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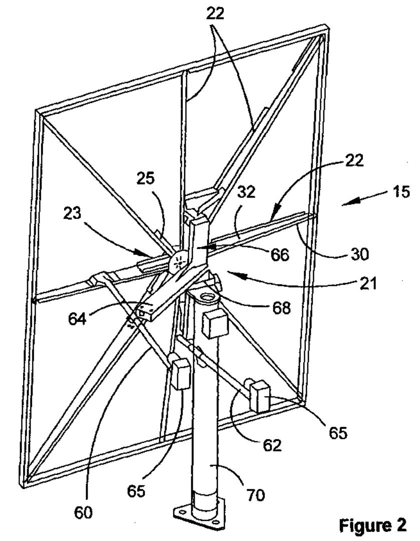

Figure 2

(57) Abstract: A parabolic mirror assembly for a heliostat comprising a mirror (14) and a backing support frame (20) for the mirror having elongate frame elements (22, 22a) arranged so that the mirror exhibits a shallow concave parabloid profile, wherein the mirror is secured to the frame elements by an adhesive layer between the frame elements and the mirror, and wherein manufacturing tolerances in the frame and/or mirror are compensated for by variations in the thickness of the adhesive. Also contemplated is a mould for forming a parabolic mirror assembly and method of use, that comprises: a mould body having a parabolic upper surface; and a plurality of recessed portions provided in said surface for receiving a frame below the upper surface; wherein a mirror can be conformably positioned on the upper surface of the mould body and adhesive applied between the frame and mirror is cured to form the mirror assembly.

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Heliostat construction

Field of the invention

The present invention relates to heliostats, and in particular to parabolic mirror assemblies for heliostats and to their method of construction. The heliostats are preferably for use with a concentrating central receiver system. Means of actuating the heliostats is also disclosed.

Background of the invention

Fossil fuels will be an important source of energy for many years, as well as a valuable export commodity. However, Australia is also recognised as having the highest solar irradiation (highest average number of sunshine hours) of any continent in the world.

Solar tower systems use an array of heliostats (large individually-tracking mirrors) to focus sunlight onto a central receiver mounted on top of a tower.

The performance of the array is dependent on its design and control. Results show that there is an optimum size heliostat for a given tower size. For the system to operate efficiently at low cost, good quality control of manufactured heliostats is necessary. The performance of the heliostats is vital to the efficient operation of the system, and small distortions in the mirrors can cause significant loss of focus.

In commercial solar power systems, the central receiver tower is high and the heliostats are very large. For these systems, heliostats often comprise multiple flat mirrors, which are individually angled to create an overall concave shape.

An optimal heliostat field needs to be efficient not just in terms of energy collection, but in the cost of materials, fabrication and installation. It needs to have a low energy footprint and be able to be easily transported. To maximise commercial success, particularly in regional areas, it is desirable for the heliostats to be assembled by an itinerant and/or unskilled workforce with minimal equipment.

The present invention endeavours to address these preferences in its different aspects.

Reference to any prior art in the specification is not, and should not be taken as, an acknowledgment or any form of suggestion that this prior art forms part of the common general knowledge in Australia or any other jurisdiction or that this prior art could reasonably be expected to be ascertained, understood and regarded as relevant by a person skilled in the art.

Summary of the invention

In a first aspect the invention provides a parabolic mirror assembly for a heliostat comprising a mirror and a backing support frame for the mirror having elongate frame elements arranged so that the mirror exhibits a shallow concave paraboloid profile, wherein the mirror is secured to the frame elements by an adhesive layer between the frame elements and the mirror, and wherein manufacturing tolerances in the frame and/or mirror are compensated for by variations in the thickness of the adhesive.

Preferably, the layer of adhesive is a substantially continuous layer between the mirror and the backing support frame. The variation in the thickness of the adhesive is preferably at least 0.1 micron, more preferably at least 0.1 mm and most preferably at least 0.5 mm. The average adhesive thickness may be in the range of 0.001 to 1.0mm.

Preferably, the slope error in the mirror is 2.0 milliradians or less, more preferably 1.5 milliradians or less, and most preferably 1.2 milliradians or less.

In its first aspect the invention further provides a heliostat including a parabolic mirror assembly as aforedescribed. The heliostat typically further includes actuator means to effect angular adjustment of the mirror assembly

In a second aspect the present invention provides a method of forming a parabolic mirror assembly for a heliostat, the method including the steps of:

placing a frame within a mould, the mould including recesses for receiving the frame below the mould's upper surface, the upper surface defining a parabolic surface profile;

applying adhesive to the upper surface of the frame, the thickness of the adhesive being greater than the distance between the upper surface of the frame and the upper surface of the mould;

positioning a mirror onto the mould, such that portions of the mirror contact the mould and portions overlying the frame contact the adhesive; and

applying pressure to the mirror such that the mirror bears against the parabolic surface of the mould, such that the adhesive conforms into the gaps to cure, holding the mirror to the frame as a mirror assembly, whereby the mirror adopts the parabolic surface of the mould.

Preferably, an upper mould is placed over the mirror, applying the pressure to clamp the mirror between the lower mould and the upper mould. The upper mould has a parabolic surface profile corresponding to the lower mould.

The present invention also provides, in a third aspect, a mould for forming a parabolic mirror assembly, the mould including:

a mould body having an upper surface defining a parabolic surface profile;

a plurality of recessed portions in the upper surface for receiving a frame below the moulds upper surface, the recessed portions including supporting structure for holding a frame within the recesses;

wherein a mirror can be positioned on top of the mould body, such that the mirror conforms to the parabolic upper surface and adhesive applied between the frame and the mirror cures, whereby the mirror adopts the parabolic surface of the mould.

The lower mould is preferably a female mould, such that the natural sag of the mirror follows the curve of the upper surface profile. The lower mould is advantageously held on a rigid jig assembly, such that it is adjustable to ensure the mould is level prior to use.

Advantageously, the mould profile is created by CNC machining the mould body to a desired parabolic shape.

The mould body may be solid between the recessed portions to create a plurality of spaced faces defining the upper surface. Alternatively, the mould body may be formed from a plurality of upstanding walls defining the edges of the recessed portions, whereby the upper face of the plurality of spaced walls define the upper surface.

There are preferably provided alignment means to ensure components are correctly aligned relative to each other and the mould. The alignment means may be located in the corners of the mould.

The mould may be made from wood such as MDF or balsa, polymer, rigid polyester foam such as Klegecell™, or foamed concrete.

The adhesive is preferably polyurethane, for example Sikaflex™. The adhesive is typically between 3-6mm thick.

Typically a manufactured mirror and frame assembly relaxes its shape after manufacture, shifting to a longer focal length. To counteract this effect, the shape of the moulds is preferably pre-distorted. This may be performed in the CAD program to cut the desired shape, but could also be achieved by shimming between the female mould and the jig table, or by applying loads to the table with adjusting screws. The amount of pre-distortion is preferably in the order 0.5 to 1mm, and is may be applied at five places. The use of pre-distortion advantageously brings the slope error down from around 1milliradian to around 0.5milliradian.

The invention further extends to a parabolic mirror assembly formed by the abovedescribed method wherein manufacturing tolerances in the frame and/or mirror are compensated for by variations in the thickness of the adhesive.

Brief description of the drawings

The invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a representative view of a solar tower system incorporating an array of heliostats;

Figure 2 is a rear perspective view of a heliostat incorporating a parabolic mirror assembly according to an embodiment of the present invention;

Figure 3 is a plan view of the heliostat depicted in Figure 2, viewed parallel to the plane of the frame;

Figure 4 is a rear elevation of the heliostat depicted in Figure 2;

Figure 5 is a side elevation of the heliostat depicted in Figure 2, viewed parallel to the plane of the frame;

Figure 6 is a front view of the heliostat depicted in Figure 2;

Figure 7 is a fragmentary perspective side view of the central hub of the heliostat frame;

Figure 8 is a plan view of a rib of the heliostat frame;

Figure 9 is a top view of a heliostat arm at a first outer left angle;

Figure 10 is a top view of the heliostat arm of Figure 9 at a second outer left angle;

Figure 11 is a top view of the heliostat arm of Figure 9 at a second outer right angle;

Figure 12 is a top view of the heliostat arm of Figure 9 at a first outer right angle;

Figures 13 and 14 are side and front views respectively of the frame support bracket of the heliostat of Figure 2;;

Figure 15a is a top view of the heliostat post including the mount of the frame support bracket;

Figure 15b is a front view of the post of Figure 15a; and

Figure 15c is a side view of the post of Figure 15a;

Figure 16a is a rear view of a parabolic mirror assembly manufactured according to one embodiment of the present invention;

Figure 16b is a cross-sectional end view through line A-A on Figure 16a;

Figure 16c is an enlarged view of the section marked C on Figure 16b;

Figure 17a is a top view of a mirror and frame in a mould during construction according to an embodiment of the present invention;

Figure 17b is a cross-sectional end view through line B-B on Figure 17a;

Figure 17c is a cross-sectional end view through line A-A on Figure 17a;

Figure 18a is a top view of a frame in a mould during construction according to an alternative embodiment of the present invention with the mirror and male mould not shown;

Figure 18b is a cross-sectional end view through line A-A on Figure 18a with the mirror and male mould shown;

Figure 19a is a top view of a frame in a mould during construction according to another alternative embodiment of the present invention with the mirror and male mould not shown;

Figure 19b is a cross-sectional end view through line A-A on Figure 19a with the mirror and male mould shown;

Figure 20 is a perspective view of the frame in the mould of Figure 19a; and

Figure 21 is a cross-section close up view of the frame and mirror in the mould of Figure 19a.

