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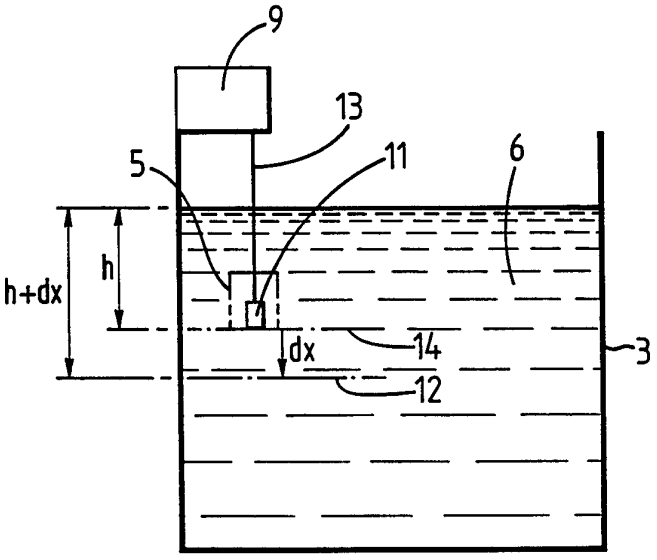
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(54) Title: DENSITY MEASUREMENT



(57) Abstract

A method and apparatus for measuring the density of a liquid (6) within a tank (3) which comprises mounting a pressure transducer (11) for movement at least in a vertical direction in the tank (3), at a first position (14) of the pressure transducer (11) taking a measurement of pressure (P_1), moving the pressure transducer (11) from the first position (14) to a second position (12) spaced from the first position (14) in a vertical direction, at the second position (12) measuring the pressure (P_2), measuring the vertical distance (dx) between the first and second positions; and calculating the difference between the pressure (P_1) at the first position (14) and the pressure (P_2) at the second position (13) and dividing the difference by the vertical distance (dx) between the first and second positions to provide a density measurement. The method and apparatus is applicable with particular advantage to liquid level measuring apparatus of the type known as Tank Gauging Systems.

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DENSITY MEASUREMENT

Field of the Invention

The invention relates to a method and apparatus for measuring the density of a liquid within a vessel.

The invention is applicable with particular advantage to a liquid level measuring apparatus for continuously monitoring the level of a liquid within a tank such as that sold by Whessoe Varec Limited of Heighington Lane Newton Aycliffe County Durham DL5 6XZ as the Intelligent Tank Gauge (referred to as the "ITG"). This tank gauging system is also described in detail in the applicants co-pending US Patent Application numbered 07/824,143.

This type of measuring system comprises a surface following sensing head which in use sits within a tank and is arranged to follow the surface of the liquid as it rises or falls, with the head being coupled to a gauge typically mounted at a fixed distance above the vessel. The distance between the sensing head and the gauge is measured continuously. Tank gauging systems of this type each include a method of accurately measuring the distance between the head and the gauge at any one time. The ITG uses a method which utilises a flexible tape including a plurality of markers which is mounted on a reel. The reel is coupled to a stepper motor and a step counter and the gauge includes a detector which detects the markers on the tape. Thus the number of steps stepped by the motor between the different markers can be counted to give an

accurate indication of the position of the head within the tank. The sensing head in the ITG comprises a capacitive sensing head which is arranged such that it senses any change in capacitance so that if the tank includes a number of immiscible liquids of different densities the head can sense the level of each of the liquids.

Such measuring systems are intended to act as total monitoring systems for liquids held within vessels and thus it is desirable to also include other sensors mounted within the tank to provide measurements of temperature and density of the liquids. At present any density measurement is carried by using a static density meter mounted within the tank. There are a number of methods available for measurement of density. The first is to use a resonant densitometer which is expensive. Alternatively a differential pressure transducer can be used which is again expensive and difficult to manufacture into a density measurement system. Alternatively two pressure transducers can be mounted within a tank to give two pressure readings at different levels within the tank to provide a method of calculating the density. However this can introduce errors given the individual error attaching to each pressure transducer. Moreover the level at which each transducer is to be mounted can be difficult to arrange given that the level of the liquid within the tank may drop beneath one of the pressure transducers thus making a density measurement impossible.

Summary of the Invention

According to the invention there is provided a method of measuring the density of a liquid comprising:-

mounting a pressure transducer for movement at least in a vertical direction in a tank containing a liquid;

at a first position of the pressure transducer, taking a measurement of pressure;

moving the pressure transducer from a first position to a second position spaced from the first position in a vertical direction;

at the second position measuring the pressure;

measuring the vertical distance between the first and second position; and

calculating the difference between the pressure at the first position and the pressure at the second position and dividing the difference by the vertical distance between the first and second positions to provide a density measurement.

Accordingly apparatus for measuring density of a liquid in a tank is provided which comprises:-

a pressure transducer mounted for movement at least in a vertical direction within a tank containing a liquid;

measuring means for continuously monitoring the vertical position of the transducer within the tank; and

microprocessing means coupled to the transducer and to the measuring means for calculating the density of the liquid from two readings of the pressure transducer.

Since pressure at the first position will be equal to the density of the liquid multiplied by the distance between the first position and the surface the difference between the pressures at the first and second position will be equal to the density multiplied by the vertical distance between the first and second position. This means that the density can be readily calculated. Conveniently the apparatus can be arranged to move the pressure transducer 1m between the first and second position in which case the density will be equal to the difference between the two pressure measurements.

Although it is possible for the invention to be applied to a system which only includes density measurement preferably the pressure transducer is mounted upon the sensing head of a liquid level measuring system since in such a system the height of the sensing head is accurately monitored.

As the sensing head moves through the liquid in the tank, pressure measurements can be made continuously. Since the exact position vertically of the head is continuously monitored, successive density measurements can be made. It is preferred that the sensing head is programmed to use

the successive density measurements to calculate and update an average density measurement.

Moreover in the event that the sensing head is a capacitive sensing head a number of different liquids of different densities can be detected. In accordance with this method the apparatus can be used to measure the density of each of the liquids within a tank.

In the ITG system the tape upon which the sensing head is mounted also serves as the power connection between the gauge or gauging head and the sensing head.

In the ITG system a microprocessor is mounted within the gauge at which position calculations of the vertical position of the sensing head take place. The pressure transducer may be arranged to feed signals representing the pressure to the tape which leads to the gauge so that the calculations of density are carried out at the gauge.

It is preferred however that the sensing head has mounted within it a microprocessor such that signals representative of the vertical distance moved by the head (and transducer) are fed from the gauge to the head and the calculation of density takes place at the microprocessor mounted within the sensing head. Signals representative of the density are then fed from the sensing head to the gauge.

The transducer may also be used to take hydrostatic measurements which may be used to obtain the mass of the product.

Brief Description of the Drawings

A liquid level measuring system in accordance with the invention will now be described, by way of an example only, with reference to the accompanying drawings in which:-

Figure 1 is a simplified schematic view of the apparatus mounted in use;

Figure 2 is an exploded schematic view of the apparatus;

Figure 3 is a perspective view of the tape;

Figure 4 is a section through the gauging head;

Figure 5 is a section through section 4;

Figure 6 is an underside view of the marker detector;

Figure 7 is a schematic section through the sensing head;

Figure 8 is a schematic section through figure 7;

Figure 9 is a section along line A-A through figure 8;

Figure 10 is a block circuit diagram of the sensing head;

Figure 11 is a schematic view of a sensing head; and,

Figure 12 is a graph of digital output against distance of head from liquid surface;

Description of the Preferred Embodiment

The apparatus illustrated in the drawings comprises an Intelligent Tank Gauge which is illustrated schematically only in Figure 1. The ITG comprises a surface following sensing head 5 which in use sits within a tank 3 and is arranged to follow the surface of the liquid as it rises or falls. The head 5 is coupled via a tape 13 to a gauge or gauging head 9 mounted at a fixed distance above the vessel. In Figure 1 the mounting means is omitted for clarity. The distance between the gauge 9 and the head 5 is accurately measured by the gauge 9. Within tank 3 is a liquid 6.

