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(54) MECHANISM AND SYSTEM FOR 3-DIMENSIONAL SCANNING OF AN ULTRASOUND BEAM

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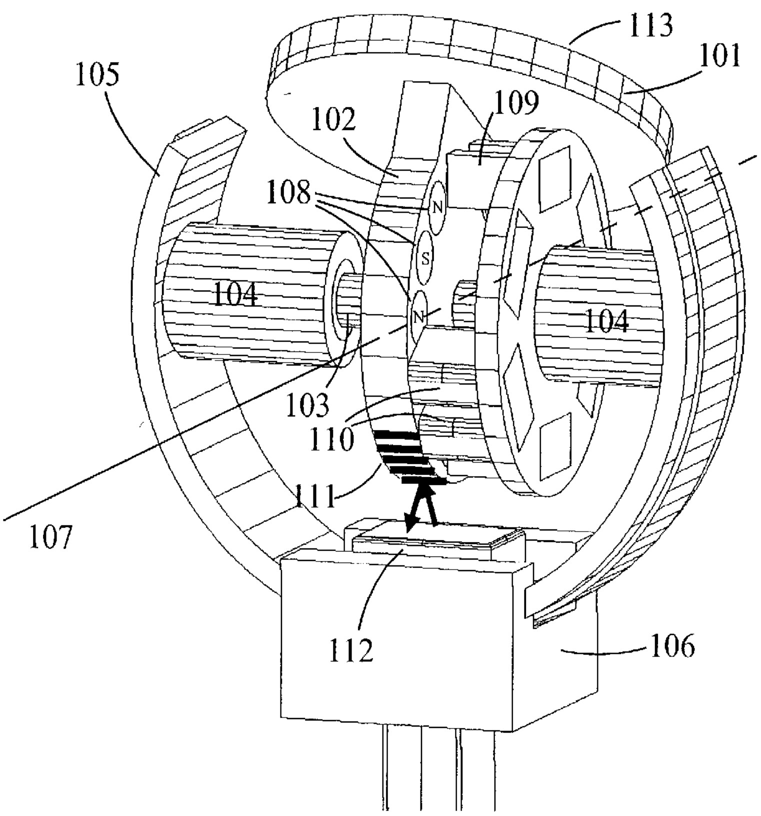
(57) **ABSTRACT**

An ultrasound probe capable of scanning an ultrasound beam in a region of 3D space, characterized by that an ultrasound transducer array is mounted to a 1$^{st}$ shaft that can rotate in bearings mounted in a fork that can be moved. The fork can be rotated around a 2$^{nd}$ shaft in a bearing, or moved through a sliding system, or a combination of the two. The shaft and the fork are connected to two separate electric motors for electric steering of the array direction within a region of 3D space. Position measurement systems are mounted to the shaft and the fork so that the beam direction can be steered with a feed-back control system.



