May 5, 1970 J. E. TURRIERE 3,510,877

ANTENNA POSITIONING DEVICE FOR FOLLOWING MOVING BODIES

Filed Sept. 7, 1967 2 Sheets-Sheet 1

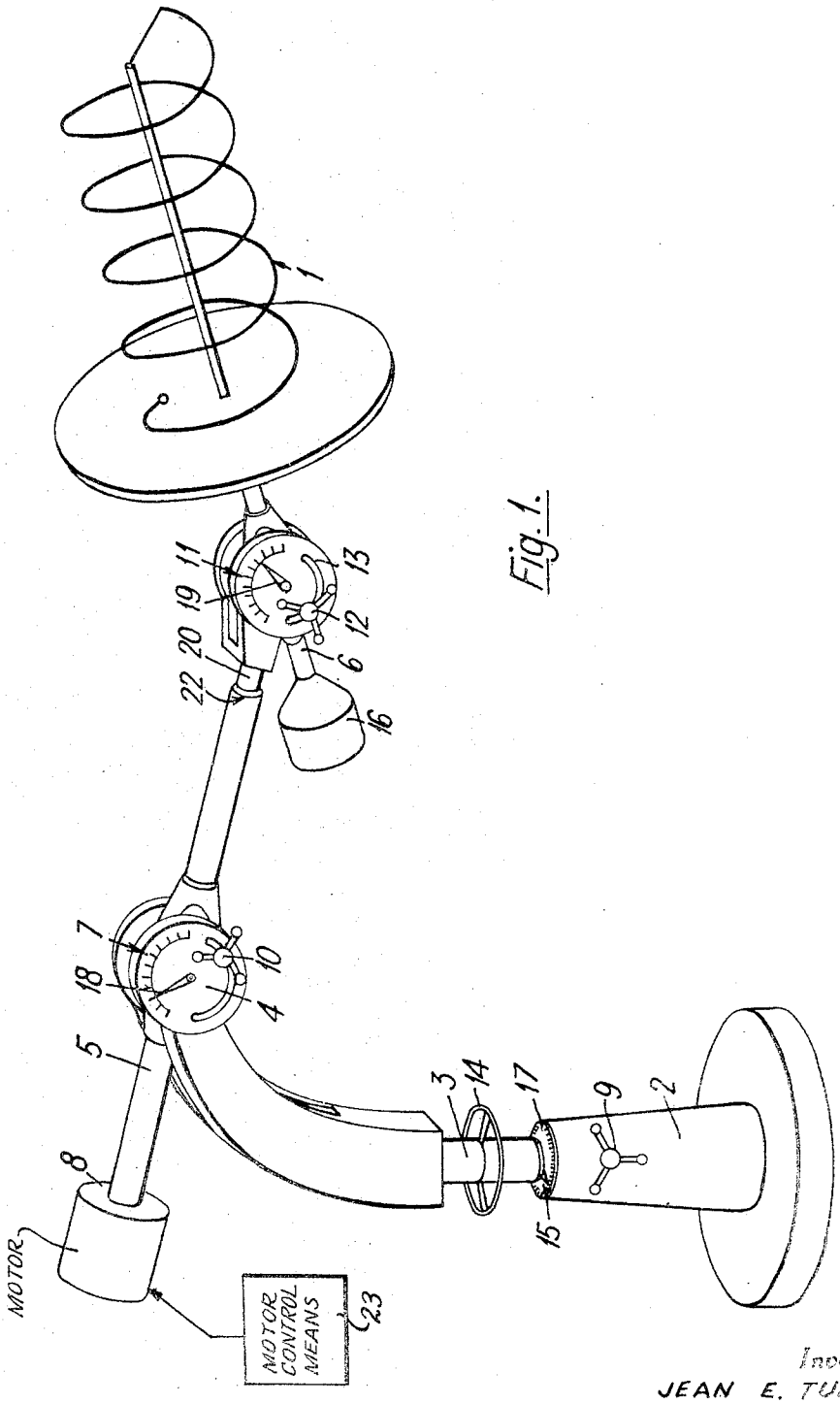


Fig. 1.