Mounted within sensing head 5 is a pressure transducer 11. The nature of the pressure transducer is not material to the invention. In this particular case the pressure transducer is a Druck Series 900 Transducer sold by Druck Limited of Fir Tree Lane, Groby, Leicester LE6 0FH, England. The gauge 9 is arranged such that the position of the sensing head 5 is continuously monitored. In order to measure the density of the liquid 6 the sensing head 5 is moved to a first position 14 whereupon a first pressure measurement is taken and then moved through a height dx to second position 12 whereupon a second pressure measurement is taken.

At the second position, the pressure P_2 will be equal to:-

$$P_2 = \text{density} \times (h + dx)$$

where h is vertical distance of second position from liquid surface

dx is vertical distance between first and second position

At the first position, the pressure P_1, will be equal

to:-

$$P_1 = \text{density} \times h$$

This means that

$$P_2 - P_1 = \text{density} \times (h + dx) - \text{density} \times h$$

Therefore

$$P_2 - P_1 = \text{density} \times dx$$

Thus

$$\text{density of liquid} = \frac{P_2 - P_1}{dx}$$

Thus the density of the liquid can be readily calculated. Preferably dx is arranged to be 1m which eliminates any need for further calculation apart from calculating the difference between the two pressures P_2 and P_1.

The only connection between gauge 9 and head 5 is tape 13 which purely provides two wires which form the plus and minus connection forming the power supply for the head 5.

The apparatus comprises a surface following sensing head 5 which is adapted to follow the surface 7 of the liquid.

A reel 10 is rotatably mounted within the gauging head 9 and has wound upon it flexible elongate tape 13 having its other end 15 connected to the sensing head 5.

The flexible tape 13 includes a plurality of level markers 17, the level markers being equally spaced one from another along the length of the tape 13, each pair of adjacent markers 17 being a pre-determined fixed distance apart.

A stepper motor 19 is mounted within the gauging head 9 and coupled to the reel 10 to rotate the reel 10 about its axis in two opposite directions. A step counter 21 is coupled to the stepping motor 19 to count the number of steps stepped by the motor 19 and the direction in which the steps are taken. A guide 23 has mounted within it a marker detector 25 through which the tape 13 passes to detect the presence or absence of a marker 17. A microprocessor indicated generally as 27 is mounted within the gauging head and coupled to the marker detector 25 and the step counter 21 to calculate and display the exact

level of the liquid by calculating the ullage (U).

The distance (d) between each pair of adjacent markers 17 is 50 millimetres. The calculation is carried out by multiplying the number of markers 17 which lie between the sensing head 15 and the marker detector 25 (N1) and multiplying this by 50. Added to this is the number of steps taken by the stepper motor 19 since the last marker passed the detector 25 (N2) divided by the number of steps moved by the motor 19 between the last two markers 17 (N3) multiplied by 50. This gives an accurate indication of the distance between marker detector 25 and sensing head 15 to give the ullage U and therefore a calculation of the distance L of the surface 7 from the base of the vessel 29.

The surface following sensing head 5 is a capacitive sensing head which does not have to contact the surface of the liquid. The sensing head is sold by Whessoe Varec of Heighington Lane, Newton Aycliffe, England as part of their gauge systems. The sensing head 5 is illustrated in more detail in Figures 7, 8 and 9 and its operation is illustrated schematically in Figures 11 and 12. The sensing head 5 comprises a cylindrical housing 501 part of which is in the form of a cylindrical cage 502. Mounted within cage 502 is the capacitor electrode plate 503 which is protected by the cage 502 which acts as a shroud. The capacitor electrode 503 is connected to circuit board 504 illustrated in Figure 8 and 9. As illustrated in Figure 10, oscillator 604 is used to charge (via charge resistor 613) the capacitive head 605 at a set frequency. The rising voltage on the capacitive head 605 is compared to a fixed reference 606 of about 50% of the charge voltage. A difference pulse is generated by the NAND gate 607 which has inputs from the trigger pulse rising edge and the output from the comparator 608. The pulse is inverted by the inverter 609 and drives a low pass filter 610 with a time constant of about 1 millisecond. The voltage at this filter 610 is proportional to the capacitance of the head 605 which is a function of the distance to the product level. This voltage is then converted by the Analogue to

Digital Converter(ADC) 612 to a digital value which corresponds to a product proximity measurement as shown in Figure 12. Using the offset adjust 611 it is possible to trim the standing capacitance and therefore sense one medium through another, which gives the unit the ability to detect a water interface on which the product is floating. Power supply lines 508 connect the circuit board 504 to tape terminals 509. The end 15 of the tape 13 includes holes which pass over the tape terminals 509 to maintain an electrical contact. For additional secure fastening of the tape 13 to the sensor head 5, a sectioned cap 512 is fixed with four bolts 514 through threaded holes 513. Here the preferred distance is 10mm which is equivalent to digital reading of 110 as produced by the ADC 612. If the distance G, is less than 10mm, the capacitive electrode is too close to the liquid level and if more than 10mm needs to be closer to the liquid level.

The sensing head 5 is electrically connected to the gauging head 9 by connector 31 which forms part of the elongated tape 13 shown in more detail in Figure 2. The conductor 31 is coupled in the microprocessor 27 which controls the stepper motor 19 to move the sensing head 5 to the level of the liquid when it detects movement in the liquid level by a change in capacitance.

Additionally, Figures 7 and 8 indicate how the sensing head contains sensors which measure water proximity using sensor 503, tank bottom proximity using sensor 601, temperature using sensor 602 and pressure using sensor 603.

The pressure transducer 603 is the transducer shown schematically as 11 and is a Druck Series 900. The liquid 6 contacts the transducer 603 via bore 614, and the transducer is coupled via connection 615 to printed circuit board 504.

The distance moved by the sensing head 5 is calculated at the microprocessor 27, and this information is fed down the tape 13 to the circuit board 504. Circuit board 504 calculates the density of the liquid as outlined. This information is then fed up the tape 13 to the

microprocessor 27 which stores successive density measurements and calculates an average density which is displayed to users. The information is displayed by display PCB 117.

The tape 13 is of stainless steel coated with PTFE (which here is that sold under the trade mark TEFZEL which is particularly durable. The length of the tape stored on reel 10 is 30 metres. It has a plurality of holes 33 punched along its length which serve as marker 17. The holes 33 are not circular but are ovals formed of two semi-circles with radius 0.5 millimetre with square of 1 millimetre between.

The distance between the centre of each pair of adjacent holes 33 is 50 millimetres.

The thickness of the tape is 0.5 millimetres. In order to provide an absolute measurement of the length of tape extending from the marker detector at any one time a set of auxiliary reference markers in the form of holes 35 are provided spaced from each metre marker 37. After the first metre marker an auxiliary hole is spaced 15 millimetres away; after the second there is an auxiliary hole 20 millimetres away, after the third 25 millimetres and so on until after the sixth metre marker, there is an auxiliary hole 40 millimetres spaced therefrom. The seventh metre marker has an auxiliary marker 15 millimetres away. This means that the absolute reference point is always measured to an absolute value of plus or minus 6 metres. Fine tuning of this measurement is made by knowing the number of one metre holes already counted before reaching the hole which reflects the diameter of tape 13 stored on the reel 10.

The gauging head 9 is illustrated in detail in Figures 4 to 6. The gauging head 9 comprises the housing 91 of hexagonal cross section having a tapered end 92. The housing 91 is an enclosed steel body apart from glass window 93 through which a display can be seen of the level being measured. An aluminium solar protective cover 94 is mounted about the housing 91 by spacers 95. The housing 91

includes an end cover 96 which is bolted to the housing 91 by bolts 97. The tapered part of the housing 92 forms a separate element which is bolted to the rest of the housing by a set of bolts 98. In order to maintain a good seal between the housing 91 and cover 96 and 92 respectively, O rings 99 and 100 are used. The housing 91 defines broadly two chambers 101 and 102 with dividing member 103 defining the two chambers but including a cylindrical hole 104 through which shaft 105 passes to connect the two chambers 101 and 102.