Detailed description of the embodiments

<u>The heliostat array and central receiver system</u>

A concentrating central receiver system 10 is shown in Figure 1 with a close-packed field 18 of two hundred heliostats 15, which each include a mirror 14. These focussing, sun-tracking mirrors 14 are of rectangular shape, typically measuring 2.4m by 1.8m, and have desired focal lengths between 15 and 38 metres. Two hundred heliostats can create a peak of over 500 kW_{th} of solar energy delivered to a central receiver 12 at equinox. The field 18 has been designed for maximum annual energy collection by a receiver aperture of 0.8m diameter at an elevation of 17 metres and an angle of 17° to the horizontal. The average mirror surface error is 3.5mrad and 1mrad tracking error.

The system may be used to produce SolarGas™, which is formed in a natural gas reforming process that stores solar energy in the chemical bonds of the gas. It is also highly suitable for other applications such as high temperature steam production, hydrogen production, spectral beam splitting and materials testing. The SolarGas™ can then be processed into solar hydrogen. This enables solar energy to be stored and transported; this technology serves as a transitional route toward higher levels of solar penetration in the energy mix.

The optical performance of the heliostat field 18 and individual heliostats 15 is fundamental to the overall system. The field 18 includes heliostats 15 that are closely packed together to improve the overall optical efficiency of the field 18. Each heliostat 12 is 2.4m by 1.8m; this relatively small size affording the illustrated solar array over 900m^2 of surface area to concentrate solar energy. The heliostats 15 are located in the field according to their mirror's focal length. The surface of each mirror 14 is slightly curved in order to direct the sun's rays 100 as a directed beam 102 to a focal point on the central receiver 12.

The close packing of the heliostats reduces the footprint of the array, making it adaptable to suburban environments where there is less room available to accommodate larger solar fields.

By using advanced optical models, each mirror has been positioned to take into account the change in seasonal position of the sun, without shadowing the mirror behind it. This has enabled the closest packing of heliostats anywhere in the world known to the applicant.

The system is able to achieve peak temperatures at the downstream reactor of over 1000°C. The field 18 and solar receiver 12 can be operated at lower temperatures by reducing the number of mirrors 14 aimed at the receiver or by controlling the flow rate of the fluid through the receiver.

<u>The heliostats</u>

A suitable heliostat 15 with respective actuators 60, 62 is illustrated in Figures 2 to 6, and certain individual components are further detailed in Figures 7 to 16.

Heliostat 15 includes a large concave mirror 14 fixed by adhesive to a backing frame 20 of rectangular profile. Frame 20 is mounted atop a stand or post 70, by means to be described, and comprises a central hub 23 and ribs 22 that extend radially from central hub 23 to peripheral edge beams 22a. The ribs 22 are pre-manufactured to have a desired shape that provides the frame with particular paraboloid curvature when the frame 20 is assembled. The ribs 22 are fastened to corresponding flat radial arms 25 of hub 23 (see Figure 7). The mirror 14 lies on the concave side. The dimensions of the components are determined by a frame pattern which is generated by software. Fasteners such as thread forming screws, rivets, spot welding or bolted joints are used throughout the frame 20.

The ribs of the frame are manufactured from sheet metal, e.g. galvanised sheet steel, laser cut (or die cut) and folded. The ribs 22 optionally have slots and tabs cut on a front curved face that may be bent by hand. The ribs 22 are shaped into a broad C or channel cross-section that defines a flat web 32 and edge flanges 28, 30: one of these abuts and is adhered to mirror 14. Web 32 tapers outwardly from a wider inner end fastened to a corresponding hub arm 25. The mirror 14 is glued directly to the frame 20 using a polyurethane based adhesive applied to folded tabs 28a on the inner edge flanges 28 of all the ribs 22, which as already noted collectively define a shallow concave paraboloid shape. The mirror is typically made of 3mm thick glass having a high reflectivity surface, such as a plastic composite, and a low iron content to reduce energy absorption. Suitable such glasses include those manufactured by Sencofein or "Miralite Solar Premium" manufactured by Saint Gobain.

The pair of linear screw actuators 60, 62 by which the heliostat orientation is controlled are positioned substantially parallel, so that they both extend generally perpendicular to the mirror 14. This prevents the actuators 60, 62 from colliding during operation whilst giving a greater range of optimal angle to the heliostat 12. The actuators 60, 62 include individual off-the-shelf DC motors 65.

The actuators 60, 62 are arranged to provide control in two orthogonal directions so that the focussing point can be maintained for any angle of incident light. One axis is controlled east to west, i.e. side to side, and the other north to south, i.e. upward tilt. However, one axis is controlled relative to the other axis. Specifically, side-to-side rotation occurs about an intermediate mount in the form of a frame support bracket 66, which is itself rotated up or down: this arrangement minimises the amount of space taken up by each heliostat 12.

The frame 20 is connected to support bracket 66 at vertically spaced hinges 67 for rotation about an upright axis joining hinges 67. The first linear actuator 60 is mounted between the mirror frame 20 and an arm 64 that projects laterally rearwardly from support bracket 66, for controlling this side-to-side or east-west rotational movement. Bracket 66 is pivotally attached in turn, by bracket pin 68 (Figures 15a-15c), to the top of post 70. Pin 68 defines an inclination axis about which the tilt angle of bracket 66, and thereby of frame 20, is adjustable. The aforementioned upright axis is generally orthogonal to the inclination axis. Arm 64 is rigidly connected to the bracket 66 as close to the inclination axis as possible. Second actuator 62 extends between post 70 and an attachment point 69 at the lower end of bracket 66 for effecting adjustment of the tilt or inclination of the mirror.

The angle of the arm 64 to the bracket 66 is selected to provide optimum actuator geometry, with different angles for each heliostat according to positions in the field. The bracket 66 may further include a number of different attachment points 69 for the actuator 62 also selectable to provide the optimum angle according to the individual heliostat's position in the field.

Magnetic sensors are used to measure the respective orientation or positional angles of each heliostat, defined by inclination and lateral orientation or declination.

Methods of forming a paraboloid mirror

The design involves forming a flat sheet of silvered glass mirror 14 into a curved shape. The desired parabolic shape is produced by subjecting the glass to forces in the z-direction. This is achieved by using the curved metal ribs 22 behind the mirror 14 and using an adhesive 34 to connect the mirror 14 to the ribs 22. The mirror will experience induced forces in the positive and negative z-direction and be elastically deformed into a focusing shape.

The design can be accurately assembled to produce a mirror 14 with small slope errors from the desired shape. The design of the frame also means it is more materially efficient than other designs. The design is able to be manufactured simply, easily and reliably.

According to a first method of forming the mirror, as shown in Figures 16a to 16c, where like reference numerals are preceded by a 2, the ribs 222 and frame 220 become the template for the mirror shape. The frame 220 is held on a jig so as to be level and adhesive 234 is applied to the top upper edge folds 228; the mirror 214 is then placed on top of the frame 220 and weight (not shown) is applied to the front surface 215 of the mirror 214. The mirror 214 is held against the ribs 222 of the frame 220 while the adhesive 234 cures. The adhesive 234 once cured is typically 0 to 1.0mm thick using this method.

In this method, the jig is typically a table having at least five legs. Tuning of the jig during the mirror forming process can be achieved by adjusting levelling feet or inserting shims.

The adhesive has a low viscosity and is thixotropic when applied. It cures to form a tough elastomeric compound with properties that are unaltered with 25 years exposure to UV and atmosphere. Suitable adhesives include a range of polyurethane compounds manufactured by Sikaflex™, and commonly used for vehicular and architectural glass bonding.

This first, thin-adhesive method is suitable for assembling mirrors on site in remote areas where there is little manufacturing support and requires simple metrology tools. This method is relatively labour intensive.

