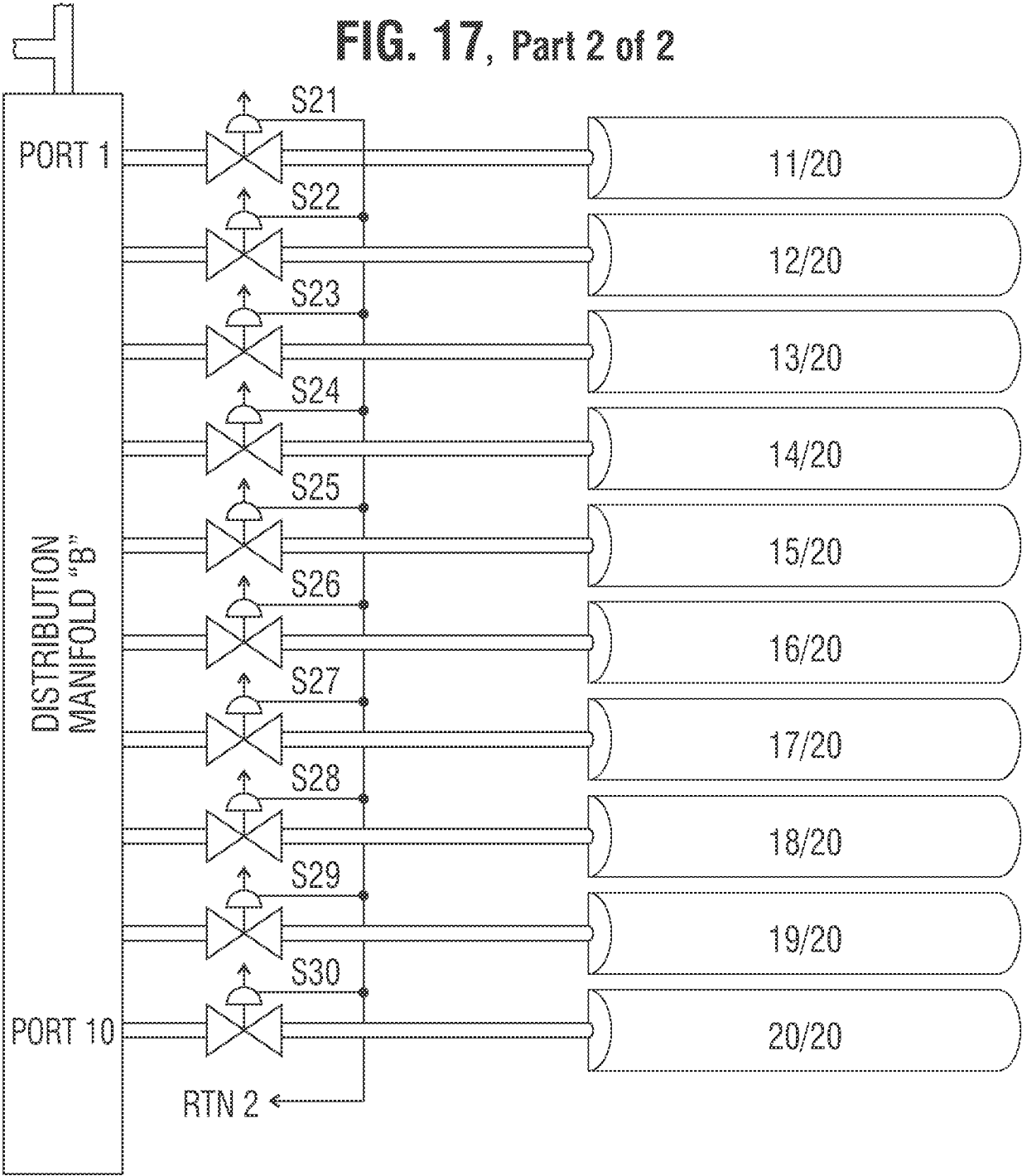


FIG. 18, ACTIVE DEFLATION: RECIRCULATING PUMP (DASHED: VENTING PUMP)

