



(43) International Publication Date
27 September 2012 (27.09.2012)

- (51) International Patent Classification: Not classified
- (21) International Application Number: PCT/US2012/025832
- (22) International Filing Date: 20 February 2012 (20.02.2012)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data: 61/445,518 22 February 2011 (22.02.2011) US
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- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,

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(54) Title: CONCENTRATING SOLAR POWER WITH GLASSHOUSES

(57) Abstract: A protective transparent enclosure, such as a greenhouse, encloses a concentrated solar power system having line-focus solar energy concentrators. The line-focus solar energy concentrators have a reflective front layer, a core layer, and a rear layer. The core and the rear layers, when bonded with the reflective front layer, enable the line-focus solar energy concentrator, in some embodiments, to retain a particular form without additional strengthening elements. In some embodiments, the core layer is a honeycomb layer. In some embodiments, the core layer and/or the rear layer are formed by removing material from a single piece of material.

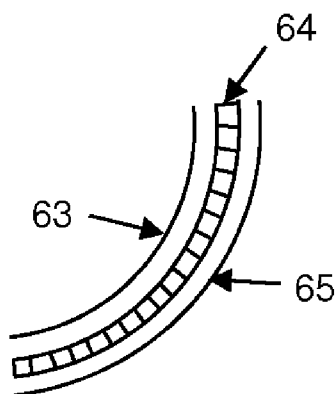


Fig. 5b



SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG). **Published:**

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

1 **CONCENTRATING SOLAR POWER WITH GLASSHOUSES**

4 **CROSS REFERENCE TO RELATED APPLICATIONS**

6 **[0001]** Priority benefit claims for this application are made in the accompanying
7 Application Data Sheet, Request, or Transmittal (as appropriate, if any). To the extent permitted
8 by the type of the instant application, this application incorporates by reference for all purposes
9 the following applications, all commonly owned with the instant application at the time the
10 invention was made:

11 PCT Application (Docket No. GP-09-01PCT and Serial No. PCT/US10/22780), filed
12 02/01/2010, first named inventor Roderick MacGregor, and entitled

13 **Concentrating Solar Power with Glasshouses;**

14 U.S. Provisional Application (Docket No. GP-10-02 and Serial No. 61/361,509), filed
15 07/05/2010, first named inventor Peter Von Behrens, and entitled

16 **Concentrating Solar Power with Glasshouses; and**

17 U.S. Provisional Application (Docket No. GP-10-02A and Serial No. 61/445,518), filed
18 02/22/2011, first named inventor Peter Von Behrens, and entitled

19 **Concentrating Solar Power with Glasshouses.**

23 **BACKGROUND**

25 **[0002]** Field: Advancements in concentrated solar thermal power (CST), photovoltaic
26 solar energy (PV), concentrated photovoltaic solar energy (CPV), and industrial use of
27 concentrated solar thermal energy are needed to provide improvements in performance,
28 efficiency, and utility of use.

30 **[0003]** Related Art: Unless expressly identified as being publicly or well known,
31 mention herein of techniques and concepts, including for context, definitions, or comparison
32 purposes, should not be construed as an admission that such techniques and concepts are
33 previously publicly known or otherwise part of the prior art. All references cited herein (if any),
34 including patents, patent applications, and publications, are hereby incorporated by reference in
35 their entireties, whether specifically incorporated or not, for all purposes.

1 **[0004]** Concentrated solar power systems use mirrors, known as concentrators, to
2 gather solar energy over a large space and aim and focus the energy at receivers that convert
3 incoming solar energy to another form, such as heat or electricity. There are several advantages,
4 in some usage scenarios, to concentrated systems over simpler systems that directly use incident
5 solar energy. One advantage is that more concentrated solar energy is more efficiently
6 transformed to heat or electricity than less concentrated solar energy. Thermal and photovoltaic
7 solar receivers operate more efficiently at higher incident solar energy levels. Another
8 advantage is that non-concentrated solar energy receivers are, in some usage scenarios, more
9 expensive than mirror systems used to concentrate sunlight. Thus, by building a system with
10 mirrors, total cost of gathering sunlight over a given area and converting the gathered sunlight to
11 useful energy is reduced.

12
13 **[0005]** A line-focus receiver is a receiver with a target that is a relatively long straight
14 line, like a pipe. A line-focus concentrator is a reflector (made up of a single smooth reflective
15 surface, multiple fixed facets, or multiple movable Fresnel facets) that receives sunlight over a
16 two dimensional space and concentrates the sunlight into a significantly smaller focal point in
17 one dimension (width) while reflecting the sunlight without concentration in the other dimension
18 (length) thus creating a focal line. A line-focus concentrator with a line-focus receiver at its
19 focal line is a basic trough system. The concentrator is optionally rotated in one dimension
20 around its focal line to track daily or seasonal (apparent) movement of the sun to improve total
21 energy capture and conversion.

22
23 **[0006]** A parabolic trough system is a line concentrating system using a monolithic
24 reflector shaped like a large half pipe having a shape defined by the equation $y^2=4fx$ where f is
25 the focal length of the trough. The reflector has a 1-dimensional curvature to focus sunlight onto
26 a line-focus receiver or approximates such curvature through multiple facets fixed relative to
27 each other.

28
29 **[0007]** A concentrating Fresnel reflector is a line concentrating system similar to the
30 parabolic trough replacing the trough with a series of mirrors, each the length of a receiver, that
31 are flat or alternatively slightly curved in width. Each mirror is individually rotated about its
32 long axis to aim incident sunlight onto the line-focus receiver.

33
34 **[0008]** In some concentrated solar systems, such as some systems with high
35 concentration ratios, overall system is cost dominated by various elements such as the
36 concentration system (such as a mirror or lens), a support system for the concentrators, and

1 motors and mechanisms that enable tracking movement of the sun. The elements dominate the
2 costs because the elements are enabled to withstand wind and weather. In some usage scenarios,
3 solar energy systems are enabled to withstand various environmental dangers such as wind, rain,
4 snow, ice, hail, dew, rodents, birds and other animals, dust, sand, moss, and other living
5 organisms. Reflectivity of a concentrator is sensitive to damage, tarnishing, and dirt buildup
6 since only directly reflected sunlight, not scattered sunlight, is effectively focused.

7
8 **[0009]** Glass mirrors are used in some concentrated systems, because of an ability to
9 maintain good optical properties over long design lives (e.g. 30 years) of concentrated solar
10 systems. Glass is relatively fragile and vulnerable to hail and other forms of damage unless it is
11 suitably thick, e.g. 4-5 mm for relatively larger mirrors. In a 400 square foot concentrating dish
12 the thickness results in a weight of close to 1000 lbs or about nine kg per square meter of
13 concentrator area. The mirror is formed in a precise curve, in one dimension for a trough, in two
14 dimensions for a dish, to focus sunlight.

15
16 **[0010]** In some concentrated systems, mirror surfaces cease to focus as intended if
17 warped. Thus, the reflector is supported and held in shape by a metal superstructure that is
18 shaped to the curved glass. The superstructure supports and protects the mirror from
19 environmental conditions such as winds of 75mph or more. The protection from winds adds an
20 additional 10,000 lbs of load beyond the 1000 lb weight of the mirror, resulting in complex
21 construction requiring roughly 20 kg of structural steel for every square meter of mirror area in a
22 dish system.

23 24 25 SYNOPSIS

26
27 **[0011]** The invention may be implemented in numerous ways, including as a process,
28 an article of manufacture, an apparatus, a system, and a composition of matter. In this
29 specification, these implementations, or any other form that the invention may take, may be
30 referred to as techniques. The Detailed Description provides an exposition of one or more
31 embodiments of the invention that enable improvements in performance, efficiency, and utility
32 of use in the field identified above. The Detailed Description includes an Introduction to
33 facilitate the more rapid understanding of the remainder of the Detailed Description. As is
34 discussed in more detail in the Conclusions, the invention encompasses all possible
35 modifications and variations within the scope of the issued claims.

Brief Description of Drawings

[0012] Fig. 1 illustrates a perspective view of selected details of a portion of an embodiment of an enclosing greenhouse and an enclosed concentrated solar energy system utilizing a parabolic trough with a unilateral extension.

[0013] Fig. 2 illustrates a cross-section view of a bilaterally symmetric trough with a symmetric portion and a unilateral extension collectively having one continuous shape.

[0014] Fig. 3 illustrates a perspective view of selected details of an embodiment of a parabolic trough solar concentrator with a unilateral extension, a solar receiver, and a suspension mechanism that enable the solar concentrator to rotate about the solar receiver.

[0015] Fig. 4 illustrates in exploded perspective view a section of a sandwich structured composite with a honeycomb core.

[0016] Fig. 5a illustrates, in plan view, an embodiment of mirror construction via a sandwich structured composite having two skins and one core, with no material removed. Each layer is illustrated separately, not as stacked during construction.

[0017] Fig. 5b illustrates, in exploded section view referenced to Section line **66** in Fig 5a, an embodiment of mirror construction via a sandwich structured composite having two skins and one core, with no material removed.

[0018] Fig. 6a illustrates, in plan view, an embodiment of mirror construction via a sandwich structured composite having two skins (front and rear) and one core, with sections removed from the core and the rear skin. Each layer is illustrated separately, not as stacked during construction.

[0019] Figs. 6b and 6c respectively illustrate exploded section views referenced, respectively, to Section lines **1 72** and **2 73** of Fig 6a.

[0020] Fig. 7a illustrates, in plan view, an embodiment of mirror construction via a sandwich structured composite having two skins (front and rear) and one core, with the core and

the rear skin sections built from strips of material. Each layer is illustrated separately, not as stacked during construction.

[0021] Figs. 7b and 7c respectively illustrate exploded section views referenced, respectively, to Section lines 1 77 and 2 78 of Fig 7a.

[0022] Fig. 8a illustrates, in plan view, an embodiment of mirror construction via a sandwich structured composite having three skins (front, middle, and rear) and two cores (front and rear), with sections removed from the rear core and the rear skin. Each layer is illustrated separately, not as stacked during construction.

[0023] Figs. 8b and 8c illustrate exploded section views referenced, respectively, to Section lines 1 87 and 2 88 of Fig 8a.

[0024] Fig. 9a illustrates, in plan view, an embodiment of mirror construction via a sandwich structured composite having three skins (front, middle, and rear) and two cores (front and rear), with the rear core and the rear skin sections built from strips of material. Each layer is illustrated separately, not as stacked during construction.

[0025] Figs. 9b and 9c illustrate exploded section views referenced, respectively, to Section lines 1 97 and 2 98 of Fig 9a.

[0026] Fig. 10 illustrates, in plan view as seen from the non-reflective (e.g. back) side of the mirror, an embodiment of mirror construction via a sandwich structured composite having multiple pre-formed mirror segments, each segment implementing a full aperture of a mirror shape as joined by flanges.

[0027] Fig. 11 illustrates, in plan view as seen from the back side of mirror, another embodiment of mirror construction via a sandwich structured composite having multiple pre-formed mirror segments, each segment implementing a portion of a full aperture of a mirror shape and a portion of a full mirror length of the mirror shape as joined by flanges.

[0028] Fig. 12 illustrates, in plan view as seen from the back side of mirror, yet another embodiment of mirror construction via a sandwich structured composite having multiple pre-formed mirror segments, each segment implementing a portion of a full mirror aperture of a

1 mirror shape, and a portion of a full mirror length of the mirror shape as joined by continuous
2 ribs.

3

4 **[0029]** Fig. 13a illustrates, in side elevation view looking down a trough of a mirror
5 lengthwise, an embodiment of a suspension mechanism of the mirror, with the mirror suspension
6 mechanism in a horizontal position.

7

8 **[0030]** Fig. 13b illustrates the elements of Fig. 13a, with the mirror suspension
9 mechanism in a vertical position.

10

11 **[0031]** Fig. 13c illustrates, in front elevation view, an embodiment of the suspension
12 mechanism of Figs. 13a and 13b.

13

14 **[0032]** Fig 14a illustrates, in perspective view, an embodiment of a bearing mechanism
15 connecting a solar receiver to a solar concentrator and to building superstructure.

16

17 **[0033]** Fig 14b illustrates selected details of Fig. 14a, with elements connecting to the
18 building superstructure omitted for clarity.

19

20 **[0034]** Fig 14c illustrates Fig. 14b in exploded view.

21

22 **[0035]** Fig 14d illustrates selected details of Fig. 14a, with elements connecting to the
23 solar concentrator omitted for clarity.

24

DETAILED DESCRIPTION

[0036] A detailed description of one or more embodiments of the invention is provided below along with accompanying figures illustrating selected details of the invention. The invention is described in connection with the embodiments. The embodiments herein are understood to be merely exemplary, the invention is expressly not limited to or by any or all of the embodiments herein, and the invention encompasses numerous alternatives, modifications, and equivalents. To avoid monotony in the exposition, a variety of word labels (including but not limited to: first, last, certain, various, further, other, particular, select, some, and notable) may be applied to separate sets of embodiments; as used herein such labels are expressly not meant to convey quality, or any form of preference or prejudice, but merely to conveniently distinguish among the separate sets. The order of some operations of disclosed processes is alterable within the scope of the invention. Wherever multiple embodiments serve to describe variations in process, method, and/or features, other embodiments are contemplated that in accordance with a predetermined or a dynamically determined criterion perform static and/or dynamic selection of one of a plurality of modes of operation corresponding respectively to a plurality of the multiple embodiments. Numerous specific details are set forth in the following description to provide a thorough understanding of the invention. The details are provided for the purpose of example and the invention may be practiced according to the claims without some or all of the details. For the purpose of clarity, technical material that is known in the technical fields related to the invention has not been described in detail so that the invention is not unnecessarily obscured.

