(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
25 November 2010 (25.11.2010)

PCT

(10) International Publication Number
WO 2010/133006 A1

(51) International Patent Classification:
G01D 5/241 (2006.01) *F15B 15/14* (2006.01)
G01B 7/02 (2006.01)

(21) International Application Number:
PCT/CN2009/000547

(22) International Filing Date:
20 May 2009 (20.05.2009)

(25) Filing Language: English

(26) Publication Language: English

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *with international search report (Art. 21(3))*

(54) Title: CAPACITIVE LINEAR DISPLACEMENT SENSOR AND CYLINDER DEVICE

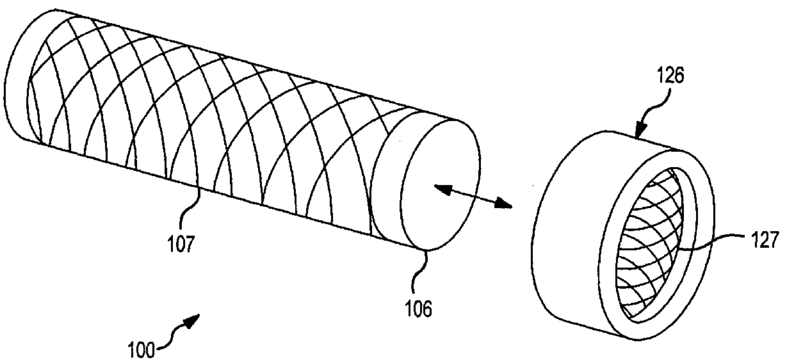


FIG. 2

(57) Abstract: A capacitive linear displacement sensor (100) includes a plunger (106), a capacitance grid (107) formed on the plunger (106), a capacitance sensor ring (126), wherein the plunger (106) is configured to move through the capacitance sensor ring (126), and a capacitive sensor portion (127) formed on an inner surface of the capacitance sensor ring (126) and configured to interact with the capacitance grid (107). The capacitive sensor portion (127) generates two positionally-varying capacitance signals related to a displacement of the plunger (106). A fluid cylinder (700) including the capacitive linear displacement sensor (100). A method of forming the capacitive linear displacement sensor.

WO 2010/133006 A1

CAPACITIVE LINEAR DISPLACEMENT SENSOR AND CYLINDER DEVICE

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The invention is related to the field of displacement sensors, and more particularly, to linear displacement sensors.

2. DESCRIPTION OF THE PRIOR ART

Pistons, cylinders, and linear actuators are pneumatic or hydraulic devices that employ or work with a pressurized fluid, such as a liquid or a gas. These devices can include pistons that move within a bore and either move in response to admission or release of pressurized fluid or move in order to force movement of the pressurized fluid.

In some applications, it is desired to know the position of the piston, especially where the piston location is highly correlated to a fluid volume or highly correlated to the movement or position of an associated mechanism. For example, a pneumatic actuator in an industrial application may be used to accurately move a work piece over a physical distance. Therefore, the reliable and accurate detection of piston location (and piston rod extension/retraction) is of great importance.

Many linear position sensors have been developed and deployed. These linear position sensors can comprise mechanical position sensors, which are of limited use in computerized or electrically controlled environments. More commonly, linear position sensors use magnetic, optical, resistive, or capacitive sensors in order to measure piston rod extension and retraction. Electrical position sensors are desired because they may not add significant mechanical resistance to the device/motion being measured and because of the nearly-universal computer control of mechanical and industrial processes. Prior art electrical position sensors have met with varying levels of success, depending on power consumption, device cost, accuracy, reliability, and dependability.

FIG. 1 shows a prior art capacitive linear displacement sensor. The prior art capacitive sensor typically comprises a fixed plate and a movable plate attached to an actuator rod. The varying capacitance is therefore a function of overlapping plate area. As the plates are moved to create a greater overlapping area, the capacitance increases. Such movement can also be used in a linear position sensor, wherein one set of plates is fixed and the other set is coupled to and moves with a linearly moving member.

However, prior art capacitive linear displacement sensors have drawbacks. The produced capacitance is not only a function of overlapping area, but also is a function of the gap between the plates. Parallel plates that can move must maintain a constant separation gap. An increase or decrease in the gap will change the resulting capacitance, even if the plates do not move linearly with respect to one another. This has been a drawback in capacitive-type linear position sensors. In addition, any rotation of one plate with respect to the other plate will affect the separation gap. Rotational stop mechanisms can be added to a prior art capacitive linear displacement sensor, but such rotational stop mechanisms also add resistance to the sensor motion. Further, any non-linear motion of a plate, even if the motion is in the plane of the plate, including side-to-side motion, will affect the overlap area and the resulting capacitance. This is referred to as tilt. Further yet, the plates require significant volume within the sensor, especially when added to a mechanical actuator or piston-type device.

What is needed, therefore, is an improved capacitive linear displacement sensor.

ASPECTS OF THE INVENTION

In some aspects of the invention, a capacitive linear displacement sensor comprises:

a plunger;

a capacitance grid formed on the plunger;

a capacitance sensor ring, wherein the plunger is configured to move through the capacitance sensor ring; and

a capacitive sensor portion formed on an inner surface of the capacitance sensor ring and configured to interact with the capacitance grid, wherein the capacitive sensor portion generates two positionally-varying capacitance signals related to a displacement of the plunger.

Preferably, the capacitance grid is affixed to an exterior surface of the plunger.

Preferably, the capacitance grid is formed into an exterior surface of the plunger.

Preferably, the capacitance grid comprises a pattern of substantially uniform and substantially equally spaced electrodes and the capacitive sensor portion includes first and second coupling electrodes that transfer two predetermined time-varying electrical signals to the electrodes and further includes upper and lower electrode arrays that receive back the two positionally-varying capacitance signals from the electrodes in response to the transfer of the two predetermined time-varying electrical signals.

Preferably, the two positionally-varying capacitance signals are processed to determine one or more of a displacement, a displacement direction, or a displacement velocity of the capacitance sensor ring with respect to the capacitance grid.