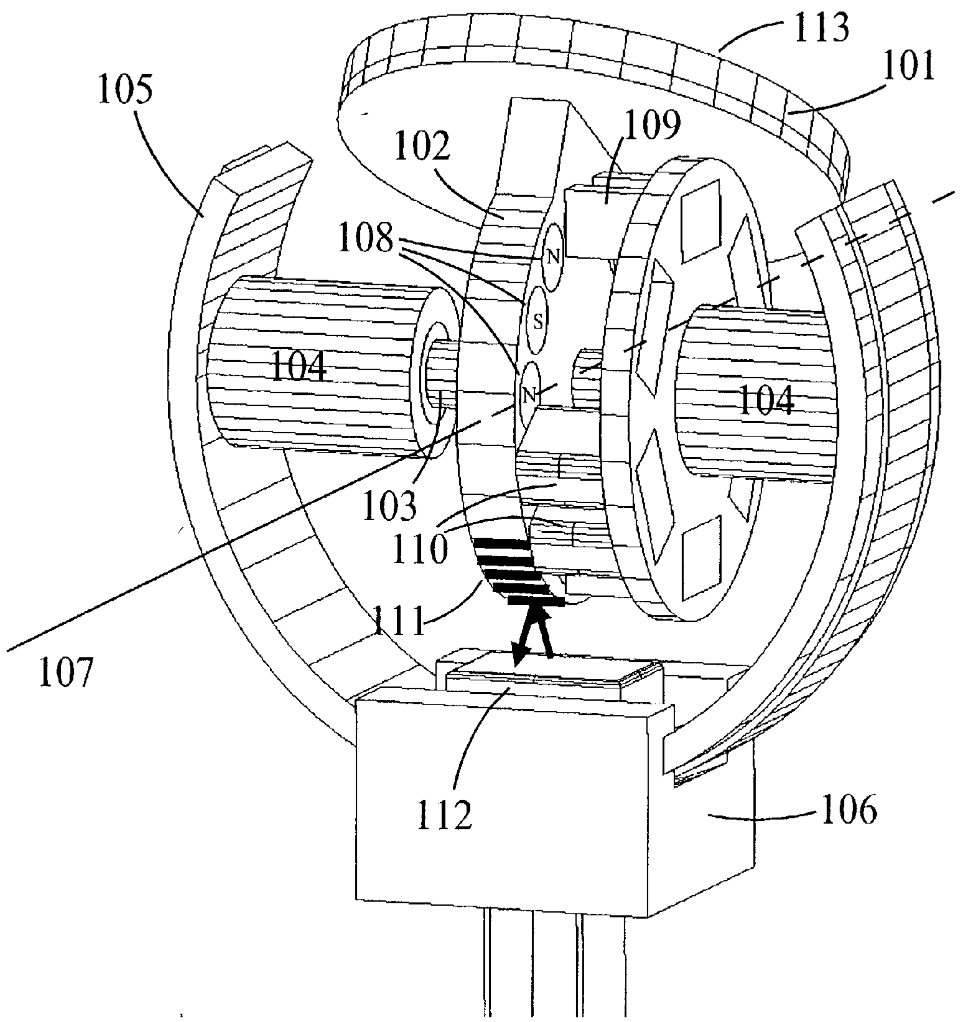



Figure 1a

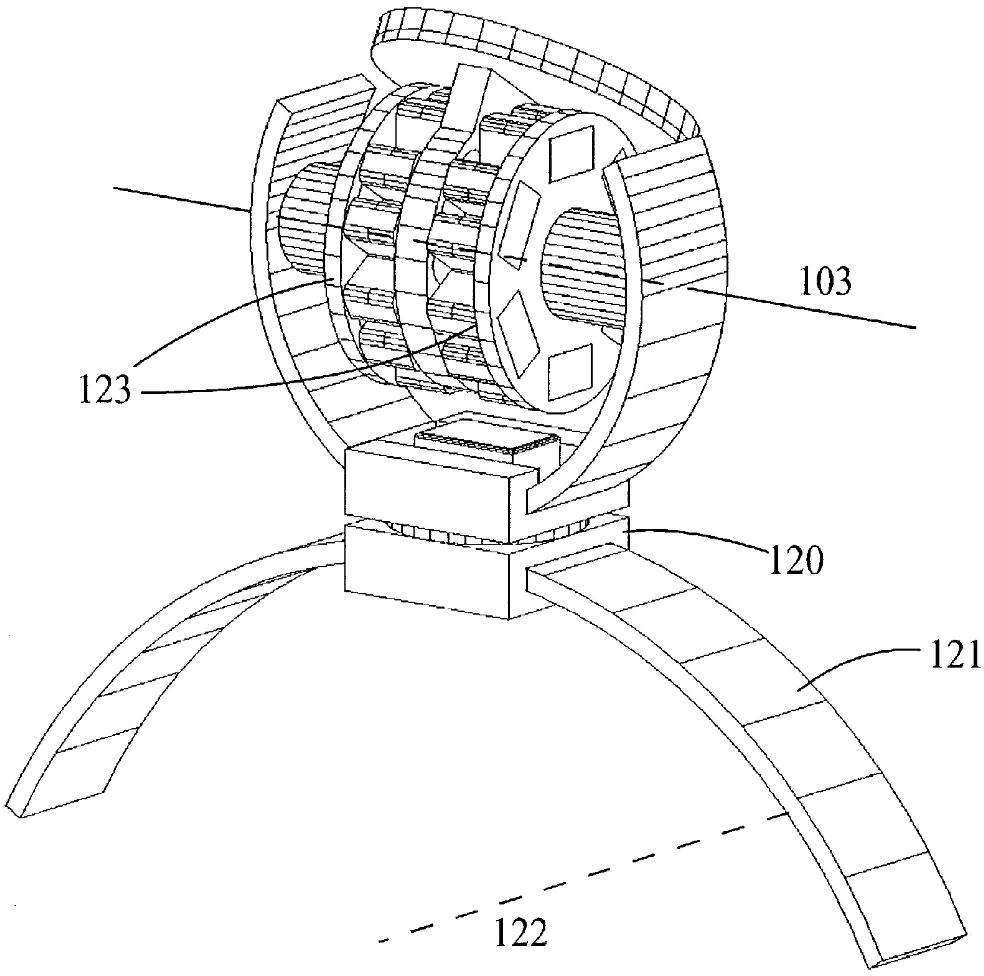



Figure 1b

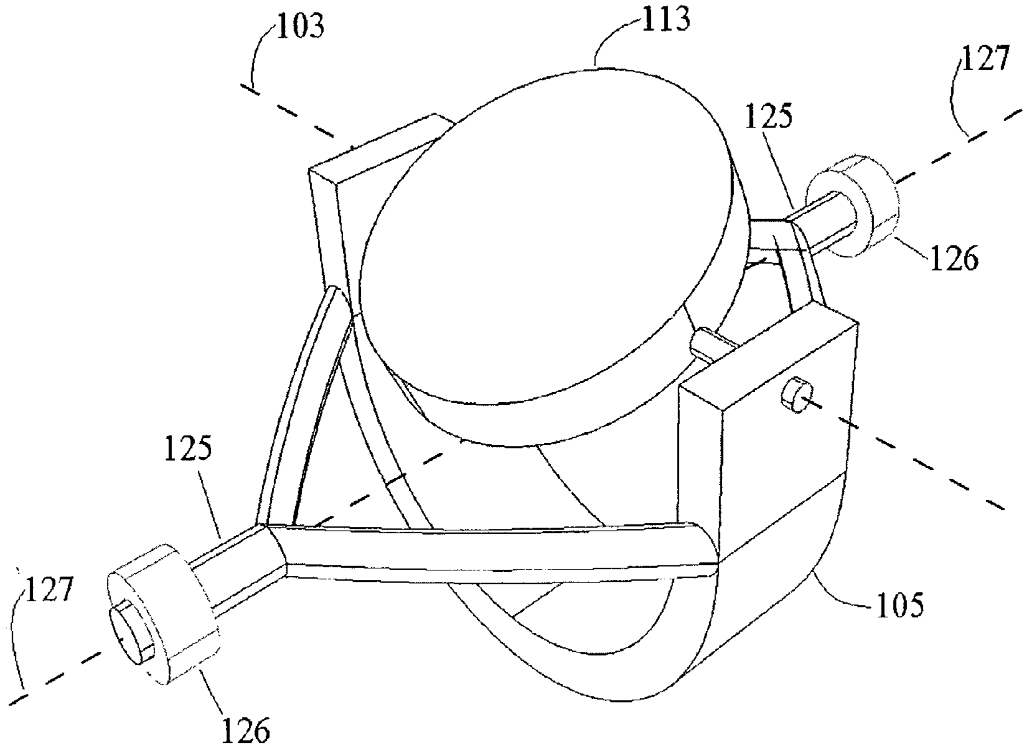



