PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G01R 27/26 | A1

(11) International Publication Number: WO 96/21159

(43) International Publication Date: 11 July 1996 (11.07.96)

(21) International Application Number: PCT/US95/16908

(22) International Filing Date: 28 December 1995 (28.12.95)

(30) Priority Data:
112218 2 January 1995 (02.01.95) IL

(71) Applicant *(for TJ only)*: NETZER, Yohay [US/IL]; 112 Yuvalim, 20142 Israel (IL).

(71)(72) Applicant and Inventor: NETZER, Yishay [IL/IL]; 112 Yuvalim, 20142 Israel (IL).

(74) Agent: FRIEDMAN, Mark, M.; Sheinbein, Robert, 2940 Birchtree Lane, Silver Spring, MD 20906 (US).

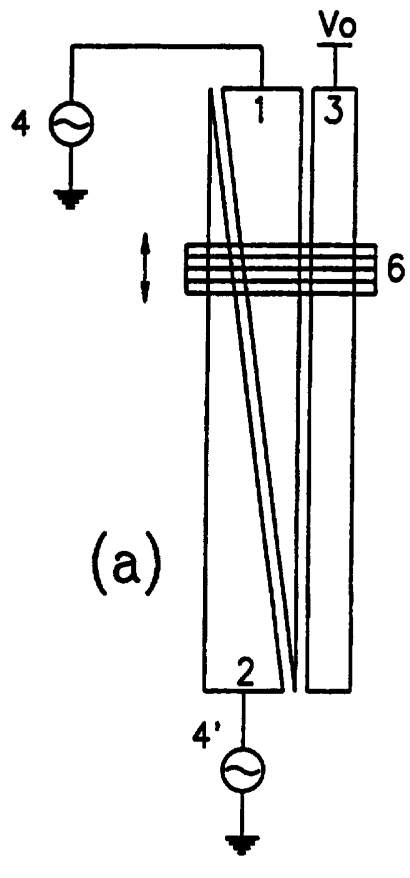
(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: A METHOD AND APPARATUS FOR MEASURING LINEAR DISPLACEMENTS

(57) Abstract

A transducer device for measuring the linear displacements of a monitored body. The device includes two stationary plates (1, 2) and a movable plate (6). The device further includes a mechanism (4) for applying an input alternating tension to one of the pair of stationary plates (1, 2) and a mechanism (16, 17, 20) for connecting the movable plate (6) to the monitored body so as to cause the displacement of the movable plate (6) to be a function of the displacement of the monitored body. The device further includes a mechanism (5) for monitoring the current induced in one of the stationary plates (1, 2). One of the stationary plates (1) and the movable plate (6) constitute a first capacitance while the other stationary plate (2) and the movable plate (6) constitute a second capacitance. The pair of stationary plates (1, 2) constitute a third capacitance. At least one of the first and second capacitances are a function of the displacement of the movable plate (6) and therefore of the displacement of the monitored body.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	**GB**	United Kingdom	**MW**	Malawi
AT	Austria	**GE**	Georgia	**MX**	Mexico
AU	Australia	**GN**	Guinea	**NE**	Niger
BB	Barbados	**GR**	Greece	**NL**	Netherlands
BE	Belgium	**HU**	Hungary	**NO**	Norway
BF	Burkina Faso	**IE**	Ireland	**NZ**	New Zealand
BG	Bulgaria	**IT**	Italy	**PL**	Poland
BJ	Benin	**JP**	Japan	**PT**	Portugal
BR	Brazil	**KE**	Kenya	**RO**	Romania
BY	Belarus	**KG**	Kyrgystan	**RU**	Russian Federation
CA	Canada	**KP**	Democratic People's Republic of Korea	**SD**	Sudan
CF	Central African Republic			**SE**	Sweden
CG	Congo	**KR**	Republic of Korea	**SG**	Singapore
CH	Switzerland	**KZ**	Kazakhstan	**SI**	Slovenia
CI	Côte d'Ivoire	**LI**	Liechtenstein	**SK**	Slovakia
CM	Cameroon	**LK**	Sri Lanka	**SN**	Senegal
CN	China	**LR**	Liberia	**SZ**	Swaziland
CS	Czechoslovakia	**LT**	Lithuania	**TD**	Chad
CZ	Czech Republic	**LU**	Luxembourg	**TG**	Togo
DE	Germany	**LV**	Latvia	**TJ**	Tajikistan
DK	Denmark	**MC**	Monaco	**TT**	Trinidad and Tobago
EE	Estonia	**MD**	Republic of Moldova	**UA**	Ukraine
ES	Spain	**MG**	Madagascar	**UG**	Uganda
FI	Finland	**ML**	Mali	**US**	United States of America
FR	France	**MN**	Mongolia	**UZ**	Uzbekistan
GA	Gabon	**MR**	Mauritania	**VN**	Viet Nam

A METHOD AND APPARATUS FOR MEASURING LINEAR DISPLACEMENTS

FIELD OF THE INVENTION

The present invention relates to displacement transducers and more particularly to capacitive linear displacement transducers.

BACKGROUND OF THE INVENTION

Several types of continuous linear displacement transducers are known. A most common one is the linear potentiometer, wherein an electrically contacting wiper slides along a resistive strip to generate a DC voltage proportional to its position. The main weakness of the linear potentiometer is the friction inherent to the sliding contact and the reliability problems associated with it. The friction results in the wear of the resistive strip and in a discontinuous electrical contact. This drawback is especially severe in applications where in measured displacement has a vibrational nature and is concentrated about a particular value. This limits the application of the linear potentiometer to cases in which a finite number of cycles is expected, typically ten millions.

Another transducer for measuring linear displacement is the Linear Variable Differential Transformer (LVDT). The operation of this transducer is based on a displacement dependent magnetic coupling between a primary winding and two secondary windings. The differential voltage induced in the secondary windings is proportional to the differential magnetic coupling between the primary and secondary windings, which is linearly dependent on the position of a moving ferromagnetic member. The advantage of this transducer is that there is no sliding electrical contact. However, the ratio of effective (linear) measurement range of the transducer to its physical length is at most 1/2 but usually closer to 1/3 - compared to almost unity in the linear potentiometer. Another disadvantage of the LVDT is its relatively high cost, which results from the labor intensive winding and encapsulation involved in its manufacturing.

