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(54) SYNCHRONIZED SOLAR CONCENTRATOR ARRAY

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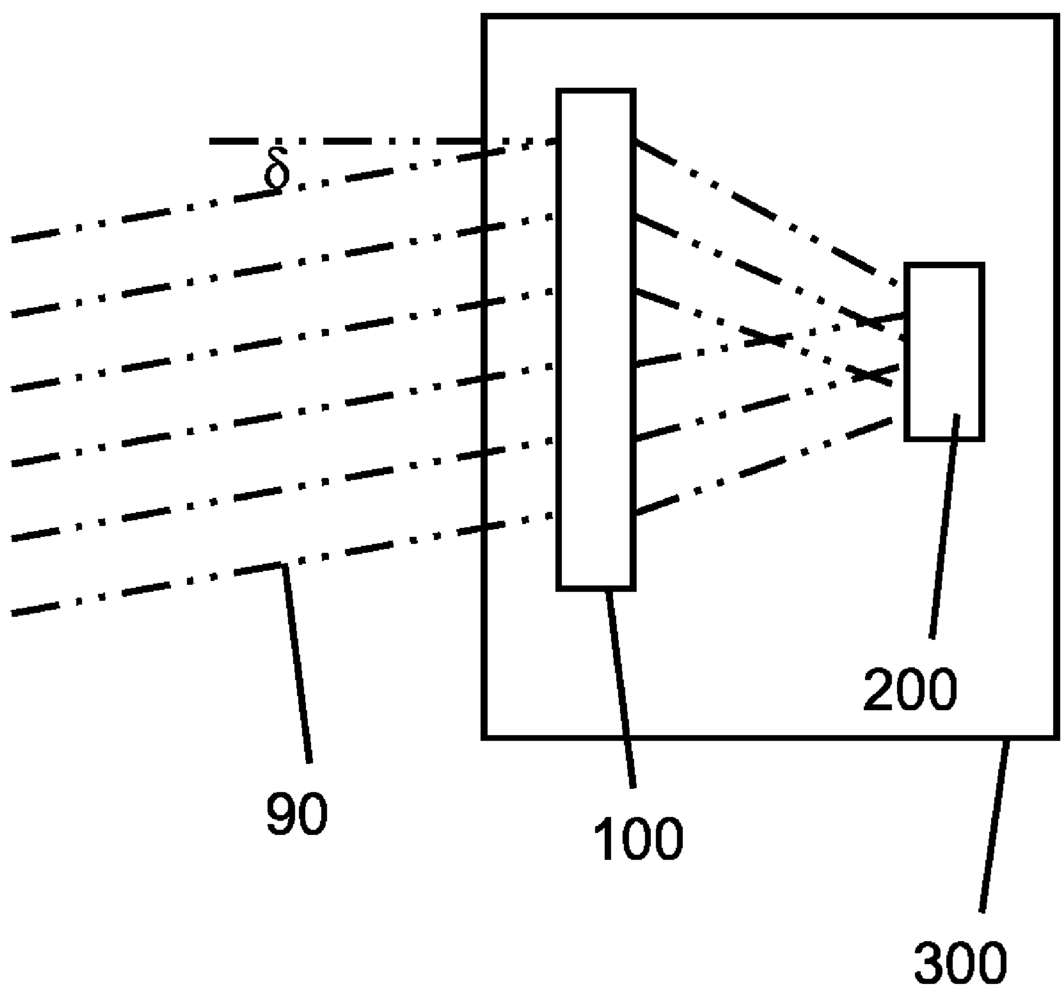
(57) ABSTRACT

A solar energy collecting device includes a rotation axis to be mounted parallel to the earth's polar axis, a solar energy collector mounted for rotation around the rotation axis at a predetermined rotation speed, the solar energy collector defining a tilt angle with respect to the rotation axis, and a tilt angle adjustment mechanism for automatically and intermittently adjusting the tilt angle. Various configurations of the solar energy collector are possible, and the rotation speed may be one revolution per day or half a revolution per day depending on the solar energy collector configuration. Many drive modes are possible, including rotating continuously throughout a day or rotating during daylight hours and rotating backward or forward at night. The tilt angle adjustment mechanism includes a handle fixed to the solar energy collector and a tilt angle change guide.



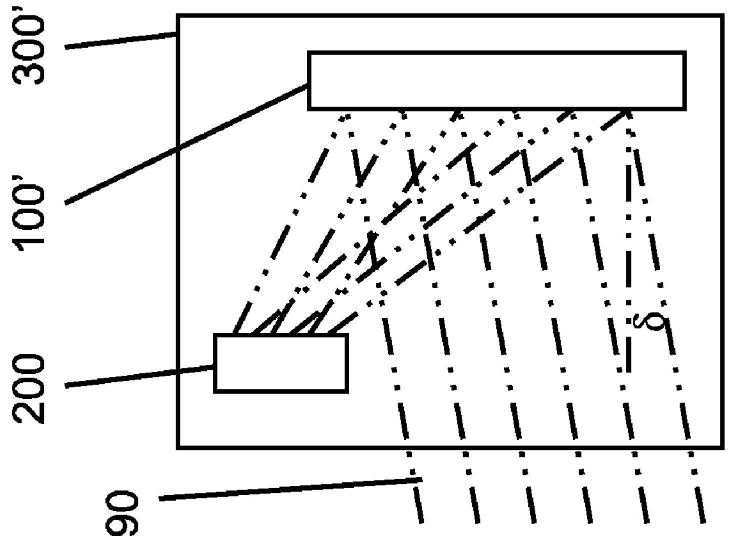


Fig. 2

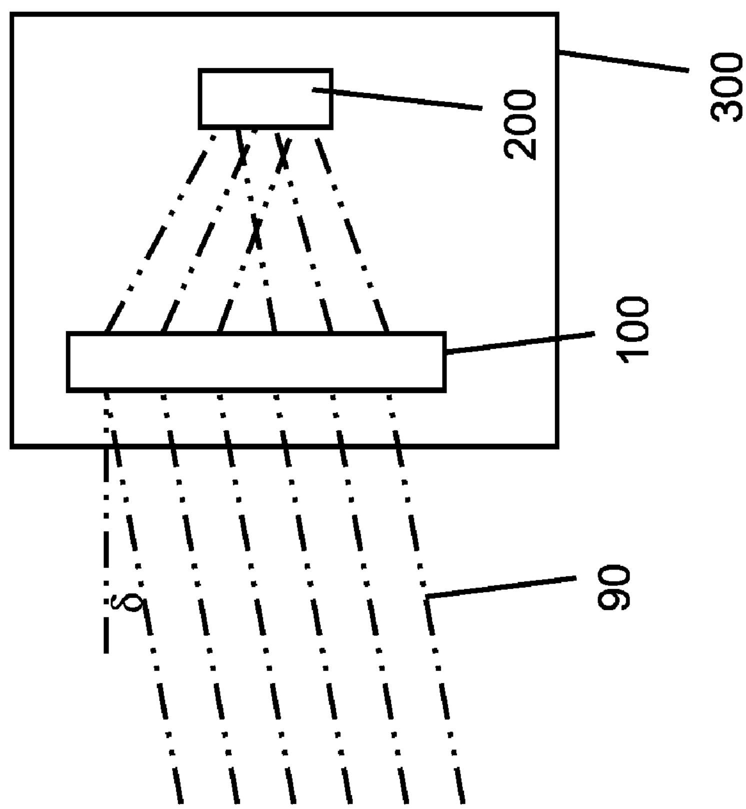


Fig. 1

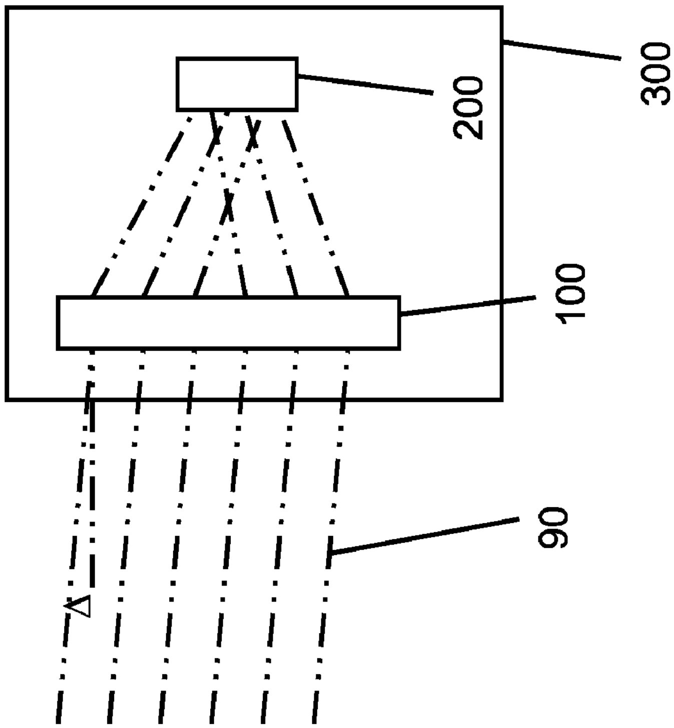


Fig. 4

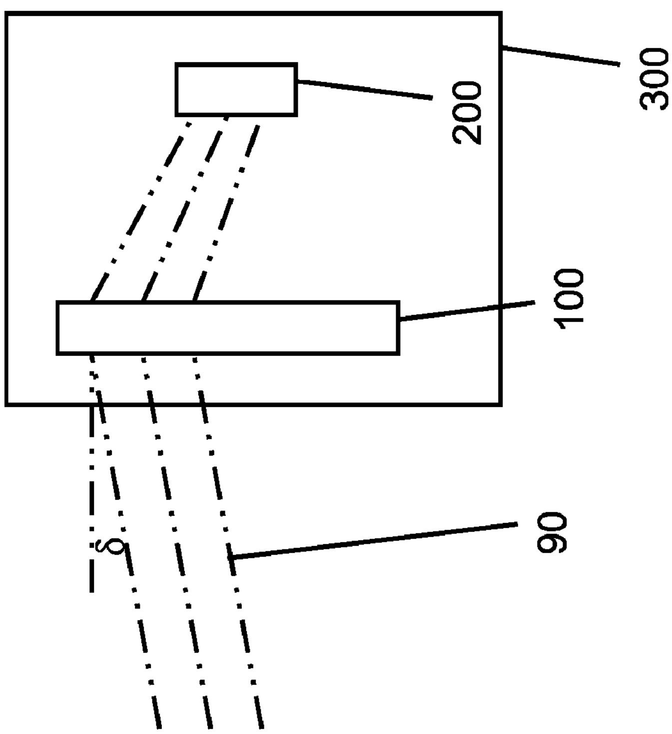


Fig. 3

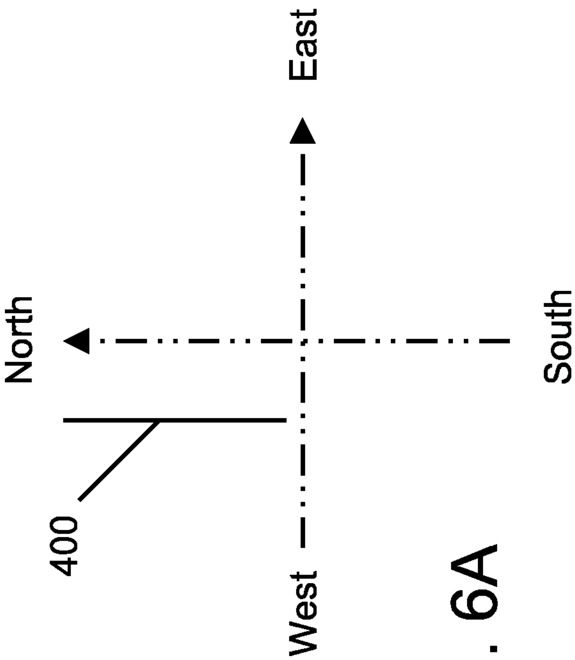


Fig. 6A

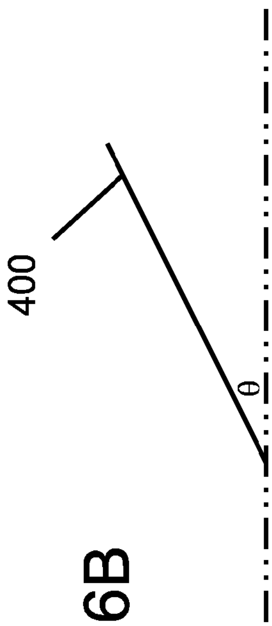
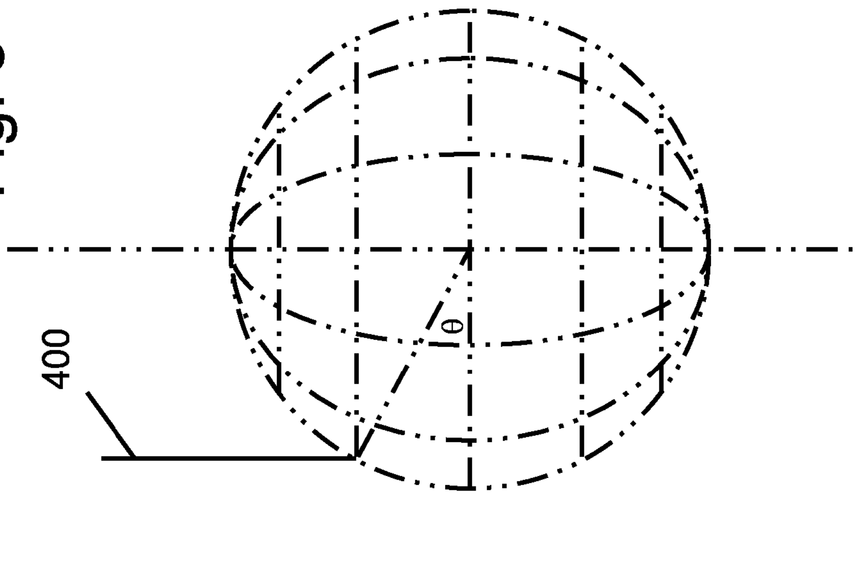


