

- 1 -

SOLAR ENERGY REFLECTOR ARRAYField of the Invention

This invention relates to a solar energy reflector
5 array that incorporates a plurality of heliostats and to a
heliostat for use in the array. In the context of the
specification the term "heliostat" is to be understood as
meaning a device which is arranged to reflect incident
solar radiation to a target (which may change from time-
10 to-time) and to be driven to follow relative movement of
the sun.

Background of the Invention

Solar arrays, including so-called multi-tower solar
15 arrays have been proposed and in some cases developed for
reflecting toward one or more target collectors solar
radiation that falls incident on heliostats within the
arrays. Various array arrangements have been proposed for
minimising mutual blocking and shading of heliostats in
20 order to maximise reflection and, hence, concentration of
incoming solar radiation. In this context, reference may
be made to International Patent Applications

PCT/AU96/00177 and PCT/AU97/00864 dated 28 March 1996 and
19 December 1997 respectively, and to the following two
25 publications:

Multi-Tower Solar Array (MTSA) with Ganged Heliostats;
Mills, D. R. and Schramek, P. - 9th International Symposium
on Solar Thermal Concentrating Technologies, Solar Paces,
Font-Romeu France, June 1998.

30 Potential of the Heliostat Field of a Multi-Tower Solar
Array; Schramek, P. and Mills, D.R. - 10th International
Symposium on Solar Thermal Concentrating Technologies,
Solar Paces, Sydney, Australia, March 2000.

- 2 -

In order to achieve optimum ground area utilisation, heliostats within a solar array must be arranged and constructed to facilitate closely-spaced positioning of the heliostats and, at the same time, to permit non-interfering relative movement of adjacent ones of the heliostats. This latter requirement applies particularly in multi-tower solar arrays, in which adjacent heliostats may be required to reflect incident radiation to different tower mounted collectors and in which any one heliostat may need be actuated to change its orientation from one collector to another. Also, in the interest of maximising drive efficiency and minimising capital costs, it is required that the heliostats be arranged and constructed to facilitate ganging of the heliostats and employment of common drive arrangements for groups of the heliostats within an array. The meeting of these requirements is assisted by the fact that, except in those instances when a heliostat is to be re-orientated, the heliostats collectively need only be moved in dependence on the movement of the sun. That is, whereas the orientations of the heliostats would normally be different from one another, depending upon their positions relative to the target collector(s), all heliostats would be driven to turn through the same angle $d\phi_H = d\phi_S/2$ in the same direction, where $d\phi_H$ is the change in angle of the reflectors of the heliostats and $d\phi_S$ is the change in angle of incident radiation. However, even when allowing for this convenience, difficulties have been experienced in designing arrangements that facilitate non-interfering close spacing of heliostats, as well as economical drive arrangements, for the very large number of heliostats that must be provided in any array that might serve to reflect

- 3 -

a useful level of solar energy to associated target collectors.

Summary of the Invention

5 The present invention is directed to a heliostat which is suitable for positioning within an array and which, in a preferred form, is arranged to meet the above-mentioned requirements.

 Broadly defined, the present invention provides a
10 heliostat which comprises:

 a reflector element,

 a carrier that is arranged to support the reflector element above a ground plane,

 a drive means arranged in use to impart pivotal drive
15 to the carrier about a fixed, first axis that is, in use of the heliostat, disposed substantially parallel to the ground plane,

 means mounting the reflector element to the carrier in a manner which permits pivotal movement of the
20 reflector element with respect to the carrier and about a second axis that is not parallel to the first axis, and

 a drive means arranged in use to impart pivotal movement to the reflector element about the second axis.

 The drive means that is arranged to impart pivotal
25 motion of the carrier preferably comprises a first drive means and the drive means that is arranged to impart pivotal movement to the reflector element preferably comprise a second drive means which is separate from the first drive means.

30 The reflector element, which may be flat or curved, may be constituted by a plurality of sub-reflector elements. Also, a plurality of the reflector elements may be supported by a single carrier. However, in order to

- 4 -

gain the full benefit of the invention with the latter arrangement, the plural reflector elements would need to be mounted to the carrier by way of non-parallel second axes.

5 The heliostat may be employed in large scale arrays, such as those that occupy ground areas in the order of 100 hectares, or in relatively small arrays such as may be located on the tops of buildings or in other confined spaces. Thus, the term "ground plane" as used in this
10 specification should be understood as designating a notional (horizontal or inclined) plane above which the heliostats are located. In the case of a large scale array, the ground plane will comprise the ground area that is occupied by the heliostats, but it should be understood
15 that the ground area of itself need not be planar. Topographical variations in the ground area may be accommodated by positional adjustment of individual ones of the reflector elements relative to one another. Also, at least a portion of the ground area that is occupied by
20 the heliostats may form a part of a hill and so be inclined to the horizontal.