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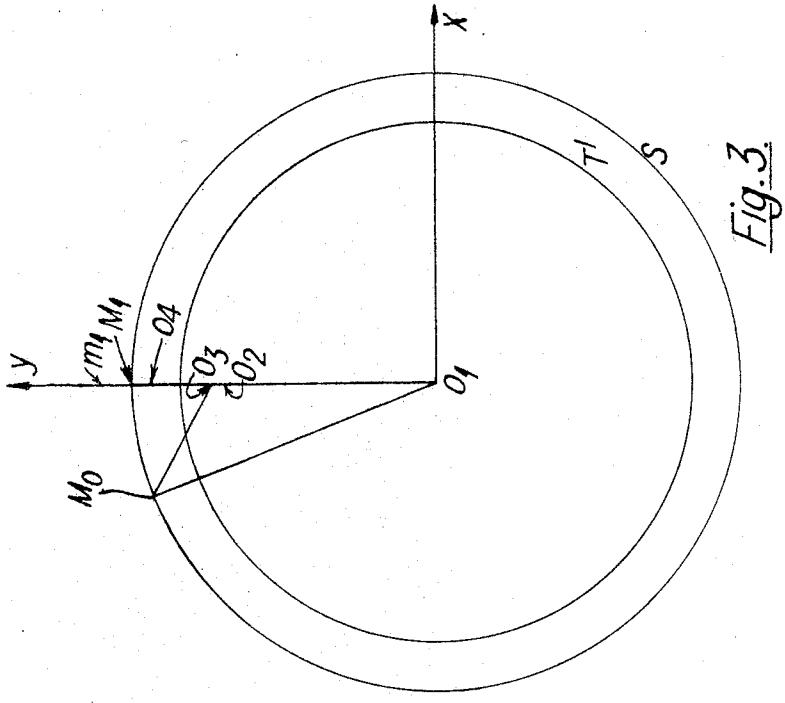


Fig. 3.

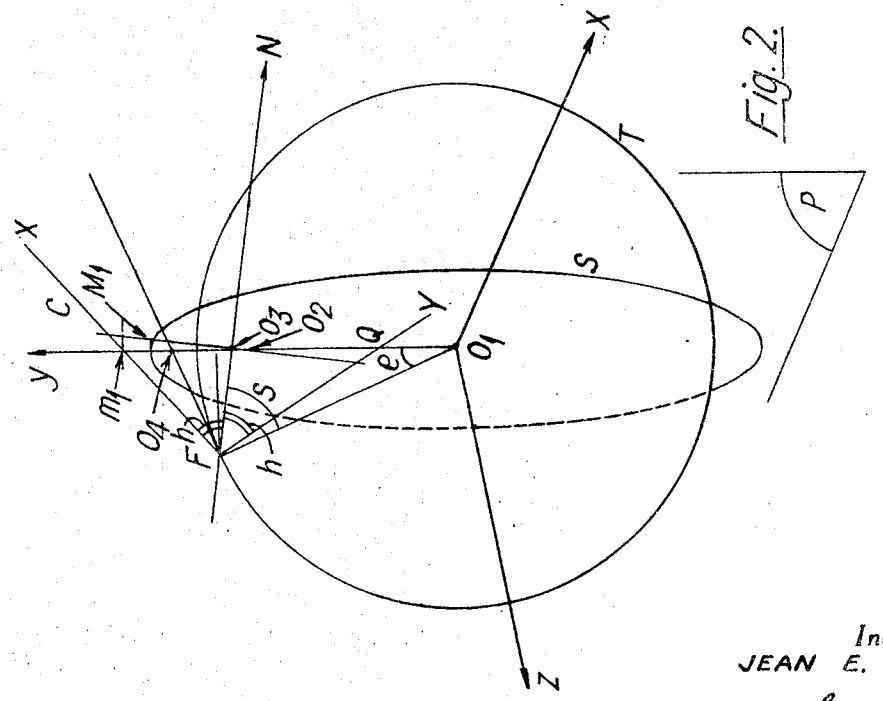


Fig. 2.

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ANTENNA POSITIONING DEVICE FOR FOLLOWING MOVING BODIES

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ABSTRACT OF THE DISCLOSURE

Apparatus for positioning an antenna to follow a moving body such as an earth satellite by means of a single motor. Two arm members are hingedly secured to a vertically oriented rotatable member. The antenna is mechanically coupled to one end of one of the arms. The other of the arms is coupled to a motor for rotating said other arm about its longitudinal axis.