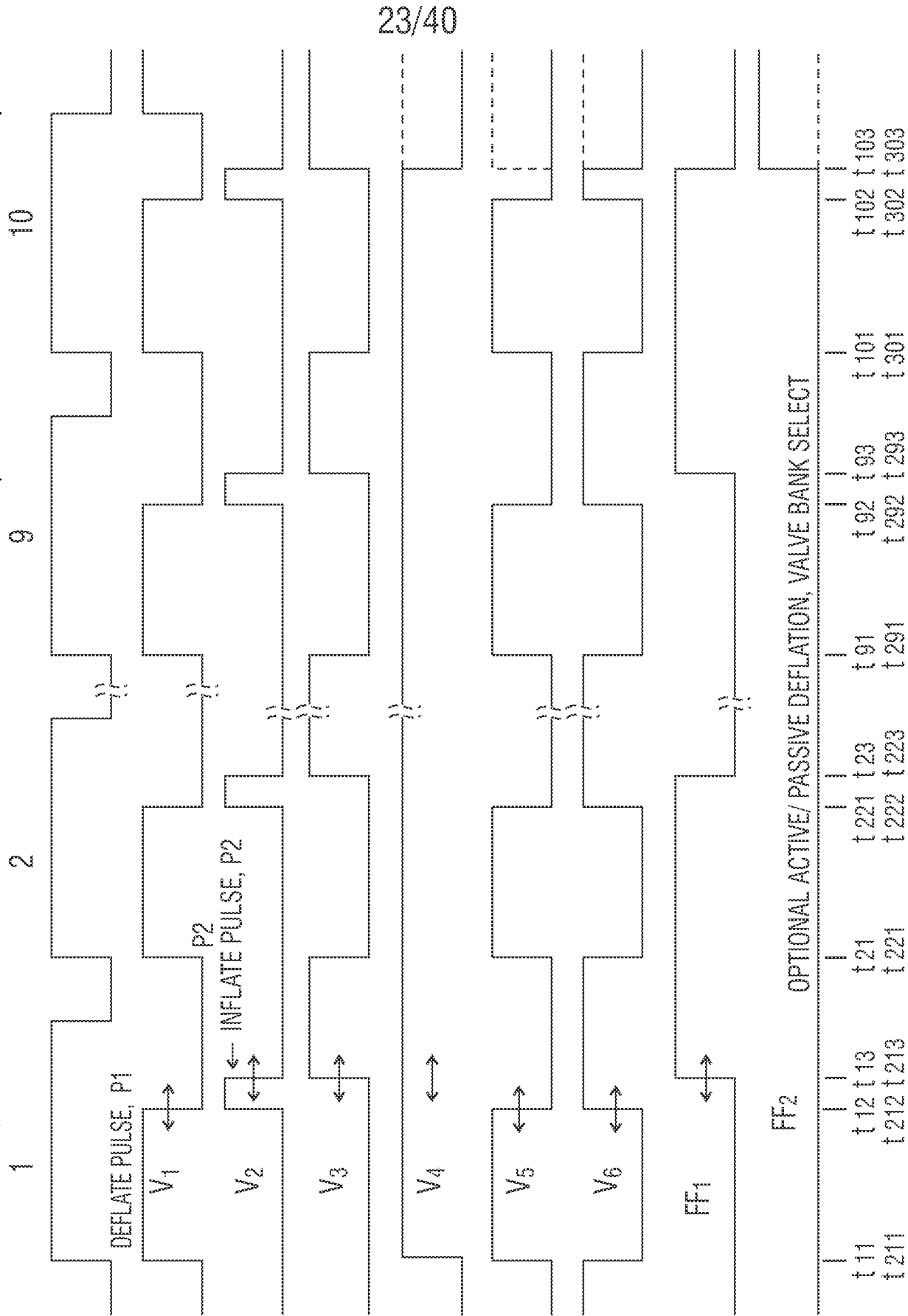
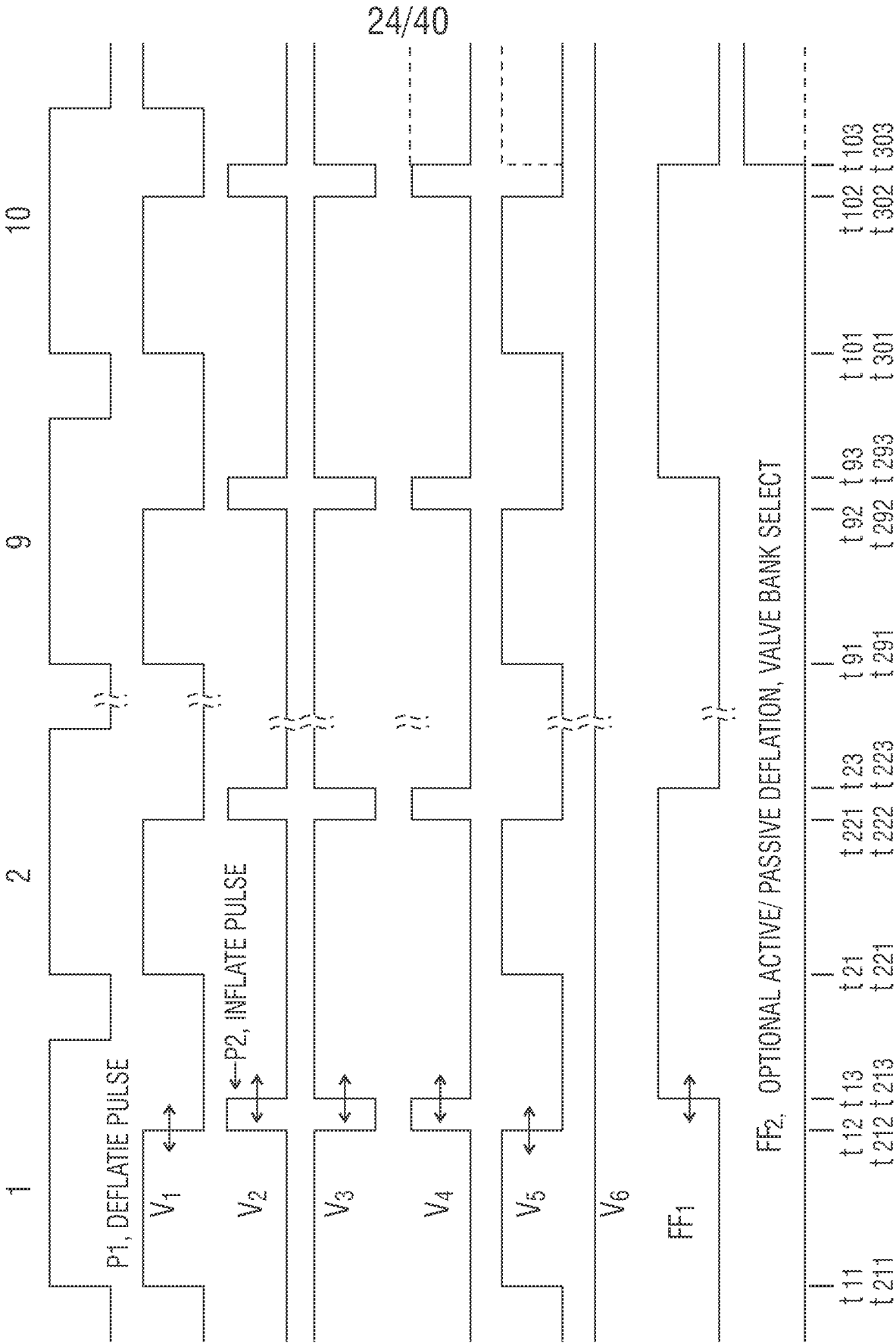
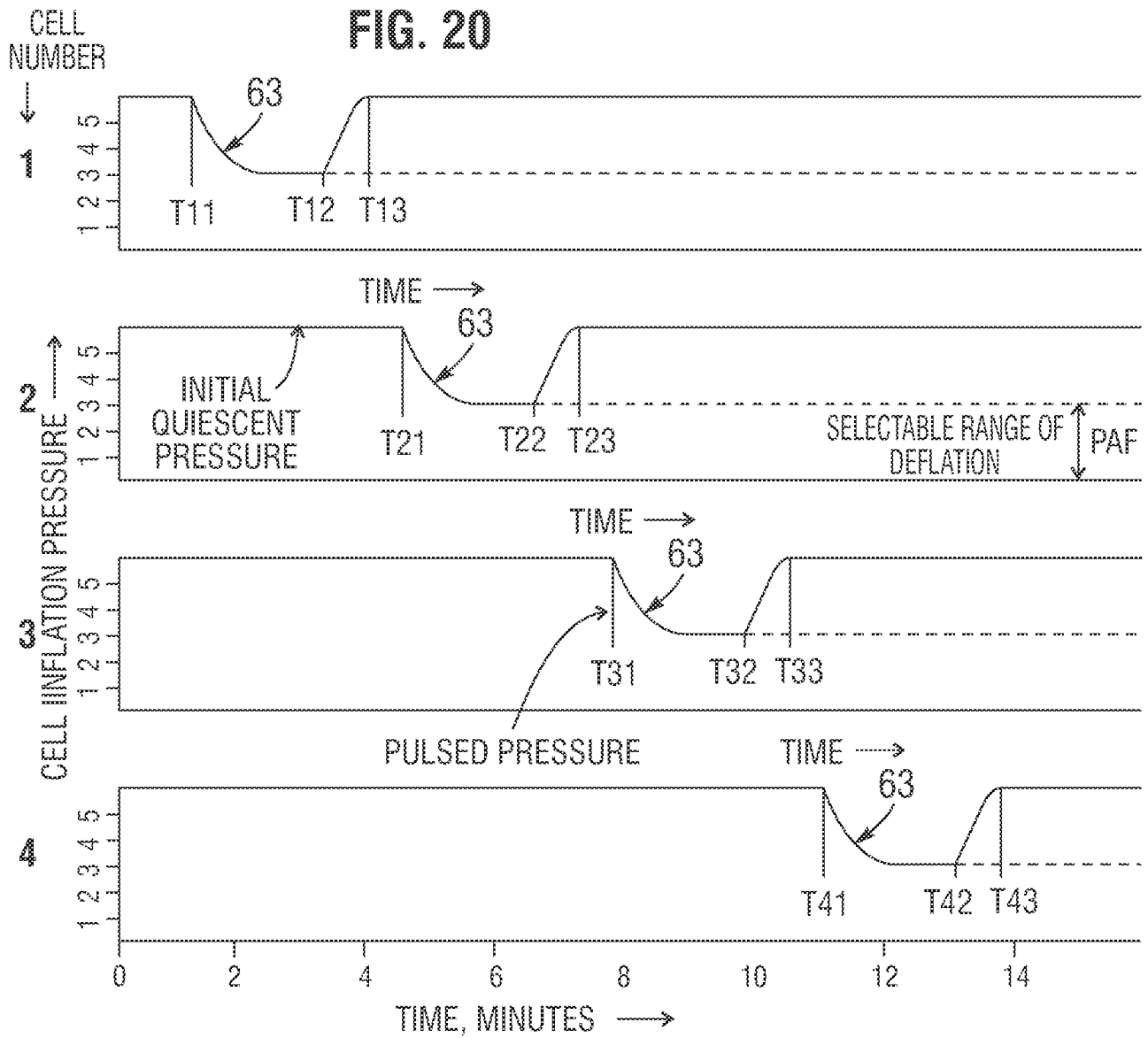