Concepts for linear displacement transducers based on variable capacitive coupling are described in US Patent 3.860.918 and US Patent 3.784.897. However, none of them proved viable for commercial use. A displacement transducer is thus desirable that combines the advantageous of the aforesaid two types of transducers.

It is a purpose of this invention to provide a variable capacitance linear displacement transducer that essentially combines the advantages of the linear potentiometer and the LVDT, i.e.:

1. Low cost.

2. Ratio of effective measurement range to physical length which is close to unity.

3. Absence of sliding contact, resulting in high reliability.

It is another purpose of this invention to provide such a displacement transducer, which is immune to extraneous magnetic and electrical fields.

It is a further purpose of this invention to provide such a displacement transducer which has low power consumption.

It is a still further purpose of this invention to provide such a displacement transducer which permits optional hermetic sealing of the moving member.

It is a still further purpose of this invention to provide such a displacement transducer which can be constructed entirely from inorganic materials to enable high-temperature operation

Other purposes and advantages of the invention will become apparent as the description proceeds.

SUMMARY OF THE INVENTION

The device for measuring the displacement of a body or element comprises a first and a second fixed or stationary member (or plate or electrode), each of said stationary members comprising one or more than one component parts; a movable member (or plate or electrode); means for applying an input alternating tension to one of said first or second stationary members; means for connecting said movable member to the body or element the displacement of which is to be measured (hereinafter "the monitored body"), whereby to cause the displacements of said movable member to be a function of the displacements of said monitored body; and means for monitoring the current induced in said second or first stationary member. Said first stationary and movable members constitute a first capacitance, said movable and second stationary members constitute a second capacitance, and said second stationary and first stationary members constitute a third capacitance. At least one, and preferably only one, of said first and second capacitances, and consequently the current induced in said second stationary member, vary as said movable member is displaced and as functions of its displacement, and therefore as a function of the displacement of said monitored body.

The means for monitoring the current induced in said second stationary member are preferably means, such as a transimpedance amplifier alternating tension. As a whole, therefore, the device produces a current or preferably a voltage that is a function of a mechanical displacement, and therefore may properly be called a transducer.

The input alternating tension is preferably applied to the first stationary member. Therefore, the first stationary member may be called hereinafter "excitation plate" or "electrode". The second stationary member may be called "signal plate" or "electrode". The movable member may be called "displacement plate" or "electrode"

In a preferred embodiment of the invention, the first stationary member comprises two stationary excitation plates, to which two opposite phase AC voltages are applied. In a particularly desirable configuration, said two plates are triangular and arranged so that the base of each of them faces the apex of the other. In a preferred constructional implementation, the stationary plates may be arranged in cylindrical form, e.g., as conductive films or layers applied to a non-conductive cylindrical base; and the movable plate may be formed on a piston which slides within said cylindrical base.

In a further preferred embodiment, each stationary plate is constituted by a plurality, e.g., a pair, of plate elements connected in parallel.

In a still further preferred embodiment, the excitation plate further comprises two additional sinusoidal electrode pairs shifted by 90 mechanical degrees, each electrode pair being excited by a complementary voltage having a different frequency.

The means for connecting the movable plate to the monitored body may be of any kind, and may be e.g., kinematic means of any convenient structure or may include an electromagnetic coupling.

The method for measuring the linear displacements of a monitored body according to the invention, comprises providing at least two capacitances including at least one movable plate, displacing said movable plate as a function of the displacements of the monitored body, applying to at least one plate of said capacitances an alternating input tension, and measuring the changes in said capacitances due to the displacements of said movable body by measuring an output tension induced by said input tension. Preferably, three capacitances including one movable plate and two stationary plates are provided.

According to an aspect of the invention, the changes in the capacities are measured by measuring the changes in the current induced in a stationary plate of one of said capacitances, preferably by transducing said current to an output voltage and measuring said voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1-a and 1-b are a diagram of a device according to a first embodiment of the invention, illustrating its basic concept, and the equivalent circuit thereof, respectively;

Figs. 2-a and 2-b are a diagram of a device according to a second embodiment of the invention and its equivalent circuit, respectively;

Figs. 3-a and 3-b are a diagram of a device according to a third embodiment of the invention and its equivalent circuit, respectively;

Fig. 4-a and 4-b show two constructional implementations, schematically illustrated as developed on a plane, of the device of Figs. 3-a and 3-b;

Fig 5 illustrates a cylindrical constructional implementation of Figs. 3-a and 3-b;

Fig. 6 shows a constructional implementation, schematically illustrated as developed on a plane, of a multiple plate embodiment of a device according to the invention;

Fig. 7 shows a constructional implementation, schematically illustrated as developed on a plane, of a device according to an embodiment of the invention including coarse and fine channels;

Fig. 8 shows an actual mask use for screen printing coarse and fine stationary plates.

Fig. 9 illustrates an hermetically sealed device according to an embodiment of the invention, with a magnetic coupling of the displacement electrode to the monitored body;

Fig. 10 illustrates a device according to a further embodiment of the invention, with a rod-less mechanical coupling of the displacement electrode to the monitored body; and

Fig. 11 illustrates a device according to a still further embodiment of the invention, with a cable mechanical coupling of the displacement electrode to the monitored body.

DETAILED DESCRIPTION OF THE INVENTION

The concept of the invention is illustrated in Fig. 1. It is based on capacitive coupling between two conductive stationary members through a movable intermediate, electrically conductive, member that is isolated from said stationary members and is displaceable with the body or element the displacement of which is to be measured.

Fig. 1(a) diagrammatically illustrates a transducer device according to a first embodiment of the invention. A first conductive, stationary member 1 - the excitation plate or electrode - is excited by an input AC voltage source 4. A second conductive, stationary member 3 - the signal plate or electrode - is connected to the virtual ground of an operational charge or transimpedance amplifier 5, that converts the current that is capacitively coupled into said second member to an output voltage. A third, movable, conductive member 6 - the displacement electrode - is operatively connected to the monitored body in such a way that its displacement is equal to or a known function of the displacement of said body. Electrode 6 is capacitively coupled to said electrodes 1 and 3.