Preferably, the plunger is at least partially formed from a non-conductive material.

Preferably, the capacitive linear displacement sensor further comprises a separator layer between the capacitance grid and the plunger.

In some aspects of the invention, a fluid cylinder including a capacitive linear displacement sensor comprises:

a cylinder body including an endplate and an endplate aperture;

a piston configured to move reciprocally within the cylinder body;

a plunger coupled to the piston and extending through the endplate aperture, wherein the plunger moves with the reciprocal movement of the piston;

a capacitance grid formed on the plunger;

a capacitance sensor ring affixed to the endplate, wherein the plunger is configured to move through the capacitance sensor ring; and

a capacitive sensor portion formed on an inner surface of the capacitance sensor ring and configured to interact with the capacitance grid, wherein the capacitive sensor portion generates two positionally-varying capacitance signals related to a displacement of the plunger.

Preferably, the capacitance grid is affixed to an exterior surface of the plunger.

Preferably, the capacitance grid is formed into an exterior surface of the plunger.

Preferably, the capacitance grid comprising a pattern of substantially uniform and substantially equally spaced electrodes and with the capacitive sensor portion including first and second coupling electrodes that transfer two predetermined time-varying electrical signals to the electrodes and further including upper and lower electrode arrays that receive back the two positionally-varying capacitance signals from the electrodes in response to the transfer of the two predetermined time-varying electrical signals.

Preferably, the two positionally-varying capacitance signals are processed to determine one or more of a displacement, a displacement direction, or a displacement velocity of the capacitance sensor ring with respect to the capacitance grid.

Preferably, the plunger is at least partially formed from a non-conductive material.

Preferably, the capacitive linear displacement sensor further comprises a separator layer between the capacitance grid and the plunger.

Preferably, the fluid cylinder further includes a seal member located in the endplate, with the seal member sealing between the endplate and the plunger as the plunger is extended and retracted.

Preferably, the two positionally-varying capacitance signals are used for open-loop control of the fluid cylinder.

Preferably, the two positionally-varying capacitance signals are used for closed-loop control of the fluid cylinder.

In some aspects of the invention, a method of forming a capacitive linear displacement sensor comprises:

providing a plunger;

forming a capacitance grid on the plunger;

providing a capacitance sensor ring, wherein the plunger is configured to move through the capacitance sensor ring; and

forming a capacitive sensor portion on an inner surface of the capacitance sensor ring and configured to interact with the capacitance grid, wherein the capacitive sensor portion generates two positionally-varying capacitance signals related to a displacement of the plunger.

Preferably, the capacitance grid is affixed to an exterior surface of the plunger.

Preferably, the capacitance grid is formed into an exterior surface of the plunger.

Preferably, the capacitance grid comprises a pattern of substantially uniform and substantially equally spaced electrodes and the capacitive sensor portion includes first and second coupling electrodes that transfer two predetermined time-varying electrical signals to the electrodes and further includes upper and lower electrode arrays that receive back the two positionally-varying capacitance signals from the electrodes in response to the transfer of the two predetermined time-varying electrical signals.

Preferably, the two positionally-varying capacitance signals are processed to determine one or more of a displacement, a displacement direction, or a displacement velocity of the capacitance sensor ring with respect to the capacitance grid.

Preferably, the method further comprises forming the plunger at least partially from a non-conductive material.

Preferably, the method further comprises providing a separator layer between the capacitance grid and the plunger.

BRIEF DESCRIPTION OF THE DRAWINGS

The same reference number represents the same element on all drawings. It should be understood that the drawings are not necessarily to scale.

FIG. 1 shows a prior art capacitive linear displacement sensor.

FIG. 2 shows a capacitive linear displacement sensor according to the invention.

FIG. 3 is a cross-section of a plunger of the capacitive linear displacement sensor according to the invention.

FIG. 4 is a cross-section of the plunger according to the invention.

FIG. 5 shows detail of a capacitance grid of the capacitive linear displacement sensor according to the invention.

FIG. 6 shows detail of the capacitive sensor portion of the capacitive linear displacement sensor according to the invention.

FIG. 7 shows a cylinder device including a capacitive linear displacement sensor according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

FIGS. 2–7 and the following description depict specific examples to teach those skilled in the art how to make and use the best mode of the invention. For the purpose of teaching inventive principles, some conventional aspects have been simplified or omitted. Those skilled in the art will appreciate variations from these examples that fall within the scope of the invention. Those skilled in the art will appreciate that the features described below can be combined in various ways to form multiple variations of the invention. As a result, the invention is not limited to the specific examples described below, but only by the claims and their equivalents.

FIG. 2 shows a capacitive linear displacement sensor 100 according to the invention. The capacitive linear displacement sensor 100 includes a plunger 106 and a capacitance sensor ring 126. The plunger 106 moves linearly in use and can be a component of the capacitive linear displacement sensor 100 or alternatively can also be a component of another device (see FIG. 7 and the accompanying discussion below). In use, the plunger 106 is positioned within and moves through the capacitance sensor ring 126. The plunger 106 can move linearly (*i.e.*, reciprocally) within the capacitance sensor ring 126. The plunger 106 is shown out away from the capacitance sensor ring 126 merely for the purpose of clarity.

The plunger 106 and the capacitance sensor ring 126 can comprise substantially cylindrical components, as shown. However, it should be understood that alternatively the plunger 106 and the capacitance sensor ring 126 can be formed in other cross-sectional shapes. Other cross-sectional shapes are contemplated and are within the scope of the description and claims.

The plunger 106 is grounded in some embodiments. The plunger 106 may be grounded in order to reduce the pickup of electrical noise in the environment. The plunger 106 may be grounded in order to more effectively place an electrical signal on the capacitance grid 107 of the capacitance sensor ring 126.

A capacitance grid 107 is included on the exterior of the plunger 106 and extends at least partially around a circumference of the plunger 106. The capacitance grid 107 comprises a plurality of connected capacitive conductor regions that comprise at least one set of capacitor elements. The two or more sets of capacitor elements can be used to determine a displacement of the plunger 106. The two or more sets of capacitor elements can be used to determine a displacement velocity of the plunger 106. The capacitance grid 107 in some embodiments comprises two or more sets of capacitor elements wherein the two or more sets of capacitor elements can be used to determine a displacement, a displacement velocity, and a displacement direction. Details of the capacitance grid 107 are discussed below in conjunction with FIGS. 5-6.