INTRODUCTION

[0037] This introduction is included only to facilitate the more rapid understanding of the Detailed Description; the invention is not limited to the concepts presented in the introduction (including explicit examples, if any), as the paragraphs of any introduction are necessarily an abridged view of the entire subject and are not meant to be an exhaustive or restrictive description. For example, the introduction that follows provides overview information limited by space and organization to only certain embodiments. There are many other embodiments, including those to which claims will ultimately be drawn, discussed throughout the balance of the specification.

1 **[0038]** In some circumstances, techniques described herein enable cost reduction of
2 concentrated solar power systems. In various embodiments, collection (concentration and
3 conversion of solar energy) is separated from protection. A protective transparent exoskeleton
4 (such as a glasshouse or a greenhouse) surrounds and/or encloses collecting elements (or
5 alternatively the collecting elements are placed in the exoskeleton), enabling the collecting
6 elements (mirrors, lenses, etc) to be less robust than otherwise required. By separating
7 collecting and protecting functions, and leveraging off-the-shelf technology (e.g. highly
8 engineered, cost effective, and proven greenhouse technology, such as glass growers greenhouse
9 technology) for the protection function, in some circumstances a reduction in cost and
10 complexity of a system (such as mirrors/lenses, support structure, foundations, tracking
11 mechanisms, etc.) is enabled with a relatively minimal impact on overall performance. The
12 glasshouse is relatively low to the ground with little wind force bearing surfaces, and is designed
13 to withstand wind and weather with a relatively minimal structural skeleton. Because the
14 glasshouse reduces wind forces acting on the collector and receiver elements, the mirrors or
15 lenses used for collection and concentration inside the exoskeletal protection of the glasshouse
16 are enabled to be lightweight, in some embodiments, to a point of seeming flimsy, and thus are
17 relatively less costly to construct, transport, support and aim, and have little or no weatherization
18 costs. Note that within this disclosure, the terms glasshouse and greenhouse are used
19 interchangeably, and are not meant to necessarily imply any sort of horticultural activity.

20

21 **[0039]** The protected embodiment techniques enable reflectors built from lighter
22 materials with simpler and lighter frames since wind, weather, and UV light are reduced inside a
23 glasshouse enclosure. Foundation, suspension, and tracking mechanisms for receivers and
24 concentrators are enabled to be simpler, lighter, and less expensive.

25

26 **[0040]** Some embodiments of a concentrated solar system inside a glasshouse have an
27 array of relatively large 2-D-freedomed, 1-D-solar-tracking parabolic troughs suspended from
28 fixed roof locations.

29

30 **[0041]** According to various embodiments, concentrators are made entirely or partially
31 of thin-gauge aluminum foil, reflective film, or other relatively reflective and lightweight
32 materials. Some of the materials have higher reflectivity than glass mirrors. Concentrators, in
33 some embodiments, are foam core combined with reflective material, enabling concentrators
34 weighing less than one kg per square meter. Lightweight construction, in some usage scenarios,
35 reduces one or more of costs associated with production, transportation, and installation of
36 concentrators. Total weight for some enclosed concentrated solar energy embodiments

(including exoskeleton and protected collector) is less than 20 kg per square meter of concentrator.

[0042] The glasshouse structure is primarily fixed and immobile, and tracking systems control and aim the less than one kg per square meter concentrators inside the structure in an environment having relatively small wind forces.

INTEGRATION OF RECEIVER AND GREENHOUSE STRUCTURE

[0043] In some embodiments, a receiver and concentrator are suspended from superstructure of an enclosing greenhouse, enabling use of substantial support infrastructure of structure of the greenhouse. Lightweight receivers and troughs, hung from the greenhouse (e.g. roof structure, trusses, and/or end posts), are held in place and aimed with relatively small members that exert force mostly in tension, thus avoiding use of relatively larger members compared to structures held in place and moved with members in compression and subject to bending. The receiver is suspended at a fixed position relative to the greenhouse and the concentrator is suspended with its focal line held on the receiver but able to rotate around the receiver to track the daily and/or seasonal motion of the sun.

DESIGN OF HANGER, ROTATING JOINT AND BEARING

[0044] In some embodiments, a hanger with a rotating joint is held in place suspended from roof superstructure of a greenhouse. A receiver tube is rigidly connected to the hanger, thus supporting the receiver tube. The rotating joint is connected to the hanger with a bearing enabling the joint to rotate around the receiver tube. A trough is suspended from the rotating joint. All the weight of the joint and the trough is carried by the rotating joint, through a bearing and to the hanger and then up to the roof superstructure. The rotating joint is enabled to rotate for small adjustments during the day, through about ½ turn from winter to summer, and another ½ turn back from summer to winter. In some usage scenarios, during an entire lifetime of the joint, it rotates the equivalent of no more than 100 revolutions and never needs to rotate more than about 1rpm. The bearing and the rotating joint are designed to avoid shading the receiver tube and to withstand high temperatures (e.g. hundreds of degrees C) since the bearing and the joint are necessarily in close thermal proximity to a high temperature thermal medium and the receiver tube.

CONCENTRATED SOLAR ENERGY SYSTEM

[0045] Industrial scale concentrated solar power systems, in some embodiments, cover multiple acres of land, with large-scale systems practical in the hundreds of acres. Fig. 1 illustrates a perspective view of selected details of an embodiment of an enclosing greenhouse and an enclosed concentrated solar energy system for a small portion of a system. Greenhouse **25** has low internal shading and low cost. According to various embodiments, the greenhouses are less than an acre to hundreds of acres in size. Suitable commercial greenhouses are available with short lead times from various vendors. Additionally, in some usage scenarios, there is a market for used greenhouses, enabling relatively easier financing of large-scale concentrated solar energy projects, such as described herein.

[0046] An optional dehumidification system reduces internal relative humidity, enabling, in some operating conditions, an extended usable lifetime of reflector materials and/or control electronics. Condensation (e.g. that occurs on a daily basis in some seasons in some locations) causes bonding of dust to surfaces and leads to corrosion reactions. Airborne humidity also accelerates corrosion reactions and performance degradation in reflector materials, as is well-understood and well-documented in lifecycle evaluations of reflector materials for concentrating solar systems. The optional dehumidification system (used, e.g., for managing relative humidity) enables using less robust and less humidity-resistant reflective concentrator materials, resulting in cost reductions and/or performance improvements, in some embodiments and/or usage scenarios.

[0047] In some embodiments, many troughs are enclosed in a single greenhouse with one front trough **27** and all the rest rear troughs such as **28**. In some embodiments, the troughs are aligned east/west, with troughs facing the equator as illustrated, and track seasonal movement of the sun. In some embodiments, the troughs are aligned north/south (not illustrated).

[0048] In Fig. 1, line-focus solar receivers are illustrated suspended from receiver pipes **12** that are in turn suspended from the roof of the enclosing greenhouse. Line-focus solar concentrators are suspended from associated solar receivers so that the focal point of the concentrator is held relatively fixed on the receiver while the concentrator body remains free to rotate around the receiver (in one degree of freedom) to track daily and seasonal motions of the sun. The arrangement of relatively fixed receivers and concentrators that rotate around the

receivers to track the sun is enabled, at least in part, by low weight of the concentrators and absence of wind forces on the concentrators.

[0049] Various embodiments suspend receiver pipes **12** and pipes **8** from trusses **1** or horizontal lattice girders. In some embodiments, solar receivers, such as implemented in part by receiver pipe **12**, are interconnected through a series of thermally insulated pipes (such as pipe **8**). The insulated pipe connects the trough receiver pipe to a next trough receiver pipe to complete a thermal fluid circuit.

SHAPE OF TROUGH AND DEFINITIONS OF TERMS AND FORMULA

[0050] Fig. 2 illustrates a shape of a parabolic trough with an extension, such as an embodiment of an asymmetric (parabolic) trough. The shape of the parabolic trough is defined by the formula $y^2 = 4fx$. With example values described following, an example parabola is defined by the formula $y^2 = 5.8x$, where $-2.29 < x < 4$. A primary symmetric portion includes two symmetric base trough sections **6a** and **6b** referred to and illustrated collectively as base trough section **6**, and also sometimes referred to as (symmetric) base portion (of the trough). A secondary extended portion includes extended trough section **7**, and is, in some embodiments, a unilateral extension of the parabolic shape. Bottom of trough **26** is the edge of the trough that is closest to the ground when the trough is held vertical to face the sun low in the sky. Top of trough **30** is the edge of the trough that is furthest from the ground when the trough is held vertical. In some embodiments, bottom of trough **26** is the edge of extended trough section **7**, and is further from the ground when the trough is horizontal, pointed at the sun high in the sky (as illustrated in Fig. 2, given an orientation of the trough such that construction line **34** is essentially horizontal to the ground). Trough focal length, illustrated by construction line **32** (e.g. having a value of 1.45 meters), is represented by the symbol f . A symmetric trough has an *aperture* (referred to as a *base aperture* in a trough with an extension), defined by a construction line between its two edges, such as illustrated by construction line **34** across the symmetric portion and ending at construction line **44**, denoting intersection of the primary and the secondary portions of the trough. Construction line **35** represents a half-portion of construction line **34** (e.g. having a value of 2.29 meters). Construction line **33** indicates an *extended aperture* (e.g. having a value of 6.29 meters) of the asymmetric trough (referred to simply as the *aperture* where clear from context), including base trough section **6** and extended trough section **7**. In some embodiments, extended trough section **7** is optionally movably connected to base trough section **6**, is optionally enabled to change shape and/or is optionally enabled to change focus at

an intersection defined by construction line **44**. Construction line **48** defines an axis of symmetry of the symmetric base portion of the trough and runs from the intersection of base trough sections **6a** and **6b** through focal point **36**. Angles **37a** and **37b** are base *rim angles* (sometimes referred to as the *base rim angle* for clarity) of the symmetric portion of the trough. Angle **38** is the *extended rim angle* of the extended portion.

SELECTED DETAILS OF A MOVABLE HINGED EXTENSION

[0051] Fig. 3 illustrates certain details of a parabolic trough with an extension, a receiver pipe, and an associated suspension mechanisms in a context free of other details to make certain details easier to understand. Extension suspension member **5** is representative of embodiments with fixed and/or movable extension suspension members, as appropriate. In the illustrated embodiment, the extension is hinged via hinged section connector **13**, and has two sections fixedly connected via section connector **15**.

[0052] In some embodiments, construction and suspension of a trough is accomplished by pinning together various elements, including suspension members **4** and **5**, base trough section **6**, and extended trough section **7**. Each segment of the concentrator is made from pre-formed mirror surfaces having sufficient internal structure to hold shape and curvature without use of other elements, while under the force of gravity and small forces imposed by suspension and positioning. The concentrators are enabled for inside use, protected by a greenhouse, and so are not strong enough to withstand wind force or environmental elements such as rain and dust. Suspension members are either light rigid members or wires. In either case, the suspension members connect to the concentrator surface, joint, hanger, or roof superstructure with pins that are readily insertable for assembly and readily removable for service.

NOTES REGARDING SELECTED FIGURES

[0053] Note that that in various embodiments, one or more of Figs. 5a, 5b, 6a, 6b, 6c, 7a, 7b, 7c, 8a, 8b, 8c, 9a, 9b, 9c, 10, 11, 12, 13a, 13b, and 13c, are not to scale. Note that in various embodiments, one or more of Figs. 5a, 6a, 7a, 8a, and 9a, are “conceptual” plan views for clarity of presentation, in that the respective illustration is as if the curvature present in the respective embodiment were not present.

SANDWICH STRUCTURED COMPOSITE SOLAR CONCENTRATORS

[0054] In some embodiments and/or usage scenarios, enclosing solar concentrators in a protecting structure enables the solar concentrators to be less robust than otherwise, since the enclosed solar concentrators are unaffected by environmental forces and/or hazards external to the structure (such as wind, rain, dust, dirt, or hail). Solar concentrators that hold shape to a relatively high degree of accuracy over time and throughout movement to aim at the sun enable efficient solar energy collection. In some embodiments and/or usage scenarios, deformation of collector/reflector shape causes reflected light to miss solar receivers and be wasted. In some situations, wind is the largest force acting on solar concentrators located external to a protecting structure. In some embodiments and/or usage scenarios, gravity and forces applied to aim collectors/reflectors are the largest forces acting on solar concentrators located internal to a protecting structure.

[0055] In some embodiments, sufficiently stiff, lightweight, and inexpensive solar concentrators are built of sandwich structured composites (see, e.g., http://en.wikipedia.org/wiki/Sandwich_structured_composite for an introduction to sandwich structured composite materials) and do not need external support structure. Such frame-less mirrors are a monocoque (see, e.g., <http://en.wikipedia.org/wiki/Monocoque> for an introduction to monocoque structures) structure where the majority of structural stress is carried in the skin of the structure.

[0056] Fig. 4 illustrates in exploded perspective view a section of a sandwich structured composite with a honeycomb core. The sandwich structure includes front skin **60**, core **61**, and rear skin **62**.