The present invention concerns improvements to antennas for tracking artificial earth satellites and more particularly, to the supporting and positioning devices of the said antennas.

The supporting and positioning devices of an antenna used for tracking an artificial earth satellite in its trajectory above the horizon of the point where the said antenna is located, are designed in such a way as to perform two movements, the one in azimuth and the other one in elevation, each one of these two movements being, for instance, programmed in order that the artificial satellite remains in the part of the antenna diagram corresponding to the minimum value of the gain required for receiving without loss the signals sent by the said satellite. Such an assembly presents the major drawback of requiring the use of two mechanical positioning devices, the one for the azimuth, and the other one for the elevation, and the control means for the said devices.

The object of the present invention is to put into operation a mechanical device for supporting and positioning a tracking antenna of artificial earth satellites, the achievement and exploitation of which are simpler.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 represents an antenna positioning device presenting characteristics of the present invention;

FIG. 2 is a geometrical figure showing the interference of the different positioning angles of the antenna;

FIG. 3 is a cross section of FIG. 2 according to the plane of the satellite trajectory.

FIG. 1 illustrates a preferred embodiment of the supporting and positioning mechanical device for an antenna **1**, this antenna **1** being, for instance, a helical antenna well known in the art. It will be observed however that this antenna **1** must be designed such that its radiation pattern presents a half-power beamwidth sufficiently large, for instance fifty degrees, in order to reduce the importance of the effects of the pointing deviations.

The whole assembly lays on the ground by means of a pedestal **2** which includes a vertical rotating axis **3**, the rotation being, for instance, manually obtained by means of a handwheel **14**. The upper end of this axis **3** has the form of a bracket and carries a hinge **4** enabling the rotation of the arm **5** in the vertical plane containing the axis **3**. This arm **5** is hollow, and comprises a rotating internal axis **20**, the rotational movement of the said axis being obtained by means of a motor **8** located at one of the ends of the arm **5** and rigidly linked to the said arm. Motor **8** is also used as a counterweight for the antenna **1** located at the other end and rigidly linked to the rotation axis

20 through a hinge **13** identical to the hinge **4**. Hinge **13** enables the rotation of the arm **6** of the antenna **1** in a plane containing the arm **5**. The end of the arm **6** opposed to the antenna **1** carries also a balancing counterweight **16**. Coupled to motor **8** is a motor control means **23** for controlling the speed thereof.

The angles of rotation of the axes and arm are measured by using, for instance, indices associated to graduated circles, these angles of rotation being defined with respect to an origin point chosen on the graduated circles. Thus, the axis **3** bears the index **15** moving in front of a graduated circle **17** rigidly linked to the pedestal **2**; the origin of the rotation angles will be determined for instance by the vertical plane containing the axis **3** and the arm **5** directed towards the geographical North; the graduations are made in such a way that the measured angles correspond to the pointing azimuth t of the arm **5**; a locking device **9** is provided for maintaining the arm **5** in a determined azimuth. The rotation allowed by the hinge **4** is measured by the index **18** and the graduated circle **7**, the said index indicating, for instance, the angle $s=90°$ when the arm **5** is horizontal, i.e. when the arm **5** is perpendicular to the vertical of the point of the antenna; a locking device **10** is also provided for maintaining angle s fixed. The position of the arm **6** of the antenna **1** is measured through an index **19** and a graduated circle **11**, the index indicating, for instance, an angle $h=90°$ when the arm **6** is perpendicular to the arm **5** and an angle h close to 0° when the arm **5** and the antenna **1** are very closely in line one with respect to the other. The element referenced **12** is a locking device to fix antenna **1** at a determined angle. The axis **20** rigidly linked to the motor **8** may also be positioned according to a certain angle r on both sides of the vertical plane containing the axes **3**, **20** and arm **6**; this angle r is measured for instance in **22**, by using as previously an index rigidly linked to the axis **20** and a graduated circle rigidly linked to the arm **5**. This index and scale is not shown for the sake of clarity.