The capacitance sensor ring 126 comprises a substantially annular element, or otherwise hollow element, that the plunger 106 passes through. The capacitance sensor ring 126 therefore corresponds in shape to the plunger 106. Both can be substantially circular in shape, as shown. Alternatively, the plunger 106 and the capacitance sensor ring 126 can be other shapes, and the various shapes are within the scope of the description and claims.

The capacitance sensor ring 126 includes a capacitive sensor portion 127. The capacitive sensor portion 127 can comprise conductors or other capacitance-sensitive portion. The conductors making up the capacitive sensor portion 127 are formed in a substantially cylindrical shell in the embodiment of the figure. The capacitive sensor portion 127 can be coupled to a processor or other sensor circuitry that receives and senses a capacitance level in order to determine a rod position. A resulting rod position displacement measurement therefore represents a position of the capacitance sensor ring 126 relative to the plunger 106. In addition, a processor or other sensor circuitry coupled to the capacitive linear displacement sensor 100 can determine a displacement velocity and a displacement direction.

The capacitance grid 107 can be connected to an electrical power source through any manner of trace, wire, et cetera. Two predetermined time-varying electrical signals can be placed across capacitance grid 107 and the capacitive sensor portion 127 (see FIG. 6 and the accompanying discussion below).

The capacitance grid 107 can comprise any manner of capacitance electrode or electrodes. The capacitance grid 107 can be formed on or into the exterior of the plunger 106. The capacitance grid 107 can be smoothly blended into the plunger 106, in some embodiments, and therefore will not interfere with a seal 709 that sealingly engages the plunger 106 (see FIG. 7). Alternatively, any manner of non-conductive coating can be placed or formed over the plunger 106, including a substantially dielectric layer, film, paint, et cetera.

The capacitive sensor 127 of the capacitance sensor ring 126 is formed on an inner surface of the capacitive sensor ring 126. A tolerance between the capacitive sensor 127 and the exterior surface of the plunger 106 may be kept to a minimum, lessening movement or slop of the plunger 106 within the capacitance sensor ring 126. The tolerance in some embodiments may be controlled by a separate element, such as the seal 709.

FIG. 3 is a cross-section of the plunger 106 of the capacitive linear displacement sensor 100 according to the invention. In this figure, the capacitance grid 107 is formed on the plunger 106. The capacitance grid 107 extends at least partially around the circumference of the plunger 106. The capacitance grid 107 may be formed directly on the plunger 106 in some embodiments.

FIG. 4 is a cross-section of the plunger 106 according to the invention. In this figure, a separator layer 108 is formed between the capacitance grid 107 and the plunger 106. The separator layer 108 can comprise a dielectric in some embodiments. Alternatively, the separator layer 108 can comprise an insulator or conductor material, for example.

FIG. 5 shows detail of the capacitance grid 107 of the capacitive linear displacement sensor 100 according to the invention. The two components 107 and 127 of the capacitive linear displacement sensor 100 are shown in two dimensions for simplicity, but it should be understood that they are three-dimensionally formed on the exterior of the plunger 106 and on the interior of the capacitance sensor ring 126. In some embodiments, they extend partially over the two surfaces, but alternatively they may extend substantially fully over the respective surface areas.

The capacitance grid 107 includes a plurality of electrodes 145 formed on a plunger substrate 146. The electrodes 145 are shown as being substantially planar, but it should be understood that the capacitance grid 107 will comprise a cylindrical shell or other shape. The plunger substrate 146 can be formed on or as part of the plunger 106 or can be applied to the plunger 106. The plunger substrate 146 can be substantially rigid or substantially flexible.

The electrodes 145 in the figure are substantially regular in shape, area, and spacing. The electrodes 145 in the figure are substantially rectangular in general shape. Therefore, substantially equal empty regions are located between individual electrodes 145. However, it should be understood that the electrodes 145 can be varied as desired. The electrodes 145 are preferably spaced very closely together in order to maximize capacitance. The electrodes 145 are not connected together. It should be understood that the grid in the figure is only one embodiment. Other capacitive electrode arrangements are contemplated and are within the scope of the description and claims.

The electrodes 145 are positioned to be substantially laterally displaced with respect to the linear motion of the plunger 106. Within practical limits, the pattern of electrodes 145 can be continued or extended indefinitely. The capacitance grid 107 can include any number of electrodes 145.

Where the plurality of electrodes 145 are regularly spaced, the spacing can be used as a displacement scale. Consequently, as the capacitive sensor 127 is moved to either the left or right over the capacitance grid 107, the capacitive sensor 127 will generate response signals corresponding to the spacing of the plurality of electrodes 145. In addition, the generated signals may also be affected by the shape and area of the electrodes 145.

Signal peaks are generated when the electrodes of the capacitive sensor 127 are substantially centered over the electrodes 145. Conversely, signal valleys are generated when the electrode regions of the capacitive sensor 127 are substantially centered over the regions between the electrodes 145.

Because the electrodes 145 in some embodiments are substantially regular in size and spacing, the signal response created by movement relative to the capacitive sensor 127 will generate predictable signals comprising peaks and valleys. The amplitude of the peaks and valleys will be controlled by the design of the sensor and by the applied electrical field. The spacing of the peaks and valleys (*i.e.*, the distance between adjacent peaks, between adjacent valleys, or between adjacent peaks and valleys) will denote the displacement velocity of the capacitance grid 107 with respect to the capacitive sensor 127. Further, the number of peaks and valleys generated by the capacitive sensor 127 together with the capacitance grid 107 will create a displacement measurement, wherein the peaks and valleys can be counted in order to determine a displacement amount. The rate of generation, *i.e.*, the time spacing between adjacent peaks and valleys, can be quantified in order to determine a displacement velocity. Faster movement of the capacitance grid 107 with respect to the capacitive sensor 127 will generate a capacitive signal wherein peaks and valleys are closer together.