[0057] Figs. 5a and 5b illustrate, in plan and exploded section views, some features of a sandwich structured composite used to form a parabolic trough solar concentrator. In various embodiments, front skin **63** that forms the mirror surface of a solar concentrator is made from polished aluminum sheet, back surface mirrored glass, or front surface mirrored glass. In various embodiments, core **64** (with the honeycomb illustrated much larger than scale) is made from aluminum honeycomb or foam sheet. In some embodiments, rear skin **65** is made from aluminum sheet or steel. Materials are selected of appropriate thickness to provide required strength (e.g. stiffness) against relatively local deformation, (e.g. due to thermal expansion and/or manufacturing variations) as well as relatively global lengthwise, widthwise, and/or

1 twisting (torsional) deformation of the trough. For a solar concentrator of 7.5 meters aperture,
2 1.95 meters focal length and 17.5 meters length, a front aluminum skin of 0.4 millimeters
3 thickness with an aluminum honeycomb core of 40 millimeters thickness and a rear aluminum
4 skin of 0.2 millimeters thickness is suitable and is optionally supportable only at 4 points (two
5 on the edge of the trough, and two in the middle of the trough) every 2.5 meters along the length
6 of the trough by supporting rods and/or supporting cables from above. A solar concentrator built
7 with these materials weighs, in some embodiments, less than 4 kilograms per square meter.
8 Materials are selected with appropriately matched thermal expansion characteristics to avoid
9 deformation stress as the solar concentrators experience a range of temperatures that in some
10 embodiments, extends from -20 degrees Celsius to 80 degrees Celsius. In some embodiments,
11 heat activated glue is used to bond the front skin, the core and the rear skin.
12
13

14 ENHANCED SANDWICH STRUCTURED COMPOSITE SOLAR CONCENTRATORS

15

16 **[0058]** In some embodiments, as illustrated in Figs. 6a, 6b, and 6c, front skin **67** is
17 sufficiently strong such that portions of a concentrator are constructed of a front skin alone with
18 no sandwich in those areas. In some embodiments, the front skin thickness is selected to provide
19 stiffness against local deformation without need for core or rear skin. Other portions of the
20 concentrator use, in some embodiments, added strength provided by sandwich structure, such as
21 illustrated by core **68** (with the honeycomb illustrated much larger than scale) and rear skin **69**.
22 In some embodiments, curvature of a concentrator trough is maintained by sandwich structure
23 portions widthwise from top to bottom of the trough at periodic intervals. In some
24 embodiments, a shape of a trough along its length is maintained by sandwich structure portions
25 from edge to edge lengthwise. In some embodiments, such as illustrated in Figs. 6a, 6b, and 6c,
26 lengthwise and widthwise sandwich structure portions are formed from a single piece of material
27 with portions removed (e.g. removed material **70** and **71**).
28

29 **[0059]** In some embodiments, such as illustrated in Figs. 7a, 7b, and 7c, front skin **74** is
30 backed by sandwich portions that are formed from strips of core **75** (with the honeycomb
31 illustrated much larger than scale) and rear skin **76** portions that are placed widthwise as
32 illustrated, and/or lengthwise (not illustrated). In some embodiments, solar concentrators
33 constructed with enhanced sandwich structured composites with portions of core or rear skin
34 material removed are lighter and/or use less material than sandwich structures without material
35 removed.
36

1 **[0060]** In some embodiments, thin (such as 10mm) core material is enabled to resist
2 some forces (such as local deformations) but thicker (such as 50mm) core material is enabled to
3 resist other forces (such as lengthwise and/or widthwise forces). In some embodiments, core
4 material is selected to satisfy the thickest core requirement. In some embodiments, such as
5 illustrated in Figs. 8a, 8b, 8c, 9a, 9b, and 9c, triple skin sandwich structured composite
6 construction is employed. In some embodiments, thin front core **81/91** (such as 10mm
7 honeycomb) is used between front skin **80/90** and middle skin **82/92**. Thick (such as 50mm
8 honeycomb) rear core **83/93** is used between middle skin **82/92** and rear skin **84/94**, while rear
9 core **83/93** and rear skin **84/94** have selected portions removed **85** and **86**, respectively (as
10 illustrated in Figs. 8a, 8b, and 8c), or are ribbed (as illustrated in Figs. 9a, 9b, and 9c).

11
12 **[0061]** In some embodiments, (not illustrated) of a triple skin structured composite, a
13 rear core and a rear skin are constructed from multiple strips of material used on portions of a
14 concentrator. In some embodiments, a hybrid solar concentrator is constructed using a triple
15 skin structured composite (conceptually replacing selected areas of a double skin structured
16 composite of a first type). The hybrid solar concentrator weighs less and/or uses less material
17 than a solar concentrator using a double skin structured composite (of the first type or a second
18 type) without using the triple skin structured composite. In various embodiments, solar
19 concentrators constructed with enhanced sandwich structured composites weigh less than 3
20 kilograms per square meter.

23 CONSTRUCTION AND TRANSPORTATION OF SOLAR CONCENTRATORS

24
25 **[0062]** Sandwich Structured Composite Solar Concentrators are, in some embodiments,
26 pre-formed in a factory using a heated mold. In some embodiments of a construction process,
27 front material is first placed over a lower mold having a desired curvature of a concentrator or a
28 concentrator section. In some embodiments, Front material is held temporarily in a proper shape
29 next to the mold by vacuum applied through holes in a face of the mold. Next glue is applied as
30 a film, a spray or other application scheme. Next core material is applied. Next glue is again
31 applied. Finally rear skin material is placed over the core and a top mold is applied to place a
32 concentrator sandwich formed from the previously assembled layers under pressure and heat to
33 cure the glue. In some embodiments with triple skin sandwich construction, additional layers
34 are applied either before the first glue is cured or in a later curing step.

35

1 **[0063]** In some embodiments, a full trough is constructed in a single operation. In
2 some embodiments, such as where trough size is too large to form on a mold in a single piece,
3 trough sections are constructed. In some embodiments, alignment holes or pins are added to
4 troughs or trough segments during construction to be used during trough mounting at a
5 destination after transportation.

6
7 **[0064]** In some embodiments, a full trough is too large for practical shipment to a
8 destination. In some embodiments, a full trough or a trough section built on a mold is cut, in
9 place, into smaller sections for convenience of transportation (e.g. shipping). In some
10 embodiments where trough sections are cut, alignment holes or pins are added during
11 manufacturing of the trough sections, the holes or pins for use in reconnecting the cut trough
12 sections during trough mounting and/or assembly at a destination.

13
14 **[0065]** In some embodiments, such as illustrated in Fig. 10, a concentrator is
15 constructed of multiple segments, each forming an entirety of a parabolic curve of a trough
16 concentrator (conceptually represented by widthwise direction of trough and direction of trough
17 curvature **101**) and a portion of length (conceptually represented by lengthwise direction of
18 trough and direction of axis of symmetry **100**) of the trough concentrator. Each segment
19 (illustrated, e.g., by one of multiple mirror segments **104**) is connected to a next segment by
20 flanges (illustrated, e.g. by one of multiple mirror connection flanges with integrated mirror
21 suspension point **103**) suspended from above at a fixed length from a solar receiver. A gap
22 (illustrated, e.g., by widthwise gap between mirror segments **102**) separates mirror segments
23 lengthwise. In some embodiments, suspension rods or cables are pre-cut to an appropriate
24 length. In some embodiments, the rods or the cables have a facility for fine adjustment of
25 length. In some embodiments, pre placed holes and pins on concentrator segments and flanges
26 are used for alignment. In various embodiments, concentrator segments and flanges are joined
27 by fasteners, rivets, or glue. In some embodiments, one or more seams between trough segments
28 are weak points. In some embodiments, segments of a trough are connected with sufficient
29 strength to hold a shape of the trough. In various embodiments, additional trough suspension
30 rods or cables are added at seams of a trough to hold the seams at a fixed distance from a solar
31 receiver. In some embodiments, tape is applied across a length of a seam to further strengthen
32 the seam.

33
34 **[0066]** In various embodiments, such as illustrated in Fig. 11, a concentrator is
35 constructed of multiple segments with seams in the lengthwise direction (conceptually
36 represented by lengthwise direction of trough and direction of axis of symmetry **110**) and the

widthwise direction (conceptually represented by widthwise direction of trough and direction of trough curvature **111**). The segments are of various sizes and arranged in an interstitial pattern to avoid long seams along a length of a solar concentrator. The various sizes are illustrated, e.g., by one of multiple 'small' and 'large' mirror segments **114** and **116**, respectively. Also illustrated are gaps between the mirror segments, as, e.g., widthwise and lengthwise gaps between mirror segments **112** and **113**, respectively. A flange is illustrated by, e.g., one of multiple mirror connection flanges with integrated mirror suspension point **115**.

[0067] In some embodiments, such as illustrated in Fig. 12, a concentrator is constructed with gaps in the lengthwise direction (conceptually represented by lengthwise direction of trough and direction of axis of symmetry **120**) and seams in the widthwise direction (conceptually represented by widthwise direction of trough and direction of trough curvature **121**). Widthwise seams are connected between concentrator segments with ribs (illustrated, e.g., by one of multiple mirror suspension ribs with multiple mirror suspension points **124**) rather than individual flanges (such as illustrated in Fig. 11). Various mirror sizes are illustrated, e.g., by one of multiple 'small' and 'large' mirror segments **123** and **125**, respectively. Also illustrated are gaps between the mirror segments, as, e.g., gap between mirror segments **122**. In some embodiments, mirror suspension ribs are constructed as sandwich structured composites. In some embodiments, mirror suspension ribs are pre-formed in a factory as connected to concentrator segments, with mirror suspension ribs extending beyond an edge of the concentrator segment to provide a connection mechanism for a next concentrator segment.

[0068] In some embodiments, such as illustrated in Figs. 13a, 13b, and 13c, ribs are suspended (e.g. from one or more solar receivers) during constructing within a glasshouse , enabling subsequent placement of elements (e.g. of one or more concentrator segments) on top of and fastened to the ribs during the constructing.

ACTIVE CONTROL OF TWISTING FORCES

[0069] In some embodiments and/or usage scenarios, a curved structure (e.g. a parabolic trough) is relatively resistant to force lengthwise orthogonal to a radius of curvature, due at least in part to the curvature. In some embodiments and/or usage scenarios, a curved structure built from a sandwich structured composite (e.g. a sandwich-composite-based parabolic trough) is relatively resistant to force along a radius of curvature, at least in part due to the sandwich structure composite. In some embodiments and/or usage scenarios, a curved

1 structure built from a sandwich structured composite (e.g. a sandwich-composite-based
2 parabolic trough) is, at least in part, further strengthened against the force of gravity by
3 suspension rods and/or suspension cables of a fixed length suspended from a solar receiver. In
4 some embodiments and/or usage scenarios, an “open” curved structure (e.g. a parabolic trough)
5 is not relatively resistant to torsion forces, due at least in part to the curved structure being open
6 rather than closed (e.g. a parabola instead of a complete circle or ellipse).

7
8 **[0070]** In various embodiments, trough concentrators are stiffened against torsion force
9 deformation via a torque tube or torque box running the length of the concentrator (behind so as
10 not to block incident light) and ribs extending from the torque tube or the box to the rear of the
11 concentrator. In various embodiments, the torque box or the torque tube and the extending ribs
12 add substantial weight and cost to the concentrator.

13
14 **[0071]** Figs. 13a, 13b, and 13c illustrate, in various views and positions, a trough
15 embodiment. Illustrated are roof superstructure **130**, receiver suspension cable/rod **131**, mirror
16 suspension cable/rod **134**, mirror suspension rib **135**, positioning cable **137**, and positioning
17 pulley **136**. Further illustrated are solar receiver pipe **132** (the inner of the two concentric circles
18 of Fig. 13a and Fig. 13c) and pipe hanger / mirror bearing **133** (the outer of the two concentric
19 circles of Fig. 13a and Fig. 13c).

20
21 **[0072]** In various embodiments, such as illustrated in Figs. 13a, 13b, and 13c, a
22 concentrator is pulled by an edge at multiple points along the length of the concentrator to
23 position the concentrator facing the sun. Multiple fixed length rods or cables suspend the
24 concentrator at a fixed distance (focal length) from a receiver. Multiple positioning rods or
25 positioning cables (either in line with the suspension rods or the suspension cables or at separate
26 points lengthwise along the concentrator) are pulled to position the concentrator more vertically
27 when the sun is low in the sky and eased to position the concentrator more horizontally when the
28 sun is high in the sky.

29
30 **[0073]** In various embodiments, the suspension rods or the suspension cables and the
31 positioning rods or the positioning cables are all held almost exclusively in tension at all times.
32 In some embodiments, the positioning cable is mounted on the concentrator on one end and on a
33 roof superstructure at an extended distance from directly above the concentrator so that when the
34 concentrator is raised the positioning cable pulls the concentrator to keep one or more of the
35 suspension cables or the suspension rods in tension. If the suspension members or the
36 positioning members were sometimes subject to compression, then the suspension cables could

1 not be used and the suspension rods would need to be substantially larger. In addition to adding
2 cost and weight to a system, the larger suspension rods would, in some embodiments, reduce
3 efficiency by blocking additional incident light.

4
5 **[0074]** In some embodiments where concentrators are oriented lengthwise from east to
6 west, positioning members (e.g. rods or cables) are only used on one side of the concentrators
7 (as illustrated). In various embodiments where concentrators are oriented lengthwise from north
8 to south, or some embodiments where concentrators are oriented lengthwise from east to west
9 and having a center of gravity necessitating pulling at times from one side and at times from the
10 other to properly track the sun during all daylight hours, positioning members are used on both
11 sides of the concentrators (not illustrated).

12
13 **[0075]** Where multiple positioning rods or positioning cables are placed lengthwise
14 along a concentrator, torsional forces are reduced and/or minimized, in some embodiments, with
15 no additional strengthening of the concentrator against torsional distortion. In some
16 embodiments, all positioning rods or positioning cables on one side of a concentrator are moved
17 together by one motor or by multiple motors controlled together by one sensor system. In some
18 embodiments, fine tuning of aiming is achieved by moving individual positioning cables under
19 control of separate motors and using local sensors to determine optimal positions of the
20 individual positioning cables. In some embodiments where multiple motors are controlled
21 separately by respective positioning control systems, additional resilience is achieved against
22 failure of any one of the motors or any one of the positioning control system because the other
23 motors under control of their individual positioning control systems remain enabled to aim the
24 concentrator.

