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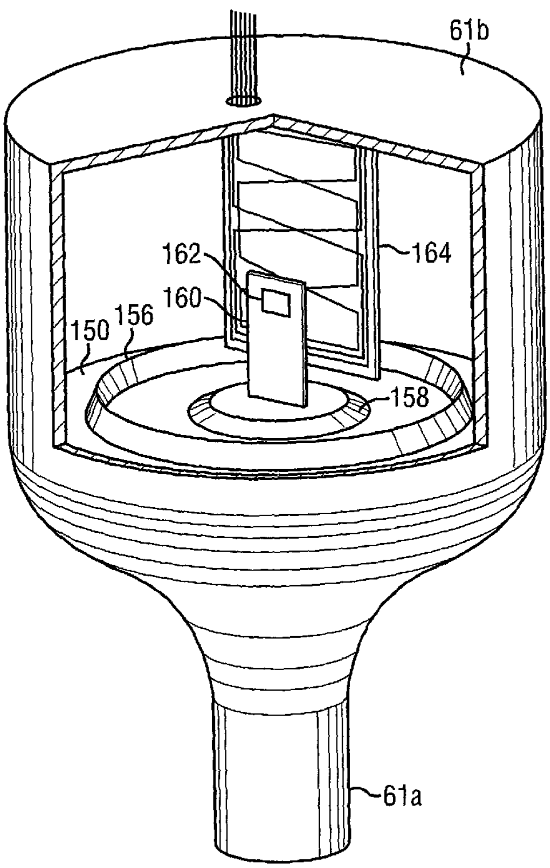
(54) Title: SENSING APPARATUS AND METHOD



(57) Abstract: There is described a number of sensors which can be incorporated within a washing machine or the like to enable greater controllability. In particular, there is described a pressure sensor which uses an inductive sensor to measure the displacement of a moveable wall of an enclosure that can form part of a water level sensor within a washing machine, There is also described a connector having two relatively moveable parts and inductive sensor, including a resonant circuit which electromagnetically couples an excitation winding and a sensor winding, for detecting the relative position of the two moveable parts. There are also described a number of LVDT type sensors in which a magnetically permeable body moves through an aperture defined by a planar substrate, and the planar substrate has formed thereon plural planar coils which spiral around the aperture and are spaced at intervals along the thickness of the planar substrate.

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SENSING APPARATUS AND METHOD

This invention relates to sensing apparatuses and methods which have particular, but not exclusive, application to washing machines.

A typical washing machine includes many sensors which are used to determine control parameters for a wash cycle. For example, a washing machine includes a user interface, which usually includes multiple sensors or switches, via which a user identifies a desired wash cycle. In addition, some washing machines include a sensor which determines the amount of water in the washing machine.

A general problem with washing machines is that a large amount of energy is required to perform a wash cycle. It has been recognised that if only a small number of articles are to be washed, the energy used can be reduced by reducing the amount of water used during a wash cycle. In existing washing machines, this has been implemented by including a "half load" switch on the user interface of the washing machine so that the user can indicate when a small load is to be washed.

Another problem with washing machines is that the weight of clothes loaded within a washing machine is not necessarily evenly distributed, which can lead to excessive vibrations at high spin speeds. These excessive vibrations can cause damage to the washing machine.

An aim of the present invention is to provide sensors which can be incorporated within a washing machine or the like to improve the control of a treatment process.

According to a first aspect of the invention, there is provided a sensor comprising an enclosure which defines a cavity, the enclosure having a deformable wall which deforms by an amount dependent upon the pressure of fluid within the cavity, and an inductive sensor for sensing the amount of deformation of the deformable wall in order to determine a value representative of the pressure of fluid in the cavity. Using an inductive sensor is advantageous because, compared to other types of sensor with comparable accuracy, inductive sensors are relatively cheap. Further, inductive sensors allow non-contact measurement of the deformation of the deformable wall.

In an embodiment, the sensor is incorporated in a washing machine with the cavity of the sensor communicating with a liquid container within the washing machine so that, when liquid enters the liquid container, gas is trapped within the cavity at a pressure which is dependent upon the amount of liquid in the container. In this way, the sensor provides a value representative of the amount of liquid within the liquid container allowing accurate control of the amount of water used during a wash cycle.

According to a second aspect of the invention, there is provided a connector having: a first part for connection with a first body; a second part for connection with a second body, wherein the second part is mounted to the first part to allow relative movement between the first and second parts along a measurement direction; and a detector comprising a resonant circuit, having an associated resonant frequency, fixed relative to the first part, at least one excitation winding fixed relative to the second part and at least one sensor winding electromagnetically coupled to the at least one excitation winding via the resonant circuit, the electromagnetic coupling between the at least one excitation winding and the at least one sensor winding varying in dependence upon the relative position of the first and second parts. By using a resonant circuit, the signal induced in the sensor winding when a signal substantially at the resonant frequency is applied to the excitation winding is increased.

According to a third aspect of the invention, there is provided a connector having: a first part for connection with a first body; a second part for connection with a second body, wherein the second part is mounted to the first part to allow relative movement between the first and second parts along a measurement direction; and a detector comprising a magnetically permeable body mounted to the first part and a planar substrate mounted to the second part, the planar substrate defining an aperture through which the magnetically permeable body passes, wherein an excitation winding and a sensor winding are provided on the planar substrate so that when an oscillating electric signal is applied to the excitation winding, an electric signal is induced in the sensor winding which varies in accordance with the relative positions of the first and second parts. The use of a planar substrate is advantageous because it reduces the production costs.

Preferably, the connector of the second or third aspects of the invention forms part of a suspension system for a washing machine so that the relative displacement between the first and second parts forms a measure of the weight of articles in the drum of the washing machine. Further, during a wash cycle the relative movement between the first and second parts can be measured to monitor the vibration of the drum of the washing machine.

According to a fourth aspect of the invention, there is provided a material treatment apparatus having a hollow container rotatably mounted to a support frame for rotation about an axis, a sensor element mounted at one axial end of the hollow container and an inductive sensor for sensing the position of the sensor element. As mentioned above, an inductive sensor is relatively cheap and accurate and also allows non-contact position measurement to be performed.

According to a fifth aspect of the invention, there is provided an apparatus comprising a main assembly and a subsidiary component detachably mountable to the main assembly, wherein the main assembly is operable to identify and cooperate with the subsidiary component when the subsidiary component is mounted to the main assembly. The subsidiary component comprises a storage compartment for storing material to be processed using the main assembly and an identifier having at least one resonant circuit defining identification data identifying a property of the subsidiary component or a property of the material stored in the storage compartment of the subsidiary component. The main assembly comprises a reader operable to determine the identification data of the identifier of the subsidiary component and a controller operable to control the main assembly in dependence upon the identification data determined by the reader.

The identification data may identify how the main assembly should process the material stored in the storage compartment of the subsidiary component. Alternatively, the identification value may verify that the subsidiary component has been manufactured by an approved manufacturer, thereby reducing the likelihood of damage to the main assembly caused by sub-standard subsidiary components.

In an embodiment, the apparatus is a washing machine and the subsidiary component is a basket which can be inserted within the washing machine to perform a wash cycle. In this way, a plurality of detachable baskets can be used as laundry baskets, each laundry basket storing articles for a different wash cycle, and when a detachable basket is inserted into the washing machine, the appropriate wash cycle is automatically selected using the identification data of the inserted baskets.

In another embodiment, the apparatus is an ink jet printer and the subsidiary component is an ink cartridge with the identification data identifying the type of ink stored in the ink cartridge. In this way, the printer is able to detect the type of ink stored in the ink cartridge and adjust its operation accordingly.

In an embodiment, both the resonant frequency and the position of the or each resonant circuit is measured to generate identification data identifying the wash associated with the detachable drum.

Various embodiments of the invention will now be described with reference to the attached figures in which:

Figure 1 shows a perspective view of a washing machine;

Figure 2 schematically shows the main internal components of the washing machine illustrated in Figure 1;

Figure 3 is a schematic block diagram showing the main components of the electrical circuitry within the washing machine illustrated in Figure 1;

Figure 4 is a schematic block diagram of a control unit illustrated in Figure 3;

Figure 5 is a schematic block diagram showing functional components of a microprocessor unit illustrated in Figure 4 together with databases stored in a read-only memory illustrated in Figure 4;

Figure 6A schematically shows a side cross-sectional view of a head portion of a water level sensor illustrated in Figure 2;

Figure 6B schematically shows a plan view of the head portion of the water level sensor illustrated in Figure 2;

Figure 6C schematically shows a perspective view of the head portion of the water level sensor shown in Figure 2 with part of a housing of the head portion cut away;

Figure 7 is a schematic block diagram showing the main components of the water level sensor illustrated in Figures 6A ro 6C;

Figure 8A is a timing diagram showing a signal applied a cosine coil of the water level sensor illustrated in Figures 6A to 6C;

Figure 8B is a timing diagram showing a first signal applied to a sine coil of the water level sensor illustrated in Figures 6A to 6C;

Figure 8C is timing diagram showing a second signal applied to the sine coil of the water level sensor illustrated in Figures 6A to 6C:

Figures 9A to 9C are timing diagrams showing signals induced in a sense coil when the signal illustrated in Figure 8A is applied to the cosine coil and the signal illustrated in Figure 8B is applied to the sine coil for three different positions of the sensor element;

Figures 10A to 10C are timing diagrams showing signals induced in the sense coil when the signal illustrated in Figure 8A is applied to the cosine coil and the signal illustrated in Figure 8C is applied to the sine coil for three different positions of the sensor element;

Figure 11 is a block diagram showing in more detail the processing circuitry of the water level sensor of the washing machine illustrated in Figures 1 and 2;

Figure 12 is a timing diagram showing pulses received at a microprocessor forming part of the processing circuitry illustrated in Figure 11;

Figure 13 schematically shows the main components of a damper which forms part of the washing machine illustrated in Figures 1 and 2;

Figures 14A to 14C show graphical interface panels which form part of a user interface illustrated in Figure 1;

Figure 14D shows a fascia plate which forms part of the user interface illustrated in Figure 1;

Figure 14E schematically shows the lay-out of a printed circuit board which forms part of the user interface of the washing machine illustrated in Figure 1;

Figures 15A to 15E are schematic plan views of coils within a sensing region of the printed circuit board illustrated in Figure 14E;

Figure 15F schematically shows an identification ID puck comprising a plurality of individual resonant circuits having a predetermined position in relationship to one another;

Figure 16 schematically shows a side view of a head portion for a water level sensor of a first alternative washing machine;

Figure 17 is a schematic plan view of a printed circuit board which forms part of the head portion illustrated in Figure 16;

Figure 18 schematically shows the main electrical components of the water level sensor for the first alternative washing machine;

Figure 19 schematically shows a side view of a damper of a second alternative washing machine;

Figure 20 schematically shows a plan view of a printed circuit board which forms part of the damper illustrated in Figure 19;

Figure 21 schematically shows the main components of a drum movement sensor of a third alternative washing machine;

Figure 22 schematically shows the main components of a drum movement sensor of a fourth alternative washing machine;

Figure 23 schematically shows components of a fifth alternative washing machine having a removable drum portion;

Figure 24 schematically shows identification elements formed on a rim portion of the removable drum, and a sensor formed on the main body, of the fifth alternative washing machine illustrated in Figure 23;

Figures 25A and 25B schematically show components of an inductive position sensor using two printed circuit boards; and

Figure 26 schematically shows a push button in which a magnetically permeable element passes through the plane of a printed circuit board which has an inductive sensor formed thereon.

FIRST EMBODIMENT

System Overview

Figure 1 shows a schematic view of the outside of a washing machine 1 which forms a first embodiment of the invention. As shown, the washing machine has a main body 10 including a drum door 12, having a handle 12a, which opens to allow access to a drum 14 housed within the main body 10. The main body 10 also includes a soap drawer 16. A compartment 20, which houses the control circuitry for the washing machine 1, is fitted to the top of the main body 10. A user interface 22, via which a user is able to enter control parameters for a wash cycle, is mounted on the front surface of the compartment 20.

Figure 2 schematically shows the main components housed within the washing machine 1 illustrated in Figure 1. The drum 14 is rotatably mounted to a watertight inner frame 30 via a drum shaft 32. The inner frame 30 is suspended from the main body 10 by springs 34a, 34b, and is also supported by dampers 36a, 36b connected between the bottom of the inner frame 30 and the main body 10. Each damper 36 is formed by a piston and cylinder assembly which damps vibrational movement of the inner frame 30 caused by rotation of the drum 14 during a wash cycle. Each of the dampers 36 includes a drum mass and vibration sensor 38a, 38b which sends a signal representative of the weight carried by the inner frame 30 and/or the vibrational movement of the inner frame 30 relative to the main body 10 to a control unit 40 housed within the compartment 20.

A motor 42, which is mounted to the inner frame 30, is connected to the drum 14 via a drive belt 43 so that the drum 14 can be rotated by applying a drive signal to the motor 42. Rotary sensors 64, 66 send signals to the control unit 40 representative of the speed of rotation of the motor 42 and the drum 14 respectively. In this way, the control unit 40 is able to adjust the drive signal applied to the motor 42 to achieve a desired rotational speed of the drum 14, or to stop the rotation of the drum 14 if slippage of the drive belt 42 is detected.

A hot water inlet pipe 44 and a cold water inlet pipe 46 allow water to be introduced into the inner frame 30 via solenoid valves 48a and 48b respectively. Each solenoid valve 48 is controlled by a signal from the control unit

40. An outlet pipe 50 allows water to be drained from the bottom of the inner frame 30 using a pump 52 which is also controlled by the control unit 40. A water level sensor 60 sends a signal representative of the amount of water within the inner frame 30 to the control unit 40. In this way, the control unit 40 is able to control the amount of water within the inner frame 30.

In this embodiment, the water level sensor 60 is a manometer formed by a feed tube 61a which at one end communicates with the bottom of the inner frame 30 so that water in the inner frame 30 enters the feed tube 61a. The other end of the feed tube 61a is connected to a head portion 61b which determines the water level in the inner frame 30 by measuring a change in pressure of air trapped within the manometer by water from the inner frame 30.

A water heater 54 is also mounted to the inner frame 30 and is connected to a heating element 56 provided within the inner frame 30. A temperature sensor 62 mounted within the inner frame 30 sends a signal representative of the temperature of water within the inner frame 30 to the control unit 40. In this way, the control unit 40 is able to apply a drive signal to the water heater 54 to achieve a desired water temperature.

As shown in Figure 2, the user interface 22 is also connected to the control unit 40.

The electrical circuitry within the washing machine 1 is summarised in Figure 3. As shown in Figure 3, the user interface 22 includes interface sensor A 70a, interface sensor B 70b, interface sensor C 70c and interface reed switches 72. The washing machine 1 also includes a soap drawer sensor 74 which senses whether or not the soap drawer 16 is open, and a door open sensor 76 which senses whether or not the door 12 is open.

As indicated in Figure 3, in this embodiment the interface sensors 70, the water level sensor 60, the drum mass and vibration sensors 38, the soap drawer sensor 74, the door open sensor 76, the motor shaft rotation sensor 64 and the drum shaft rotation sensor 66 are all inductive sensors. In particular, in this embodiment each of the inductive sensors outputs a signal corresponding to the position of a sensor element relative to an aerial. Using the same type of inductive sensor to sense many different parameters is advantageous because at least some common circuitry can be used within the control unit 40 for sending drive signals to, and processing signals from, these inductive sensors.

The control unit 40 has an output via which a drive signal is sent to the drum motor 42 to cause rotation of the drum 14. Similarly, the control unit 40 has outputs via which drive signals are respectively sent to the water solenoid valves 48 to introduce water into the inner frame 30, to the pump 52 to drain water from the inner frame, to the water heater 54 to heat water within the inner frame 30 to a desired temperature, to interface LEDs 78 forming part of the user interface 22 to indicate operational details to a user, and to a drum door release solenoid 80 which locks and unlocks the door 12.

Figure 4 shows the main components of the control unit 40. As shown, the control unit 40 has a microprocessor unit 90 to which a read only memory (ROM) 92, a random access memory (RAM) 94 and a clock 96 are connected. The ROM 92 stores control programs and reference data which are used by the microprocessor unit 90 during operation of the washing machine 1, and the RAM 94 provides working memory. The clock 96 outputs a signal indicating the present time which is input to the microprocessor unit 90.

An output from the microprocessor unit 90 is connected to inductive sensor drive circuitry 98 which selectively supplies, via a multiplexer 100, drive signals to the inductive sensors. Another output from the microprocessor unit 90 supplies a signal to the multiplexer 100 indicating which of the inductive sensors is to be selectively interrogated. The signals received from the inductive sensors are input, via a demultiplexer 102, to inductive sensor receive circuitry 104 which converts the signals into a digital format suitable for processing by the microprocessor unit 90. In use, the microprocessor unit 90 outputs a signal to the demultiplexer 102 indicating which of the inductive sensors is currently being interrogated, and the demultiplexer 102 directs the signal received from the indicated inductive sensor to the inductive sensor receive circuitry 104.

The control unit 40 also includes reed switches drive and receive circuitry 106 which sends a drive signal to the interface reed switches 72 in response to a signal output by the microprocessor unit 90, and converts a signal from the interface reed switches 72 into a digital signal which is output to the microprocessor unit 90. Further, the control unit includes temperature sensor drive and receive circuitry 108 which sends a drive signal to the temperature sensor 62 in response to a signal output by the microprocessor unit 90, and converts a signal from the temperature sensor 92 into a digital signal which is output to the microprocessor unit 90.

The microprocessor unit 90 also outputs control signals to a motor driver 110 which outputs drive signals to the motor 42, to a water solenoid valves driver 112 which outputs drive signals to the water solenoid valves 48, to a heater driver 114 which outputs control signals to the water heater 54, to an LED driver 116 which outputs control signals to the interface LEDs 78, to a door release solenoid driver 118 which outputs a control signal to the drum door release solenoid 80 and to a pump driver 120 which outputs drive signals to the pump 52.

Figure 5 schematically shows the functional configuration of the microprocessor unit 90. As shown, a control module 130 determines the signals to be sent to the motor driver 110, the water solenoid valves driver 112, the heater driver 114, the LED driver 116 and the door release solenoid driver 180 in dependence upon the signals received from the sensors. In order to receive a signal from one of the inductive sensors, the control module 140 outputs a signal identifying the desired inductive sensor to each of the multiplexer 100 and the demultiplexer 102, and outputs a signal to a signal generator 132 to generate a digital drive signal which is output to the inductive sensor drive circuitry 98. The signal from the inductive sensor receive circuitry 104, which is representative of a relative position between the sensor element and the aerial of the interrogated inductive sensor, is input to a position calculator 134 which processes the received signal to calculate the relative position.

The position calculator 134 outputs the calculated relative position to a conversion unit 136 which converts the calculated position to a value for the sensed parameter using a look-up table forming part of a look-up tables database 138 stored in the ROM 92. In particular, in this embodiment the signal output by the control module 130 to the demultiplexer 102 is monitored by the conversion unit 136. When the conversion unit 136 receives a calculated position from the position calculator 134, the conversion unit 136 uses the signal sent to the demultiplexer to determine which of the inductive sensors is being interrogated, and then selects a look-up table stored in the look-up tables data base 138 corresponding to the interrogated inductive sensor. The value for the sensed parameter is then output by the conversion unit 136 to the control module 130.

In use, the control module 130 first interrogates the sensors of the user interface 22 to determine the wash cycle indicated by a user. In this embodiment, the user either enters a custom wash cycle or indicates a preset wash cycle which can be retrieved by the control module 130 from a preset washes database 140 stored in the ROM 92. After determining the desired wash cycle, the control module 130 interrogates the soap drawer sensor 74 and door open sensor 76 until signals are received confirming that both the soap drawer 16 and the door 12 are closed. The control module 130 then outputs a control signal to the door release solenoid driver to lock the door 12.

The control module 130 then determines the weight of items which have been placed in the drum 14 by interrogating the drum mass and vibration sensors 38 of the dampers 36. In this embodiment, the control module 130 automatically adjusts the amount of water used in different stages of the wash cycle in dependence upon the weight of items within the drum 14. This has the advantage that the amount of water used can be reduced, and the electricity used to heat the water can be correspondingly reduced.

During the wash cycle, to introduce water into the drum 14, the control module 130 sends a control signal to the water solenoid valves driver 112 to open the water solenoid valves 48. While the water is being introduced into the inner frame 30, the control module 130 interrogates the water level sensor 60 to monitor the amount of water in the inner frame 30. When the water level sensor 60 indicates that the desired water level has been reached, the control module 130 sends a control signal to the water solenoid valves driver 112 to close the water solenoid valves, preventing further water being introduced into the inner frame 30.

To drain water from the inner frame 30 during the wash cycle, the control module 130 sends a control signal to the pump driver 120 to cause the pump 52 to drain water from the inner frame 30. While water is being drained from the inner frame 30 the control module 130 interrogates the water level sensor 60 to monitor the amount of water in the inner frame 30. When the water level sensor 60 indicates that the desired amount of water has been drained from the inner frame 30, the control module 130 sends a control signal to the pump driver 120 to turn off the pump 52.

To heat water within the inner frame 30 during the wash cycle, the control module 130 outputs a signal to the heater driver 114 which causes the water heater 54 to heat the water within the inner frame 30. While the water is being heated, the control module 130 interrogates the temperature sensor 62 to monitor the temperature of the water within the inner frame 30. When the temperature sensor 62 indicates that the desired temperature has been reached, the control module 130 sends a control signal to the heater driver 114 which turns off the heating.

In order to rotate the drum 14, the control module 130 sends a control signal to the motor driver 110 which drives the motor 42 to rotate the drum 14. While the drum is rotating, the control module 130 interrogates the motor shaft rotation sensor 64 and drum shaft rotation sensor 66 to ensure that the drum shaft and the motor shaft are rotating at the desired speeds. Those skilled in the art will appreciate that, as the distribution of the clothes within the drum 14 while the drum 14 is rotating is generally not uniform, excessive vibration can sometimes occur. In view of this, the control module 130 interrogates the drum mass and vibration sensors 38 while the drum 14 is rotating, and if excessive vibration is sensed the control module 130 outputs a control signal to the motor driver 110 causing the motor 42 to rotate the drum 14 at a reduced rate until the clothes within the drum 14 have been redistributed.

The operation of the sensors within the washing machine 1 will now be described in more detail.

Water Level Sensor

As described above, in this embodiment the water level sensor 60 is a manometer having a feed tube 61a which at one end communicates with the bottom of the inner frame 30 and at the other communicates with a head portion 61b. Figures 6A to 6C show in more detail the head portion 61b of the water level sensor 60.

As shown in Figure 6A, a diaphragm 150 separates the head portion 61b into an upper chamber 152 and a lower chamber 154. In particular, the diaphragm 150 provides an airtight seal between the upper chamber 152 and the lower chamber 154, and the feed tube 61a communicates with the lower chamber 154 so that the feed tube 61a and the lower chamber 154 form an enclosure with a single opening at the end of the feed tube 61a which communicates with the inner frame 30. The diaphragm 150 is resiliently flexible and therefore deforms if there is a pressure difference between the upper chamber 152 and the lower chamber 154. In use, as water enters the inner frame 30, and consequently enters the feed tube 61a, the pressure of the air trapped in the lower chamber 154 and in the feed tube 61a increases with increasing water level, thereby causing a corresponding deformation of the diaphragm 150. This deformation of the diaphragm 150 is measured in order to obtain a measure of the water level within the inner frame 30.