FIG. 19, PASSIVE DEFLATION

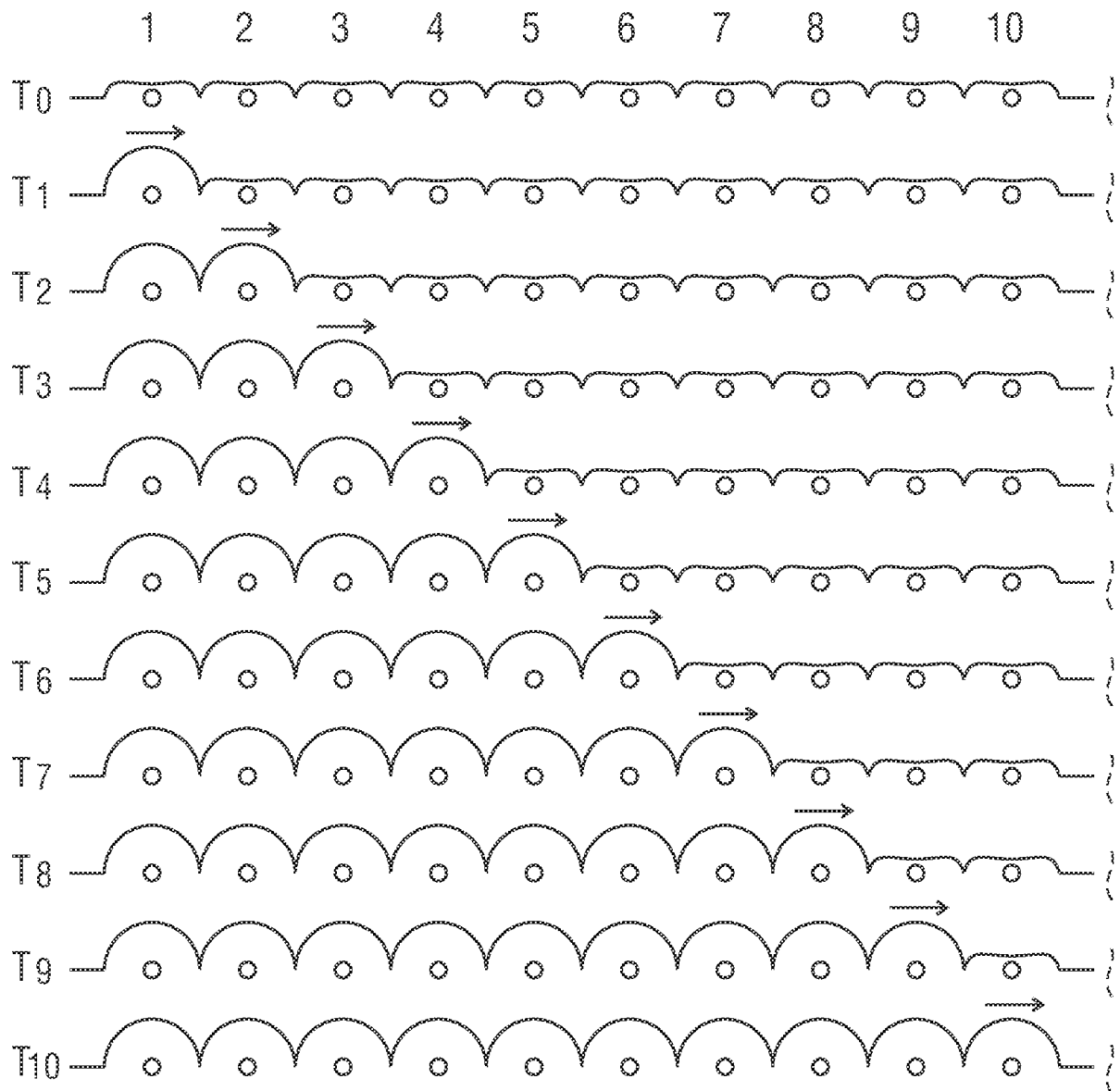


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FIG. 20



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**FIG. 21A**

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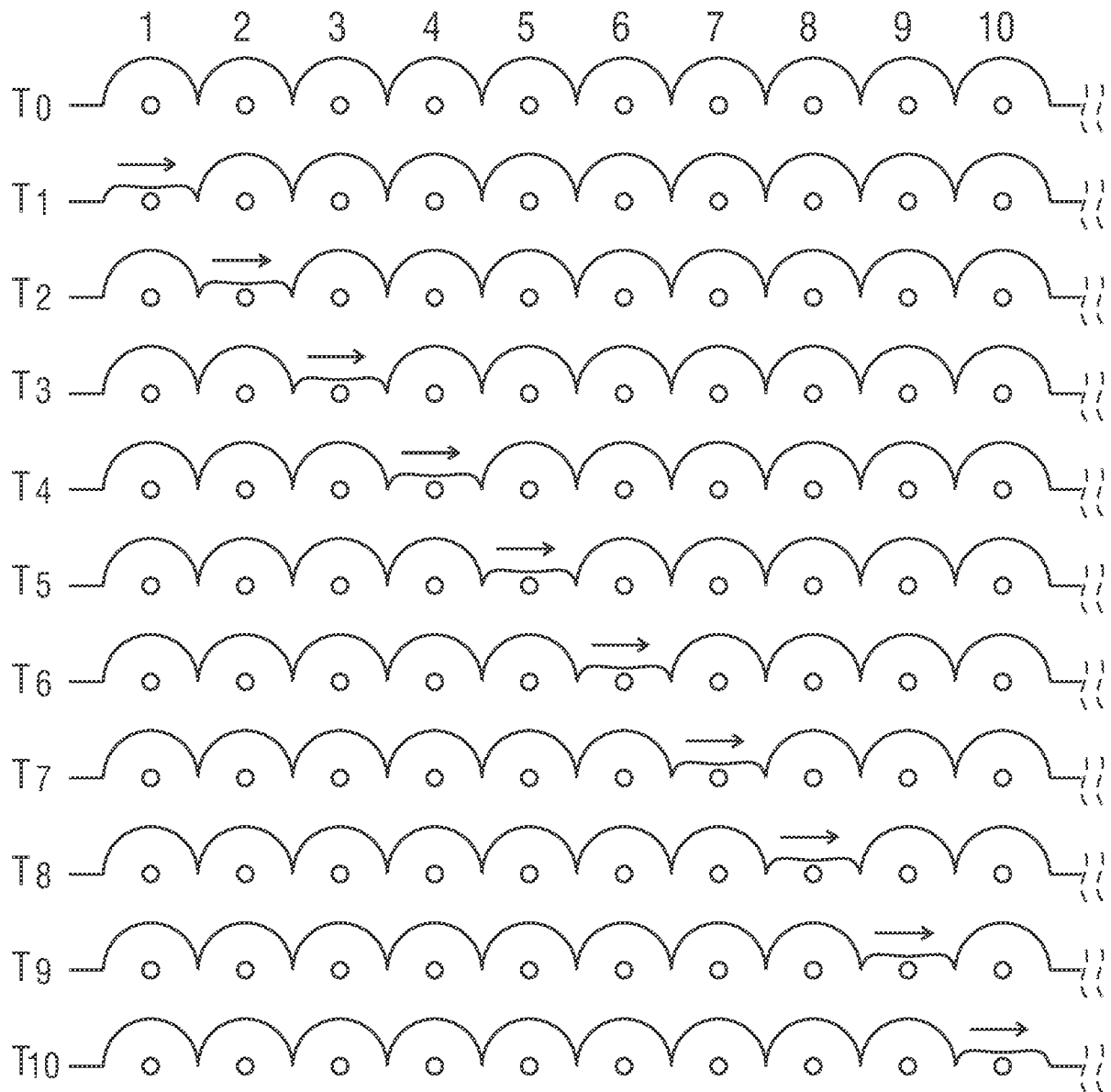
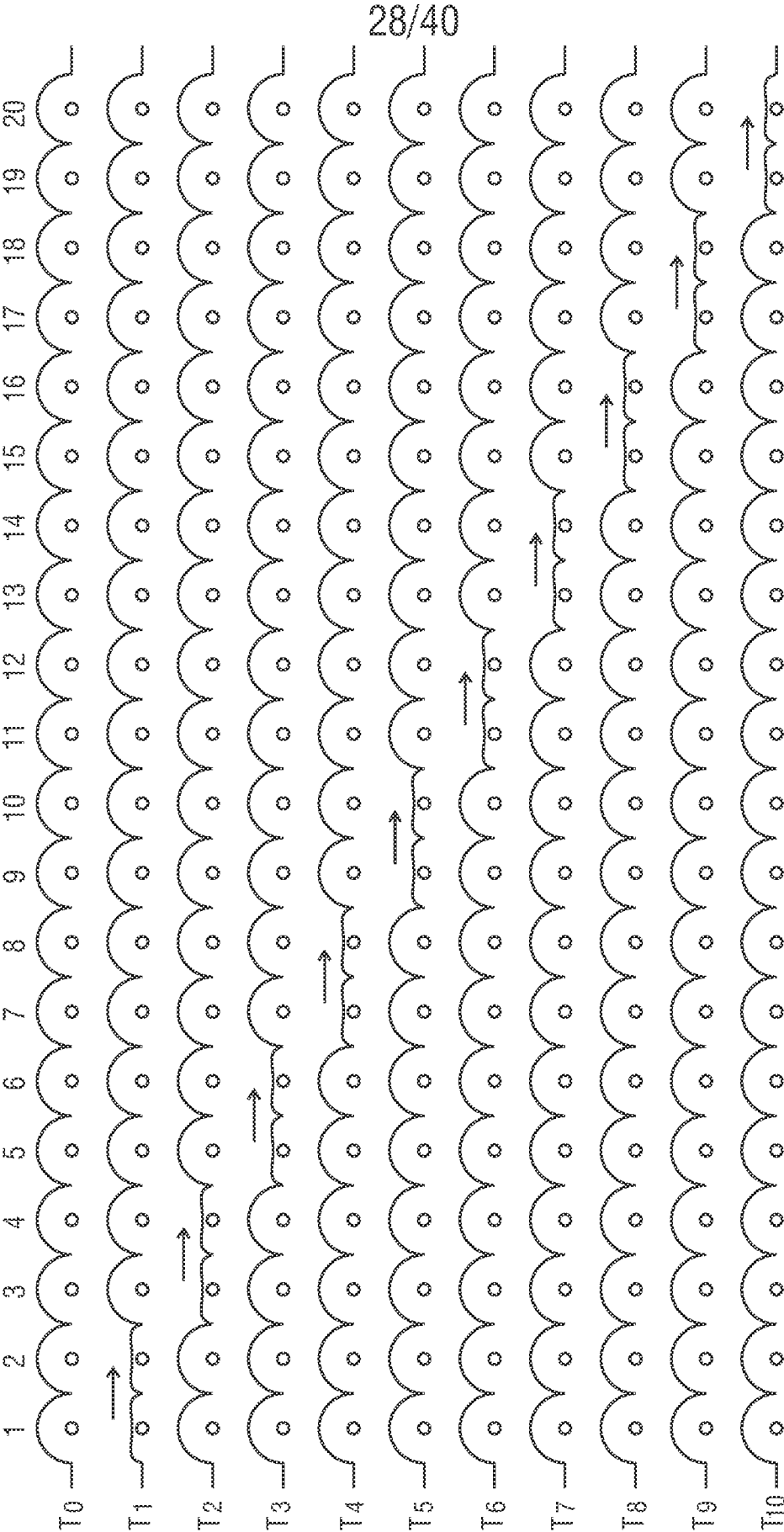
**FIG. 21B**