Figure 1C

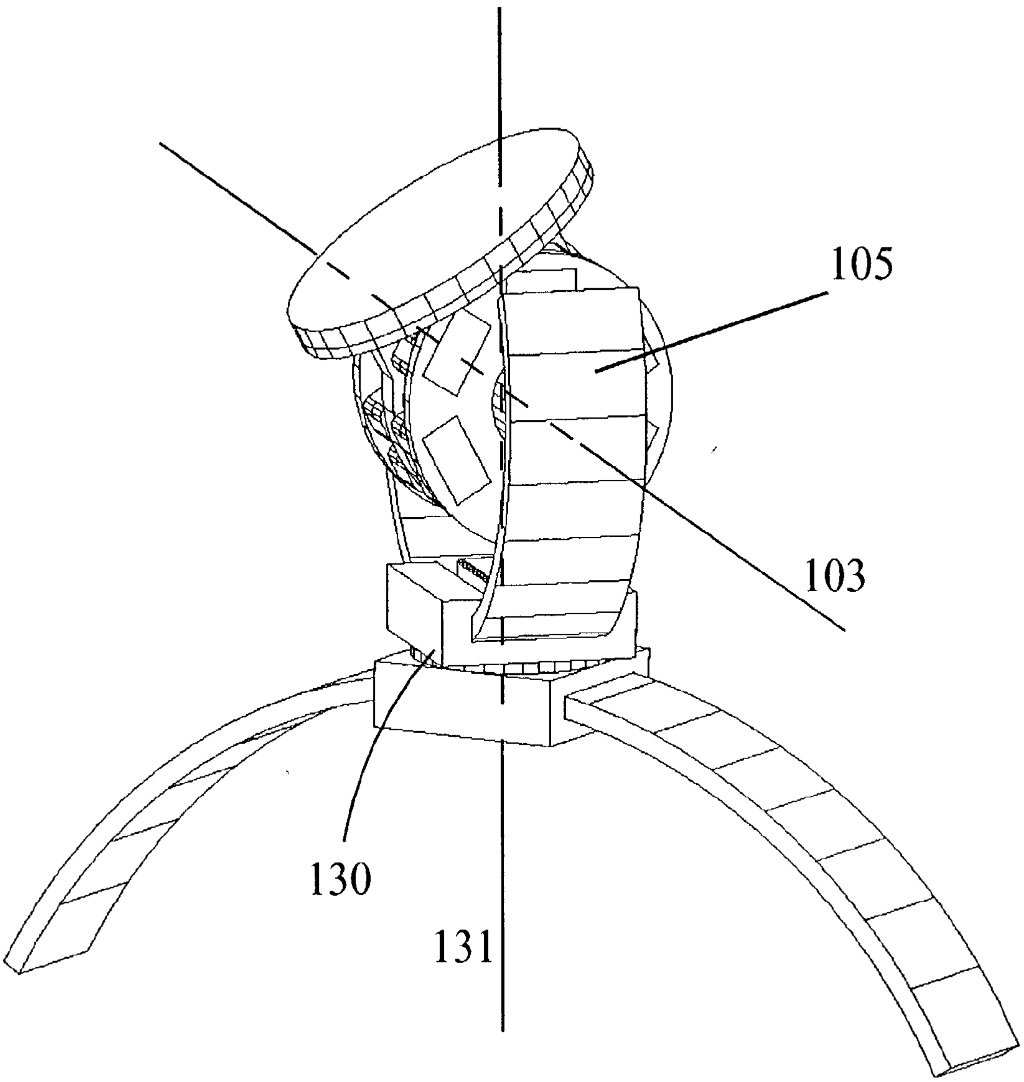



Figure 1d

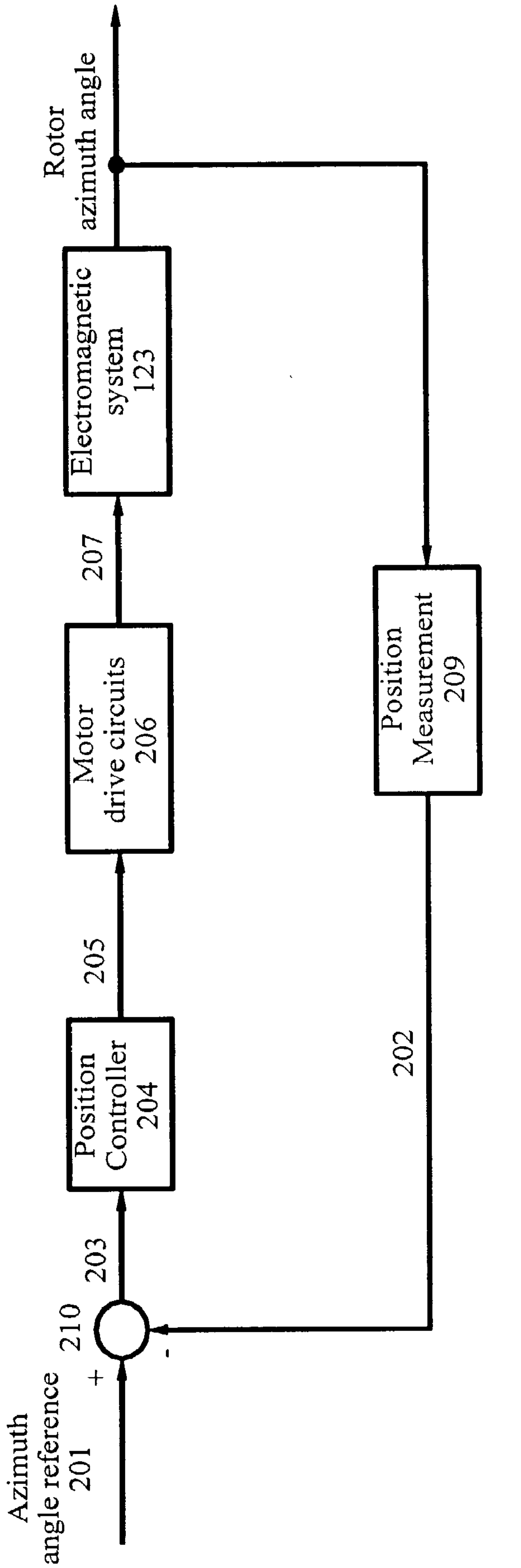

Rotor
azimuth angle
Electromagnetic
system
123
207
Motor
drive circuits
206
205
Position
Controller
204
203
210
+
-
Azimuth
angle reference
201
Position
Measurement
209
202