Movement of the capacitance grid 107 will cause a capacitive signal to be generated. The capacitive signal will include voltage peaks and valleys. The peaks will occur when electrodes 145 of the capacitance grid 107 align with and are maximally covered by the capacitive sensor 127. The signal valleys occur when the electrodes 145 maximally align with the empty regions between the outer portions 144A and 144C of the electrodes 145.

FIG. 6 shows detail of the capacitive sensor portion 127 of the capacitive linear displacement sensor 100 according to some embodiments of the invention. The capacitive sensor portion 127 includes a ring substrate 170 and two pluralities of electrodes formed on the ring substrate 170. As in the capacitance grid 107, the ring substrate 170 can be substantially rigid or substantially flexible and is disposed on an inner surface of the capacitance sensor ring 126. The capacitive sensor portion 127 includes a first coupling electrode 174, a second coupling electrode 175, an upper array 178, and a lower array 179. Each of the upper electrode array 178 and the lower electrode array 179 comprises two array portions disposed above and below the two coupling electrodes 174 and 175. The upper and lower electrode arrays 178 and 179 each comprise a series of electrodes. The electrodes are regular in size, shape, and spacing. The electrodes in some embodiments are substantially planar and substantially rectangular. The capacitive sensor portion 127 may further include ground planes 172 above and below the other components. The ground planes 172 reduce electrical noise in the various capacitive elements.

The first and second coupling electrodes 174 and 175 are positioned between the two separate portions of the upper array 178 and lower array 179. Two electrical signals are communicated to the electrodes 145 of the capacitance grid 107 by the first and second coupling electrodes 174 and 175. Two separate electrical signals are used, a first signal that is capacitively transmitted using the upper electrode array 178 and a second signal that is capacitively transmitted using the lower electrode array 179. The first and second signals comprise two predetermined time-varying electrical signals. The second signal is phase-shifted by ninety degrees from the first signal, where the two predetermined time-varying electrical signals comprise a sine signal and a cosine signal.

The upper electrode array 178 and the lower electrode array 179 subsequently interact with the capacitance grid 107 and pick up resulting signals in the form of two positionally-varying capacitive signals related to a displacement of the plunger 106. The electrode arrays 178 and 179 capacitively couple with the electrodes 145 of the capacitance grid 107 and receive a portion of the electrical signal as the two electrical signals are capacitively coupled and transmitted back from the capacitance grid 107 to the upper and lower electrode arrays 178 and 179, interacting with the capacitance grid 107. As a result, the capacitive sensor portion 127 generates the two positionally-varying capacitance signals. The two positionally-varying capacitance signals can be discriminated by the ninety degree phase shift and can be used to determine the displacement of the plunger 106.

The combined electrode arrays 178 and 179 have a height H2 that is approximately equal to the height H1 of the electrodes 145 of the capacitance grid 107. In addition, the capacitive sensor portion 127 has a length L2. The length L2 will be less than the length L1. The length L2 may be independent of the length L1 of the capacitance grid 107.

It should be understood that the capacitive grid 107 and the capacitive sensor portion 127 must substantially correspond in height, H1 versus H2. However, the lengths L1 and L2 of each can be varied. For example, the length L1 of the capacitance grid 107 can be set to suit the length of the plunger 106 or to suit a measurable span of the plunger 106. Likewise, the length L2 of the capacitive sensor portion 127 can be set according to the size of the capacitance sensor ring 126 and is typically only a fraction of the length L1.

Each of the electrode arrays 178 and 179 is composed of a plurality of elongate elements 188 and 189. Each elongate element 188 or 189 of an array is electrically coupled to the other elements 188 or 189 of the array. Consequently, the electrodes of each array 178 and 179 are interleaved. As a result, a point in an electrode 145 of the capacitance grid 107 will be covered by an elongate element 188 of the upper electrode array 178, then by an elongate element 189 of the lower electrode array 179, then by an elongate element 188 of the upper electrode array 178, and so on, as the capacitance grid 107 moves with respect to the capacitive sensor portion 127. The interleaving guarantees that the upper electrode array 178 and the lower electrode array 179 interact equally, and alternatingly, with the electrodes 145 of the capacitance grid 107.

The elongate elements 183 of the electrode arrays 178 and 179 are of uniform width and spacing except for the spacing of the two central elongate elements 188', which correspond to the space between the first and second coupling electrodes 174 and 175, where a quarter of the otherwise standard spacing is added to divide the electrode arrays 178 and 179 into two corresponding portions in space or phase quadrature with each other.

The capacitance grid 107 and the capacitor sensor portion 127 are shown substantially to scale in relation to each other. Consequently, the height H1 of the electrodes 145 of the capacitance grid 107 are substantially the same as the height H2 of the upper and lower arrays 178 and 179 of the capacitive sensor portion 127, as previously discussed.

Excitation signals of two distinct phases are separately applied to the upper electrode array 178 and the lower electrode array 179. In operation, these signals are capacitively coupled to the outer end portions 144A and 144C of the electrodes 145. The signals that are impressed on the electrodes 145 (which in operation are located over the electrodes 145) are sensed via the first and second coupling electrodes 174 and 174.

FIG. 7 shows a cylinder device 700 including a capacitive linear displacement sensor 100 according to the invention. The cylinder device 700 includes a cylinder body 702, a cylinder chamber 704, an endplate 710, and a piston 706 disposed in the cylinder chamber 704. The piston 706 can reciprocate in the cylinder chamber 704. The plunger 106 is coupled to the piston 706 and extends out from an endplate aperture 712. The plunger 106 can provide a force/displacement to the piston 706 in order to move the piston 706 within the cylinder chamber 704. Alternatively, the piston 706 can move within the cylinder chamber 704 and transfer a force/displacement to the plunger 106. The cylinder device 700 can additionally include a seal or seals 709 coupled to the endplate 710 and that seal the plunger 106 to the endplate aperture 712. The seal or seals 709 can comprise a portion of the capacitance sensor ring 126 or can be independent of the capacitance sensor ring 126. The capacitive linear displacement sensor 100 can therefore generate signals that indicate the displacement, displacement velocity, and/or the displacement direction of the plunger 106.