Fig. 6B

Fig. 5



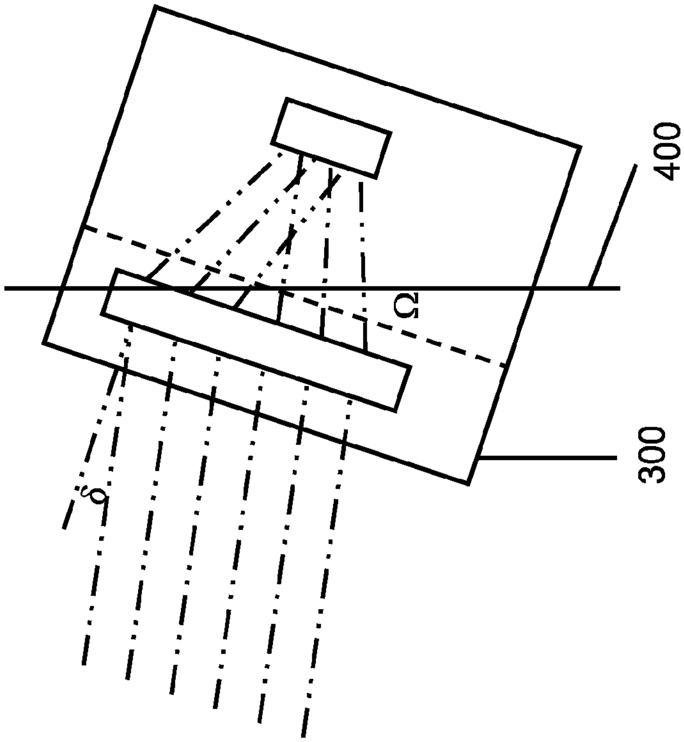


Fig. 7B

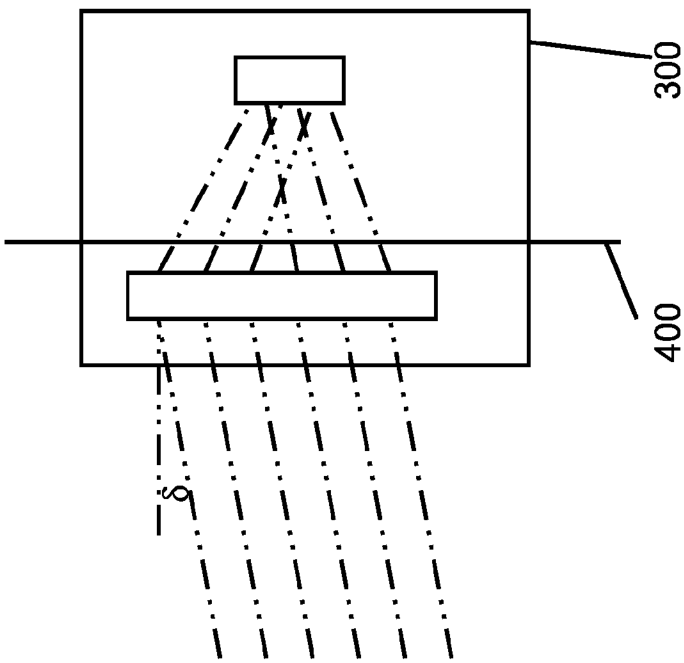


Fig. 7A

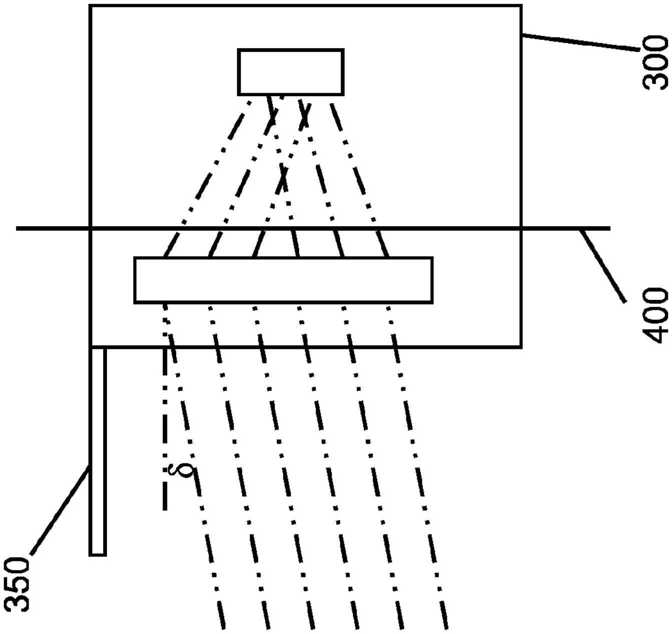


Fig. 8

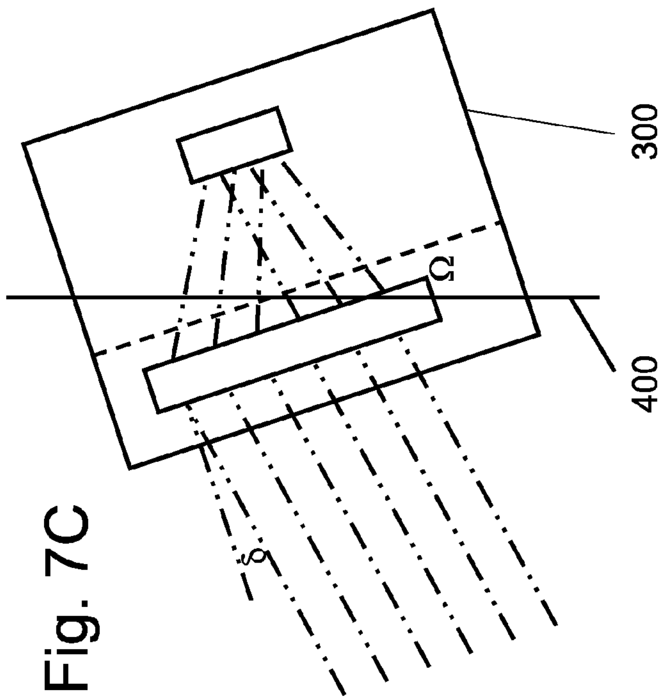


Fig. 7C

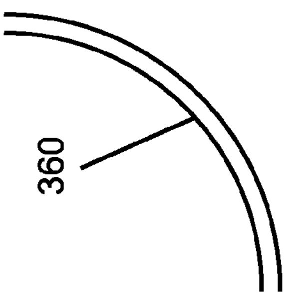


Fig. 9A

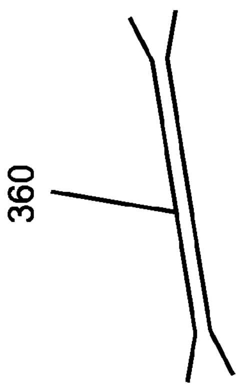


Fig. 9B

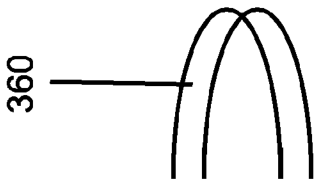


Fig. 9C

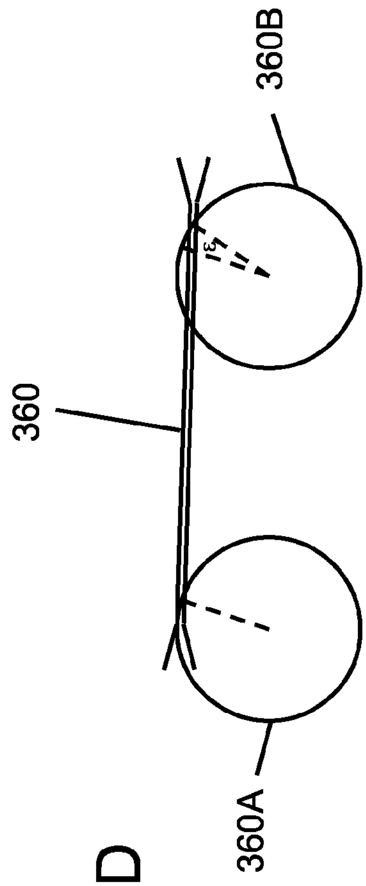


Fig. 9D

Fig. 11A

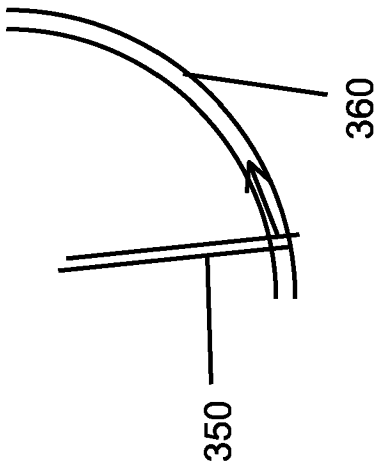


Fig. 11B

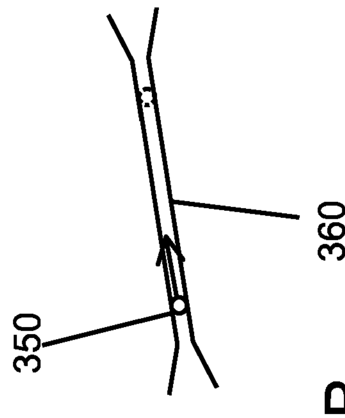
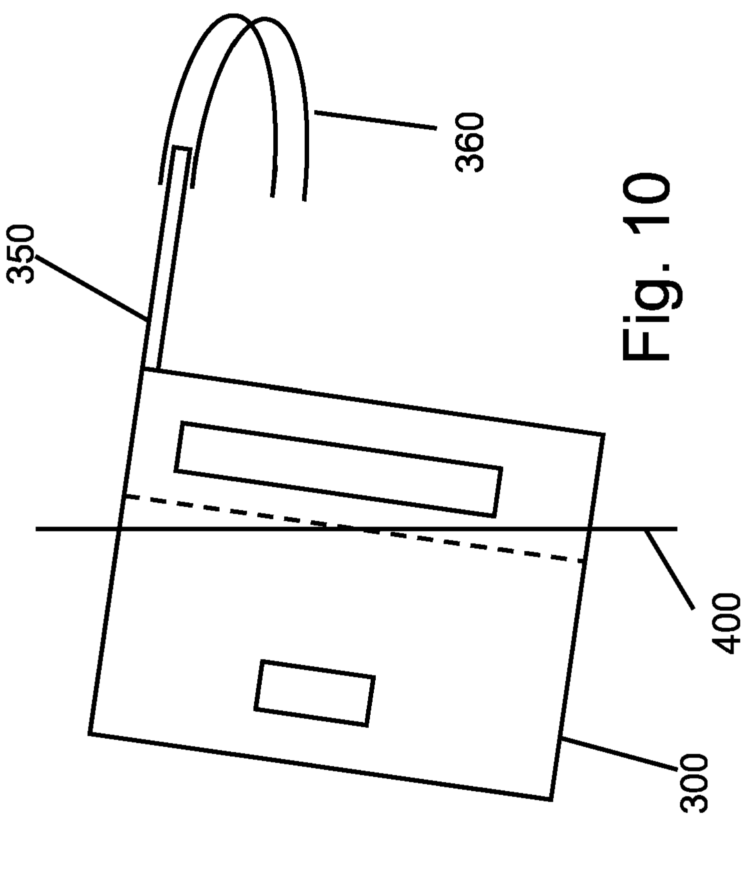