Figure 2

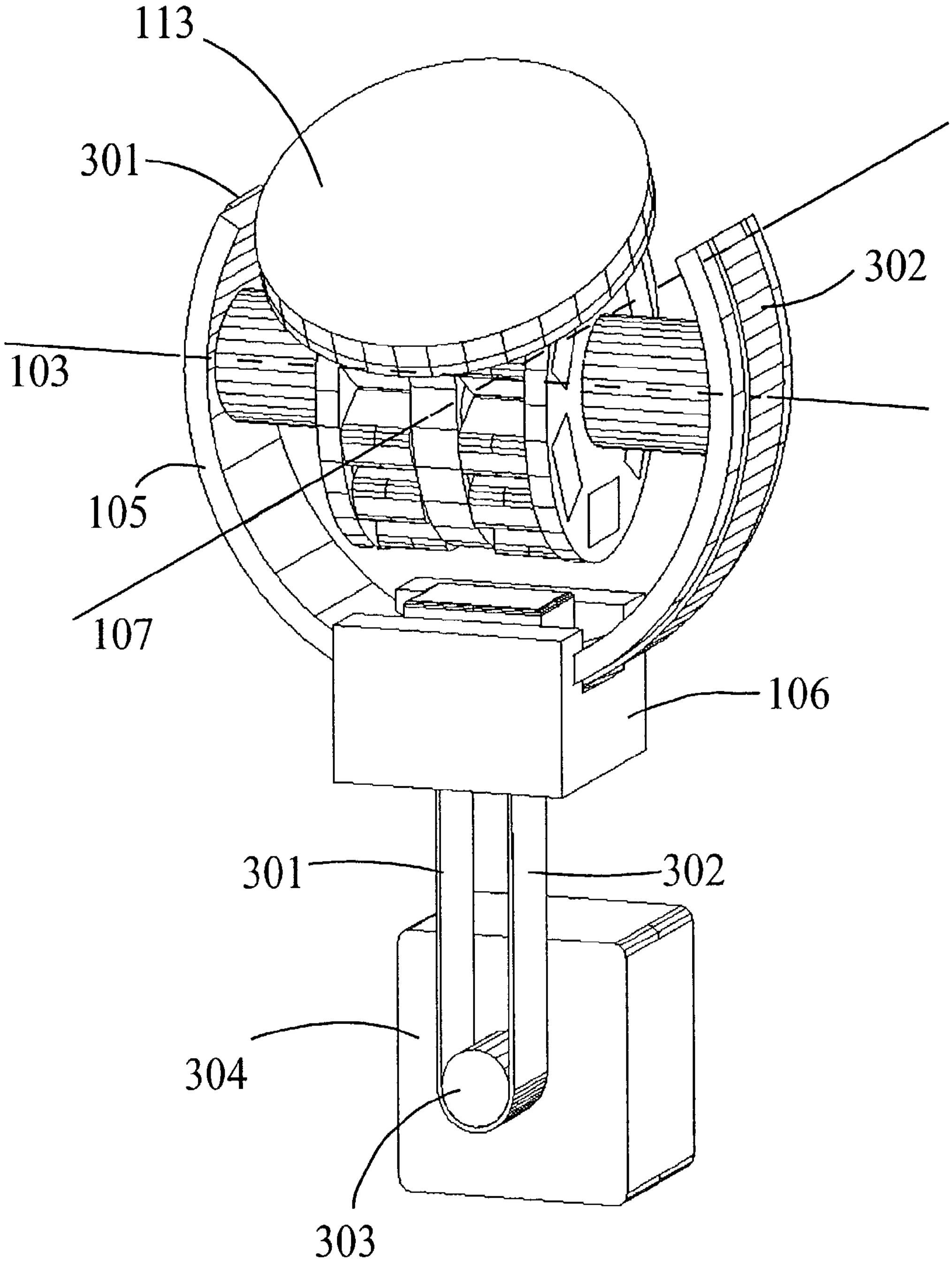



Figure 3

# MECHANISM AND SYSTEM FOR 3-DIMENSIONAL SCANNING OF AN ULTRASOUND BEAM

## BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention is directed to technology and methods for scanning an ultrasound beam in a free direction within a region of 3D space. The technology has particular applications within 3D medical ultrasound imaging, but also has applications in other areas of ultrasound imaging or other areas where mechanical movement of an object in 3D space is required.

[0003] 2. Description of the Related Art

[0004] Three-dimensional (3D) ultrasound imaging of biological structures can be done by scanning a pulsed ultrasound beam in a 3D manner, and recording the back-scattered ultrasound signal in each beam direction. The principle was described already in the 50'ies, and several instruments have been build that applies the method.