Advantageously, the three-dimensional nature of the plunger 106 and the capacitance sensor ring 126 provides benefits over a prior art planar displacement sensor. The capacitive linear displacement sensor according to the invention presents minimal friction to movement and does not interfere with or restrict linear motion of the plunger. The capacitive linear displacement sensor is minimally affected by non-axial movement of the plunger. The capacitive linear displacement sensor can be applied to plungers of various shapes and sizes. The capacitive linear displacement sensor is highly suitable for applications where seals are used or required. The capacitive linear displacement sensor functions well where the gap between capacitive elements cannot change, as the movement of the plunger may be controlled by a seal or seals that also prevent changes in the gap between sensor components. The capacitive linear displacement sensor is compact in size and does not require an interfering or space-consuming structure independent of the plunger. The capacitive linear displacement sensor is easily incorporated into cylinders or other linear mechanical devices.

We claim:

1. A capacitive linear displacement sensor (100), comprising:
a plunger (106);
a capacitance grid (107) formed on the plunger (106);
a capacitance sensor ring (126), wherein the plunger (106) is configured to move through the capacitance sensor ring (126); and
a capacitive sensor portion (127) formed on an inner surface of the capacitance sensor ring (126) and configured to interact with the capacitance grid (107), wherein the capacitive sensor portion (127) generates two positionally-varying capacitance signals related to a displacement of the plunger (106).

2. The sensor (100) of claim 1, wherein the capacitance grid (107) is affixed to an exterior surface of the plunger (106).

3. The sensor (100) of claim 1, wherein the capacitance grid (107) is formed into an exterior surface of the plunger (106).

4. The sensor (100) of claim 1, with the capacitance grid (107) comprising a pattern of substantially uniform and substantially equally spaced electrodes (145) and with the capacitive sensor portion (127) including first and second coupling electrodes (174) and (175) that transfer two predetermined time-varying electrical signals to the electrodes (145) and further including upper and lower electrode arrays (178) and (179) that receive back the two positionally-varying capacitance signals from the electrodes (145) in response to the transfer of the two predetermined time-varying electrical signals.

5. The sensor (100) of claim 4, wherein the two positionally-varying capacitance signals are processed to determine one or more of a displacement, a displacement direction, or a displacement velocity of the capacitance sensor ring (126) with respect to the capacitance grid (107).

6. The sensor (100) of claim 1, wherein the plunger (106) is at least partially formed from a non-conductive material.

7. The sensor (100) of claim 1, with the capacitive linear displacement sensor (100) further comprising a separator layer (108) between the capacitance grid (107) and the plunger (106).

8. A fluid cylinder (700) including a capacitive linear displacement sensor (100), comprising:

a cylinder body (102) including an endplate (710) and an endplate aperture (712);

a piston (104) configured to move reciprocally within the cylinder body (102);

a plunger (106) coupled to the piston (104) and extending through the endplate aperture (712), wherein the plunger (106) moves with the reciprocal movement of the piston (104);

a capacitance grid (107) formed on the plunger (106);

a capacitance sensor ring (126) affixed to the endplate (710), wherein the plunger (106) is configured to move through the capacitance sensor ring (126); and

a capacitive sensor portion (127) formed on an inner surface of the capacitance sensor ring (126) and configured to interact with the capacitance grid (107), wherein the capacitive sensor portion (127) generates two positionally-varying capacitance signals related to a displacement of the plunger (106).

9. The fluid cylinder (700) of claim 8, wherein the capacitance grid (107) is affixed to an exterior surface of the plunger (106).

10. The fluid cylinder (700) of claim 8, wherein the capacitance grid (107) is formed into an exterior surface of the plunger (106).

11. The fluid cylinder (700) of claim 8, with the capacitance grid (107) comprising a pattern of substantially uniform and substantially equally spaced electrodes (145) and

with the capacitive sensor portion (127) including first and second coupling electrodes (174) and (175) that transfer two predetermined time-varying electrical signals to the electrodes (145) and further including upper and lower electrode arrays (178) and (179) that receive back the two positionally-varying capacitance signals from the electrodes (145) in response to the transfer of the two predetermined time-varying electrical signals.

12. The fluid cylinder (700) of claim 11, wherein the two positionally-varying capacitance signals are processed to determine one or more of a displacement, a displacement direction, or a displacement velocity of the capacitance sensor ring (126) with respect to the capacitance grid (107).

13. The fluid cylinder (700) of claim 8, wherein the plunger (106) is at least partially formed from a non-conductive material.

14. The fluid cylinder (700) of claim 8, with the capacitive linear displacement sensor (100) further comprising a separator layer (108) between the capacitance grid (107) and the plunger (106).

15. The fluid cylinder (700) of claim 8, further including a seal member (709) located in the endplate (710), with the seal member (709) sealing between the endplate (710) and the plunger (106) as the plunger (106) is extended and retracted.

16. The fluid cylinder (700) of claim 8, wherein the two positionally-varying capacitance signals are used for open-loop control of the fluid cylinder (700).

17. The fluid cylinder (700) of claim 8, wherein the two positionally-varying capacitance signals are used for closed-loop control of the fluid cylinder (700).

18. A method of forming a capacitive linear displacement sensor, the method comprising:

providing a plunger;

forming a capacitance grid on the plunger;

providing a capacitance sensor ring, wherein the plunger is configured to move through the capacitance sensor ring; and

forming a capacitive sensor portion on an inner surface of the capacitance sensor ring and configured to interact with the capacitance grid, wherein the capacitive sensor portion generates two positionally-varying capacitance signals related to a displacement of the plunger.