FIG. 21C



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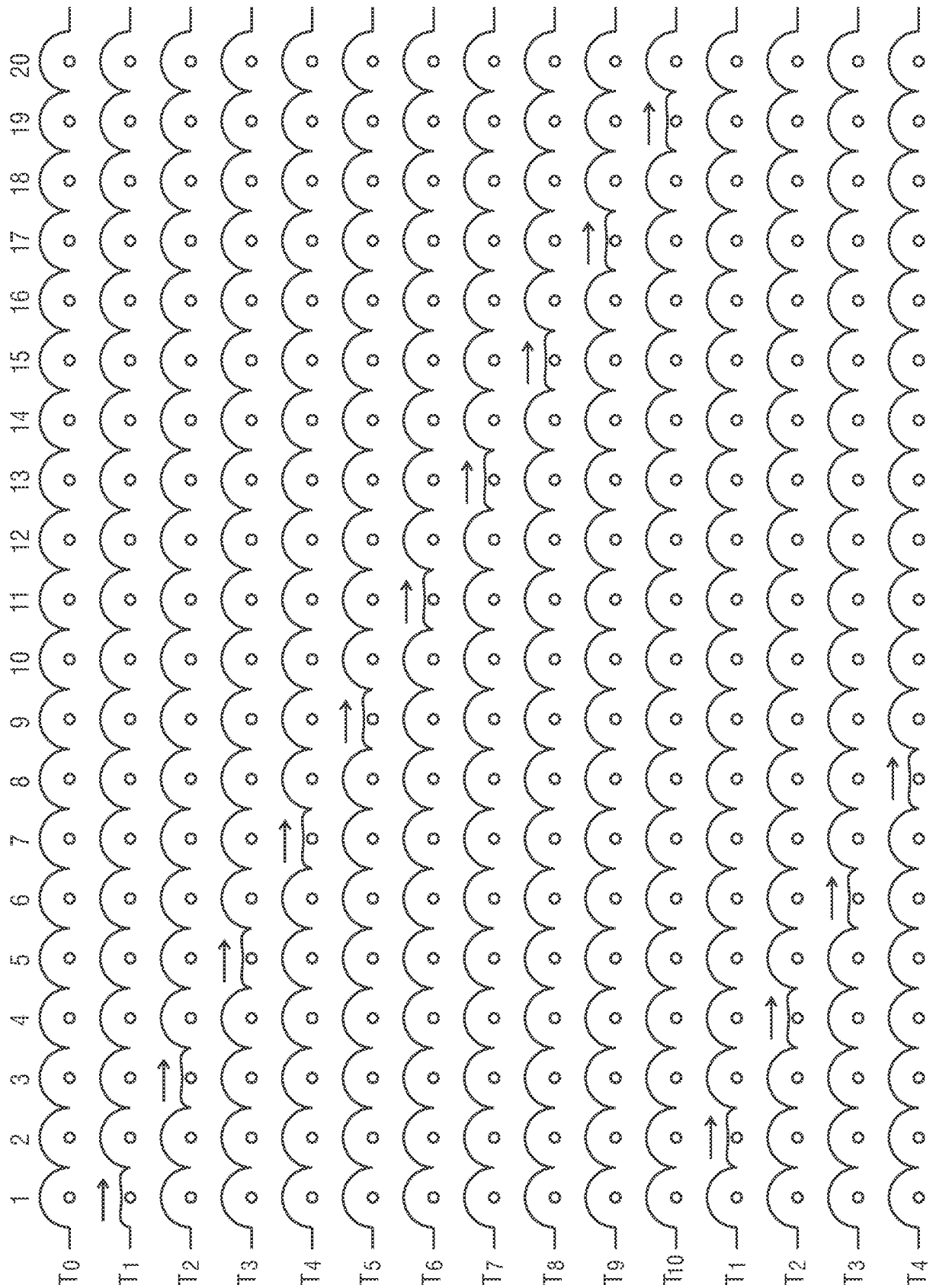


FIG. 21E

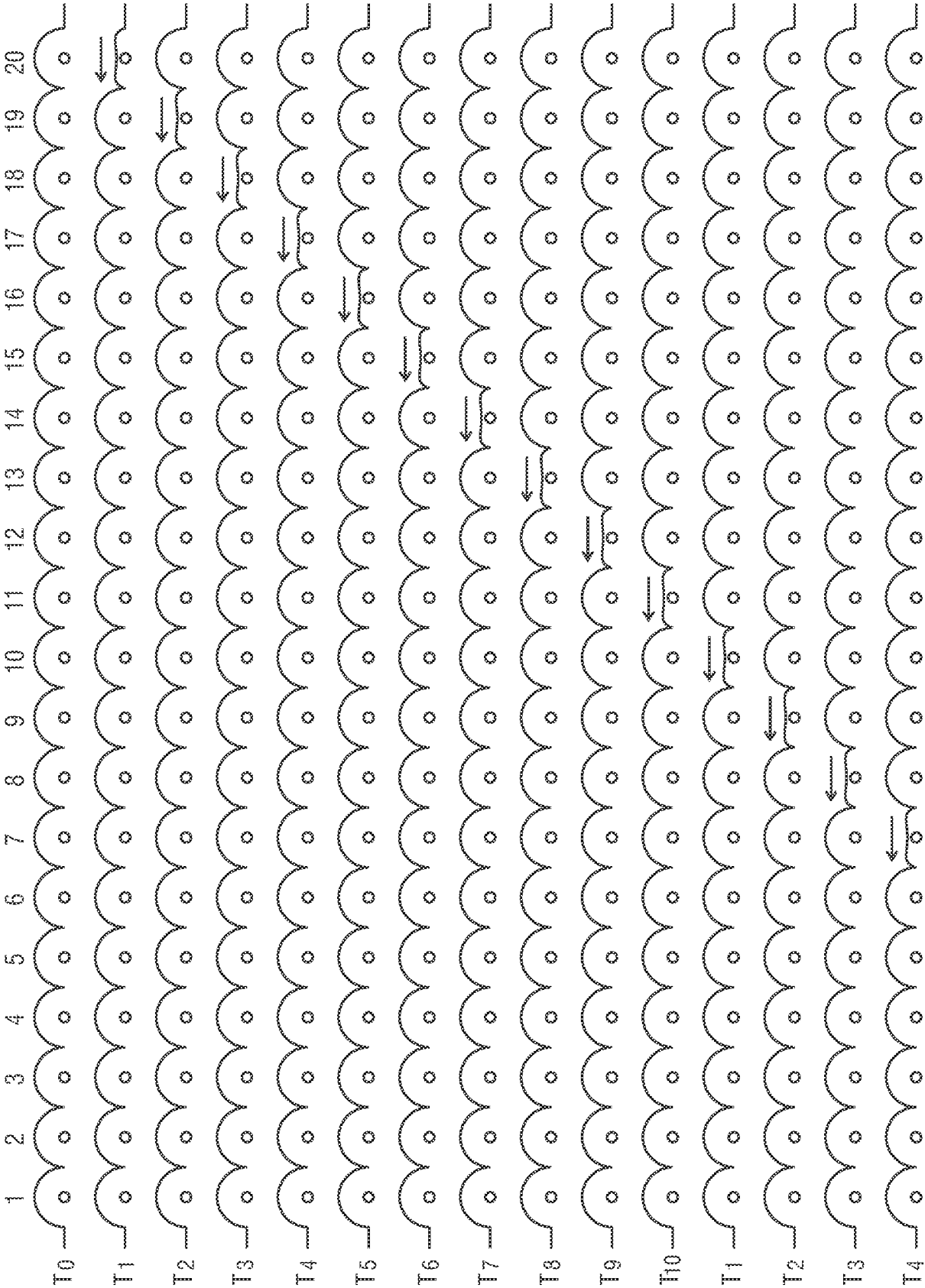
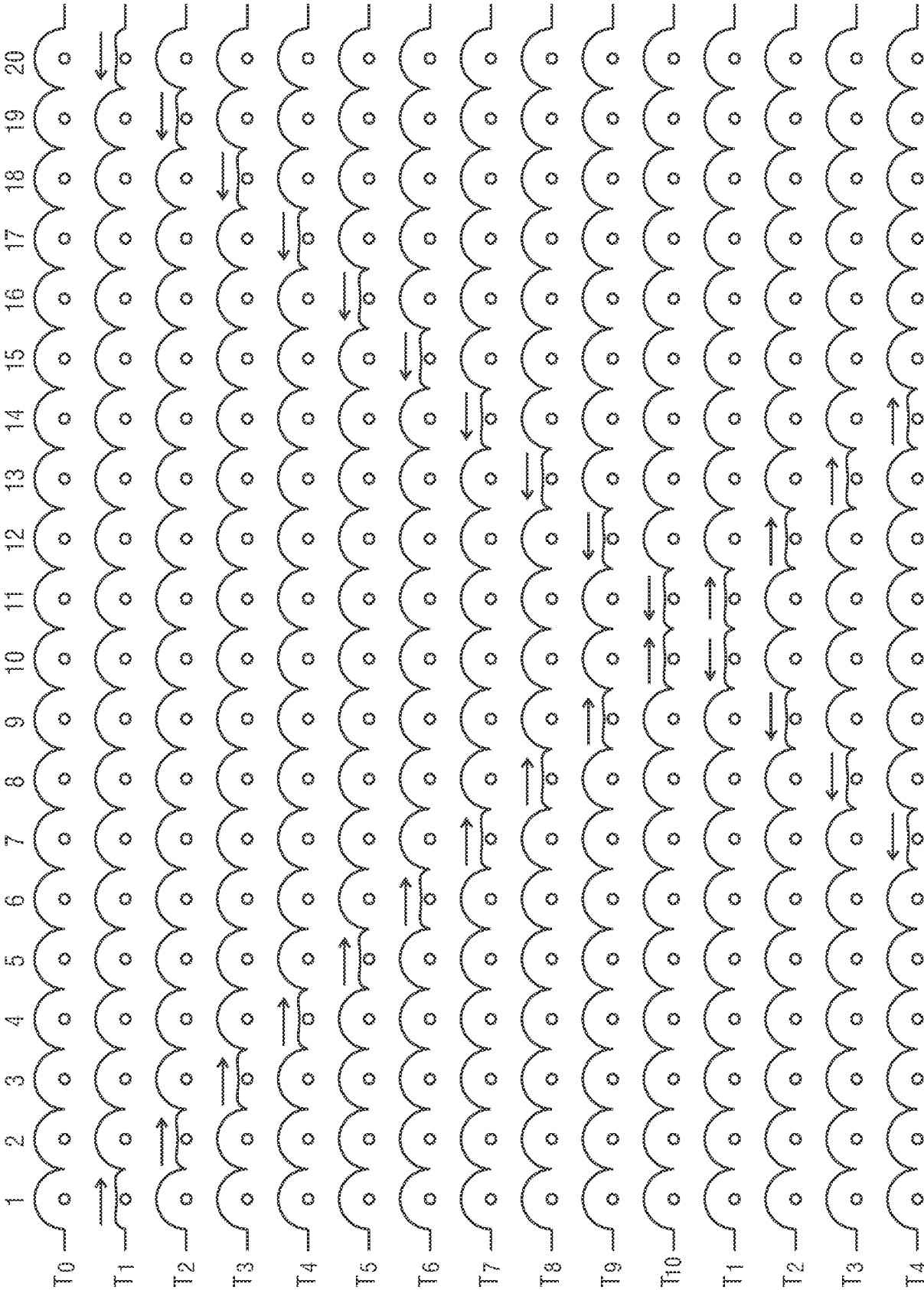
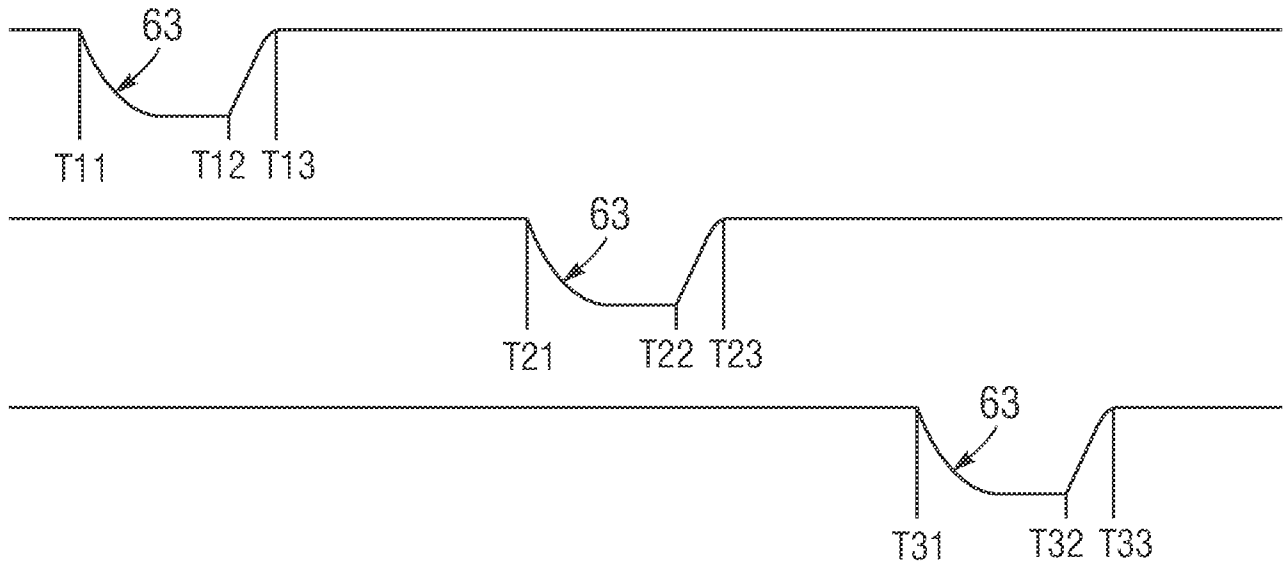