[0005] With 3D imaging, it is important that the ultrasound beam is maximally focused, symmetrically in all directions around the beam axis, as one wants to observe the object from any direction (perspective), and small objects can be interrogated with a variety of beam directions. Such symmetric focusing can be obtained by subdividing the elements of a linear transducer array in the elevation direction, i.e. the direction normal to the two-dimensional (2D) scan plane. The 2D scan plane is often referred to as the azimuth scan plane, while the direction normal to the 2D scan plane is referred to as the elevation direction. Linear arrays with subdivision of the elements in the elevation direction are referred to as 1.5D or 1.75D arrays, depending on whether the elements can be symmetrically or individually steered around the azimuth mid plane. A problem with the subdivision of the elements is that the size of the elements are reduced, increasing the element impedance and hence also noise. The subdivision also gives a large total number of elements, leading to a large number of wires between the array elements and the electronic beam former. This increases cable losses and hence sensitivity of the array.

[0006] Symmetric focusing of the beam can be obtained with much fewer and larger elements with an array of concentric annular elements, the so-called annular array. The larger elements provide lower element impedances and hence less noise and cable losses. Another advantage with the annular array, is that it is covered in a dome, so that the array itself is not pushed against the body or other objects as the linear arrays typically are done. This allows the use of materials with lower characteristic impedance for mechanical backing support with the annular array compared to the linear arrays, giving less acoustic backing losses and hence better sensitivity with the annular array.

[0007] Hence the annular array provides better sensitivity for symmetrical focusing of the beam around the beam axis than the linear arrays, due to the large elements and low impedance backing material. The increased sensitivity in turn allows the use of higher ultrasound frequencies and hence better resolution for a given depth, than the linear arrays. The low number of elements also reduces the number of connecting cables and hence gives a lower manufacturing cost of the array.

[0008] A problem with the annular array for 3D beam scanning, is that scanning of the beam direction requires mechanical movement of the array. 3D scanning of the beam with small size of the whole scanning mechanism is then difficult, and the present invention provides a solution to this problem. With a particular embodiment of the invention, the annular array beam can be scanned in a 3D sector with more than 200 deg opening angle in both the elevation and the azimuth directions, with a dimension of the scan-head only slightly larger than the active radiation aperture of the array. The narrow head and wide scanning angle provide a probe that is small and easy to handle, and has special advantages for endoluminal and surgical imaging, where the probe is placed in narrow channels with limited possibilities to direction steer the probe, like for example with transvaginal, transrectal, transesophageal, transgastric, and transintestinal imaging, and imaging from narrow surgical wounds.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0009] In the drawings:

[0010] **FIG. 1** shows particular embodiments according to the invention that provides rotation of a transducer or transducer array around an azimuth axis defined by a 1$^{st}$ shaft that rotates in bearings mounted in a fork that can be moved, where **FIG. 1***a* shows sliding of the fork in a sliding system that provides rotation of the array around an elevation axis normal and close to the azimuth axis;

[0011] **FIG. 1***b* shows sliding of the fork in a sliding system that provides rotation of the array around an elevation axis normal to the azimuth axis and at a distance from the azimuth axis;

[0012] **FIG. 1***c* shows rotation of the fork around a 2$^{nd}$ shaft that provides rotation of the array around an elevation axis;

[0013] **FIG. 1***d* shows combined rotation of fork around a roll axis;

[0014] **FIG. 2** shows an example of a control system for driving the rotation of the transducer around the azimuth axis to follow an azimuth reference signal; and

[0015] **FIG. 3** shows a system with flexible bands thread around a pulley wheel attached to an electric motor for moving the fork in a sliding system.

## DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

[0016] A particular embodiment of the invention will be described with reference to the drawings. In **FIG. 1***a* **101** shows an annular array that is attached to the rotor **102** of an electric motor that is attached to a shaft **103** that is free to move in bearings **104** mounted in a fork **105**. Rotating the array around the shaft **103** scans the ultrasound beam in an angular direction referred to as the azimuth direction, within a 2D plane referred to as the azimuth plane. The fork **105** is mounted in a sliding system **106** which allows movement of the shaft. In this particular embodiment, the fork has a circular shape so that sliding of the fork through the sliding system produces a rotation of the shaft **103** around an axis **107**, normal to the shaft, which allows angular scanning of the beam in what is referred to as the elevation direction. Moreover, this particular embodiment produces a rotation of the shaft around an axis on the same side of the sliding system as the shaft itself, and the axis **107** goes through the center of the shaft **103**. This embodiment allows for a compact size of the mechanism in relation to the size of radiating acoustic surface aperture **113** of the transducer array **101**.