Mounted within chamber 101 is reel 10 which comprises a polyamide hub 106 bolted to central shaft 107 by bolt 108. Shaft 107 passes through the central hole 105 in partition 103 and is mounted to rotate through bush 109 and bearing 110 the drive to the shaft being provided by stepper motor 19 via slip ring assembly 111. The stepper motor 19 operates via motor printed circuit board 112. A motor control PCB 113 instructs the stepper motor 19 to operate in a given direction. A microprocessor PCB 114 and peripheral power supply PCB 115 are coupled to the motor PCBs 112 and 113 via a vertical PCB 116. A display PCB 117 is controlled by the microprocessor PCB 114 to provide a display of the lidge and level of liquid. The PCBs are all connected by electrical connectors not shown. Together PCBs 114, 115, 117 and 116 can be regarded as the microprocessor 27. Spacer rods 118 hold the circuit boards in the required position.

The stepper motor 19 is a standard bipolar stepper motor and the choice of an appropriate motor will be readily apparent to the skilled addressee of the specification. It steps 4800 times per turn of the reel 10. Each turn of the reel 10 represents from 300 to 520 millimetres of tape 13 dependent on whether the reel is storing 0 or 30 metres of tape. Thus one step of the motor represents approximately 0.1 millimetre of movement of the sensing head. However, the apparatus is arranged such that the calculation of level of the surface 7 is not dependent upon total number of steps moved by the stepper motor 19, only on a

comparison of number of steps taken from the last hole 31 as against the number of steps taken between the last two holes - this reduces any error due to effective diameter of the reel (reel plus stored tape) to a negligible amount.

The step counter is formed by the motor control circuit board 113 coupled to the stepper motor 19.

The tape 13 enters the housing 91 through cylindrical opening 119. It passes through a guide 23 which has mounted within it an inductive sensor 25.

The guide 23 is mounted on sensor support 120 which is mounted by bolts 121 to member 103. The guide 23 comprises two parts 41 and 43 between which is defined a slot 45 through which tape 13 passes. The two parts 41 and 43 are brought together by two spring clamps 122. The inductive sensor 25 is an inductive proximity switch comprising an oscillator, trigger and amplifier mounted within sensor head 25 which generates an electro-magnetic field of a radio frequency. The presence of a metallic target within that field causes eddy currents to be generated on the surface of the target. The oscillator is loaded by this generation and the oscillations are damped. The trigger detects this change and switches the output circuit via the amplifier. Thus, as can be seen in Figure 6, as a hole in the tape passes the sensor head 25, the signal through the amplifier will be different from when no hole is present. The signal is fed via conductors surrounded by protective cover 123 to sensor support 121 and then through to the microprocessor 127.

As a hole passes through the inductive sensor, the level of induced current changes. In order to eliminate hysteresis errors, the movement of the tape in two opposite directions is used to calculate error e and then microprocessor 27 is used to calculate the exact position of the hole centre. Thus, throughout the level measurement, the hole centre can be accurately detected. The inductive hole sensor 25 senses holes with an accuracy of + or - 0.1 millimetres. Any possible sensor drift is automatically compensated for by the microprocessor.

In order to eliminate any errors caused by surface turbulence an integration takes place, which produces an average value of the instantaneous surface level 7 are calculated. The system is programmable to change the time over which an integration takes place. This can be from 0.2 to 30 seconds but typically will be 2 seconds. During the set time period, 128 samples are taken and an average value is produced. If the average value changes then the sensor head 5 will move. Changes in level translated by the sensing head 5 into variations of current are measured by the microprocessor situated on circuit board 504 mounted within the sensing head 5. The electronics within the gauge head have a number of purposes. They provide power and communicate with the sensing head 5 and detect variations in product proximity from sensing head 5 which determines the direction of motor rotation of motor 19 and adjust the speed of the motor 19 proportional to the gap between the sensor head 5 and the liquid level 7. The surface turbulence is then integrated. The steps made by the motor 19 are counted and deducted by the microprocessor 27. The number of tape holes 17 which have passed the detector 25 are counted and deducted and the sensing head is maintained at liquid level.

The measurement of the level is given by a formula:

$$L = H - \frac{(N_1 + N_2)\ 50\ \text{mm}}{N_3}$$

where:

H = the reference point outside the gauge

N1 = the number of perforations outside the gauge

N2 = the number of steps made by the motor since the last hole

N3 = the number of steps between the last two holes.

The display PCB displays a figure indicative of the depth of the liquid within vessel 3. The window 93 allows the information to be read easily.

The power to the gauging head 9 is controlled by peripheral PCB 115.

Claims

1. A method of measuring the density of a liquid comprising:-

mounting a pressure transducer for movement at least in a vertical direction in a tank containing a liquid;

at a first position of the pressure transducer, taking a measurement of pressure;

moving the pressure transducer from the first position to a second position spaced from the first position in a vertical direction;

at the second position measuring the pressure;

measuring the vertical distance between the first and second position; and

calculating the difference between the pressure at the first position and the pressure at the second position and dividing the difference by the vertical distance between the first and second positions to provide a density measurement.

2. Apparatus for measuring density of a liquid in a tank comprising:-

a pressure transducer (11) mounted for movement at least in a vertical direction within a tank (3) containing a liquid (6);

measuring means (9) for continuously monitoring the vertical position of the transducer (11) within the tank (3); and

microprocessing means (504, 27) coupled to the transducer (11) and to the measuring means (9) for calculating the density of the liquid (6) from two readings of the pressure transducer (11).

3. Apparatus according to claim 2, in which the pressure transducer (11) is moved by moving means (19) controlled by the microprocessing means (504, 27) the moving means (19)

being controlled to move the transducer 1m between the positions at which pressure readings are taken.

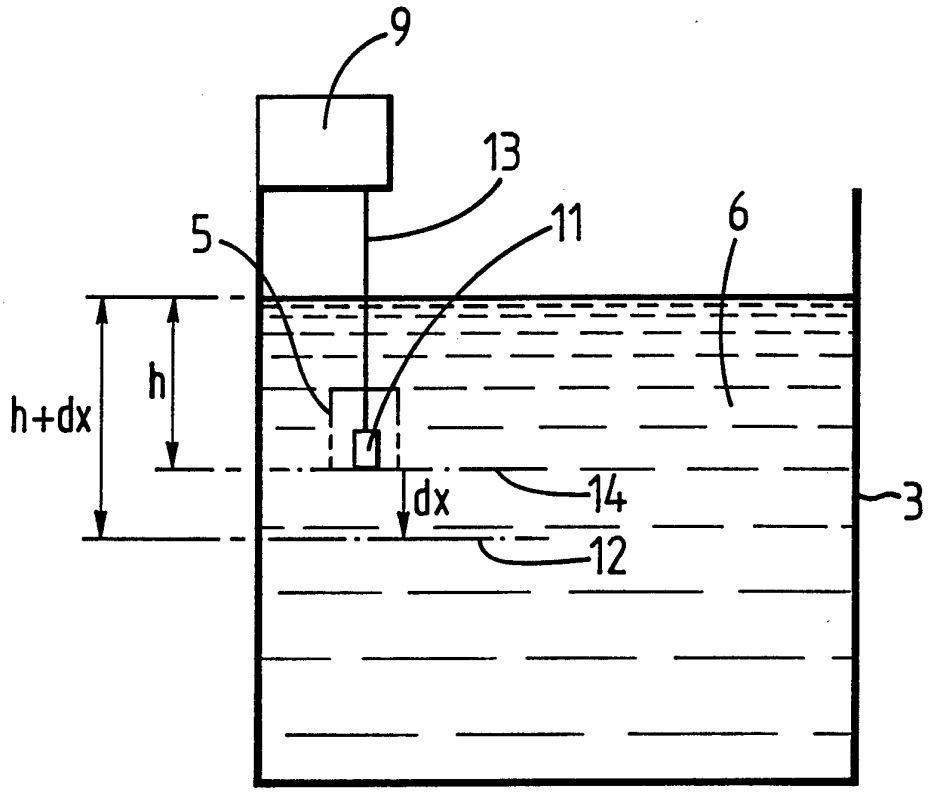
4. Apparatus according to claim 2 or 3, in which the transducer (11) is mounted within a sensing head (5) of a liquid level measuring system.