25 26 27 CONCENTRATOR SUSPENSION MECHANISM DESIGN CONSIDERATIONS

28
29 **[0076]** Figs. 14a, 14b, 14c, and 14d illustrate, in various views, an embodiment of a
30 bearing mechanism connecting a solar receiver to a solar concentrator (not illustrated) and to
31 building infrastructure (not illustrated). Illustrated and specifically identified in Fig. 14a are
32 solar receiver **140**, solar concentrator suspension rod **141** (multiple instances), and solar receiver
33 suspension rod **142** (multiple instances). Illustrated and specifically identified in Fig. 14c are
34 concentrator hanging top portion with bearing outer ring **143**, split bearing raceway **144**, and
35 concentrator hanger bearing strap **145**. Illustrated and specifically identified in Fig. 14d are
36 receiver hanger **149**, six fasteners **146** connecting split bearing raceway **144** to receiver hanger

1 149 and split ring tightening mechanism, and bolt 148 to attach solar receiver hanger 149 to
2 solar receiver 140 by closing ring to specified torque. Also identified in Fig. 14d are solar
3 receiver 140, solar receiver suspension rod 142 (multiple instances), and split bearing raceway
4 144.

5
6 [0077] In some embodiments, a continuous solar receiver is a combination (e.g.
7 connected in series and/or in parallel) of out (e.g. outlet) and back (e.g. inlet) pipes suspended
8 from a roof of a greenhouse, attached at one end to a wall of the greenhouse and free to move at
9 the other end. The suspension mechanism enables a continuous solar receiver to expand and
10 contract as the continuous solar receiver heats and cools while being held in straight lines by a
11 suspension mechanism. A solar concentrator is suspended from the continuous solar receiver
12 with a focal line of the solar concentrator fixed on the solar receiver and with the solar
13 concentrator enabled to rotate around the continuous solar receiver to track the sun. In some
14 embodiments, a mechanism to connect a solar receiver to a greenhouse roof and a solar
15 concentrator to the solar receiver is built from a single joint clamped to the solar receiver as
16 illustrated in Fig. 14a. A clamping mechanism enables tightening of the joint mechanism to the
17 solar receiver while allowing for manufacturing variation in an outside diameter of the solar
18 receiver. Structure of the joint structure is illustrated with various elements omitted in Figs. 14b,
19 14c, and 14d. Fig. 14b omits elements of Fig. 14a that connect to the building superstructure,
20 and Fig. 14c is an exploded view of Fig. 14b. Fig. 14d omits elements of Fig. 14a that connect
21 to the solar concentrator.

22
23 [0078] In some embodiments, light is reflected by a solar concentrator and is incident
24 upon a joint mechanism. In some embodiments, joint mechanism width is minimized so as to
25 block as little incident light as possible. In some embodiments, as illustrated in Fig 14c, a
26 concentrator suspension mechanism is built with a thin strip of material forming an outer portion
27 of a rotating bearing (operable as a concentrator hanger bearing strap) to minimize an amount of
28 material between incident light reflected by a solar concentrator and a solar receiver under a
29 joint mechanism. The thinness of the concentrator hanger bearing strap is enabled by the
30 concentrator bearing rotating only through part of a full circle and always maintaining a position
31 such that weight on the solar concentrator is supported by concentrator hanging top portion with
32 bearing outer ring 143. The thin concentrator hanger bearing strap provides a low resistance
33 thermal path between a concentrator and a concentrator hanger top portion. In some
34 embodiments, a concentrator hanger bearing strap is coated with a selective coating the same as
35 or similar to a selective coating applied to a solar receiver to maximize absorption of incident
36 solar radiation and/or to minimize emission of radiation from the solar receiver when heated. In

1 some embodiments, a concentrator hanger bearing strap is coated with a non-selective coating to
2 maximize absorption of incident solar radiation but to allow emission of radiation from a
3 concentrator hanger bearing strap in case a thermal path between a concentrator hanger bearing
4 strap and a solar receiver is insufficient to maintain the concentrator hanger bearing strap below
5 a maximum operating temperature.

6
7
8 **SELECTED EMBODIMENT DETAILS**
9

10 **[0079]** In various embodiments and/or usage scenarios, the illustrated embodiments are
11 related to each other. For example, in some embodiments and/or usage scenarios, mirrors, as
12 depicted in Figs. 5a, 5b, 6a, 6b, 6c, 7a, 7b, 7c, 8a, 8b, 8c, 9a, 9b, and 9c, are implementation
13 techniques for all or any portion(s) of solar concentrators (e.g. of Figs. 1, 13a, and 13b),
14 reflective surface(s) of troughs (e.g. of Fig. 2), and mirrors (e.g. of Fig. 3). For example, in
15 some embodiments and/or usage scenarios, positioning member 9 of Fig. 1 is an alternate
16 embodiment of positioning cable 137 of Figs. 13a and 13b.

17
18 **[0080]** While the forgoing embodiments are described as having roof systems with
19 peaks and gutters, other embodiments use alternate roof systems, such as peaked, arched,
20 mansard, and Quonset-style roof systems, as well as variations and combinations thereof. In
21 various embodiments, a partially transparent protective enclosure (such as a glasshouse or a
22 greenhouse) uses glass to provide the transparency, and other embodiments use alternative
23 transparent materials such as plastic, polyethylene, fiberglass-reinforced plastic, acrylic,
24 polycarbonate, or any other material having suitable transparency to sunlight and sufficient
25 strength (in combination with a supporting framework) to provide environmental protection.

CONCLUSION

[0081] Certain choices have been made in the description merely for convenience in preparing the text and drawings and unless there is an indication to the contrary the choices should not be construed per se as conveying additional information regarding structure or operation of the embodiments described. Examples of the choices include: the particular organization or assignment of the designations used for the figure numbering and the particular organization or assignment of the element identifiers (the callouts or numerical designators, e.g.) used to identify and reference the features and elements of the embodiments.

[0082] The words “includes” or “including” are specifically intended to be construed as abstractions describing logical sets of open-ended scope and are not meant to convey physical containment unless explicitly followed by the word “within.”

[0083] Although the foregoing embodiments have been described in some detail for purposes of clarity of description and understanding, the invention is not limited to the details provided. There are many embodiments of the invention. The disclosed embodiments are exemplary and not restrictive.

[0084] It will be understood that many variations in construction, arrangement, and use are possible, consistent with the description, and are within the scope of the claims of the issued patent. The names given to elements are merely exemplary, and should not be construed as limiting the concepts described. Also, unless specifically stated to the contrary, value ranges specified, maximum and minimum values used, or other particular specifications, are merely those of the described embodiments, are expected to track improvements and changes in implementation technology, and should not be construed as limitations.

[0085] Functionally equivalent techniques known in the art are employable instead of those described to implement various components, sub-systems, operations, functions, or portions thereof.

[0086] The embodiments have been described with detail and environmental context well beyond that required for a minimal implementation of many aspects of the embodiments described. Those of ordinary skill in the art will recognize that some embodiments omit disclosed components or features without altering the basic cooperation among the remaining elements. It is thus understood that much of the details disclosed are not required to implement

1 various aspects of the embodiments described. To the extent that the remaining elements are
2 distinguishable from the prior art, components and features that are omitted are not limiting on
3 the concepts described herein.

4

5 **[0087]** All such variations in design are insubstantial changes over the teachings
6 conveyed by the described embodiments. It is also understood that the embodiments described
7 herein have broad applicability to other applications, and are not limited to the particular
8 application or industry of the described embodiments. The invention is thus to be construed as
9 including all possible modifications and variations encompassed within the scope of the claims
10 of the issued patent.

WHAT IS CLAIMED IS:

- 1 1. A system comprising:
 - 2 a front layer having outer and inner surfaces, the front layer being reflective to incident
 - 3 solar radiation;
 - 4 a core layer;
 - 5 a rear layer having outer and inner surfaces;
 - 6 wherein at least a portion of the core layer is situated between the inner surfaces of the
 - 7 front and the rear layers;
 - 8 wherein the front, the rear, and the core layers are laminated to collectively operate as a
 - 9 line-focus solar energy concentrator of the incident solar radiation.
- 1 2. The system of claim 1, wherein glue bonds the front layer, the core layer, and the rear layer.
- 1 3. The system of claim 2, wherein the core layer is a honeycomb layer.
- 1 4. The system of claim 3, wherein the front layer comprises polished aluminum sheet, the core
2 layer comprises aluminum honeycomb, and the rear layer comprises aluminum sheet.
- 1 5. The system of claim 2, wherein the front layer comprises mirrored glass sheet and the rear
2 layer comprises steel sheet.
- 1 6. The system of claim 2, wherein the front layer comprises one of polished aluminum sheet,
2 back surface mirrored glass, and front surface mirrored glass.
- 1 7. The system of claim 2, wherein a cross-section of the bonded layers approximates a segment
2 of a parabolic curve.
- 1 8. The system of claim 2, further comprising one or more ribs enabled to support a section of
2 the bonded layers via the outer surface of the rear layer.
- 1 9. The system of claim 8, wherein the ribs are comprised of laminated composites.

- 1 10. A system comprising:
2 a front layer having outer and inner surfaces, the front layer being reflective to incident
3 solar radiation;
4 a backing structure comprising a honeycomb portion and a rear portion bonded to each
5 other;
6 wherein a portion less than all of the front layer is bonded to at least a portion of the
7 backing structure to enable the front layer to retain a particular form; and
8 wherein the particular form enables the front layer and the backing structure to
9 collectively operate as a line-focus solar energy concentrator of the incident
10 solar radiation.
- 1 11. The system of claim 10, wherein the particular form comprises a particular shape.
- 1 12. The system of claim 11, wherein the backing structure comprises a plurality of backing
2 structure portions that are arranged at intervals and each of the backing structure portions is
3 oriented with a respective major axis that is parallel to a focus line of the line-focus solar energy
4 concentrator.
- 1 13. The system of claim 10, wherein the particular form comprises a particular curvature.
- 1 14. The system of claim 13, wherein the particular curvature is an approximation of a segment
2 of a parabolic curve.
- 1 15. The system of claim 13, wherein the backing structure comprises a plurality of backing
2 structure portions that are arranged at intervals and each of the backing structure portions is
3 oriented with a respective major axis that lies within a respective plane that a focus line of the
4 line-focus solar energy concentrator is orthogonal to.
- 1 16. The system of claim 10, wherein the honeycomb portion is situated between the front layer
2 and the rear portion.
- 1 17. The system of claim 10, wherein the honeycomb portion and/or the rear portion are formed
2 at least in part by removing one or more sections of material from a single piece of material.
- 1 18. The system of claim 10, wherein one or more sub-portions of the honeycomb portion and/or
2 one or more sub-portions of the rear portion are formed at least in part from strips of material.

- 1 19. A method comprising:
 - 2 suspending one or more ribs from a solar receiver;
 - 3 placing one or more solar concentrator segments on the ribs; and
 - 4 fastening the solar concentrator segments to the ribs.
- 1 20. The method of claim 19, wherein the suspending, the placing, and the fastening are within a
 - 2 transparent enclosure.
- 1 21. The method of claim 20, wherein the solar receiver is suspended from a portion of the
 - 2 transparent enclosure.
- 1 22. The method of claim 19, wherein the placing is such that a focal line of the placed solar
 - 2 concentrator segments is fixed on the solar receiver.
- 1 23. The method of claim 22, wherein a cross-section of one or more of the placed solar
 - 2 concentrator segments approximates a segment of a parabolic curve.
- 1 24. The method of claim 19, wherein at least one of the ribs comprises laminated composites.
- 1 25. The method of claim 24, wherein at least one of the solar concentrator segments comprises a
 - 2 laminate with a honeycomb core layer.