19. The method of claim 18, wherein the capacitance grid is affixed to an exterior surface of the plunger.

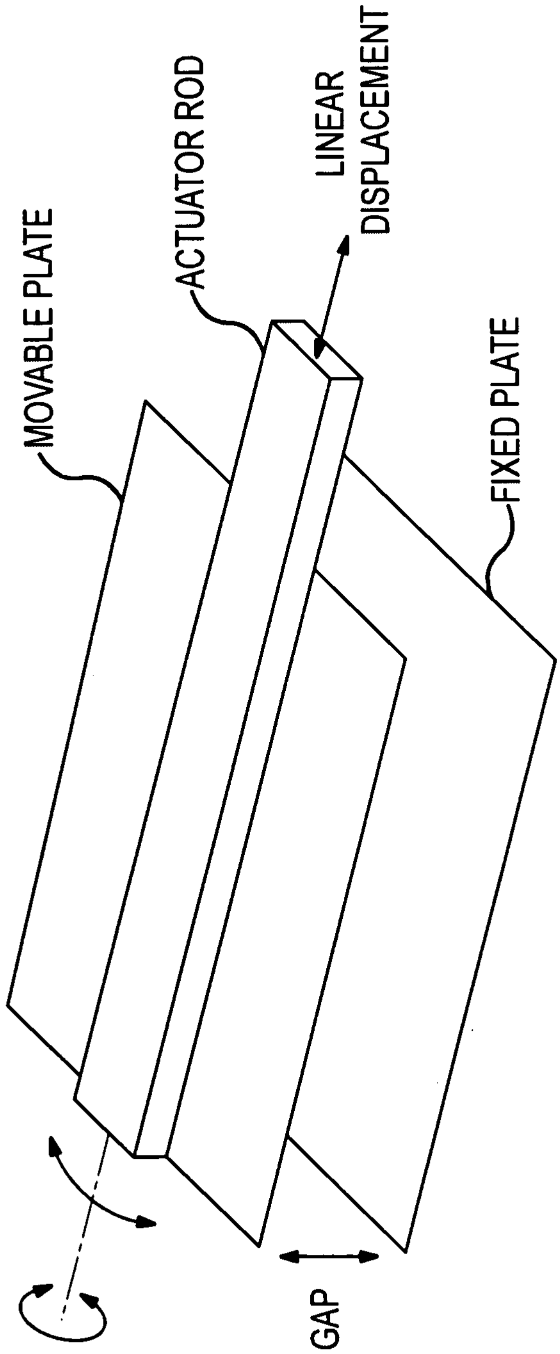
20. The method of claim 18, wherein the capacitance grid is formed into an exterior surface of the plunger.

21. The method of claim 18, with the capacitance grid comprising a pattern of substantially uniform and substantially equally spaced electrodes and with the capacitive sensor portion including first and second coupling electrodes that transfer two predetermined time-varying electrical signals to the electrodes and further including upper and lower electrode arrays that receive back the two positionally-varying capacitance signals from the electrodes in response to the transfer of the two predetermined time-varying electrical signals.

22. The method of claim 21, wherein the two positionally-varying capacitance signals are processed to determine one or more of a displacement, a displacement direction, or a displacement velocity of the capacitance sensor ring with respect to the capacitance grid.