The equivalent circuit of the transducer device of Fig 1(a) is shown in Fig. 1(b) which illustrates the fact that the total capacitance between members 1 and 3 consists of a fixed capacitance C_{1-3} and two displacement-dependent, variable capacitances C_{1-6} and C_{6-3}. Capacities C_{1-6} and C_{6-3} vary as a function of the displacement of element 6.

Therefore the charge in said two capacities, and consequently the current from C_{6-3} to C_{1-3} also varies as a function of the said displacement. The voltage V_0 , which is the output of the transimpedance amplifier 5, also varies as a function of the displacement of movable plate 6, and therefore of the monitored body, so that it provides a measure of the displacement of the monitored body. If V_{ex} is the excitation voltage applied to stationary plate 1, $V_0 = V_{ex} \cdot C_{1-6}/C_1$, and if C_1 is small relatively to the C_{1-6}, the said output voltage is approximately proportional to the said excitation voltage.

A modified configuration of the transducer device is shown in Fig. 2(a), wherein the area of member 6 is such that the mutual capacitance C_{6-3} between members 1 and 6 is constant regardless of displacement of member 6 in the direction of the arrow over a certain range. The equivalent circuit is shown in Fig. 2(b), which is self-explanatory. The capacitance C_{1-6} is the only displacement-dependent one in this case.

Fig. 3(a) illustrates an embodiment wherein the first stationary member is constituted by two excitation plates 1 and 2, which are excited with two opposite phase AC voltages 4 and 4'. As shown in the equivalent circuit of Fig. 3(b), said two plates induce two currents of opposite polarities in the signal plate 3, through the displacement plate 6, the net sum of said currents being converted to an output voltage signal by amplifier 5 as before. In addition, two mutually canceling parasitic currents are coupled through capacitances $C_{1\text{-}3}$ and $C_{2\text{-}3}$. As displacement electrode 6 is translated along the direction of the arrow, the magnitude and phase of the output voltage varies and is indicative of the sense and magnitude of its displacement and therefore of the monitored body displacement.

It will be obvious to those skilled in the art that the roles of said excitation and signal members can be reversed by connecting each of members 1 and 2 to the virtual ground input of a separate charge amplifier and exciting member 3 with a single AC voltage source. The output voltages of said charge amplifiers would then be subtracted to provide a differential signal indicative of the displacement of member 6, whereas the sum signal can be used to normalize the differential signal against common mode effects, such as amplitude variations in the excitation voltage and geometrical variations that symmetrically affect the stationary members. A like arrangement is applicable to any embodiment of the invention: in other words, the input AC voltage can be applied to the signal plate instead of to the first stationary plate, no matter how this is structured.

The actual structural implementation of the conductive members in Figs. 1, 2, and 3, is dependent upon the particular embodiment of the invention. One such structure is illustrated in Fig. 4(a), which shows a top view of a plane differential configuration of an embodiment in accordance with Fig. 3. The plates can actually be flat bodies, or the drawing can be understood to represent the development on a plane of plates that are actually not flat bodies. Excitation plates 1 and 2 are triangular, disposed in such a way that the tip of each of them faces the base of the other, so that their cumulative cross-section is the same along all their length, and are electrically coupled to signal plate 3, also illustrated as a plane body, through movable, signal plate 6, which is held at a fixed distance from the common plane of plates 1, 2, and 3. Capacitance C_{6-3} is therefore constant and capacitances C_{1-6} and C_{2-6} are linearly and oppositely dependent on the displacement of plate 6 along the axis represented by the arrows. The net induced current in the signal plate is zero, when the movable plate 6 is in the center position - viz. the position in which it faces portions of excitation plates 1 and 2 of the same width - and attains its maximum value with the appropriate polarity at the extreme positions - viz. the positions corresponding to the maximum width of one of the excitation plates and the minimum width of the other. The effective measurement range of the configuration in Fig. 4(a) substantially equals the length of the fixed plates 1 and 2 less the length of the movable plate 6 along the travel direction, i.e., almost the full length of the fixed plates. The smaller the dimension of the moving plate in the travel direction compared to the length of the fixed plates, the closer to 1 is the ratio of the effective measurement range to the physical length of the transducer device.

Fig. 4(b) illustrates a modification to the configuration of Fig. 4(a) wherein the parasitic capacitance between signal plate 3 and excitation plates is decreased by enclosing it with guard plates 7 which are held at the same electrical potential, i.e., ground potential in the specific case shown.

A different embodiment of the invention, wherein the electrode plates have a different configuration, is schematically illustrated in Fig. 5. The stationary plates are cylindrical, in particular, they are disposed on a hollow, non-conductive cylinder 8, and the movable member 9 is in the shape of a piston. For example, the stationary plates can be made by depositing a conductive film or coating on the outer surface of a glass cylinder. Figs. 4(a) or 4(b) can be taken as representing the surface of the device, viz. the stationary plates, as it would look if the device were cut along a generatrix of the cylinder and developed on a plane, while the movable piston can be made from a low friction conductive material such as graphite. Alternatively, the piston can be made from a Teflon-coated metal cylinder, the non-conductive cylinder from a plastic tube, and the conductive, stationary plates by selectively metallizing the said tube. The embodiment of Fig. 5 includes a rod 10 that serves mechanically to couple the monitored body to the movable piston 9 of the transducer device.

The piston-and-cylinder construction of the embodiment of Fig. 5 enables the application of the invention to pneumatic actuators of the piston-and-cylinder type in which the cylinder is non-metallic, so that the stationary, conductive plates can be applied to it. The resulting integrated actuator/displacement transducer is useful in various pneumatic systems, by enabling a cost-effective closed-loop servo-control.

The stationary plates of the transducer of the present invention are sensitive to parasitic capacitive coupling from neighboring conductive and dielectric objects. A preferred embodiment of the configuration of Fig. 5 includes a grounded metallic concentric sleeve 11, that serves both as a screen for protecting the electrodes and as a housing for mechanical protection of cylinder 8.