With the foregoing in mind, the present invention may be defined further as providing a solar energy reflector array which comprises a plurality of the above defined
25 heliostats located in rows and arranged to reflect incident solar radiation to at least one target collector. The carriers of at least some of the heliostats in each row of the array preferably are coupled to one another, and the reflector elements of at least some of the
30 heliostats in each row of the array preferably are coupled to one another.

Thus, in the preferred arrangement, each of the first and second drive means may be employed to impart pivotal

- 5 -

motion to a plurality of the heliostats, and control of the drive means may be shared for a large number of the heliostats within an array. This is important in terms of capital cost savings to be obtained in large area arrays.

5 Common drive control is made possible by the potential for ganging a large number of the heliostats and this in turn is facilitated by the pivotal mounting of the reflector element of each heliostat to its pivotally mounted carrier. This also facilitates close spacing of
10 the heliostats within an array, even with relative movement occurring between adjacent reflector elements.

The target collector or, in the case of multi-tower solar arrays, the target collectors may comprise any type of collector that is capable of receiving solar energy and
15 converting it to another form of energy. For example, each target collector may comprise a bank of solar absorptive collector elements through which a heat exchange fluid is passed. Alternatively, in a smaller scale system, the target collector may comprise an array
20 of photo-voltaic cells.

Preferred Features of the Invention

The reflector element of the heliostat preferably comprises a glass mirror that is pivotally mounted to the
25 carrier. Also, the second axis about which the reflector element is pivotally mounted to the carrier preferably is disposed orthogonally with respect to the first axis. Thus, in the preferred arrangement, the carrier is mounted for pivotal movement about a fixed, first axis that is
30 disposed parallel to the ground plane and the reflector element is mounted to the carrier for pivotal movement about a second axis that is orthogonal to the first axis.

- 6 -

The reflector element of the heliostat preferably has a polygonal shape and, in order to achieve maximised ground coverage, most preferably is mounted to the carrier in a manner such that the second axis lies in a line that passes through two most distant points on the periphery of the reflector element. The reflector element may, for example, have a square form, in which case the second axis preferably will lie in the line of a diagonal of the reflector element. As a further alternative, the reflector element may (and preferably will) have an hexagonal form. In this case, the second axis will lie in a line that intersects oppositely disposed angles of the hexagon and preferably will pass through two most distant points.

The reflector element most preferably has an hexagonal form comprising three pairs of substantially parallel sides. In this case the hexagon may notionally be divided into a rectangular central portion and two triangular end portions.

The sides of the hexagonal configuration are most preferably proportioned such that arcs of an imaginary circle that passes through the four corners of the rectangular portion will lie wholly within the triangular end portions and, in the limiting condition, will lie tangential to two adjacent sides of each of the triangular portions. It has been determined that the use of a plurality of such reflectors permits up to 100% ground coverage.

The first drive means preferably includes a drive shaft that is supported for rotation about an axis that lies parallel to the first axis and which is arranged to impart rotary drive to the heliostat carrier. When a plurality of heliostats is located in an array, the

- 7 -

carrier of at least some of the heliostats in each row of the array may be coupled together by a common such drive shaft. Also, the first drive means preferably incorporates a single motor for imparting drive to a plurality of the drive shafts in an array of the heliostats. Furthermore, in the case of a relatively small array, a single motor most preferably will be employed to impart drive to all of the drive shafts in the heliostat array.

10 The second drive means preferably includes a drive member which is connected to the rear (non-reflecting) side of the reflector element of the heliostat and which is arranged to be driven in a manner to impart pivotal movement to the reflector element about the second axis.

15 Also, the drive member preferably is connected to the rear side of the reflector element by way of a lockable ball joint (or other universal joint) to permit positional adjustment of the reflector element relative to the drive member. This arrangement permits adjacent reflector

20 elements to be positioned individually during the setting-up of an array of the heliostats and permits the drive members within a given row of heliostats to be positioned parallel to one another, regardless of the relative angular positions of adjacent reflector elements within

25 the array.

 A plurality of the reflector elements within a given row of an array of the heliostats preferably is coupled together by connecting respective ones of the drive members to a common motion translating mechanism which

30 forms a part of the second drive means. Ganged motion translation may then be imparted to the plural drive members by either adjusting the length of the drive members or adjusting the operating plane of the motion

- 8 -

translating mechanism to accommodate angular travel of the drive members.