A second method is shown in Figures 17a to 17c, where like reference numerals are preceded by a 3. The shape of the mirror 314 is defined by curvature elements of a mould 336. In this method a male mould element 338 is held on a jig 340 and has an upper surface 342 of the desired parabolic shape of the mirror 314. The mirror 314 is draped over the male mould and the natural sag conforms to the shape of the upper surface 342 under its own weight.

Adhesive 334 is then applied to the upper edge folds 328 of the frame 320, which is then placed over the mirror 314. The weight of the frame 320 assists in conforming the mirror to the parabolic shape. When the adhesive is cured, the mirror is permanently affixed to the frame and in the desired parabolic shape. The adhesive in this method is similar to the first method, being 0 to 1.0mm thick.

A third, and preferred method, is shown in Figures 18a, 18b, and in Figures 19a, 19b, 20 where like reference numerals are preceded by a 4. The difference between the embodiment shown in Figures 18a, 18b and Figures 19a, 19b, 20 is that the female mould in Figure 18a is solid, whereas the female mould in Figure 19a is walled with voids 447. The preferred embodiment shown in Figure 19a, 19b, 20 will therefore be described, with that shown in Figures 18a, 18b being equivalent.

A mould 436 includes a mould body, being a female mould element 444 that is held on a jig 440. The female element 444 has an upper surface 442 defining a parabolic surface profile. The female element 444 is made from eight box constructions 446 spaced apart by recessed portions 448. The box constructions 446 are made up of four walls 450 having upper faces 452 that cumulatively create the upper surface 442. The recessed portions 448 form channels in the upper surface and receive the frame 420. Supporting structure 454 is provided so that the frame sits at the optimum level below the mould's upper surface 442. There is therefore a gap 443 in vertical distance created between the upper surface, or upper edge fold 428, of the frame 420 and the upper surface, or upper faces 452, of the mould.

An adhesive 434 is then applied to the upper surface of the frame 420 on upper edge folds 428 at a thickness greater than the gap so to be to, or above, the upper faces 452. The gap is typically 3 to 6mm. A mirror is then positioned on top of the female mould 444, such that its natural sag conforms it to the parabolic upper surface 442 of the female mould 444. Downward pressure is then applied to the front of the mirror 414, typically using a male mould element 438, whereby the adhesive 434 is squeezed to the sides of the mirror and frame until the rear of the mirror contacts against the upper surface 442. It is then held in this position until the adhesive cures and sets, whereby when it is released from the mould the mirror adopts the parabolic surface of the mould. The male mould element 438 may also be made of a box construction having walls 451.

The jig, which is typically a huge table designed to be very rigid, would, for example, be welded up from 100mm x 100mm x 5mm RHS (rectangular hollow section) steel and may include adjustable legs to ensure leveling of the mould for specific locations.

The mould elements are precisely machined to the desired curvature by CNC machines.

The solid mould method shown in Figures 18a and 18b requires a lot of molding material, and would be best suited to a low density material like balsa, rigid polyester foam (Klegecell™), or foamed concrete. The voided mould method shown in Figures 19a, 19b and 20 enables the mold to be made from thick sheets of wood (MDF) or polymer. The result is a much lighter mould, which is faster to machine to create the paraboloid surface.

In the frame/mirror assembly formed by the above methods, manufacturing tolerances in the frame and/or mirror are compensated for by variations in the thickness of the adhesive. For example, the variation in the thickness of the adhesive is at least 0.1 micron, preferably at least 0.1mm and more preferably at least 0.5mm. The average adhesive thickness is preferably in the range 0.001 to 1.0mm. Slope error in the mirror is typically 2.0 milliradians for less, preferably 1.5 milliradians or less, and more preferably 1.2 milliradians or less. Moreover, the layer of adhesive is a substantially continuous layer between the mirror and the backing support frame.

All the various forming methods require alignment means 435, typically in the corners, to ensure that the mirror is correctly aligned with respect to the frame and that the frame is correctly aligned to the mould, so that the subsequent aligning of the mirror results in the correct paraboloid shape.

The preferred method of creating the curvature of the mold shapes is to place the entire assembled jig and mould into a CNC machine, and machine the surface in one operation.

Typically a manufactured mirror and frame assembly relaxes its shape after manufacture, shifting to a longer focal length (with a slight astigmatism for rectangular mirrors). To counteract this effect, the shape of the moulds can be pre-distorted; this is easily performed in the CAD program to cut the desired shape, but could also be achieved by shimming between the female mould and the jig table, or by applying loads to the table with adjusting screws. The amount of pre-distortion is of the order 0.5 to 1mm, and is sufficient to be applied at 5 places only (top, bottom, left, right and centre, as the diagonals are fixed). The use of pre-distortion will typically bring the slope error down from around 1milliradian to around 0.5milliradian.

The jig with the CNC machined mould will typically need to be removed from the CNC machine before gluing can take place. Once in its new location, the jig needs to be securely bolted to the floor, acclimatized to the area, and then be leveled to within +/-0.1mm across the diagonals. Ideally the curvature should be checked again before first use, and regularly thereafter as a quality control measure, using a laser metrology method.

The pressure exerted is some methods may be via elastomeric, dead weight, pneumatic or hydrostatic means, to force the mirror to conform to the desired shape. The parabolic surface that the mould generates needs to be held to an accuracy of the order +/-0.1mm, and the weight of the top and bottom moulds will deflect the jig more than this, so the jig design needs to incorporate this effect, typical effects are observed post-cure, when jigging stresses are relieved, and the edges are below the desired curve and the centre is above the desired curve.

Claims

1. A parabolic mirror assembly for a heliostat comprising a mirror and a backing support frame for the mirror having elongate frame elements arranged so that the mirror exhibits a shallow concave parabloid profile, wherein the mirror is secured to the frame elements by an adhesive layer between the frame elements and the mirror, and wherein manufacturing tolerances in the frame and/or mirror are compensated for by variations in the thickness of the adhesive.

2. A parabolic mirror assembly according to claim 1 wherein said layer of adhesive is a substantially continuous layer between the mirror and the backing support frame.

3. The parabolic mirror assembly according to claim 1 or 2, wherein slope error in the mirror is 2.0 milliradians or less, preferably 1.5 milliradians or less, and more preferably 1.2 milliradians or less.

4. The parabolic mirror assembly according to claim 1, 2 or 3, wherein the variation in the thickness of the adhesive is at least 0.1 micron, preferably at least 0.1 mm and more preferably at least 0.5 mm.

5. The parabolic mirror assembly according to any one of claims 1 to 4 wherein the average adhesive thickness is in the range of 0.001 to 1.0mm.

6. A heliostat including a parabolic mirror assembly according to any one of claims 1 to 5.

7. A heliostat according to claim 6 further including actuator means to effect angular adjustment of the mirror assembly.

8. A method of forming a parabolic mirror assembly for a heliostat, the method including the steps of:

placing a frame within a mould, the mould including recessed portions for receiving the frame below the mould's upper surface, the upper surface defining a parabolic surface profile;

applying adhesive to the upper surface of the frame, the thickness of the adhesive being greater than the distance between the upper surface of the frame and the upper surface of the mould;

positioning a mirror onto the mould, such that portions of the mirror contact the mould and portions overlying the frame contact the adhesive; and

applying pressure to the mirror such that the mirror bears against the parabolic surface of the mould, such that the adhesive conforms into the gaps to cure, holding the mirror to the frame as a mirror assembly, whereby the mirror adopts the parabolic surface of the mould.

9. A method according to claim 8 wherein said application of pressure to the mirror is by placing over the mirror an upper mould that has a parabolic surface profile corresponding to the lower mound, and applying the pressure to clamp the mirror between the lower mount and the upper mould.

10. A method according to claim 8 or 9 wherein the lower mould is a female mould, such that the natural sag of the mirror follows the curve of the upper surface profile.

11. A method according to claim 8, 9 or 10 wherein the lower mould is held on a rigid jig assembly, such that it is adjustable to ensure the mould is level prior to use.

12. A method according to any one of claims 8 to 11 wherein the mould profile is created by CNC machining the mould body to a desired parabolic shape.

13. A method according to any one of claims 8 to 12 wherein the mould has a body that is solid between the recessed portions to create a plurality of spaced faces defining the upper surface.

14. A method according to any one of claims 8 to 13 wherein the mould has a body that comprises a plurality of upstanding walls defining the edges of the recessed portions, whereby the upper faces of the plurality of spaced walls define the upper surface.

15. A method according to any one of claims 8 to 14 including providing alignment means to ensure components are correctly aligned relative to each other and the mould.

16. A method according to any one of claims 8 to 15 wherein the mould is pre-distorted to counteract relaxation of the mirror after manufacture resulting in a longer focal length.

17. A parabolic mirror assembly formed by a method according to any one of claims 8 to 16, wherein manufacturing tolerances in the frame and/or mirror are compensated for by variations in the thickness of the adhesive.