As shown in Figures 6A to 6C, the diaphragm 150 includes a circular ridge 156 which regulates the deformation of the diaphragm 150 so that the diaphragm 150 deforms more uniformly. A rigid disc 158 is attached to the centre of the diaphragm 150, concentric with the ridge 156, on the upper chamber 152 side of the diaphragm 150. A support member 160 projects perpendicularly from the rigid disc 158 into the upper chamber 152, and a sensor element 162 is mounted at the end of the support member 160 away from the diaphragm 150. The sensor element 162 generally moves along a linear measurement direction (the direction X in Figure 6A) as the pressure difference between the upper chamber 152 and the lower chamber 154 varies.

A printed circuit board 164 is suspended from the ceiling of the upper chamber 152 and extends along the measurement direction adjacent to the upstanding member 162. The PCB 164 has printed thereon conductive tracks which form a sine coil 166, a cosine coil 168 and a sense coil 170, each of which are connected to the control unit 40. As shown in Figure 6A, the PCB 164 is generally rectangular in shape with the lengthwise axis aligned with the measurement direction and the widthwise axis aligned perpendicular to the measurement direction. The sine coil 166, the cosine coil 168 and the sense coil 170 are connected to the control unit 40 via the lengthwise edge of the PCB 164 adjacent the ceiling, which corresponds to a position value of x = 0, and the position value increases along the length of the PCB 164 from the lengthwise edge corresponding to x = 0.

An overview of the operation of the water level sensor illustrated in Figures 6A to 6C will now be given with reference to Figure 7. As shown, a quadrature signal generator 180 (formed by the microprocessor unit 90 and the inductive sensor drive circuitry 98 of the control unit 40) generates an in-phase signal I(t) and a quadrature signal Q(t) at respective different outputs. The in-phase signal I(t) is generated by amplitude modulating an oscillating carrier signal having a carrier frequency f_0, which in this embodiment is 2MHz, using a first modulation signal which oscillates at a modulation frequency f_1, which in this embodiment is 3.9kHz. The in-phase signal I(t) is therefore of the form:

$$I(t) = A\sin 2\pi f_1 t \cos 2\pi f_0 t \qquad (1)$$

Similarly, the quadrature signal Q(t) is generated by amplitude modulating the oscillating carrier signal having carrier frequency f_0 using a second modulation signal which oscillates at the modulation frequency f_1, with the second modulation signal being π/2 radians (90°) out of phase with the first modulation signal. The quadrature signal Q(t) is therefore of the form:

$$Q(t) = A\cos 2\pi f_1 t \cos 2\pi f_0 t \qquad (2)$$

The in-phase signal I(t) is applied to the sine coil 166 and the quadrature signal Q(t) is applied to the cosine coil 168.

The sine coil 166 is formed in a pattern which causes current flowing through the sine coil 166 to produce a first magnetic field whose field strength component B_1 resolved perpendicular to the PCB 164 varies sinusoidally along the measurement direction in accordance with the function:

$$B_1 = B\sin\left(2\pi x/L\right) \qquad (3)$$

where L is the period of the sine coil in the x direction.

Similarly, the cosine coil 168 is formed in a pattern which causes current flowing through the cosine coil 168 to produce a second magnetic field whose field strength component B_2 resolved perpendicular to the PCB 164 also varies sinusoidally along the measurement direction, but with a phase difference of π/2 radians (90°) from the phase of the first magnetic field B_1, giving:

$$B_2 = B\cos\left(2\pi x/L\right) \qquad (4)$$

In this way, the total magnetic field component B_T generated perpendicular to the PCB 164 at any position along the measurement direction is formed by the combination of the first magnetic field strength component B_1 and the second magnetic field strength component B_2 for that position, with the magnitudes of the first and second magnetic field strength components B_1, B_2 varying along the measurement direction.

By applying the in-phase signal I(t) and the quadrature signal Q(t) to the sine coil 166 and the cosine coil 168 respectively, the generated total magnetic field component B_T oscillates at the carrier frequency f_0 in accordance with an amplitude envelope function which varies at the modulation frequency f_1, with the phase of the amplitude envelope function varying along the measurement direction. Thus:

$$B_T \propto \cos 2\pi f_0 t . \cos\left(2\pi f_1 t - \frac{2\pi x}{L}\right) \qquad (5)$$

In effect, the phase of the amplitude envelope function rotates along the measurement direction.

In this embodiment, the sensor element 162 includes a resonant circuit having a resonant frequency substantially equal to the carrier frequency f_0. The total magnetic field component B_T therefore induces an electric signal in the resonant circuit which oscillates at the carrier frequency f_0 and has an amplitude which is modulated at the modulation frequency f_1 with a phase which is dependent upon the position of the sensor element 162 along the measurement direction. The electric signal induced in the resonant circuit in turn generates a magnetic field which induces a sensed electric signal S(t) in the sense coil 170, with the sensed electric signal S(t) oscillating at the carrier frequency f_0. The amplitude of the sensed signal S(t) is also modulated at the modulation frequency f_1 with a phase which is dependent upon the position of the sensor element 1 along the measurement direction. The sensed signal S(t) is input to a position detector 182 (corresponding to the inductive sensor receive circuitry 106 and the position calculator 134 function of the microprocessor unit 90 of the control unit 40) which demodulates the sensed signal S(t), removes the component at the carrier frequency f_0, and calculates the position from the phase of the remaining amplitude envelope function relative to the excitation waveform. The position detector 182 then outputs a position signal P(t) representative of the detected position to the conversion unit 136, which converts the detected position into a corresponding water level value using a water level look-up table 184 stored in the ROM 92.

By using a carrier frequency f_0 which is greater than the modulation frequency f_1, the inductive coupling is performed at frequencies away from low-frequency noise sources such as the electric mains at 50/60 Hz, while the signal processing is performed at a relatively low frequency which is better suited to digital processing. Further, increasing the carrier frequency f_0 facilitates making the sensor element 162 small, which is a significant advantage in many applications. Increasing the carrier frequency f_0 also produces higher signal strengths.

The quadrature signals generated by the quadrature signal generator 180 and applied as drive signals to the sine coil 166 and the cosine coil 168 will now be described in more detail with reference to Figures 8A to 8C.

As shown in Figure 8A, the quadrature signal generator 180 generates the quadrature signal Q(t) by modulating the carrier signal using the first modulation signal. As shown, in this embodiment the first modulation signal does not apply a "full" modulation to the carrier signal. In other words, the amplitude envelope function indicated by dashed lines in Figure 8A does not reach zero amplitude. The actual quadrature signal Q(t) is therefore given by:

$$Q(t) = C\cos 2\pi f_0 t + A\cos 2\pi f_1 t \cos 2\pi f_0 t \qquad (6)$$

As shown in Figure 8B, the quadrature signal generator 180 generates the in-phase signal I(t) by modulating the amplitude of the carrier signal using the second modulation signal, whose phase lags the phase of the first modulation signal by π/2 radians (i.e. 90°). Again, in this embodiment the second modulation signal does not apply a full modulation to the carrier signal. The actual in-phase signal I(t) is therefore given by:

$$I(t) = C\cos 2\pi f_0 t + A\sin 2\pi f_1 t \cos 2\pi f_0 t \qquad (7)$$

The in-phase signal I(t) and the quadrature signal Q(t) each comprise three frequency components, one at f_0, one at $(f_0 + f_1)$ and one at $(f_0 - f_1)$. Each of these three components induces an electric signal in the resonant circuit of the sensor element 162 with a respective different phase lag, which results in a phase shift in the sensed signal S(t) which needs to be corrected in order to obtain an accurate position measurement, bearing in mind that the phase of the sensed signal S(t) is used to determine the position of the sensor element 162. In this embodiment, as will be discussed in more detail hereafter, this correction is achieved by performing a second phase measurement for which the in-phase signal I(t) is replaced by an "anti-phase" signal $\bar{I}(t)$.

As shown in Figure 8C, the quadrature signal generator 180 generates the anti-phase signal $\bar{I}(t)$ by modulating the carrier signal (having carrier frequency f_0) by a third modulation signal which is also at the modulation frequency f_1 but whose phase leads the phase of the first modulation signal by π/2 radians (i.e. 90°). Again, in this embodiment the third modulation signal does not apply a full modulation to the carrier signal. Thus, the anti-phase signal $\bar{I}(t)$ is given by:

$$\bar{I}(t) = C\cos 2\pi f_0 t - A\sin 2\pi f_1 t \cos 2\pi f_0 t \qquad (8)$$

The sensed signals S(t) induced in the sense coil 170 when the in-phase signal I(t) and the quadrature signal Q(t) are respectively applied to the sine coil 166 and cosine coil 168 will now be described with reference to Figures 9A to 9C. In Figures 9A to 9C, it has been assumed that no phase shift is introduced by the resonant circuit so that the phase shift is entirely due to the position of sensor element 162.

Figure 9A shows the sensed signal S(t) when the sensor element 162 is positioned adjacent the point where x equals L/4 identified in Figure 7. At this point, the field strength of the magnetic field component B_2 perpendicular to the PCB 164 generated by the cosine coil 168 is approximately zero and therefore, assuming no phase shift due to the resonant circuit, the sensed signal S(t) matches the in-phase signal I(t). Therefore, the sensed signal S(t) has a phase lag of π/2 radians

(90°) compared to the quadrature signal Q(t).

Figure 9B shows the sensed signal S(t) when the sensor element 162 is positioned adjacent the point where x equals 3L/8, at which point the magnetic field components perpendicular to the PCB 164 generated by the sine coil 166 and the cosine coil 168 are approximately equal and therefore, assuming no phase shift due to the resonant circuit, the sensed signal S(t) has a phase lag of $\pi/4$ radians (45°) compared to the quadrature signal Q(t).

Figure 9C shows the sensed signal S(t) when the sensor element 1 is positioned adjacent the point where x equals L/2, at which point the magnetic field component B_1 perpendicular to the PCB 164 generated by the sine coil 166 is approximately zero and therefore, assuming no phase shift due to the resonant circuit, the sensed signal S(t) matches the quadrature signal Q(t). Therefore, the sensed signal S(t) is in phase with the quadrature signal Q(t).

From equation 5 above, it can be seen that the phase of the sensed signal S(t) decreases as the position value increases when the in-phase signal I(t) and the quadrature signal Q(t) are applied to the sine coil 166 and the cosine coil 168 respectively.

The sensed signals S(t) induced in the sense coil 170 when the anti-phase signal $\bar{I}(t)$ and the quadrature signal Q(t) are respectively applied to the sine coil 166 and the cosine coil 168 will now be described with reference to Figures 10A to 10C. Again, it has been assumed that no phase shift is introduced by the resonant circuit so that the phase shift is entirely due to the position of sensor element 162.

Figure 10A shows the sensed signal S(t) when the sensor element 162 is positioned adjacent the point where x equals L/4, at which point the field strength of the magnetic field component B_2 perpendicular to the PCB 164 generated by the cosine coil 168 is approximately zero and therefore, assuming no phase shift is introduced by the resonant circuit, the sensed signal S(t) matches the anti-phase signal $\bar{I}(t)$. Therefore, the phase of the sensed signal S(t) leads the phase of the quadrature signal Q(t) by $\pi/2$ radians (90°).

Figure 10B shows the sensed signal S(t) when the sensor element 162 is positioned adjacent the point where x equals 3L/8, at which point the field strength of the magnetic field components generated by the sine coil 166 and the cosine coil 168 is approximately equal and therefore, assuming no phase shift is introduced by the resonant circuit, the phase of the sensed signal S(t) leads the phase of the quadrature signal Q(t) by $\pi/4$ radians (45°).

Figure 10C shows the sensed signal S(t) when the sensor element 162 is positioned adjacent the point where x equals L/2, at which point the field strength of the magnetic field component B_1 generated by the sine coil 166 is approximately zero and therefore, assuming no phase shift is introduced by the resonant circuit, the sensed signal S(t) is in phase with the quadrature signal Q(t).

As illustrated by Figures 10A to 10C, the phase of the sensed signal S(t) increases linearly with the position value when the anti-phase signal $\bar{I}(t)$ and the quadrature signal Q(t) are applied to the sine coil 166 and the cosine coil 168 respectively.

As described above, assuming no phase shift is introduced by the resonant circuit, for each position x in the measurement direction a position-related phase shift $\phi(x)$ is introduced when the in-phase signal I(t) and the quadrature signal Q(t) are applied, and a position-related phase shift $-\phi(x)$ is introduced when the anti-phase signal $\bar{I}(t)$ and the quadrature signal Q(t) are applied. In practice, the resonant circuit does introduce a phase shift ϕ_{RC}, but the phase shift ϕ_{RC} is the same whether the in-phase signal I(t) or the anti-phase signal $\bar{I}(t)$ is applied to the sine coil 166. Therefore, in this embodiment the phase shift measured when applying the anti-phase signal $\bar{I}(t)$ is subtracted from the phase shift measured when applying the in-phase signal I(t), resulting in the phase shift ϕ_{RC} introduced by the resonant circuit being cancelled to give a resultant phase which is equal to twice the position-dependent phase shift $\phi(x)$.

The processing circuitry used to generate the in-phase signal I(t), the quadrature signal Q(t) and the anti-phase signal $\bar{I}(t)$, and to process the sensed signal S(t) to determine a position value, will now be described with reference to Figure 11. As shown in Figure 11, the processing circuitry consists of the microprocessor unit 90, digital components 230, analogue driving circuitry 250 and analogue signal processing components 260.

The signal generator 132 (indicated by dashed lines in Figure 11) of the microprocessor 90 includes a first square wave oscillator 210 which generates a square wave signal at twice the carrier frequency f_0 (i.e. at 4 MHz). This square wave signal is output from the microprocessor 90 to a quadrature divider unit 232 which forms an in-phase digital carrier signal +I at the carrier frequency, an anti-phase digital carrier signal -I at the carrier frequency and a quadrature digital carrier signal +Q, also at the carrier frequency. As described hereafter, the quadrature digital carrier signal +Q is modulated to form the drive signals applied to the sine coil 166 and the cosine coil 168, while the in-phase and anti-phase digital carrier signals ±I are used to perform synchronous detection in order to demodulate the sensed signal S(t).

The signal generator 132 also includes a second square wave oscillator 212 which outputs a modulation synchronisation signal MOD_SYNC at the modulation frequency f_1 to provide a reference timing. The modulation synchronisation signal MOD_SYNC is input to a Pulse Width Modulation (PWM) type pattern generator 214 which generates digital data streams at 2MHz representative of the modulation signals at the modulation frequency f_1, i.e. 3.9 kHz. In particular, the PWM type pattern generator 214 generates two modulation signals which are in phase quadrature with each other, namely a cosine signal COS and either a plus sine or a minus sine signal ±SIN in dependence upon whether the in-phase signal I(t) or the anti-phase signal $\bar{I}(t)$ is to be generated.

The cosine signal COS is output by the microprocessor 90 and applied to a first digital mixer 234, in this embodiment a NOR gate, which mixes the cosine signal with the quadrature digital carrier signal, +Q, to generate a digital representation of the quadrature signal Q(t). The sine signal ±SIN is output by the microprocessor and applied to a second digital mixer 236, in this embodiment a NOR gate, together with the quadrature digital carrier signal +Q to generate a digital representation of either the in-phase signal I(t) or the anti-phase signal $\bar{I}(t)$. The digital signals output from the first and second digital mixers 234, 236 are input to first and second coil driver circuits 252, 254 respectively and the amplified signals output by the coil drivers 252, 254 are then applied to the cosine coil 168 and sine coil 166 respectively.

The digital generation of the drive signals applied to the sine coil 166 and the cosine coil 168 introduces high frequency harmonic noise. However, the coil drivers 252, 254 remove some of this high frequency harmonic noise, as does the frequency response characteristics of the cosine and sine coils 168, 166. In addition, the resonant circuit within the sensor element 162 will not respond to signals significantly away from the resonant frequency and therefore the resonant circuit will also filter out a portion of the unwanted high frequency harmonic noise.

As discussed above, the signals applied to the sine coil 166 and the cosine coil 168 induce an electric signal in the resonant circuit of the sensor element 162 which in turn induces the sensed signal S(t) in the sense coil 170. The sensed signal S(t) is passed through the analogue signal processing components 260. In particular, the sensed signal S(t) is initially passed through a high pass filter amplifier 262 which both amplifies the received signal, and removes low frequency noise (e.g. from a 50 Hertz mains electricity supply device) and any DC offset. The amplified signal output from the high pass filter 262 is then input to a crossover analogue switch 264 which performs synchronous detection at the carrier frequency of 2 MHz, using the in-phase and anti-phase square wave carrier signals ±I generated by the quadrature divider 232. The in-phase and anti-phase digital carrier signals, which are 90 degrees out of phase with the quadrature digital carrier signal +Q used to generate the drive signals applied to the sine coil 166 and the cosine coil 168, are used for the synchronous detection because, as discussed above, the resonant circuit of the sensor element 162 introduces a substantially 90 degrees phase shift to the carrier signal.

The signal output from the crossover analogue switch 264 substantially corresponds to a fully rectified version of the signal input to the crossover analogue switch 264 (i.e. with the negative voltage troughs in the signal folded over the zero voltage line to form voltage peaks lying between the original voltage peaks). This rectified signal is then passed through a low pass filter amplifier 266 which essentially produces a time-averaged or smoothed signal having a DC component and a component at the modulation frequency f_1. The DC component appears as a result of the rectification performed by the synchronous detection process.

The signal output from the low pass filter amplifier 266 is then input to a band-pass filter amplifier 268, centred at the modulation frequency f_1, which removes the DC component. The signal output from the bandpass filter amplifier 268 is input to a comparator 270 which converts the input signal to a square wave signal whose timing is compared with the timing of the modulation synchronisation signal MOD_SYNC to determine the position of the sensor element 162. The square wave signal output by the comparator 270 (which is in effect a digital signal) is applied to a digital gate 238, which in this embodiment is a NOR gate, together with the quadrature digital carrier signal +Q output by the quadrature divider 232. The digital gate 238 therefore outputs a series of pulses at the carrier frequency f_0 when the output from the comparator 270 is low, and no signal when the output of the comparator 270 is high. Figure 12 shows an example of the output from the digital gate 238 for one period of the MOD_SYNC signal, which will hereafter be termed a frame.

As shown in Figure 11, the pulses output from the digital gate 238 are input to the position calculator 134 which forms part of the microprocessor unit 90. In this embodiment, the position calculator 134 comprises a counter 216 and a processing unit 218, and the pulses output by the digital gate 238 are input to the counter 216. The MOD_SYNC signal output by the second square wave oscillator 212 is input to a frequency multiplier 220 which, in this embodiment, multiplies the frequency of the MOD_SYNC signal by 16 and outputs the multiplied signal to the counter 216. Each period τ_N of the multiplied signal will hereafter be called a window so that a frame corresponds to 16 windows, referred to as window 1 to window 16. In this embodiment, the modulation frequency is set to $2MHz/2^9$ = 3.9kHZ. This means that each frame corresponds to 512 periods of the carrier signal +Q input to the digital gate 238, and each window corresponds to 32 periods (512/16) of the carrier signal +Q.

The count value of the counter 216 is noted and stored by the processing unit 218 after each window within a frame, and then reset to zero. Thus, for each frame the processing unit 216 receives 16 count values from which the processing unit 218 determines the position of the sensor element 162 and outputs a signal representative of the determined position to the conversion unit 136, which converts the determined position into a water level value using the water level look-up table 184. The conversion unit 136 then outputs the water level to the control module 130.

Further details of the inductive sensor used in the water level sensor 60 can be found in co-pending International Patent Application No. PCT/GB02/01204, whose contents are incorporated herein by reference.

Drum Mass and Vibration Sensors

Figure 13 schematically shows one of the dampers 36 and the associated drum mass and vibration sensor 38. As shown, the damper 36 includes a piston 300 which is slidably mounted within a cylinder 302 to allow relative movement between the piston 300 and the cylinder 302 along a linear direction. A first bolt hole 304 is provided on the cylinder 302 to enable the cylinder 302 to be bolted on to the main body 10. A second bolt hole 306 is provided on the piston 300 to enable the piston 300 to be bolted to the inner frame 30.

In this embodiment, the cylinder 302 holds hydraulic oil which damps the movement of the piston 300 in a conventional manner. As schematically shown in Figure 13, a spring 314 interconnects the cylinder 302 and the piston 300 to provide a restoring force urging the piston 300 towards a datum position relative to the cylinder 302 at which the spring 314 is in a natural (i.e. unstressed) state. In this way, as items are added onto the drum 14 the piston 300 moves from an unloaded position to a position where the restoring force provided by the spring 314 balances the weight of the items within the drum 14. When the items are removed from the drum 14, the spring 314 applies a force which returns the piston 300 to the unloaded position.

In this embodiment, a sensor element 318 having a resonant circuit identical to that used in the water level sensor 60 is attached to the piston 300, and an aerial (having a sine coil 320, cosine coil 322 and sense coil 324 identical to the sine coil, cosine coil and sense coil of the water level sensor 60) is mounted to the cylinder 302, with the measurement direction of the aerial being aligned along the direction of movement of the piston 300 within the cylinder 302.

In the same manner as for the water level sensor 60, the control unit 40 sends, via the multiplexer 100, an in-phase (or anti-phase) signal I(t) to the sine coil 320 and a quadrature signal to the cosine coil 322, and directs, via the demultiplexer 102, the signal induced in the sense coil 324 to the inductive sensor receive circuitry 104. The digital signal output by the inductive sensor receive circuitry 104 is processed by the position calculator 134 of the microprocessor unit 90 to determine a value representative of the position of the sensor element 318 within the cylinder 302.

In use, the position of the sensor element 318 within the cylinder 302 is measured before loading laundry into the drum 14 and after the laundry has been loaded in the drum 14. The difference between these two position measurements is representative of the weight of articles inserted into the drum 14. The conversion unit 136 within the microprocessor unit 90 converts the determined difference into a corresponding weight using a look-up table stored in the ROM 92. The control module 130 then adjusts the wash cycle in dependence upon the determined weight in order to improve the energy efficiency of the washing machine.

In this embodiment, the control module measures the position of the sensor element 318 in the cylinder 302 immediately before laundry is loaded into the drum 14. This is advantageous because hysterisis within the suspension system supporting the inner frame 30 will cause the position of the sensor element 318 within the cylinder 302 when the drum 14 is empty to vary overtime.

Further, during a wash cycle, by monitoring the position of the sensor element 318 during rotation of the drum 14, the processor unit 90 can determine if the vibration of the inner frame 30 becomes excessive, in which case the control module 130 reduces the speed of rotation of the drum 14 until the vibration has subsided.

User Interface

In this embodiment, the layout of the user interface 22 is substantially the same as the user interface described in international patent application WO 01/42865, whose contents are incorporated herein by reference, but the interface sensors of the user interface 22 use inductive sensors which operate generally in the same manner as the inductive sensors forming the water level sensor 60 and the drum mass and vibration sensors 38.