The carrier for the reflector element of the heliostat preferably has an arcuate shape and is connected
5 at each of its ends to the rear side of the reflector element. The carrier most preferably has a semi-circular shape and, in both cases, will have its centre of radius coincident with the geometric centre of the reflecting surface of the reflector element.

10 The invention will be more fully understood from the following description of a preferred embodiment of a heliostat and a heliostat array. The description is provided with reference to the accompanying drawings.

15 Brief Description of the Drawings

In the drawings:

Figure 1 shows a diagrammatic representation of a rectangular reflector element mounted to a carrier,

20 Figure 2 shows a plan view of a portion of an array of square reflector elements,

Figure 3 shows a plan view of a portion of an array of hexagonal reflector elements,

25 Figure 4 shows diagrammatically a side view of a heliostat having a single reflector element mounted to an arcuate carrier,

Figure 5 shows a single row of the heliostats and, diagrammatically, first and second drive means for imparting pivotal movement to the carriers and reflector elements of the heliostats,

30 Figure 6 illustrates an array composed of plural rows of the heliostats shown in Figure 5,

Figures 7 and 8 show alternative ways of translating motion to a reflector element of a single heliostat, to

- 9 -

effect pivoting of the reflector element with respect to its carrier,

Figure 9 shows diagrammatically the mounting of one reflector element to a reduced size carrier, and

5 Figure 10 shows three, alternative, preferred geometric configurations of the reflector elements.

Detailed Description of Embodiments of the Invention

Figure 1 shows in plan a diagrammatic representation
10 of a heliostat that has a rectangular reflector element 10 which is supported within a carrier 11 in the form of a rectangular frame 12. The carrier 11 functions to support the reflector element above a ground plane 13 (as shown in Figure 4) and the carrier is itself pivotally mounted to a
15 support structure 14. The pivot axis 15 for the carrier (herein referred to as the "first axis") is fixed and lies parallel to the ground plane 13.

The reflector element 10 is pivotally mounted to the carrier 11 about a pivot axis 16 (herein referred to as
20 the "second axis") that is orthogonally disposed with respect to the first axis 15. Thus, the reflector element 10 may be regarded as being supported in a gymbal mounting such that the carrier 11 and the supported reflector element may be turned about the first, fixed axis 15
25 whilst the reflector element is independently pivotable, relative to the carrier, about the second axis 16. As a development of this arrangement it may be shown that a heliostat array may be constructed to provide optimised ground coverage if:

30 1. the first axis 15 is disposed in fixed, parallel relationship to the ground plane 13,

- 10 -

2. the second axis 16 lies in a line that passes through the most distant points of the reflector element 10, and
3. the reflector element 10 has a shape that
5 permits close packing of the heliostats.

The second criterion is not met in the case of the arrangement shown in Figure 1, to the extent that the second axis 16 does not pass through the diagonal of the rectangle. Also, it will be established later in this
10 specification that the third criterion may best be met by the employment of hexagonal reflectors having specifically defined geometrical forms.

Figures 2 and 3 do show arrangements that are superior to that shown in Figure 1, in that Figure 2 shows
15 an array of square reflector elements 10 which are pivotably mounted to respective carriers 11 by way of second axes 16 that pass through diagonals of the squares. Similarly, Figure 3 shows an array of hexagonal reflector elements 10 which are pivotably mounted to respective
20 carriers 11 by way of second axes 16 that pass through opposing angles of the hexagons.

However in the arrangements shown in Figures 2 and 3, at least some of the carriers 11 may shade the reflectors from incident solar radiation under certain inclinations
25 of the carriers and/or the reflector elements within the carriers. This will reduce the performance of the array and it will be necessary to separate at least some of the heliostats within the array and thereby reduce the effective ground coverage. Moreover, the carriers may
30 themselves preclude an arrangement that provides for optimum ground coverage.

These problems may be avoided by adopting the carrier arrangement as shown diagrammatically in Figures 4 to 6.

- 11 -

As illustrated in Figures 4 to 6, the carrier 11 extends rearwardly from the reflector element 10 and has an arcuate or, more specifically, a semi-circular shape. The radius centre 17 of the carrier is coincident with the
5 geometric centre of the reflecting surface of the reflector element and is aligned with the first axis 15. End portions 18 of the carrier are connected to the reflector element by bearing-supported axles (not shown) that are positioned coincidentally with the second axis
10 16.

Although it is shown in a diagrammatic way, the carrier 11 would normally be fabricated as a metal or plastics material frame and be mounted upon a supporting structure 19 to position the reflector element 10 at a
15 required height above the ground plane 13.