23. The method of claim 18, forming the plunger at least partially from a non-conductive material.

24. The method of claim 18, further comprising providing a separator layer between the capacitance grid and the plunger.



PRIOR ART
FIG. 1

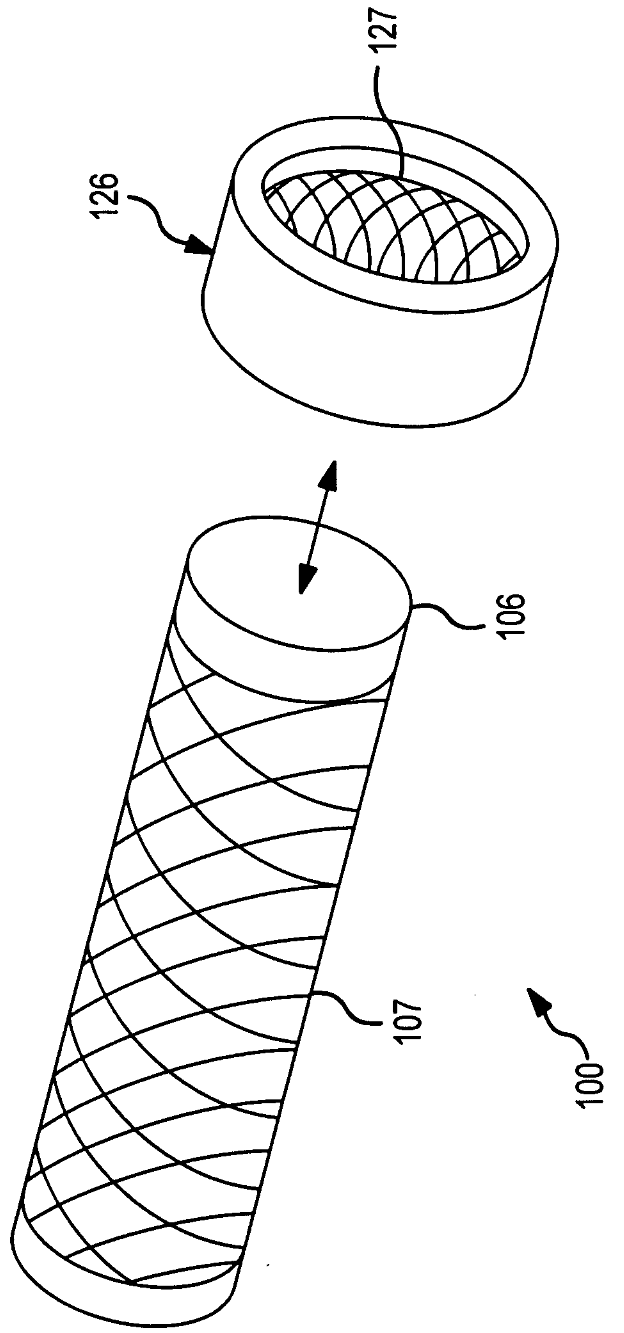


FIG. 2

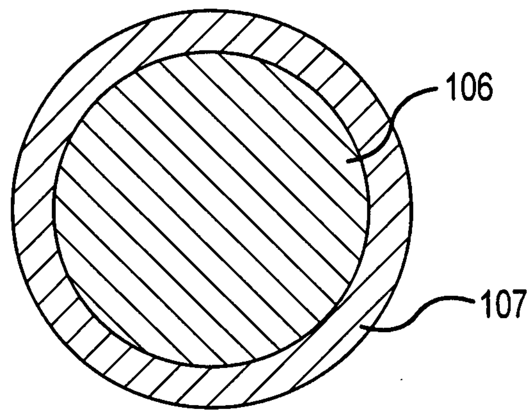


FIG. 3

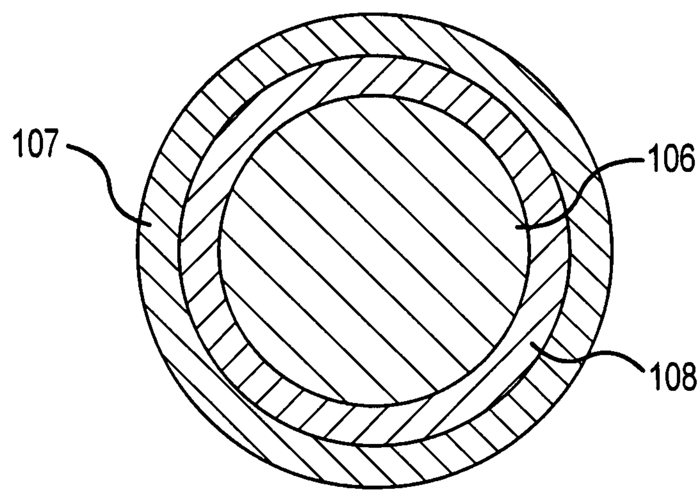
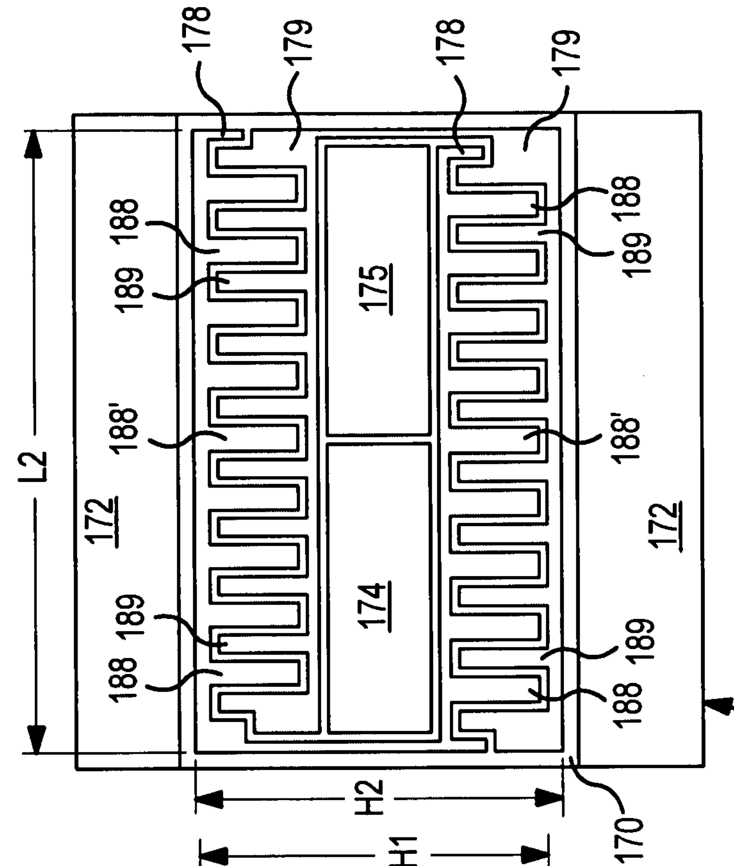


FIG. 4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179
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179
188
189
188'
189
188
L2
172
175
174
172
H2
170
127