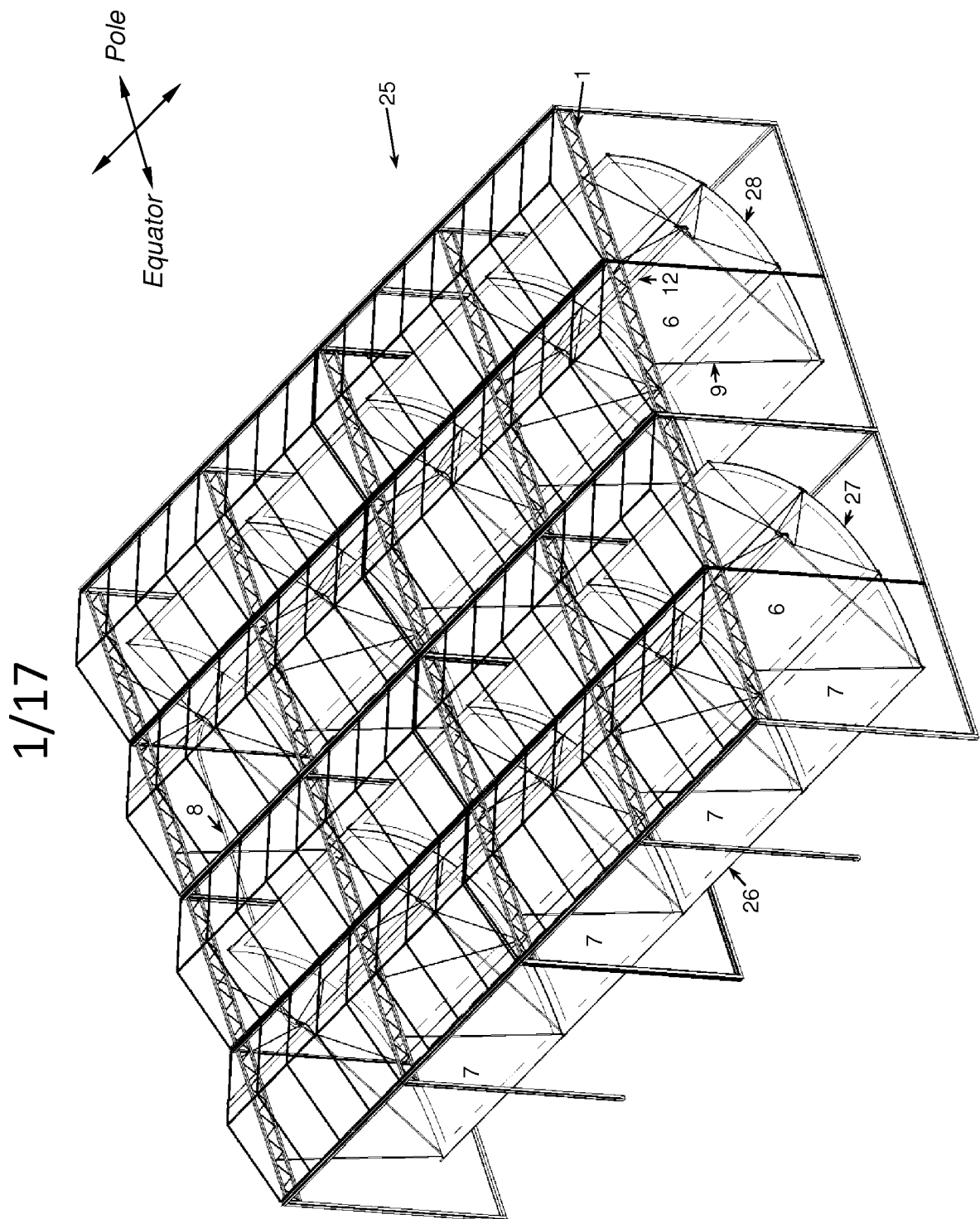


Fig. 1

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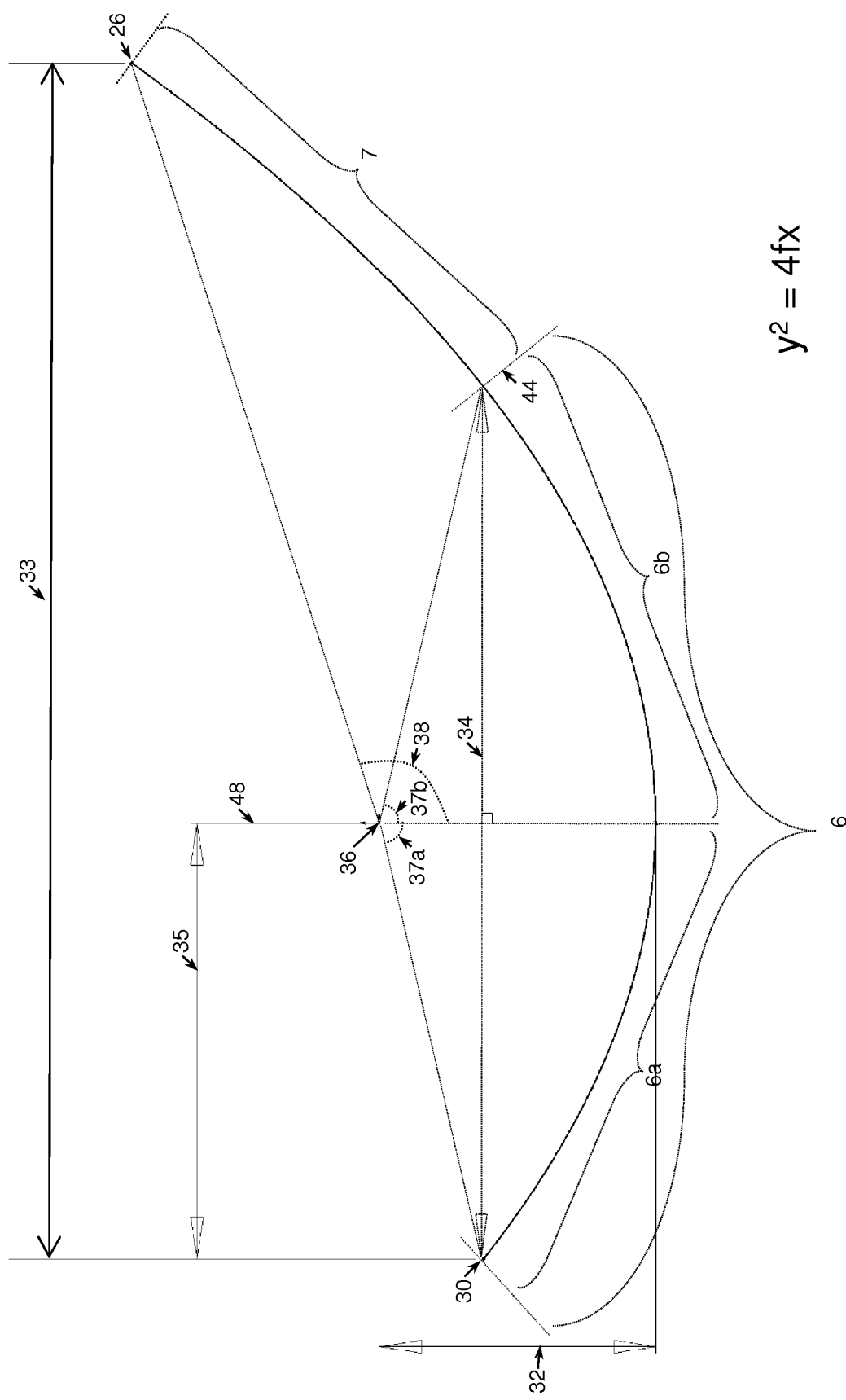


Fig. 2

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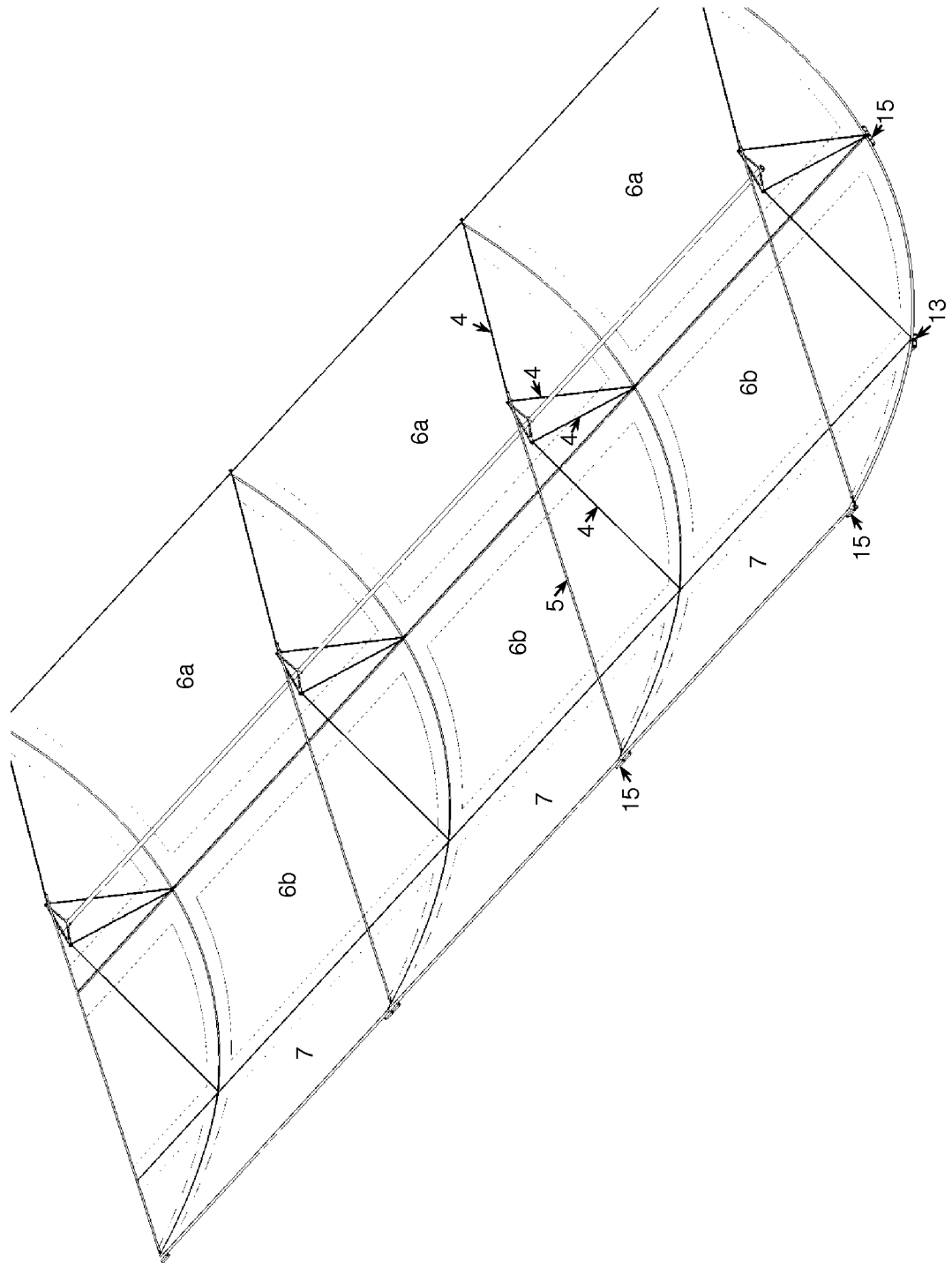


Fig. 3

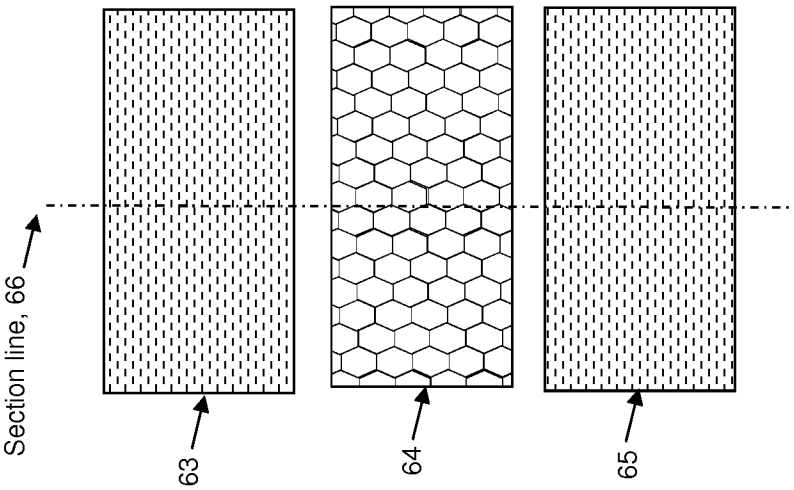
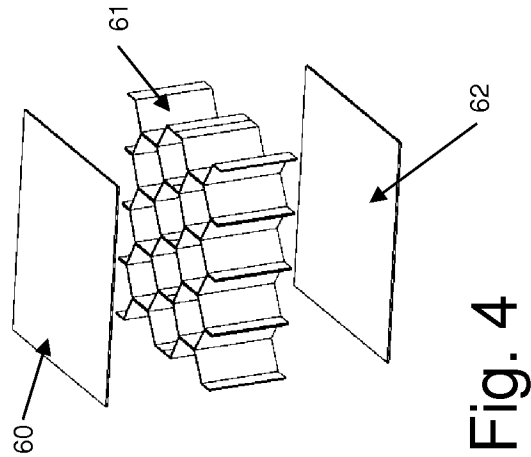