The carrier 11 is supported upon idler rollers 20 that accommodate rotary motion of the carrier about the radius centre 17, and a drive shaft 21 is provided for imparting rotary drive to the carrier by way of a geared
20 connection (not shown) between the drive shaft and the carrier. The axis of the drive shaft 21 lies parallel with the first axis 15 and, also not shown, the drive shaft 21 is coupled to an electric or hydraulic motor which is energised when required to impart turning motion
25 to the reflector element 10 about the first axis.

A drive member 22 is connected to the rear side of the reflector element 10 by way of a lockable ball joint (not shown), so that the reflector element may initially be orientated in a required direction relative to the
30 drive member 22. A linearly movable motion translating mechanism 23 (see Figures 5 and 6) is employed to impart pivotal movement to the drive member 22 and, so, to effect

- 12 -

pivoting of the reflector element 10 about the second axis 16.

Figure 5 of the drawings shows a plurality of carrier-mounted reflector elements positioned in a row, and Figure 6 shows a number of the rows located within a small array of heliostats. In each case the heliostats within each row are coupled together by a single drive shaft 21. Also, the plurality of parallel drive members 22 that extend rearwardly from the respective reflector elements 10 are coupled together in each row by a single motion translating shaft 23.

Figures 7 and 8 show alternative ways of translating motion to the reflector element 10 of a single heliostat, to effect pivoting of the reflector element about the second axis 16 with respect to the carrier 11. Given that the drive member 22 will change its effective length (in a vertical direction) as it pivots to effect turning of the reflector element 10, provision needs to be made to maintain the coupling between the drive member 22 and the motion translating shaft 23. This may be achieved as shown in Figure 8, by making the drive member telescopic or, as shown in Figure 7, by raising and lowering the motion translating shaft 23 with application of pivoting drive to the drive member 22.

Although the carrier 11 has been illustrated in most of the figures as having a length between its end portions 18 that corresponds with the length of the major axis of the reflector element 10, in the interest of avoiding shading between adjacent heliostats, the carrier 11 may beneficially be made with a smaller dimension. This is illustrated in Figure 9 and it will be understood that with this change in dimension, special arrangements may

- 13 -

need to be made to facilitate application of drive to the drive members 22.

As indicated previously, the reflector element 10 should be shaped in a manner to permit optimum, close
5 packing of the heliostats. This may be achieved by forming the reflector element in one or other of the (generalised) ways indicated in Figures 10A, B and C. In each case the reflector element 10 has an hexagonal configuration comprising three pairs of parallel sides and
10 as a consequence four sides 24 having equal length. Also, in each case, the major diagonal a has a length that is greater than that of the distance b between two opposing sides 25 of each element. The sides of the hexagonal configuration are proportioned such that arcs 27 of an
15 imaginary circle that passes through the four corners of the rectangular portion lie wholly within the triangular end portions 26 and, in the limiting condition, lie tangential to two adjacent sides of each of the triangular portions. In this case the proportions of the hexagon
20 satisfy the criteria

$$\underline{a} \geq \underline{c} + \underline{b}^2/\underline{c} \quad \text{Eq.1}$$

wherein in any one case c corresponds to the length of
25 each side 25. It has been determined that in an array of closely spaced reflectors with each of the reflectors proportioned such that Eq.1 is satisfied, collision of the reflectors can be avoided when the heliostats are driven. As a consequence such an array facilitates up to 100%
30 ground coverage even when the reflectors are closely spaced.

- 14 -

It is to be understood that, the references that are made to prior art documents

- PCT/AU96/00177 dated 28 March 1996,
- and PCT/AU97/00864 dated 19 December 1997,
- 5 • *Multi-Tower Solar Array (MTSA) with Ganged Heliostats*, Mills, D. R. and Schramek, P. - 9th International Symposium on Solar Thermal Concentrating Technologies, Solar Paces, Font-Romeu France, June 1998, and
- 10 • *Potential of the Heliostat Field of a Multi-Tower Solar Array*, Schramek, P. and Mills, D.R. - 10th International Symposium on Solar Thermal Concentrating Technologies, Solar Paces, Sydney, Australia, March 2000,
- 15 do not constitute an admission that these prior art documents form a part of the common general knowledge in the art, in Australia or any other country.

Variations and modifications may be made in the
20 invention as above described and as defined in the following statements of claim.