5. Apparatus according to claim 4, in which the sensing head (5) is a capacitive sensing head capable of detecting a plurality of liquids within the tank (3) and the microprocessing means (27, 504) is programmed to operate the transducer (11) within each liquid to measure the densities of each of the liquids.

6. Apparatus according to claim 4 or 5, in which the sensing head (5) is mounted upon a tape (13) coupled to a gauge (9), and the tape (13) serves as the power connection between the gauge (9) and the sensing head (5).

7. Apparatus according to claim 2, in which the microprocessing means (27, 504) are programmed such that the pressure transducer (11) is moved through a plurality of positions a pressure reading being taken at each position, and in which a succession of density measurements are calculated, where the microprocessing means (27, 504) is programmed to calculate the average density of the liquid.

FIG. 1



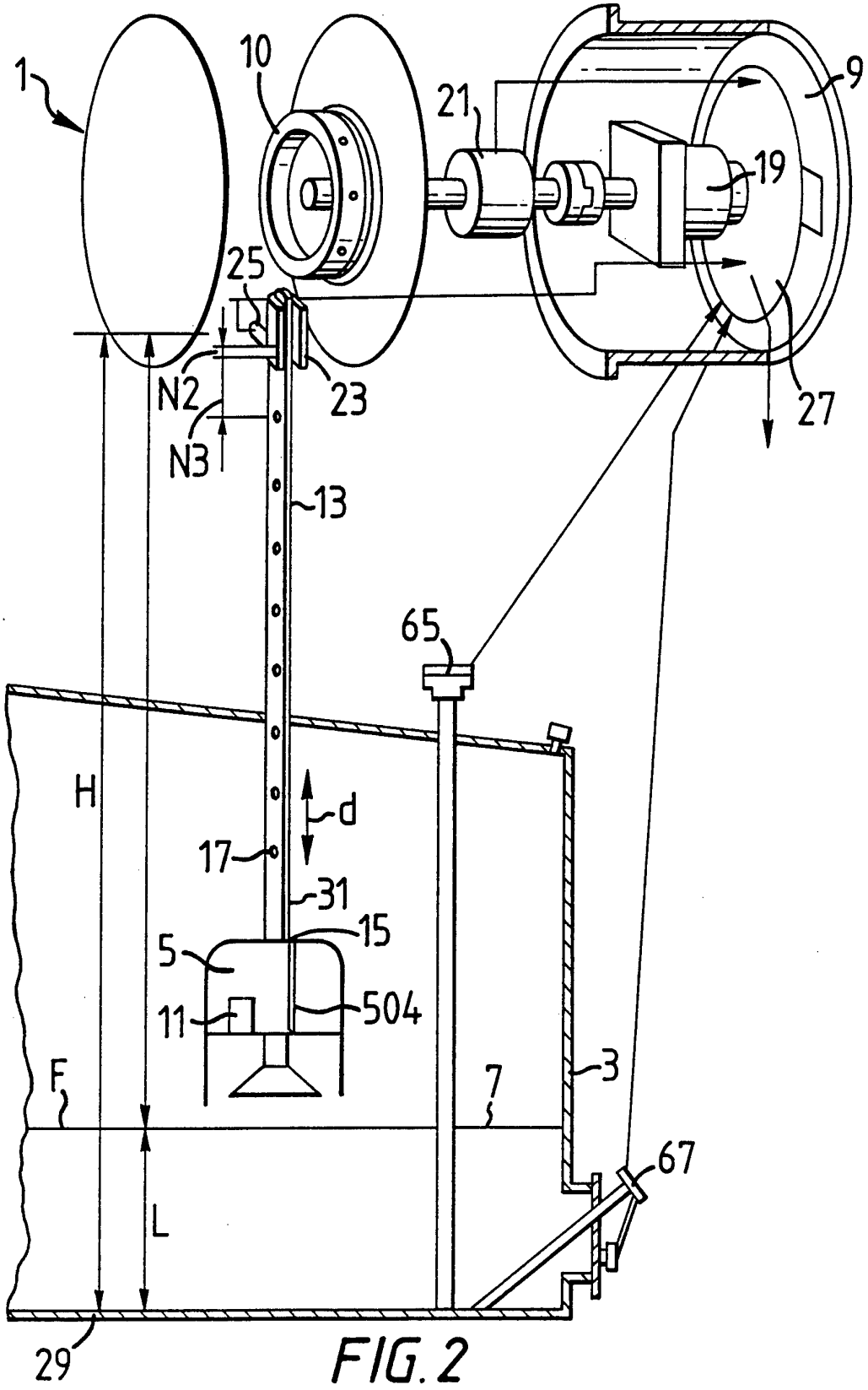


FIG. 2

FIG. 3a

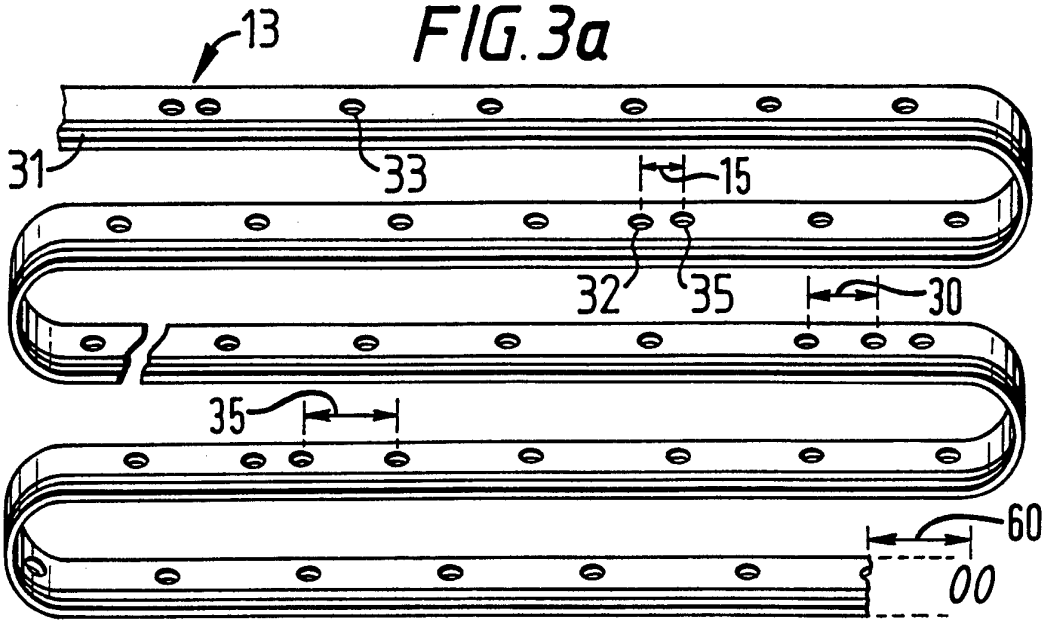


FIG. 3b

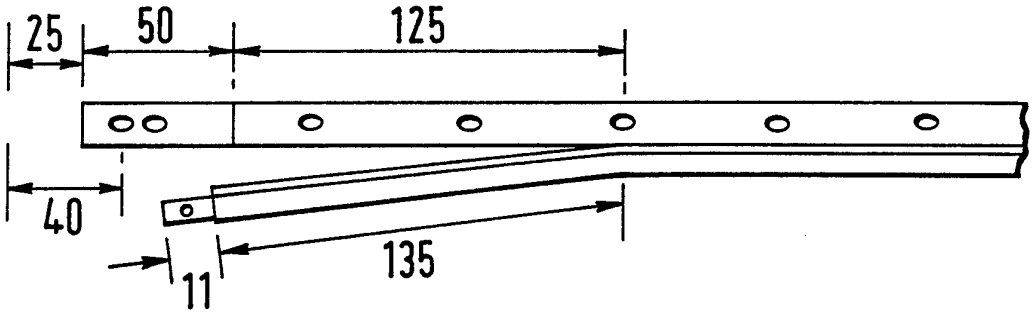
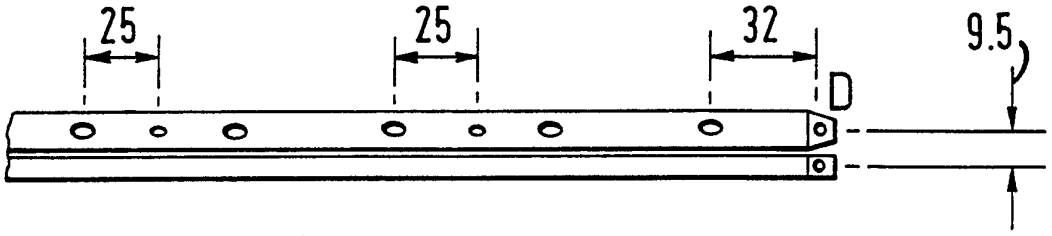