Fig. 10



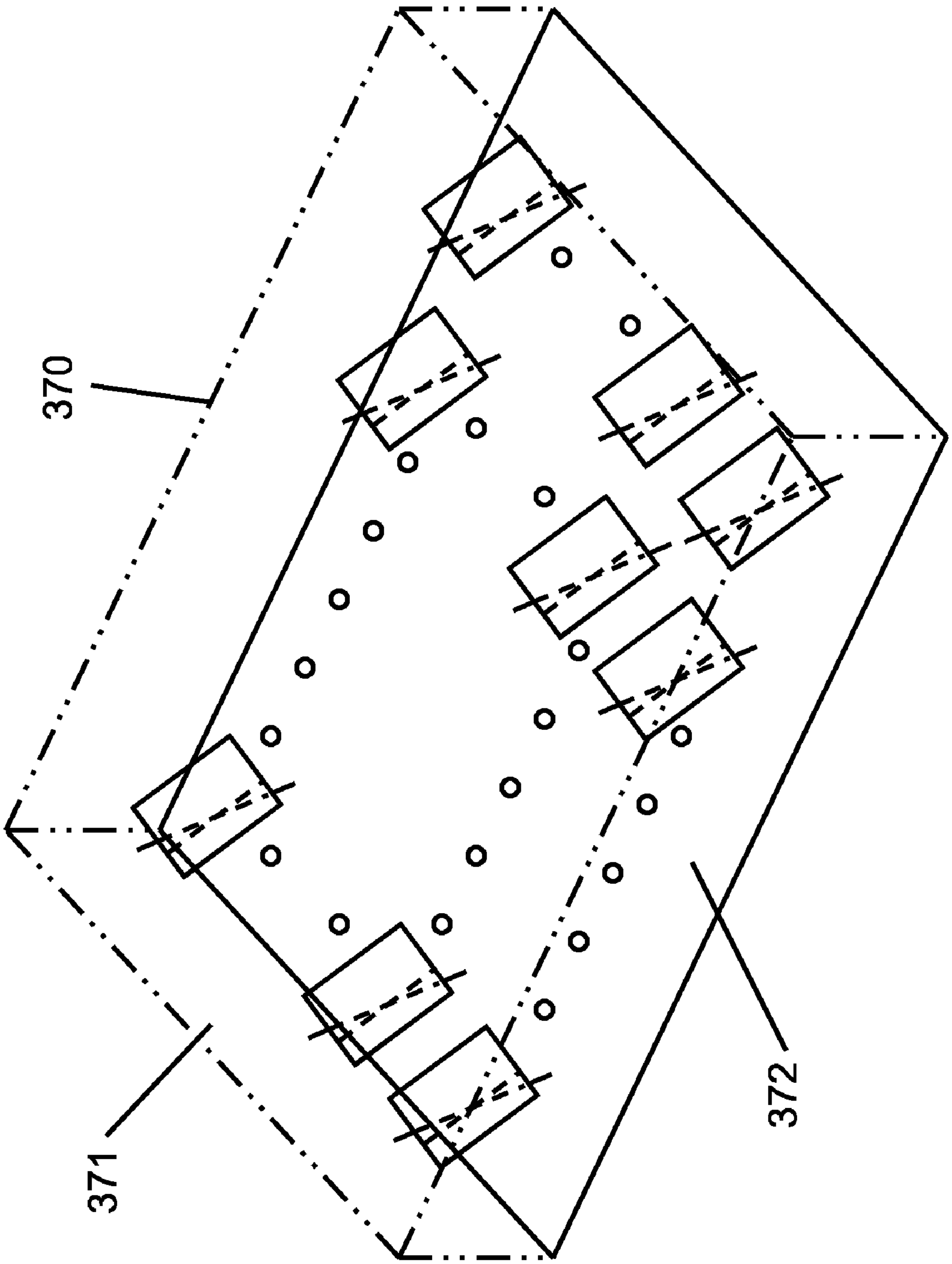


Fig. 12

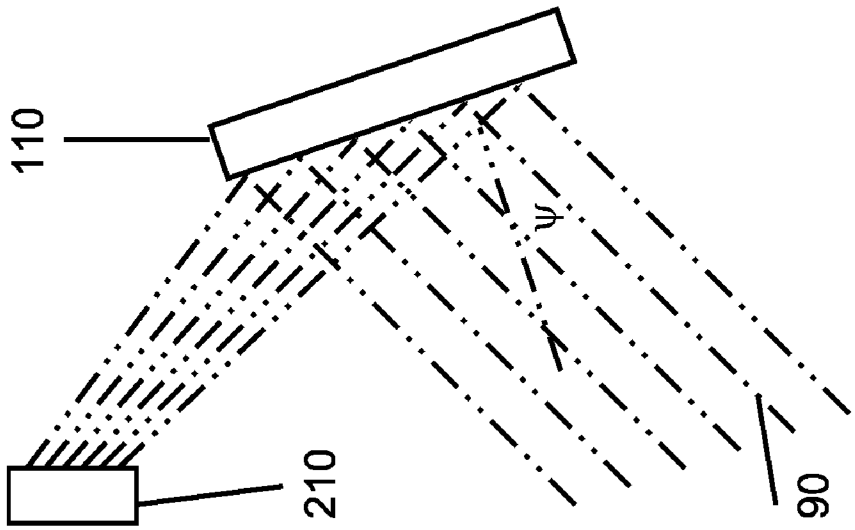


Fig. 14

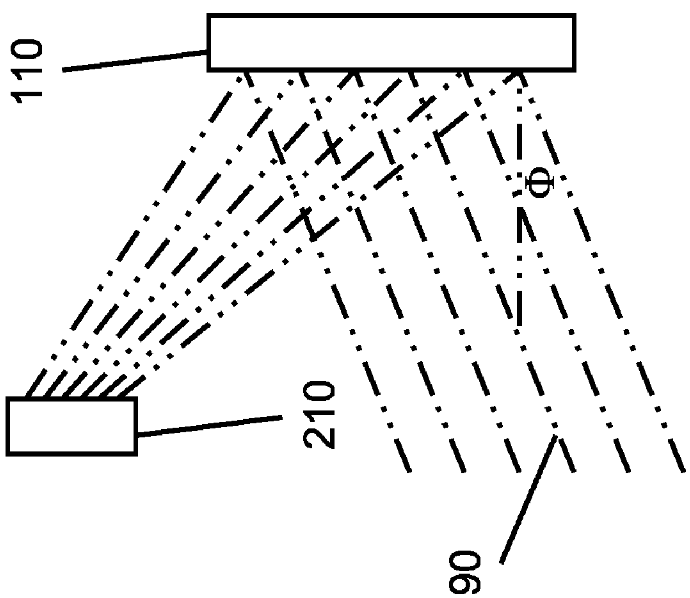


Fig. 13

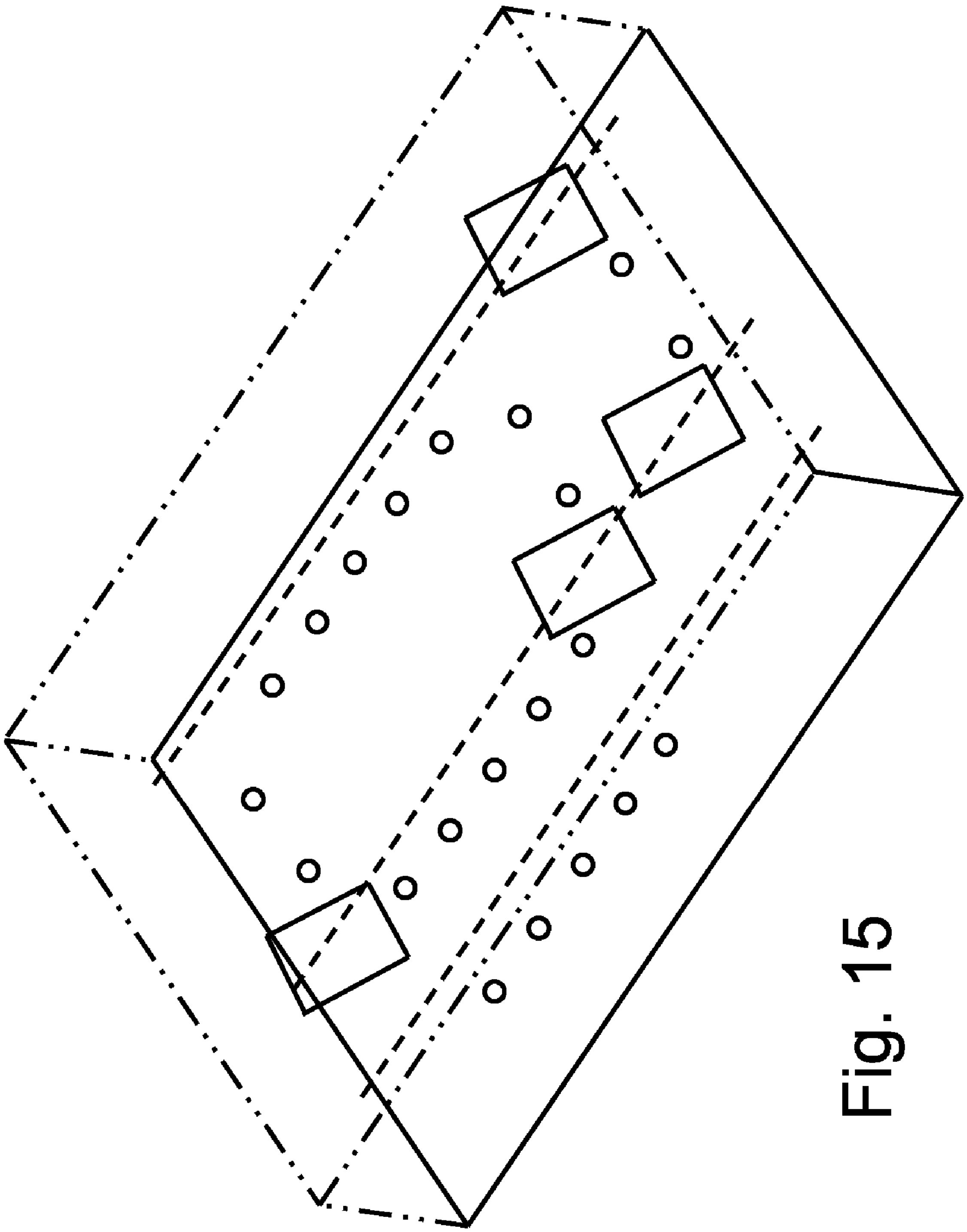


Fig. 15

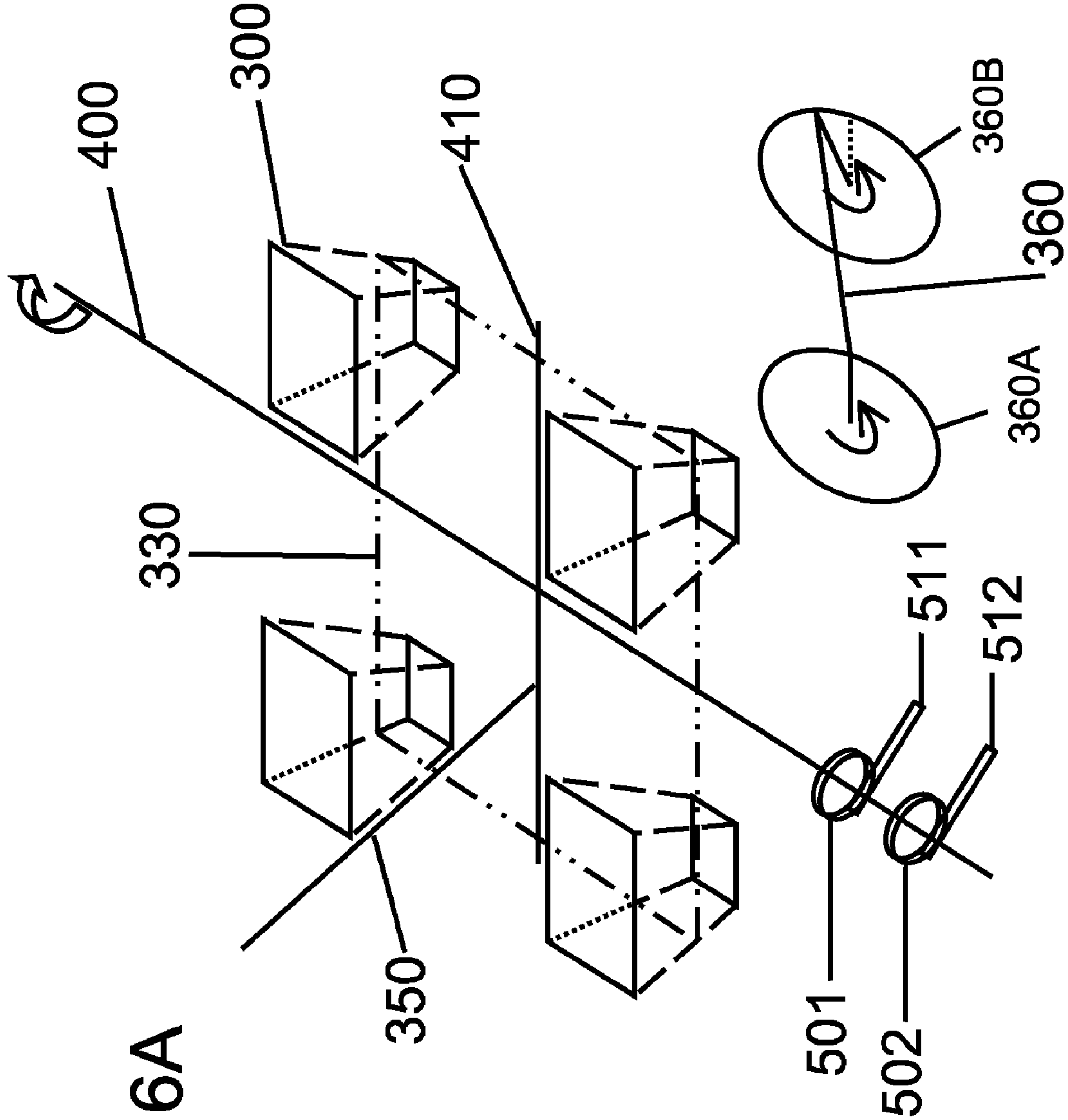


Fig. 16A

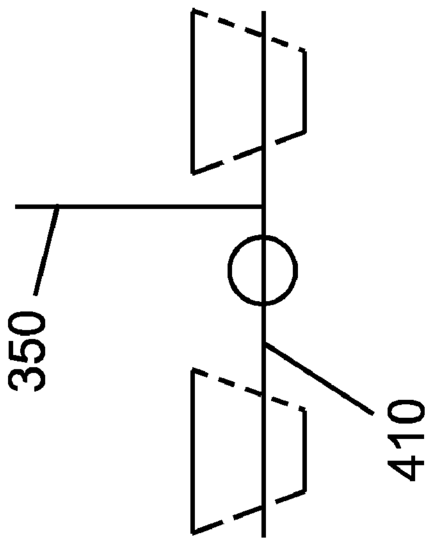


Fig. 16D

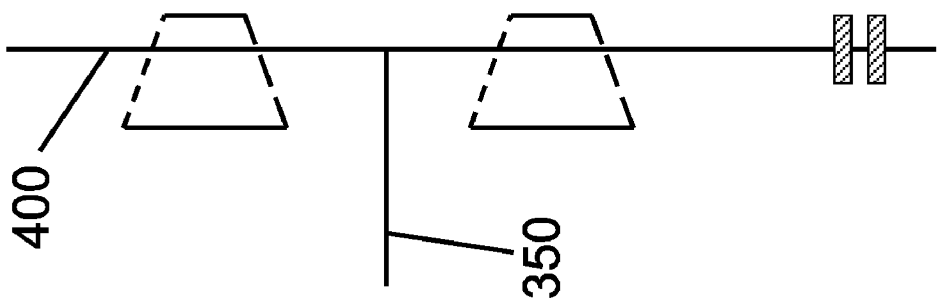


Fig. 16C

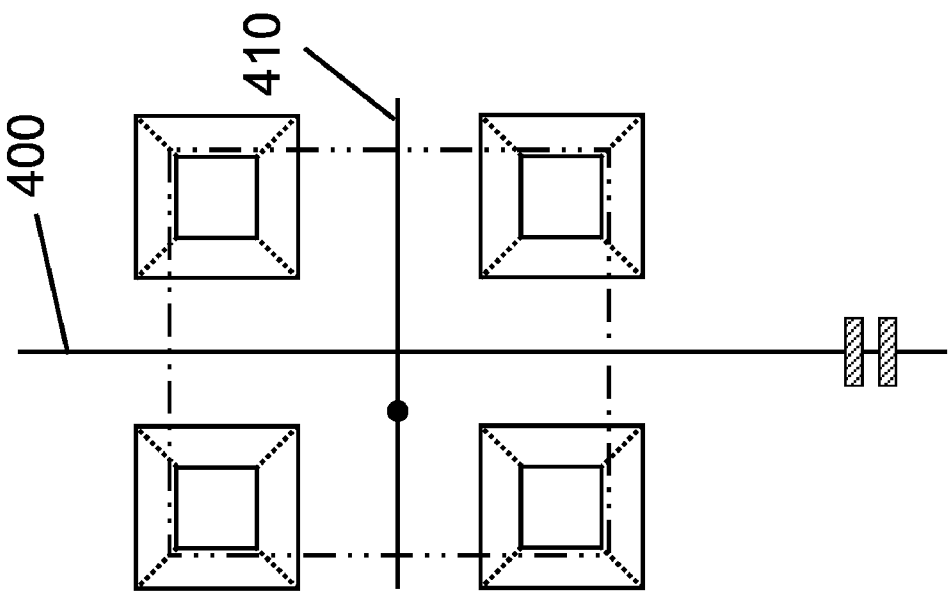


Fig. 16B

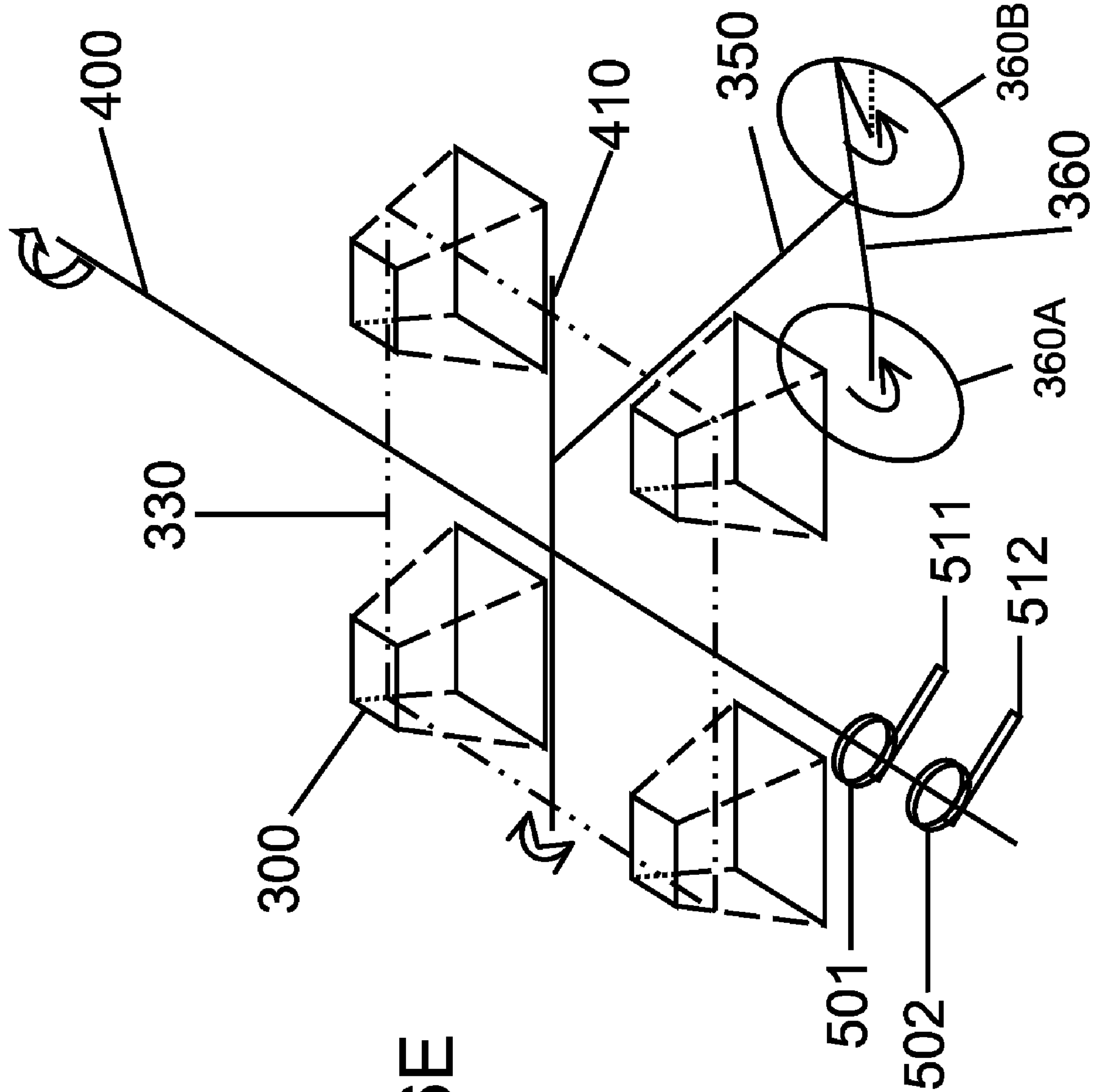


Fig. 16E

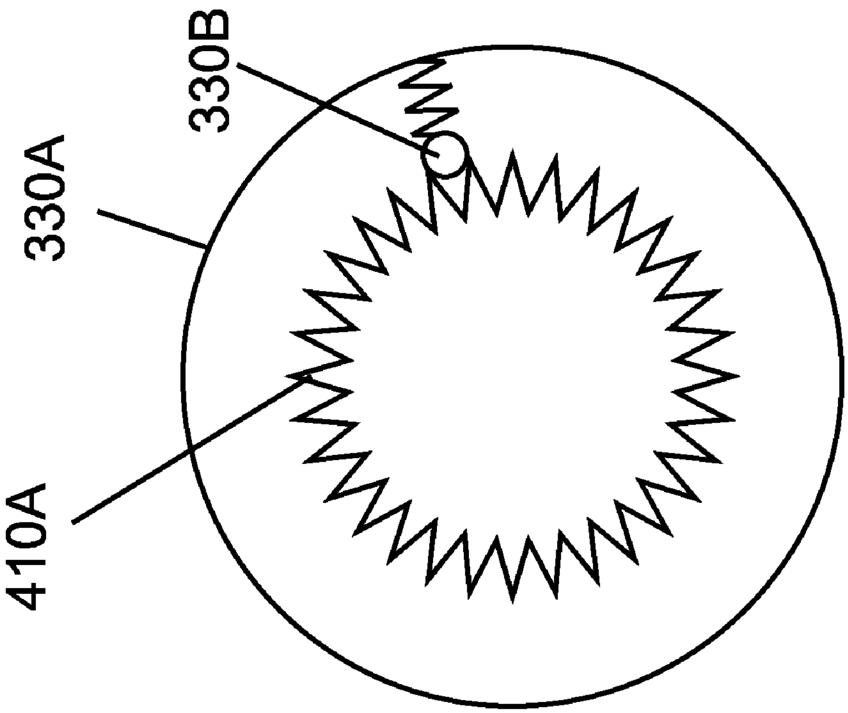


Fig. 18

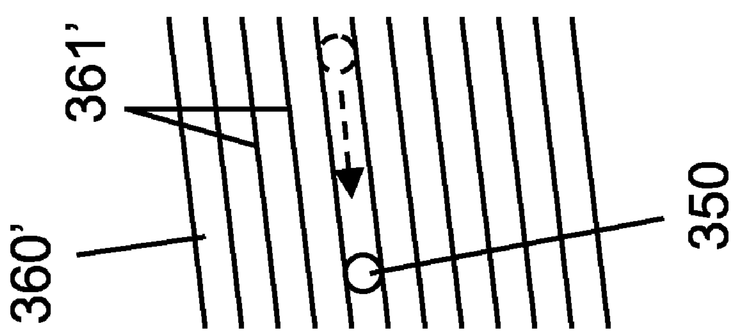


Fig. 17B

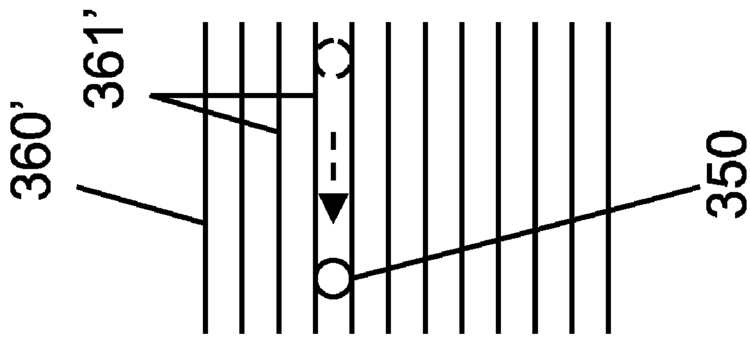


Fig. 17A

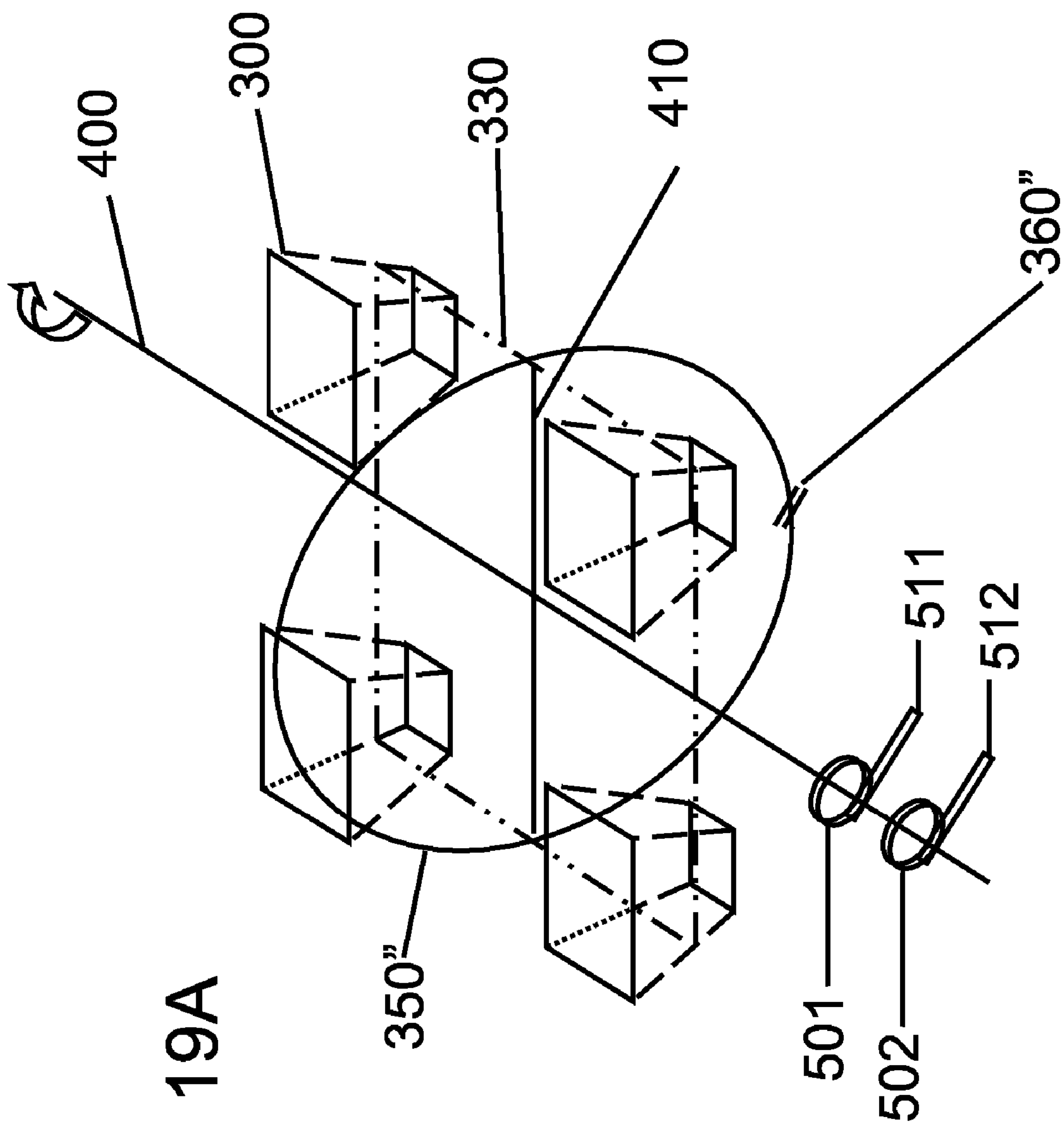


Fig. 19A

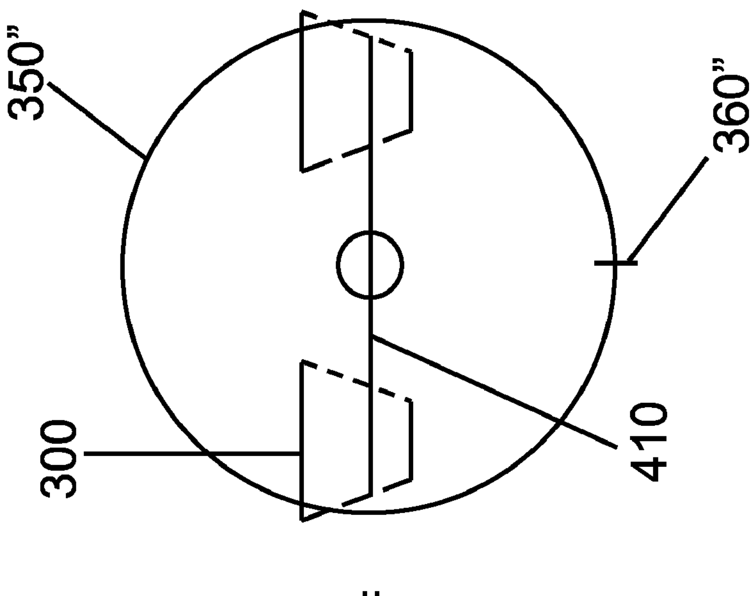


Fig. 19D