- 15 -

THE CLAIMS:

1. A heliostat which comprises:
a reflector element,
5 a carrier that is arranged to support the reflector element above a ground plane,
a drive means arranged in use to impart pivotal drive to the carrier about a fixed, first axis that is, in use of the heliostat, disposed substantially parallel to the
10 ground plane,
means mounting the reflector element to the carrier in a manner which permits pivotal movement of the reflector element with respect to the carrier and about a second axis that is not parallel to the first axis, and
15 a drive means arranged in use to impart pivotal movement to the reflector element about the second axis.
2. The heliostat as claimed in claim 1 wherein the drive means that is arranged to impart pivotal motion of the
20 carrier comprises a first drive means and wherein the drive means that is arranged to impart pivotal movement to the reflector element comprises a second drive means which is separate from the first drive means.
- 25 3. The heliostat as claimed in claim 1 or 2 wherein the reflector element comprises a glass mirror.
4. The heliostat as claimed in claim 1 or claim 2 wherein the reflector element comprises a metallic mirror.
30
5. The heliostat as claimed in any one of the preceding claims wherein the second axis about which the reflector

- 16 -

element is pivotally mounted to the carrier is disposed orthogonally with respect to the first axis.

6. The heliostat as claimed in any one of the preceding
5 claims wherein the reflector element has a polygonal shape.

7. The heliostat as claimed in any one of the preceding
10 claims wherein the reflector element is mounted to the carrier in a manner such that the second axis lies in a line that passes through two most distant points on the periphery of the reflector element.

8. The heliostat as claimed in claim 6 wherein the
15 reflector element has a hexagonal form.

9. The heliostat as claimed in claim 8 wherein the
hexagonal form of the reflector element comprises three
pairs of substantially parallel sides embracing a central
20 rectangular portion and two triangular end portions.

10. The heliostat as claimed in claim 9 wherein the sides
of the hexagonal configuration are proportioned such that
arcs of an imaginary circle that passes through the four
25 corners of the rectangular portion will lie wholly within the triangular end portions and, in the limiting condition, will lie tangential to two adjacent sides of each of the triangular portions.

30 11. The heliostat as claimed in any one of the claims 2 to 10 wherein the first drive means includes a drive shaft that is supported for rotation about an axis that lies

- 17 -

parallel to the first axis and which is arranged to impart rotary drive to the heliostat carrier.

12. The heliostat as claimed in any one of the claims 2
5 to 11 wherein the second drive means includes a drive member which is connected to the rear (non-reflecting) side of the reflector element of the heliostat and which is arranged to be driven in a manner to impart pivotal movement to the reflector element about the second axis.

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13. The heliostat as claimed in claim 12 wherein the drive member is connected to the rear side of the reflector element by way of an adjustable joint.

15 14. The heliostat as claimed in any one of the preceding claims wherein the carrier for the reflector element of the heliostat has an arcuate shape and is connected at each of its ends of the reflector element.

20 15. The heliostat as claimed in any one of the preceding claims wherein the carrier has a semi-circular shape and has its centre of radius coincident with the geometric centre of the reflecting surface of the reflector element.

25 16. The heliostat as claimed in any one of the preceding claims wherein the reflector element has a flat reflecting surface.

17. The heliostat as claimed in any one of the claims 1
30 to 15 wherein the reflector element has a curved reflecting surface.

- 18 -

18. A solar energy reflector array comprising a plurality of heliostats as claimed in any one of the preceding claims and wherein the heliostats are arranged in rows to reflect incident solar radiation to at least one target
5 collector.

19. The solar energy reflector array as claimed in claim 18 when dependant on claim 11 wherein the carriers of at least some of the heliostats in each row of the array are
10 coupled together by a common said drive shaft.

20. The solar energy reflector array as claimed in claim 19 wherein at least some of the first drive means incorporate a single motor for imparting drive to a
15 plurality of the drive shafts.

21. The solar energy reflector array as claimed in claim 19 wherein a single motor is employed to impart drive to all of the drive shafts in the heliostat array.
20

22. The solar energy reflector array as claimed in any one of claims 18 to 21 wherein a plurality of the reflector elements within a given row of the array is coupled together by connecting respective ones of the
25 drive members to a common motion translating mechanism which forms a part of the second drive means.

23. The solar energy reflector array as claimed in claim 22 wherein means are provided for adjusting the length of the drive members whereby ganged motion translation may be
30 imparted to the plural drive members by adjusting the length of the drive members.

- 19 -

24. The solar energy reflector array as claimed in claim
22 wherein means are provided for adjusting the length of
the drive members whereby ganged motion translation is
imparted to the plural drive members by adjusting the
5 operating plane of the motion translating mechanism to
accommodate angular travel of the drive members.