FIG. 3c



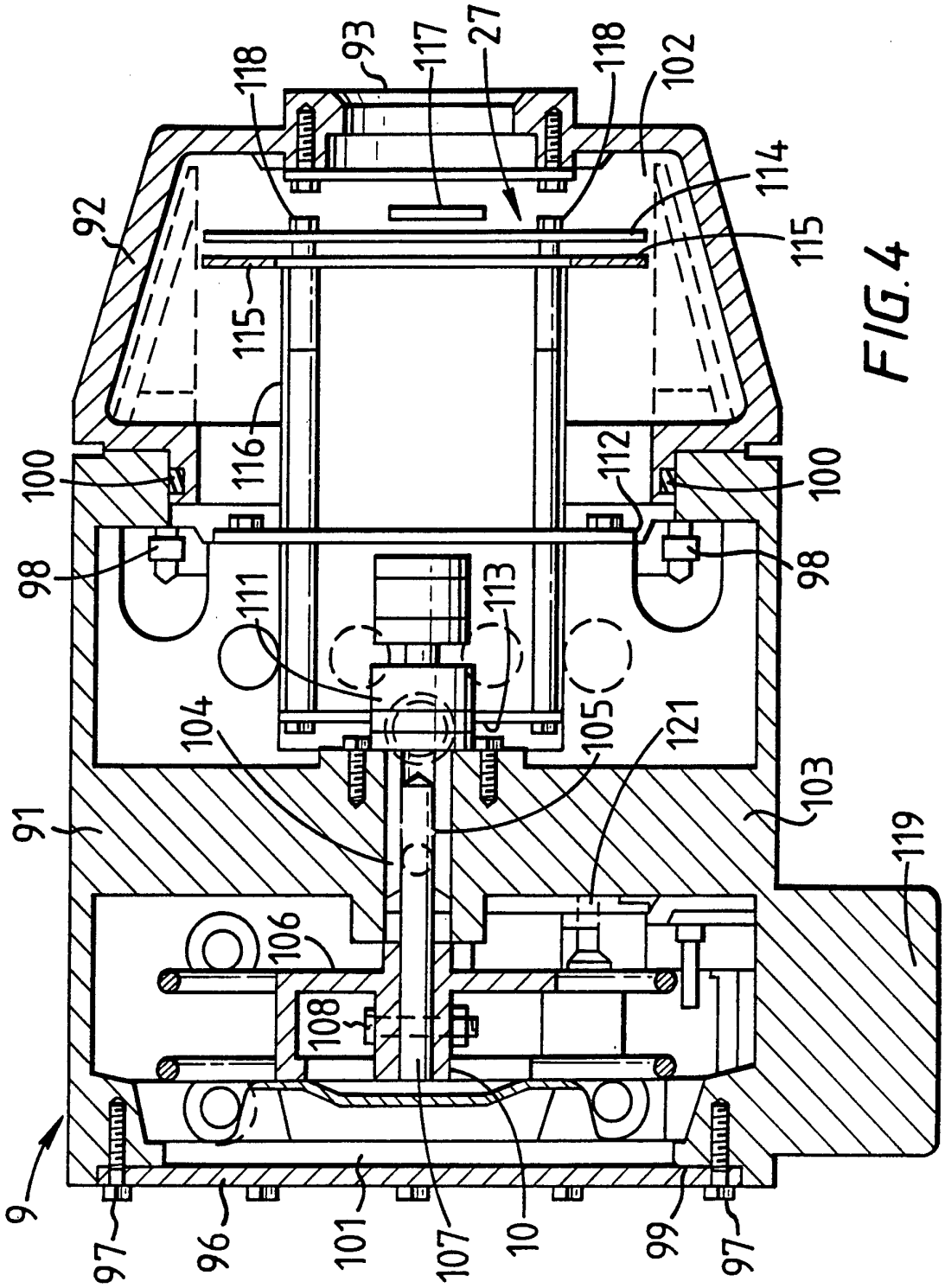

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FIG. 4

FIG.5