Briefly, the user interface 22 includes six loose-leaf ring-bound graphical interface panels 350, 360, 370, 380, 390, 400, illustrated in Figures 14A to 14C, forming three left panels, which allow a user to indicate the material of the clothes being washed (in particular wool, cotton or synthetic), and three right panels, which enable wash program parameters to be set by the user. The user interface 22 also includes a fascia plate 410, shown in Figure 14D, which is removably affixed to the front surface of the compartment 20. Figure 14E is a schematic view of a printed circuit board (PCB) 420 on which the majority of the sensing electronic components of the user interface 22 are mounted. The PCB 420 is located immediately inside the front face of the compartment 20 so as to be substantially in registry with the fascia plate 410.

As shown in Figure 14E, the PCB 420 has the LEDs 78a to 78i, the interface reed switches 72a to 72e and the interface sensors 70a to 70c of the user interface mounted thereon. When the fascia plate 410 is mounted to the compartment 20, the LEDs 78 are aligned with a transparent portion 412 of the fascia plate 410 so that they are visible to the user. Further, the reed switches 72 are aligned with a temperature control knob 414 which is rotatably mounted on the fascia plate 410. In particular, the temperature control knob 414 includes a magnet 416 which is selectively positioned by the user to correspond with one of the reed switches 72 in order to switch the corresponding reed switch.

The interface sensor A 70a detects which of the three left panels 350, 370, 390 are being used by the user, and also detects a user ID which is held in place by a permanent magnet 422 mounted behind the PCB 420. The interface sensor B 70b and the interface sensor C 70c detect which of the three right panels 360, 380, 400 is being used by the user and the wash program parameters input by the user using the detected right panel.

In this embodiment, the interface sensors 70 detect the two-dimensional position of a plurality of sensor elements, each sensor element having a resonant circuit with a respective different resonant frequency. In particular, the resonant frequency of each sensor element is selected from a predetermined set of resonant frequencies so that the control unit can cycle the carrier frequency through the predetermined set of resonant frequencies to identify the resonant frequency and position of a sensor element.

In order to achieve the two-dimensional position measurement, a sine coil and a cosine coil pair is aligned in each of two orthogonal measurement directions, which will hereafter be referred to as the X direction and the Y direction. Figures 15A to 15E show the conductive tracks which form the aerial of one of the interface sensors 70. In particular, Figure 15A and 15B respectively show the sine coil 461 and the cosine coil 462 for the X direction, Figure 15C and 15D respectively show the sine coil 463 and the cosine coil 464 for the Y direction, and Figure 15E shows the sense coil 465.

In use, in order to sense the position of a sensor element in the X direction, the control unit 40 applies an in-phase signal I(t) (or anti-phase signal) to the sine coil 461 for the X direction and a quadrature signal Q(t) to the cosine coil 462 for the X direction, with the carrier frequency of the in-phase signal I(t) and the quadrature signal Q(t) substantially matching the resonant frequency of the sensed sensor element, and measures the phase of the signal induced, via the resonant circuit of the sensor element, in the sense coil 465. Similarly, in order to sense the position of a sensor element in the Y direction, the control unit 40 applies the same in-phase signal I(t) (or anti-phase signal) to the sine coil 463 for the Y direction and the same quadrature signal Q(t) to the cosine coil 464 for the Y direction and measures the phase of the signal induced, via the sensor element, in the sense coil 465. In this embodiment the position of the sensor element in the X direction and the position of the sensor element in the Y direction are separately measured.

In order to measure the position of a different sensor element, having a resonant circuit with a different resonant frequency, the control unit changes the carrier frequency of the applied in-phase signal I(t) and quadrature signal Q(t) to match the resonant frequency of the new sensor element. For example, in this embodiment a fascia plate ID puck 418, illustrated in Figure 15F, forms part of the fascia plate 410 and has three sensor elements whose respective resonant frequencies f_{16}, f_{17} and f_{18} and relative positions indicate the model of the washing machine associated with that fascia plate. In use, the control unit 40 scans through the set of predetermined resonant frequencies, and identifies the resonant frequencies f_{16}, f_{17} and f_{18} and the relative positions of the associated resonant circuits, thereby enabling identification of the fascia plate 410.

Motor Shaft and Drum Shaft Rotation Sensors

In this embodiment, the motor shaft rotation sensor 64 and the drum shaft rotation sensor 66 are rotary versions of the linear sensors used for the water level sensor 60 and the drum mass and vibration sensor 38.

Soap Drawer Sensor and Door Open Sensor

In this embodiment, a sensor element is attached to the soap drawer 16 and an aerial is positioned on the main body 10 so that when the soap drawer 16 is closed the sensor element of the soap drawer 16 is adjacent the aerial. In this way, the control unit 40 detects whether or not the soap drawer 16 is closed. Similarly, a sensor element is attached to the door 12 and an aerial is attached to the main body so that when the door 12 is closed, the sensor element on the door 12 is adjacent the aerial enabling the control unit 40 to detect whether or not the door 12 is closed.

SECOND EMBODIMENT

A second embodiment will now be described, with reference to Figures 16 to 18, in which the water level sensor 60 of the first embodiment is replaced by an alternative water level sensor in which a linear variable differential transducer (LVDT) type arrangement is used to detect the deflection of the diaphragm 150. In Figures 16 and 17, components which are identical to corresponding components of the first embodiment have been referenced with the same numerals and will not be described in detail again.

As shown in Figure 16, an elongated ferrite element 500, which forms the core of the LVDT, is fixed to the rigid disc 158 with the longitudinal axis of the ferrite element extending perpendicular to the plane of the rigid disc 158 into the upper chamber 152. In this embodiment, the ferrite element 500 is a cylindrical rod having a diameter of 3mm and a length of 15mm.

A circular multi-layer PCB 502 is included in the upper chamber 152 with the plane of the multi-layer PCB 502 extending parallel with the natural position of the diaphragm 150 (i.e. the position of the diaphragm 150 in the absence of a pressure difference between the lower chamber 154 and the upper chamber 152). The multi-layer

PCB 502 has three insulating layers 504, 506, 508, and a hole is formed completely through the centre of the multi-layer PCB 502. In this embodiment, the multi-layer PCB 502 has a thickness of 2mm and the hole has a circular cross-section with a diameter of 5mm.

A conductive track is provided on each insulating layer of the multi-layer PCB 502. As schematically shown in Figure 17, which for illustrative purposes shows the conductive tracks formed on all three insulating layers of the multi-layer PCB 500 as if formed on a single layer, each conductive track forms an annular coil around the hole. In this embodiment, the inner diameter of each annular coil is 6mm and the outer diameter of each annular coil is 15mm and each conductive track is formed by etching copper tracks onto the corresponding insulating substrate circuit board, such as commonly referred to as Fire Resistant 4 (FR4). The conductive track on the central insulating layer 506 forms an input coil 510 having an inductance of 5μH and the conductive tracks respectively formed on the outer insulating layers 504, 508 form a balanced pair of output coils 512, 514 each having an inductance of 5μH. As each conductive track is provided on a respective different insulating layer of the PCB 502, the conductive tracks are spaced at 0.67mm intervals along the direction normal to the plane of the PCB 502.

Returning to Figure 16, the ferrite rod 500 passes through the hole in the multi-layer PCB 502. The mutual inductance between the input coil 510 and each of the outer coils 512, 514 therefore varies in dependence upon the position of the ferrite rod 500, which in turn varies in dependence upon the water level in the inner frame 30. In particular, as the water level within the inner frame

30 increases, the mutual inductance between the input coil 510 and one of the output coils 512 increases while the mutual inductance between the input coil 510 and the other output coil 514 decreases.

As shown in Figure 18, an AC signal generator 516 (formed by the microprocessor unit 90 and the inductive sensor drive circuitry 98 of the control unit 40) applies an AC signal having a frequency of 2MHz to the input coil 510 which generates a magnetic field that induces an oscillating signal in each of the output coils 512, 514, the amplitude of the oscillating signal induced in each output coil 512,514 being dependent upon the mutual inductance between the input coil 510 and that output coil 512, 514. The signals induced in the output coils 512, 514 are input to a comparator 518 which outputs a pulse-width modulated signal whose duty factor varies in dependence on the difference in amplitude between the two induced signals. The duty factor of the pulse-width modulated signal is therefore indicative of the water level in the inner frame 30.

The pulse-width modulated signal is input to the microprocessor unit 90 which converts the duty factor into a corresponding water level value using a pre-stored look-up table. The control module 130 is then able to control the introduction of water into, and the draining of water from, the inner frame 30 using the determined value.

In this embodiment, the duty factor of the pulse-width modulated signal varies approximately linearly with the position of the ferrite rod 500 in the measurement direction for a range of movement of the ferrite rod 500 in the measurement direction (i.e. perpendicular to the plane of the printed circuit board) of approximately 8mm.

THIRD EMBODIMENT

A third embodiment of the invention will now be described, with reference to Figures 19 and 20, in which the PCB-LVDT sensor arrangement described in the second embodiment for a water level sensor is applied to a drum mass and vibration sensor in a damper 36. In Figures 19 and 20, components which are identical to corresponding components of the first embodiment have been referenced with the same numerals and will not be described in detail again.

As shown in Figure 19, in this embodiment an elongated ferrite rod 530 extends from the piston 300 with the longitudinal axis of the ferrite rod 530 being aligned along the direction of movement of the piston 300 within the cylinder 302. In this embodiment, the ferrite rod 530 is identical to the ferrite rod of the second embodiment. A multi-layer PCB 532 is fixed to the cylinder 302 between the first part 310 and the second part 312 of the piston 300. Two holes are formed in the multi-layer PCB 532, with the spring 314 passing through one of the holes and the ferrite rod 530 passing through the other hole, the hole through which the ferrite rod 530 passes having a diameter of 5mm.

As in the second embodiment, the multi-layer PCB 532 has three insulating layers which each have a conductive track etched thereon in th shape of an annular coil, having an inner diameter of 6mm and an outer diameter of 15mm, around the hole through which the ferrite rod 530 passes. These conductive tracks are schematically shown in Figure 20, which for illustrative purposes shows the three conductive tracks as if formed on a single layer, and have an identical lay-out to the conductive tracks for the second embodiment. Thus, the conductive track on the central insulating layer forms an input coil 534 having an inductance of 5μH and the conductive tracks respectively formed on the outer insulating layers form a balanced pair of output coils 536, 538 each having an inductance of 5μH.

In use, as in the second embodiment, an AC signal having a frequency of 2MHz is applied across the input coil 534 and the oscillating signals induced in the output coils 536, 538 are compared to generate a pulse-width modulated signal whose duty factor varies in dependence upon the position of the ferrite rod 530. This position is then converted into a measure of the weight carried by, or the vibration of, the inner frame 30.

FOURTH EMBODIMENT

In the first embodiment, the drum mass and vibration sensors 38 measure the displacement of a piston within a cylinder of a damper 36 to determine the weight of clothes or the like carried by the drum 14 and the vibration of the inner frame 30. A fourth embodiment will now be described, with reference to Figure 21, in which the displacement of the drum 14 is directly measured.

As schematically shown in Figure 21, a disc-shaped pulley 550 is connected to the drive shaft 552 of the drum 14 and the drive belt 43 is looped around the perimeter of the pulley 550 so that when the drive belt 43 is rotated by the motor 42, friction between the drive belt 43 and the pulley 550 causes the drum 14 to rotate. In this embodiment, two sensor elements 554, 556 are mounted to the circular end surface 558 of the pulley 550 away from the drum 14, with the sensor elements 554, 556 being spaced apart from each other. Each sensor element 554, 556 has a resonant circuit with a respective different resonant frequency.

A PCB 560, which is fixed relative to the main body 10 of the washing machine 1, is positioned adjacent the pulley 550 with the plane of the PCB 560 being substantially perpendicular to the axis of rotation of the drum 14. An aerial 562 is formed by conductive tracks printed on the PCB 560. In this embodiment, the aerial 562 has the same coil structure as, and is operated in the same manner as, the interface sensors 70 of the first embodiment. In other words, the carrier frequency of the signals applied to the sine and cosine coils of the aerial is set to match the resonant frequency of the first sensor element 554 and the position of the first sensor element in orthogonal X and Y directions is detected, and then the carrier frequency is set to match the resonant frequency of the second sensor element 556 and the position of the second sensor element is sequentially detected in the X and Y directions. Thus, the two-dimensional position of each of the sensor elements 554, 556 is measured.

The reason why the position of two sensor elements is detected rather than one is that, as the circular end surface 558 of the pulley 550 is significantly larger than each of the sensor elements, it can be difficult to identify correctly the movement of the drum 14 from the detected position of a single sensor element. For example, the sensor element may move linearly while the movement of the drum 14 includes a rotational component.

Therefore, the use of two sensor elements enables the movement of the drum to be more accurately analysed.

In this embodiment, before a wash cycle starts the static positions of the two sensor elements 554, 556 is indicative of the weight of articles loaded within the drum 14. Thus, the control unit 40 of the washing machine is able to determine the weight of articles loaded within the drum 14 by measuring the respective positions of the two sensor elements 554,556 when the drum 14 is empty and subsequently measuring the position of the two sensor elements 554, 556 after the drum 14 has been loaded with laundry. The control unit then adjusts the amount of water used in the wash cycle in dependence upon the weight of articles to be washed in the wash cycle.

During a wash cycle, the positions of the two sensor elements are monitored by the control unit 40 of the washing machine to check for excess vibration of the inner frame 30. Further, as the rotation of the drum shaft can be determined by monitoring the positions of the two sensor elements 554, 556, the control unit 40 is able to check for any slippage of the drive belt 43 by comparing the drum speed with the speed of the motor drive.

FIFTH EMBODIMENT

In the fourth embodiment, an aerial is formed on a PCB 560 and the lateral positions of two sensor elements, which are mounted to the drum 14, relative to the PCB 560 are measured. However, vibrations of the drum 14 during rotation also occur along the axis of rotation.

A fifth embodiment will now be described with reference to Figure 22 in which a PCB-LVDT sensor (as described in the second and third embodiments) is combined with the drum mass and position sensor of the fourth embodiment so that both lateral and axial movement of the drum 14 is detected. In Figure 22, components which are identical to corresponding components of the fourth embodiment have been referenced with the same numerals and will not be described again.

As shown in Figure 22, in addition to the two sensor elements 554, 556 on the end surface 558 of the pulley 550, a ferrite rod 570 projects from the end surface 558 of the pulley 550 along the axis of rotation of the drum 14. The ferrite rod 570 passes through a hole formed in a multi-layer PCB 572 which includes a layer having formed thereon an aerial substantially identical to the aerial of the fourth embodiment, and has three layers each having a conductive track printed thereon forming a coil around the hole in substantially the same manner as the PCB-LVDT sensors of the second and third embodiments.

In use, the position of the drum in directions parallel to the plane of the multi-layer PCB 572 are determined by using the aerial to detect the position of the sensor elements 554, 556, while the PCB-LVDT formed by the ferrite rod 570 and the coils around the hole in the multi-layer PCB 572 is used to detect the position of the drum 14 in the direction perpendicular to the multi-layer PCB 572.

SIXTH EMBODIMENT

As described in the first embodiment with reference to the ID puck 418 for the fascia plate 410, an inductive sensor can be used to "read" an identification mark on a component of a system.

A sixth embodiment will now be described with reference to Figures 23 and 24, in which the drum 14 for the washing machine 1 comprises a removable basket, in the same manner as described in International Patent Application WO 98/21391 whose contents are incorporated herein by reference. With such a washing machine, the user can use the removable basket 600, when removed from the washing machine, as a laundry basket for storing items awaiting washing.

In this embodiment, plural removable baskets 600 are provided with each basket 600 being used to store clothes for a respective different wash. For example, one basket 600 is used to store white items while another basket 600 is used to store coloured items. Each basket 600 has a corresponding identification device storing identification data which is indicative of the items stored in the basket. When one of the baskets is inserted into the washing machine prior to a wash, the washing machine automatically determines from the corresponding identification device an appropriate wash cycle.

In this embodiment, each removable basket 600 is a hollow cylinder with an open end. As shown in Figure 23, a rim 604 is formed around the open end. When the removable basket 600 is inserted into the body 602 of the washing machine, the basket 600 engages the rotary drum of the washing machine with the rim 604 adjacent a lip portion 606 of the body 602 of the washing machine.

As shown most clearly in Figure 24, in this embodiment the identification device comprises three sensor elements 608a, 608b and 608c which are located on the rim 604 of the basket 600, with each sensor element 608 comprising a resonant circuit with a respective resonant frequency. An aerial 610, which in this embodiment is identical to the aerial of the water level sensor 60 of the first embodiment, is located on the lip portion 606. In response to a user instruction, the washing machine rotates the drum so that each sensor element passes by the aerial 610. In a similar manner to the inductive sensors of the user interface, the carrier frequency of the signals applied to the aerial 610 is scanned to determine the resonant frequencies associated with each of the sensor elements 608, and a look-up table is used to identify a wash cycle associated with the determined resonant frequencies.

MODIFICATIONS AND FURTHER EMBODIMENTS

As illustrated in Figures 1 and 2, the described embodiments are in the form of front-loading washing machines. Those skilled in the art will appreciate that the invention is equally applicable to top-loading washing machines.

Although in the described embodiments the term water level sensor has been used, it will be appreciated that the described water level sensors could measure liquids other than water. For example, a liquid level sensor substantially identical to the described water level sensors could be used to measure the level of oil in a heating oil container or, in an industrial dyeing apparatus for dyeing materials, the amount of liquid dye added to a container holding the materials. Another application of the described liquid level sensors is in an industrial chemical manufacturing apparatus for measuring quantities of chemicals introduced into a reaction chamber.

Similarly, the described drum mass and vibration sensors can be applied to machines other than washing machines. For example, the described drum mass and vibration sensors could be used in a cement mixer.

In the first and third embodiments, the drum mass and vibration sensors form part of a piston-and-cylinder assembly. It will be appreciated that piston-and-cylinder assemblies employing such sensors could be incorporated in automotive vehicles, for example interconnecting the vehicle chassis and the wheel axles.

The identification system described in the sixth embodiment also has wide application. For example, an identification device comprising one or more resonant circuits could be attached to an ink cartridge of a printer, with either or both of the position and resonant frequency of the or each resonant circuit identifying the type of ink stored in the ink cartridge. Then, when the ink cartridge is inserted into the printer, the printer can detect the type of ink stored in the ink cartridge in the same manner as described in the sixth embodiment. In this way, the printer can adjust the drive signals applied to the printhead in accordance with the detected type of ink. Preferably, the identification device also identifies the manufacturer of the ink cartridge, and the printer only works with ink cartridges from approved manufacturers to reduce the chance of damage to the printer caused by sub-standard ink cartridges.

In general, the identification system described in the sixth embodiment can be used for any system in which a main assembly either processes materials stored in a detachable subsidiary component or uses the material stored in the detachable subsidiary component during operation. In particular, the identification device can identify either or both of the type of material stored in the subsidiary component or the manufacture of the subsidiary component. The material stored in the subsidiary component could be a lubricant or a detergent.

In the first embodiment, a preferred type of inductive sensor is described in which an excitation signal is applied having a carrier frequency modulated by an excitation frequency which is less than the carrier frequency. This enables the inductive coupling to be performed at a relatively high frequency, while allowing digital processing techniques to be used to process, after demodulation, the signal induced in the sensor winding. However, those skilled in the art will appreciate that alternative inductive sensing systems could also be used.

In the first embodiment, the PCB 164 is provided within the housing of the head portion 61b of the water level sensor 60. This is not, however essential because the aerial formed by the sine coil 166, cosine coil 168 and sense coil 170 could be located outside of the head portion 61a. Similarly, the PCB used in the drum mass and vibration sensor of the first embodiment could be attached to the exterior of the cylinder of the damper 36.

In the first embodiment, the water level sensor is formed by a manometer having a diaphragm which moves in dependence upon a difference in the pressure applied to each side of the diaphragm. Alternatively, a Bourdon tube arrangement could be used in which deflection of a flexible tube, caused by a pressure difference between the inside and the outside of the tube, is measured. Further, a bellows type arrangement could be used in which the bellows expand or contract dependent upon the water level in the inner frame. In all these arrangements, a moveable portion has a first surface facing a cavity communicating with the inner frame and a second surface opposing the cavity, and the moveable portion moves by an amount dependent on the difference in the pressure applied to the first and second surfaces.

In the first embodiment, the sensor element is directly connected to the diaphragm of the water level sensor 60. Alternatively, a linkage mechanism could be connected between the sensor element and the diaphragm to magnify the displacement of the sensor element. Alternatively, the linkage mechanism could convert the linear movement of the diaphragm into a rotary movement of the sensor element. Preferably, the linkage mechanism includes a limit switch which is triggered if the water level within the inner frame 30 exceeds a predetermined amount. In this way, if for any reason the inductive sensor of the water level sensor is not working properly, the amount of water introduced into the inner frame 30 is still limited.

The damper of the first and third embodiments uses a hydraulic oil to provide a damping force to damp relative movement between the main body 10 and the inner frame 30 of the washing machine. Alternatively, a friction damper could be used. However, if a friction damper is used the absolute relative position of the piston and the cylinder no longer represents the weight carried by the inner frame 30 and therefore a more complicated scheme is required to determine the carried weight. For example, a change in relative position between the piston and the cylinder could be correlated with the carried weight.

In an embodiment, the piston comprises two parts interconnected by a spring, with the part innermost within the cylinder forming a tight fit with the cylinder so that friction between the innermost part and the cylinder provides a damping force. The spring interconnecting the first and second parts acts as a shock absorber to absorb high frequency vibrations.

In the first and third embodiments, a spring interconnects the piston and the cylinder to provide a restoring force to urge the piston to a datum position relative to the cylinder. It will be appreciated that this spring is not essential because the springs 34a, 34b interconnecting the main body 10 and the inner frame 30 provide a restoring force. Further, the position sensor also need not be integrated with the damper, as the suspension system could comprise separate springs, dampers and position sensors.

It will be appreciated that the damper need not be a piston and cylinder assembly, and need only have a first part, connected to the inner frame, and a second part, connected to the main body, which are moveable relative to each other in a measurement direction.

In the described embodiments, the way in which the inner frame 30 of a washing machine vibrates is monitored by either directly measuring displacement of the drum 14 or by monitoring the suspension system of the washing machine. By monitoring the movement of the inner frame 30 while the drum 14 rotates, the rotation of the drum 14 can be reduced if there is excessive vibration. Further, the movement of the inner frame 30 can be used to determine the amount of soap suds in the drum 14 because the pattern of movement of the inner frame 30 depends upon the amount of soap suds. Therefore, by monitoring the movement of the inner frame 30 it is possible to identify when there are excessive soap suds (which may be caused by using too much, or the wrong type of, detergent). In an embodiment, if the control unit detects excessive soapsuds, the control unit switches off the motor to prevent further soapsuds being formed.

The temperature sensor of the described embodiments can be replaced by an inductive temperature sensor such as described in International Patent Application No. PCT/GB02/01204.