Provision is made for abutments in the hinges **4** and **13**, as well as on the motor **8** in order to limit the rotation of the different axes and arm. The movements of the arm **5**, of the arm **6**, and of the axis **3**, are obtained manually. However, it will be observed that it is possible to associate to this antenna more elaborate positioning devices known in the art, thereby enabling the remote positioning of the different axes and arm.

Knowing the different elements which determine the trajectory of the satellite as well as the position F of the antenna on the earth surface, it is possible to determine for a given revolution of the satellite the value of the positioning angles s, t, h of the axes and arm of the antenna, in order that the curve of intersection by the plane of the trajectory of the cone described by the arm **6** of the antenna **1**, when the axis of the motor **8** rotates by an angle the value of which is limited by the abutments, presents a part the angular deviation of which with respect to the visible part of the satellite trajectory be equal at the maximum to the half-power beamwidth of the antenna radiation pattern. The value of the positioning angle r of the axis **20** may also be determined in such a way that the arm **6** of the antenna **1** should be directed towards the point of appearance of the satellite above the horizon of the point F. Furthermore, it is possible to know the apparent average angular speed of the satellite seen from the point F and to control the rotational movement of the motor **8** by means of the motor control means **23** in order that the axis **20** rotates at this average angular speed; the starting of the said motor is at the instant expected for the appearance of the satellite above the horizon and its stopping is after a time equal to the time of passage of the satellite above the horizon. It is pointed out that the motor control means **23** is of such a

nature that it may be designed by one ordinarily skilled in the art within the spirit of this invetnion. Therefore, a more detailed description thereof is deemed unnecessary for a proper understanding of the instant invention.

The following description in relation with the FIGS. 2 and 3 is to show a calculation of the angles *t*, *s*, *h* and *r*, in relation with the parameters of the trajectory of the satellite and of the position of the point F on the earth surface. This calculation has been made in the particular case of an earth artificial satellite having a circular orbit, as is the case for the meteorology satellites, the tracking of which the supporting and positioning device according to the present invention is particularly well adapted. It has also been assumed that the Earth is spherical.

The principle of calculation is the following: first, the equation of the intersection ellipse of the arm **6** of the antenna **1** with the plane of the satellite orbit is first determined in relation with the angles *s* and *h*, which have to be determined, and with the angle *e* corresponding to the angular deviation measured at the center of the Earth between two earth radii, one passing through the point F and the other one passing through the point of maximum elevation M_1 of the satellite above the horizon, this angle *e* being calculated at the instant of passage at this maximum elevation. It is understood that this angle *e* may be deduced from the parameters of the orbit and the position of the antenna on the earth surface. Afterwards, *s* and *h* may be determined by successive approximations, in such a way as the arm **6** of the antenna passes through the point of appearance of the satellite above the horizon and presents a minimum deviation with the said satellite when this latter passes at the maximum elevation point M_1.

It will be observed that such a calculation is not complete since it does not take into account the rotation of the Earth. However, this rotation may be neglected in the case of satellites of low or average altitude, since their time of passage is at maximum of twenty minutes, this corresponding to a rotation of the Earth of a few degrees, i.e. an angle of rotation small with respect to the half-power beamwidth of the antenna diagram.

If the Earth is assumed fixed during the time of passage of the satellite above the horizon, the curve described by the satellite above the horizon is symmetrical with respect to the maximum elevation point M_1 and the pointing angle *t* of the arm **5** is chosen equal to the azimuth angle of passage at this maximum elevation.

FIG. 2 shows how the different angles *s*, *h* and *e*, interfere in the calculation of the equation of the intersection ellipse. Let us call P the plane of the trajectory S of the satellite M, this plane being assumed fixed in space, and let us call F the position of the antenna on the earth sphere, a great circle of which T of center O_1 passing by the point F has been represented, the said great circle being contained in the plane perpendicular to the plane P which contains the point M_1 of passage of the satellite M at the maximum elevation point above the horizon of the point F. This is tantamount to saying that FIG. 2 represents the respective positions of the point F and of the satellite M when this latter passes at the maximum elevation point M_1. Let us call *e* the angle between the earth radius O_1F and the radius O_1M_1.