FIG. 21F

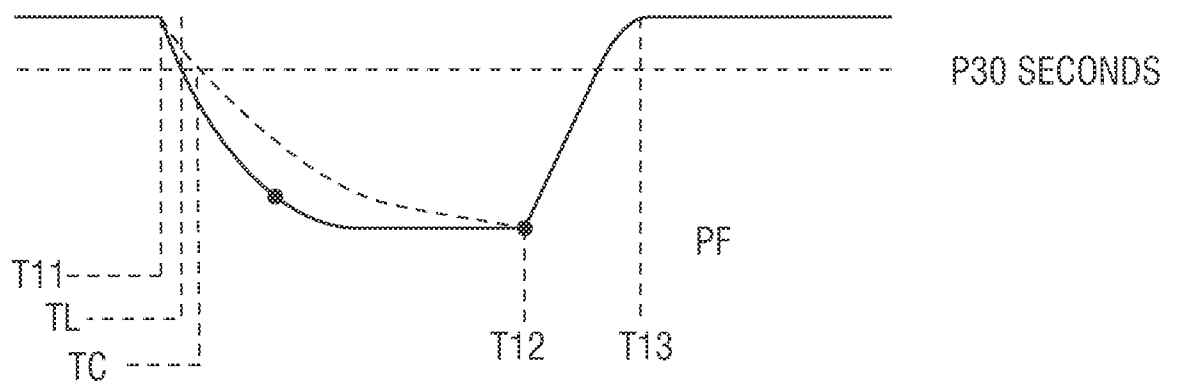


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**FIG. 22**

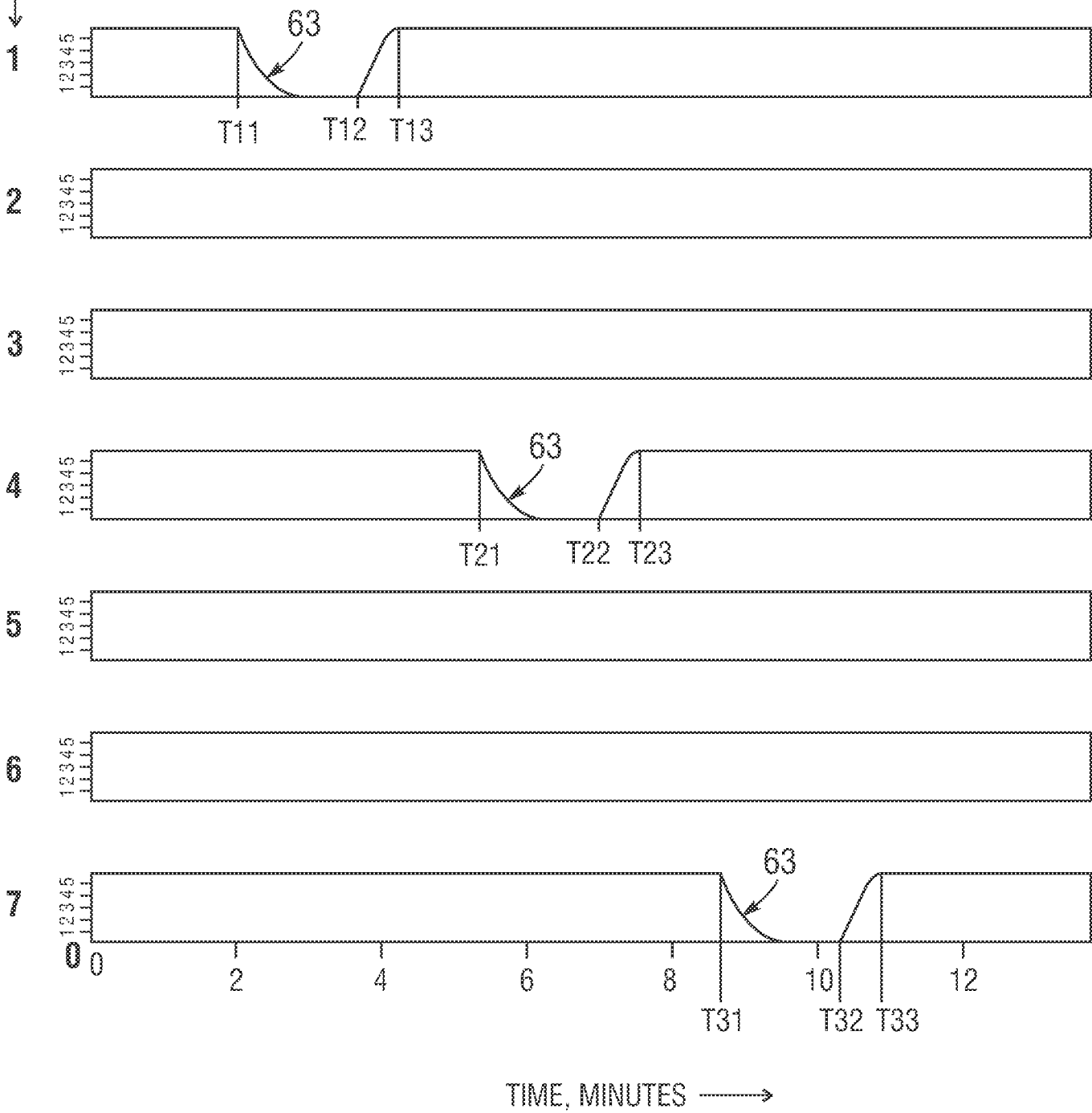


**FIG. 23**



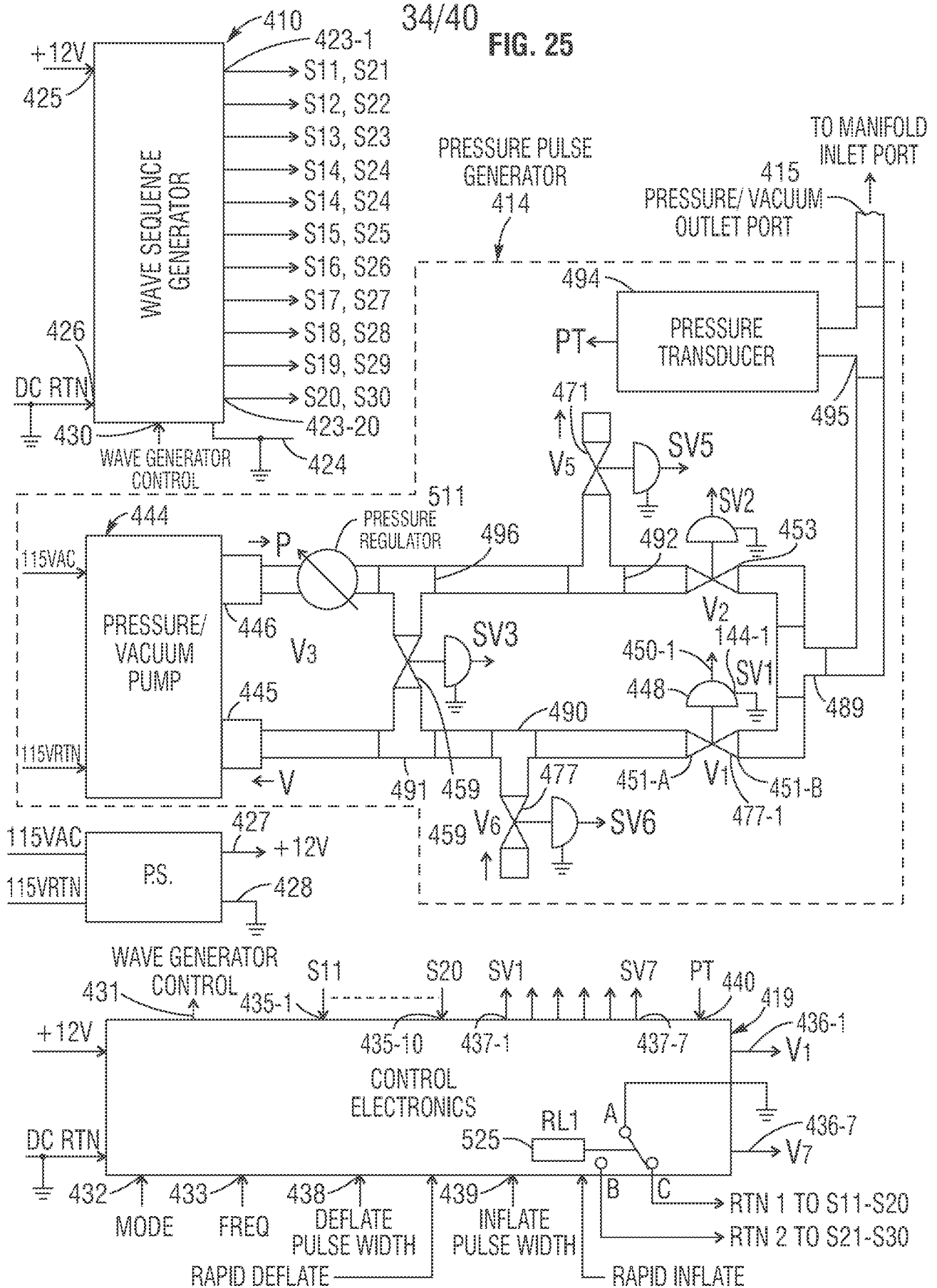
CELL  