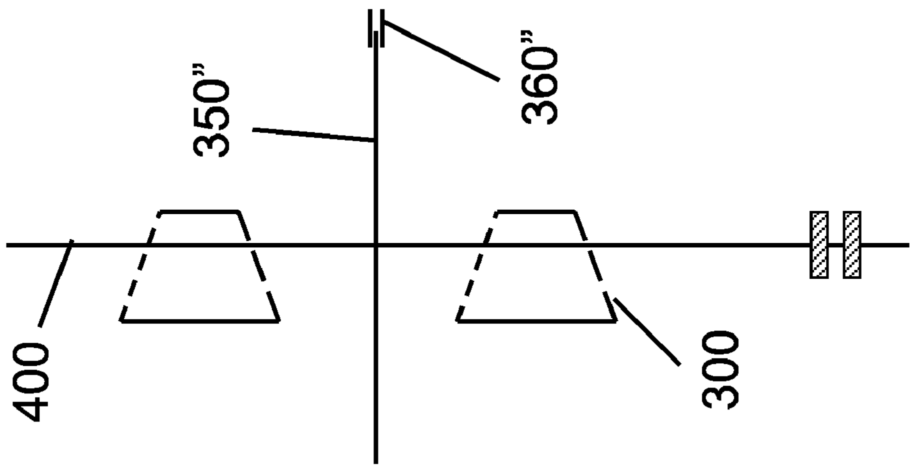


Fig. 19C

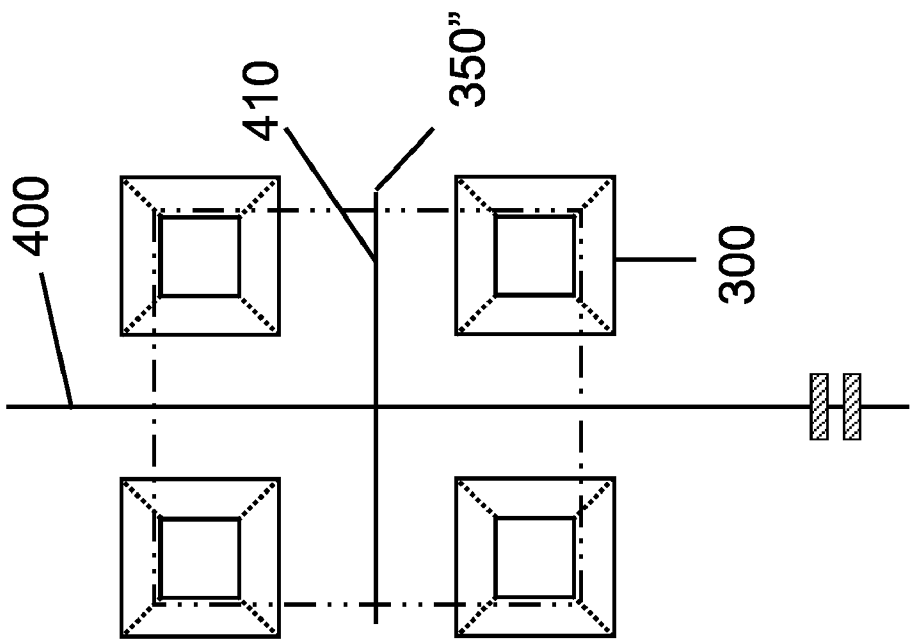


Fig. 19B

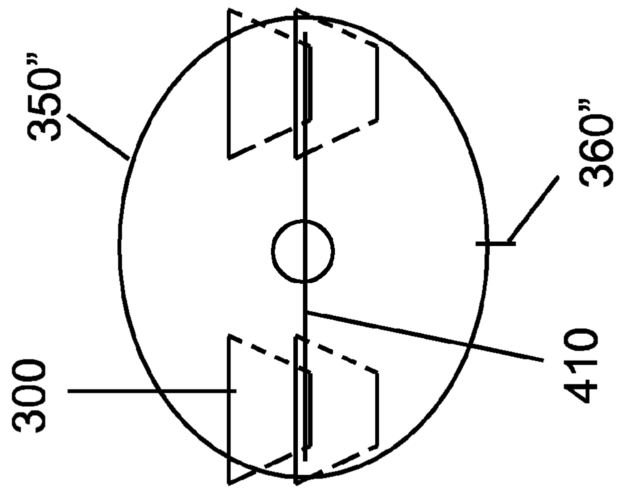


Fig. 19G

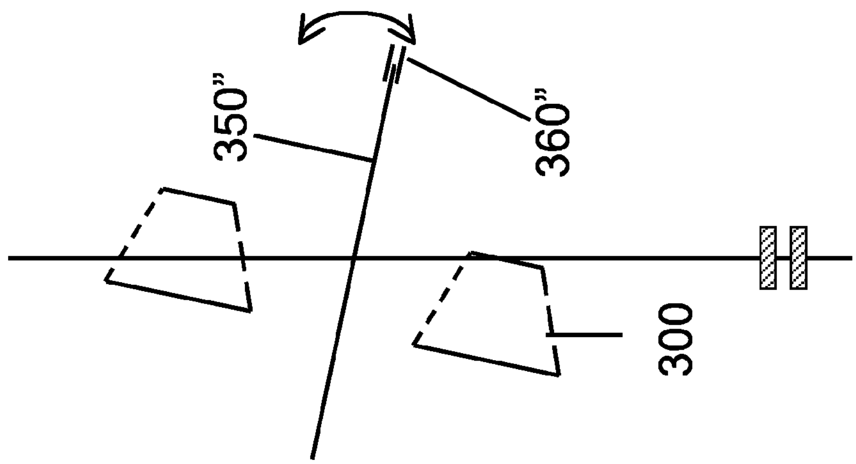


Fig. 19F

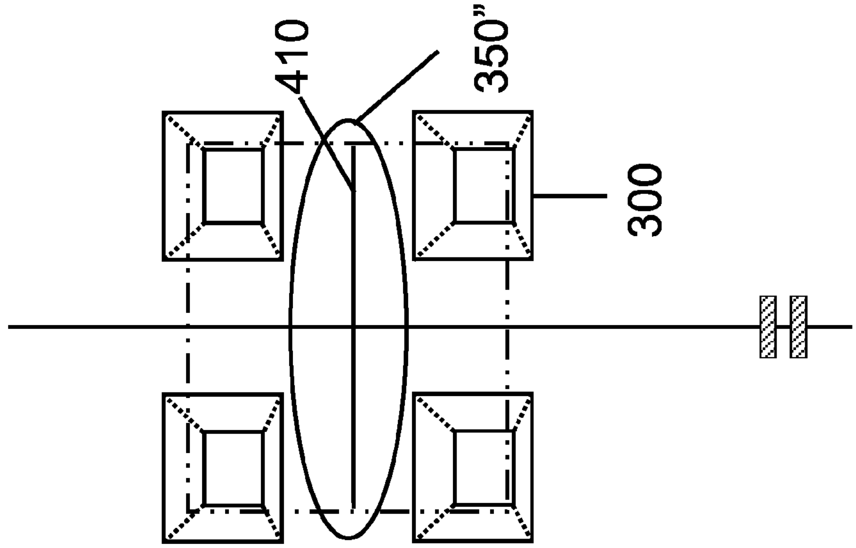


Fig. 19E

SYNCHRONIZED SOLAR CONCENTRATOR ARRAY

[0001] This application claims priority as a continuation-in-part of U.S. Provisional Patent Application No. 60/810,808, filed Jun. 5, 2006, which is herein incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] This invention relates to solar energy collection, and in particular, to solar tracking and sunlight concentration and collection.

[0004] 2. Description of the Related Art

[0005] Effective use of solar energy has been an important research subject. Various applications on concentrated or non-concentrated solar energy have been invented. The main obstacle is the cost. There is no successful for-profit solar utility exists today. Recently solar panels have been widely installed on roof tops, however, solar panel is still expensive because it uses photovoltaic solar cells at non-concentrated solar illumination condition. Photovoltaic solar cell, made from semiconductor materials such as silicon or gallium arsenide, is the most expensive part of the solar panel. It would use much less solar cell if sunlight is first concentrated; also the sunlight to electricity conversion efficiency of the solar cell can be improved under the concentrated sunlight intensity.