In the first embodiment, the phase shift ϕ_{RC} introduced by the resonator circuit in the sensor element 162 of the water level sensor 60 is removed by effectively taking two measurements of the position with the phase of the signal applied to the sine coil 166 being reversed between measurements. It will be appreciated that in alternative embodiments, the reverse measurement need only be performed intermittently to determine a value for the phase shift ϕ_{RC} which has the advantage of increasing the measurement update rate. Alternatively, a predetermined value for the phase shift ϕ_{RC}, determined by a factory calibration, could be subtracted from a single phase measurement. However, this is not preferred because it cannot allow for environmental factors which affect the resonant frequency f_{res} and quality factor of the resonant circuit and therefore vary the phase shift

ϕ_{RC}.

In the first embodiment, the sine coil 166 and cosine coil 168 of the water level sensor 60 are arranged so that their relative contributions to the total magnetic field component perpendicular to the PCB 164 vary in accordance with position along the measurement direction. In particular, the sine and cosine coils have an alternate twisted loop structure. However, it would be apparent to a person skilled in the art that an enormous variety of different excitation winding geometries could be employed to form transmit aerials which achieve the objective of causing the relative proportions of the first and second transmit signals appearing in the ultimately detected combined signal to depend upon the position of the sensor element in the measurement direction.

While in the first embodiment, the excitation windings are formed by conductive tracks on a printed circuit board, they could also be provided on a different planar substrate or, if sufficiently rigid, could even be free standing. Further, it is not essential that the excitation windings are planar because, for example, cylindrical windings could also be used with the sensor element moving along the cylindrical axis of the cylindrical winding.

In the first embodiment, a quadrature pair of modulation signals are applied to a carrier signal to generate first and second excitation signals which are applied to the sine coil 166 and cosine coil 168 respectively. However, this is not essential because it is merely required that the information carrying components of the excitation signals are distinct in some way so that the relative contributions from the first and second excitation signals can be derived by processing the combined signal. For example, the modulation signals could have the same frequency and a phase which differs by an amount other than 90 degrees. Alternatively, the modulation signals could have slightly different frequencies thus giving rise to a continuously varying phase difference between the two signals.

In the first embodiment, a passive resonator is used in the sensor element 162. However, in some circumstances it may be advantageous to use a powered resonator so that the signal induced in the resonator is considerably amplified, thus reducing the requirements on the signal processing circuitry.

Instead of detecting the phase of the information carrying components of the combined signal, it is also possible to perform parallel synchronous detection of the combined signal, one synchronous detection using an in-phase modulation signal and the other synchronous detection using a quadrature modulation signal, and then to perform an arctangent operation on the ratio of the detected magnitudes of the demodulated signals. In such an embodiment, by using excitation signals which comprise a carrier frequency signal and a modulation signal so that the modulation signals can have a relatively low frequency, the detection of the magnitude of the modulation signals and the ensuing arctangent calculation (or reference to a look-up table) can be performed in the digital domain after down-conversion from the carrier frequency. An alternative method of detection of the information carrying part of the signal after down-conversion from the carrier frequency signal to baseband is to perform a fast Fourier transform detection. As will be appreciated, this could be done either using some additional specialised dedicated hardware (e.g. an application specific integrated circuit) or by suitably programming the microprocessor. Such a method of detection would be particularly convenient in an arrangement in which more than one degree of freedom of movement of a target is to be detected.

It is preferable that the phase of the carrier signal is identical in all of the transmit coils, as in the first embodiment, as otherwise a phase shift is induced in the information carrying modulation signal which introduces a phase error and hence a position error (this happens because the gain of the synchronous detector is sensitive to the phase of the carrier signal). It is therefore preferable to use a common carrier signal and to provide similar paths from the signal generator to the coil drivers.

In the first embodiment, the modulating signals are described as digital representations of sinusoidal signals. This is not strictly necessary and it is often convenient to use modulating signals that can be more easily generated using simple electronics. For example, the modulating signals could be digital representations of triangular waveforms. The phase of the modulation can be decoded in the usual way by only looking at the fundamental frequency of the modulated signals, i.e. by filtering out the higher harmonics present in the triangular waveform. Note that some filtering will be performed as a result of the physical and electrical properties of, and the electromagnetic coupling between, the transmit and receive aerials. Alternatively, if no filtering is used, the zero crossing point of the demodulated waveform will still vary with the target position in some predictable, albeit non-linear, manner which could be converted to a linear measurement of position by using look-up table or a similar technique.

In order to minimise susceptibility to unwanted noise derived from, for example, an external device, one or more additional sense coils may be added to the basic structure of the receive aerial in order to balance the first sense coil. Such additional coils are preferably displaced in a direction transverse to the measurement path such that the signal received by the sense coils does not vary with the relative position of the two moveable members. However, because the detected signal is a combined signal in which only the phase information is required, it is not essential for this to be the case.

In the water level sensor 60 of the first embodiment, the measurement path extends only over a single period of the spatial variation of the two transmit coils (i.e. the sine coil 166 and the cosine coil 9). However, this need not be the case and the measurement path could extend over more or less than a single period of the spatial variation of the transmit coils. In such a case, it is preferable to include a mechanism for resolving period ambiguity (i.e. the fact that the basic phase of the information carrying component of the combined signal will be identical for the same corresponding position in different spatial periods of the transmit coils). Mechanisms for overcoming spatial period ambiguity which can be employed include providing a single reference position detected, for example, by a single location position sensor (e.g. by having a single localised transmit coil transmitting a third transmit signal at a different modulation frequency to add with the first and second transmit aerials, or by using an opto-switch) and thereafter counting the periods from the reference position, and maintaining a record in a register within the microprocessor of the particular period within which the sensor element is currently located. Alternatively, an additional set of transmit coils transmitting at a different modulation frequency (or transmitting in a time multiplexed manner), could be used with either a slightly varying spatial frequency to provide a vernier scale effect, or with a widely varying spatial frequency to provide coarse position detection using a large scale set of transmit coils and fine scale position detection using small scale transmission coils.

In the first embodiment, a modulation frequency of 3.9 kHz is used because it is well suited to digital processing techniques. This generally applies to frequencies in the range 100 Hz to 100 kHz.

In the first embodiment, a carrier frequency of 2 MHz is used. Using a carrier frequency above 1 MHz facilitates making the sensor element small. However, in some applications it may be desirable to use a carrier frequency below 100 kHz, for example if a sheet of non-metallic stainless steel separates the sensor element from the excitation and sensor windings, because the skin depth of the non-magnetic stainless steel is greater at lower frequencies.

Both the interface sensors 70 of the user interface 22 of the first embodiment and the drum mass and vibration sensor of the fourth embodiment detect the position of sensor elements in two dimensions by providing plural pairs of excitation coils, each aligned with a respective different direction. In the described embodiments, the pairs of coils are sequentially interrogated so that the position in each direction is separately calculated. Alternatively, the position could be simultaneously detected in both directions by applying a first pair of excitation signals, in which the carrier signal is respectively modulated by a first pair of modulation signals at a first modulation frequency, to one of the pairs of excitation coils, and a second pair of excitation signals, in which the carrier signal is respectively modulated by a second pair of modulation signals at a second modulation frequency and then filtering the signal induced in the sense coil to isolate the components at the first and second modulation frequencies.

In the second, third and sixth embodiments a PCB-LVDT sensor is used which allows high levels of accuracy due to the high accuracy at which conventional PCB techniques can lay down conductive tracks on a printed circuit board.

Although a specific example of a PCB-LVDT sensor has been described, those skilled in the art will appreciate that this example can be varied. It has been found that:

1. The exact position of the ferrite rod within the hole in the PCB is not critical.

2. The outer diameter of the coils should be of the same order as the length of the ferrite rod. In particular, the outer diameter of the coils should be between 0.5 and 2 times the length of the ferrite rod to achieve optimal measurement.

3. The area covered by the coils should be approximately two to ten times the area of the hole

to achieve optimal measurement.

4. The AC signal applied to the input coil of the PCB-LVDT is preferably in the frequency range of 100kHz to 5MHz.

5. A reasonably linear measurement range of up to 1.5 times the diameter of the hole can be achieved.

Although printed circuit boards have been used in LVDTs which detect displacement parallel to the plane of the printed circuit board, the described PCB-LVDT is able to measure displacements, of the order of 1 to 25mm, perpendicular to the plane of the printed circuit board.

In the described embodiments, a ferrite rod has been used as the core of the PCB-LVDT. Those skilled in the art will appreciate that any other magnetically permeable substance could be used for the core.

In the second, third and fifth embodiment the PCB-LDVT has an inner coil and two outer coils, with an excitation signal being applied to the inner coil in order to induce signals in the outer coil. Those skilled in the art will appreciate that other LDVT configurations could also be used. For example, matched coils could be formed on either side of a printed circuit board, with the match coils being connected in series with each other and in parallel with a pair or matched resistors in order to form a bridge arrangement. In this way, by monitoring the potential difference between the connection point between the two coils and the connection point between the two resistors when a oscillating signal is applied across the two coil, the position of a ferrite rod passing through a whole in the printed circuit board around which the coils are formed can be determined.

In the second embodiment, the comparator outputs a pulse-width modulated signal whose duty factor varies with position of the ferrite rod. Other forms of digital data streams could, however, be output by the comparator.

A larger range of displacement can be achieved by utilising more than one PCB-LVDT. Figures 25A and 25B show an embodiment in which two printed circuit boards 620, 622 are spaced apart with their planes parallel, each printed circuit board having three insulating layers with a coil formed on each insulating layer as in the previously described embodiments. As shown, a rod 624 projects perpendicularly from a planar surface 626 (which could, for example, be the rigid disc attached to the diaphragm of a water level sensor) through holes provided in the printed circuit boards 620, 622.

The rod 624 is generally insulating apart from two ferrite portions 628a, 628b which are spaced apart by a distance which is less than the distance between the two printed circuit boards 620, 622. In particular, the two magnetic portions 628 are spaced so that when the first magnetic portion 628a is within the linear measurement range of the first printed circuit board 620, as shown in Figure 25A, the second magnetic portion 628b is outside the linear measurement range of the second printed circuit board 622. However, as the first magnetic portion 628a leaves the linear measurement range of the first printed circuit board 620 in the direction of the second printed circuit board 622, the second magnetic portion 628b enters the linear measurement range of the second printed circuit board 622, as shown in Figure 25B. In this way, the effective linear measurement range can be almost doubled. Those skilled in the art will appreciate that by using either or both of additional magnetic portions and additional printed circuit boards, the linear measurement range can be still further increased.

As shown in Figure 26, the described PCB-LVDT sensor could also be used in a push button. In Figure 26, the push button comprises a resiliently flexible membrane 640 mounted to one side of a planar substrate 642. The planar substrate has a hole formed therethrough and the membrane 640 is arranged to arc above the hole. A multi-layer printed circuit board 644 is mounted to the face of the substrate 642 opposing the flexible membrane 640, and has a hole which is aligned with the centre of the hole through the planar substrate 643.

An elongated rod 646 is connected to the arced portion of the membrane 640 such that it projects through the hole in the substrate 642 and PCB 644. The rod 646 includes a ferrite portion which is generally aligned with the hole through the PCB 644. The multilayer PCB 644 has coils formed around the hole in the same manner as described with reference to the to the water level sensor of the second embodiment so that when a user presses the arced portion of the membrane 640, movement of the ferrite element 648 is measured.

An advantage of this kind of push button is that the membrane 640 can form a hermetic seal isolating the processing electronics of the push button. This is particularly advantageous in situations where liquids and dirt may come into contact with the push button. For example, this type of switch is particularly advantageous for electrical equipment within medical operating theatres.

It will be appreciated that the switch described in Figure 26 could be used to control a parameter over a range of levels by making the level of depression of the push button correspond to either a corresponding value of the parameter or a rate of change of the parameter. Alternatively, the push button could operate as a switch by making a first position of the push button correspond to an off state and a second position of the push button correspond to an on state.

The push button illustrated in Figure 26 could be combined with a plurality of similar push buttons, preferably utilising a common flexible membrane and a common multi-layer PCB, to form a keyboard.

Although in the described embodiments planar aerials have been formed on printed circuit boards, planar aerials could alternatively be formed on other planar substrates. However, using printed circuit boards is preferred due to the maturity of printed circuit board manufacturing techniques which allow high quality aerials to be made at a relatively low cost.

CLAIMS

1. A sensor comprising:

an enclosure defining a cavity, the enclosure having a moveable portion which has a first surface facing the cavity and a second surface opposing the cavity, wherein the moveable portion is operable to move by an amount dependent upon a pressure difference between a first pressure applied to the first surface and a second pressure applied to the second surface; and

a detector comprising a magnetic field generator operable to generate a magnetic field and a sensor element, the magnetic field generator and the sensor element being mounted to move relative to each other in dependence upon movement of the moveable portion, wherein the detector is operable to generate a detection signal dependent upon the position of the sensor element relative to the magnetic field generator, and therefore the detection signal is indicative of said pressure difference,

wherein the detector comprises at least one winding arranged so that an electric current flowing through the or each winding resulting from the magnetic field generated by the magnetic field generator varies in dependence upon the relative position of the sensor element and the magnetic field generator, and wherein said detection signal is dependent upon said electric current.

2. A sensor according to claim 1, wherein the enclosure has an opening for allowing fluid to communicate with the cavity.

3. A sensor according to claim 2, wherein the opening is formed by one end of a tube, the other end of the tube

communicating with a head portion.

4. A sensor according to claim 3, wherein the moveable portion comprises a diaphragm hermetically separating the head portion into a first chamber and a second chamber, and wherein the tube communicates with the first chamber.

5. A sensor according any of claims 2 to 4, wherein the opening communicates with a container operable to hold a liquid such that when liquid enters the container, gas is trapped in the cavity at a pressure which varies in dependence upon the amount of liquid in the container, whereby said detection signal is representative of the amount of liquid within the container.

6. A sensor according to any preceding claim, wherein the magnetic field generator comprises at least one excitation winding, and wherein said sensor further comprises a signal generator arranged to apply an excitation signal to the or each excitation winding to generate said magnetic field.

7. A sensor according to either claim 5 or claim 6, wherein the excitation winding is provided by a conductive track on a first planar substrate.

8. A sensor according to any preceding claim, wherein said at least one winding comprises a sensor winding provided by a conductive track on a second planar substrate.

9. A sensor according to claims 7 and 8, wherein the excitation winding and the sensor winding are provided on a common planar substrate.

10. A sensor according to any of claims 7 to 9, wherein the planar substrate is a printed circuit board.

11. A sensor according to any of claims 7 to 10, wherein said sensor element and said magnetic field generator are mounted to move relative to each other along a rectilinear direction in response to movement of the moveable portion, and wherein the plane of the planar substrate is aligned parallel with said rectilinear direction.

12. A sensor according to any of claims 6 to 11, wherein the excitation winding is electromagnetically coupled to said at least one winding via a resonant circuit having an associated resonant frequency.

13. A sensor according to claim 12, wherein the resonant circuit forms part of the sensor element.

14. A sensor according to either claim 12 or claim 13, wherein the resonant circuit is a passive resonant circuit.

15. A sensor according to either claim 12 or claim 13, wherein the resonant circuit comprises an amplifier for amplifying the power of a signal induced in the resonant circuit.

16. A sensor according to any of claims 12 to 15, wherein the signal generator is operable to generate an excitation signal comprising a periodic carrier signal having a first frequency, the first frequency being substantially equal to the resonant frequency of the resonant circuit, modulated by a periodic modulation signal having a second frequency, the second frequency

being less than the first frequency.

17. A sensor according to any preceding claim, further comprising a processor operable to process the detection signal to determine a value representative of said pressure difference.

18. A sensor according to claim 17 when dependent on claim 16, wherein the processor is operable to measure a timing of a component of the detection signal at the second frequency in order to determine said value representative of said pressure difference.

19. A sensor according to claim 18, wherein the processor is operable to perform digital processing of the detection signal to determine said value representative of said pressure difference.

20. A sensor according to any of claims 6 to 10, wherein said sensor element and said detector are mounted to move relative to each other along a measurement direction in response to movement of the moveable portion, and wherein the plane of the first planar substrate is aligned transverse to said measurement direction.

21. A sensor according to claim 20, wherein the sensor element comprises a magnetically permeable body arranged to move through an aperture defined by the first planar substrate in response to movement of said moveable portion,

wherein said planar substrate comprises multiple planar layers, the excitation winding being provided on a first layer surface of the planar substrate, and a first and second sensor windings being respectively provided on second and third layer surfaces of the planar substrate spaced on either side of the first layer surface in the rectilinear direction, and

wherein the excitation winding and the first and second sensor windings are formed by conductive tracks arranged in a spiral around the aperture defined by the first planar substrate.

22. A sensor according to claim 21, wherein the perpendicular distance between the first layer surface and the second layer surface is less than 2mm.

23. A sensor according to claim 21 or claim 22, wherein the perpendicular distance between the first layer surface and the third layer surface is less than 2mm.

24. A sensor according to any of claims 21 to 23, wherein each of the excitation winding and the first and second sensor windings covers a respective area which is in the range of two to ten times the area of the hole.

25. A sensor according to any of claims 21 to 24, wherein the signal generator is operable to generate an oscillating signal having a frequency in the range 100kHz to 5MHz.

26. A washing machine comprising:

a container operable to hold liquid;

a drum rotatably mounted to the container;

an inlet operable to introduce liquid into the container;

an outlet operable to drain liquid from the container;

and a sensor operable to determine a value representative of an amount of liquid in the container,

wherein the sensor comprises:

an enclosure defining a cavity and having an opening communicating with the container such that when liquid enters the container, gas is trapped in the cavity at a pressure which varies in dependence on the amount of liquid within the container, wherein the enclosure has a moveable portion which has a first surface facing the cavity and a second surface opposing the cavity, the moveable portion being operable to deform by an amount dependent upon a pressure difference between a first pressure applied to the first surface and a second pressure applied to the second surface;

a detector comprising a magnetic field generator operable to generate a magnetic field and a sensor element, the magnetic field generator and the sensor element being mounted to move relative to each other in dependence upon movement of the moveable portion, wherein the detector is operable to generate a detection signal dependent upon the position of the sensor element relative to the magnetic field generator, and therefore the detection signal is indicative of said pressure difference; and

a processor operable to process the detection signal generated by the detector to determine said value representative of the amount of liquid in the frame,

wherein the detector comprises at least one winding arranged so that an electric current flowing through the or each winding resulting from the magnetic field generated by the magnetic field generator varies in dependence upon the relative position of the sensor element and the magnetic field generator, and wherein said detection signal is dependent upon said electric current.

27. A washing machine according to claim 26, wherein the detector forms part of a controller,

wherein the washing machine further comprising an inlet valve operable to allow liquid to enter the frame via the inlet in response to an inlet control signal generated by the controller; and

wherein the controller is arranged to generate the inlet control signal in dependence upon said value representative of the amount of liquid in the frame.

28. A washing machine according to claim 27, further comprising a weight sensor operable to sense a weight value representative of the weight of items added to the drum for washing,

wherein the controller is operable to generate the control signal in dependence upon said weight value.

29. A connector for connecting a first body to a second body, the connector comprising:

a first part for connection with the first body;

a second part for connection with the second body, wherein the second part is mounted to the first part so as to allow relative movement between the first and second parts along a measurement direction;

a damper operable to apply a damping force to oppose relative movement between the first and second connectors along said measurement direction; and

a position sensor operable to generate a detection signal representative of the relative position of the first and second connectors along the measurement direction,

wherein the position sensor comprises a resonant circuit, having an associated resonant frequency, fixed relative to the first part, at least one excitation winding fixed relative to the second part and at least one sensor winding electromagnetically coupled to the at least one excitation winding via the resonant circuit, the electromagnetic coupling between the at least one excitation winding and the at least one sensor winding varying in dependence upon the relative position of the first and second parts so that when an excitation signal substantially at the resonant frequency is applied to the or each excitation winding, an electric signal is induced in the or each sensor winding indicative of the relative position of the first and second parts.

30. A connector according to claim 29, further comprising resilient biassing means operable to apply a bias force urging the first part towards a datum position relative to the second part.

31. A connector for connecting a first body to a second body, the connector comprising:

a first part for connection with the first body;

a second part for connection with the second body, wherein the second part is mounted to the first part so as to allow relative movement between the first and second parts along a measurement direction;

resilient biassing means operable to apply a bias force urging the first part towards a datum position relative to the second part; and

a position sensor operable to generate a detection signal representative of the relative position of the first and second connectors along the measurement direction,

wherein the position sensor comprises a resonant circuit, having an associated resonant frequency, fixed relative to the first part, at least one excitation winding fixed relative to the second part and at least one sensor winding electromagnetically coupled to the at least one excitation winding via the resonant circuit, the electromagnetic coupling between the at least one excitation winding and the at least one sensor winding varying in dependence upon the relative position of the first and second parts so that when an excitation signal substantially at the resonant frequency is applied to the or each excitation winding, an electric signal is induced in the or each sensor winding indicative of the relative position of the first and second parts.

32. A connector according to any of claims 29 to 31, wherein the excitation winding is provided by a conductive track on a planar substrate.

33. A connector according to any of claims 29 to 31, wherein the sensor winding is provided by a conductive track on a planar substrate.

34. A connector according to claims 32 and 33, wherein the excitation winding and the sensor winding are provided on a common planar substrate.

35. A connector according to any of claims 32 to 34, wherein the planar substrate is a printed circuit board.

36. A connector according to any of claims 32 to 34, wherein the planar substrate is aligned along said linear direction.

37. A connector according to any of claims 29 to 36, wherein the resonant circuit is a passive resonant circuit.

38. A connector according to any of claims 29 to 36, wherein the resonant circuit comprises an amplifier for amplifying the power of a signal induced in the resonant circuit.

39. A connector for connecting a first body to a second body, the connector comprising:

a first part for connection with the first body;

a second part for connection with the second body, wherein the second part is mounted to the first part so as to allow relative movement of the first and second parts along a measurement direction;

a damper operable to apply a damping force to oppose relative movement between the first and second parts along said measurement direction; and

a position sensor operable to generate a detection signal representative of the relative position of the first and second parts along the measurement direction,

wherein the position sensor comprises a magnetically permeable body mounted to the first part and at least one planar substrate mounted to the second part, the or each planar substrate defining an aperture through which the measurement direction of the magnetically permeable body passes, and

wherein at least two planar windings, spaced apart along the measurement direction, are provided on said at least one planar substrate, each planar winding being formed in spiral about the aperture so that the inductance of each winding varies in dependence upon the position of the magnetically permeable element in the measurement direction.

40. A connector according to claim 39, comprising three planar windings spaced apart along the measurement direction, wherein the sensor further comprises a signal generator operable to apply an oscillating signal to the middle one of the three planar windings, and wherein the detection signal is obtained by comparing the signals induced in the outer planar windings in response to the oscillating signal being applied to the middle planar

winding.

41. An apparatus according to either claim 39 or claim 40, wherein said at least two planar windings are provided on a common substrate.

42. A connector according to claim 41, wherein the common substrate is a multi-layer substrate.

43. A connector according to any of claims 39 to 42, wherein the at least one planar substrate comprises at least one printed circuit board.

44. A connector according to any of claims 39 to 43, wherein the at least two planar windings are spaced at intervals separated by less than 5mm along the measurement direction.

45. A connector according to any of claims 39 to 44, wherein each of the planar windings covers a respective area which is in the range of 2 to 10 times the area of the aperture.