NUMBER  
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FIG. 24



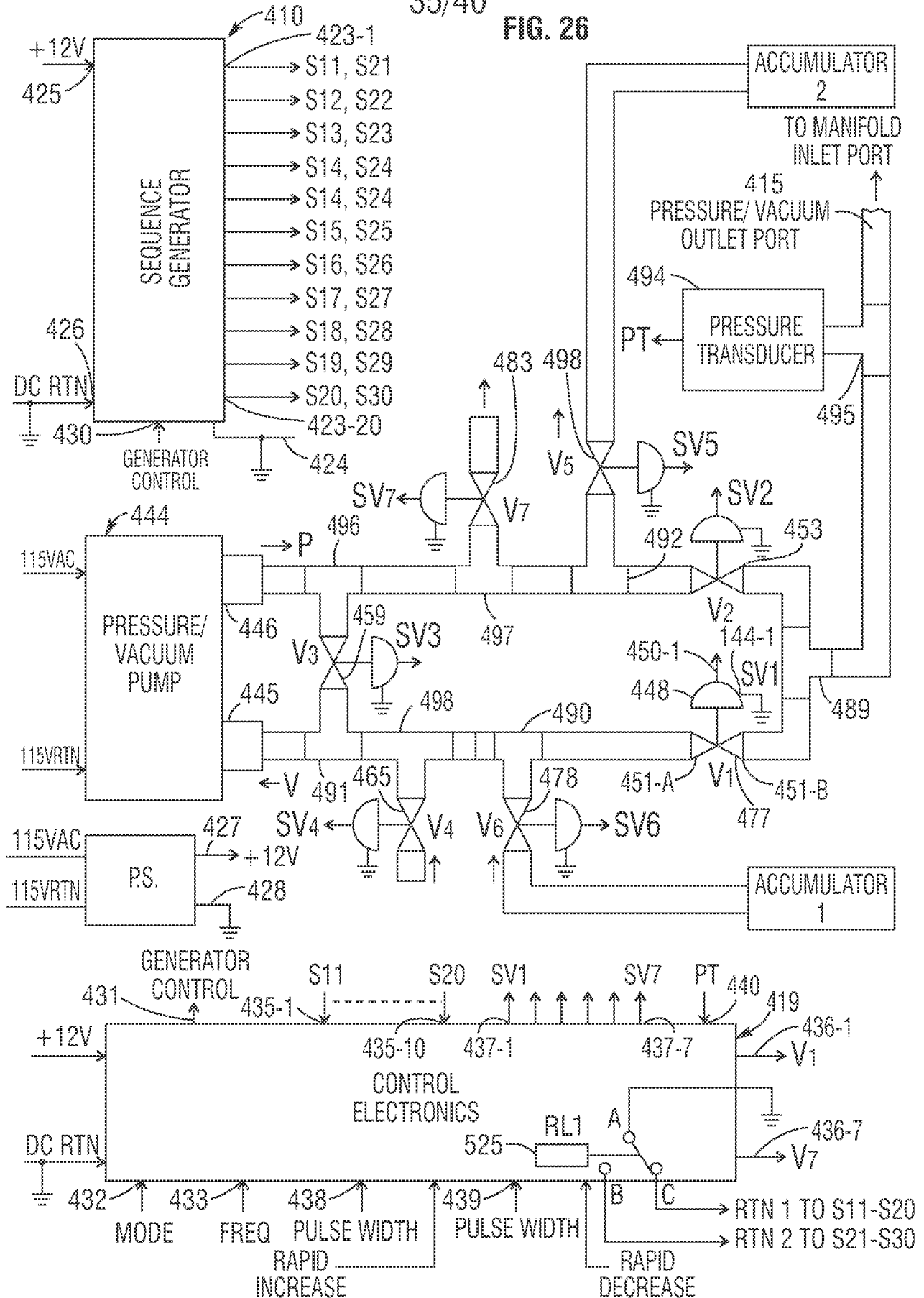
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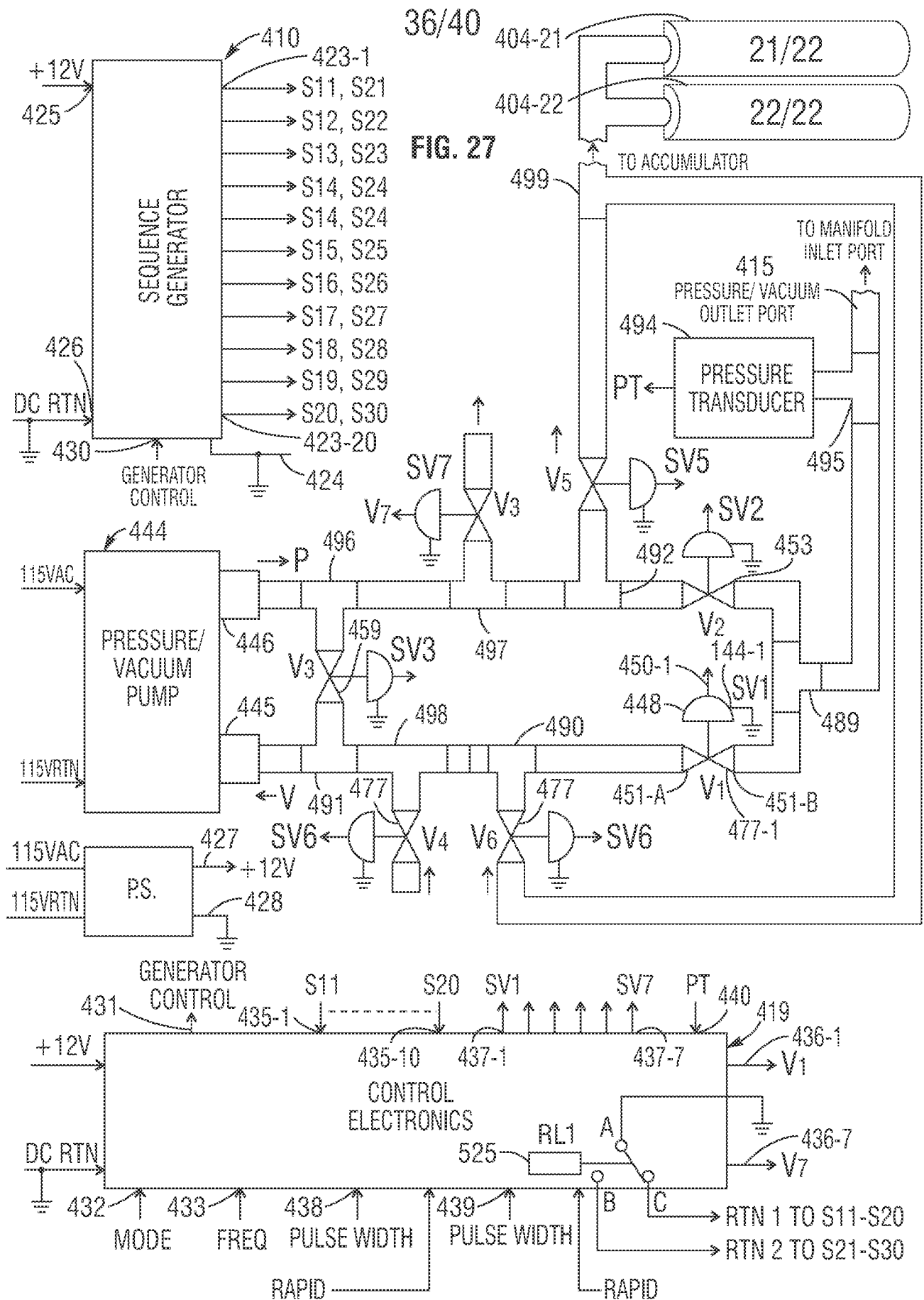
FIG. 25