[0006] Solar concentrator can reduce the energy receiver size and cost. However, solar concentrator usually needs to track sun's motion, and tracking systems tend to be bulky, complicated, expensive, and unreliable and awkward to implement. One type of solar tracking systems uses dual axial tracking, where continuous rotation around two non-parallel axes is required. Another type of tracking systems uses polar tracking, where the solar energy receiver or concentrator rotates around a polar axis, i.e. an axis parallel to the rotation axis of the earth. For example, U.S. Pat. No. 6,284,968 describes a "solar-tracking system that provides a polar rotation at a constant velocity of 366.25 revolutions clockwise per year, and orbital revolution that is one revolution per year in the counter-clockwise direction. The support for the orbital drive system is tilted from polar drive system at an angle of 23.45 degrees, and is constant, which angle is equal to the earth's axis tilt from orbital axis." (Abstract.) U.S. Pat. No. 5,632,823 also describes a solar tracking system using polar tracking, where the inclination angle (i.e. the angle between the solar collector and the polar rotation axis) is adjusted empirically: "The sun shadow of a pointer normal to the solar collector panel serves to properly align the panel. Alternately, the current generated by the solar cells is measured and its maximum indicates that the solar panel is properly aligned with the sun." (Abstract.)

SUMMARY OF THE INVENTION

[0007] The present invention is directed to a solar energy collecting device and system that substantially obviates one or more of the problems due to limitations and disadvantages of the related art.

[0008] An object of the present invention is to provide a polar tracking system for solar energy collection that has a simple structure and is easy to implement.

[0009] Additional features and advantages of the invention will be set forth in the descriptions that follow and in part will be apparent from the description, or may be learned by practice of the invention. The objectives and other advantages of the invention will be realized and attained by the structure particularly pointed out in the written description and claims thereof as well as the appended drawings.

[0010] To achieve these and other advantages and in accordance with the purpose of the present invention, as embodied and broadly described, the present invention provides a solar energy collecting device which includes a rotation axis; a solar energy collector mounted for rotation around the rotation axis, the solar energy collector defining a tilt angle with respect to the rotation axis; a driving mechanism for driving the solar energy collector to rotate around the rotation axis at a predetermined rotation speed during at least part of a day; and a tilt angle adjustment mechanism for automatically and intermittently adjusting the tilt angle. Various configurations of the solar energy collector are possible, and the rotation speed may be one revolution per day or half a revolution per day depending on the solar energy collector configuration. Various drive modes are possible, including rotating continuously throughout a day or rotating during daylight hours and rotating backward or forward at night to a starting position and restarting the rotation the next day.

[0011] One embodiment of the tilt angle adjustment mechanism includes a handle fixed to the solar energy collector and a tilt angle change guide.

[0012] In another aspect, the present invention provides a solar energy collecting system comprising a plurality of such solar energy collecting devices, the system further including a base on which the rotation axes of the plurality of solar energy collecting devices are mounted and an enclosure for enclosing the plurality of solar energy collecting devices.

[0013] In yet another aspect, the present invention provides a method for collecting solar energy, the method including mounting a rotation axis parallel to a polar axis of the earth; mounting a solar energy collector for rotation around the rotation axis, the solar energy collector defining a tilt angle with respect to the rotation axis; rotating the solar energy collector around the rotation axis at a predetermined rotation speed during at least part of a day; and automatically and intermittently adjusting the tilt angle.

[0014] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. 1 illustrates a solar energy collection unit according to an embodiment of the present invention.

[0016] FIG. 2 illustrates a solar energy collection unit with alternative configuration according to another embodiment of the present invention.

[0017] FIG. 3 illustrates the solar energy collection unit of FIG. 1 when the incident sunlight is partially blocked.

[0018] FIG. 4 illustrates the solar energy collection unit of FIG. 1 when the incident sunlight is from a direction that is deviated from the desired angle.

[0019] FIG. **5** is a global view of a polar axis at any place with latitude θ.

[0020] FIG. **6**A is a local top view of the polar axis.

[0021] FIG. **6**B is the local side view of the polar axis view along an east-west direction.

[0022] FIG. **7**A illustrates a solar energy collection unit being mounted on a polar axis without any tilt.

[0023] FIG. **7**B illustrates the solar energy collection unit being mounted on a polar axis with an upward tilt angle for summer time.

[0024] FIG. **7**C illustrates the solar energy collection unit being mounted on a polar oriented axis with a downward tilt angle for winter time.

[0025] FIG. **8** shows a solar energy collection unit with a handle attached to it for tilt angle adjustment according to an embodiment of the present invention.

[0026] FIGS. **9**A, **9**B and **9**C are top, right side and front side views, respectively, of a tilt angle change guide according to an embodiment of the present invention.

[0027] FIG. **9**D shows a mounting configuration for the tilt angle change guide according to an embodiment of the present invention.

[0028] FIG. **10** is a front side view of the positions of the solar energy collection unit with the handle relative to the tilt angle change guide.

[0029] FIGS. **11**A and **11**B are top and right side views, respectively, illustrating the motion of the handle along the tilt angle change guide.

[0030] FIG. **12** illustrates an array of solar energy collection units under a transparent cover.

[0031] FIG. **13** illustrates a solar energy collection element with a centralized energy receiver.

[0032] FIG. **14** illustrates the solar energy collection element of FIG. **13** when the sunlight comes from a different direction.

[0033] FIG. **15** illustrates a system including illustrated solar energy collection element of FIG. **12**, where the entire enclosure is tilted to an angle that is equal to the latitude.

[0034] FIGS. **16**A-D show a solar energy collection system with a handle attached to a rigid body for tilt angle adjustment according to another embodiment of the present invention. FIG. **16**A is a perspective view, and FIGS. **16**B-D are side views.

[0035] FIG. **16**E shows the solar energy collection system of FIG. **16**A when rotated to a different orientation.

[0036] FIG. **17**A-B show an alternative tilt angle change guide.

[0037] FIG. **18** shows the cross-sectional view of a latching device for mounting the rigid body of FIG. **16**A on the crossbar.

[0038] FIGS. **19**A-G show an alternative embodiment of handle and tilt angle change guide, where FIG. **19**A is a perspective view, FIGS. **19**B-D are side views from three orthogonal directions for a zero tilt angle, and FIGS. **19**E-G are side views from three orthogonal directions for a non-zero tilt angle.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0039] Embodiments of the present invention provide a solar energy collection system that uses a polar tracking method to track the sun. In one embodiment, the solar energy collection system is formed by a plurality of solar energy collection unit **300**. As shown in FIGS. **1** and **2**, each solar energy collection unit **300** or **300'** includes a solar energy concentrator **100** or **100'** which receives sunlight and directs it to a target energy receiver **200** such as a solar cell. The solar energy concentrator **100** in the embodiment of FIG. **1** is a transmission type concentrator such as a lens, where the target energy receiver **200** is on the opposite side of the solar energy concentrator as the sun. The solar energy concentrator **100'** in the embodiment of FIG. **2** is a reflection type concentrator such as a mirror, where the target energy receiver **200** is on the same side of the solar energy concentrator as the sun. In both types of solar energy collection units **300** and **300'**, the spatial relationship between the solar energy concentrator **100** and **100'** and the target energy receiver **200** is fixed. Because of solar concentration, for certain type of applications such as concentrated photovoltaic (CPV), the solar energy receiver may have an appropriate cooling mechanism as needed.

[0040] As another alternative (not shown), the solar energy collection units may include only an energy receiver without a solar energy concentrator. In this disclosure, the term "solar energy receiving surface" refers to the surface of the solar energy concentrator if one is present, or refers to the surface of the target energy receiver if no solar energy concentrator is present. The descriptions below use the solar energy collection units **300** of FIG. **1** as an example, but the same principles apply to the solar energy collection units **300'** of FIG. **2** unless specifically noted otherwise.

[0041] As shown in FIG. **1**, the sunlight **90** shines upon the concentrator **100** at a pre-determined incident angle δ, and the concentrator **100** directs sunlight **90** to the target energy receiver **200**. Usually the preferred incident angle δ is zero, i.e., the sunlight is perpendicular to the concentrator surface, for maximum solar flux collection. However, any other pre-determined incident angle δ is acceptable depends on system designs. For certain applications where uniform illumination upon the energy receiver is required, such as when photovoltaic (PV) cell is used as the energy receiver, the concentrator **100** is preferably capable of directing incident sunlight **90** substantially uniformly to the target energy receiver **200** even when the surface of the concentrator **100** is partially blocked. FIG. **3** illustrates such a situation for the solar energy collection unit **300** of FIG. **1**, where only a portion of the concentrator **100** is exposed to sunlight, and the concentrator **100** directs the uneven sunlight **90** to the target energy receiver **200** so that it falls substantially uniformly on the target energy receiver. Such uniformity preferably exists on the entire 2-dimensional surface of the concentrator. A properly designed non-imaging concentrator can perform such a function.

[0042] The solar energy collection unit **300** is mounted on a tracking structure for tracking the position of the sun. The solar energy collection unit **300** may tolerate certain margin of error in tracking. As shown in FIG. **4**, when the incoming sunlight **90** shines upon the concentrator **100** at an incident angle Δ different from the pre-determined incident angle δ shown in FIG. **1**, the target is still receiving full, or nearly full light energy, if the incident angle deviation is within a design limit. While this deviation may or may not result in loss of sunlight energy, depends on the concentrator design, it provides certain error tolerance for system design and operation.

[0043] The principles of polar coordinate system and polar tracking are described below. FIG. **5** is a global view illustrating a polar axis **400**, which is an axis parallel to the rotation axis of the earth at any location on earth. The latitude of the location is indicated as θ. FIG. **6**A and FIG. **6**B illustrate the orientation of the polar axis **400** in a local coordinate system. FIG. **6**A is a local top view, showing the polar axis **400** is long the north-south direction; FIG. **6**B is a local side view taken along the east-west direction, showing the polar axis **400** being tilted up by an angle θ with respect to the ground, where θ is the latitude at that location.

[0044] As shown in FIG. **7**A, at vernal equinox or autumnal equinox, the sun is in the equatorial plane, so the solar energy collection unit **300** is mounted on the polar axis **400** without any tilt. In the summer, the sun's angle with respect to the equatorial plane is higher. FIG. **7**B shows the solar energy collection unit **300** being tilted up with respect to the polar axis **400** by an amount Ω (the tilt angle) equal to the sun's angle with respect to the equatorial plane. In the winter, the sun's angle with respect to the equatorial plane is lower, and the solar energy collection unit **300** is tilted down accordingly by a tilt angle Ω, as shown in FIG. **7**C. The angle of the sun with respect to the equatorial plane varies seasonally, slowly from one day to the next (the maximum tilt angle change between two consecutive days being about 0.4°), with a maximum angle of 23.45° on both sides of the equatorial plane. Thus, preferably, the tilt angle of the solar energy collection unit **300** with respect to the polar axis **400** is adjusted seasonably. The tilt angle may be adjusted constantly, or intermittently, preferably everyday, or every few days for simplicity of implementation.

[0045] According to embodiments of the present invention, the solar energy collection units **300** are mounted to rotate around a rotation axis that is parallel to the polar axis in an installed solar energy collection system. (In the instant disclosure, the rotation axis is sometimes referred to as the polar axis where the context makes the meaning clear.) The solar energy collection units **300** rotate along the polar axis **400** at a speed of approximately one turn per day to track the sun. Looking from the celestial North Pole, the rotation direction is clockwise to counter the effect of the earth rotation, so that the solar energy collection unit **300** is always facing the sun at the same angle.

[0046] In a simple implementation, the solar energy collection unit **300** may rotate around the rotation axis **400** continuously at a substantially constant speed of approximately one revolution per day. Alternatively, it may rotate at a speed of approximately one revolution per day during the day to collect the solar energy, and rotate backward or forward at a different speed during the night (non-collection time) to an appropriate position, and re-start the rotation at an appropriate time of the day for the next day's operation.

[0047] The solar energy collection unit **300** is mounted on rotational axis with a tilt angle that is adjustable. Some examples of the tilt angle adjustment mechanism are described with reference to FIGS. **8-11** and **16-19**. These examples use a handle fixedly attached to the energy collection unit to interact with a tilt angle change guide to change the tilt angle. The handle is attached to a single energy collection unit **300** in the example shown in FIGS. **8** and **10**, and attached to a rigid body formed by ganging a number of energy collection units **300** together in the example shown in FIGS. **16**A-D and FIGS. **19**A-G, but the same mechanism of tilt angle adjustment can be applied.

[0048] In the example shown in FIG. **8**, a handle **350** is fixedly attached to the solar energy collection unit **300** and is used to adjust the tilt angle of the solar energy collection unit **300** with respect to the rotation axis **400**, which is parallel to the polar axis in the installed system. In the example shown in FIG. **16**A (perspective view) and FIGS. **16**B-D (top view and two orthogonal side views, respectively), a crossbar **410** is attached to the rotation axis **400**, and rotates around the rotation axis approximately one revolution per day. The crossbar **410** is preferably perpendicular to the rotation axis **400** and is fixed to that axis. One or more solar energy collection units **300** (four are shown in FIG. **16**A as an example) are ganged together to form a rigid body **330**. The rigid body **330** is attached to the crossbar **410** by a hinge so that it can rotate around the crossbar, at least within a certain angular range, to accommodate the necessary tilt angle adjustment. It is preferred that through a symmetrical arrangement and other design considerations, the rigid body **330** is balanced with respect to the crossbar **410** and is balanced with respect to the rotational axis **400** at all possible tilt angle. Optionally, two or more rings **501** and **502** are mounted on the rotation axis **400**, each ring being in contact with a corresponding brush **511** and **512** to conduct the electricity out as such arrangement may be necessary for perpetual rotation. The handle **350** is fixedly attached to the rigid body **330** so that by moving the handle **350** to different positions, the entire rigid body **330** rotates around the crossbar **410** and thus changes its tilt angle respect to the rotation axis **400**.