In the embodiment shown in Fig. 5 the capacitive coupling between the stationary plates and piston 9 is sensitive to radial misalignment of the piston in the cylinder, which misalignment would result in erroneous output signal. This sensitivity can be decreased by employing, in place of single stationary plates, sets of stationary plates, each of which comprises a number of plates - in the embodiment illustrated, a pair, such as 1-1, 2-2, and 3-3 - that are connected in parallel, as shown in Fig. 6. This construction decreases the said sensitivity, due to a compensating effect in diametrically opposing set of plates. In Fig. 6, each set of stationary plates is constituted by a pair, but it could be constituted by any number of plates, such as four.

Fig. 7 illustrates another embodiment of the invention, wherein an additional, fine channel is added to provide an improved accuracy. The additional channel comprises two periodic patterns, shown as triangular in the figure, that are shifted by 90 mechanical degrees. The first pattern includes the electrodes 12 and 13 whereas the second pattern includes electrodes 14 and 15 . Each electrodes pair is excited with two opposite polarity voltages of a frequency different from those of the other pair, and is capacitively coupled to the common signal electrode 3 via piston 9. In the preferred embodiment of this version the length of the piston element is substantially one half the period length of the periodic pattern (not to scale in the figure) in order to maximize the output signal. By demodulating the output signal that is derived from the signal electrode 3, three separate signals are obtained:

1. A signal that is linearly proportional to the displacement of movable member 6.

2. A fine-channel signal that is sinusoidally proportional to the displacement.

3. A fine-channel signal that is cosinusoidally proportional to the displacement.

The fine channels enable an interpolation within an individual cycle but are unable to identify the cycle. By combining the linear (coarse) and fine channels information the individual cycle can be identified and the interpolation enables an improved accuracy.

Fig. 8 illustrates an actual mask used for screen printing plates on a cylindrical glass transducer.

The mechanical coupling to the moving piston 9 to the monitored body, in the embodiment illustrated in Fig. 5, is provided by means of a rod 10. Although this is a convenient coupling means, it does not permit totally to seal the transducer device against external contaminating materials when used in an uncontrolled environment. Fig. 9 illustrates another embodiment of the invention, wherein the coupling of piston 9 to the monitored body is obtained by the interaction between two concentric magnets. Numeral 8 designates a non-conductive cylinder as in Fig. 5. A first cylindrical magnet 16 is mounted within piston 9 and a second annular magnet 17 is concentric to the first one. The two magnets are axially magnetized, but in opposite senses. As a result, they exert an attractive force on one another that maintains the internal magnet within the external one. By attaching the external magnet to the monitored body, piston 9 follows its displacement with an accuracy that depends on the friction between it and the cylinder and on the attractive force between the two magnets. An error of 0.5 mm is typical in a transducer that comprises a glass cylinder and a graphite piston and employs Samarium-Cobalt coupling magnets. A further advantage of the transducer illustrated in Fig. 9 is that the total space needed is substantially one half that of the embodiment in Fig. 5, since there is no need for the space occupied by the rod while in full excursion.

A further embodiment of the invention is illustrated in Fig. 10. This embodiment incorporates a cylinder that has an elongated slot 18 along its length to enable a direct mechanical coupling to the moving element by means of an electrically non-conductive connection member 19. Although this embodiment cannot be hermetically sealed, it occupies the same reduced space as in Fig. 9.

A further embodiment of the invention is illustrated in Fig. 11. In this embodiment the mechanical coupling of piston 9 to the monitored body is obtained by means of two flexible cables 20 and 21 which enable mechanical flexibility in certain situations.

Although a number of embodiments have been described by way of illustration, it will be understood that the invention may be carried out by persons skilled in the art with many modifications, variations and adaptations, without departing from its spirit or exceeding the scope of the claims.

WHAT IS CLAIMED:

1. Transducer device for measuring the linear displacements of a monitored body, comprising a first and a second stationary plate; a movable plate; means for applying an input alternating tension to one of said first or second stationary plates; means for connecting said movable plate to the monitored body, whereby to cause the displacements of said movable plate to be a function of the displacements of said monitored body; and means for monitoring the current induced in said second or first stationary plate; said first stationary and movable plates constituting a first capacitance, said movable and second stationary plates constituting a second capacitance, and said second stationary and first stationary plates constituting a third capacitance, at least one of said first and second capacitances being a function of the displacement of said movable plate and therefore of the displacement of said monitored body.

2. Transducer device according to claim 1, wherein the second capacitance is fixed with respect to the displacement of the movable plate.

3. Transducer device according to claim 1, wherein the means for monitoring the current induced in the second stationary plate is means for transducing said current into an output alternating tension.

4. Transducer device according to claim 3, wherein the means for monitoring the current induced in the second stationary plate is a transimpedance amplifier.

5. Transducer device according to claim 1, wherein the input alternating tension is applied to the first stationary plate.

6. Transducer device according to claim 1, wherein the first stationary plate comprises two stationary excitation plates, to which two opposite phase AC voltages are applied.

7. Transducer device according to claim 6, wherein the two stationary excitation plates are essentially triangular and arranged so that the base of each of them faces the base of the other.

8. Transducer device according to claim 1, wherein the stationary plates are formed on a cylinder and the movable plate is a piston which slides within said cylinder.

9. Transducer device according to claim 8, wherein the stationary plates are conductive films applied to a non-conductive cylindrical base.

10. Transducer device according to claim 1, wherein each stationary plate is constituted by a plurality of plate elements connected in parallel.

11. Transducer device according to claim 1, wherein the first stationary plate comprises two additional sinusoidal electrode pairs shifted by 90 mechanical degrees, each electrode pair being excited by a complementary voltage having a different frequency.

12. Transducer device according to claim 1, wherein the movable plate is connected to the monitored body through a kinematic coupling.

13. Transducer device according to claim 1, wherein the movable plate is connected to the monitored body through a magnetic coupling

14. Transducer device according to claim 8, wherein the stationary plates are formed on a glass cylinder and the piston is made of graphite.

15. Transducer device according to claim 12, wherein the kinematic coupling comprises a rod.

16. Transducer device according to claim 13, wherein the movable plate is a piston movable in a cylinder and the magnetic coupling comprise a first permanent magnet within said piston, actuated by a second permanent magnet external to said cylinder.