Fig. 5a

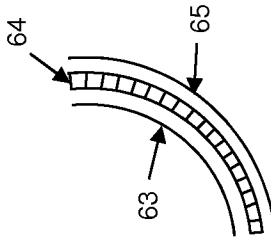


Fig. 5b

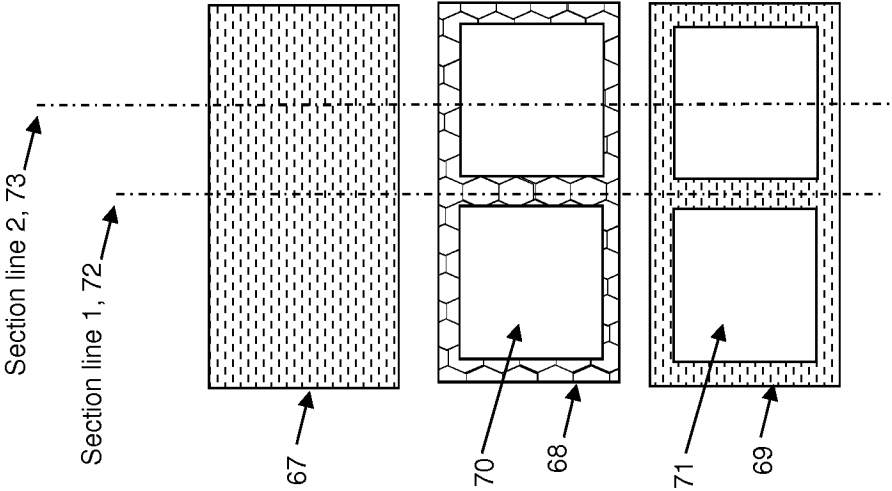


Fig. 6a

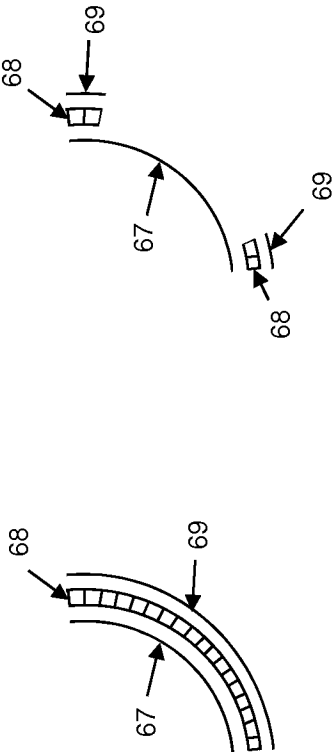


Fig. 6b

Fig. 6c

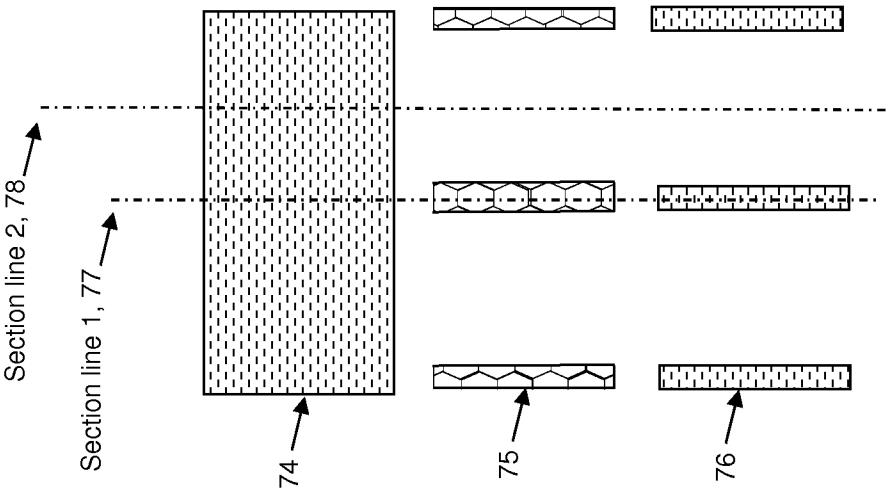


Fig. 7a

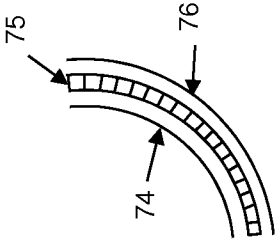


Fig. 7b

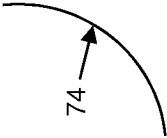


Fig. 7c

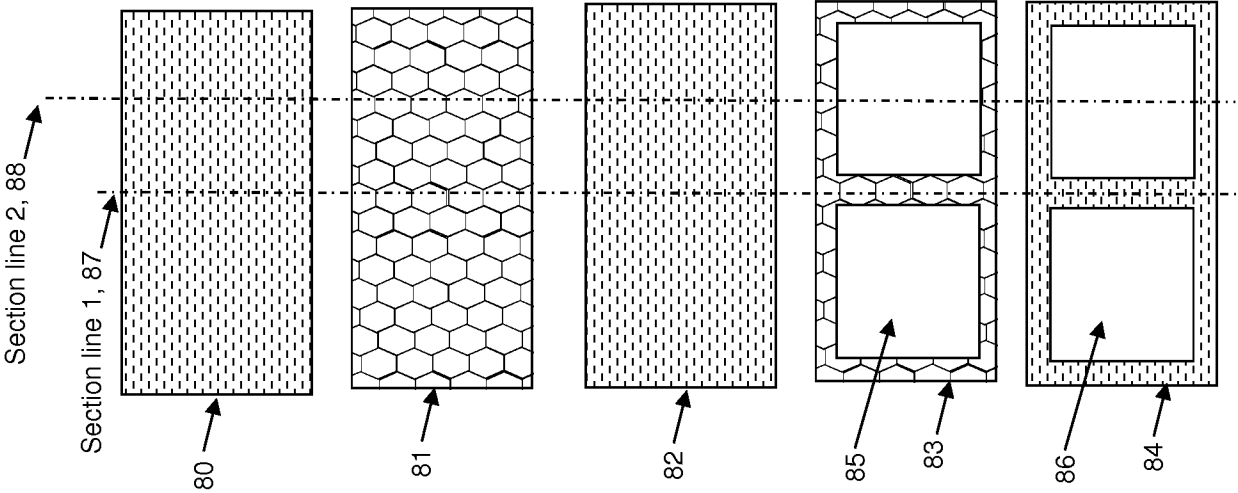


Fig. 8a

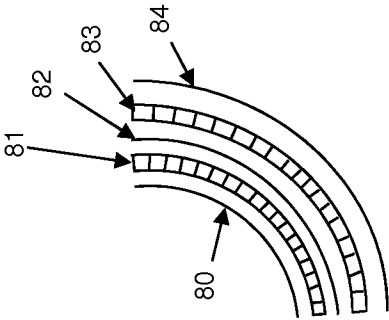


Fig. 8b

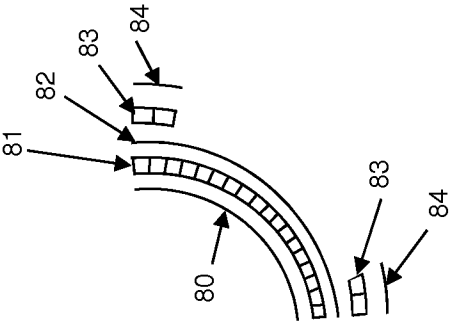