46. A connector according to any of claims 29 to 45, wherein the first part comprises one of a piston and a cylinder of a piston and cylinder assembly, and wherein the second part comprises the other of the position and the cylinder of the piston an cylinder assembly.

47. A washing machine comprising:

a housing;

a support frame mounted to the housing, the support frame supporting a rotary drum; and

at least one connector according to any of claims 29 to 46 connected between the housing and the support frame.

48. A material treatment apparatus comprising:

a housing;

a hollow container rotatably mounted to the housing for rotation about an axis;

a sensor element mounted at one axial end of the hollow container;

at least one excitation winding fixed relative to the housing adjacent to said one axial end of the hollow container;

a signal generator operable to apply an excitation signal to the or each excitation winding;

at least one sensor winding electromagnetically coupled to the excitation winding, whereby when the signal generator applies the excitation signal to the excitation winding, an electric signal is induced in the sensor winding which varies in dependence upon the position of the sensor element relative to the support frame; and

a processor operable to process the signal induced in the sensor winding when the excitation signal is applied to the excitation winding to determine a value representative of the position of the sensor element relative to the support frame.

49. A material treatment apparatus according to claim 48, further comprising a support frame mounted to the housing with at least one damper connected between the housing and the support frame,

wherein the hollow container is rotatably mounted to the support frame.

50. A material treatment apparatus according to either claim 48 or claim 49, wherein the at least one excitation

winding is provided on a planar substrate mounted to said housing.

51. A material treatment apparatus according to either claim 48 or claim 49, wherein the at least one sensor winding is provided on a planar substrate mounted to said housing.

52. A material treatment apparatus according to claims 50 and 51, wherein the at least one excitation winding and the at least one sensor winding are provided on a common substrate.

53. A material treatment apparatus according to any of claims 48 to 52, wherein said planar substrate is a printed circuit board.

54. A material treatment apparatus according to any of claims 48 to 52, wherein the plane of the planar substrate is substantially perpendicular to the axis of rotation of the hollow container.

55. A material treatment apparatus according to any of claims 46 to 54, wherein the sensor element comprises a resonant circuit having an associated resonant frequency, wherein the excitation winding is electromagnetically coupled to the sensor winding via the resonant circuit.

56. A material treatment apparatus according to claim 55, wherein the resonant circuit is a passive resonant circuit.

57. A material treatment apparatus according to claim 55, wherein the resonant circuit comprises an amplifier for amplifying the power of a signal induced in the

resonant circuit.

58. A material treatment apparatus according to any of claims 48 to 58, wherein a plurality of spaced apart sensor elements are provided at the axial end of the hollow container.

59. A material treatment apparatus according to any of claims 48 to 58, further comprising a magnetically permeable body extending from one axial end of the hollow container along the axis of rotation,

wherein the magnetically permeable body forms the core of a linear variable differential transducer so that the linear variable differential transducer is operable to measure displacement of the hollow container along the axis of rotation.

60. A material treatment apparatus according to claim 59, wherein the linear variable differential transducer comprises an excitation winding, a first sensor winding and a second sensor winding provided on respective layers of a multi-layer planar substrate.

61. A material treatment apparatus according to any of claims 48 to 60, wherein the material treatment apparatus is a washing machine.

62. An apparatus comprising a main assembly and a subsidiary component detachably mountable to the main assembly, wherein the main assembly is operable to identify and cooperate with the subsidiary component when the subsidiary component is mounted to main assembly, the subsidiary component comprising:

a storage compartment for storing material to be processed using the main assembly; and an identifier having at least one resonant circuit defining identification data identifying a property of the subsidiary component or a property of the material stored in the storage compartment of the subsidiary component,

and the main assembly comprising:

a reader operable to determine the identification data of the identifier of the subsidiary component; and

a controller operable to control the main assembly in dependence upon the identification data determined by the reader.

63. An apparatus according to claim 62, wherein the or each resonant circuit of the identifier has an associated resonant frequency, and wherein the reader is operable to measure the resonant frequency of the or each resonant circuit and to determine the identification data using the or each measured resonant frequency.

64. An apparatus according to either claim 62 or claim 63, wherein each resonant circuit has an associated position, and wherein the reader is operable to detect the position of the or each resonant circuit and to determine the identification data using the or each detected position.

65. An apparatus according to any of claims 62 to 64, wherein the main assembly is a washing machine and the subsidiary component is a basket mountable within the washing machine.

66. An apparatus according to claim 65, wherein the identification data identifies the type of clothes stored in the basket, wherein the controller is operable to

select a wash cycle corresponding to the identified type of clothes.

67. An apparatus according to any of claims 62 to 64, wherein the main assembly is a printing apparatus and the separate component is a process cartridge for the printing apparatus, the process cartridge storing ink.

68. An apparatus according to claim 67, wherein the identification data identifies the type of ink stored in the process cartridge, and wherein the controller is operable to control printing operations in accordance with the determined type of ink.

69. A subsidiary component detachably mountable to a main assembly of an apparatus, wherein the main assembly is operable to identify and cooperate with the subsidiary component when the subsidiary component is mounted to main assembly, the subsidiary component comprising:

a storage compartment for storing material to be processed using the main assembly; and

an identifier having at least one resonant circuit defining an identification data identifying a property of the subsidiary component or a property of the material stored in the storage compartment of the subsidiary component.

70. A push button comprising:

a planar substrate defining an aperture;

an actuator operable to move a magnetically permeable body through the aperture along a measurement direction; and

a sensor for sensing the position of the magnetically permeable body relative to the planar substrate, wherein the sensor comprises at least two planar windings, spaced apart along the measurement direction, provided on said at least one planar substrate, each planar winding being formed in a spiral about the aperture so that the inductance of each winding varies in dependence upon the position of the magnetically permeable element in the measurement direction.

71. A push button according to claim 70, wherein the planar substrate comprises a printed circuit board.

72. A keyboard comprising a plurality of push buttons as claimed in either claim 70 or 71.

73. A keyboard according to claim 72, wherein the plurality of push buttons have a common planar substrate.

74. A keyboard according to either claim 72 or claim 73, wherein the magnetically permeable body of the actuator of each push button is connected to a common membrane.

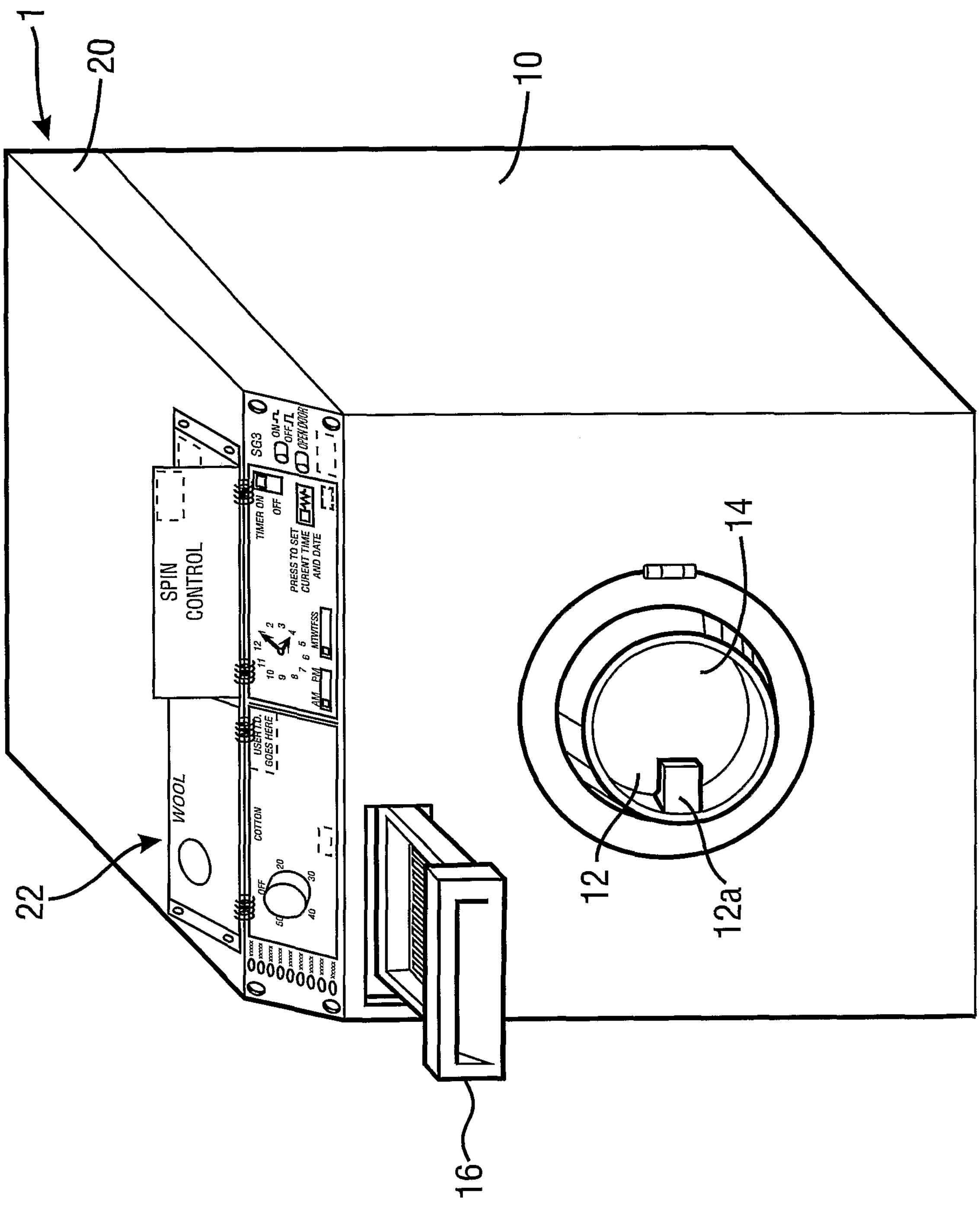

1
20
10
22
SPIN CONTROL
WOOL
COTTON
USER I.D. GOES HERE
TIMER ON
OFF
PRESS TO SET CURENT TIME AND DATE
SG3
ON
OFF
OPEN DOOR
AM PM
MTWTFSS
14
12
12a
16

Fig. 1

Fig. 2

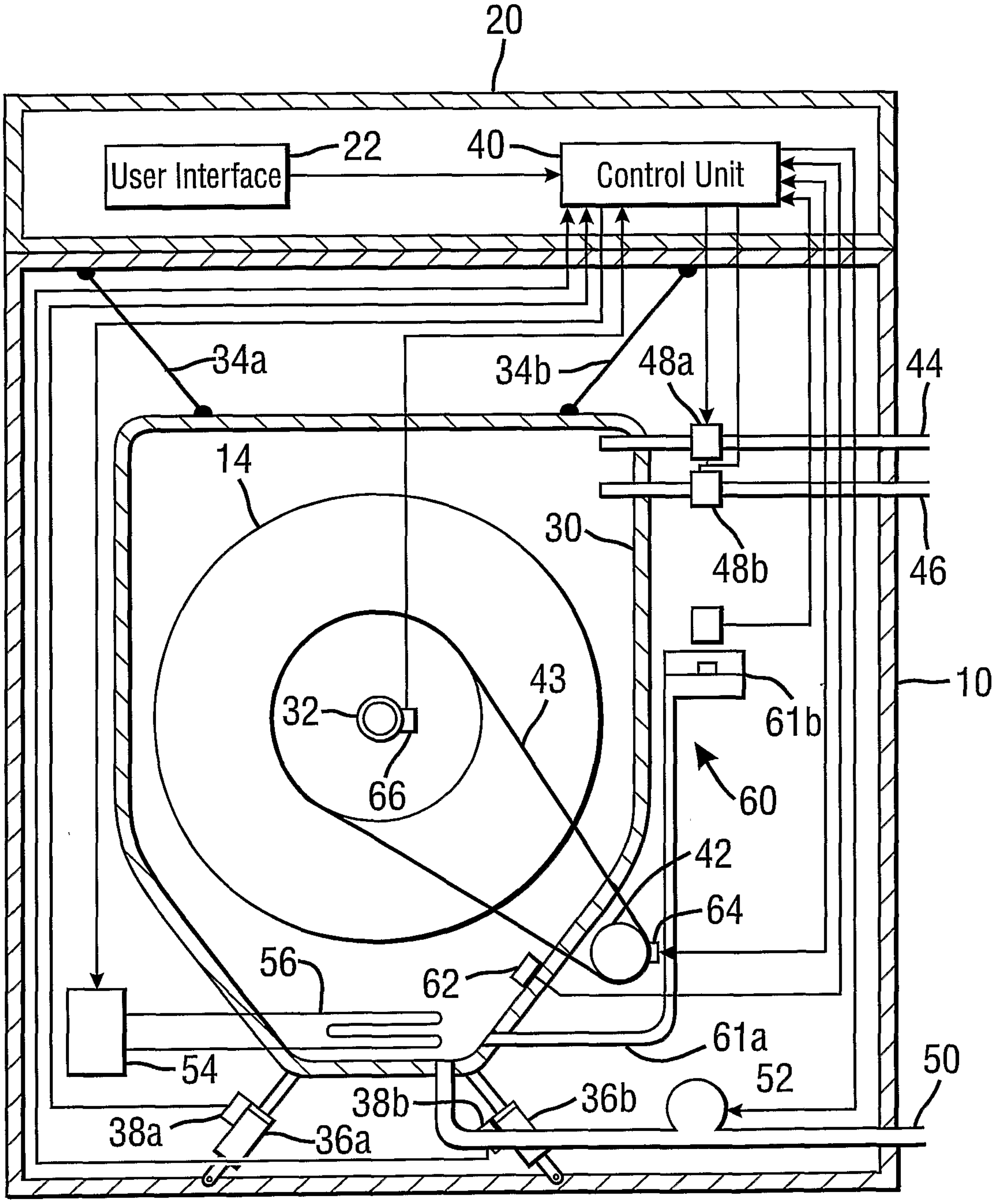

20
User Interface
22
40
Control Unit
34a
34b
48a
44
14
30
48b
46
10
43
32
66
61b
60
42
64
56
62
61a
50
52
54
38b
36b
38a
36a

Fig. 3

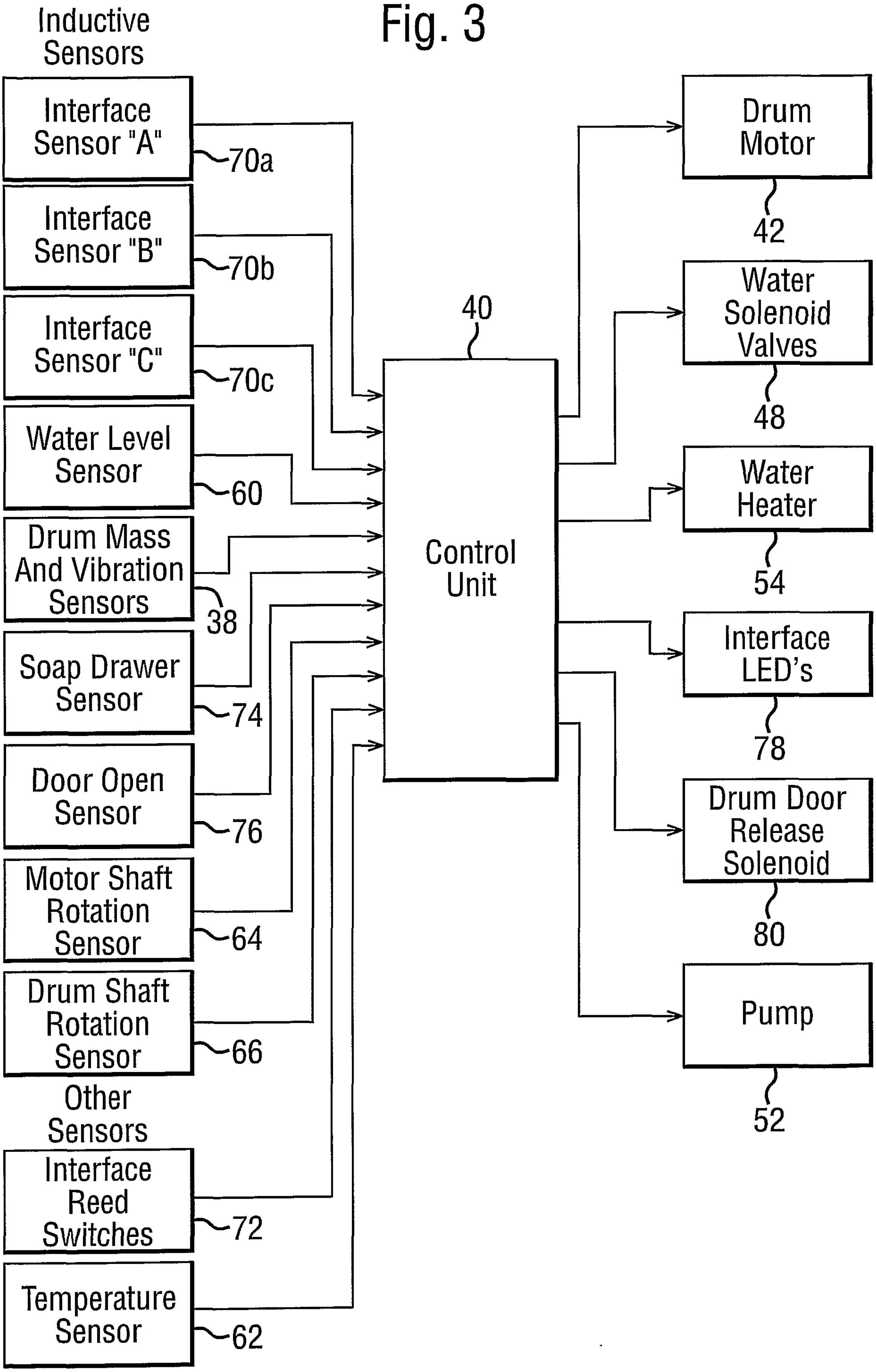
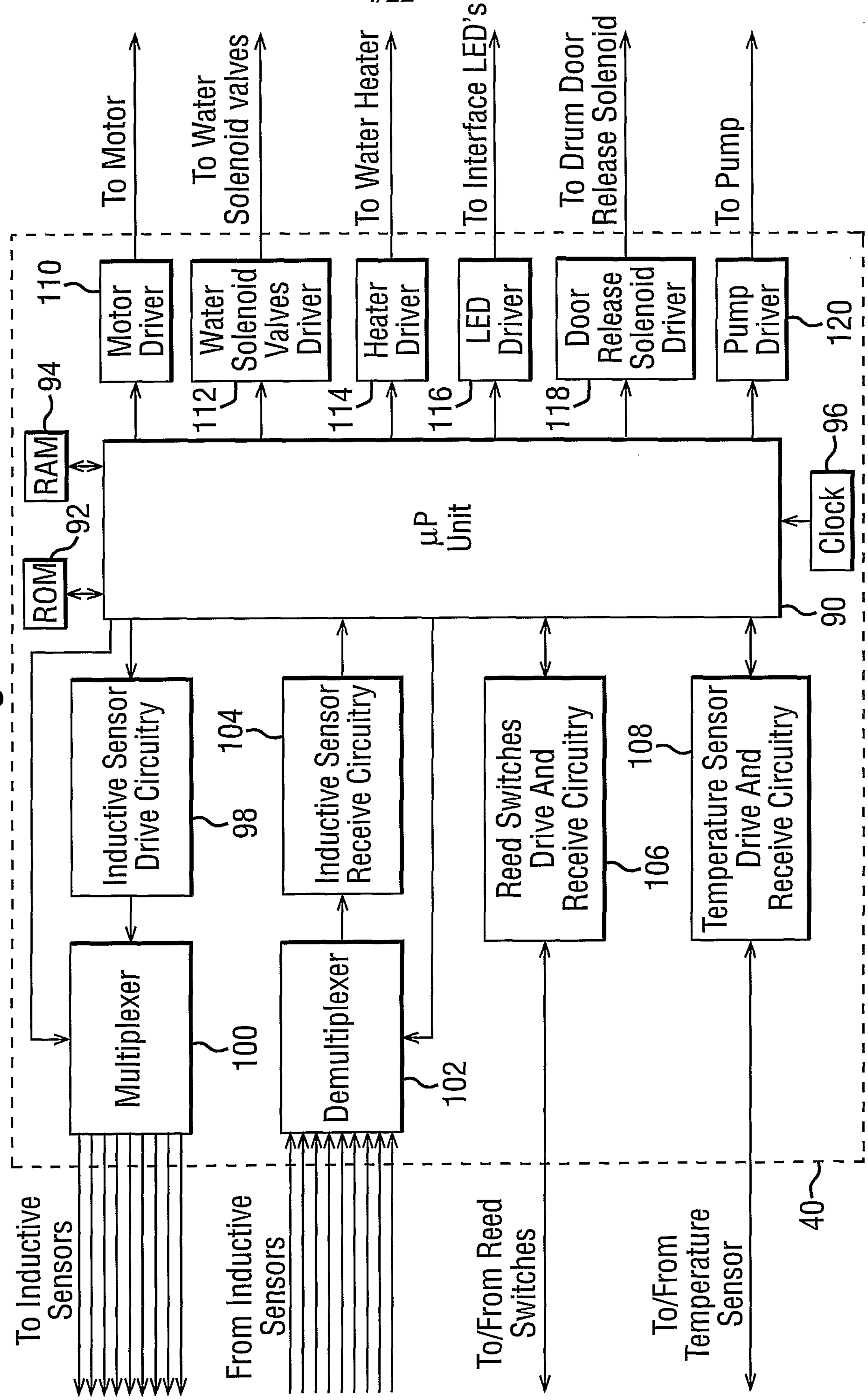

Inductive Sensors
Interface Sensor "A"
70a
Interface Sensor "B"
70b
Interface Sensor "C"
70c
Water Level Sensor
60
Drum Mass And Vibration Sensors
38
Soap Drawer Sensor
74
Door Open Sensor
76
Motor Shaft Rotation Sensor
64
Drum Shaft Rotation Sensor
66
Other Sensors
Interface Reed Switches
72
Temperature Sensor
62
40
Control Unit
Drum Motor
42
Water Solenoid Valves
48
Water Heater
54
Interface LED's
78
Drum Door Release Solenoid
80
Pump
52

Fig. 4


To Motor
To Water Solenoid valves
To Water Heater
To Interface LED's
To Drum Door Release Solenoid
To Pump
Motor Driver
110
Water Solenoid Valves Driver
112
Heater Driver
114
LED Driver
116
Door Release Solenoid Driver
118
Pump Driver
120
RAM
94
ROM
92
µP Unit
90
Clock
96
Inductive Sensor Drive Circuitry
98
Inductive Sensor Receive Circuitry
104
Reed Switches Drive And Receive Circuitry
106
Temperature Sensor Drive And Receive Circuitry
108
Multiplexer
100
Demultiplexer
102
To Inductive Sensors
From Inductive Sensors
To/From Reed Switches
To/From Temperature Sensor
40