17. Transducer device according to claim 13, wherein the cylinder is sealed.

18. Transducer device according to claim 12, wherein the kinematic coupling comprises two cables.

19. Transducer device according to claim 8, wherein the cylinder is slotted along its length to enable mechanical connection of the piston to the monitored body

20. Transducer device according to claim 1, which is incorporated in a pneumatic cylinder.

21. Method for measuring the linear displacements of a monitored body, comprising providing at least two capacitances including at least one movable plate, displacing said movable plate as a function of the displacements of the monitored body, applying to at least one plate of

said capacitances an alternating input tension, and measuring the changes in said capacitances due to the displacements of said movable body by measuring an output tension induced by said input tension.

22. Method according to claim 22, wherein the changes in the capacities are measured by measuring the changes in the current induced in a stationary plate of one of said capacitances.

23. Method according to claim 22, wherein the changes in the current induced in a stationary plate of one of the capacitances are measured by transducing said current to an output voltage and measuring said voltage.

24. Method according to claim 22, wherein three capacitances including one movable plate and two stationary plates are provided.

25. Transducer device for measuring the linear displacements of a monitored body, substantially as described and illustrated.

26. Method for measuring the linear displacements of a monitored body, substantially as described and illustrated.

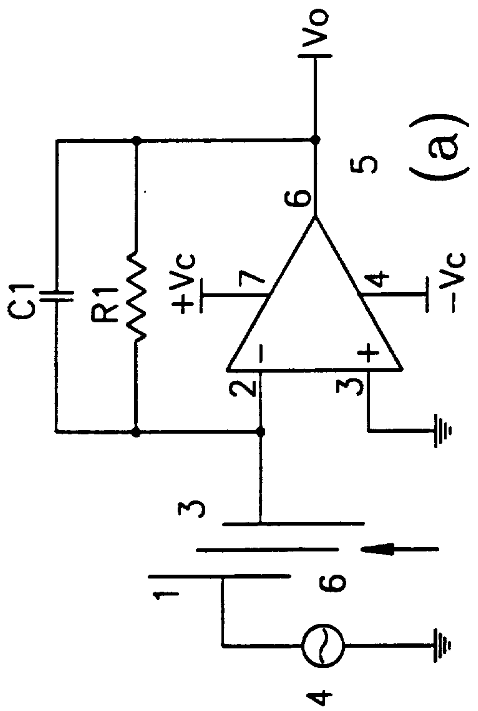


FIG.1A

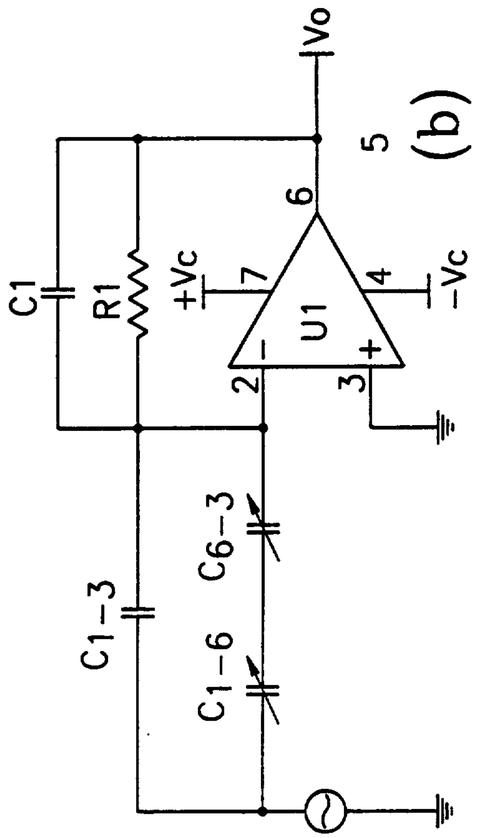


FIG.1B

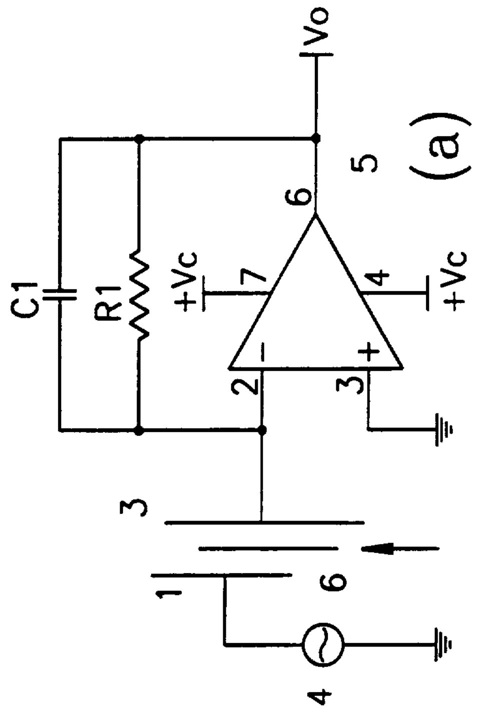


FIG.2A

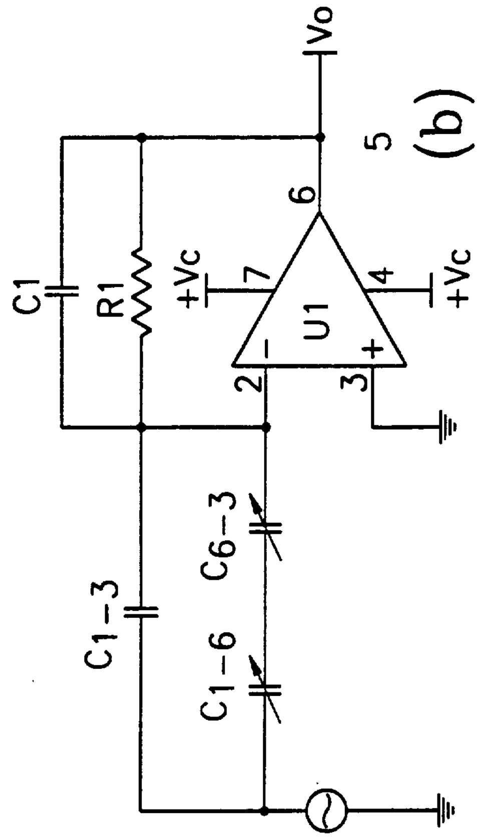


FIG.2B

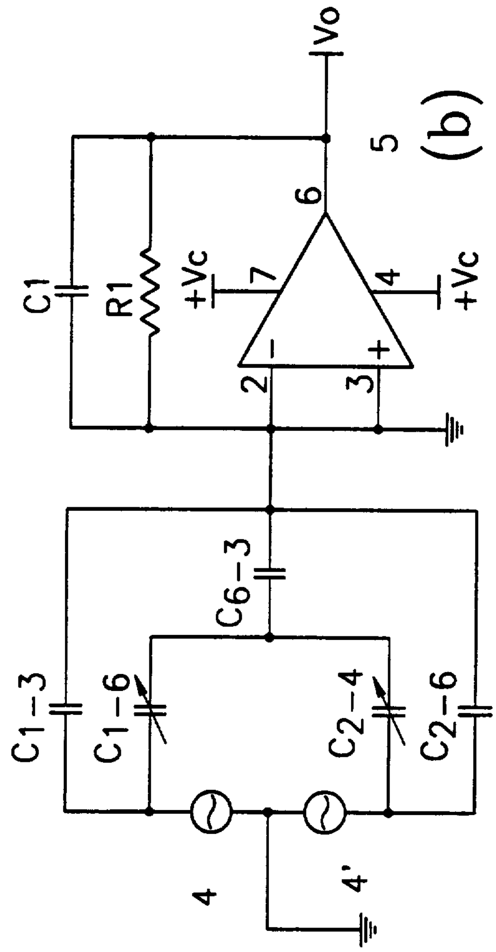

Vo
5
(b)
6
C1
R1
+Vc
7
4
+Vc
2
3
C6−3
C1−3
C1−6
C2−4
C2−6
4
4'

FIG.3B

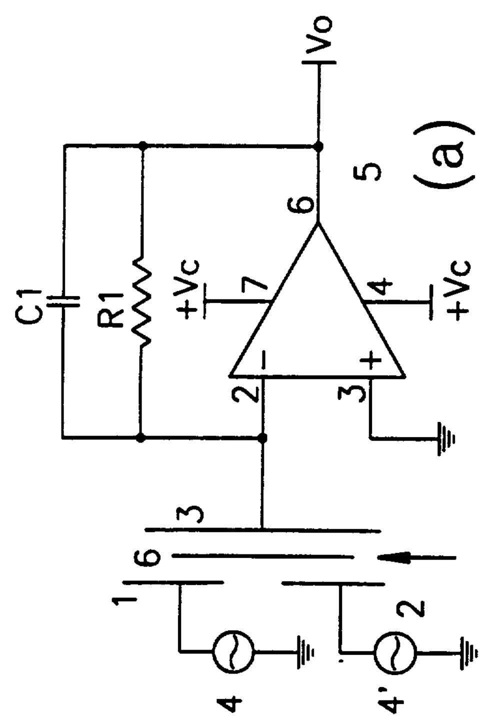

Vo
5
(a)
6
C1
R1
+Vc
7
4
+Vc
2
3
3
6
1
2
4
4'