Fig. 8c

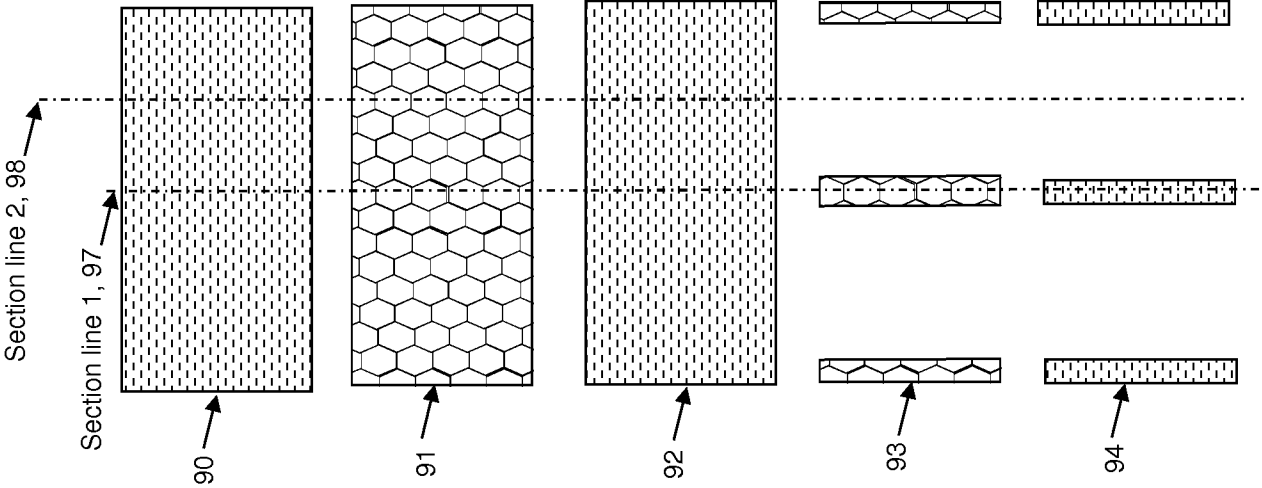


Fig. 9a

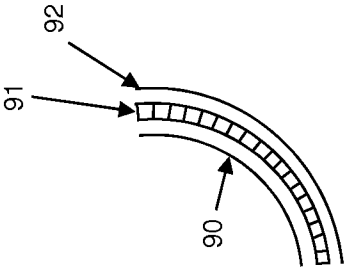


Fig. 9c

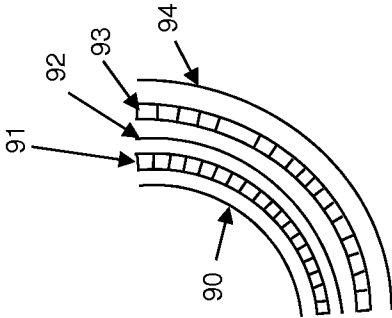


Fig. 9b

9/17

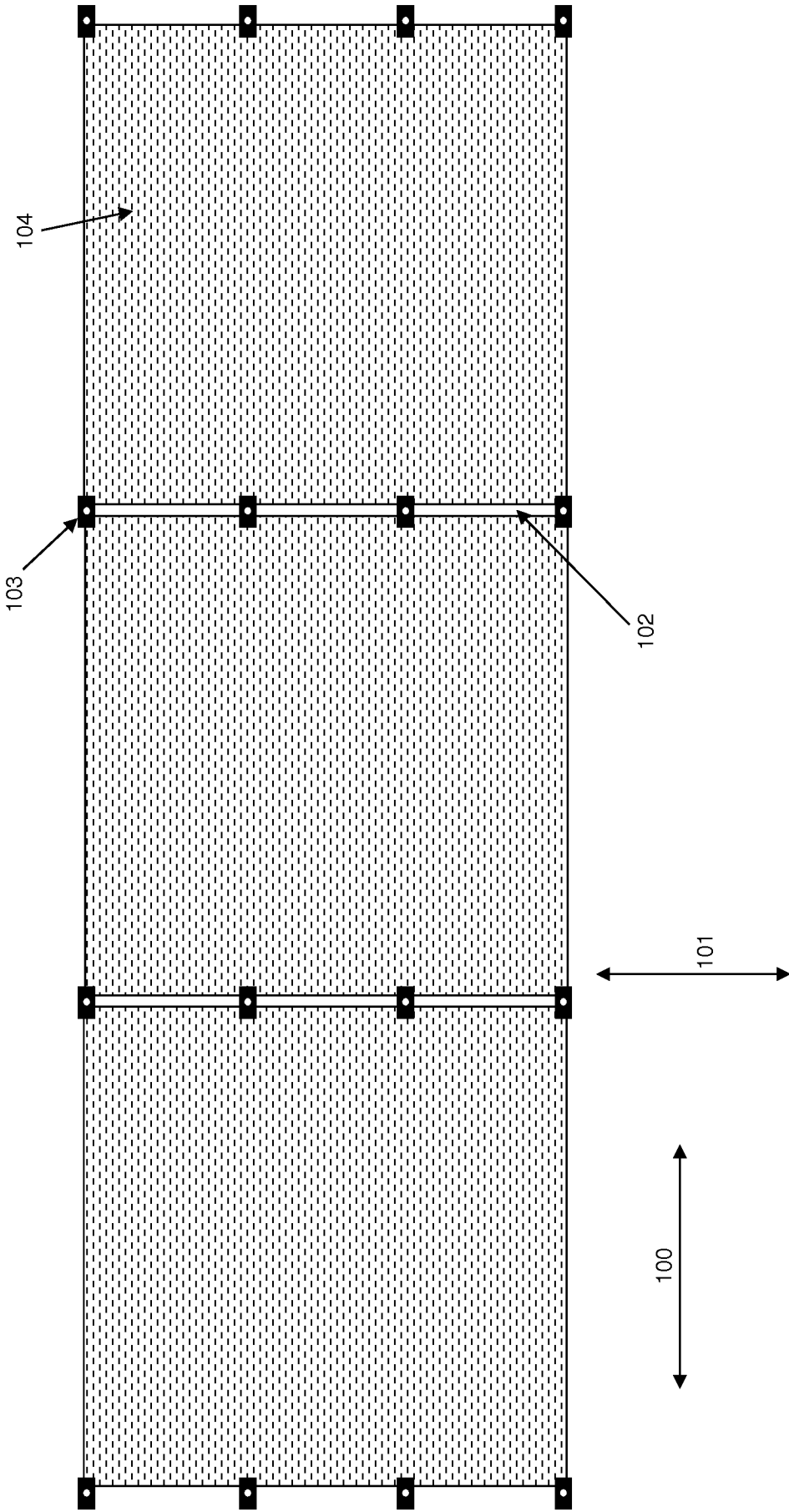


Fig. 10

10/17

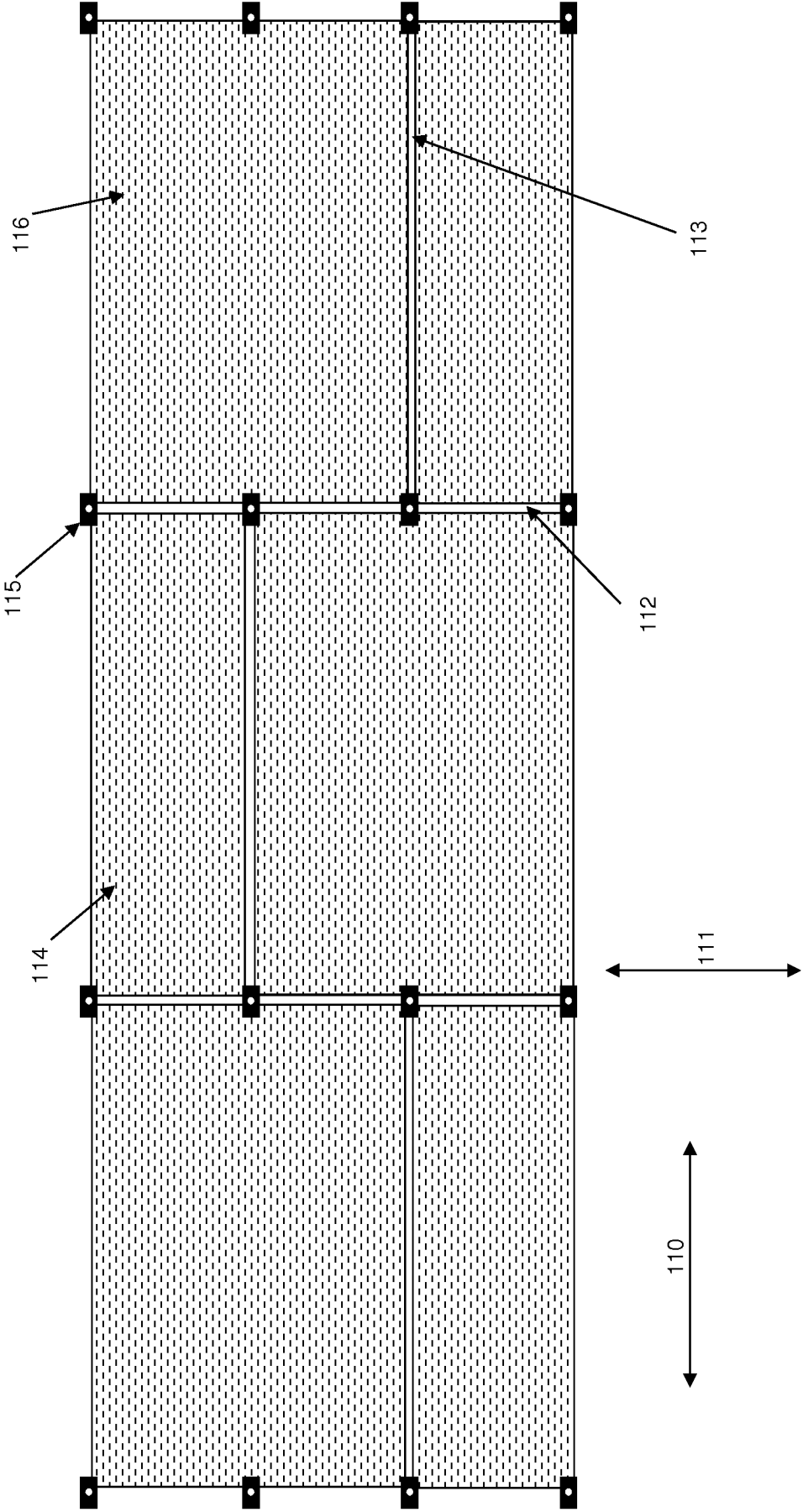


Fig. 11

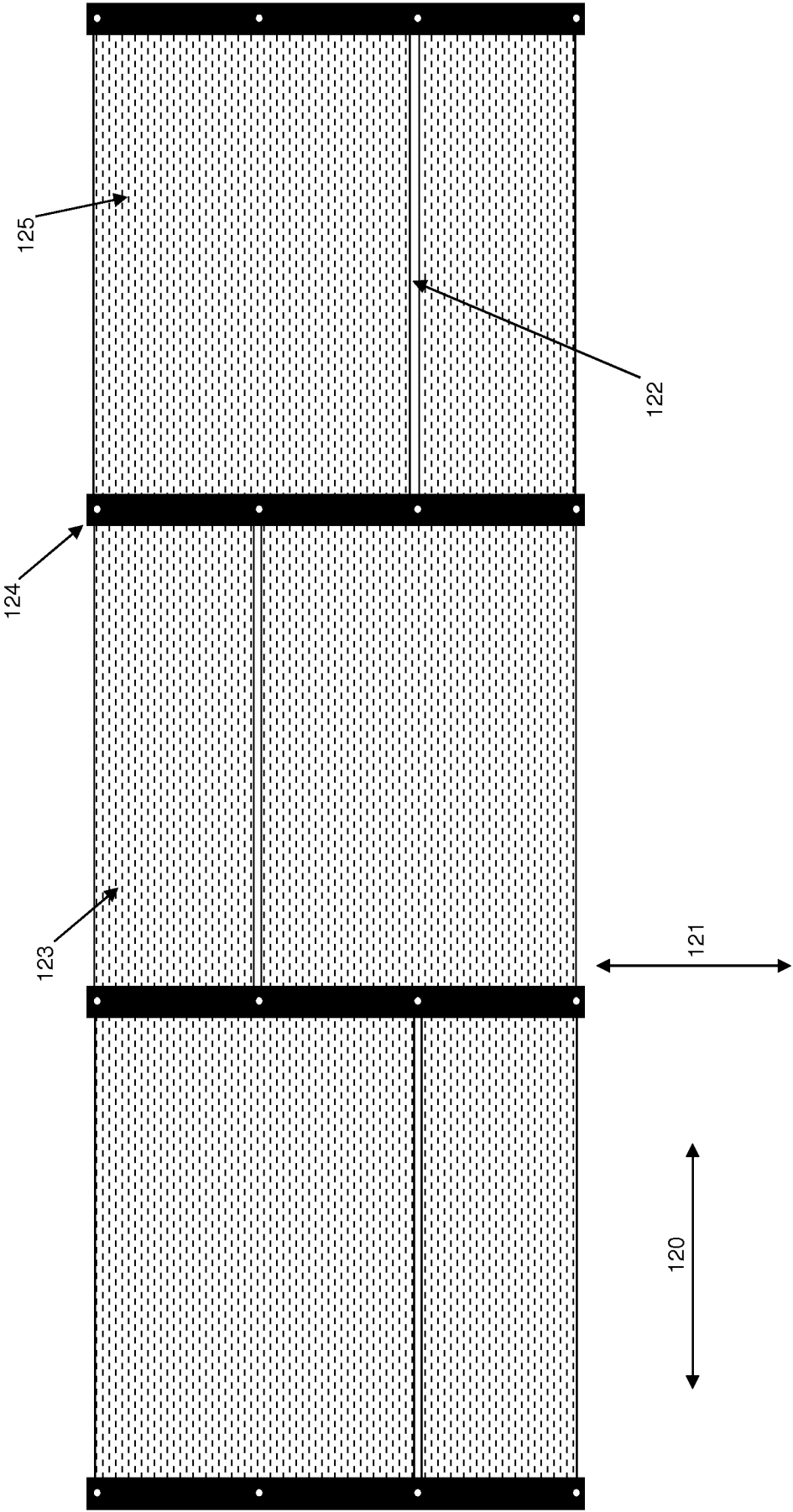


Fig. 12

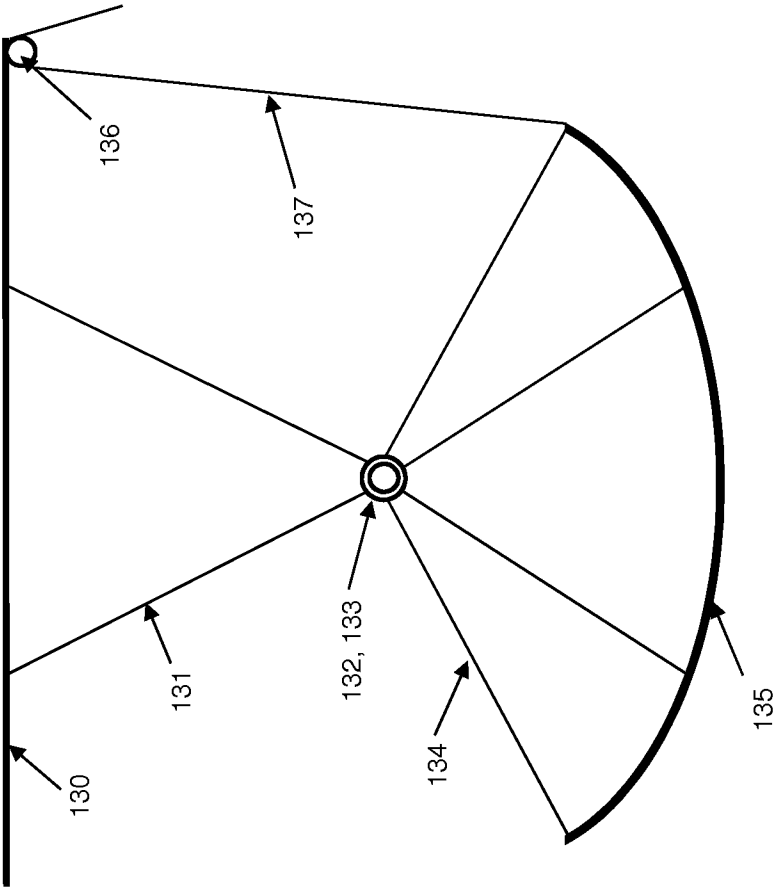


Fig. 13a

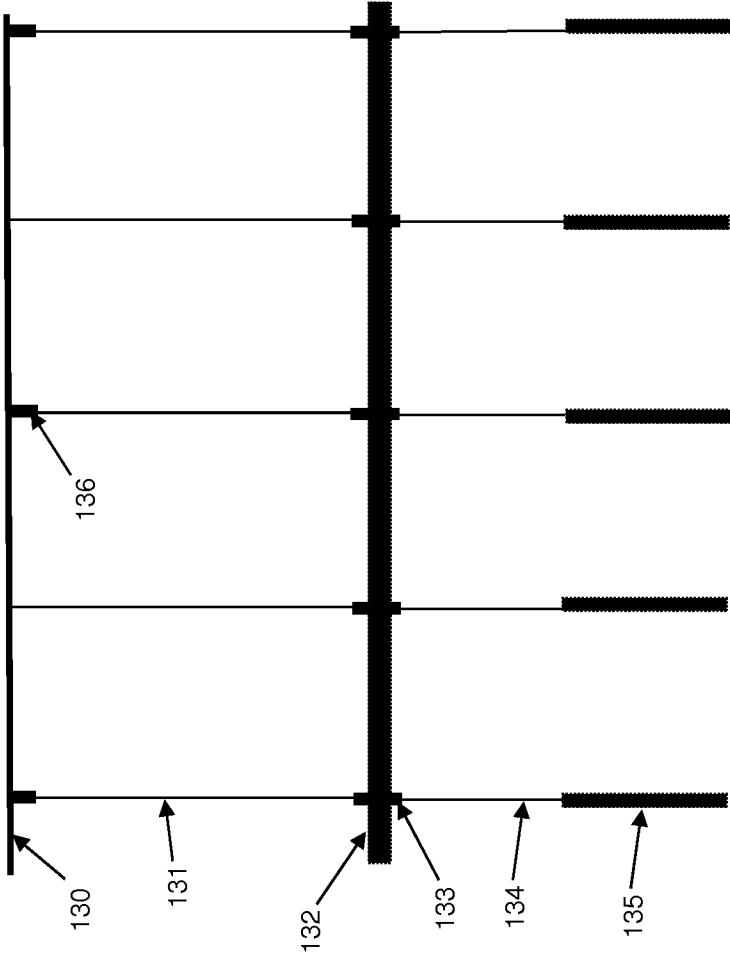


Fig. 13c