[**0017**] **FIG. 1***b* shows a modification of the embodiment where the sliding system **120** slides along a fork **121**, arranged so that the shaft **103** rotates around an axis **122** on the side of the sliding system opposite to the shaft axis **103**. An advantage of this sliding system is that the width of the beam scanning area becomes wider at the probe surface, than for the scanning system in **FIG. 1***a*. The scanning system in **FIG. 1***a*, however, produces a small outer dimension of the probe.

[**0018**] The rotor **102** of **FIG. 1***a* contains a set of permanent magnets distributed around the rotor in a sequence with opposite polarities, where in the drawing 3 magnets **108** are visible. Rotation of the rotor **102** causes the magnets to slide between the poles of a set of electromagnets with iron cores **109** with surrounding coils **110**. In **FIG. 1***a*, some of the magnets are removed for clarity, the cores **109** are shown without coils for some magnets, while the coils **110** around the cores are shown for other magnets. In **FIG. 1***b* an embodiment of an entire electromagnet system **123** is shown. By controlling the current in the coils according to standard methods for those skilled in the art, a torque is developed on the rotor that causes the transducer array to rotate around the shaft axis **103**.

[**0019**] For this particular embodiment, an optical reflectance grating **111** in **FIG. 1***a* is mounted around the rotor periphery. The grating is illuminated with a light emitting diode contained in the unit **112**. The light reflected from the grating is picked up with two light detection diodes tin the unit **112** that are offset a distance. By monitoring the signals from the two detector diodes one can both observe the direction of movement of the rotor, and its rotation angle measured in steps of ¼ of the angle between the reflection stripes of the position grating **111**, according to well known principles.

[**0020**] The system hence provides both a motor to produce a torque on the shaft **103** and a position system to measure the direction and angular rotation of the transducer array around the shaft axis. The motor and the position measurement system can hence be connected in a feedback control system for rotation of the transducer array around the shaft **103** under feed-back control. This allows precise direction steering of the array around the shaft axis, for example with an electronic control system as shown in **FIG. 2**.

[**0021**] In this Figure, the azimuth angle of the transducer array is measured in a unit **209**, which includes **111** and **112** of **FIG. 1***a*, producing a measured azimuth angle signal **202**. The measured azimuth angle signal **202** is compared with an azimuth angle reference signal **201** in the unit **210** that produces the angular position error **203** as the difference between the reference and the measured position. The position error signal is fed to a controller unit **204** that provides inputs **205** to the motor drive unit **206** that provides a set of electric drive signals **207** for the motor electromagnetic system **123** of **FIG. 1***b*. The control system hence drives the rotor azimuth angle to follow the azimuth angle reference.

[**0022**] To scan the beam in the elevation direction in **FIG. 1***a*, the fork is moved in the sliding system **106**. A system to control such sliding according to the embodiment, is shown in **FIG. 3**. Two flexible bands **301** and **302** are attached to the fork **105**, so that when one of the bands are pulled, the fork slides in the sliding system **106**. This sliding produces a movement of the azimuth rotation axis of the shaft **103**, where in this particular embodiment the shaft rotates around an elevation axis **107** normal to the shaft axis. The combined rotation around the azimuth shaft axis **103** and the elevation fork axis **107**, produces a 3D sector scanning of the beam in both the azimuth and the elevation directions. In this embodiment, the two flexible bands **301** and **302** are connected together in a loop around a pulley wheel **303** connected to a rotating electrical motor **304**. Angle controlled rotation of the motor **304**, for example by a control system similar to that in **FIG. 2**, causes a controlled rotation of the transducer around the elevation axis **107**.

[**0023**] A third method according the invention of moving the azimuth rotation axis **103** is illustrated in **FIG. 1***c*, where the fork **105** is connected to a 2nd shaft **125** that can rotate in the bearing system **126** to rotate the array **113** around both the elevation axis **127** and the azimuth axis **103**.

[**0024**] A fourth method according the invention of moving the azimuth rotation axis **103** is illustrated in **FIG. 1***d*, where the fork **105** is mounted in a shaft-bearing system **130** that allows the fork and hence the azimuth axis **103** to rotate around the roll axis **131**, normal to the azimuth axis. Combined rotation around the azimuth axis **103** and the roll axis **131** produces a 3D scanning of the beam direction. Rotation around the roll axis **131** can be obtained by an electric motor with direct coupling, coupling through a gear or through a set of pulleys.

[**0025**] Thus, while there have shown and described and pointed out fundamental novel features of the invention as applied to a preferred embodiment thereof, it will be understood that various omissions and substitutions and changes in the form and details of the devices illustrated, and in their operation, may be made by those skilled in the art without departing from the spirit of the invention. For example, it is expressly intended that all combinations of those elements and/or method steps which perform substantially the same function in substantially the same way to achieve the same results are within the scope of the invention. Moreover, it should be recognized that structures and/or elements and/or method steps shown and/or described in connection with any disclosed form or embodiment of the invention may be incorporated in any other disclosed or described or suggested form or embodiment as a general matter of design choice. It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto.