FIG.3A

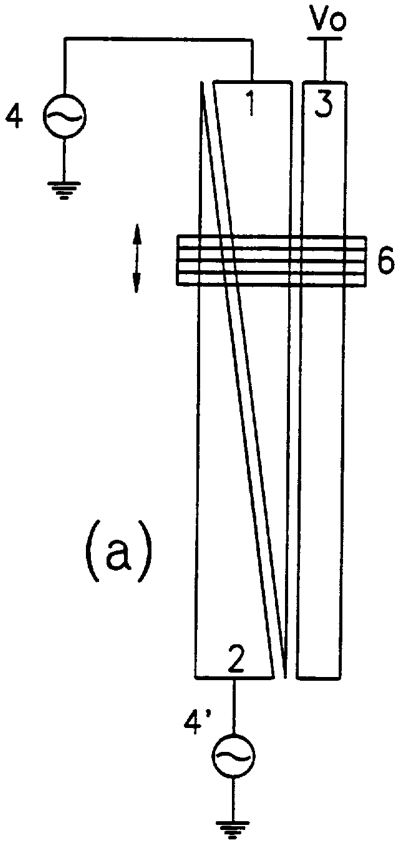


FIG.4A

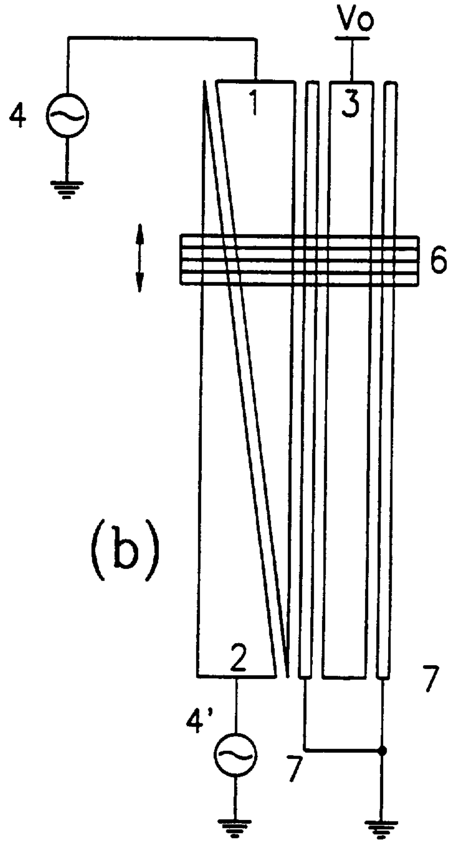


FIG.4B

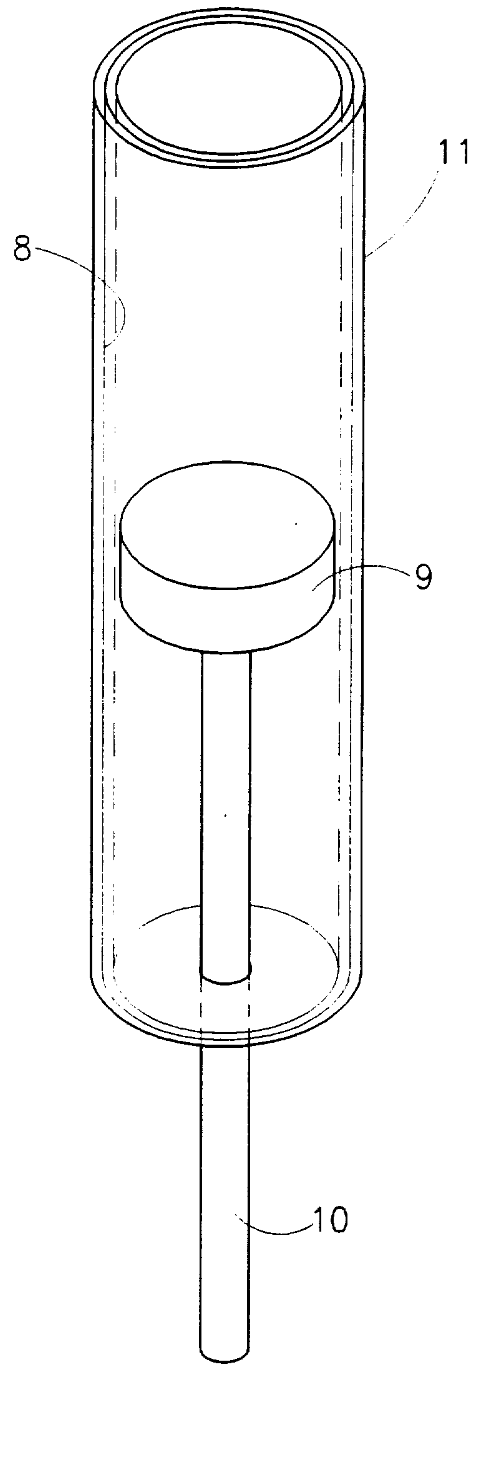


FIG.5

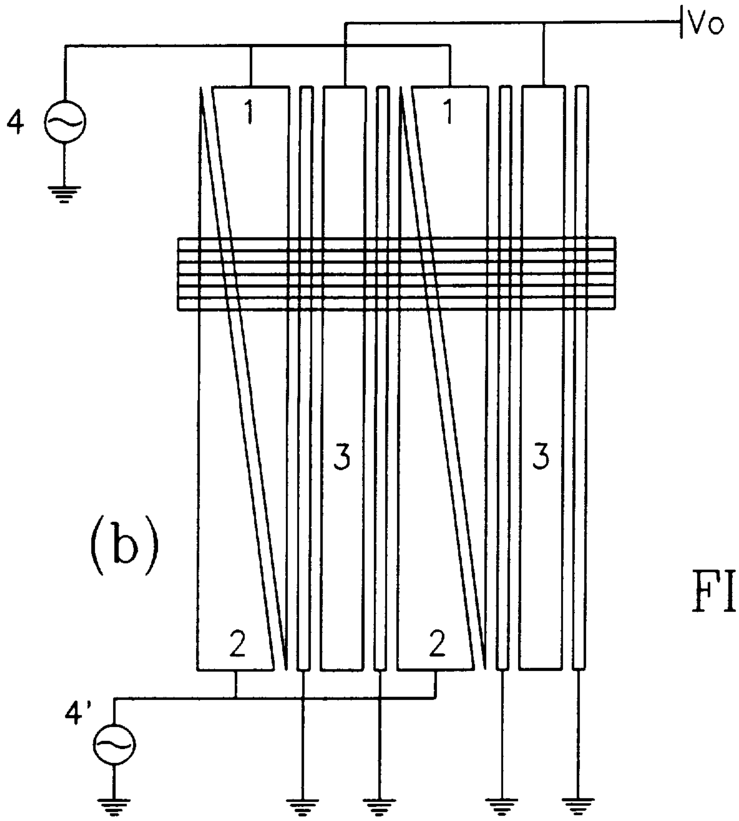


FIG.6

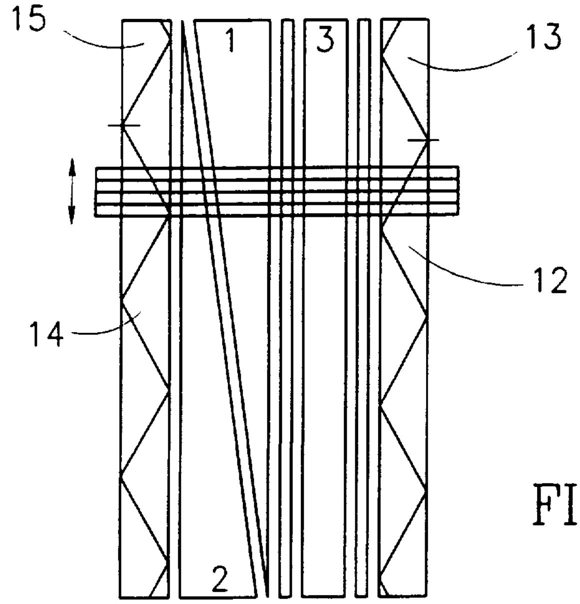


FIG.7

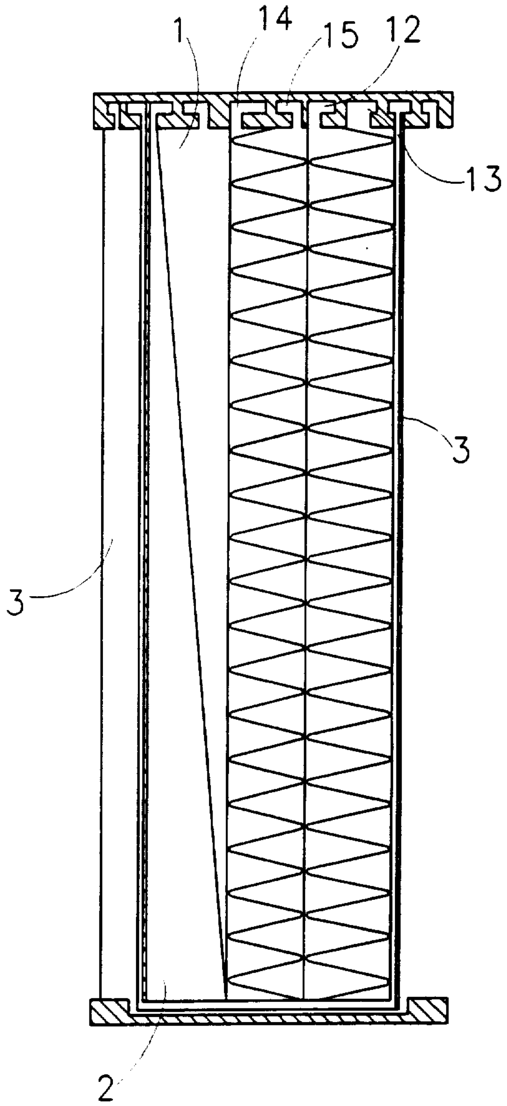


FIG.8

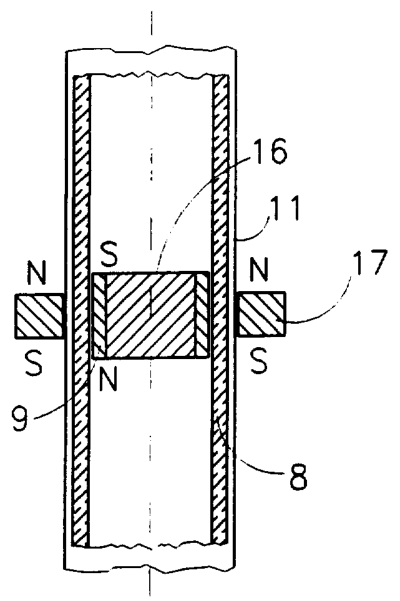


FIG.9

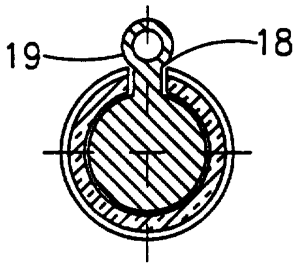


FIG.10A

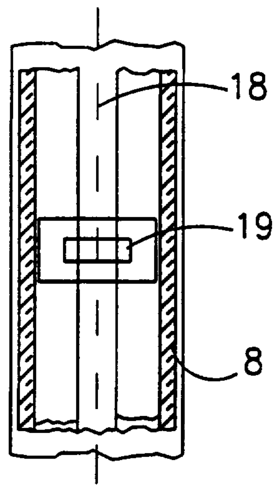


FIG.10B

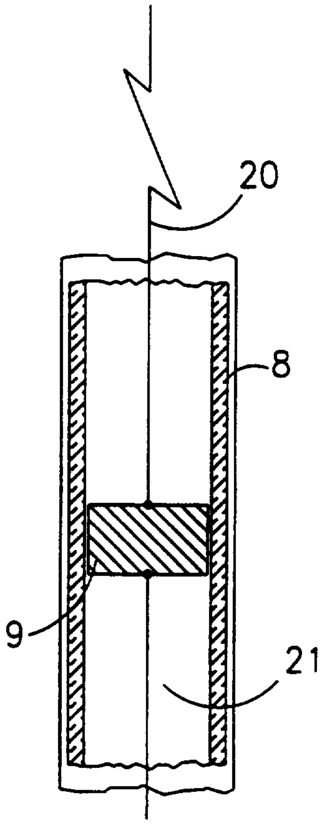


FIG.11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/16908

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G01R 27/26
US CL :324/660
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)

U.S. : 324/660, 658, 661, 662, 686

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 practicable, 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.
X	US, A, 3,784,897 (NORRIE) 08 January 1974, see entire document.	1-3, 5-9, 11, 12, 15, 21-24
X	US, A, 3,860,918 (CENCEL) 14 January 1975, Figs. 2 and 3, and col. 3, line 11 et seq.	1-4, 12, 21-24
X	US, A, 4,303,919 (DIMEFF) 01 December 1981, Figs. 2, 6, and 11, and corresponding disclosure.	1-5, 12, 21-24
X --- Y	US, A, 4,434,391 (SWARTZ ET AL.) 28 February 1984, Fig. 1, and col. 3, lines 14-56.	1-3, 12, 18, 21-24 --- 7

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

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