On this FIG. 2, the straight line FN corresponds to the arm **5** of the antenna and thus makes an angle *s* with the earth radius O_1F which is, by definition, the vertical of the point F; this straight line FN makes an angle *t* with the geographical North not shown on FIG. 2, this azimuth angle *t* being determined as described hereabove. When the axis contained in the arm **5** makes a complete rotation, the arm **6** of the antenna describes a cone of revolution of axis FN, and of apex half-angle *h*, its intersection by the plane of FIG. 2 is constituted by two straight lines FX and FY, which intersect the radius O_1M_1 respectively at the points m_1 and Q. The intersection of this cone of revolution by the plane P of the trajectory S is an ellipse, one of the axes of which, for instance the major axis, is

the segment $Qm_1=2a$ of the radius O_1M_1; the minor axis of length $2b$ of the ellipse passes through the middle point O_2 of the segment Qm_1.

If one chooses as reference axis, in order to set up the equation of the intersection ellipse, the axis O_1y merged with the radius O_1M_1 and the axis O_1x perpendicular to this latter in the plane P, the said equation is written by taking $g=O_1O_2$:

$$\frac{x^2}{b^2}+\frac{(y-g)^2}{a^2}=1 \qquad (1)$$

a, *b* and *g* are then determined in relation with the earth radius R and with the angles *s*, *h* and *e*; the following is thus obtained:

$$a=\frac{R \sin e \sin 2h}{\cos 2h+\sin (e+s)}$$

$$b^2=\frac{R^2 \sin^2 e \sin^2 2h}{2 \cos^2 h \cos 2h-\cos 2(e+s)}$$

$$g=R \cos e-\frac{R \sin e \sin 2(e+s)}{\cos 2h-\cos 2(e+s)}$$

As it has been indicated previously, the ellipse equation is determined in such a way as it passes by the point of appearance M_0 (FIG. 3) of the satellite above the horizon of the point F, this point M_0 having the following coordinates in the plane P:

$$y_0=O_1O_4=\frac{R}{\cos e} \text{ and } x_0=O_4M_0=\sqrt{(R+H)^2-\frac{R^2}{\cos^2 e}}$$

H being the altitude of the satellite, this altitude being constant since the particular case of a circular orbit satellite is considered.

This FIG. 3 is a cross section of FIG. 2, according to the plane P in which the different points of the FIG. 2 have been represented by means of reminder lines, the circle T' is the great earth circle contained in the plane P.

By replacing in the Equation 1, *a*, *b*, *g* by their values, *x* and *y* by x_0 and y_0, an equation is obtained which comprises known terms R, H and *e*, and terms *s* and *h* which have to be calculated. This equation does not enable to calculate directly the values of the angles *s* and *h* for a given passage of the satellite of constant altitude H, i.e. for a certain value of the angle *e*. However, one may calculate the deviation $M_1m_1=d=g+a-(R+H)$, first for different values of *s*, *h* remaining fixed, then carry out the same calculations for different values of *h*, *s* remaining fixed; the couple of values (*s*, *h*) which gives the minimum value of the deviation *d*, is chosen afterwards.

The preceding calculations made for a certain value of the angle *e*, i.e. for a certain passage of the satellite M and for a satellite of altitude H, may be carried out once again for values of *e* varying degree by degree, starting from zero degree to a maximum value depending upon the altitude H of the satellite, this maximum value being that for which the maximum elevation point M_1 passes at the horizon of the point F, i.e. when the point O_4 is merged with the point M_1. A table is thus obtained which enables, by knowing otherwise the angle *e*, to determine the value of the positioning angles *s* and *h*, for a given passage of the satellite M of altitude H above the horizon.

Tables identical to the preceding one may also be set up for other satellites of circular orbits, i.e. satellites having different altitudes.

The positioning angle *r* of the axis **20** must be such as the arm **6** of the antenna must be directed towards the point of appearance M_0 (FIG. 3) of the satellite above the horizon, the angles *s*, *h* and *t* having been previously positioned. This angle *r* is the angle through which the plane defined by O_1y and the axis FN of the antenna (FIG. 2) must rotate around this axis FN, in order to pass by the point M_0 (FIG. 3) of appearance of the satellite above the horizon; this angle *r* is thus the angle of two planes in the space, one P_1 containing the axes O_1y and FN and the other P_2 containing the axis FN and the

point M_0. Now, in analytical geometry, it is demonstrated that the angle r of the two planes P_1 and P_2 having respectively the equations: $Ax+By+Cz+D=0$ and