18. A parabolic mirror assembly according to claim 17, wherein said layer of adhesive is a substantially continuous layer between the mirror and the backing support frame.

19. The parabolic mirror assembly according to claim 17 or 18, wherein slope error in the mirror is 2.0 milliradians or less, preferably 1.5 milliradians or less, and more preferably 1.2 milliradians or less.

20. The parabolic mirror assembly according to claim 17, 18 or 19, wherein the variation in the thickness of the adhesive is at least 0.1 micron, preferably at least 0.1 mm and more preferably at least 0.5mm.

21. The parabolic mirror assembly according to any one of claims 17 to 20 wherein the average adhesive thickness is in the range 0.001 to 1.0mm.

22 . A mould for forming a parabolic mirror assembly, the mould including:

a mould body having an upper surface defining a parabolic surface profile; and a plurality of recessed portions in the upper surface for receiving a frame below the mould's upper surface, the recessed portions including supporting structure for holding a frame within the recessed portions;

wherein a mirror can be positioned on top of the mould body, such that the mirror conforms to the parabolic upper surface and adhesive applied between the frame and the mirror cures, whereby the mirror adopts the parabolic surface of the mould.

23. A mould according to claim 22 wherein the lower mould is a female mould, such that the natural sag of the mirror follows the curve of the upper surface profile.

24. A mould according to claim 22 or 23 wherein the mould has a body that is solid between the recessed portions to create a plurality of spaced faces defining the upper surface.

25. A mould according to claim 22 or 23 wherein the mould has a body that comprises a plurality of upstanding walls defining the edges of the recessed portions, whereby the upper faces of the plurality of spaced walls define the upper surface.