FIG. 6

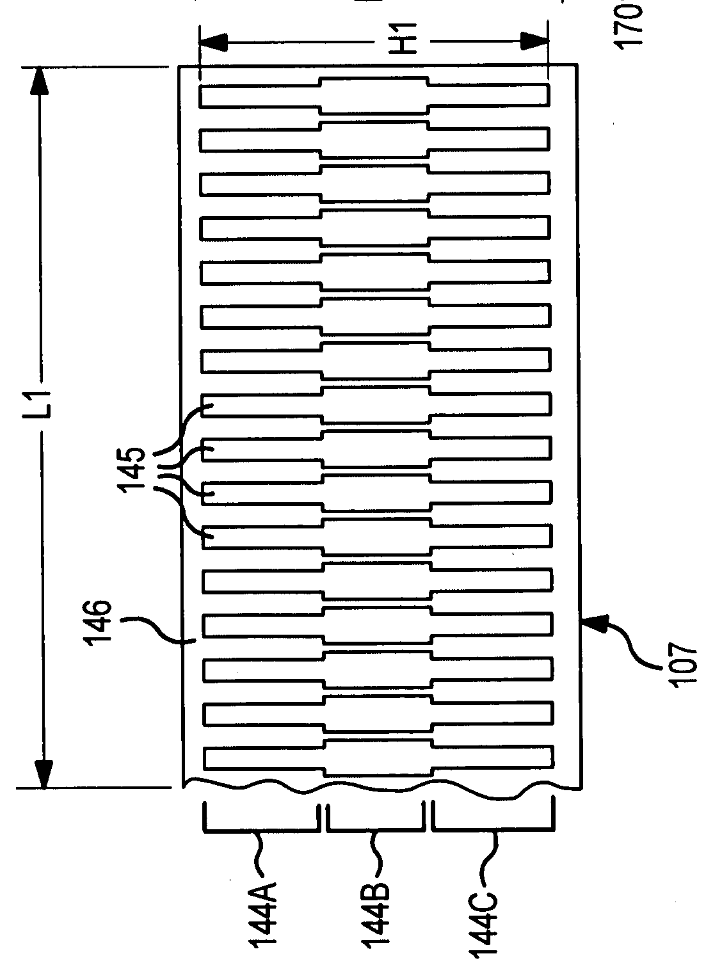
H1
L1
145
146
107
144A
144B
144C

FIG. 5

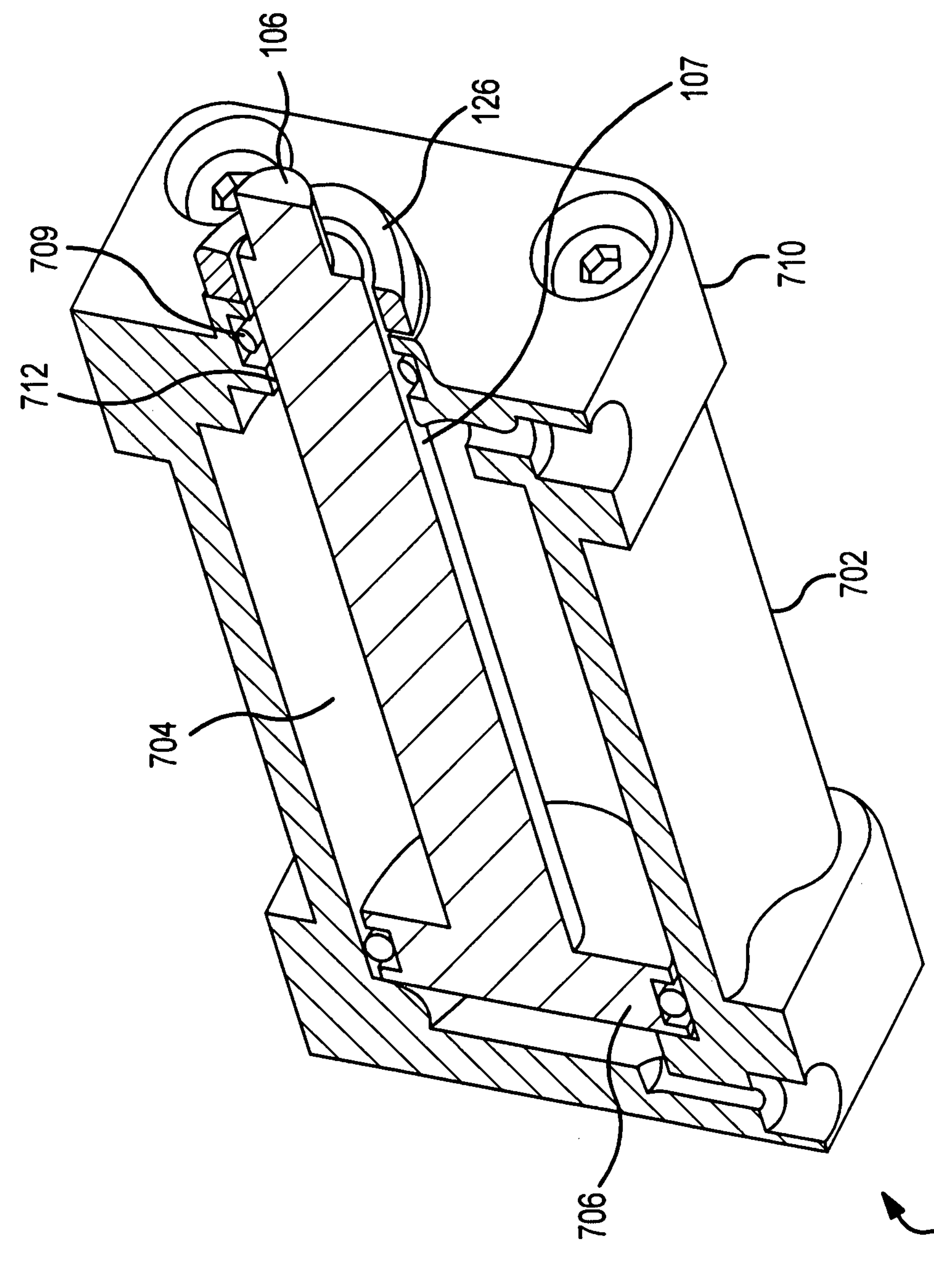

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2009/000547

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

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：G01B, G01D, F15B

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)

EPODOC，WPI，PAJ，CNPAT，CNKI：capacit+, grid, cylinder, piston, rod

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DE4205048A1（SIEMENS AG）26 Aug.1993（26.08.1993），figures 1-3, column 2 line 40 to column 5 line 55	1-3, 6-10, 13-20, 23-24
Y	GB2155638A（WOLFENDALE P C）25 Sept.1985（25.09.1985），figure 1, column 1 line 5 to column 3 line 20	1-3, 6-10, 13-20, 23-24
A	CN101089406A（KAYABA IND CO LTD）19 Dec.2007（19.12.2007），the whole document	1-24
A	US6327791B1（NAT INST STANDARDS & TECHNOLOG ET AL）11 Dec.2001（11.12.2001），the whole document	1-24
A	DE102005043107A1（INDEAS EINGABE & ANTRIEBS-SYSTEME GMBH）22 Mar.2007（22.03.2007），the whole document	1-24

☐ 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 application or patent but 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
15 Jan. 2010(15.01.2010)	**04 Feb. 2010 (04.02.2010)**

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Facsimile No. 86-10-62019451

Authorized officer
SHU,Chang
Telephone No. (86-10)62085724

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2009/000547

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
DE4205048A1	26.08.1993	NONE	
GB2155638A	25.09.1985	NONE	
CN101089406A	19.12.2007	EP1867880A1	19.12.2007
		EP1867880B1	17.06.2009
		JP2007333122A	27.12.2007
		ES2326005T	28.09.2009
US6327791B1	11.12.2001	WO0077472A	21.12.2000
		AU5737600A	02.01.2001
		EP1192412A	03.04.2002
DE102005043107A1	22.03.2007	NONE	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2009/000547

CLASSIFICATION OF SUBJECT MATTER

G01D 5/241 （2006.01）i
G01B 7/02 （2006.01）i
F15B 15/14 （2006.01）i