We claim:

**1**. An ultrasound transducer probe for scanning the direction and focus of an ultrasound beam in 3D space, characterized by

an ultrasound transducer array attached to a 1st shaft that is able to rotate in a bearing mounted in a fork,

the fork being moveable so that the 1st shaft is moved, so that the transducer array can be directed freely in any direction within a region of 3D space.

**2**. An ultrasound transducer probe according to claim 1, where the fork is moved through rotation around a 2nd shaft mounted in a bearing.

**3**. An ultrasound transducer probe according to claim 2, where the 2nd shaft axis is normal to the 1st shaft axis.

**4**. An ultrasound transducer probe according to claim 3, where the 2nd shaft axis crosses the 1st shaft axis.

**5**. An ultrasound transducer probe according to claim 1, where the fork is moved through sliding in a sliding system.

**6**. An ultrasound transducer probe according to claim 1, where the ultrasound array is an annular array.

**7**. An ultrasound transducer probe according to claim 1, where

a 1st electric motor is coupled to the shaft enabling the shaft attached to the array to rotate in the bearing,

and a 2nd electric motor is arranged to move the fork, so that through electric drive signals on the motors, the transducer array can be directed freely in any direction within a region of 3D space.

**8**. An ultrasound transducer probe according to claim 7, where the stator of the 1st electric motor is mounted to the fork and the rotor of the 1st electric motor is mounted to the shaft, enabling the shaft attached to the array to rotate in the bearing mounted in the fork.

**9**. An ultrasound transducer probe according to claim 5, where the fork has a circular shape and the sliding system is mounted so relative to the fork that the sliding provides a rotation of the shaft around an axis normal to the shaft.

**10**. An ultrasound transducer probe according to claim 5, where the sliding system is mounted so relative to the fork that the sliding provides a lateral displacement of the shaft in the plane of the shaft.

**11**. An ultrasound transducer probe according to claim 5, where the sliding system is mounted so relative to the fork that the sliding provides a rotation of the shaft around an axis on the shaft side of the sliding system, normal to the shaft.

**12**. An ultrasound transducer probe according to claim 1, where the fork is attached to at least one flexible band, and the movement of the fork is obtained by pulling the flexible band.

**13**. An ultrasound transducer probe according to claim 12, where the fork is attached to a flexible band on one side, and a spring system on the other side so that bi-directional movement of the fork is obtained by combined action of the spring system and pulling of the flexible band, where pulling of the flexible band moves the fork in one direction and the spring pulls the fork in the opposite direction when the pull in the flexible band is released.

**14**. An ultrasound transducer probe according to claim 12, where the fork on each side is attached to separate flexible band, and bi-directional movement of the fork is obtained by selectively pulling one of the bands.

**15**. An ultrasound transducer probe according to claim 12, where the pulling of the flexible band(s) is done by an electric motor.

**16**. An ultrasound transducer probe according to claim 13, where the pulling of the flexible band(s) is done by an electric motor.

**17**. An ultrasound transducer probe according to claim 14, where the pulling of the flexible band(s) is done by an electric motor.

**18**. An ultrasound transducer probe according to claim 2, where the second shaft-bearing system is mounted to a sliding system that allows movement of position and direction of the second shaft-bearing system, a 3rd electric motor being connected to the sliding system to move the position and direction of the second shaft-bearing system.

**19**. An ultrasound transducer probe according to claim 7, where the angular position of the 1st shaft and the position of the fork is measured, the position signals being fed to a feed-back controller that provides drive signals for the electric motors, so that the direction of the ultrasound beam can be steered so that the measured position of the shaft and the fork follows close to a reference signal.

* * * * *

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| 当前申请(专利权)人(译) | PREXION CORPORATION | | |
| [标]发明人 | ANGELSEN BJORN A J<br>JOHANSEN TONNI F<br>KJODE STIG B | | |
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摘要(译)

一种能够在3D空间区域中扫描超声波束的超声探头，其特征在于，超声换能器阵列安装在第一轴上，该第一轴可以在安装在可移动的叉中的轴承中旋转。叉可绕轴承中的第二轴旋转，或通过滑动系统或两者的组合移动。轴和叉连接到两个单独的电动机，用于在3D空间的区域内对阵列方向进行电动转向。位置测量系统安装在轴和叉上，以便通过反馈控制系统控制光束方向。