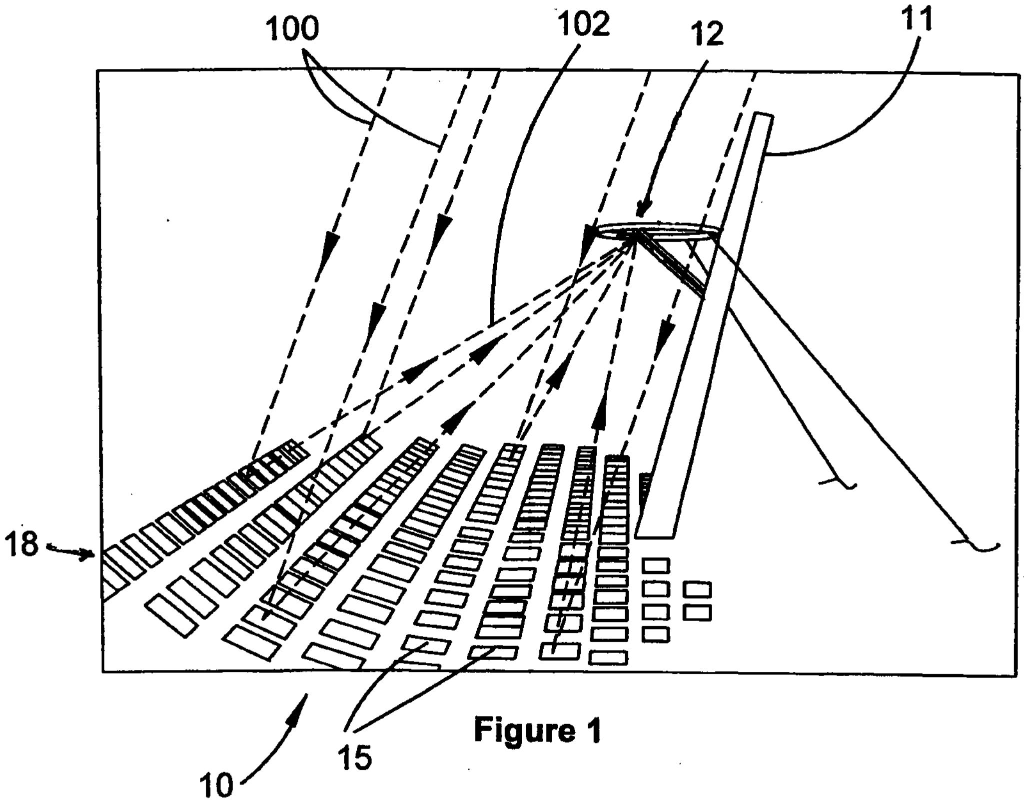

Figure 1

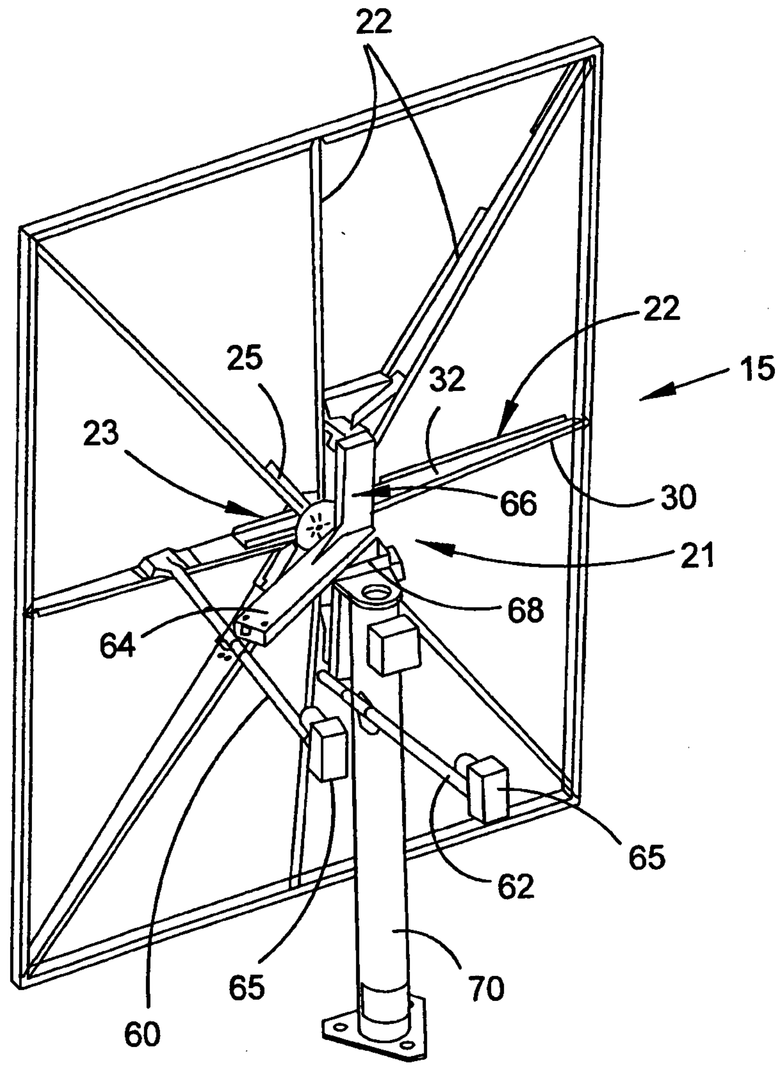

Figure 2

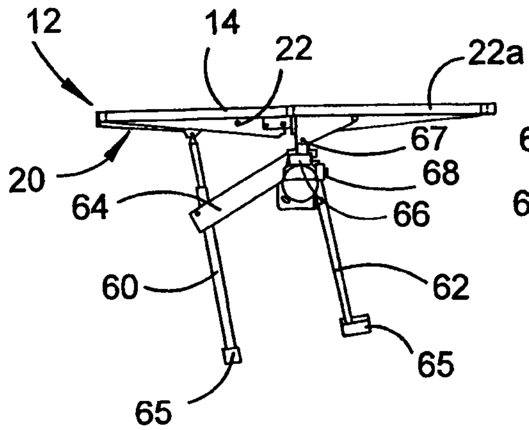

Figure 3

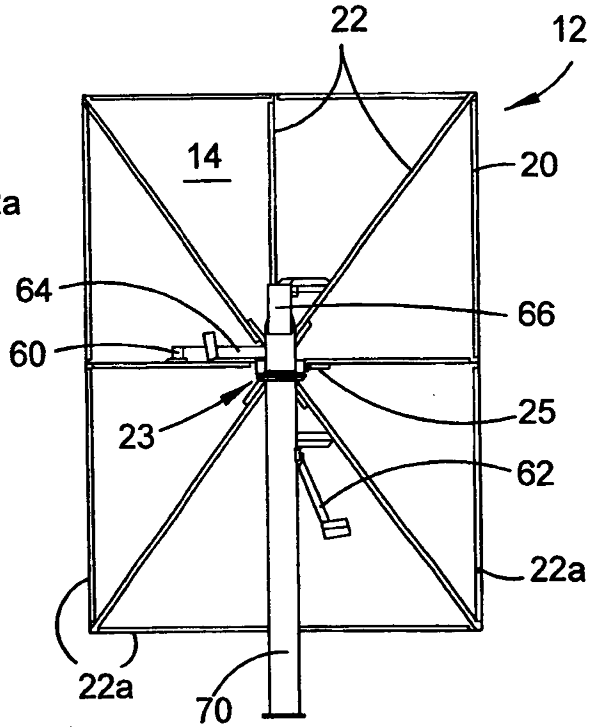

Figure 4

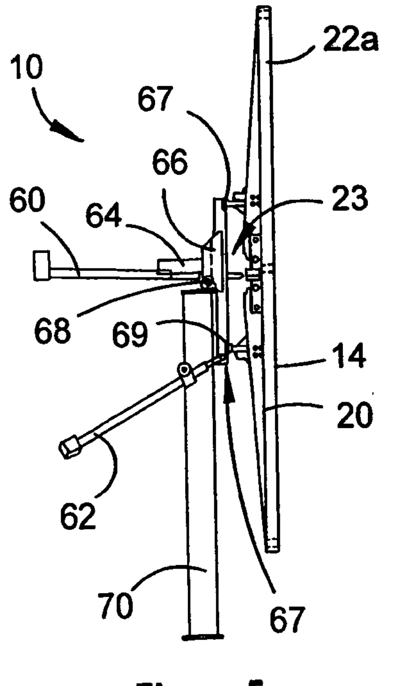

Figure 5

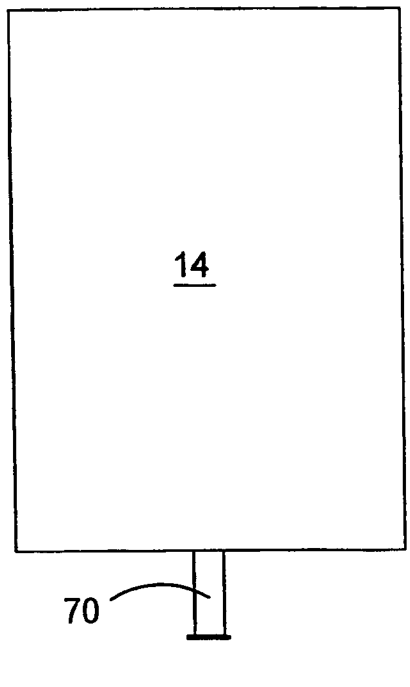

Figure 6

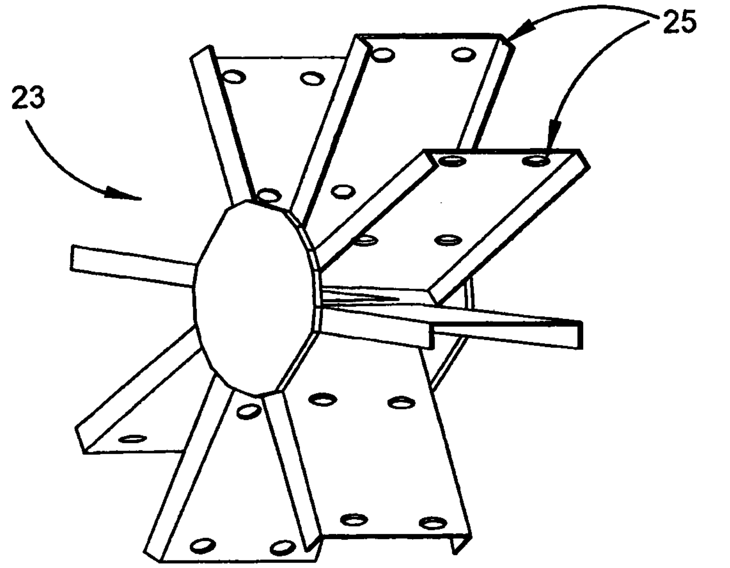

Figure 7

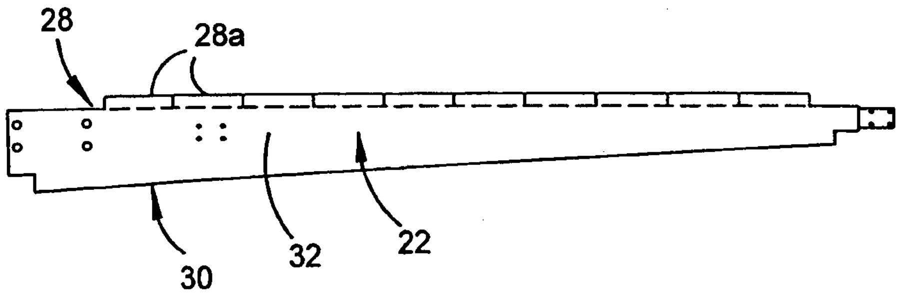

Figure 8

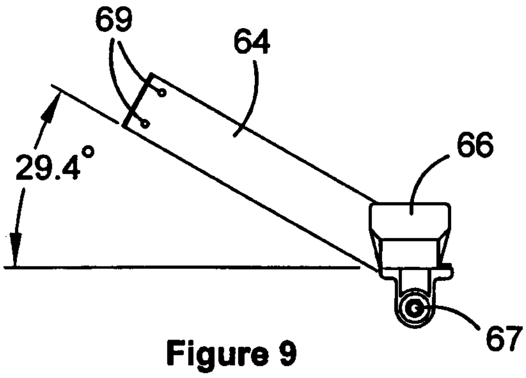

Figure 9

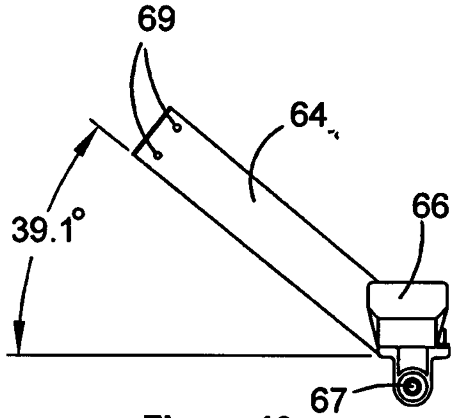

Figure 10

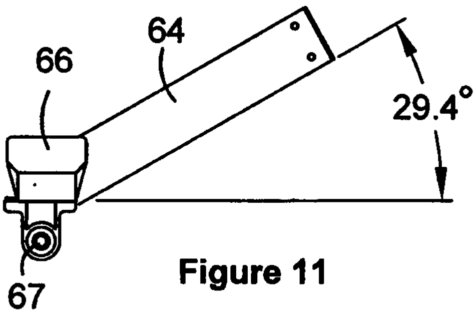

Figure 11

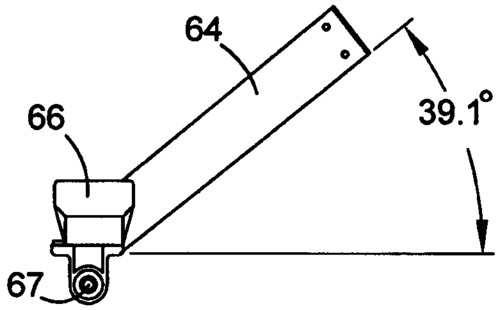

Figure 12

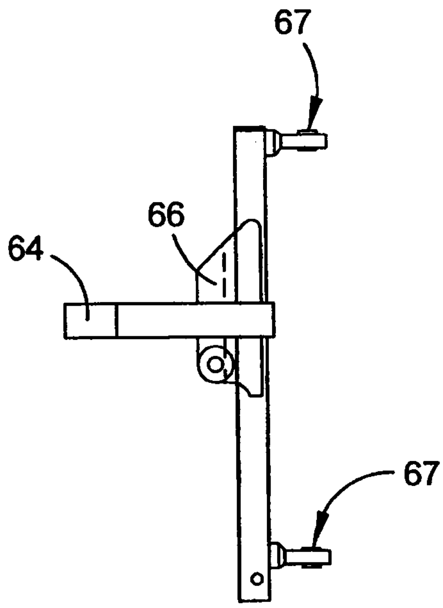

Figure 13

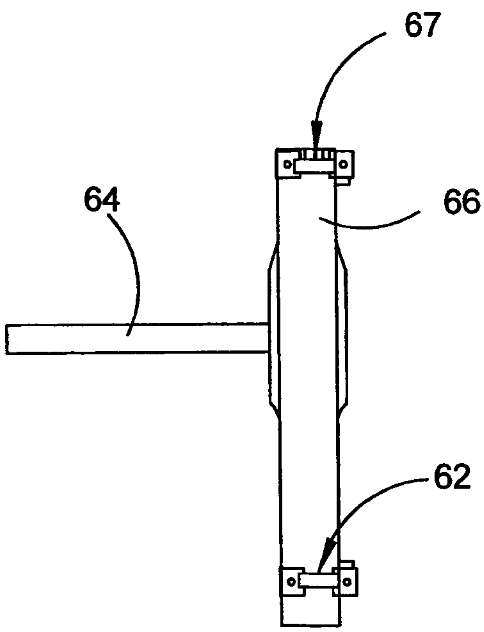

Figure 14

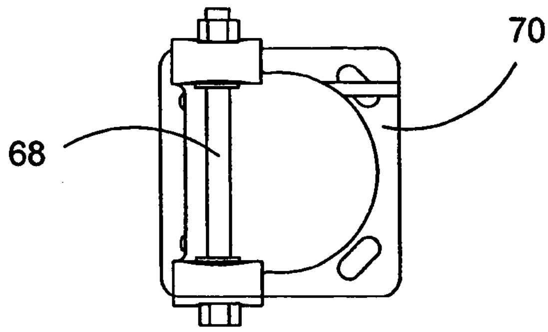

Figure 15a

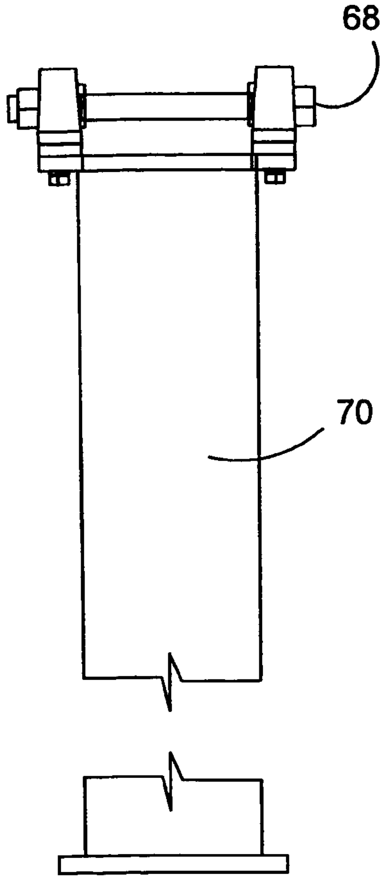

Figure 15b

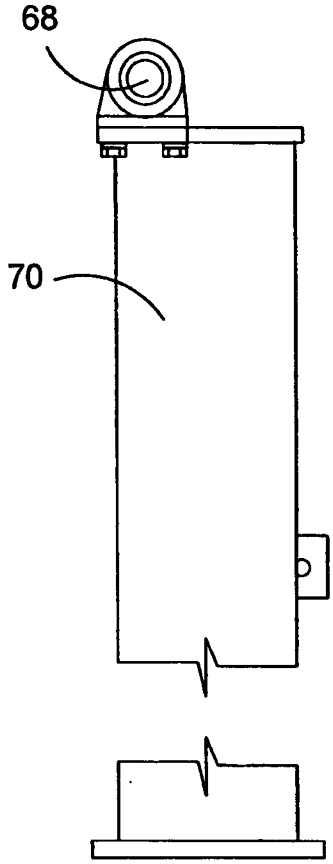

Figure 15c

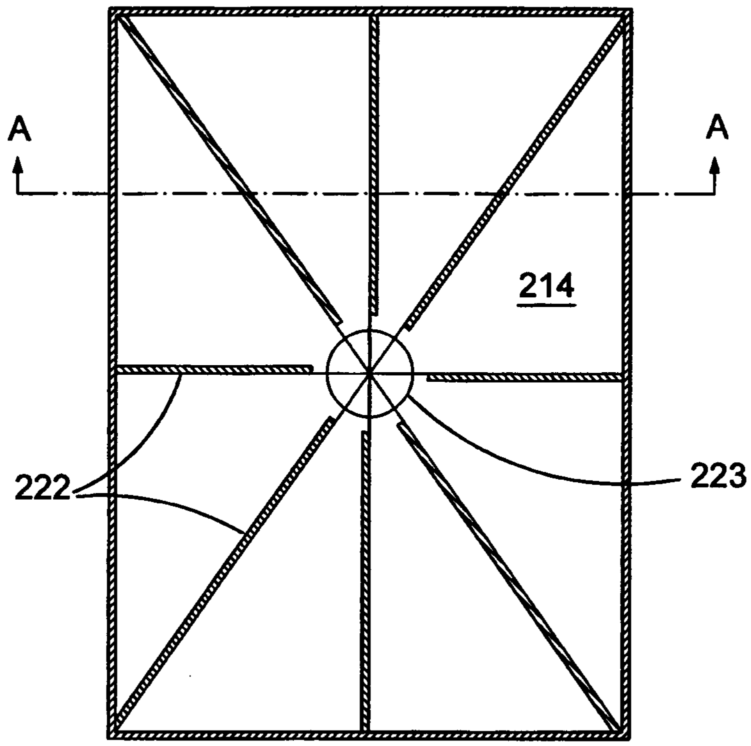

Figure 16a

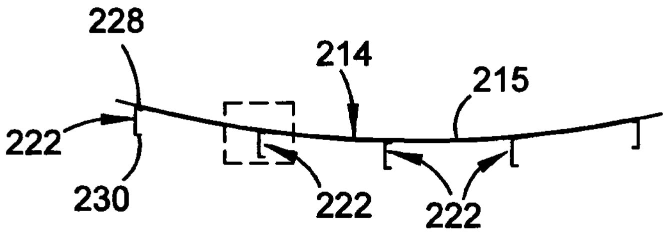

Figure 16b

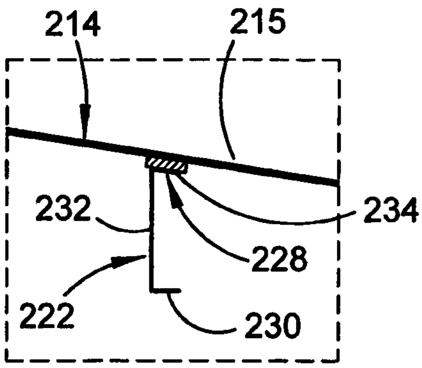

Figure 16c

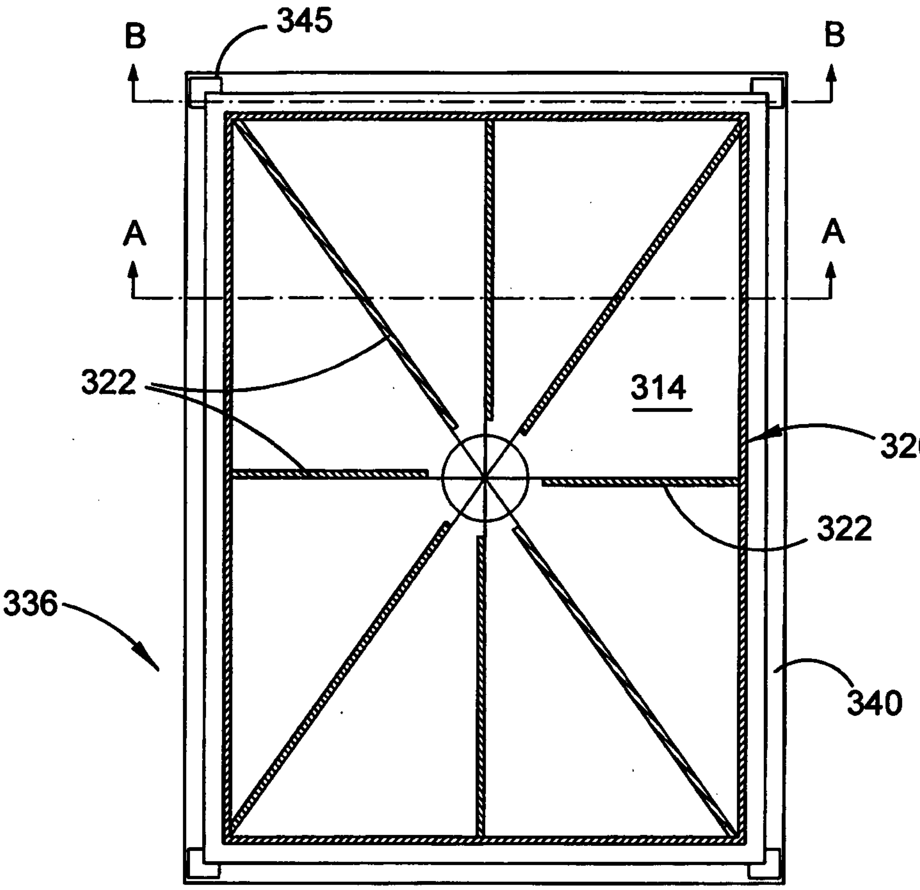

Figure 17a

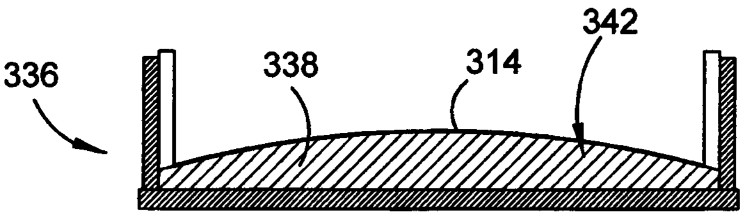

Figure 17b

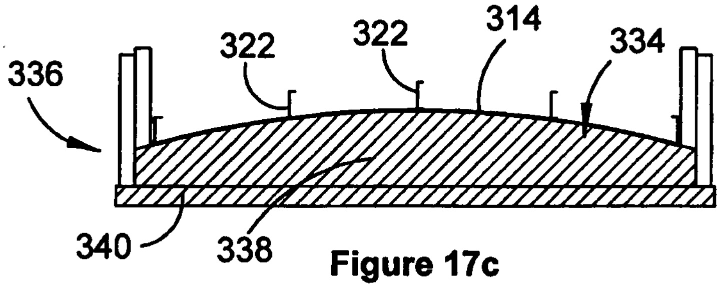

Figure 17c

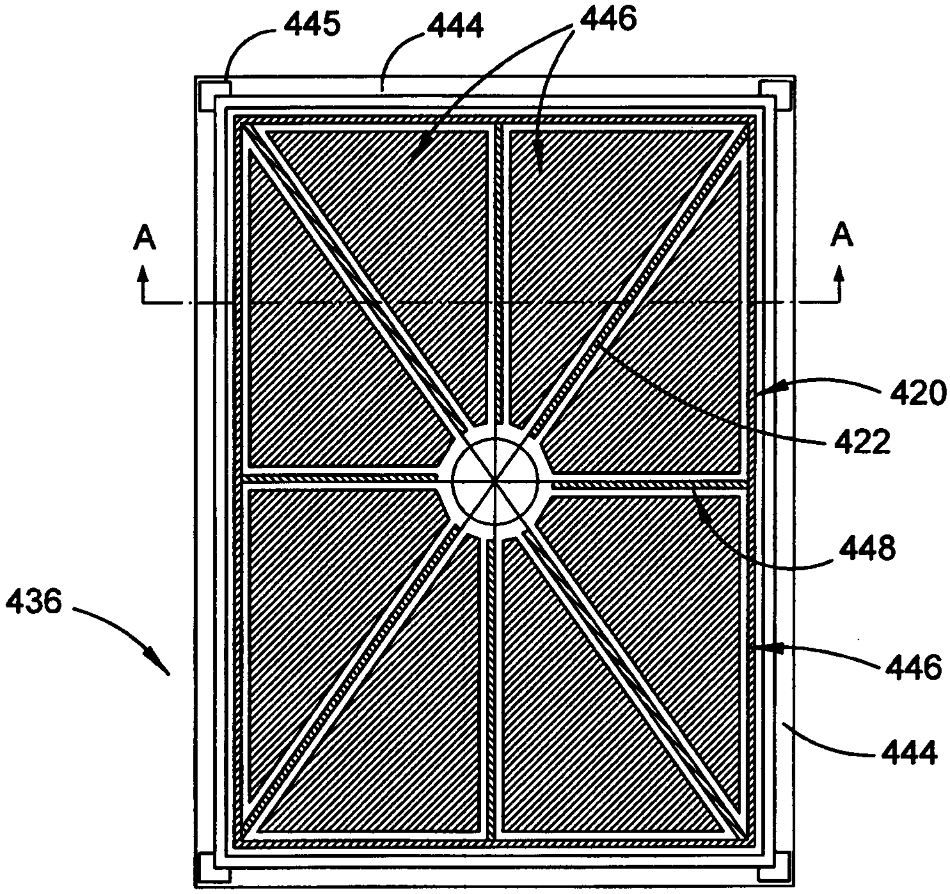

Figure 18a

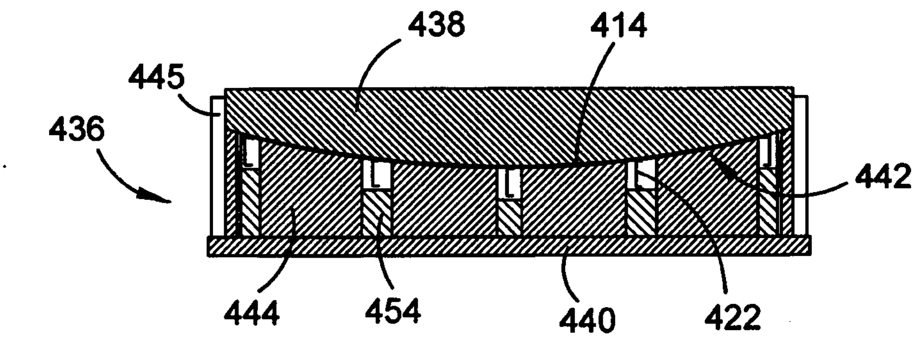

Figure 18b

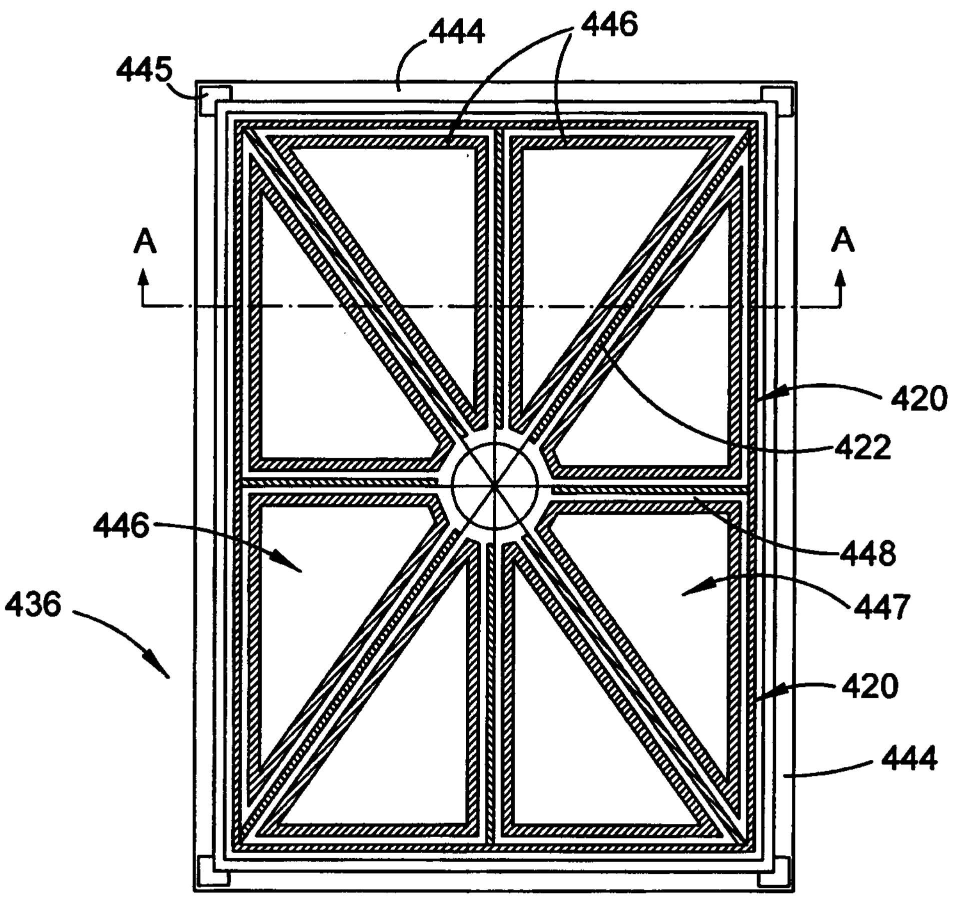

Figure 19a

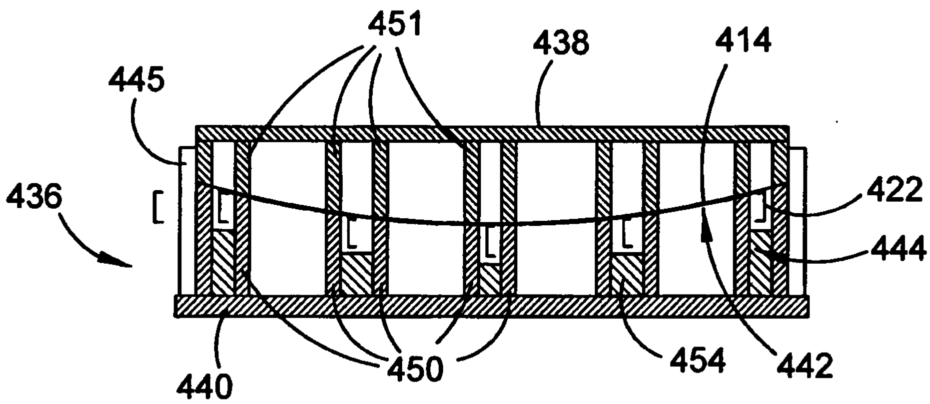

Figure 19b

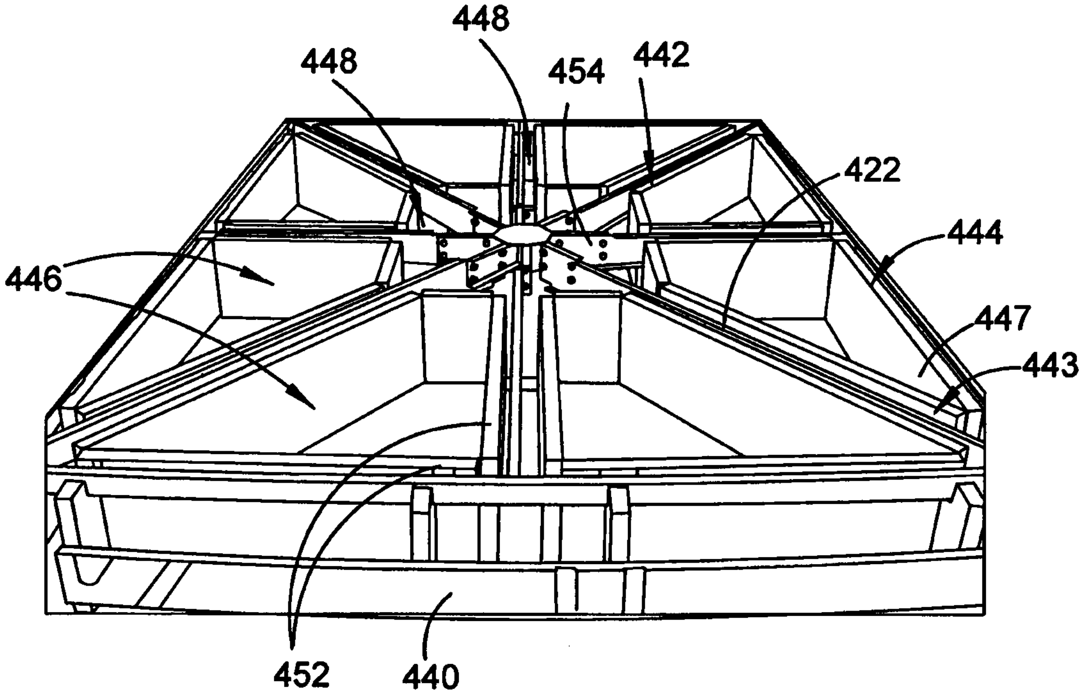

Figure 20

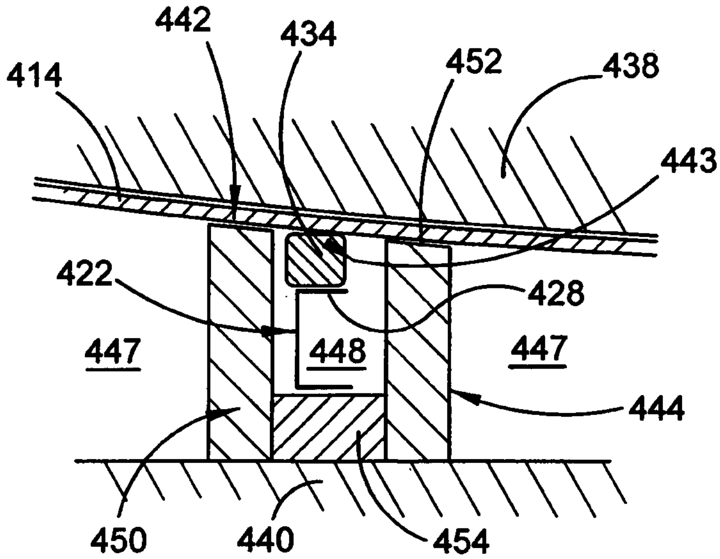

Figure 21

INTERNATIONAL SEARCH REPORT	International application No. **PCT/AU2011/001667**

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