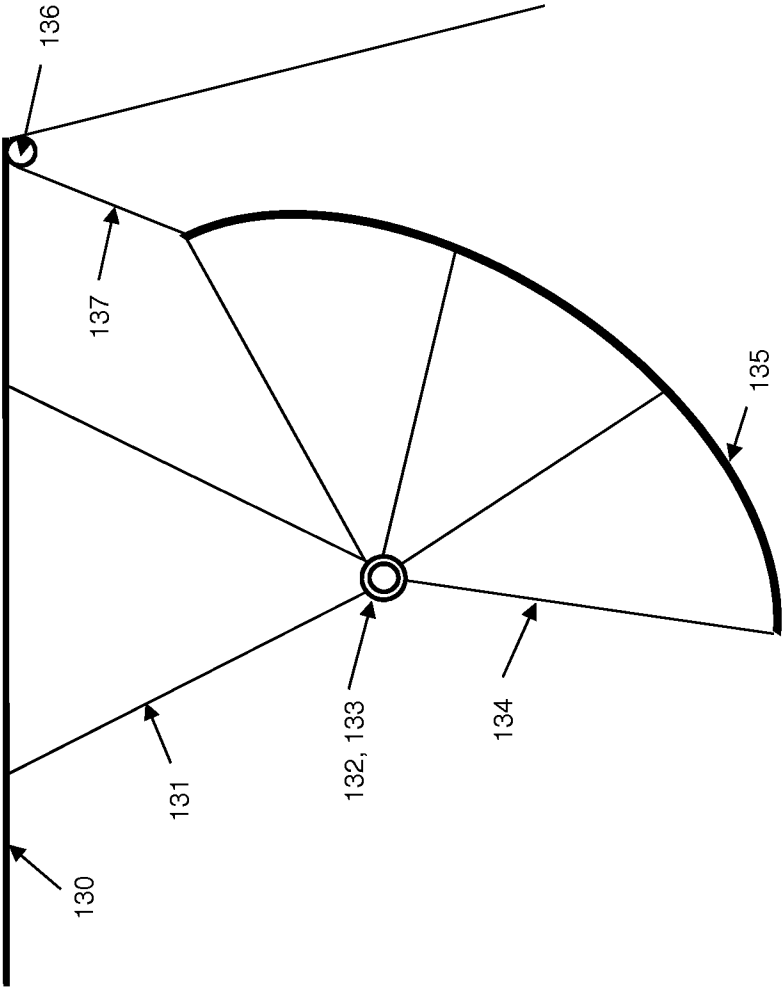


Fig. 13b

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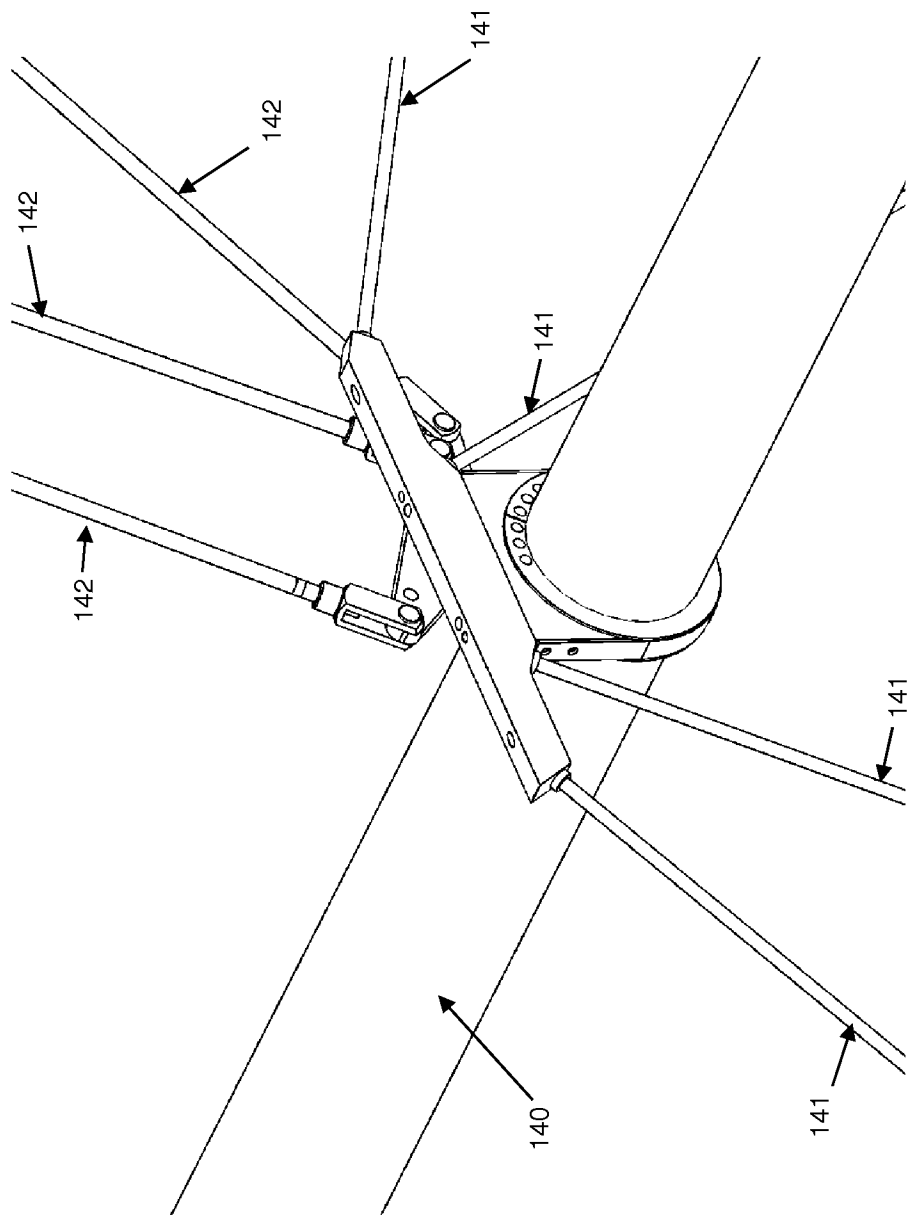


Fig. 14a

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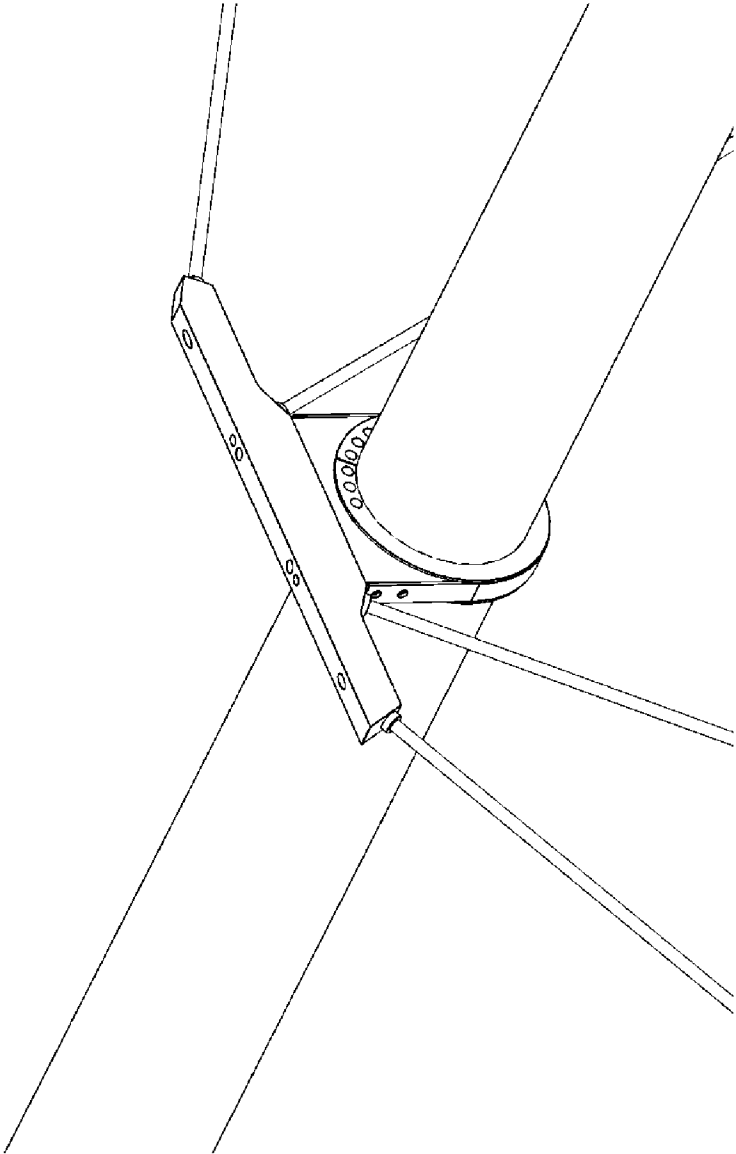


Fig. 14b

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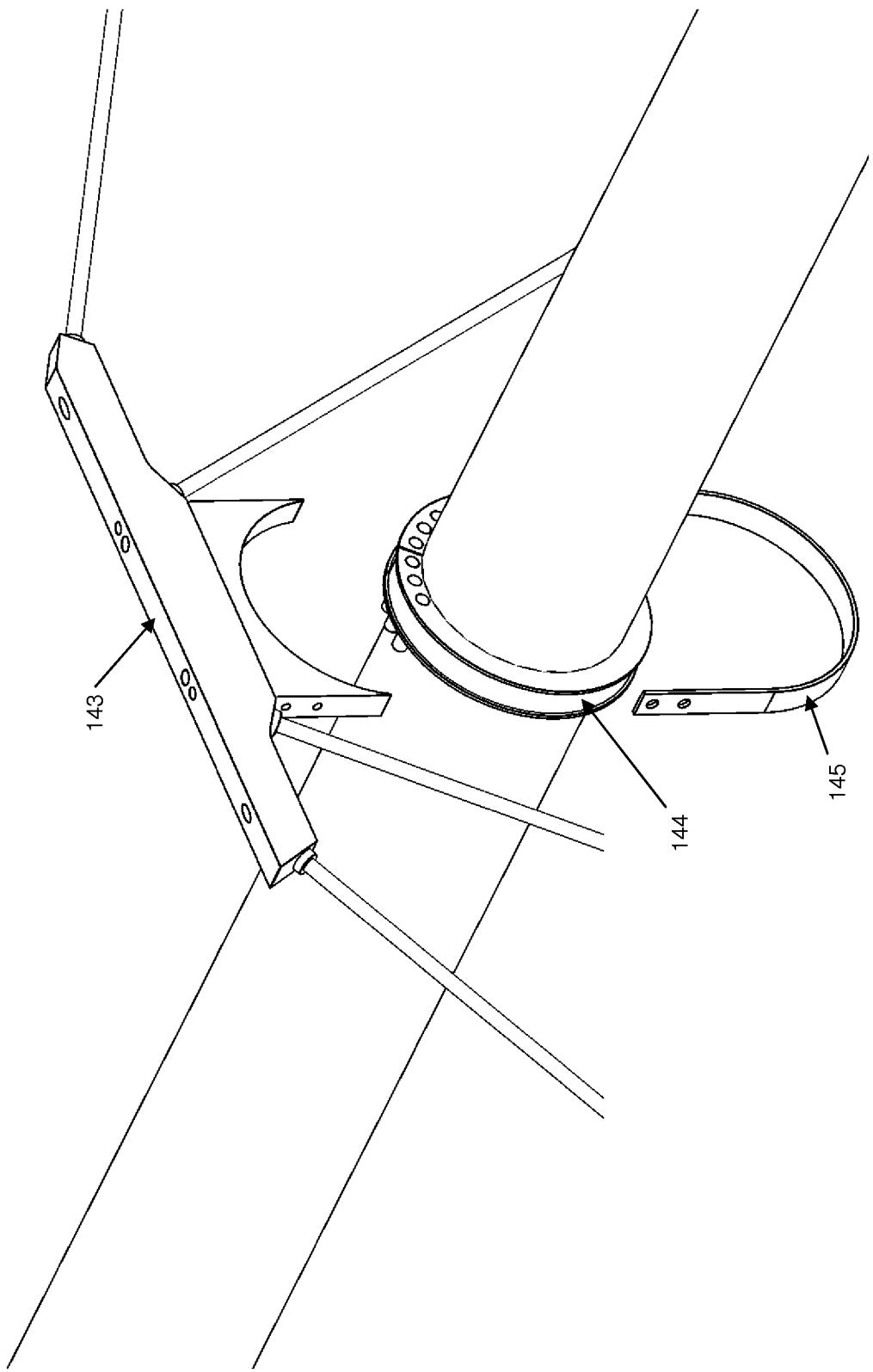


Fig. 14c

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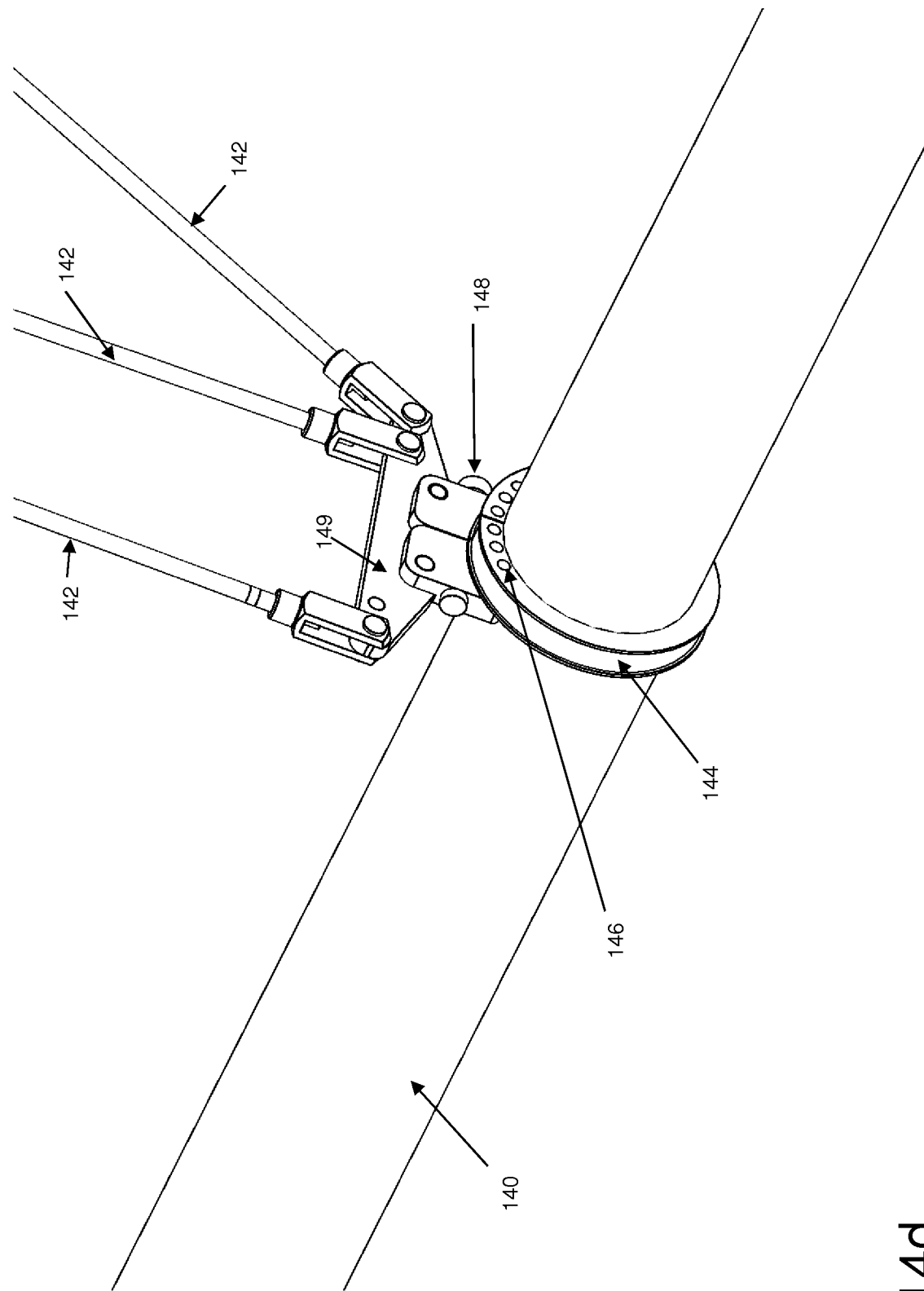


Fig. 14d