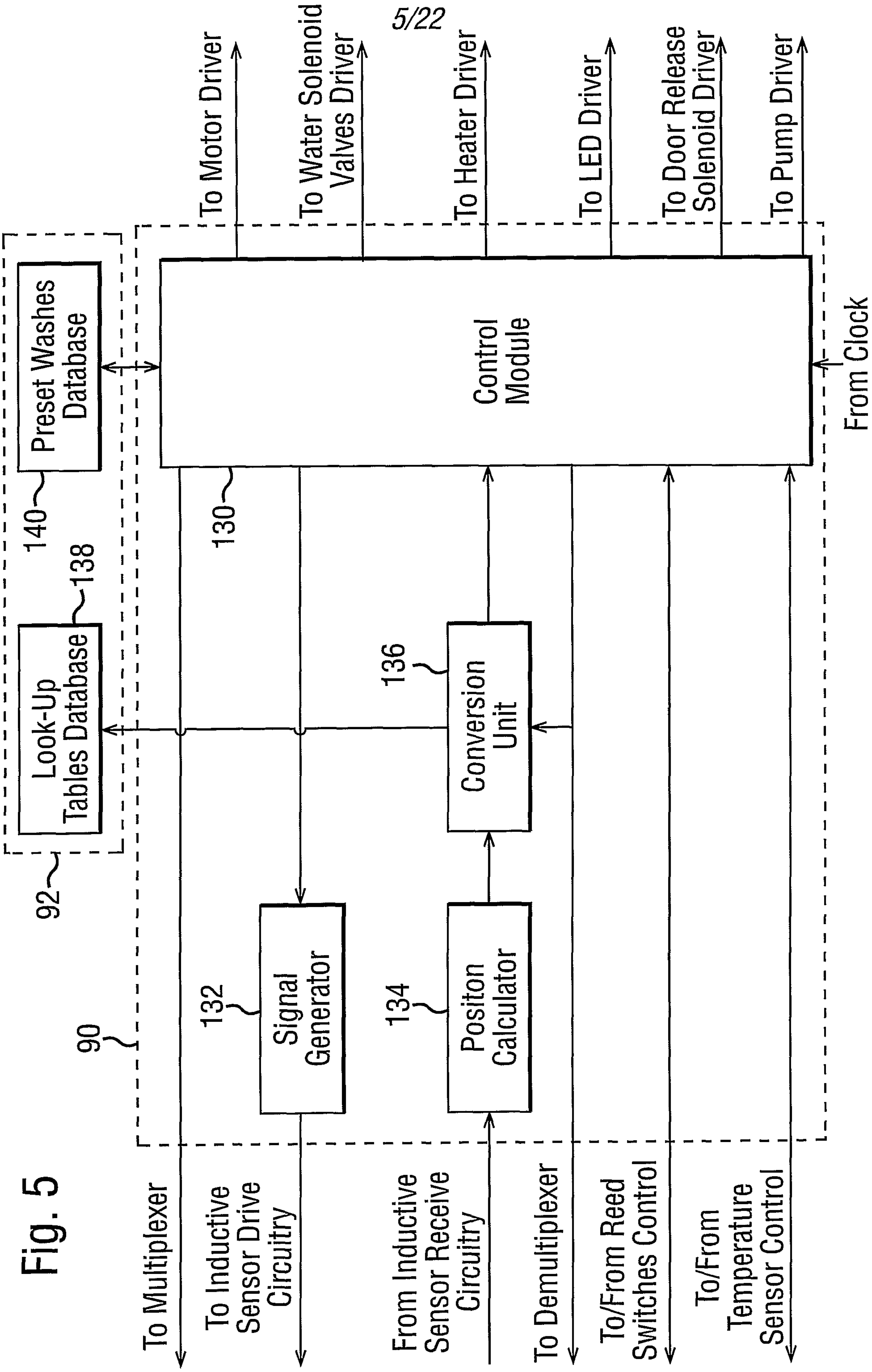

To Motor Driver
To Water Solenoid Valves Driver
To Heater Driver
To LED Driver
To Door Release Solenoid Driver
To Pump Driver
Preset Washes Database
140
Control Module
130
From Clock
138
Look-Up Tables Database
92
136
Conversion Unit
132
Signal Generator
134
Positon Calculator
90
To Multiplexer
To Inductive Sensor Drive Circuitry
From Inductive Sensor Receive Circuitry
To Demultiplexer
To/From Reed Switches Control
To/From Temperature Sensor Control

Fig. 5

Fig. 6A

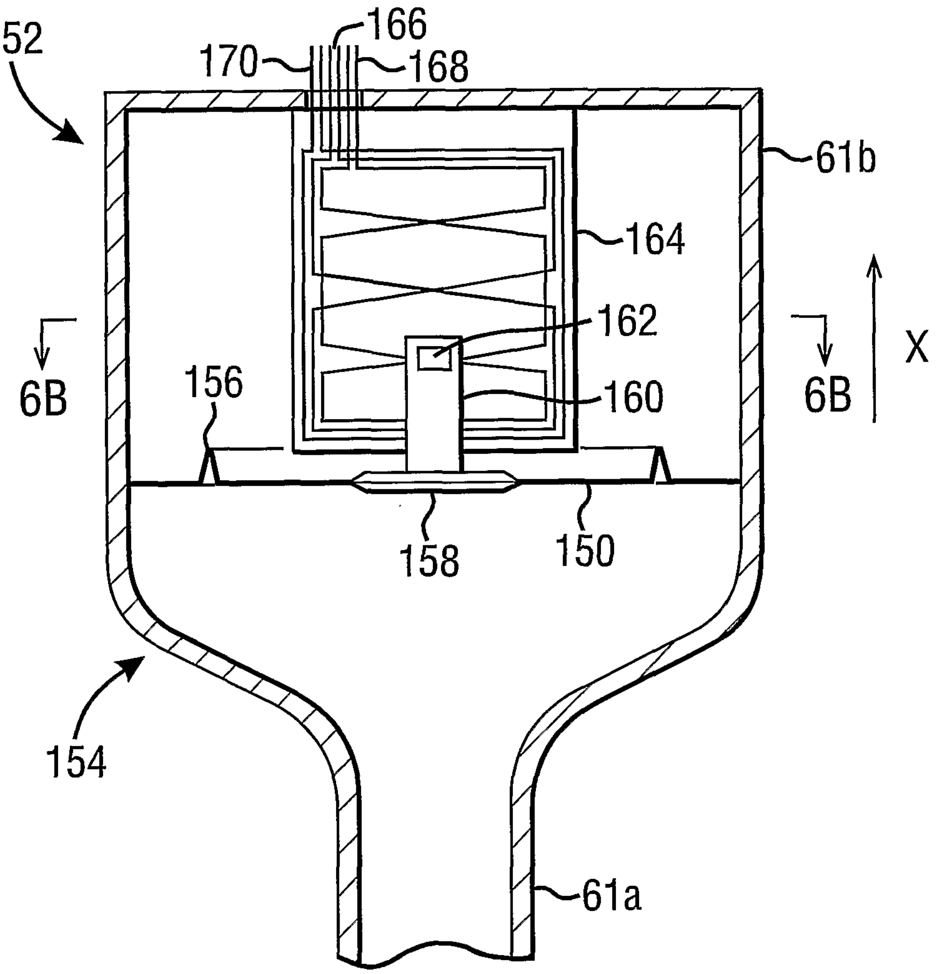

152
166
170
168
61b
164
162
X
6B
6B
156
160
158
150
154
61a

Fig. 6B

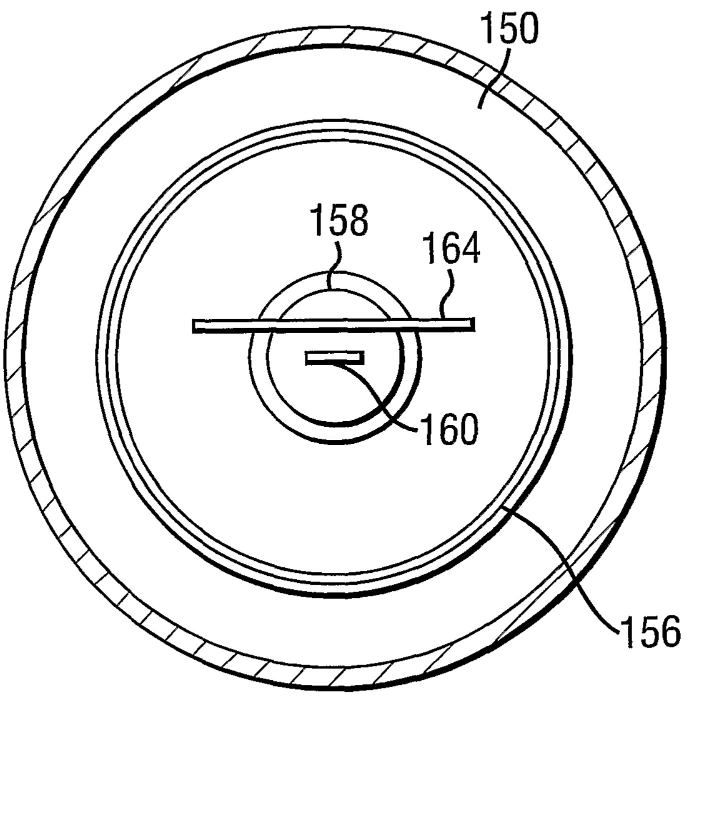

150
158
164
160
156

Fig. 6C

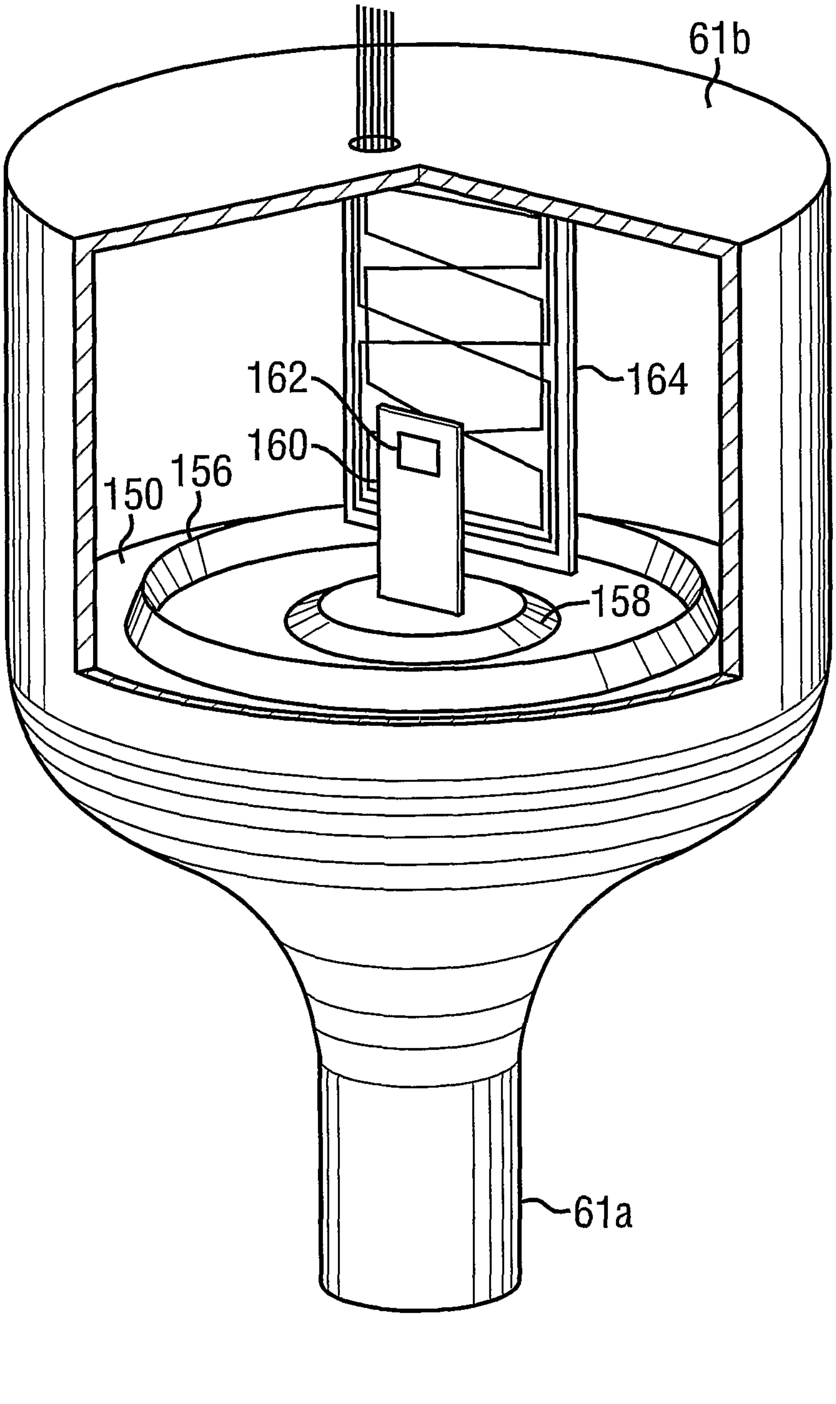


Fig. 7

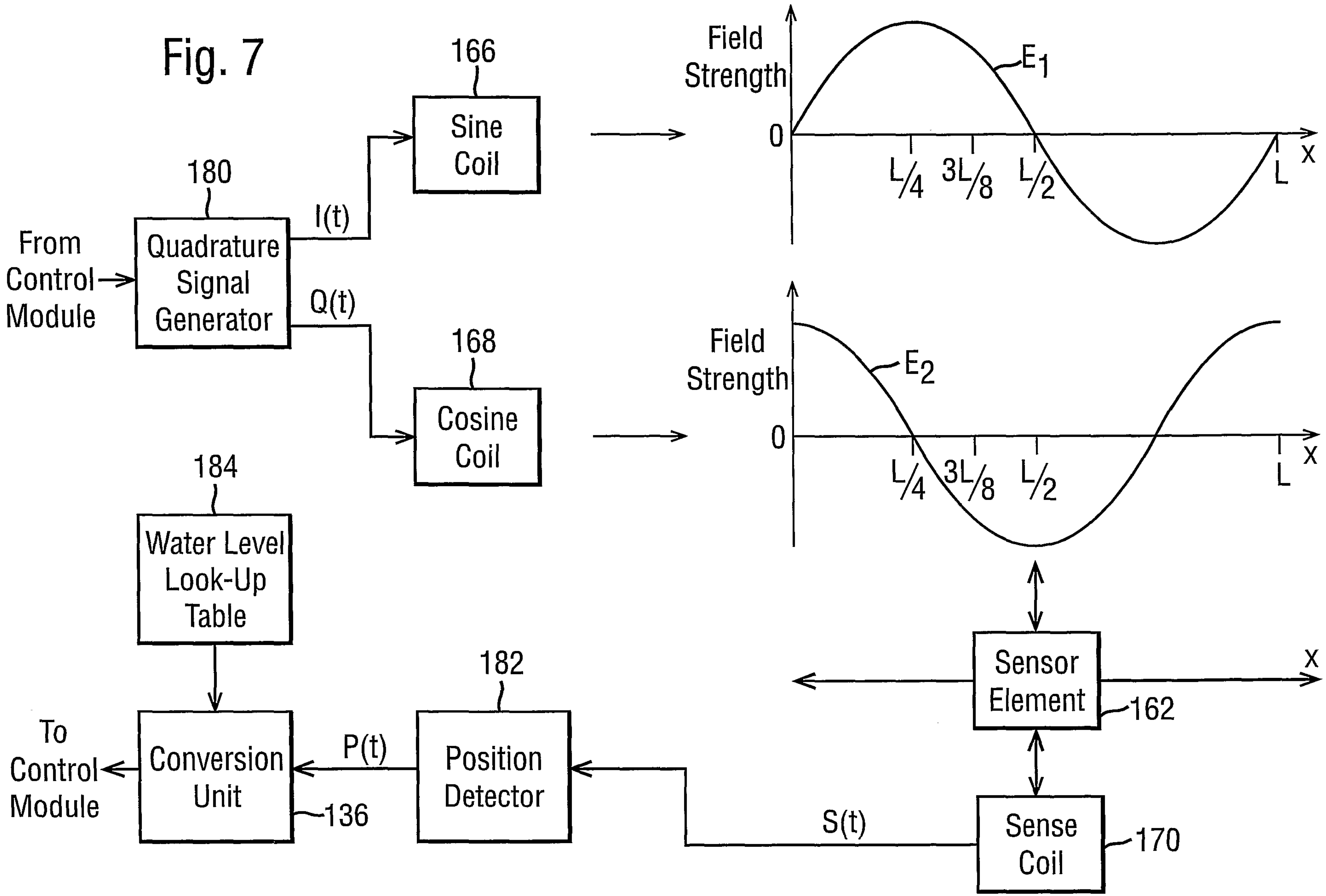

166
Sine Coil
180
Quadrature Signal Generator
From Control Module
I(t)
Q(t)
168
Cosine Coil
184
Water Level Look-Up Table
Conversion Unit
136
To Control Module
P(t)
182
Position Detector
S(t)
Field Strength
0
E1
L/4
3L/8
L/2
L
X
Field Strength
0
E2
L/4
3L/8
L/2
L
X
Sensor Element
162
X
Sense Coil
170

Fig. 8A

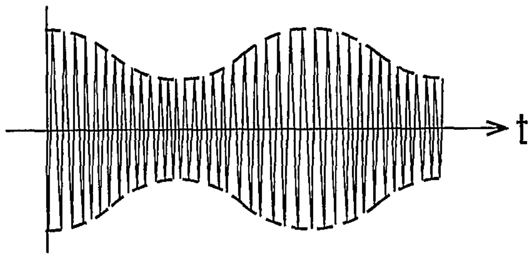


Fig. 8B

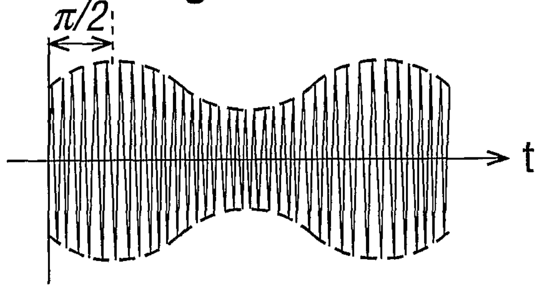
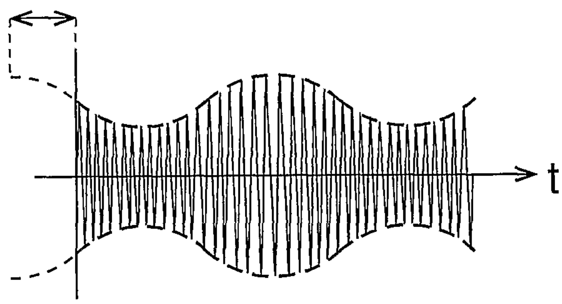


Fig. 8C



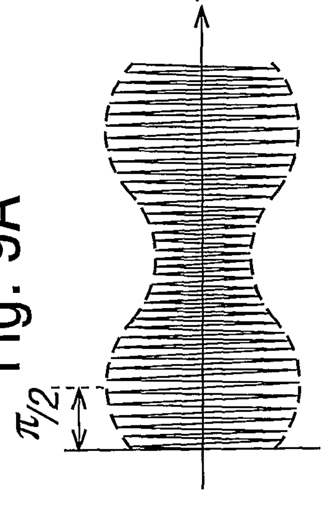


Fig. 9A

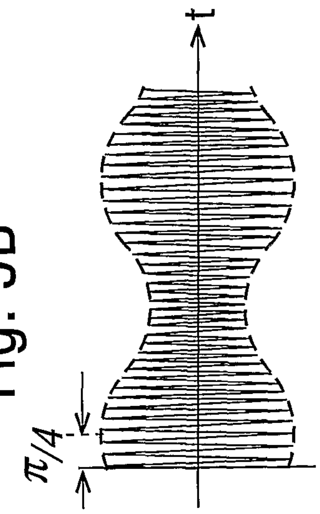


Fig. 9B

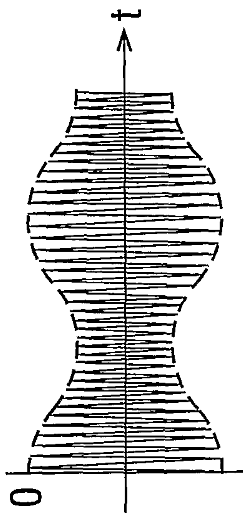


Fig. 19C

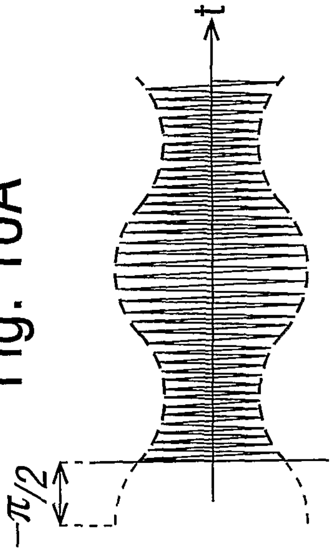


Fig. 10A

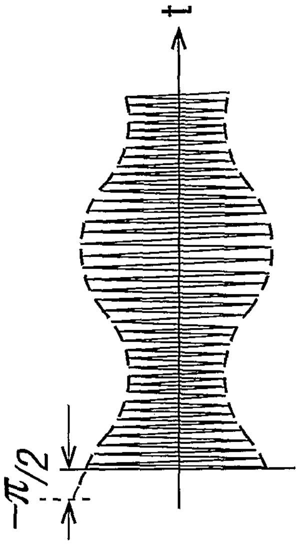


Fig. 10B

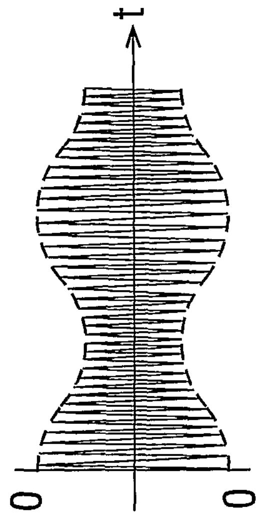


Fig. 10C

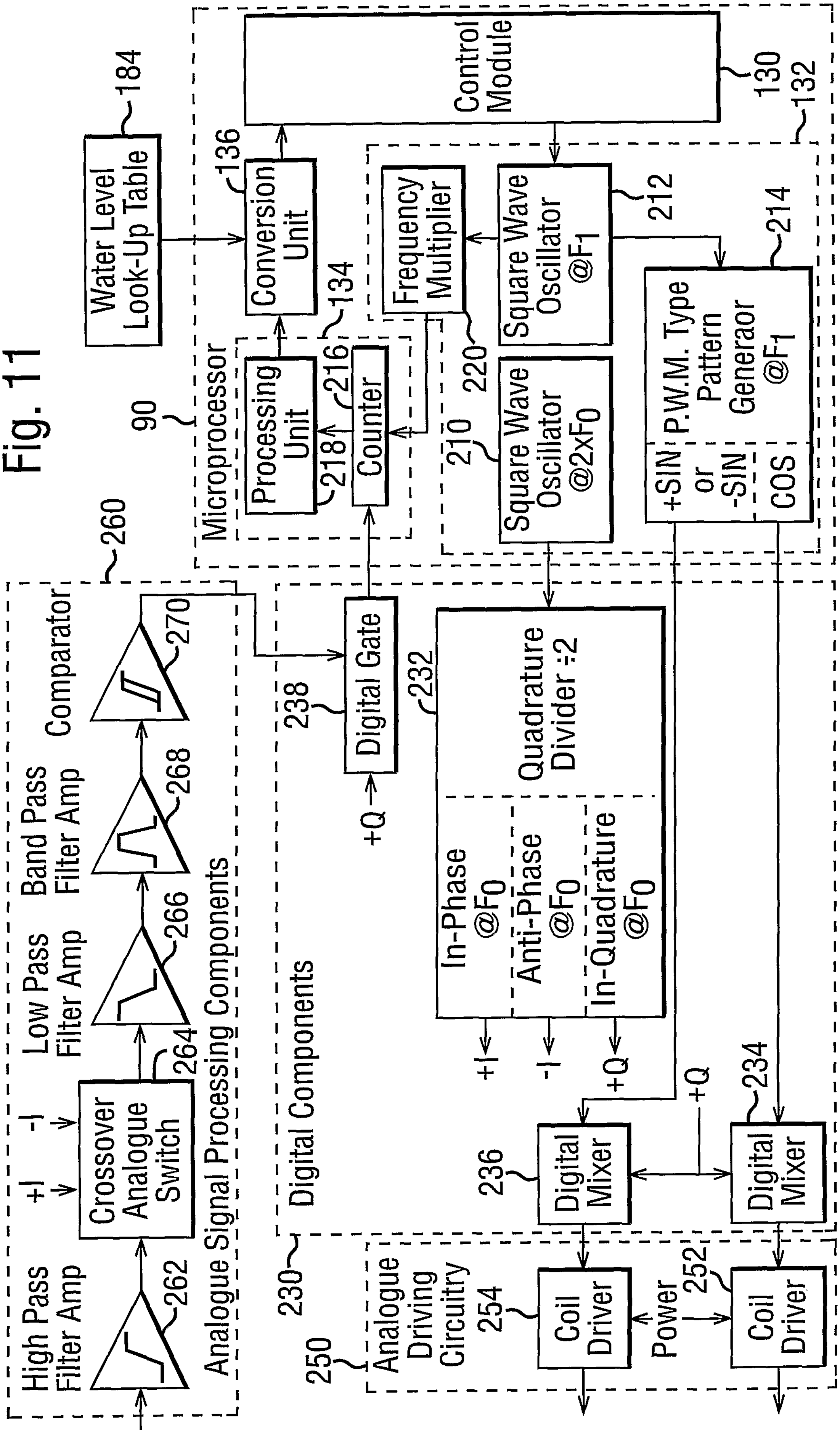

Water Level Look-Up Table
184
Control Module
130
132
136
Conversion Unit
134
Frequency Multiplier
Square Wave Oscillator @F1
212
214
P.W.M. Type Pattern Generaor @F1
+SIN or -SIN
COS
220
Microprocessor
90
Processing Unit
216
218
Counter
210
Square Wave Oscillator @2xF0
260
Comparator
270
Digital Gate
238
232
Quadrature Divider ÷2
+Q
In-Phase @F0
Anti-Phase @F0
In-Quadrature @F0
+I
-I
+Q
+Q
Band Pass Filter Amp
268
Low Pass Filter Amp
266
264
+I
-I
Crossover Analogue Switch
High Pass Filter Amp
262
Analogue Signal Processing Components
Digital Components
236
Digital Mixer
234
Digital Mixer
230
250
Analogue Driving Circuitry
254
Coil Driver
Power
252
Coil Driver