G02B 5/10 (2006.01) ***F24J 2/12*** (2006.01) ***F24J 2/46*** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI and EPODOC: parabolic, paraboloid, curved; mirror, reflector, heliostat; adhesive, glue; frame, support, rib, mount; adhere, attach; tolerance, gap, difference; elongate, tube, rod, bar; recess, void, groove, cavity, channel; mould, jig; AND LIKE TERMS INSPEC: parabolic, curved; mirror, reflector, heliostat; mould; rib, frame, support, mount; adhesive, glue; paraboloid; tolerance, gap, difference; AND LIKE TERMS. Google Scholar: parabolic; mirror; mould; rib; AND LIKE TERMS.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4268332 A (WINDERS) 19 May 1981 column 4 line 39 to column 5 line 18, column 6 lines 29 to 53, column 6 lines 60 to 66, column 7 lines 6 to 10, figures 1 to 2B and 4	17-21
A	Abstract, column 2 line 66 to column 3 line 28, column 3 line 51 to column 8 line 3, figures 1 to 4	1-16, 22-25
A	US 3490405 A (READER, et al.) 20 January 1970 Abstract, column 1 lines 27 to 65, column 2 line 14 to column 3 line 43, figures 1 to 7	1-25
A	US 4124277 A (STANG) 7 November 1978 Abstract, column 1 line 31 to column 2 line 41, column 2 line 67 to column 4 line 63, figures 1 to 6	1-25

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

*	Special categories of cited documents:		
"A"	document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
15 February 2012	20 FEBRUARY 2012
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. +61 2 6283 7999	Authorized officer **RICHARD BAKER** AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No : +61 2 6283 2583

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2009/146511 A1 (WIZARD POWER PTY LTD, et al.) 10 December 2009 Abstract, page 1 paragraph 6 to page 6 paragraph 4, page 8 paragraph 2 to page 19 paragraph 6, figures 1 to 21	1-25

INTERNATIONAL SEARCH REPORT	International application No. PCT/AU2011/001667

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

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

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