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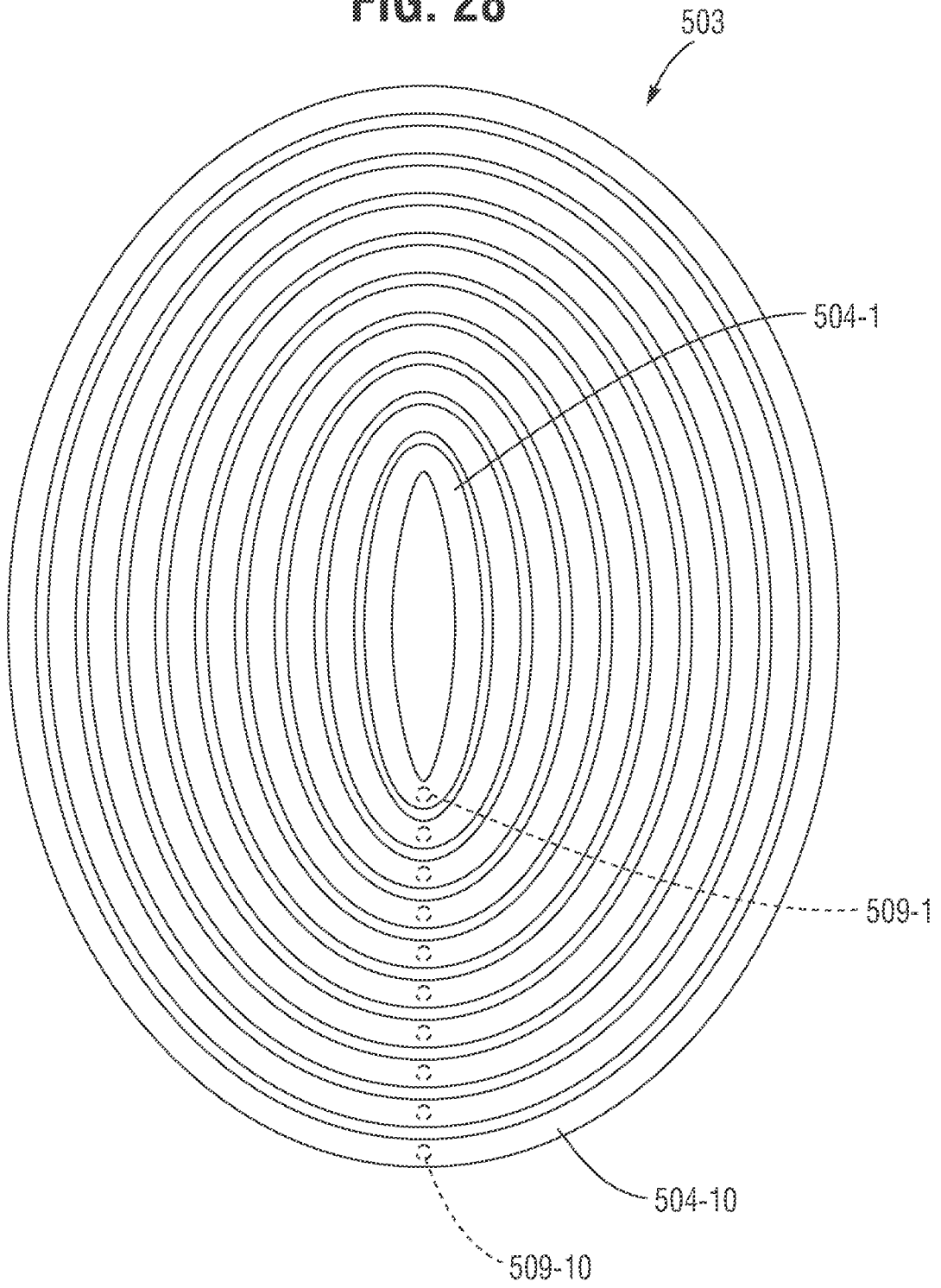
FIG. 26