Fig. 11

Fig. 12

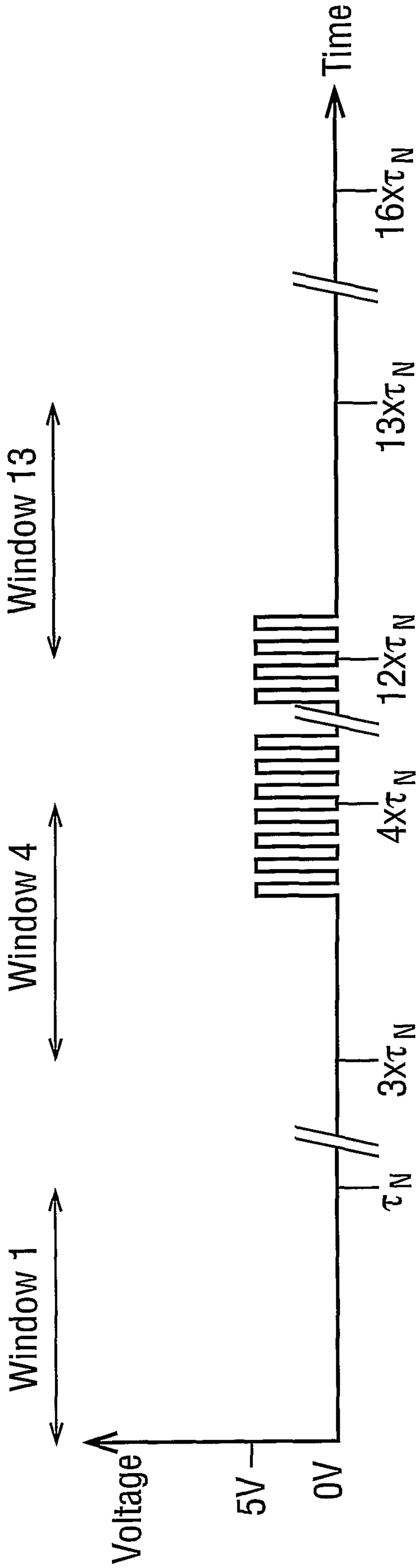
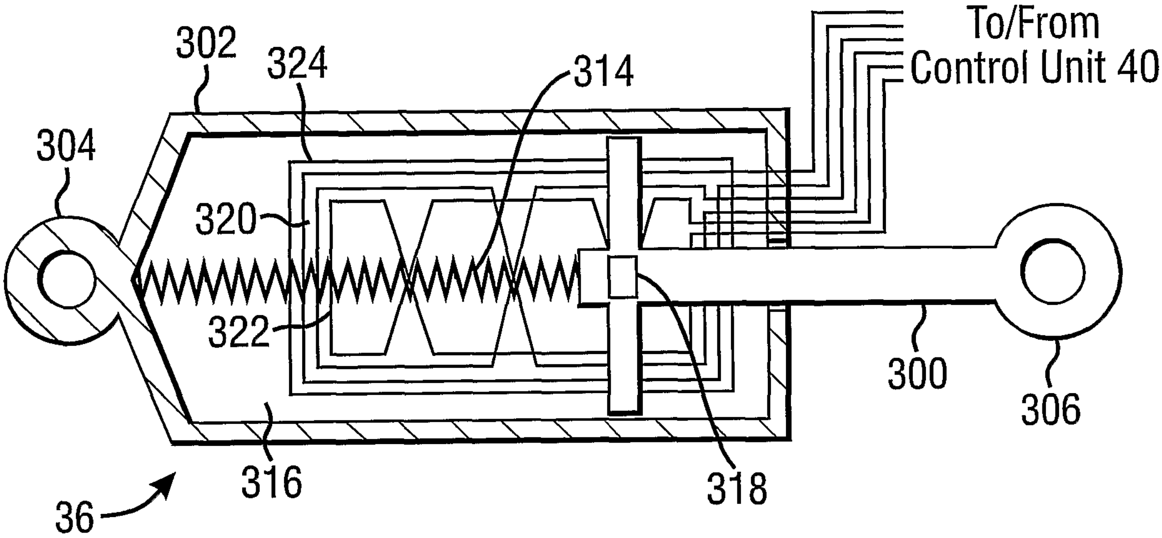

Voltage
5V
0V
Time
Window 1
Window 4
Window 13
τ_N
$3x\tau_N$
$4x\tau_N$
$12x\tau_N$
$13x\tau_N$
$16x\tau_N$