[0049] A tilt angle change guide **360** is provided to engage the distal portion of the handle **350** during some part of daily rotation to change the tilt angle of the rigid body **330**. In FIG. **16**A, the rigid body **330** is shown in its position during daytime, and the handle **350** is pointed away from the tilt angle change guide **360**. In FIG. **16**E, the rigid body **330** is shown in its position during nighttime, and the handle **350** is pointed toward and its distal portion is engaged with the tilt angle change guide **360**.

[0050] One example of a tilt angle change guide **360** is illustrated in FIGS. **9**A-**9**C. FIG. **9**A is a view taken along the rotation axis **400**; FIG. **9**B is a view taken along the handle **350** as it engages the tilt angle change guide **360**; and FIG. **9**C is a view taken along a direction perpendicular to the above two directions. As the rigid body **330** together with the handle **350** rotates around the rotation axis **400**, the distal portion of the handle **350** glides along the tilt angle change guide **360** as shown in FIGS. **10**, **11**A and **11**B. The shape of the tilt angle change guide **360** is designed so that as the distal portion of the handle **350** slides along the tilt angle change guide **360**, the handle is pushed so that the rigid body **330** rotates slightly around the crossbar **410**. As a result, the tilt angle of the rigid body **330** when the handle exits the tilt angle change guide **360** is different from the tilt angle with it enters the tilt angle change guide. The amount of change in the tilt angle is determined by the position of the entrance of the tilt angle change guide **360** when the handle enters it and the position of the exit of the tilt angle change guide when the handle exits it.

[0051] The rigid body **330** is fixedly attached to the crossbar **410** by a clamp, latch or other suitable tilting attachment most of the time so that it rotates around the rotation axis **400** at a fixed tilt angle, except during the brief period when the handle **350** is engaged with the tilt angle change guide **360**. During that period, the tilting attachment loosens, so that the rigid body **330** can rotate around the crossbar **410** (i.e. change the tilt angle) as the handle **350** is pushed by the tilt angle change guide **360**. After the handle exits the tilt angle change guide, the tilting attachment is re-fastened. In practice, if the rigid body **330** is designed to be well balanced, and the friction between the rigid body and the crossbar **410** is strong enough to hold the tilt angle unchanged, yet weak enough to allow the tilt angle to change when the handle is pushed by the tilt angle change guide **360**, the tiling attachment may not necessarily need to be explicitly loosened and re-fastened.

[0052] An example of a tilting attachment is shown in FIG. **18**, which is a view along the crossbar **410**. A serrated section **410**A of the crossbar **410** is provided with a plurality of teeth along its periphery. An inner surface **330**A of the rigid body **330** surrounds the section **410**A with a gap in between, and a spring-loaded ball **330**B fits between the teeth of the serrated section **410**A and the inner surface **330**A. When the tilt angle is not being changed, the spring tension keeps the ball **330**B within a valley between two teeth, and the rigid body **330** does not rotate with respect to the crossbar **410**. When the tilt angle is being changed, the handle pushes the rigid body **330** to rotate with respect to the crossbar **410** and the ball falls into the next valley.

[0053] Tilt angle adjustment may be automatically carried out at a desired time of the day. In the embodiment shown in FIGS. **16**A-E, tilt angle is adjusted at night when the handle rotates to location of the tilt angle change guide; tilt angle may be adjusted at other times of the day by changing the relative locations of the handle **350** and the tilt angle change guide **360**. Further, the tilt angle may be adjusted daily, or more or less frequently. For example, to make adjustments twice a day, two handles and/or two tilt angle change guides may be provided. If the adjustment is less frequently than once a day, an appropriate moving mechanism is provided to move the tilt angle change guide **360** out of the path of the handle for the days when adjustment is not to be performed, and move it back into the path of the handle for the days when adjustment is to be performed. In a preferred embodiment, the tilt angle adjustment is made daily.

[0054] For a given tilt angle adjustment schedule, the amount of tilt angle change for each adjustment is determined by the season (time of the year) and the length of time between successive adjustments. For each adjustment, the tilt angle change guide **360** is re-positioned so that its entrance location approximately corresponds to the current tilt angle and its exit location corresponds to the target tilt angle. At the entrance end, a flared shape may be provided (see FIG. **9**B) to help the handle **350** enter the tilt angle change guide even when the handle does not perfectly line up with the entrance of the guide.

[0055] One example for re-positioning the tilt angle change guide **360** is shown in FIGS. **16**A, **16**E and **9**D. The tilt angle change guide **360** is attached near its two ends to two wheels **360**A and **360**B, where both wheels rotate at a rate of one rotation per year. The two attachment points on the two wheels have a fixed phase angle difference of $\epsilon=2\pi(1-\eta)/365.242199$, where η is the portion of the day that the handle is engaged with the guide. For example, if it takes 3 hours for the handle to glide through the guide, then $\eta=3/24=0.125$. The radii of the two wheels are selected such that the maximum tilt angle achieved by the tilt angle change guide **360** is 23.45 degree on both sides of the equatorial plane.

[0056] Another example of a tilt angle change guide **360'** is shown in FIGS. **17**A-B. The tilt angle change guide **360'** is made of a number of parallel guide walls **361'** forming parallel guide grooves between them. The right-hand ends of the guide walls can be shifted up or down by a predetermined amount, e.g., the width of one groove, from a central position. At the central position, shown in FIG. **17**A, the handle **350** enters and exits a guide groove without changing the tilt angle; i.e., the entrance and the exit of a groove correspond to the same tilt angle. When the right-hand ends of the guide walls **361'** are shifted up, as shown in FIG. **17**B, the exit and entrance of a groove correspond to different tilt angles. Thus, the handle **350** is pushed as it slides along the groove, thereby changing the tilt angle. The position of the right-hand ends of the guide walls **361'** can be programmed so that on some days, they are located at the central location (FIG. **17**A) and no tilt angle adjustment occurs, and on some other days, the right-hand ends of the guide walls **361'** are shifted up (FIG. **17**B) or down so that tilt angle adjustment occurs. The amount of tilt angle change caused by each adjustment depends on the design of the guide **360'**, such as the shape of the grooves, etc. As pointed out earlier, the tilt angle of the sun changes relatively slowly, and changes by different amounts per day throughout the year. Thus, the tilt angle change guide **360'** may be programmed to change tilt angle according to a suitable schedule throughout the year.

[0057] The handle and the tilt angle change guide may be implemented in many forms in addition to the examples described above. For example, an alternative design is shown in FIGS. **19**A-G. FIG. **19**A is a perspective view showing the circular handle **350"** and the tilt angle change guide **360"**. FIGS. **19**B-D are a top view and two side views of the system shown in FIG. **19**A when the tilt angle is zero degrees. FIGS. **19**E-G show a top view and two side views of the system when the tilt angle is non-zero. As shown in FIG. **19**A, the handle **350"** has a circular shape in a plane which contains crossbar **410** and is perpendicular to the rigid body **330** and centered at the rotation axis **400**. The tilt angle change guide **360"** has a slot constantly engaging a part of the circular handle **350"**. The tilt angle change guide is mounted on the frame of the solar energy collection system and moves up and down (as shown by the arrows in FIG. **19**F) during the course of a day to engage the handle and adjust the tilt angle. The daily up and down motion of the tilt angle change guide **360"** may be approximately described by the equation Z=A cos(wt+phase), where the amplitude A and the phase of this daily motion define the tilt angle.

[0058] In the polar tracking system, the rotation around the polar axis is synchronized to the sun's position relative to the earth. By using counters and comparators, accurate angular control can be monitored and controlled at various stages of the transmission between the motor and the slow rotating array, so that precise rotation motion of the axes will match the predicted position of the sun. It may be used for an accurate adjustment for different daylight length, sunrise time, etc. Correct timing and reliability are important, and redundancy, sense and feedback can help to keep the tracking system accurate and reliable.

[0059] With the input of latitude and longitude of the installation location and accurate date and time, it is easy to set the initial tracking direction. For example, the sun passes the meridian at noon local time. Once tracking started, the apparatus can turn at one rotation per day continuously, or back and forth during night and day to reset positions.

[0060] A suitable control circuit, which preferably employs a self-calibrated clock, may be used to control the motion of the solar energy collection units. Optionally, a universal standard time source, such as the GPS time signals or standard radio time source, may be used to eliminate any time error accumulation. Preferably, software control is used. A solar sensor could also be used for auxiliary tracking.

[0061] In one implementation, an array of the solar energy collection unit mounted on their rotation axes are connected together by means of chains, gears, or other synchronization means, which may be driven by one power source. All units rotate continuously at the same speed. Because of the slow and continuous rotation at the speed of one turn per day, and the very slow tilt angle adjustment, an array of such solar energy collection units can be driven simultaneously and continuously by a low powered motor.

[0062] FIG. **12** shows a solar energy collection system that includes an array of energy collection units **300** each mounted to rotate around its own rotation axis **400**. All axes **400** are parallel to each other. All solar energy collection units rotate at the same speed, and their tilt angles are adjusted as described earlier. Preferably, all energy collection units are driven by a common power source. The energy collection units **300** together with their tracking mechanisms are enclosed in an enclosure **371** with a transparent cover **370**. In such a system, the array of energy collection units **300** enclosed in an enclosure form a static flat panel **371** which can be installed as a unit. The enclosure also reduces environmental impacts on individual solar energy collection units **300**.

[0063] To allow the panel to operate independently of external power sources, a small but sufficient energy storage device, such as a rechargeable battery or a super capacitor is preferably provided as an energy source to allow the motor in the tracking mechanism to continue to work during night and cloudy/rainy days. It may contain a control circuitry described earlier. Both such energy storage device and control circuitry can also be external, particularly when multiple similar panels are installed at the same location.

[0064] The panel **371** must be constructed and mounted in a way such that the rotation axes **400** are parallel to the polar axis of the earth. In one embodiment, the panel is constructed so that all rotation axes **400** are parallel to the base **372** of the enclosure. Such a panel should be installed such that the base is tilted up with respect to the horizontal plane with an angel equal to the latitude at the installation location, and the rotation axes **400** are oriented along a north-south direction in the top view, as shown in FIG. **15**. In an alternative embodiment, the panel is constructed so that all rotation axes **400** are tilted with respect to the base **372** by an angle that is equal to the latitude at the installation location (assuming that the location is know at the time of manufacturing). Such a panel may be installed with the base parallel to the horizontal plane, and the rotation axes **400** are oriented along a north-south direction in the top view. In yet another alternative embodiment, when the panel is to be installed on a slanted surface, such as a rooftop, and when the orientation and slant angle of the surface is known, the panel can be constructed to orient the rotation axes with respect to the base in such a way that, when the panel is mounted flat on the rooftop in a designed orientation, the rotation axes are parallel to the polar axis at the installation location.

[0065] FIGS. **13** and **14** illustrate an alternative solar energy collection system that has one or more target energy receivers **210** that are stationary and one or more concentrators **110** that rotate to track the sun.

[0066] As shown in FIG. **13**, the sunlight **90** shines upon a concentrator **110** at a pre-determined incident angle Φ, and the concentrator **110** redirects sunlight to the target energy receiver **210**. The relative position of the concentrator **110** and the target energy receiver **210** is not fixed. Each target energy receiver **210** may receive redirected sunlight from one or more concentrators **110**. In other words, a number of concentrators **110** may direct sunlight to one target energy receiver **210**, which may be referred to as a centralized energy receiver (in this case an array of concentrators **110** behave as a static heliostat); or alternatively, each concentrators **110** may direct sunlight to its own target energy receiver, referred to as a distributed energy receiver. Similar to the system shown in FIGS. **1** and **2**, the concentrators **110** may be a reflection type or a transmission type; i.e., the incident sunlight **90** and the target energy receiver **210** may be located at the same or different side of the concentrator **110**. The concentrator **110** is preferably capable of generating uniform density light output even when incident sunlight is partially blocked for certain application. The concentrators **110** preferably have a certain tolerance for tracking error.

[0067] As shown in FIG. **14**, the sunlight **90** shines at another direction at a different time of the day, and the concentrator **110** also changes its position so that the incident angle becomes Ψ, the concentrator **110** will still redirect sunlight to the centralized energy receiver **210**. The position of the centralized energy receiver **210** is fixed, while the position of the concentrator **110** changes.

[0068] In an embodiment employing stationary target energy receivers **210** (either centralized or distributed) as shown in FIGS. **13** and **14**, the concentrator **110** rotates around the polar axis at a speed different from that of the solar energy collection units **300** having moving energy receivers **200** as shown in FIGS. **1** and **2**. In one implementation using stationary energy receivers, the concentrator **110** is a two-sided mirror which rotates around a polar axis at a speed of half a revolution per day, and the tilt angle is adjusted half the amount as that in the embodiment using moving energy receivers. In general, the rotation speed and the tilt adjustment amount depend on the design of the concentrator, as shown in FIG. **13** and FIG. **14**. The structures for tilt angle adjustment for the concentrator **110** may be a similar to the tilt angle adjustment structure described earlier.