$$A'x+B'y+C'z+D'=0$$

is given by the formula:

$$\cos r=\frac{AA'+BB'+CC'}{\pm\sqrt{(A^2-B^2+C^2)(A'^2+B'^2+C'^2)}}$$

In the system of axes O_1x, O_1y, O_1z, it is seen that the equation of the plane P_1 is reduced to $x=0$ this corresponding to $A=1$, $B=0$, $C=0$ and $D=0$; it is also possible to calculate the coefficients A', B', C' and D' of the equation of the plane P_2 by observing that this plane passes by three points F, O_3 and M_0, the coordinates of which are known in relation with R, H and the angles e and s. It is clear that this angle r must be measured on both sides of the axis O_1y in order to take into account the direction of rotation, whatever it may be, of the satellites the antenna would be required to track; thus, for a satellite which, seen from the point F, rotates in the clockwise direction, the angle r will be for instance negative; on the contrary, it will be positive in the case of a satellite rotating in the counter-clockwise direction.

The four angles t, s, h, r having been determined, to rotation speed of the motor **8** is still to be determined in order that the antenna follows the satellite in its trajectory. When the look angular speed of the satellite above the horizon deviates little from the average look angular speed, a constant rotation velocity w of the motor may be chosen, this velocity w being equal to the average look angular speed of the satellite above the horizon, viz.

$$w=\frac{2|r|}{T_p}$$

T_P being the time of passage of the satellite above the horizon. However, when the look angular speed of the satellite deviates largely from the average look angular speed, it is possible to program the movement of rotation of the motor **8** in relation with the look angular speed of the satellite above the horizon by means of control means **23**.

The method of utilization of such an antenna is then the following: once having determined for one given revolution of the satellite, the value of the angles t, s, h and r, by means of the tables which are obtained according to the method stated above, these different angles are then positioned manually. Knowing, on the other hand, the hour of apparition of the satellite above the horizon of the point F, the motor **8** is started at this instant, the motor control means **23** being set in such a way that the angular velocity of the motor is, for instance, substantially constant and equal to w.

This angular velocity is not generally the same for a given satellite from one visible revolution to the following one, and a fortiori from one satellite to the other and it is thus understood that such a motor **8** must be provided with an accurate speed variator. Other devices known otherwise may also be put into operation, in order to obtain different possible angular speeds of the axis of rotation **20**. The devices performing a step by step advance of the motor will be quoted for memory, these steps either unequal at equal time intervals or equal at unequal time intervals.

In certain instances motor control means **23** may take the form of a computer.

The method of calculation of the angles s, h, r has been described in the particular case of a circular orbit satellite, this enabling to simplify the calculations. However, it is possible to put this method into operation in the case of an elliptical orbit satellite, the time of passage above the horizon of which is such as the effect of rotation of the Earth may be neglected.

What I claim is:

1. Apparatus for positioning an antenna to follow a moving body comprising:

a base member;

a vertically oriented member rotatably mounted in said base member;

a first arm member;

first hinge means mechanically coupling said first arm member to said vertically oriented member for movement of said first arm member in a vertical plane;

a second arm member;

second hinge means mechanically coupling said second arm member to said first arm member;

a directive antenna mounted on said second arm member; and

means for controllably rotating said first arm member about its longitudinal axis for following said moving body.

2. Apparatus according to claim **1** wherein said controllably rotating means includes a motor coupled to said first arm member.

3. Apparatus according to claim **2**, further comprising means coupled to said motor for controlling the rotational speed thereof in accordance with the trajectory of the moving body to be followed.

4. Apparatus according to claim **1** further comprising means coupled to said first and second hinge members for controlling the orientation of said antenna in accordance with the trajectory of the moving body to be followed.

5. Apparatus according to claim **4** further comprising motor means coupled to said first arm for controllably rotating said first arm member about its longitudinal axis in accordance with the trajectory of the moving body to be followed.

6. Apparatus according to claim **1** further comprising means coupled to said base member and to said vertically oriented member for rotating said vertically oriented member in said base member.

7. Apparatus according to claim **5** further comprising indexing means coupled to said first and second hinge means for determining the relative positions of said arm members and said vertically oriented member.

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