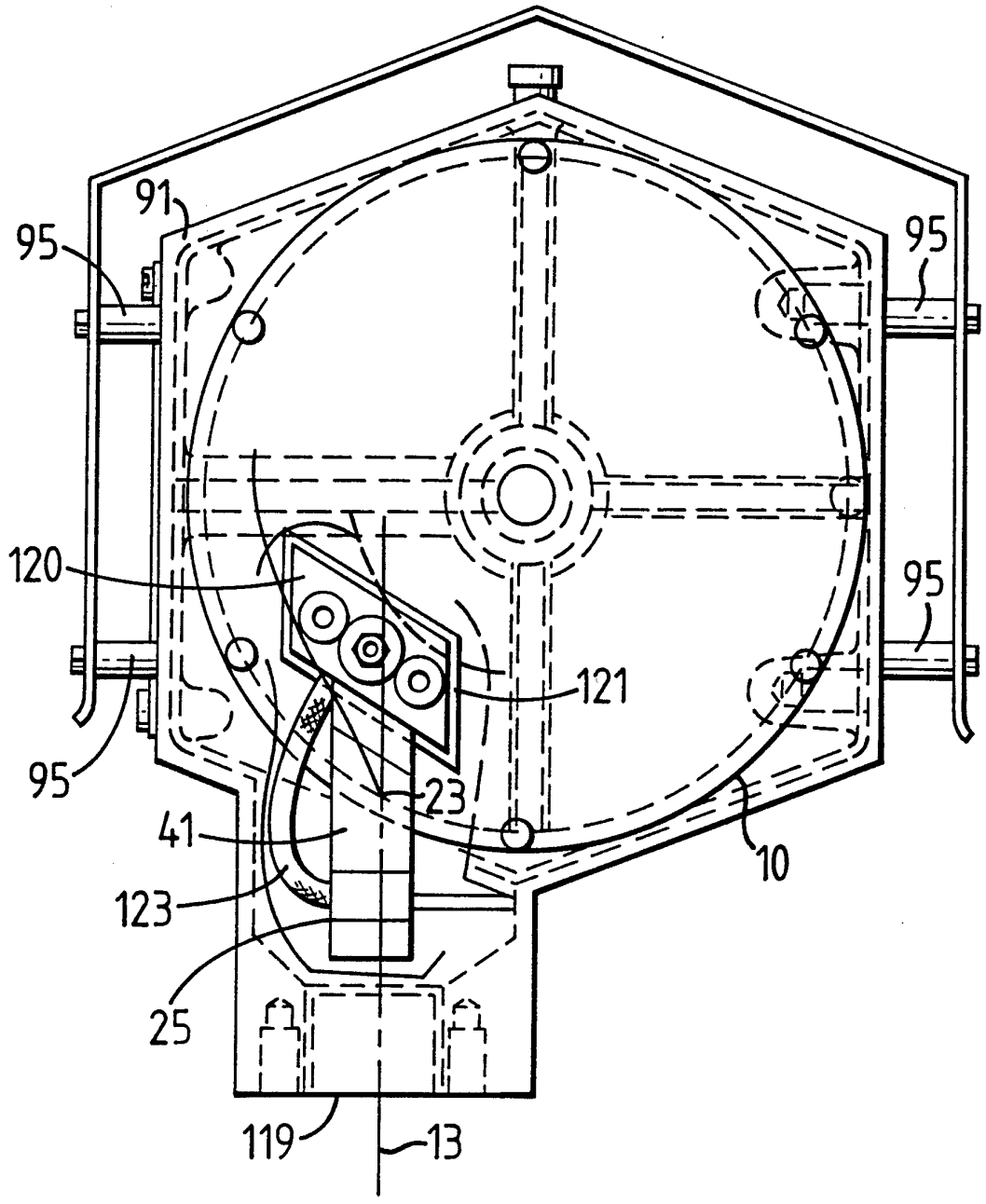


FIG.6

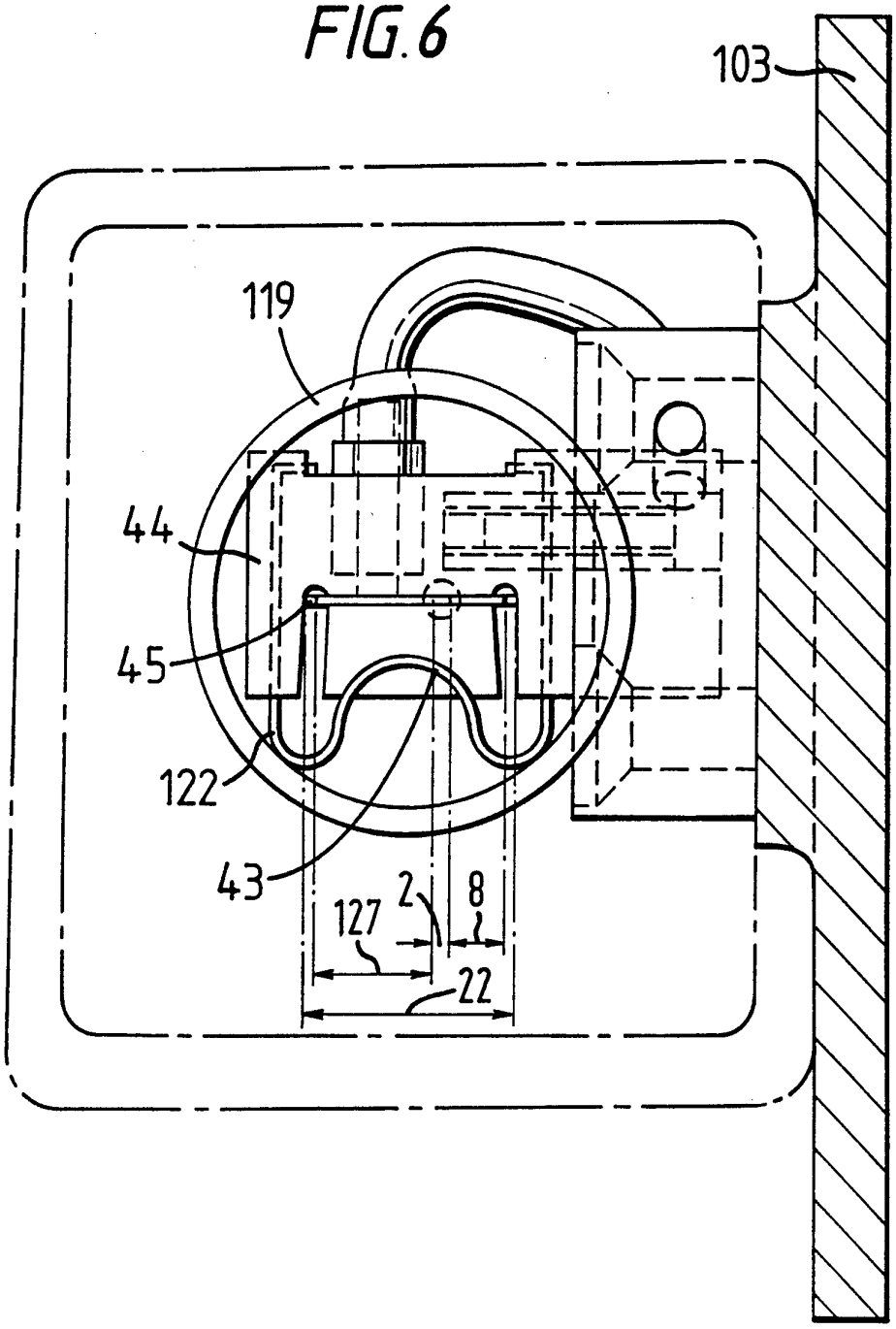


FIG. 7

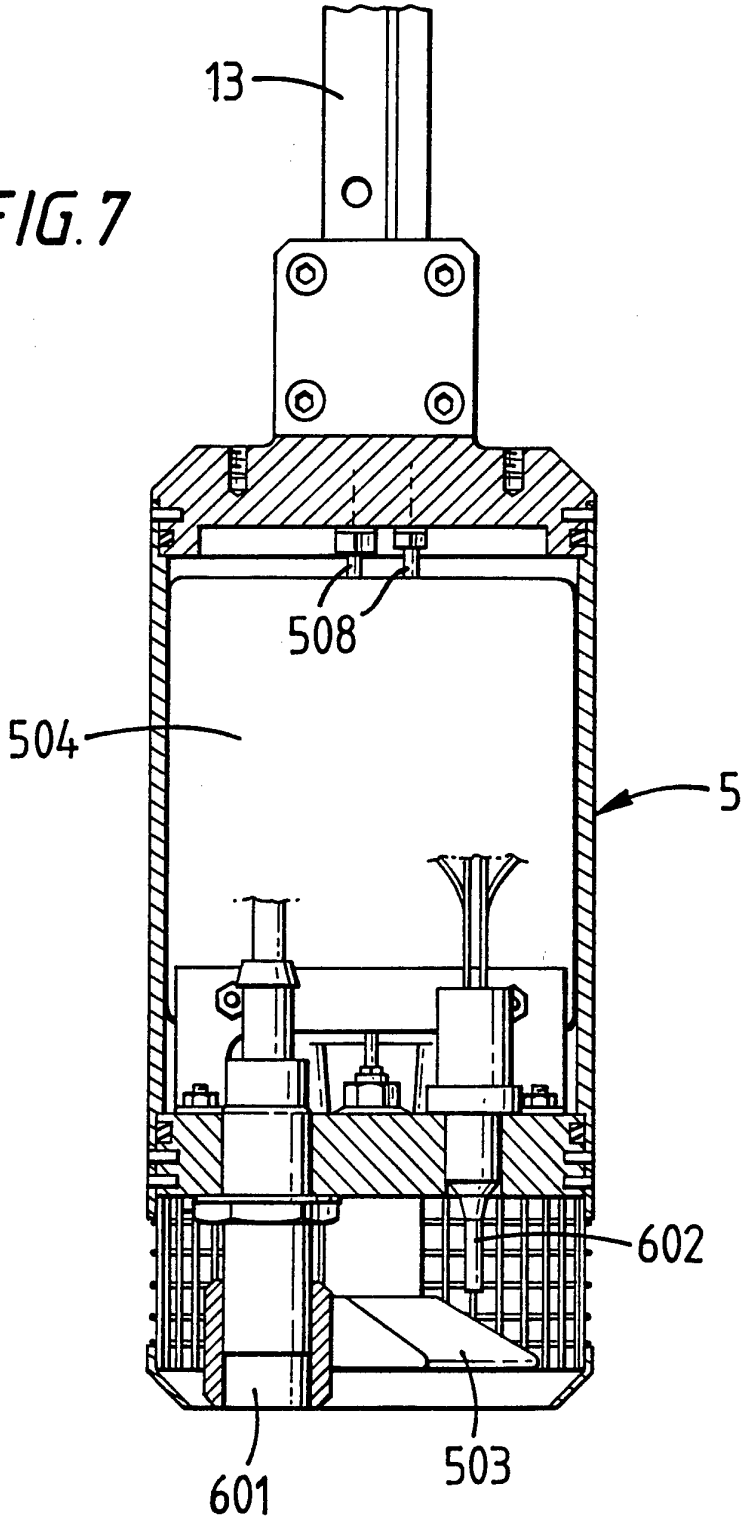


FIG.8