Fig. 13


To/From
Control Unit 40
302
324
314
304
320
322
300
306
316
318
36

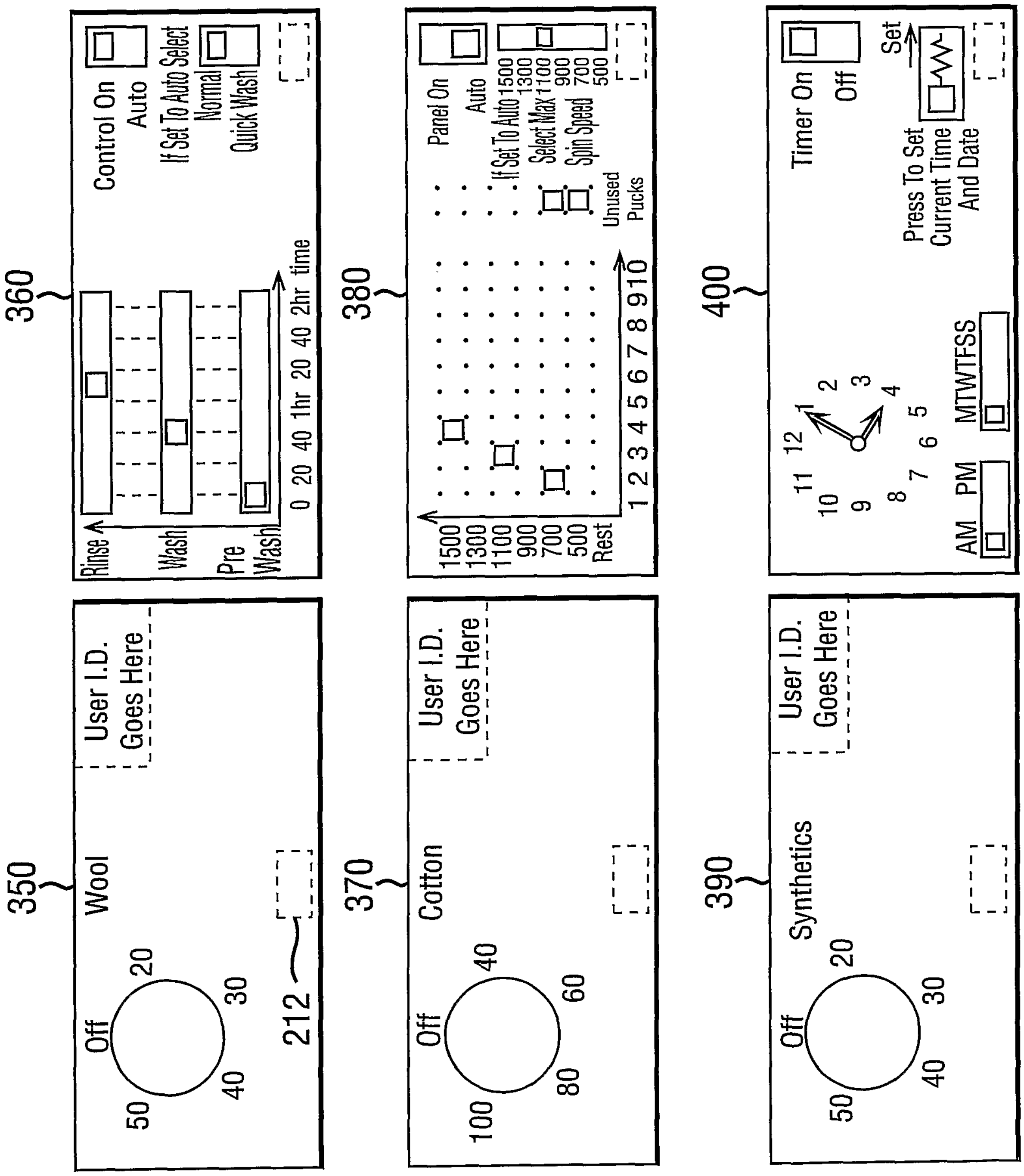


Fig. 14A

Fig. 14B

Fig. 14C

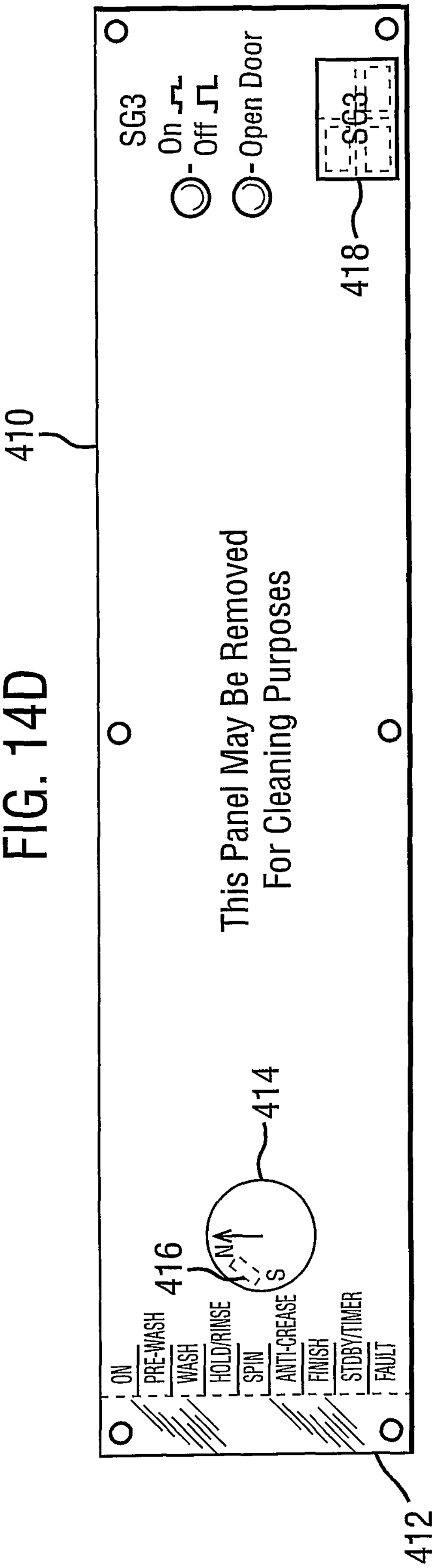


FIG. 14D

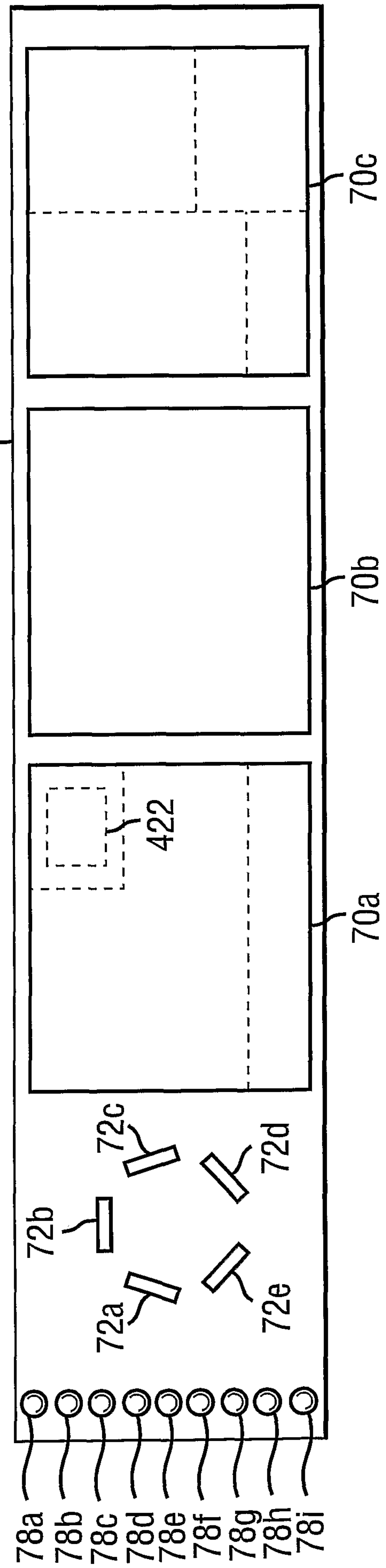


FIG. 14E

Fig. 15A

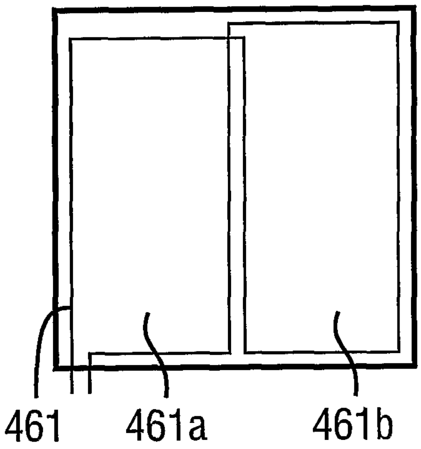


Fig. 15B

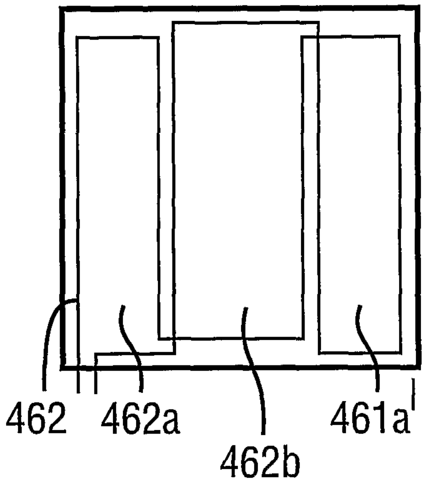


Fig. 15C

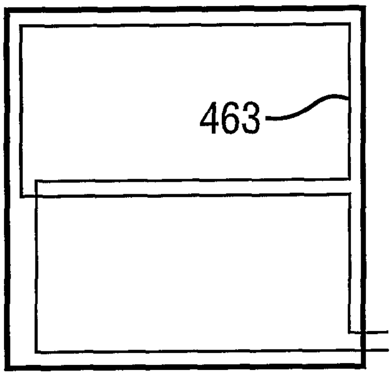


Fig. 15D

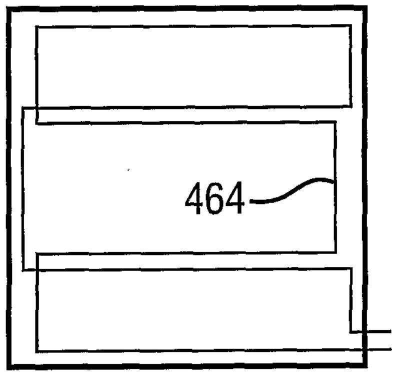


Fig. 15E

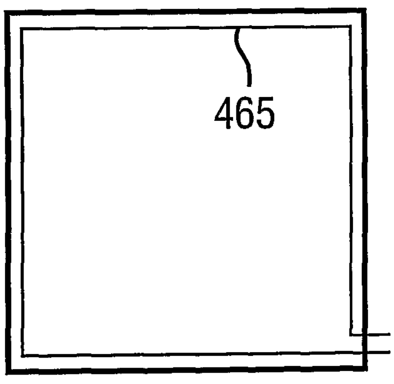


Fig. 15F

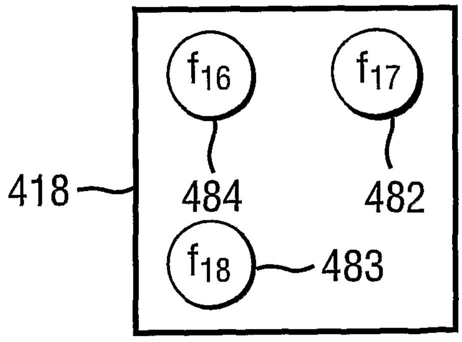


Fig. 16

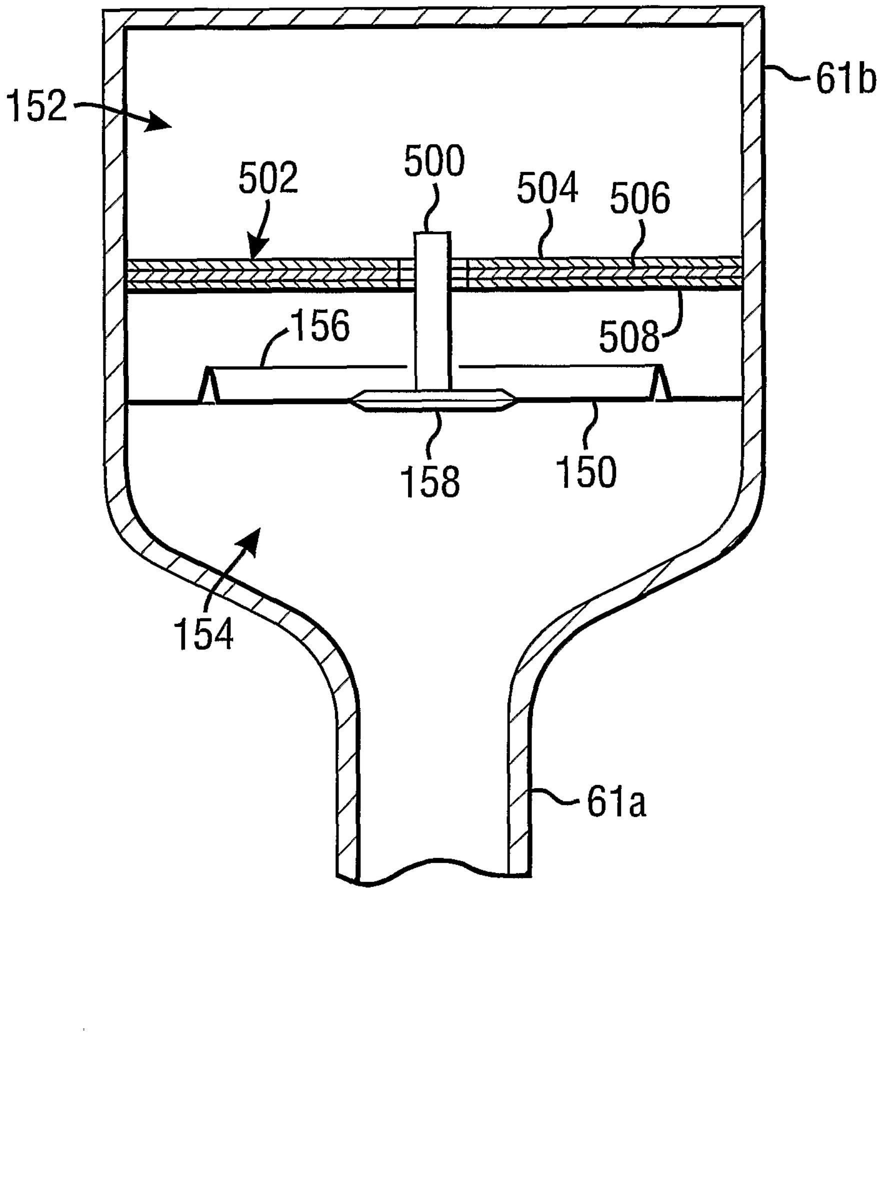


Fig. 17

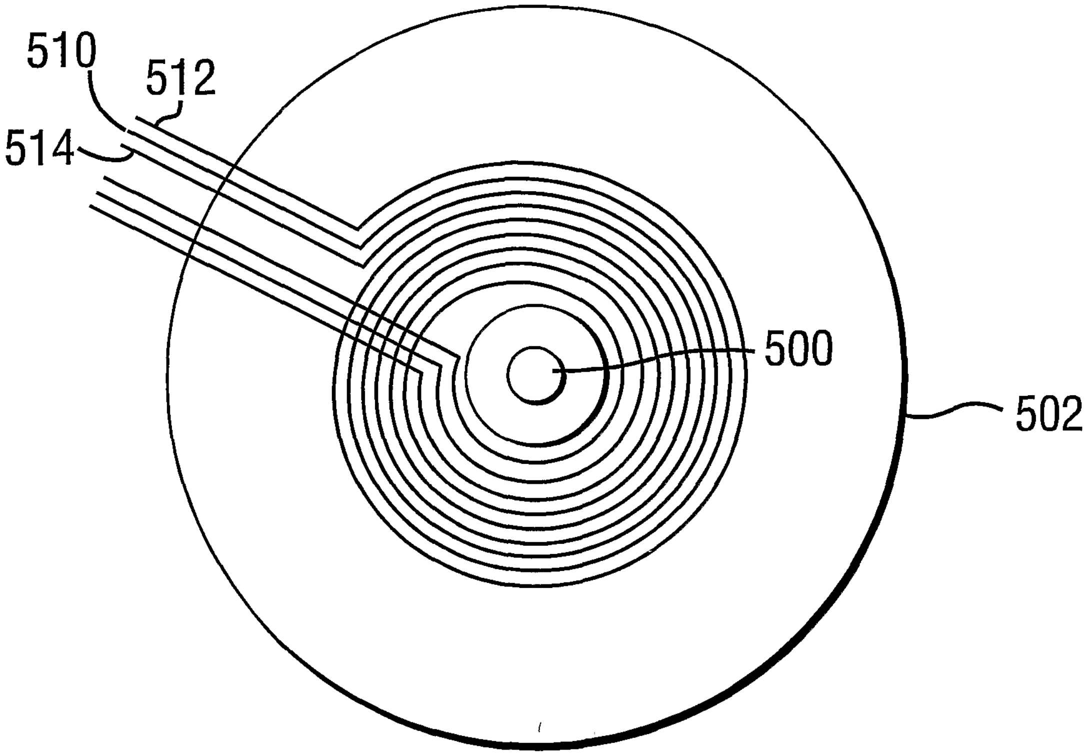

510
512
514
500
502

Fig. 18

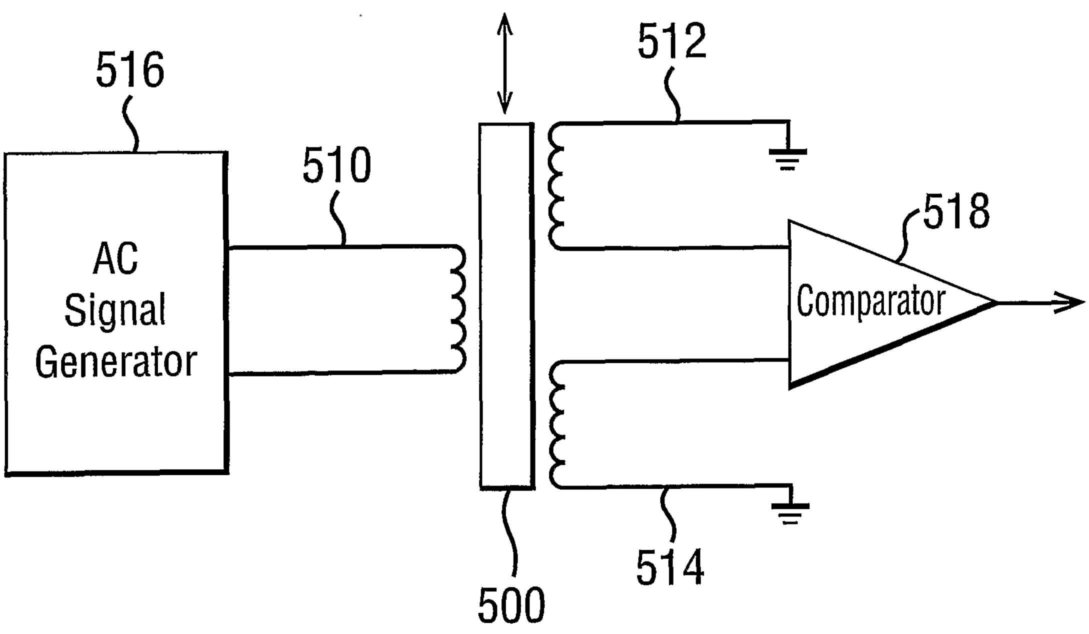

516
AC
Signal
Generator
510
512
518
Comparator
500
514

Fig. 19

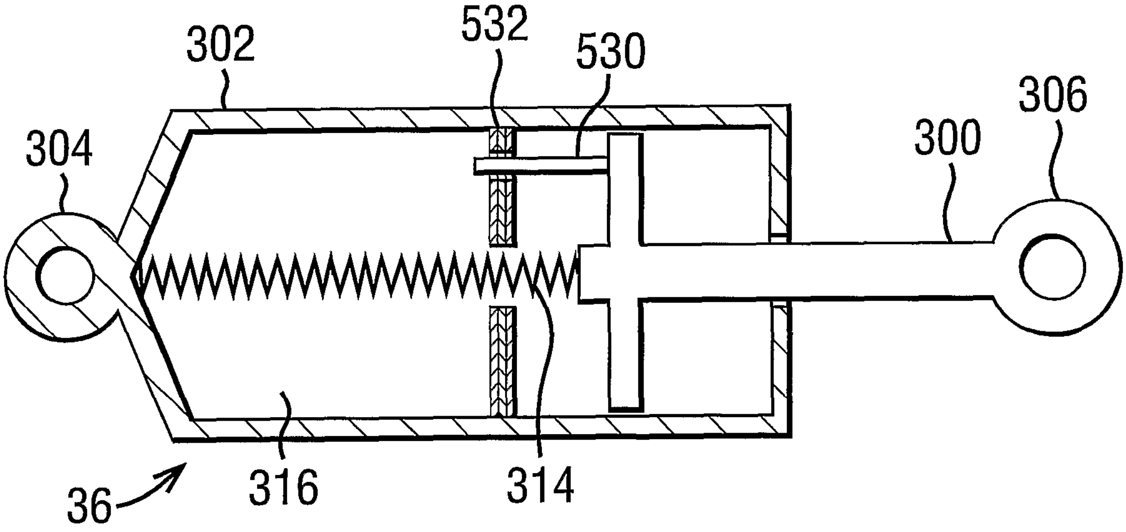


Fig. 20

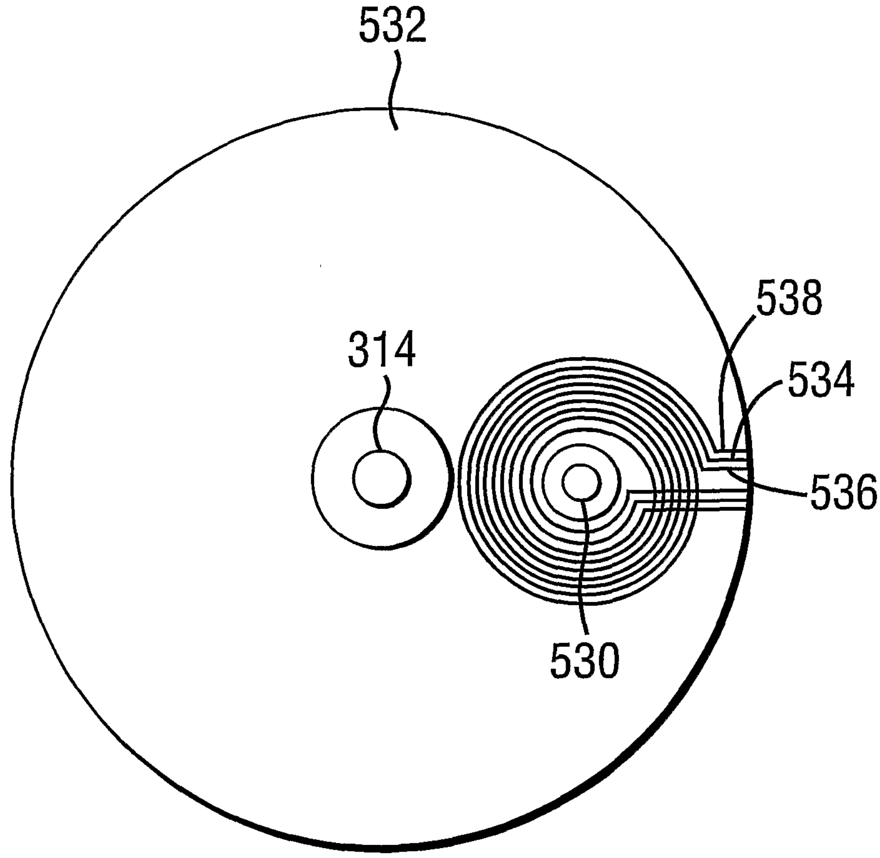


Fig. 21

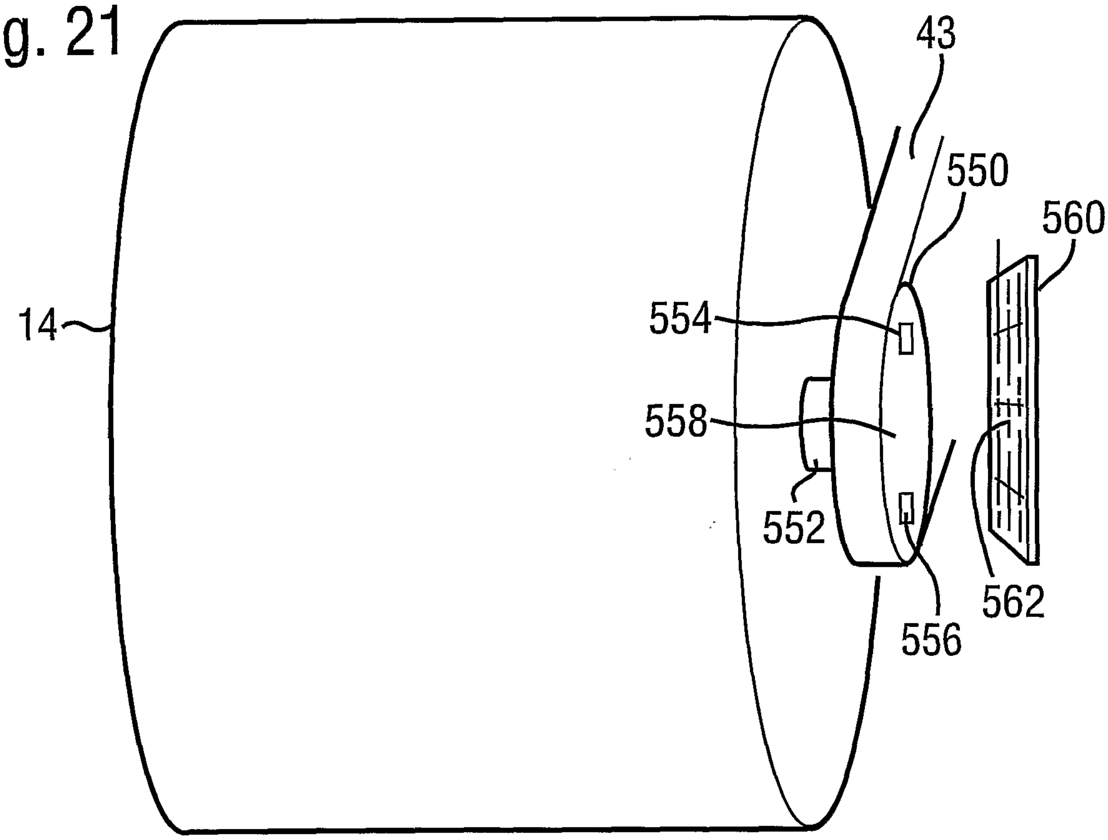

43
550
560
554
14
558
552
562
556

Fig. 22

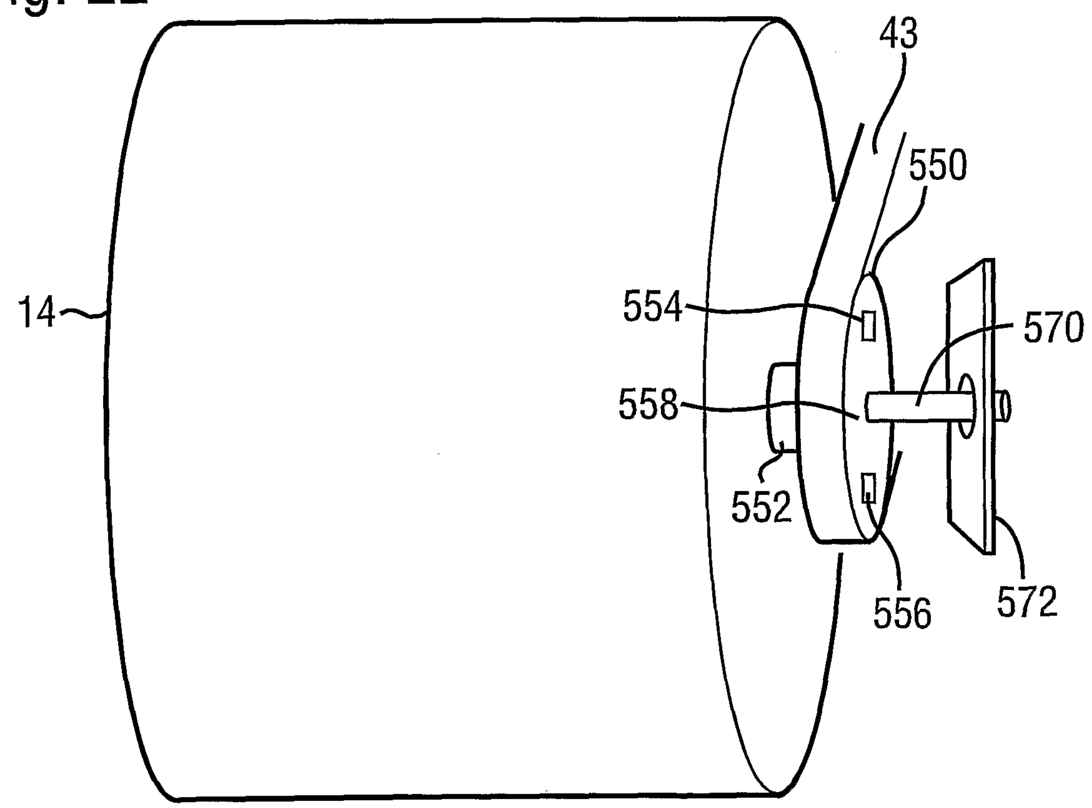

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Fig. 23

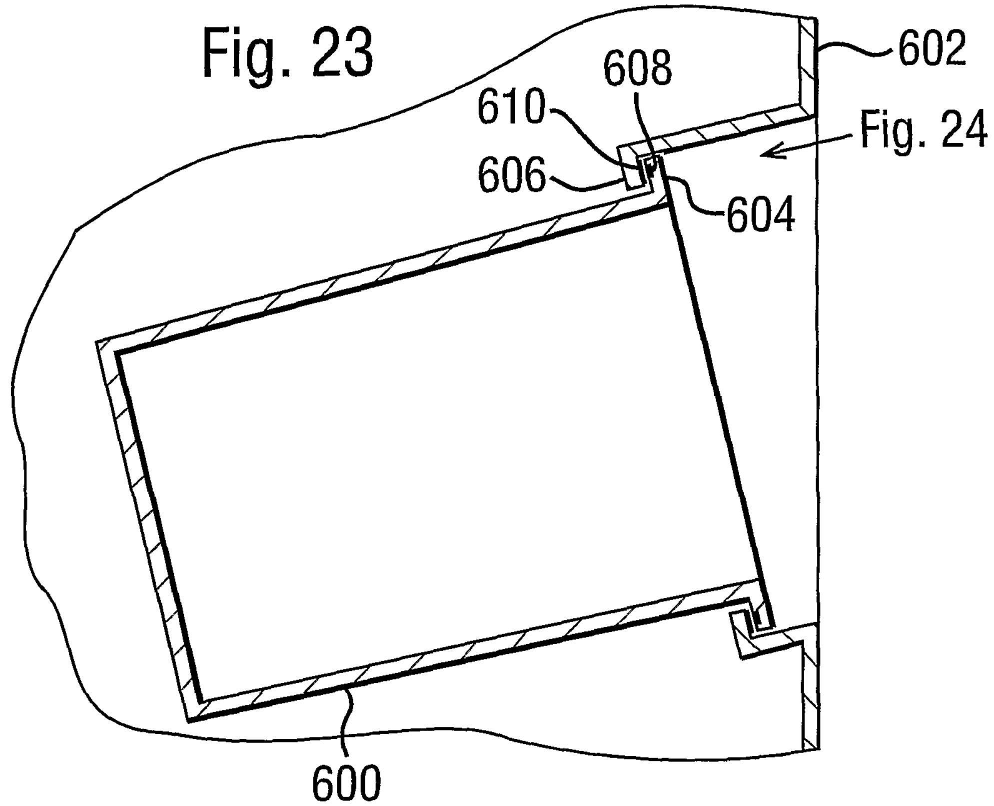


Fig. 24

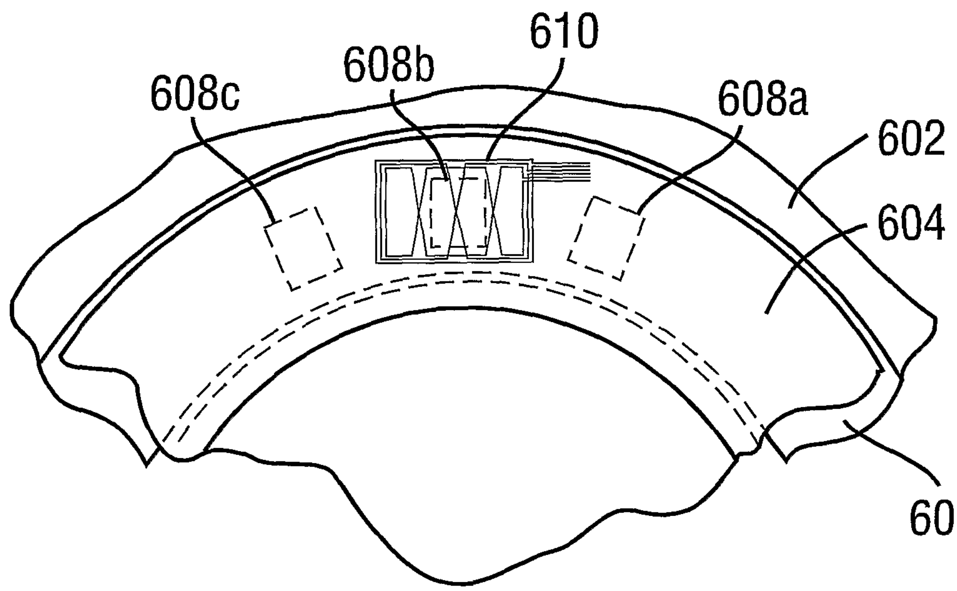


Fig. 25A

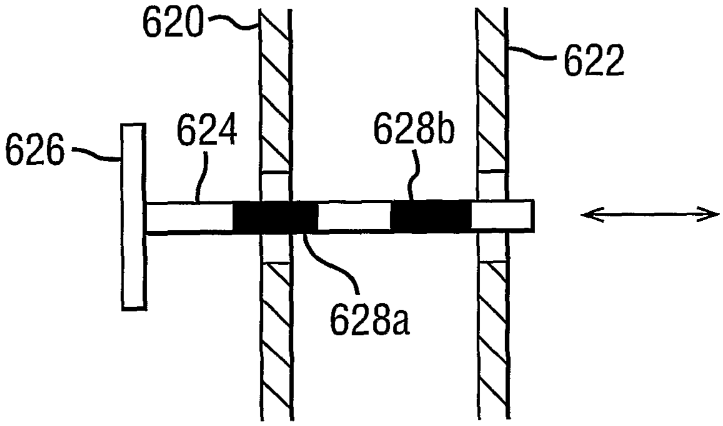


Fig. 25B

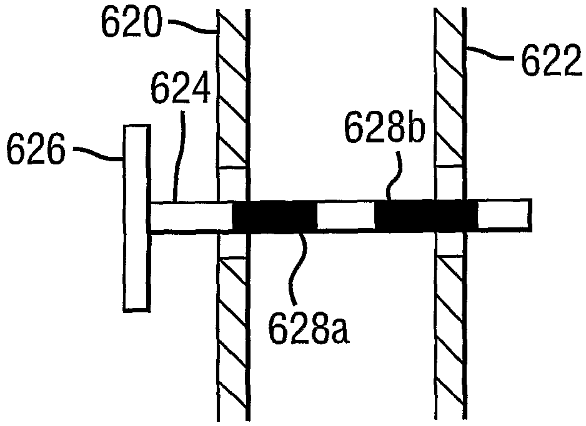
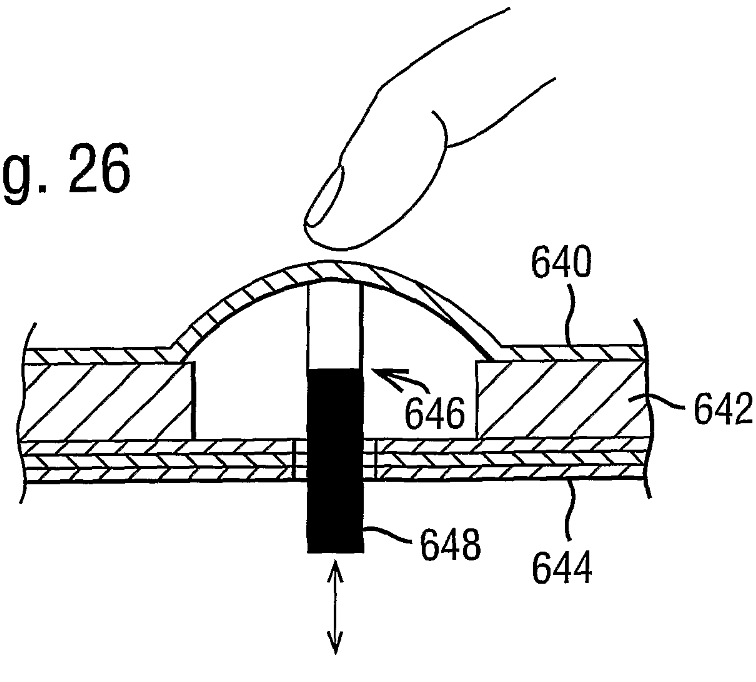


Fig. 26



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 02/01707

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01D5/20 G01F23/16 D06F39/08 D06F39/00

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 7 G01D G01F D06F G01L G07F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	WO 01 42865 A (DOYLE RICHARD ANTHONY ;HOWARD MARK ANTHONY (GB); SCIENT GENERICS L) 14 June 2001 (2001-06-14) cited in the application the whole document	1-61
A	US 4 671 116 A (GLENNON THOMAS F ET AL) 9 June 1987 (1987-06-09) column 2, line 46 -column 3, line 48; figures	1-5, 39-53
A	US 5 793 302 A (STAMBLER LEON) 11 August 1998 (1998-08-11) column 5, line 16 - line 24; figures	16

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

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
6 August 2002	13/08/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ramboer, P

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 02/01707

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