[0069] Similar to solar energy collection units **300** using moving target energy receivers **200**, an energy collection unit using stationary target energy receivers **210** may be arranged in an array and enclosed in an enclosure with a transparent cover in a similar manner as shown in FIG. **12**.

[0070] In an array of solar energy collection units, one structural element may partially block the incident sunlight on another solar energy concentrator during certain times. For some applications, such as solar thermal, non-uniform illumination on the energy receiver is acceptable; for other applications, such as photovoltaic (PV) which require uniform light illumination for optimal performance, a non-imaging concentrator, which could produce uniform output illumination when input sun light is partially blocked, is preferably used.

[0071] Many different variations of a solar energy collection system are described above. One common feature of the different variations is that a solar energy collector (which is either a solar energy concentrator (**100**/**110**) for directing sunlight to a solar energy receiver (**200**/**210**), or a solar energy receiver without a concentrator) is mounted to rotate around a polar axis at a predetermined rotation speed during at least a part of a day, with automatic and intermittent tilt angle adjustment. The variations include:

[0072] The predetermined rotation speed is approximately one revolution per day if the solar energy collector is a solar energy concentrator (**100**) used with a solar energy receiver (**200**) that rotates with the concentrator, or if the solar energy collector is a solar energy receiver without a concentrator (not shown in the drawings). The predetermined rotation speed is approximately half a revolution per day if the solar energy collector is a solar energy concentrator (**110**) used with a stationary solar energy receiver (**210**) that is fixed in space. "To rotate at a predetermined rotation speed during at least part of a day" includes various drive modes such as rotating continuously throughout a day (i.e. 24 hours a day), or rotating during a part of the day (e.g., during daylight hours) and rotating backward or forward (preferably at a faster speed) to a starting position so that it can restart the rotation the next day. Further, the word "rotation" includes intermittent rotation, i.e., rotating by an appropriate angle once every short time period such as a minute, as long as the average speed is the predetermined rotation speed. "Approximately one revolution per day" or "approximately half a revolution per day" means the rotation speed may deviate from an ideal value of 360 degrees (or 180 degrees) per 24 hours.

[0073] Generally, a relatively inexpensive timing device (clock) can achieve an accuracy of ±1 degree per 24 hours (equivalent to ±4 minutes per 24 hours). Accumulated timing error may be corrected from time to time using a universal standard time source, such as the GPS time signals or standard radio time source. Further, although more accurate tracking results in more efficient solar energy collection, tracking (rotation) speed may deviate from the ideal speed by a larger amount (e.g. 10 or even 20 degrees per 24 hours) if a less-than-optimized energy collection efficiency can be accepted. Moreover, the solar energy collector may be designed so that collection efficiency remains relatively high for a large range of sunlight incident angle, in which case an even larger tracking error may be acceptable. Thus, it should be understood that the above described deviations from the ideal case of a constant rotation at a speed of 360 (or 180) degrees per 24 hours fall within the scope of the present invention. In addition, due to the finite eccentricity (0.0167) of the earth's orbit around the sun, the exact length of each day can be longer or shorter than 24 hours. The tracking device may be designed to adjust to this variation of the length of the day, either by changing the rotation speed or by correcting for accumulated errors from time to time. All of such variations in the rotation speed of the tracking system are within the scope of the present invention.

[0074] "Automatic and intermittent tilt angle adjustment" means the adjustment occurs automatically without human intervention, and occurs more than once a day, once a day or less frequently than once a day. The advantage of intermittent tilt angle adjustment is that it can be achieved with relatively simple mechanical structures, such as the handle **350** in the illustrated embodiments.

[0075] Also described is a solar energy collecting system in which a plurality of such solar energy collectors are mounted on a base and driven by a common power source to rotate at the same speed. The solar energy collector can be any one of the above variations. The plurality of solar energy collectors can be enclosed in an enclosure which can then be installed as a unit.

[0076] As seen from the above descriptions, a synchronized solar concentrator array according to embodiments of the present invention has only one set of fixed axis, but can achieve the tracking accuracy of conventional two-axis tracking. All moving elements in the array rotate at the same speed and direction, around their own fixed axes; therefore, no complex control mechanism is required. Each concentrator does not need to be large or bulky. Using repetitive, small, and simple module can reduce manufacturing cost. As a result, the overall system cost can be reduced. In addition, the energy collection units can rotate at a constant speed (although it's not a requirement) and can be synchronized to a universal standard time source (such as GPS signals or a standard radio time source), eliminating problem associated with systems using a solar sensor or a local clock.

[0077] By using concentrators, solar cell material usage for a panel of the same power rating can be significantly reduced. By using an effective solar tracking method, the overhead cost from solar tracking is insignificant. Because each solar energy collection unit can have a small size, an array of them can be arranged in a plane and a low profile flat panel can be constructed.

[0078] One particular application of panels constructed related to FIG. **13** and FIG. **14** is a static heliostat, which is very desirable for a centralized energy receiver.

[0079] Advantages of solar energy collection systems according to embodiments of the present invention are as follows:

[0080] one fixed axis tracking for accurate solar energy collection;

[0081] individual axis or arrays of axes are all parallel to the earth rotation axis

[0082] using less solar energy conversion element because of concentrator;

[0083] array of synchronized solar concentrators could be driven by one small power source;

[0084] synchronized rotation at controlled, nearly constant, slow speed;

[0085] seasonal tilt angle slight adjustment as needed

[0086] could be used in both distributed energy receiver, or in a centralized energy receiver;

[0087] with a cover, it will look like a static flat panel, or a static heliostat.

[0088] It will be apparent to those skilled in the art that various modification and variations can be made in the solar energy collection system of the present invention without departing from the spirit or scope of the invention. Thus, it is intended that the present invention cover modifications and variations that come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A solar energy collecting device comprising:

a rotation axis;

a solar energy collector mounted for rotation around the rotation axis, the solar energy collector defining a tilt angle with respect to the rotation axis;

a driving mechanism for driving the solar energy collector to rotate around the rotation axis at a predetermined rotation speed during at least part of a day; and

a tilt angle adjustment mechanism for automatically and intermittently adjusting the tilt angle.

2. The solar energy collecting device of claim 1, wherein the tilt angle adjustment mechanism comprises:

a handle fixed to the solar energy collector and rotates with it around the rotation axis;

a tilt angle change guide having an elongated opening adapted to receive a part of the handle, the tilt angle change guide being positioned such that the handle enters a first end of the opening, slides along the opening, and exits a second end of the opening during a portion of the rotation of the solar energy collector, wherein the tilt angle of the solar energy collector is a first value when the handle enters the first end of the opening and a second value when the handle exits the second end of the opening; and

a tilt angle change guide adjusting mechanism for seasonally adjusting the position of the tilt angle change guide.

3. The solar energy collecting device of claim 2, further includes a clamp or latch for fixing the solar energy collector to the rotation axis at a fixed tilt angle, wherein the clamp or latch is disengaged when the handle enters the first end of the opening of the tilt angle change guide, and reengaged when the handle exits the second end of the opening.

4. The solar energy collecting device of claim 2, wherein the handle and the tilt angle change guide are located such that the handle enters the opening of the tilt angle change guide during non-energy collection time.

5. The solar energy collecting device of claim 1, wherein the solar energy collector is a solar energy receiver, and wherein the predetermined rotation speed is approximately one revolution per day.

6. The solar energy collecting device of claim 1, wherein the solar energy collector is a solar energy concentrator, wherein the solar energy collecting device further includes a solar energy receiver having a fixed spatial position relative to the solar energy concentrator, wherein the solar energy concentrator directs sunlight to the solar energy receiver, and wherein the predetermined rotation speed is approximately one revolution per day.

7. The solar energy collecting device of claim 1, wherein the solar energy collector is a solar energy concentrator, wherein the solar energy collecting device further includes a stationary solar energy receiver that is fixed in space, wherein the solar energy concentrator directs sunlight to the solar energy receiver, and wherein the predetermined rotation speed is approximately half a revolution per day.

8. The solar energy collecting device of claim 7, wherein the solar energy concentrator is a two-sided mirror.

9. The solar energy collecting device of claim 1, wherein the drive mechanism drives the solar energy collector to rotate continuously throughout a day.

10. The solar energy collecting device of claim 1, wherein the drive mechanism drives the solar energy collector to rotate during daylight time of a day and to rotate backward or forward during night time to a starting position and restarts the rotation the next day.

11. The solar energy collecting device of claim 1 further including a solar energy receiver, wherein the solar energy collector is a solar energy concentrator for directing sunlight to the solar energy receiver, and wherein the solar energy concentrator is a non-imaging concentrator that produces substantially uniform light output when partially illuminated.

12. The solar energy collecting device of claim 1 further including a solar energy receiver, wherein the solar energy collector is a solar energy concentrator for directing sunlight to the solar energy receiver, and wherein the solar energy concentrator is a non-imaging concentrator that directs substantially all incident sunlight to the energy receiver when the sunlight illuminates on the solar energy concentrator at an angle within a predefined range.

13. The solar energy collecting device of claim 1, further including a control circuit for controlling the driving mechanism, the control circuit receiving a universal standard time signal for synchronizing the rotation of the solar energy collector to the rotation of the earth relative to the sun.

14. A solar energy collecting device of claim 1, comprising a plurality of solar energy collectors forming a rigid body, the device further comprising a crossbar mounted for rotating around the rotation axis, wherein the rigid body is attached to the crossbar at a tilt angle and rotates around the rotation axis with the crossbar, wherein the rigid body is balanced with respect to the crossbar and is balanced with respect to the rotational axis at all tilt angles, and wherein the tilt angle adjustment mechanism adjusts the tilt angle of the rigid body.

15. A solar energy collecting system comprising a plurality of solar energy collecting devices of claim 1, the system further comprising:

a base on which the rotation axes of the plurality of solar energy collecting devices are mounted; and

an enclosure for enclosing the plurality of solar energy collecting devices.

16. The solar energy collecting system of claim 15, wherein the rotation axes of the plurality of solar energy collecting devices are parallel to each other, the system further comprising:

a power source for providing a drive power; and

a drive system for transmitting the drive power to the driving mechanisms of the plurality of solar energy collecting devices to drive them to rotate at the same speed.

17. The solar energy collecting system of claim 16, further comprising:

a control circuit for controlling the drive system; and

an energy storage device for storing energy for the power source,

wherein the control circuit and the energy storage device are located outside the enclosure.

18. The solar energy collecting system of claim 15, wherein the rotation axes of the plurality of solar energy collecting devices are parallel to the base.

19. The solar energy collecting system of claim 15, wherein the rotation axes of the plurality of solar energy collecting devices are tilted with respect to the base by a predetermined angle.

20. The solar energy collecting system of claim 15 further comprising a stationary solar energy receiver, wherein the solar energy collector of each solar energy collecting device is a solar energy concentrator that directs sunlight to the solar energy receiver.

21. The solar energy collecting system of claim 15, wherein each solar energy collecting device further includes a solar energy receiver, wherein the solar energy collector of each solar energy collecting device is a solar energy concentrator that directs sunlight to the respective solar energy receiver.

22. A method for collecting solar energy, comprising:

mounting a rotation axis parallel to a polar axis of the earth;

mounting a solar energy collector for rotation around the rotation axis, the solar energy collector defining a tilt angle with respect to the rotation axis;

rotating the solar energy collector around the rotation axis at a predetermined rotation speed during at least part of a day; and

automatically and intermittently adjusting the tilt angle.

23. A solar energy collecting device comprising:

a rotation axis;

a solar energy collector mounted for rotation around the rotation axis, the solar energy collector defining a tilt angle with respect to the rotation axis;

a driving mechanism for driving the solar energy collector to rotate around the rotation axis at a predetermined rotation speed during at least part of a day; and

a tilt angle adjustment mechanism for automatically adjusting the tilt angle, tilt angle adjustment mechanism including:

a handle fixed on the solar energy collector and rotates with it around the rotation axis,

a tilt angle change guide engaging the handle during at least a part of the rotation of the handle around the rotation axis, and

a tilt angle change guide adjusting mechanism for seasonally adjusting the position of the tilt angle change guide.

24. The solar energy collecting device of claim 23, wherein the tilt angle change guide has an elongated opening adapted to receive a part of the handle, the tilt angle change guide being positioned such that the handle enters a first end of the opening, slides along the opening, and exits a second end of the opening during a portion of the rotation of the solar energy collector, wherein the tilt angle of the solar energy collector is a first value when the handle enters the first end of the opening and a second value when the handle exits the second end of the opening.

25. The solar energy collecting device of claim 24, wherein the tilt angle change guide has a plurality of parallel openings.

26. The solar energy collecting device of claim 23, wherein the handle has a circular shape and the tilt angle change guide engages the handle constantly.

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