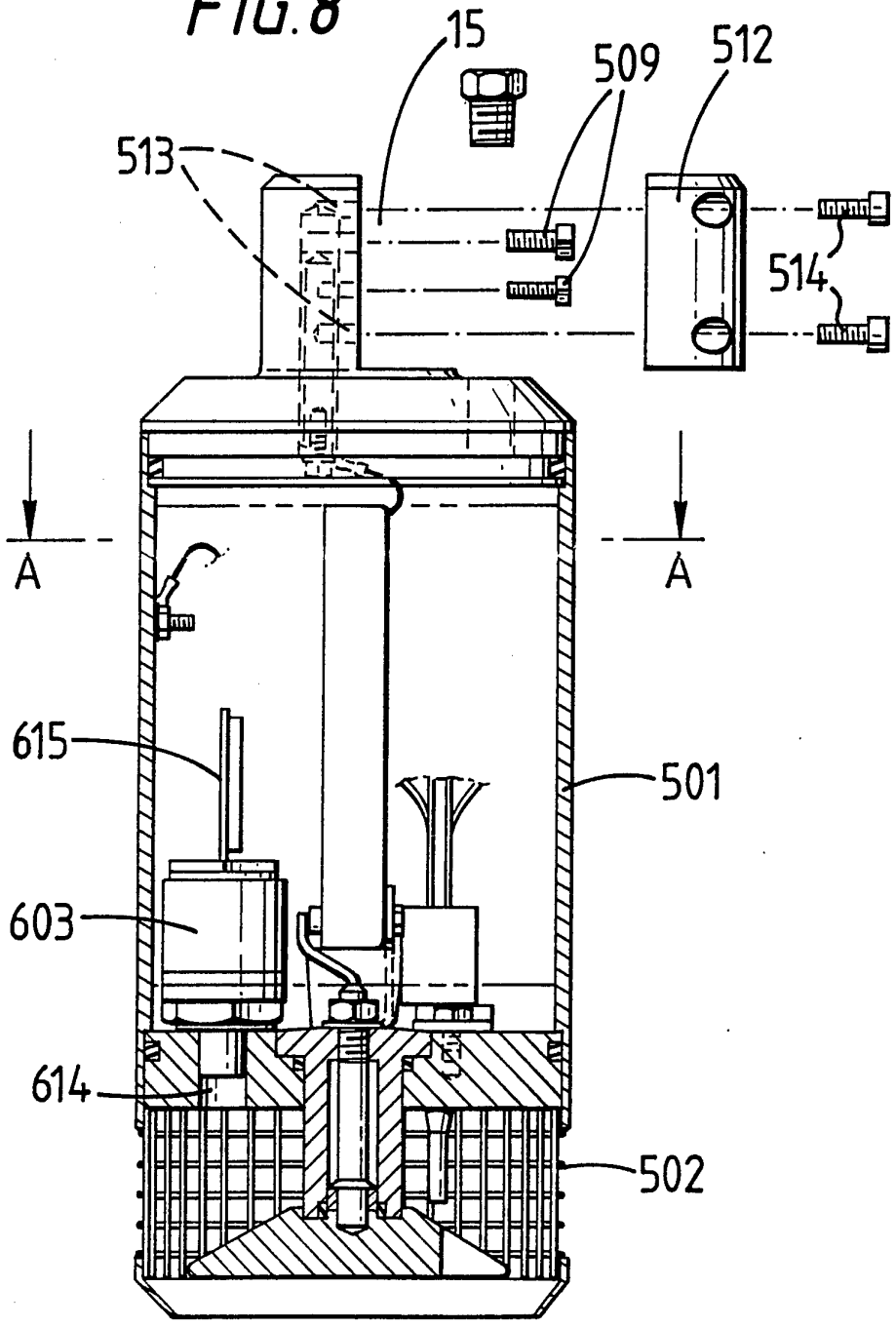


FIG. 9

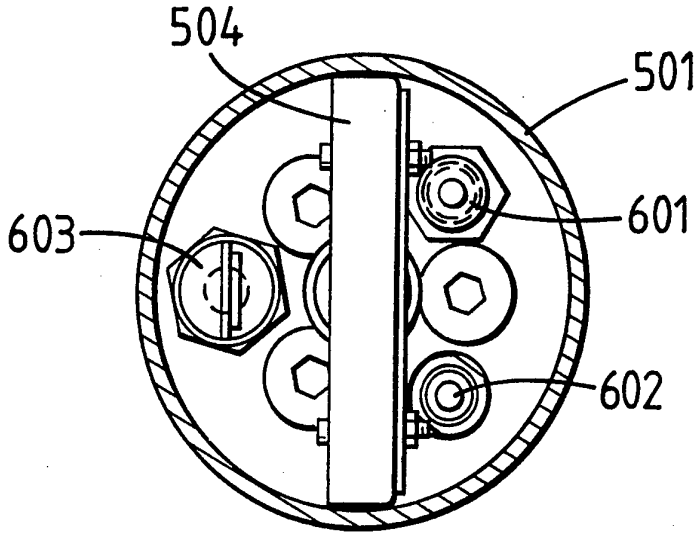
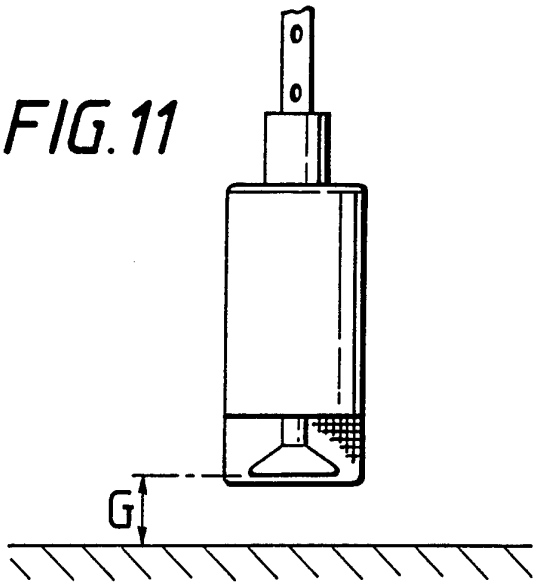