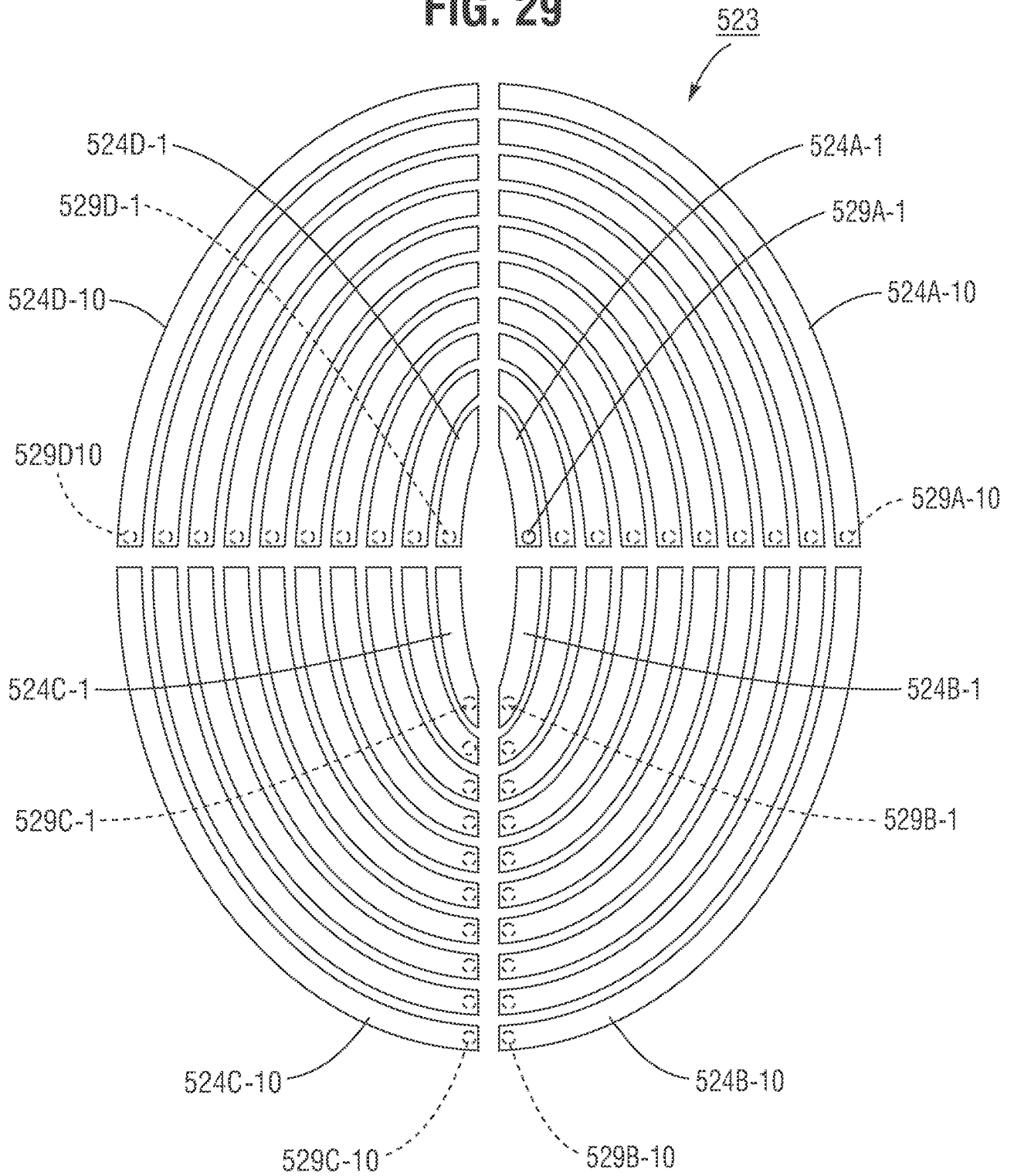


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**FIG. 28**

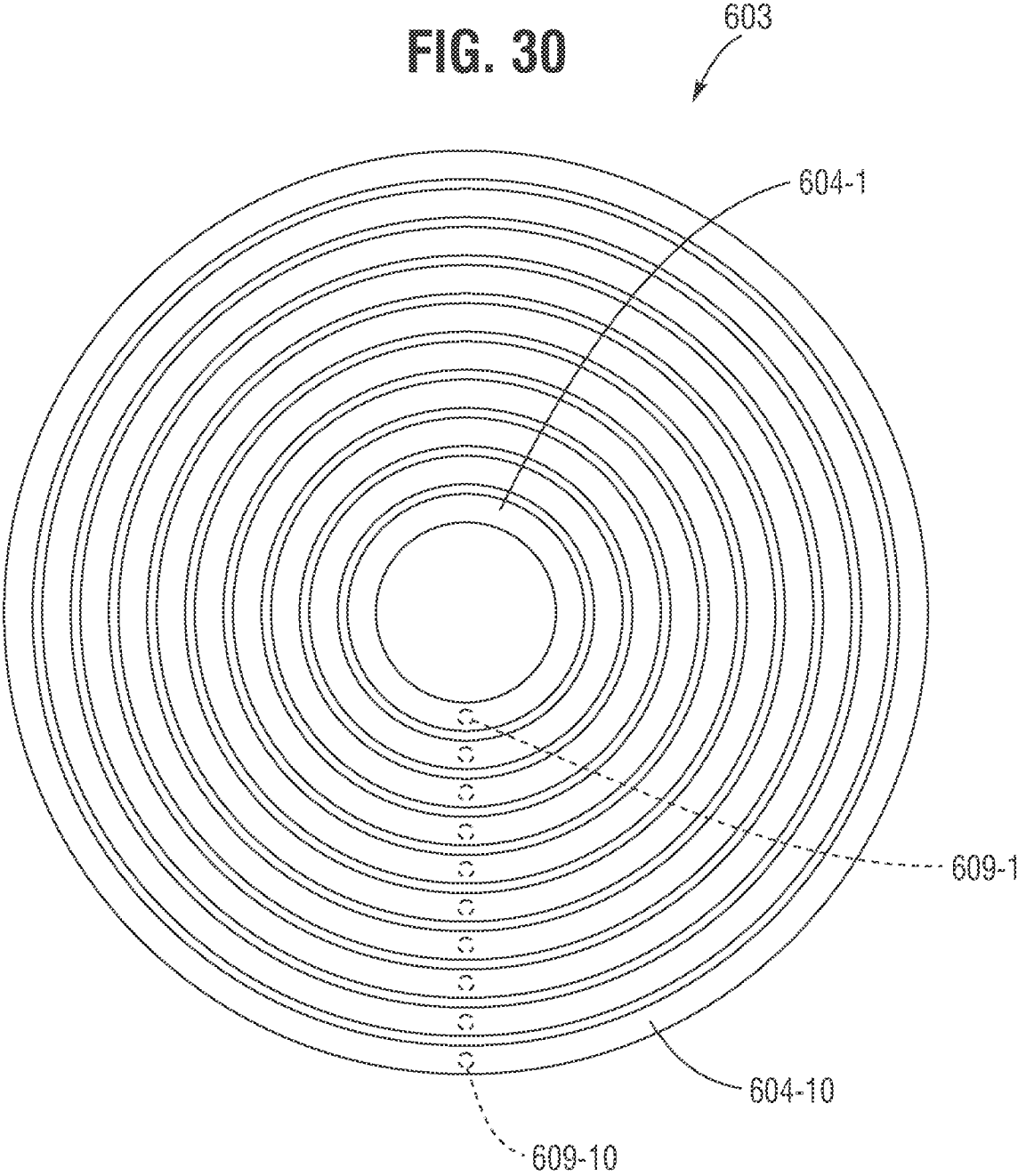


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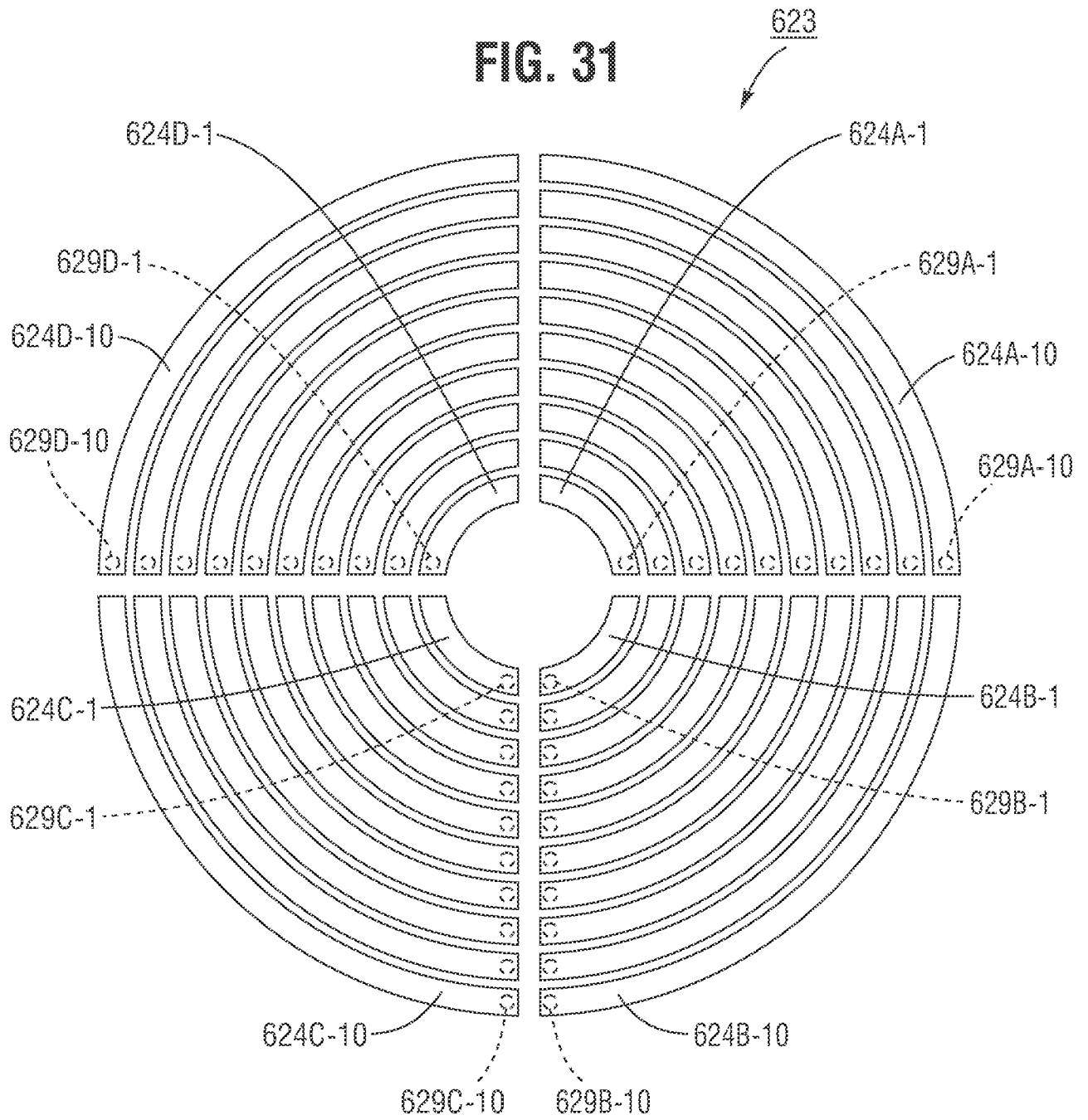
**FIG. 29**

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FIG. 30



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**FIG. 31**

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(8) - A47C 21/10 (2015.01)

CPC - A47C 21/10 (2015.04)

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - A47C 7/02, 17/00, 19/00, 23/00, 27/10 (2015.01)

CPC - A47C 21/00, 21/048, 27/00, 27/08, 27/081, 27/083, 27/10; A61G 7/00, 7/057, 7/05769, 7/0577 (2015.04) (keyword delimited)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
USPC - 5/421, 710, 711, 713

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

PatBase, Google Patent, Google, YouTube

Search terms used: soliton, pulse, packet, traveling wave mattress, wave pressure, control unit, adjust pressure, mattress force gradient, pulsed air wave, pump, deflate, cushion bladder, flexible bladders, series, predefined load, prevention mattress

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                     | Relevant to claim No. |
|-----------|------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y         | WO 2012/172421 A1 (PICARD HEALTHCARE TECHNOLOGY (DONGGUAN) CO LTD et al) 20 December 2012 (20.12.2012) entire document | 65, 66                |
| Y         | US 2013/0031725 A1 (RILEY et al) 07 February 2013 (07.02.2013) entire document                                         | 65, 66                |
| A         | US 4,982,466 A (HIGGINS et al) 08 January 1991 (09.01.1991) entire document                                            | 1-67                  |
| A         | US 5,267,364 A (VOLK) 07 December 1993 (07.12.1993) entire document                                                    | 1-67                  |
| A         | US 6,711,711 B2 (COOK et al) 30 March 2004 (30.03.2004) entire document                                                | 1-67                  |
| A,T       | US 2014/02236645 A1 (CHAPIN) 14 August 2014 (14.08.2014) entire document                                               | 1-67                  |

☐ Further documents are listed in the continuation of Box C.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search

15 April 2015

Date of mailing of the international search report

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