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 MARCH 1996	21 May 1996 (21.05.96)

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	GLENN BROWN
Facsimile No. (703) 305-3230	Telephone No. (703) 305-4700

Form PCT/ISA/210 (second sheet)(July 1992)★

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/16908

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,837,500 (ABBRINGH) 06 June 1989, Figs. 1 and 2, and col. 2, line 4 et seq.	1, 2, 4, 5, 8, 9, 12, 15, 18, 21-24
X	US, A, 4,841,225 (MEYER) 20 June 1989, Fig. 1.	1, 3-5, 10, 12, 21-24
X	US, A, 5,053,715 (ANDERMO) 01 October 1991, Figs. 1A and 4A, and corresponding disclosure.	1, 3-5, 10-12, 21-24
X --- Y	US, A, 5,239,307 (ANDERMO) 24 August 1993, Figs. 2, 6, 7, and 16, and corresponding disclosure.	1-3, 5, 8-12, 21-24 --------------- 7
Y	US, A, 5,317,351 (TAKAHARA ET AL.) 31 May 1994, Fig. 9, and col.6, line 4 et seq.	1, 7-9, 12, 15, 21, 22, 24
X, P	US, A, 5,461,319 (PETERS) 24 October 1995, Figs. 1, 3a, and 4a, and col. 6, line 25 et seq.	1-5, 8, 19, 21-24
X, P ---- Y	US, A, 5,461,320 (STRACK ET AL.) 24 October 1995, Fig. 1, and corresponding disclosure.	21-24 -------- 1, 3, 4, 10, 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/16908

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 25 and 26
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

the claims fail to point out what is included or excluded by the claim language

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.