FIG. 11



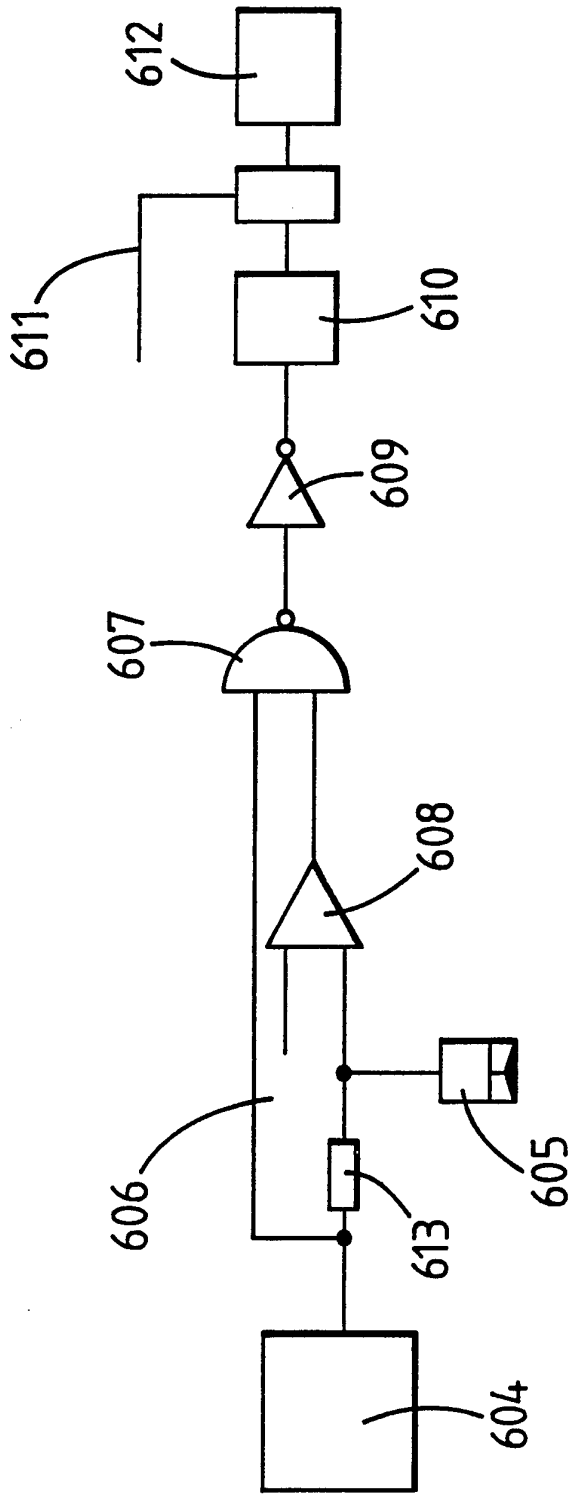


FIG. 10

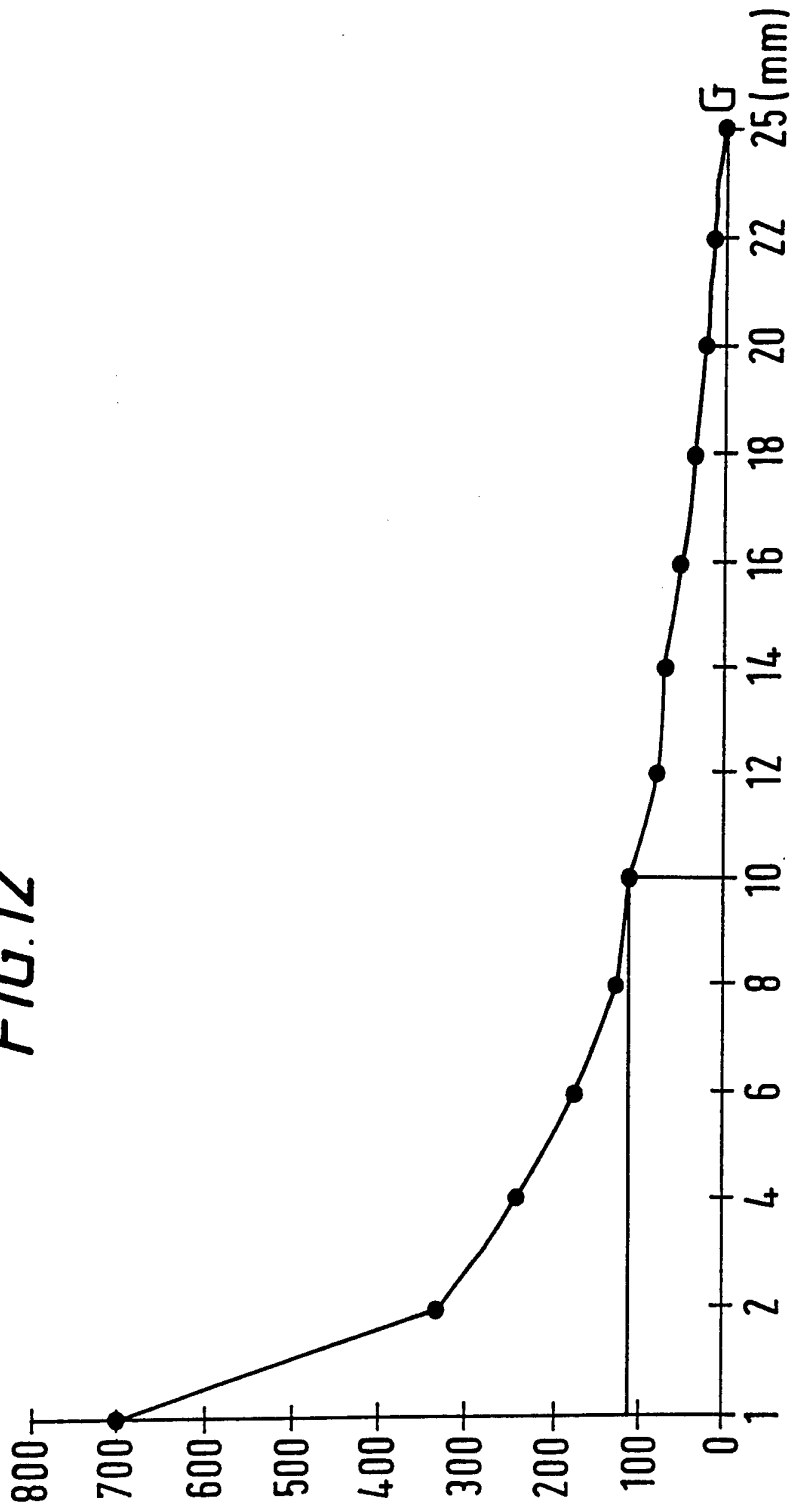


FIG.12

INTERNATIONAL SEARCH REPORT

Inter nal Application No
PCT/GB 93/01906

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 G01N9/26 G01F23/00

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 5 G01N G01F G01C

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)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	US,A,5 211 678 (S.V. STEPHENSON ET AL.) 18 May 1993	1-5,7
P,A	see column 2, line 46 - line 58 see column 5, line 31 - column 7, line 14 see column 7, line 49 - column 8, line 20; figures 1,4-6	6

X	EP,A,0 049 933 (VEEN ROMKE V D) 21 April 1982	1-4,7
	see page 7, line 11 - line 30; figures 1,4,5 see page 5, line 7 - page 6, line 24	

X	NL,A,8 902 592 (STICHTING WATERBOUWKUNDIG LAB) 16 May 1991	1,2
	see page 2, line 18 - line 35	

	-/--	

[X] Further documents are listed in the continuation of box C.

[X] 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
5 January 1994	14. 01. 94

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	Hodson, C

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A,4 471 656 (SANDERS P J ET AL) 18 September 1984 see column 1, line 36 - column 2, line 25 see column 2, line 63 - column 3, line 10; figures	1-7
A	US,A,4 942 351 (P.D. KRONAU) 17 July 1990	
A	PATENT ABSTRACTS OF JAPAN vol. 010, no. 278 (P-499)20 September 1986 & JP,A,61 099 838 (OVAL ENG CO LTD) 17 May 1986 see abstract	
A	US,A,3 616 688 (R. ROUSSIN ET AL.) 2 November 1971	

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte nal Application No
PCT/GB 93/01906

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		CA-A- 1167162	08-05-84
		JP-A- 57094634	12-06-82
		US-A- 4438651	27-03-84
NL-A-8902592	16-05-91	NONE	
US-A-4471656	18-09-84	NONE	
US-A-4942351	17-07-90	NONE	
US-A-3616688	02-11-71	FR-A- 2049511	26-03-71