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

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

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
[See Supplemental Box]

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

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

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Supplemental Box
(To be used when the space in any of Boxes I to IV is not sufficient)

Continuation of Box No: III

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

This Authority has found that there are different inventions based on the following features that separate the claims into distinct groups:

- Claims 1 to 7 are directed to a parabolic mirror assembly for a heliostat comprising a mirror and a backing support frame for the mirror having elongate frame elements arranged so that the mirror exhibits a shallow concave parabloid profile, wherein the mirror is secured to the frame elements by an adhesive layer between the frame elements and the mirror, and wherein manufacturing tolerances in the frame and/or mirror are compensated for by variations in the thickness of the adhesive. The feature of a parabolic mirror assembly with the above set of features is specific to this group of claims.

- Claims 8 to 16 and 22 to 25 are directed to a method of forming a parabolic mirror assembly for a heliostat and a mould for forming a parabolic mirror assembly that comprises the features of: a mould body having an upper surface defining a parabolic surface profile with a plurality of recessed portions in the upper surface for receiving a frame below the mould's upper surface, applying adhesive to the upper surface of the frame, positioning a mirror onto the mould so that the mirror conforms to the parabolic upper surface of the mould, and also contacts the adhesive, allowing the adhesive to cure, thereby holding the mirror to the frame, whereby the mirror adopts the parabolic surface of the mould. The feature of a method of forming a parabolic mirror assembly for a heliostat and a mould for forming a parabolic mirror assembly with the above combination of features is specific to this group of claims.

- Claims 17 to 21 are directed to a parabolic mirror assembly that comprises a parabolic mirror that is attached to a frame using adhesive, and wherein manufacturing tolerances in the frame and/or mirror are compensated for by variations in the thickness of the adhesive. The feature of a parabolic mirror assembly with the above combination of features is specific to this group of claims.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

When there is no special technical feature common to all the claimed inventions there is no unity of invention.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. The only features common to all of the claimed inventions and which provides a technical relationship among them are a parabolic mirror assembly that comprises a mirror with a parabolic profile which is attached to a frame using adhesive. However these features do not make a contribution over the prior art because they are disclosed in:

US 4268332 A (WINDERS) 19 May 1981
See column 4 line 39 to column 5 line 18, column 6 lines 29 to 38, column 7 lines 6 to 10, figures 1 to 2B and 4.

Therefore in the light of this document this common feature cannot be a special technical feature. Therefore there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied *a posteriori*.

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	4268332	NONE					
US	3490405	US	3541825				
US	4124277	NONE					
WO	2009146511	AU	2009253860	CN	102099637	EP	2315981
		US	2011242689				

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX