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(54) UNIFORMLY-PARTITIONED HIGH-PRECISION SUB-REFLECTOR DEVICE WITH TWO-STAGE POSE ADJUSTMENT FUNCTION

(57) The present invention discloses a uniformly-partitioned high-precision sub-reflector device with a two-stage position and pose adjustment function, relating to technical fields of communication, measurement and control, radio astronomy etc. The sub-reflector device of the present invention comprises an adjustment device, a sub-reflector, a single-layer space frame backup structure and a panel precise adjustment device. The adjustment device adopts movable and fixed platforms as a multi-rod six-degree-of-freedom sub-reflector adjustment mechanism for a plane truss to realize a primary pose adjustment of the sub-reflector; the sub-reflector is composed of a polygonal panel and several sectorial panels which are uniformly partitioned; the ratio of the number of inner and outer sides of the single-layer space frame backup structure is 1: 2, so as to provide a structural support for the sub-reflector; and the panel precise adjustment device is used for achieving a secondary pose adjustment of the sub-reflector. This device not only realizes a two-stage position and pose adjustment of the sub-reflector, but also improves the integral stiffness and reduces the overall weight of the sub-reflector, while improving the installation and adjustment efficiency and the adjustment precision.

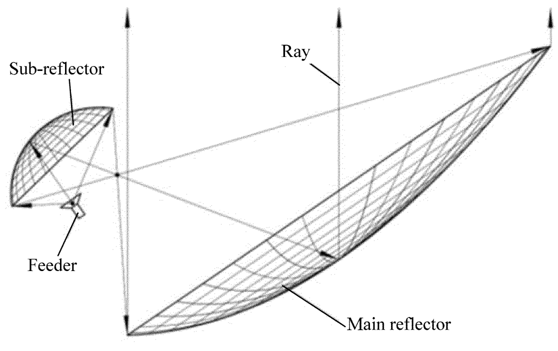

FIG. 1

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Description

TECHNICAL FIELD

[0001] The present invention relates to technical fields of communication, Telemetry, Track and Command (TT&C), and radio astronomy etc., and particularly to a uniformly-partitioned high-precision sub-reflector device with a two-stage position and pose adjustment function.

BACKGROUND

[0002] A dual-offset antenna has the characteristics that a main reflector is offset from a sub-reflector and the sub-reflector is offset from a feed. The dual-offset antenna overcomes not only an blockage of the sub-reflector to the main reflector, but also blockages of the feed and a supporting arm to the sub-reflector, thereby improving paraxial sidelobe characteristics of an antenna pattern and input voltage standing wave ratio characteristics of the feed, and achieving high antenna efficiency.

[0003] Dual-offset Gregorian antenna has a compact structure with a large space between a primary feed and a sub-reflector, which can reduce a near-field effect and easily realize far-field conditions, and so is widely used. A feed-down offset antenna is employed in a lot of projects due to a low center of gravity and advantages for installation and maintenance of a receiving system.

[0004] Just because of the above advantages of the dual-offset antenna, an international large scale scientific project - the Square Kilometre Array (SKA) radio telescope project adopts the feed-down dual-offset Gregorian reflector antenna.

[0005] In the dual-offset antenna, a geometric size of the sub-reflector and a relative positional relationship between the sub-reflector and the main reflector are both quite different from those of a circularly symmetric reflector antenna. How to precisely adjust the sub-reflector to a theoretical position is a key design problem. Otherwise, the position relationship between the main reflector and the sub-reflector will be incorrect, resulting in low antenna efficiency.

[0006] The SKA project consists of 2,500 dual-offset reflector antennas with an aperture of 15 meters to receive weak radio signals from distant universe. Therefore, the antenna is required to have the characteristics of high efficiency, low noise, low cost and quick installation, wherein the antenna efficiency is required to be greater than 88% at 15GHz.

[0007] At present, the SKA project has completed three pathfinder antennas. A document 'DVA-C: A Chinese Dish Prototype for the Square Kilometre Array' (2015 International Symposium on Antennas and Promotion) introduces a development of a SKA prototype in China. A document 'The Design of the MeerKAT Dish Optics' (Electromagnetism in Advanced Applications, 2012 International Conference) introduces a development of a SKA prototype in South Africa. A document 'Update on the SKA offset optics design for the U.S. Technology Development Project' (Aerospace, IEEE Conference, March 2011) introduces a development of a SKA prototype in Canada. The above three principle prototypes adopt an integral sub-reflector made of a composite material. Although this molding mode can simplify manufacturing procedures, the following defects are existed for the SKA project:

(1) A mold required by the integral sub-reflector is also of an integral structure with a large geometric size, which leads to a low processing precision. In a molding procedure of a large-size composite material, it is easy to cause defects of internal stress and uneven shrinkage, which leads to a decrease of an overall precision of the molded sub-reflector.
(2) The above three integral sub-reflectors are not provided with precision adjustment points, and the precision of the molded sub-reflector cannot be controlled, which reduces the yield.
(3) The above three types of sub-reflector have few structural supporting points, and when the antenna travels in elevation, it is easy to cause a deformation and affect the efficiency of the antenna.

[0008] With the improvement of computing power, a parallel mechanism has been applied to the adjustment of sub-reflectors of a plurality of reflector antennas. A Chinese patent with a publication No. CN202712431U, entitled 'Antenna Sub-Reflector System Comprising Fixed Adjusting Mechanism', discloses a device for adjusting a sub-reflector using a classical Stewart parallel mechanism. A Chinese patent with a publication No. CN105226370A, entitled 'Antenna Structure System Based On 6/6-Upu Parallel Mechanism', discloses a device that uses a hexapod parallel mechanism as an antenna pedestal to realize a vertex tracking function. A Chinese patent with a publication No. CN106450653A, entitled 'Parallel Type Six-Freedom-Degree Redundant Driving Antenna Structural System', discloses a mechanism that realizes a negative angle in elevation for antenna by combining a hexapod parallel mechanism with a cone. A document 'Orientation of Radio-Telescope Secondary Mirror Via Parallel Platform' (Electrical Engineering, Computing Science and Automatic Control, 2015 12th International Conference) introduces a parallel mechanism with a six-degree-of-freedom adjustment for a sub-reflector. A document 'Stiffness Study of a Hexapod Telescope Platform' (Antennas and Propagation, IEEE Transactions, 2011) introduces a device using a hexapod mechanism as a pedestal of a planar antenna array.

The above parallel mechanisms can realize a six-degree-of-freedom adjustment of an antenna or a sub-reflector, but for applications such as an adjustment of a sub-reflector of a dual-offset reflector antenna, the following defects are existed:

(1) The local stiffness is low. The traditional parallel mechanism generally consists of six driving rods, a movable platform and a fixed platform, and the movable platform is connected to the driving rods through three supporting points. When an aperture of a sub-reflector is large, the movable platform, which serves as an installation foundation of the sub-reflector, may cause a low stiffness at a connection position due to too few supporting points, thereby reducing the surface accuracy of the sub-reflector.
(2) The designability is poor. In order to meet the demand of space solution, the position distribution of rod cannot be arbitrarily configured in the traditional parallel mechanism. Particularly, in the dual-offset antenna, when the fixed platform is required to be located outside the aperture of the sub-reflector, great difficulties will be brought to the structural design.
(3) There is no redundant design. The hexapod parallel mechanism adopts six driving systems. When one driver or rod fails, the system cannot work normally, and even the device safety will be affected.

[0009] For a reflector of a partitioned antenna, a back of each panel needs to be provided with adjustment points. The traditional adjustment method of an antenna panel adopts several studs which are arranged on the back of the panel and then connected to an antenna backup structure. During adjustment, a movement of the antenna panel is realized by adjusting a screwing length of the studs. A Chinese patent with a publication No. CN202004142U, entitled 'Positioning Connection Device of Combined Antenna Panel', discloses an antenna panel connection device using a combination of taper pins and screw nuts. A Chinese patent with a publication No. CN108172970A, entitled 'antenna panel assembling structure', discloses an antenna panel adjustment structure with a spherical hinge. A Chinese patent with a publication No. CN108155482A, entitled 'Structure of High-Precision Reflector Antenna Composite Panel and Adjustment Method thereof', discloses an adjustment method of a composite panel with a normal adjustment function. A document 'Design, construction, and performance of the Leighton 10.4-m-diameter radio telescopes' (Proceedings of the IEEE, May 1994) introduces a panel adjustment device with an aluminum honeycomb sandwich structure. A document 'Surface adjustment of the IRAM 30 m radio telescope' (Microwaves, Antennas & Propagation, IET, 2009) introduces an adjustment device with a truss structure panel. Although the above partitioned panel adjustment structures can meet the requirement of a reflector antenna with a certain precision or a circularly symmetric reflector antenna, the following defects are existed for a sub-reflector of a dual-offset reflector antenna requiring high position precision and high surface accuracy:

(1) An adjustment method of a planar movement of the panel is not mentioned. The above adjustment devices can realize an axial continuous adjustment of the panel by means of threads, but there is no corresponding continuous adjustment mode for movement and adjustment in a horizontal plane of the panel.
(2) The antenna panel needs to overcome the gravity adjustment in different poses, and the operation is difficult. As well known, the reflector antenna is in the form of a paraboloid, and a single panel has different poses when the position of the reflector is varied. For example, the signal panel has a small slope when being close to a central position of the reflector, while has a large slope when being at an edge of the reflector. When a panel with a very large slope is to be moved and adjusted, a counterweight thereof should be overcome, and a slip can easily occur during the adjustment. Particularly, great difficulties and even dangers will be brought to the operators working at a high altitude.
(3) The adjustment efficiency is low, and it is easy to cause the adjustment position not to converge. In case of a device without a continuous movement or adjustment, it depends entirely on artificial experiences, and when a direction is to be adjusted, other adjusted directions will be affected, resulting in a vicious circle that the adjustment position of the panel does not converge.

SUMMARY

[0010] An objective of the present invention is to overcome the defects of the prior arts, and provides a uniformly-partitioned high-precision sub-reflector device with a two-stage position and pose adjustment function, which has the characteristics of high surface accuracy, high adjustment precision, high adjustment efficiency, high stiffness and light weight.

[0011] In order to achieve the above objective, the present invention adopts the following technical solutions:

[0012] A uniformly-partitioned high-precision sub-reflector device with a two-stage position and pose adjustment function, comprising an adjustment device 1, a sub-reflector 2, a single-layer space frame backup structure 3 and a panel precise adjustment device 4;

wherein the adjustment device 1 is located in a direction of an aperture of the sub-reflector 2 and comprises a movable platform 1-1, a fixed platform 1-2, a primary adjustment rod 1-3, an auxiliary adjustment rod 1-4, a movable platform spherical joint 1-5 and a fixed platform spherical joint 1-6; the movable platform 1-1 is connected to the single-layer space frame backup structure 3, and the fixed platform 1-2 is located outside the aperture of the sub-reflector 2; the fixed platform 1-2 is a plane truss structure with an N-polygonal shape, wherein N is a natural number and N≥4; the fixed platform 1-2 is composed of N fixed platform rods 1-2-1 to 1-2-N, every two of which are connected by the fixed platform spherical joint 1-6; the movable platform 1-1 is a plane truss structure with a 2N-polygonal shape, and is composed of 2N movable platform rods 1-1-1 to 1-1-2N, every two of which are connected by the movable platform spherical joint 1-5; the movable platform rod 1-1-1 to 1-1-2N, the fixed platform rod 1-2-1 to 1-2-N, the primary adjustment rod 1-3 and the auxiliary adjustment rod 1-4 form a mesh structure with a plurality of triangular space regions;

the sub-reflector 2 is composed of an N-polygonal panel 2-1 and N sectorial panels 2-2, with the N sectorial panels 2-2 being radially distributed around the N-polygonal panel 2-1 and each having an area substantially equal to that of the N-polygonal panel 2-1, and the sub-reflector 2 being connected to the single-layer space frame backup structure 3 through the panel precise adjustment device 4;

the single-layer space frame backup structure 3 is composed of an inner ring support 3-1, a main rod 3-2, a diagonal rod 3-3 and an inner ring spherical joint 3-4; wherein the inner ring support 3-1 has an N-polygonal shape and is composed of N inner ring rods 3-1-1 to 3-1-N, every two of which are connected to each other through the inner ring spherical joint 3-4; the inner ring rod 3-1-1, the movable platform rod 1-1-1 to 1-1-2N, the main rod 3-2 and the diagonal rod 3-3 form a mesh structure with a plurality of triangular space regions;

the panel precise adjustment device 4 comprises a positioning mechanism 4-1 and an adjustment mechanism (4-2), with the positioning mechanism (4-1) being located at connection points between the N-polygonal panel 2-1 and the inner ring spherical joint 3-4 of the single-layer space frame backup structure 3, and connection points between the N sectorial panels 2-2 and the inner ring spherical joint 3-4 of the single-layer space frame backup structure 3; and the adjustment mechanism 4-2 being located at a non-working side of an antenna panel.

[0013] Compared with the background art, the present invention has the following advantageous effects:

(1) Compared with the prior arts, the two-stage adjustment device adopted by the present invention has the characteristics of high adjustment precision and high adjustment efficiency. The adjustment device is a multi-rod parallel mechanism which can realize a primary six-degree-of-freedom pose adjustment of the sub-reflector; and the panel precise adjustment device can realize a surface accuracy adjustment and a secondary pose adjustment of the sub-reflector.

(2) Each of the adjustment device and the single-layer space frame backup structure in the present invention is composed of a plurality of triangular units, thereby having a stable mechanical performance, effectively resisting a gravity deformation of the antenna during the elevation travelling, improving the dynamic performance of the antenna system, and achieving the advantages of high stiffness and light weight.

(3) The parallel mechanism adopted by the adjustment device of the present invention is of a redundant design, and the number of adjustment rod is more than that of the traditional hexapod structure. When some rods fail or invalid, the adjustment device can still work normally, and the structure is stable without affecting the antenna system, which achieves the characteristics of high reliability.

(4) In the partitioning method adopted by the sub-reflector of the present invention, the reflector is composed of a polygon, and several sectorial units which are positioned through outer edges of the polygon, thereby overcoming the defect that the sectorial units are difficult to be positioned in the circumferential direction in the traditional method.

(5) The panel precise adjustment device of the present invention adds a lateral connection for the panel and improves the dynamic performance of the antenna. The adjustment mechanism not only provides a continuous adjustment in the plane direction, but also provides a lateral support for the antenna panel in two directions. When the antenna is in an elevation motion, this lateral support can reduce the movement of the panel, thereby improving the overall precision and the dynamic performance of the antenna system.

(6) The present invention provides an equation for calculating an adjustment amount of the panel precise adjustment device of the sub-reflector, and the corresponding adjustment amount can be calculated according to this equation, thereby providing a data basis for the precise adjustment of the panel.

(7) In the present invention, the movable platform and the fixed platform which constitute the adjustment device adopt a hollow plane truss structure, which is located outside the aperture of the sub-reflector to form an unobstructed electromagnetic channel.

(8) The adjustment device of the present invention is easy for operation, which improves the adjusting efficiency of the panel. Regardless of the posture of the antenna panel, an operator can realize the adjustments of rotation and movement of the panel by rotating corresponding rod, thereby overcoming the disadvantages of the traditional adjustment that manually pushes the panel, and achieving the characteristics of high adjustment efficiency and safe

operation.

[0014] To sum up, the present invention is ingenious in conceptions, clear in ideas and easy to be realized, which not only solves the problems of the poor precision and the low efficiency of the traditional single-stage adjustment, but also improves the reliability and the design flexibility of the parallel mechanism, thereby achieving an important improvement of the prior arts.

BRIEF DESCRIPTION OF DRAWINGS

[0015]

Fig. 1 is a schematic diagram of a system composition according to an embodiment of the present invention;
Fig. 2 is a schematic diagram of an overall structure composition according to an embodiment of the present invention;
Fig. 3 is a schematic diagram of a structure composition of an adjustment device according to an embodiment of the present invention;
Fig. 4 is a schematic diagram of partitioning of a sub-reflector according to an embodiment of the present invention;
Fig. 5 is a schematic diagram of a structure composition of a single-layer space frame backup structure according to an embodiment of the present invention;
Fig. 6 is a schematic diagram of an overall distribution of a panel precise adjustment device according to an embodiment of the present invention;
Fig. 7 is a schematic diagram of a structure composition of a panel precise adjustment device according to an embodiment of the present invention;
Fig. 8 is a schematic diagram of a structure composition of a positioning mechanism according to an embodiment of the present invention;
Fig. 9 is a schematic diagram of calculation parameters of an adjustment mechanism according to an embodiment of the present invention;
Fig. 10 is a structural diagram of a link of an adjustment mechanism according to an embodiment of the present invention;
Fig. 11 is a structural diagram of a joint of a single-layer space frame backup structure according to an embodiment of the present invention;
Fig. 12 is a gravity deformation diagram of an antenna panel in an x-direction in the background art;
Fig. 13 is a gravity deformation diagram of an antenna panel in a Y direction in the background art;
Fig. 14 is a gravity deformation diagram of an antenna panel in an x-direction in the present invention;
Fig. 15 is a gravity deformation diagram of an antenna panel in a Y direction in the present invention;
Fig. 16 is a deformation diagram of a sub-reflector in a vertical state according to an embodiment of the present invention;
Fig. 17 is a deformation diagram of a sub-reflector in a horizontal state according to an embodiment of the present invention;
Fig. 18 is a surface accuracy curve of a sub-reflector at different elevation angles according to an embodiment of the present invention.

[0016] Description of the reference numerals:

adjustment device 1, movable platform 1-1, movable platform rod 1-1-1, movable platform rod 1-1-2, movable platform rod 1-1-3, movable platform rod 1-1-4, movable platform rod 1-1-5, movable platform rod 1-1-6, movable platform rod 1-1-7, movable platform rod 1-1-8, movable platform rod 1-1-9, movable platform rod 1-1-10, fixed platform 1-2, fixed platform rod 1-2-1, fixed platform rod 1-2-2, fixed platform rod 1-2-3, fixed platform rod 1-2-4, fixed platform rod 1-2-5, main adjustment rod 1-3, auxiliary adjustment rod 1-4, movable platform spherical joint 1-5, fixed platform spherical joint 1-6;
sub-reflector 2, pentagonal panel 2-1, sectorial panel 2-2;
single-layer space frame backup structure 3, inner ring support 3-1, inner ring rod 3-1-1, inner ring rod 3-1-2, inner ring rod 3-1-3, inner ring rod 3-1-4, inner ring rod 3-1-5, main rod 3-2, diagonal rod 3-3, inner ring spherical joint 3-4;
panel precise adjustment device 4, positioning mechanism 4-1, main supporting rod 4-1-1, independent supporting rod 4-1-2, first direction connection plate 4-1-3, second direction connection plate 4-1-4, screw nut 4-1-5, spherical washer 4-1-6, conical washer 4-1-7, adjustment mechanism 4-2, V-shaped rod 4-2-1, A-link 4-2-1-1, B-link 4-2-1-2, unidirectional rod 4-2-2, dual-joint support 4-2-3, single-joint support 4-2-4.

DESCRIPTION OF EMBODIMENTS

[0017] The present invention will be further described below with reference to the drawings and specific embodiments.

[0018] As illustrated in Fig. 1, a dual-bias antenna is generally composed of a main reflector, a sub-reflector and a feed, wherein the sub-reflector is in the middle of an electromagnetic path between the main reflector and the feed for a secondary reflection of electromagnetic waves. The surface accuracy and position precision of the sub-reflector directly determine key specifications of the dual-offset antenna, such as efficiency, sidelobe and cross polarization.

[0019] In this embodiment, a sub-reflector adjustment device with an aperture of 5 meters in the dual-offset antenna is taken as an example. As illustrated in Fig. 2, a sub-reflector device of the present invention comprises an adjustment device 1, a sub-reflector 2, a single-layer space frame backup structure 3 and a panel precise adjustment device 4.

[0020] As illustrated in Fig. 3, the adjustment device 1 is located in a direction of an aperture of the sub-reflector 2 and does not obstruct the sub-reflector 2, and comprises a movable platform 1-1, a fixed platform 1-2, a primary adjustment rod 1-3, an auxiliary adjustment rod 1-4, a movable platform spherical joint 1-5 and a fixed platform spherical joint 1-6. The movable platform 1-1 is connected to the single-layer space frame backup structure 3, the fixed platform 1-2 is located outside the aperture of the sub-reflector 2, and an included angle between a plane where the movable platform 1-1 is located and a plane where the fixed platform 1-2 is located is 0° to 30°.

[0021] In this example, an included angle α between a plane A where the movable platform 1-1 is located and a plane B where the fixed platform 1-2 is located is 15°.

[0022] The fixed platform 1-2 is a plane truss structure with a N-polygonal shape, wherein N is a natural number and $N \geq 4$. The fixed platform 1-2 is composed of N fixed platform rods 1-2-1 to 1-2-N, every two of which are connected by the fixed platform spherical joint 1-6.

[0023] In this example, the fixed platform 1-2 has a pentagonal shape, and is composed of a fixed platform rod 1-2-1, a fixed platform rod 1-2-2, a fixed platform rod 1-2-3, a fixed platform rod 1-2-4 and a fixed platform rod 1-2-5.

[0024] The movable platform 1-1 is a plane truss structure with a 2N-polygonal shape, and is composed of 2N movable platform rods 1-1-1 to 1-1-2N, every two of which are connected by the movable platform spherical joint 1-5.

[0025] In this example, the movable platform 1-1 has a decagonal shape, and is composed of a movable platform rod 1-1-1, a movable platform rod 1-1-2, a movable platform rod 1-1-3, a movable platform rod 1-1-4, a movable platform rod 1-1-5, a movable platform rod 1-1-6, a movable platform rod 1-1-7, a movable platform rod 1-1-8, a movable platform rod 1-1-9 and a movable platform rod 1-1-10.

[0026] At least one of the N fixed platform spherical joints 1-6 is corresponding to the movable platform spherical joint 1-5.

[0027] In this example, five joints of the fixed platform spherical joints 1-6 are corresponding to the movable platform spherical joints 1-5.

[0028] The primary adjustment rod 1-3 is composed of N rod, with two ends connected to the movable platform spherical joint 1-5 and the fixed platform spherical joint 1-6, respectively, and the number of the primary adjustment rods 1-3 is N.

[0029] In this example, the number of the primary adjustment rods 1-3 is 5.

[0030] Two ends of the auxiliary adjustment rod 1-4 are connected to the movable platform spherical joint 1-5 and the fixed platform spherical joint 1-6, respectively, and the number of the auxiliary adjustment rods 1-4 is 2N.

[0031] In this example, the number of the auxiliary adjustment rods 1-4 is 10.

[0032] Each of the primary adjustment rod 1-3 and the auxiliary adjustment rod 1-4 comprises spherical hinges located at the two ends thereof, and a threaded structure with an adjustable length located in the middle thereof. The movable platform rod 1-1, the fixed platform rod 1-2, the primary adjustment rod 1-3 and the auxiliary adjustment rod 1-4 form a mesh structure with a plurality of triangular space regions.

[0033] In this example, the adjustment device 1 is a mesh structure composed of 15 triangular space regions.

[0034] As illustrated in Fig. 4, the sub-reflector 2 is composed of an N-polygonal panel 2-1 and N sectorial panels 2-2, wherein the N sectorial panels 2-2 are radially distributed around the N-polygonal panel 2-1 and each has an area substantially equal to that of the N-polygonal panel 2-1, and the sub-reflector 2 is connected to the single-layer space frame backup structure 3 through the panel precise adjustment device 4.

[0035] In this example, the sub-reflector 2 is composed of a pentagonal panel 2-1 and five sectorial panels 2-2, with an area of the pentagonal panel 2-1 being $3.7m^2$ and an area of the sectorial panel 2-2 being $3.4m^2$.

[0036] As illustrated in Fig. 5, the single-layer space frame back frame 3 is composed of an inner ring support 3-1, a main rod 3-2, a diagonal rod 3-3 and an inner spherical joint 3-4.

[0037] The inner ring support 3-1 and the movable platform 1-1 are respectively located in two planes with a distance of 500 mm to 3000 mm therebetween.

[0038] In this example, the distance between the two planes is 1000 mm.

[0039] The inner ring support 3-1 has an N-polygonal shape, and is composed of N inner ring rods 3-1-1 to 3-1-N, every two of which are connected to each other through the inner ring spherical joint 3-4.

[0040] In this example, the inner ring support 3-1 has a pentagonal shape, and is composed of an inner ring rod 3-1-1, an inner ring rod 3-1-2, an inner ring rod 3-1-3, an inner ring rod 3-1-4 and an inner ring rod 3-1-5.

[0041] At least one of the N inner ring spherical joints 3-4 is corresponding to the movable platform spherical joint 1-5.

[0042] In this example, the five inner ring spherical joints 3-4 are all corresponding to the movable platform spherical joints 1-5.

[0043] Two ends of the main rod 3-2 are connected to the inner ring spherical joint 3-4 and the movable platform spherical joint 1-5, respectively, and the number of the main rods 3-2 is N.

[0044] In this example, the number of the main rods 3-2 is 5.

[0045] Two ends of the diagonal rod 3-3 are connected to the inner ring spherical joint 3-4 and the movable platform spherical joints 1-5, respectively, and the number of the diagonal rods 3-3 is 2N.

[0046] In this example, the number of the diagonal rods 3-3 is 10.

[0047] The inner ring rod 3-1-1, the movable platform rod 1-1-1 to 1-1-2n, the main rod 3-2 and the diagonal rod 3-3 form a mesh structure with a plurality of triangular space regions.

[0048] In this example, the single-layer space frame backup structure 3 is a mesh structure composed of 15 triangular space regions.

[0049] As illustrated in Fig. 6, the panel precise adjustment device 4 comprises a positioning mechanism 4-1 and an adjustment mechanism 4-2. The positioning mechanism 4-1 is located at connection points between the N-polygonal panel 2-1 and the inner ring spherical joint 3-4 of the single-layer space frame backup structure 3, and connection points between the N sectorial panels 2-2 and the inner ring spherical joint 3-4 of the single-layer space frame backup structure 3.

[0050] In this example, the number of the positioning mechanisms 4-1 is 10.

[0051] As illustrated in Figs. 7 and 8, the positioning mechanism 4-1 is composed of a main supporting rod 4-1-1, an independent supporting rod 4-1-2, a first direction connection plate 4-1-3, a second direction connection plate 4-1-4, a screw nut 4-1-5, a spherical washer 4-1-6, and a conical washer 4-1-7. An axial direction of the main supporting rod 4-1-1 is the same as a normal direction of the panel at the position of the main supporting rod 4-1-1. The first direction connection plate 4-1-3 is connected to the single-layer space frame backup structure 3 through the main supporting rod 4-1-1. The second direction connection plate 4-1-4 is connected to the panel through a fastener or glue. The first direction connection plate 4-1-3 and the second direction connection plate 4-1-4 are provided with oblong holes having extending directions orthogonal to each other. The independent supporting rod 4-1-2 is located between the first direction connection plate 4-1-3 and the second direction connection plate 4-1-4, with an upper end thereof located in the oblong hole of the second direction connection plate 4-1-4 and fixed by the screw nut 4-1-5, and a lower end thereof located in the oblong hole of the first direction connection plate 4-1-3 and fixed by the nut 4-1-5, the spherical washer 4-1-6, and the conical washer 4-1-7.

[0052] As illustrated in Fig. 7, the adjustment mechanism 4-2 is located at a non-working side of the antenna panel and composed of a V-shaped rod 4-2-1, a unidirectional rod 4-2-2, a dual-joint support 4-2-3 and a single-joint support 4-2-4. The V-shaped rod 4-2-1 comprises an A-link 4-2-1-1 and a B-link 4-2-1-2 with adjustable lengths and each having spherical hinges at two ends. One end of each of the A-link 4-2-1-1 and the B-link 4-2-1-2 is connected to the single-layer space frame backup structure 3, and the other end thereof is connected to the dual-joint support 4-2-3. The unidirectional rod 4-2-2 has an adjustable length and provided with spherical hinges at two ends thereof, wherein one end is connected to the single-layer space frame backup structure 3, and the other end is connected to the single-joint support 4-2-4.

[0053] As illustrated in Fig. 9, an adjustment amount of the panel by the adjustment mechanism 4-2 may be calculated in the following equations:

$$\Delta L_{Ax} = \sqrt{(L\sin\alpha + \Delta x)^2 + (L\cos\alpha)^2} - L$$

$$\Delta L_{Bx} = L - \sqrt{(L\sin\alpha - \Delta x)^2 + (L\cos\alpha)^2}$$

wherein ΔL_{Ax} is an adjustment amount of the A-link in an x direction, ΔL_{Bx} is an adjustment amount of the B-link in the x direction, L is an initial length of the A-link and the B-link, α is a half angle between the A-link and the B-link, and Δx is an adjustment amount of the given panel in the x-direction;

$$\Delta L_y = L - \sqrt{(L\cos\alpha - \Delta y)^2 + (L\sin\alpha)^2}$$

wherein ΔL_y is an adjustment amount of the A-link and the B-link in a y-direction; and Δy is an adjustment amount of the given panel in the y-direction;

$$\Delta R_x = R - \sqrt{(R\cos\beta - \Delta x)^2 + (R\sin\beta)^2}$$

$$\Delta R_y = \sqrt{(R\sin\beta + \Delta y)^2 + (R\cos\beta)^2} - R$$

wherein ΔR_x is an adjustment amount of the unidirectional rod in the x-direction, ΔR_y is an adjustment amount of the unidirectional rod in the y-direction, R is an initial length of the unidirectional rod, β is an included angle between the unidirectional rod and a horizontal axis, Δx is an adjustment amount of the given panel in the x-direction, and Δy is an adjustment amount of the given panel in the y-direction.

[0054] A ratio of a maximum curved surface area to a minimum curved surface area among the N-polygonal panel 2-1 and the N sectorial panels 2-2 is 1 to 1.3.

[0055] In this example, the ratio of the maximum curved surface area to the minimum curved surface area among the pentagonal panel 2-1 and five sectorial panels 2-2 is 1.1.

[0056] As illustrated in Fig. 10, an intermediate threaded structure of the main adjustment rod 1-3 and the auxiliary adjustment rod 1-4 has an adjustable length and has left-handed and right-handed threads in combination. The spherical hinges at the two ends of each of the primary adjustment rod 1-3 and the auxiliary adjustment rod 1-4 are ball bearings.

[0057] As illustrated in Fig. 11, the inner ring rods 3-1-1 to 3-1-5, the movable platform rods 1-1-1 to 1-1-10, the main rod 3-2 and the diagonal rod 3-3 each comprises a circular tube, a conical head, a high-strength bolt and a screw nut.

[0058] An intermediate threaded structure of the A-link 4-2-1-1, the B-link 4-2-1-2 and the unidirectional rod 4-2-2 has an adjustable length and has left-handed and right-handed threads in combination.

[0059] The screw nut 4-1-5, the spherical washers 4-1-6 and the conical washers 4-1-7 are symmetrically distributed on two sides of the first direction connection plate 4-1-3.

[0060] The dual-joint support 4-2-3 is located at a center of gravity of the antenna panel and connected thereto through a fastener or glue. The single-joint support 4-2-4 is located under the antenna panel and connected thereto through a fastener or glue.

[0061] A gap between the N-polygonal panel 2-1 and the N sectorial panels 2-2 constituting the sub-reflector 2 is 0.2 to 5 mm.

[0062] In this example, the gap between the pentagonal panel 2-1 and five sectorial panels 2-2 is 2 mm.

[0063] The adjustment principle of the sub-reflector device of the present invention is as follows:

(1) Primary adjustment. Firstly, measuring the main reflector to determine adjustment information of the sub-reflector, which mainly includes displacement adjustment amount and rotation adjustment amount; performing a gradation process on the adjustment information of the sub-reflector to obtain primary adjustment values of the displacement adjustment amount and the rotation adjustment amount; rotating the primary adjustment rod and the auxiliary adjustment rod to adjust the displacement amount and the rotation amount of the sub-reflector , until reaching the primary adjustment values of the displacement adjustment amount and the rotation adjustment amount.

(2) Secondary adjustment. Determining secondary adjustment information based on residuals after the primary adjustment; adjusting the positioning mechanism and the adjustment mechanism of the central N-polygonal panel to meet the requirement of the secondary adjustment amount; and adjusting the positioning mechanisms and the adjustment mechanisms of N peripheral sectorial panels respectively, to make the whole sub-reflector meet the requirement of the surface accuracy specification.

[0064] The advantages of the panel precise adjustment device adopted in the present invention can be further illustrated by the following simulation analysis.

(1) Model illustration. In order to illustrate the advantageous effects of the present invention, two mechanical simulation models are established, wherein one is the background art, and the other is the method of the present invention. The geometric sizes, materials and boundary conditions of the panels in the two simulation models are the same. During the operation of the antenna, 70% of the external load comes from gravity. Therefore, according to the two models, two representative working conditions are selected, i.e., an x-direction gravity analysis and a y-direction gravity analysis.

(2) Calculation results. As illustrated in Figs. 12 to 15, Figs. 12 and 13 are gravity deformation diagrams of an antenna

panel in x-direction and y-direction in the background art, respectively. Figs. 14 and 15 are gravity deformation diagrams of an antenna panel in x-direction and y-direction in the present invention, respectively.

(3) Implementation effects. As illustrated in Table 1, it can be seen from the calculation results that in the background art, a maximum gravity deformation of the panel in the x-direction is 61.5 μm and a maximum gravity deformation thereof in the y-direction is 49.9 μm. In the present invention, a maximum gravity deformation of the panel in the x-direction is 27.1 μm, and a maximum gravity deformation thereof in the y-direction is 24.5 μm. Since the adjustment mechanism in the present invention includes a lateral support to the panel, the deformation of the panel is greatly improved, and the deformations in the x-direction and y-direction are substantially equal, with a change rate of only 9.6%, while in the background art the change rate is 18.9%. Compared with the background art, improvement rates of the maximum deformations of the panel in the x-direction and y-direction are 55.9% and 50.9% respectively in the present invention.

Table 1 Comparison of gravity deformation results of panels in the present invention and the background art

Compared content	Background art	Method of the present invention
Maximum gravity deformation in x-direction	61.5μm	27.1μm
Maximum gravity deformation in y-direction	49.9μm	24.5μm
Relative rate of x\y deformations in the background art	18.9%	
Relative rate of x\y deformations in the present invention	9.6%	
Maximum deformation improvement rate in the present invention	Gravity in x-direction	55.9%
	Gravity in y-direction	50.9%

[0065] The final implementation effect of the present invention is further illustrated by a mechanical simulation analysis:

(1) Calculation content. The calculation content is the gravity deformation of the sub-reflector of the dual-offset antenna in the elevation range of 0° to 90°. The calculated elevation angles comprise 0°, 15°, 30°, 45°, 50°, 60°, 75° and 90°.

(2) Calculation results. According to the calculated deformation data of the sub-reflector, a precision analysis is carried out to obtain the surface accuracy of the sub-reflector at different elevation angles. Figs. 16 and 17 are gravity deformation diagrams of a sub-reflector at different elevation angles, and Fig. 18 illustrates surface accuracy of a sub-reflector at different elevation angles. From the calculation results, it can be seen that the surface accuracy of the sub-reflector is greater than 52 μm in the elevation range of 0° to 90°, which is very suitable for the dual-offset antenna working in a high frequency band.

[0066] To sum up, the sub-reflector device of the present invention comprises an adjustment device, a sub-reflector, a single-layer space frame backup structure and a panel precise adjustment device. The adjustment device adopts movable and fixed platforms as a multi-rod six-degree-of-freedom sub-reflector adjustment mechanism for a plane truss to realize a primary pose adjustment of the sub-reflector. The sub-reflector is composed of a polygonal panel and several sectorial panels, and an area of each sectorial panel is substantially equal to that of the polygonal panel. The numbers of inner and outer sides of the single-layer space frame backup structure is in a ratio of 1: 2, which provides a support stiffness for the sub-reflector. The panel precise adjustment device comprises a positioning mechanism for adjusting the panel in a normal direction and an adjustment mechanism for adjusting a movement of the sub-reflector. Such a sub-reflector device not only realizes a two-stage position and pose adjustment of the sub-reflector, but also improves the integral stiffness and reduces the overall weight of the sub-reflector system, while improving the installation and adjustment efficiency and reducing the manufacturing cost.

[0067] Described above is merely preferred embodiments of the present invention, rather than limitations thereto. Any modifications, variation or equivalent structural change made to the above embodiments without departing from the concepts and principles of this invention shall fall within the scope of the present invention.

Claims

1. A uniformly-partitioned high-precision sub-reflector device with a two-stage position and pose adjustment function,

comprising an adjustment device (1), a sub-reflector (2), a single-layer space frame backup structure (3) and a panel precise adjustment device (4);

wherein the adjustment device (1) is located in a direction of an aperture of the sub-reflector (2) and comprises a movable platform (1-1), a fixed platform (1-2), a primary adjustment rod (1-3), an auxiliary adjustment rod (1-4), a movable platform spherical joint (1-5) and a fixed platform spherical joint (1-6); the movable platform (1-1) is connected to the single-layer space frame backup structure (3), and the fixed platform (1-2) is located outside the aperture of the sub-reflector (2); the fixed platform (1-2) is a plane truss structure with an N-polygonal shape, wherein N is a natural number and N≥4; the fixed platform (1-2) is composed of N fixed platform rods (1-2-1 to 1-2-N), every two of which are connected by the fixed platform spherical joint (1-6); the movable platform (1-1) is a plane truss structure with a 2N-polygonal shape, and is composed of 2N movable platform rods (1-1-1 to 1-1-2N), every two of which are connected by the movable platform spherical joint (1-5); the movable platform rod (1-1-1 to 1-1-2N), the fixed platform rod (1-2-1 to 1-2-N), the primary adjustment rod (1-3) and the auxiliary adjustment rod (1-4) form a mesh structure with a plurality of triangular space regions;
the sub-reflector (2) is composed of an N-polygonal panel (2-1) and N sectorial panels (2-2), with the N sectorial panels (2-2) being radially distributed around the N-polygonal panel (2-1) and each having an area substantially equal to that of the N-polygonal panel (2-1), and the sub-reflector (2) being connected to the single-layer space frame backup structure (3) through the panel precise adjustment device (4);
the single-layer space frame backup structure (3) is composed of an inner ring support (3-1), a main rod (3-2), a diagonal rod (3-3) and an inner ring spherical joint (3-4); wherein the inner ring support (3-1) has an N-polygonal shape and is composed of N inner ring rods (3-1-1 to 3-1-N), every two of which are connected to each other through the inner ring spherical joint (3-4); the inner ring rod (3-1-1), the movable platform rod (1-1-1 to 1-1-2N), the main rod (3-2) and the diagonal rod (3-3) form a mesh structure with a plurality of triangular space regions;
the panel precise adjustment device (4) comprises a positioning mechanism (4-1) and an adjustment mechanism (4-2), with the positioning mechanism (4-1) being located at connection points between the N-polygonal panel (2-1) and the inner ring spherical joint (3-4) of the single-layer space frame backup structure (3), and connection points between the N sectorial panels (2-2) and the inner ring spherical joint (3-4) of the single-layer space frame backup structure (3); and the adjustment mechanism (4-2) being located at a non-working side of an antenna panel.

2. The uniformly-partitioned high-precision sub-reflector device according to claim 1, wherein an included angle between a plane where the movable platform (1-1) is located and a plane where the fixed platform (1-2) is located is 0° to 30°.

3. The uniformly-partitioned high-precision sub-reflector device according to claim 2, wherein at least one of the N fixed platform spherical joints (1-6) is corresponding to the movable platform spherical joint (1-5).

4. The uniformly-partitioned high-precision sub-reflector device according to claim 3, wherein the primary adjustment rod (1-3) is composed of N rod, with two ends connected to the movable platform spherical joint (1-5) and the fixed platform spherical joint (1-6), respectively, and the number of the primary adjustment rods (1-3) is N.

5. The uniformly-partitioned high-precision sub-reflector device according to claim 4, wherein two ends of the auxiliary adjustment rod (1-4) are connected to the movable platform spherical joint (1-5) and the fixed platform spherical joint (1-6), respectively, and the number of the auxiliary adjustment rods (1-4) is 2N.

6. The uniformly-partitioned high-precision sub-reflector device according to claim 5, wherein each of the primary adjustment rod (1-3) and the auxiliary adjustment rod (1-4) comprises spherical hinges located at the two ends thereof, and a threaded structure with an adjustable length located in the middle thereof.

7. The uniformly-partitioned high-precision sub-reflector device according to claim 6, wherein the inner ring support (3-1) and the movable platform (1-1) are respectively located in two planes with a distance of 500 mm to 3000 mm therebetween.

8. The uniformly-partitioned high-precision sub-reflector device according to claim 7, wherein at least one of the N inner ring spherical joints (3-4) is corresponding to the movable platform spherical joint (1-5).

9. The uniformly-partitioned high-precision sub-reflector device according to claim 8, wherein two ends of the main rod (3-2) are connected to the inner ring spherical joint (3-4) and the movable platform spherical joint (1-5), respec-

tively, and the number of the main rods (3-2) is N.

10. The uniformly-partitioned high-precision sub-reflector device according to claim 9, wherein two ends of the diagonal rod (3-3) are connected to the inner ring spherical joint (3-4) and the movable platform spherical joint (1-5), respectively, and the number of the diagonal rods (3-3) is 2N.

11. The uniformly-partitioned high-precision sub-reflector device according to claim 10, wherein the positioning mechanism (4-1) is composed of a main supporting rod (4-1-1), an independent supporting rod (4-1-2), a first direction connection plate (4-1-3), a second direction connection plate (4-1-4), a screw nut (4-1-5), a spherical washer (4-1-6) and a conical washer (4-1-7); wherein an axial direction of the main supporting rod (4-1-1) is the same as a normal direction of the panel at the position of the main supporting rod (4-1-1); the first direction connection plate (4-1-3) is connected to the single-layer space frame backup structure (3) through the main supporting rod (4-1-1); the second direction connection plate (4-1-4) is connected to the panel through a fastener or glue; and the independent supporting rod (4-1-2) is located between the first direction connection plate (4-1-3) and the second direction connection plate (4-1-4).

12. The uniformly-partitioned high-precision sub-reflector device according to claim 11, wherein the first direction connection plate (4-1-3) and the second direction connection plate (4-1-4) are provided with oblong holes having extending directions orthogonal to each other.

13. The uniformly-partitioned high-precision sub-reflector device according to claim 12, wherein an upper end of the independent supporting rod (4-1-2) is located in the oblong hole of the second direction connection plate (4-1-4) and fixed by the screw nut (4-1-5), and a lower end of the independent supporting rod (4-1-2) is located in the oblong hole of the first direction connection plate (4-1-3) and fixed by the screw nut (4-1-5), the spherical washer (4-1-6), and the conical washer (4-1-7).

14. The uniformly-partitioned high-precision sub-reflector device according to claim 13, wherein the adjustment mechanism (4-2) is composed of a V-shaped rod (4-2-1), a unidirectional rod (4-2-2), a dual-joint support (4-2-3) and a single-joint support (4-2-4); wherein the V-shaped rod (4-2-1) comprises an A-link (4-2-1-1) and a B-link (4-2-1-2) with adjustable lengths and each having spherical hinges at two ends; one end of each of the A-link (4-2-1-1) and the B-link (4-2-1-2) is connected to the single-layer space frame backup structure (3), and the other end thereof is connected to the dual-joint support (4-2-3); the unidirectional rod (4-2-2) has an adjustable length and provided with spherical hinges at two ends thereof, wherein one end is connected to the single-layer space frame backup structure (3), and the other end is connected to the single-joint support (4-2-4).

15. The uniformly-partitioned high-precision sub-reflector device according to claim 14, wherein an adjustment amount of the panel by the adjustment mechanism (4-2) satisfies the following equations:

$$\Delta L_{Ax} = \sqrt{(L\sin\alpha + \Delta x)^2 + (L\cos\alpha)^2} - L$$

$$\Delta L_{Bx} = L - \sqrt{(L\sin\alpha - \Delta x)^2 + (L\cos\alpha)^2}$$

wherein ΔL_{Ax} is an adjustment amount of the A-link in an x direction, ΔL_{Bx} is an adjustment amount of the B-link in the x direction, L is an initial length of the A-link and the B-link, α is a half angle between the A-link and the B-link, and Δx is an adjustment amount of the given panel in the x-direction;

16. The uniformly-partitioned high-precision sub-reflector device according to claim 15, wherein an adjustment amount of the A-link and the B-link in a y-direction satisfies the following equation:

$$\Delta L_y = L - \sqrt{(L\cos\alpha - \Delta y)^2 + (L\sin\alpha)^2}$$

wherein ΔL_y is an adjustment amount of the A-link and the B-link in a y-direction; and Δy is an adjustment amount of the given panel in the y-direction;

17. The uniformly-partitioned high-precision sub-reflector device according to claim 16, wherein an adjustment amount of the unidirectional rod in the x-direction and an adjustment amount of the unidirectional rod in the y-direction satisfy the following equations:

$$\Delta R_x = R - \sqrt{(R\cos\beta - \Delta x)^2 + (R\sin\beta)^2}$$

$$\Delta R_y = \sqrt{(R\sin\beta + \Delta y)^2 + (R\cos\beta)^2} - R$$

wherein ΔR_x is an adjustment amount of the unidirectional rod in the x-direction, ΔR_y is an adjustment amount of the unidirectional rod in the y-direction, R is an initial length of the unidirectional rod, β is an included angle between the unidirectional rod and a horizontal axis, Δx is an adjustment amount of the given panel in the x-direction, and Δy is an adjustment amount of the given panel in the y-direction.

18. The uniformly-partitioned high-precision sub-reflector device according to claim 17, wherein a ratio of a maximum curved surface area to a minimum curved surface area among the N-polygonal panel (2-1) and the N sectorial panels (2-2) is 1 to 1.3.

19. The uniformly-partitioned high-precision sub-reflector device according to claim 18, wherein an intermediate threaded structure of the primary adjustment rod (1-3) and the auxiliary adjustment rod (1-4) has an adjustable length and has left-handed and right-handed threads in combination.

20. The uniformly-partitioned high-precision sub-reflector device according to claim 19, wherein the spherical hinges at the two ends of each of the primary adjustment rod (1-3) and the auxiliary adjustment rod (1-4) are ball bearings.

21. The uniformly-partitioned high-precision sub-reflector device according to claim 20, wherein the inner ring rod (3-1-1 to 3-1-N), the movable platform rod (1-1-1 to 1-1-2N), the main rod (3-2) and the diagonal rod (3-3) each comprises a circular tube, a conical head, a high-strength bolt and a screw nut.

22. The uniformly-partitioned high-precision sub-reflector device according to claim 21, wherein an intermediate threaded structure of the A-link (4-2-1-1), the B-link (4-2-1-2) and the unidirectional rod (4-2-2) has an adjustable length and has left-handed and right-handed threads in combination.

23. The uniformly-partitioned high-precision sub-reflector device according to claim 22, wherein the screw nut (4-1-5), the spherical washer (4-1-6) and the conical washer (4-1-7) are symmetrically distributed on two sides of the first direction connection plate (4-1-3).

24. The uniformly-partitioned high-precision sub-reflector device according to claim 23, wherein the dual-joint support (4-2-3) is located at a center of gravity of the antenna panel and connected thereto through a fastener or glue; and the single-joint support (4-2-4) is located under the antenna panel and connected thereto through a fastener or glue.

25. The uniformly-partitioned high-precision sub-reflector device according to claim 24, wherein a gap between the N-polygonal panel (2-1) and the N sectorial panels (2-2) constituting the sub-reflector (2) is 0.2 mm to 5 mm.

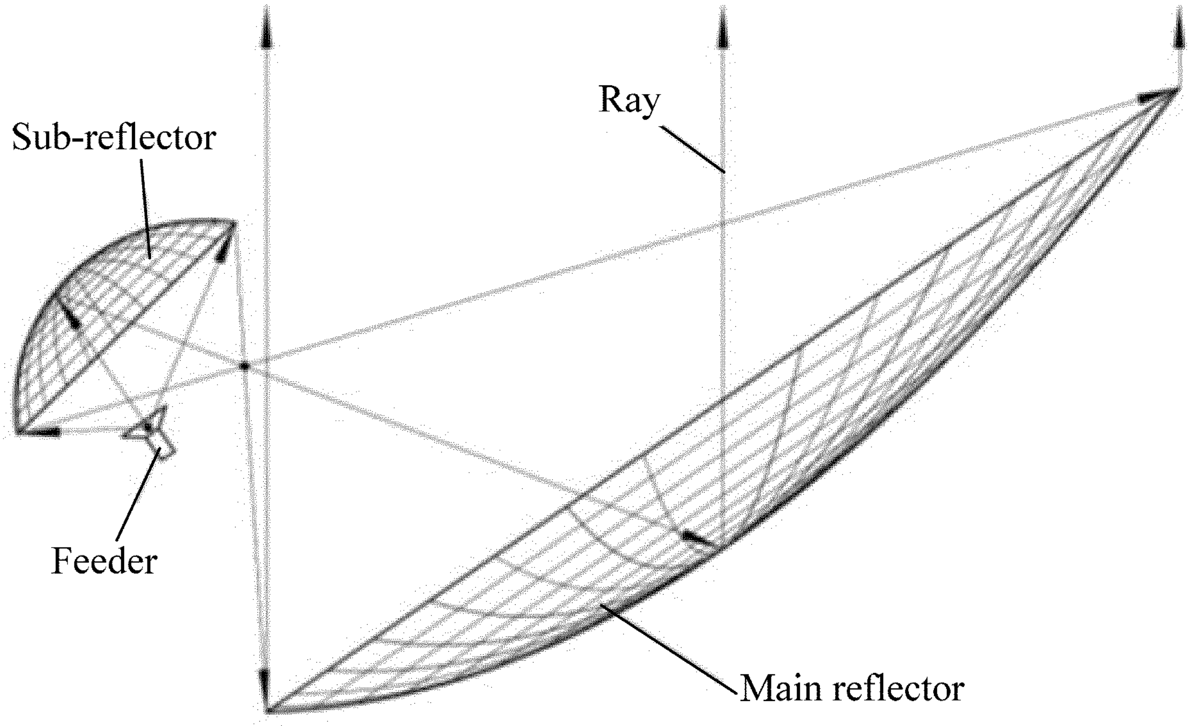


FIG. 1

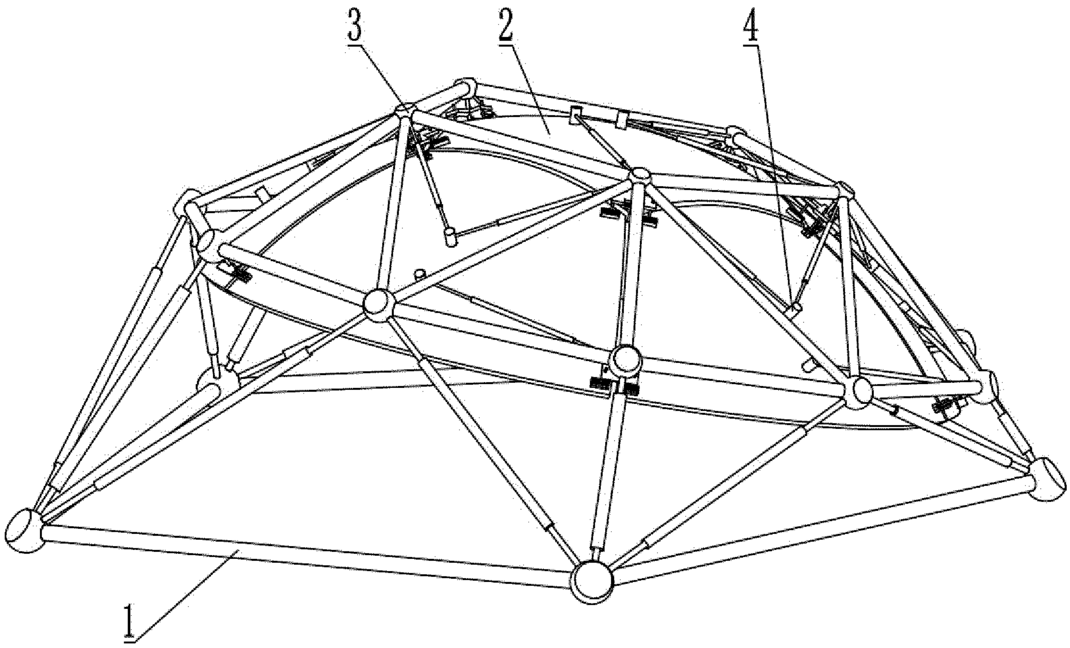
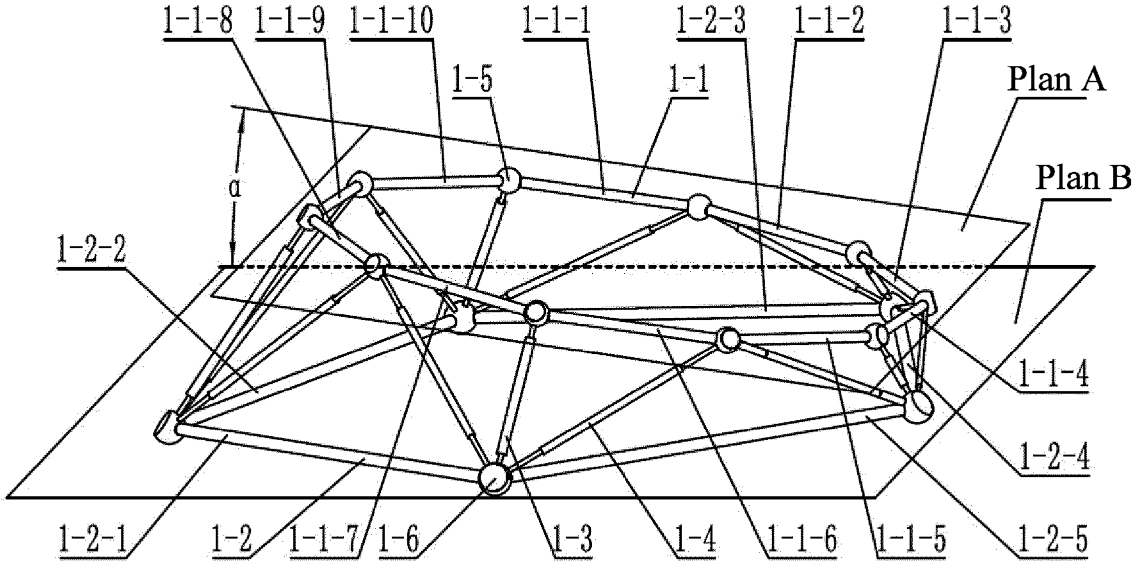


FIG. 2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Plan B
α
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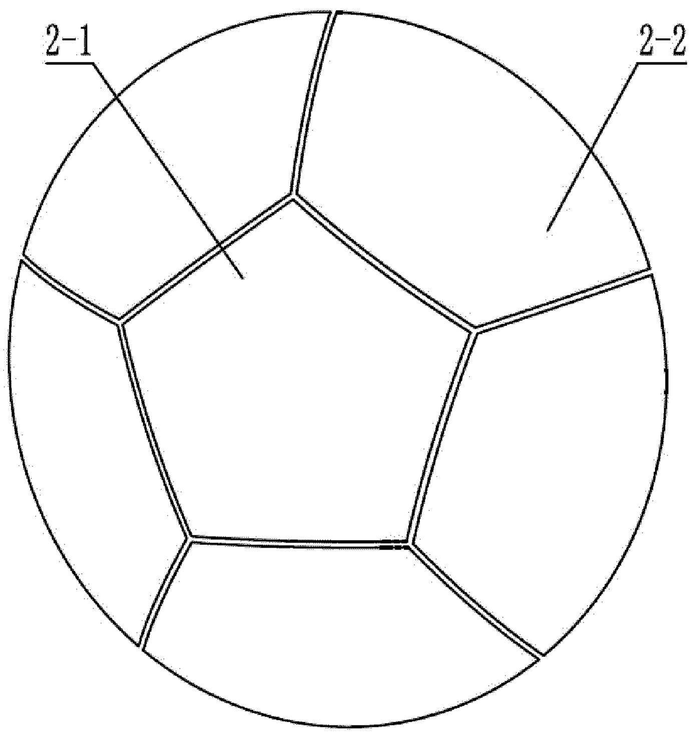
FIG. 3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2-2

FIG. 4

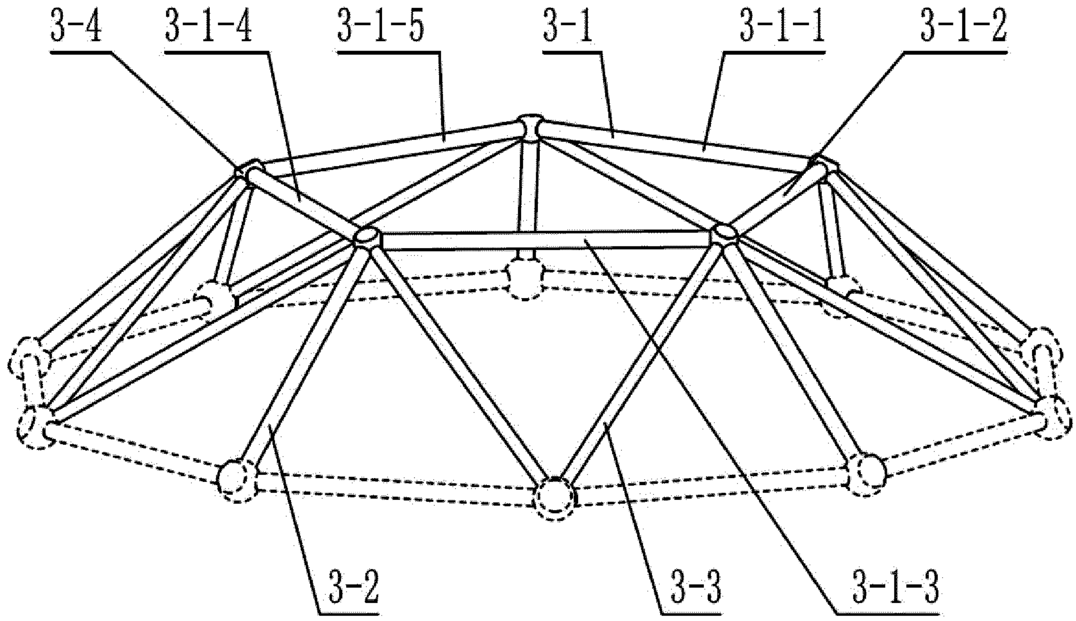

FIG. 5

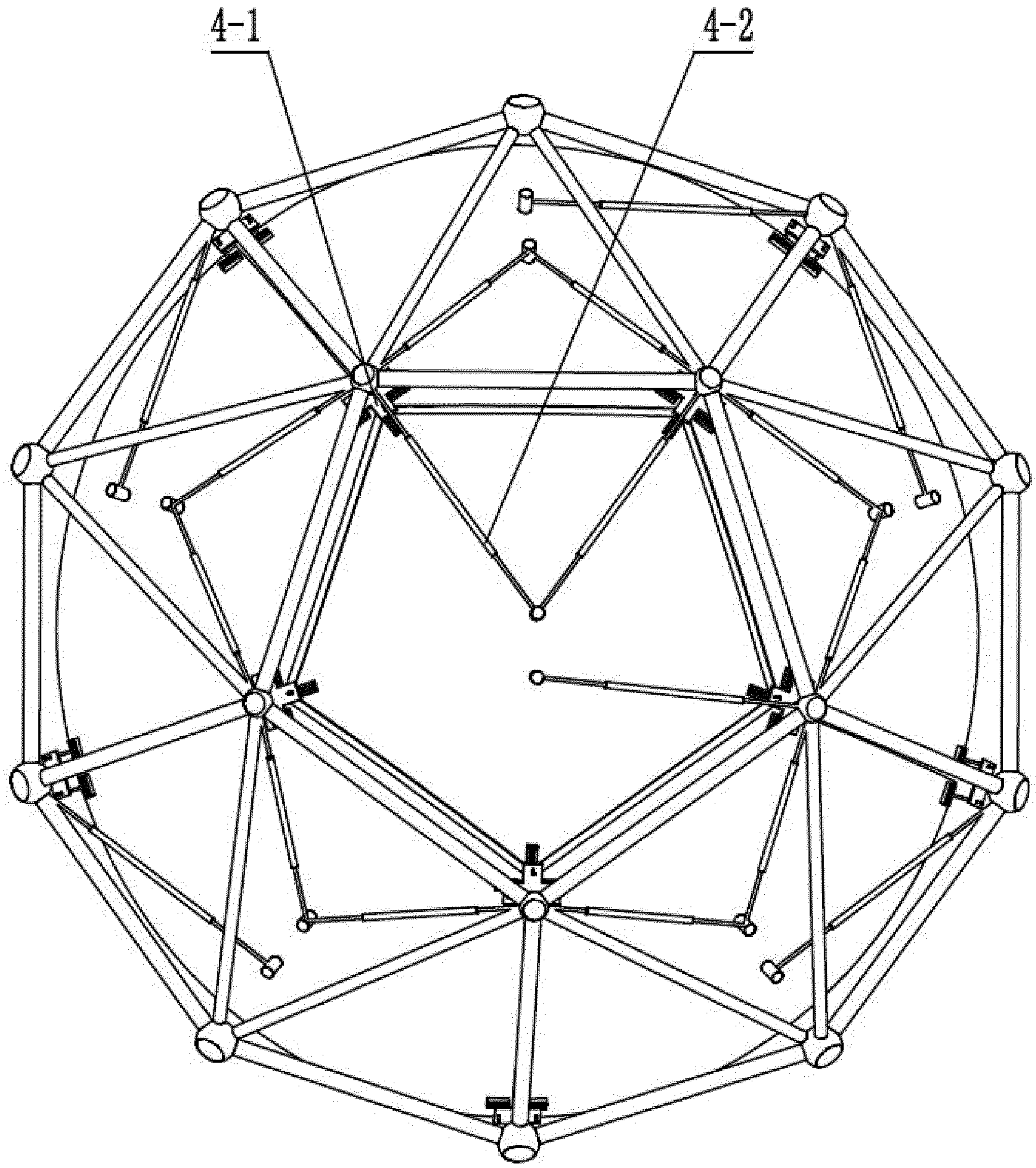

FIG. 6

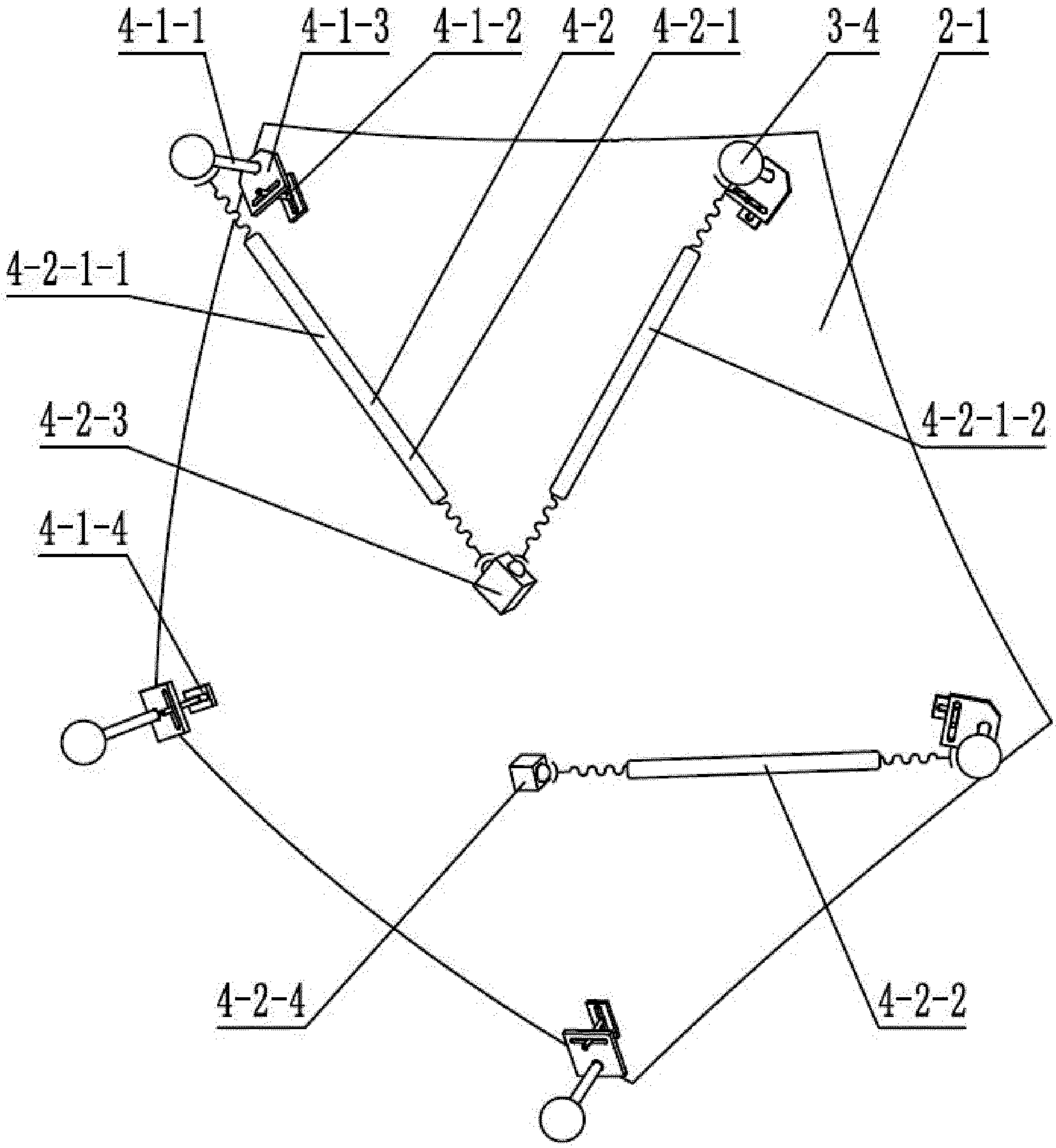

FIG. 7

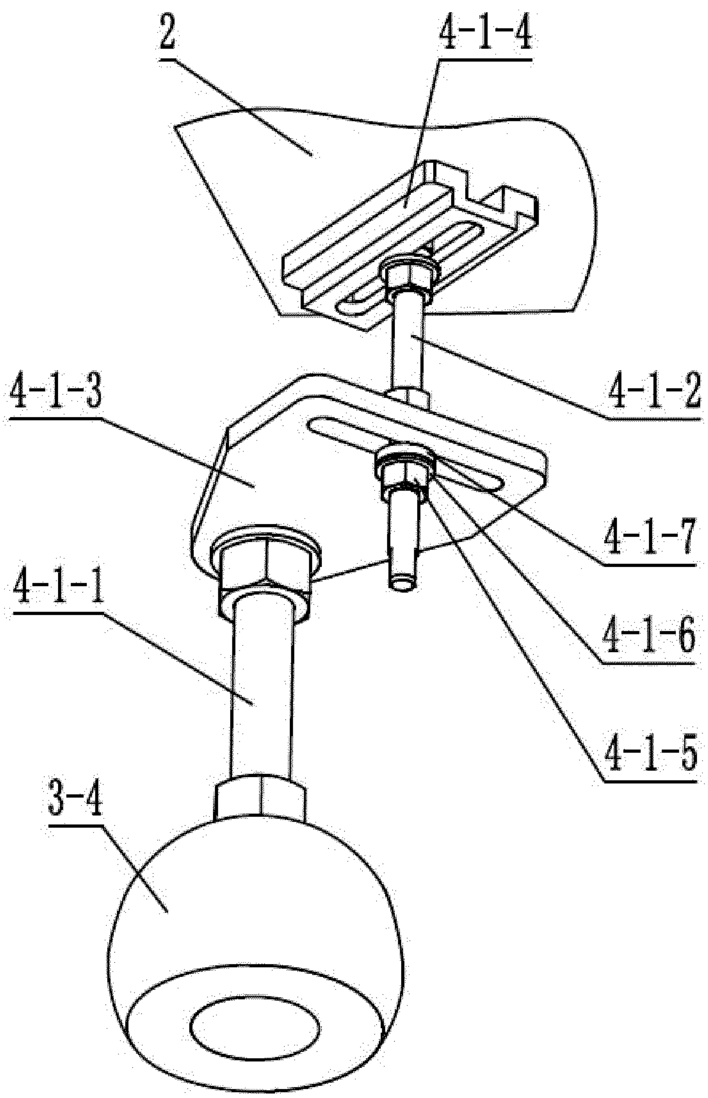

FIG. 8

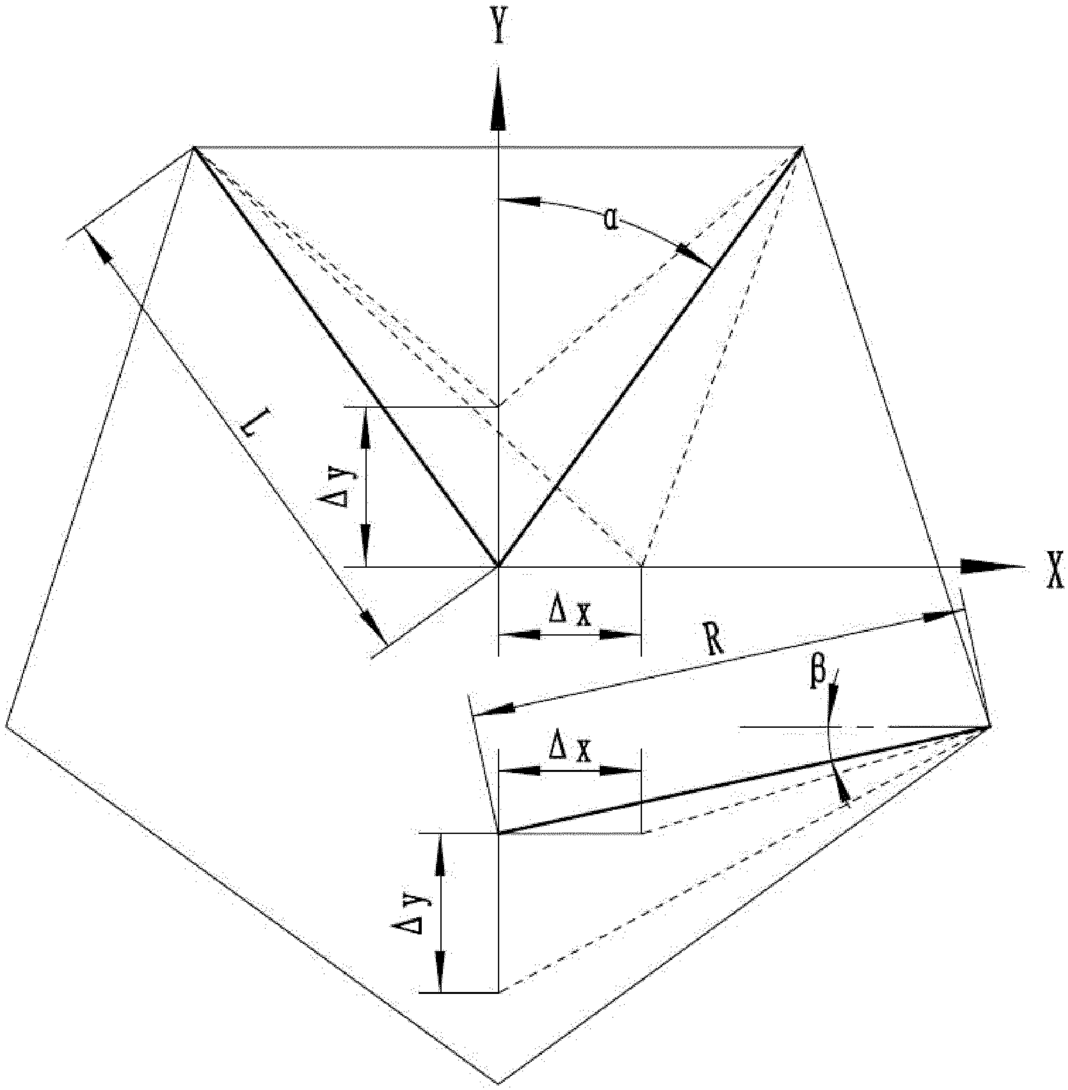

FIG. 9

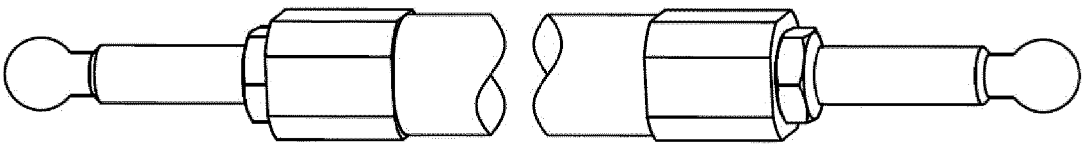
FIG. 10

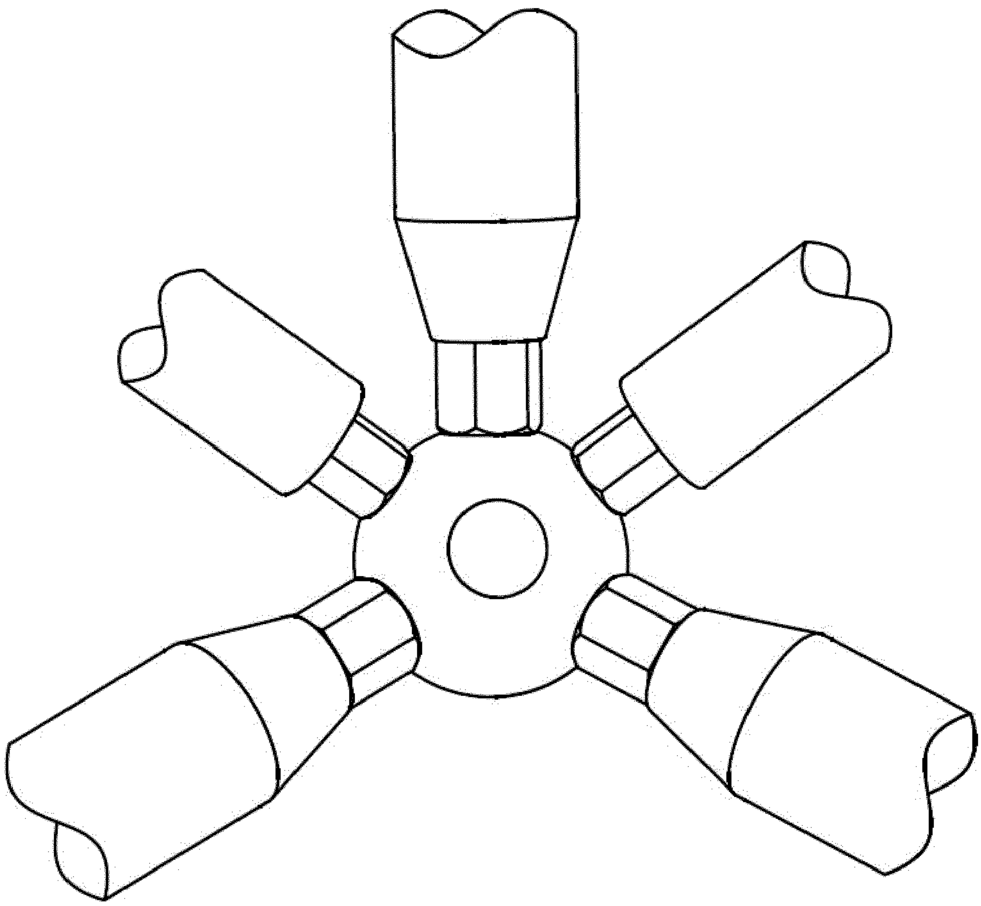

FIG. 11

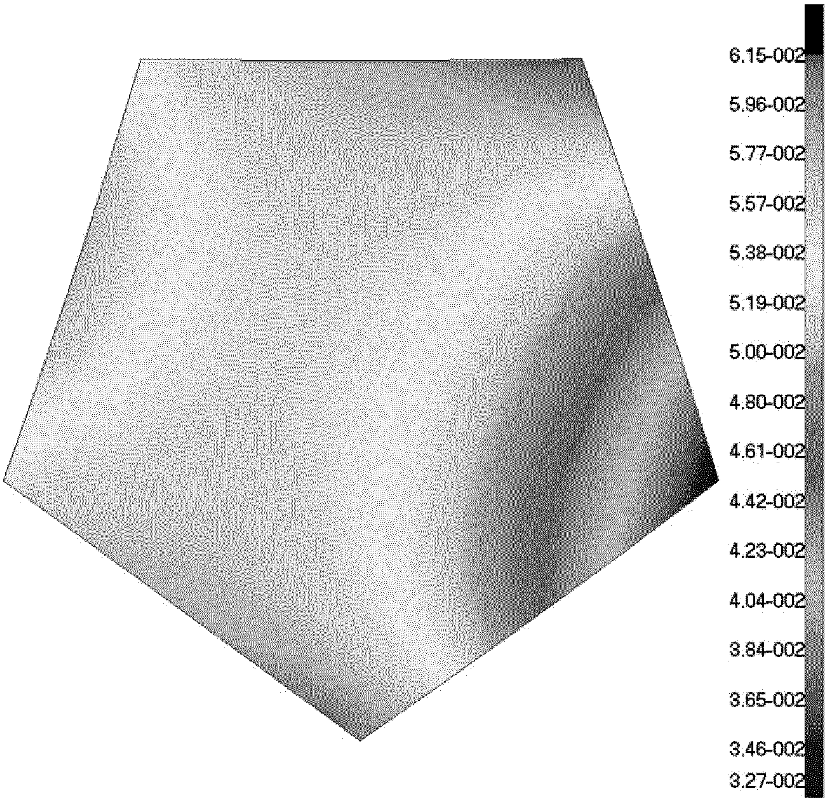
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FIG. 12

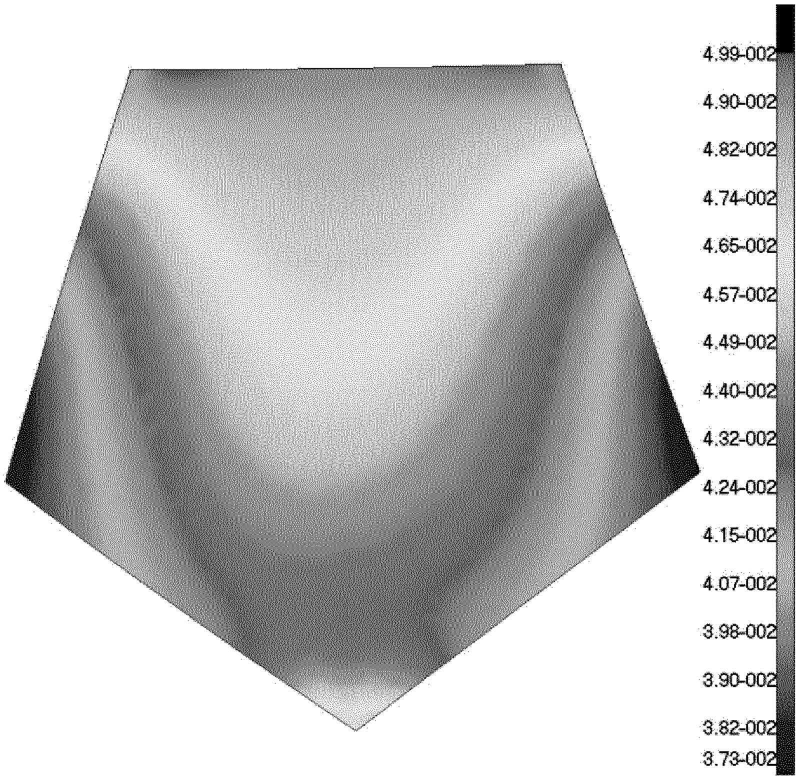
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FIG. 13

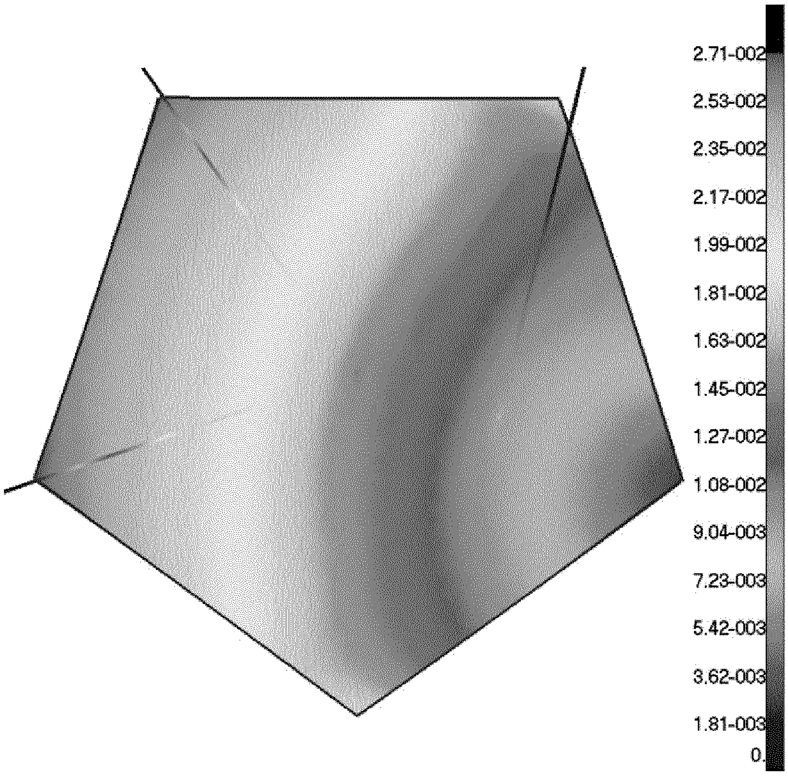
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FIG. 14

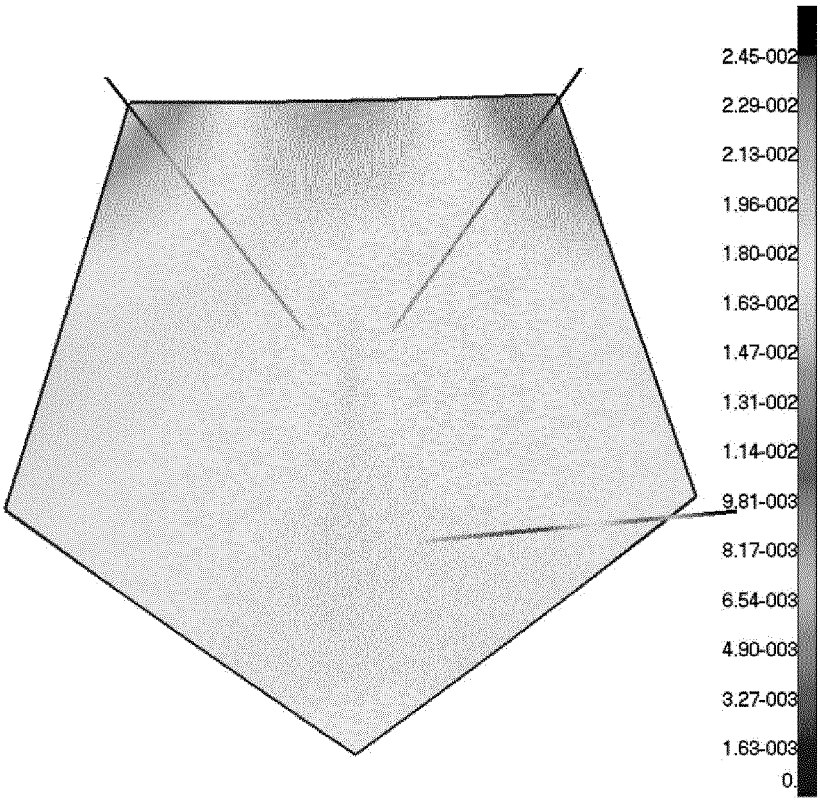
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FIG. 15

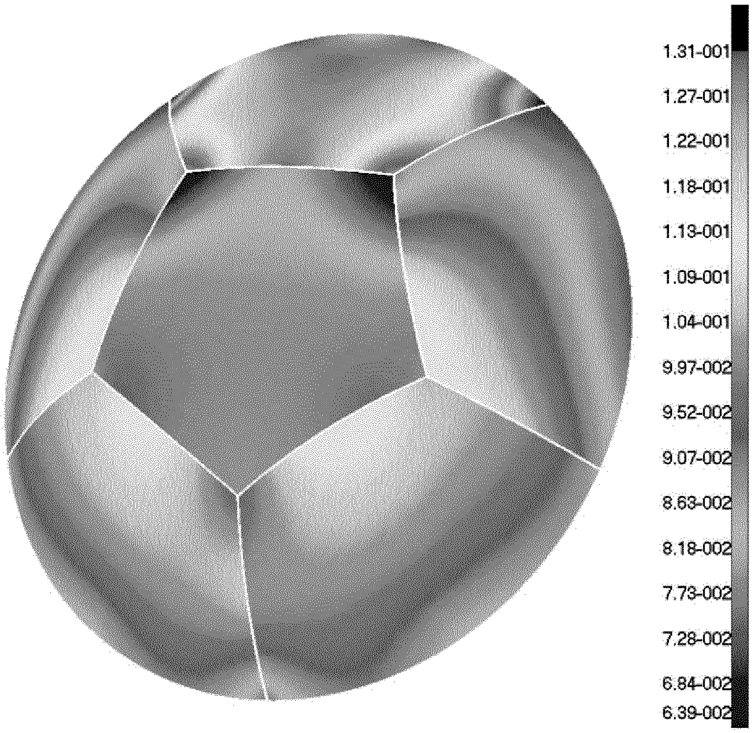

1.31-001
1.27-001
1.22-001
1.18-001
1.13-001
1.09-001
1.04-001
9.97-002
9.52-002
9.07-002
8.63-002
8.18-002
7.73-002
7.28-002
6.84-002
6.39-002

FIG. 16

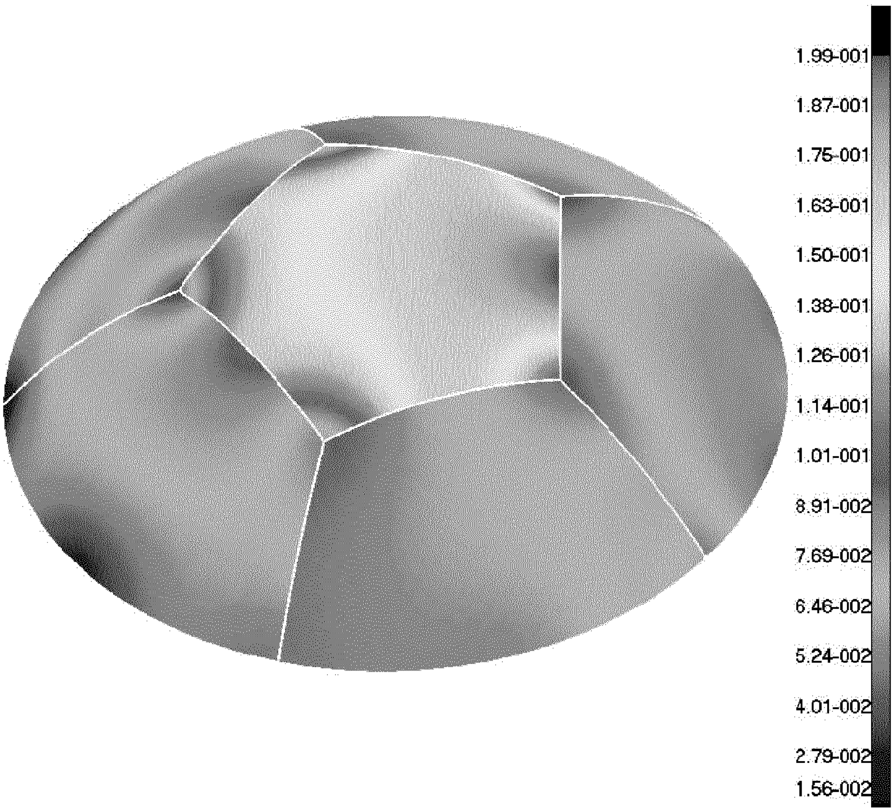
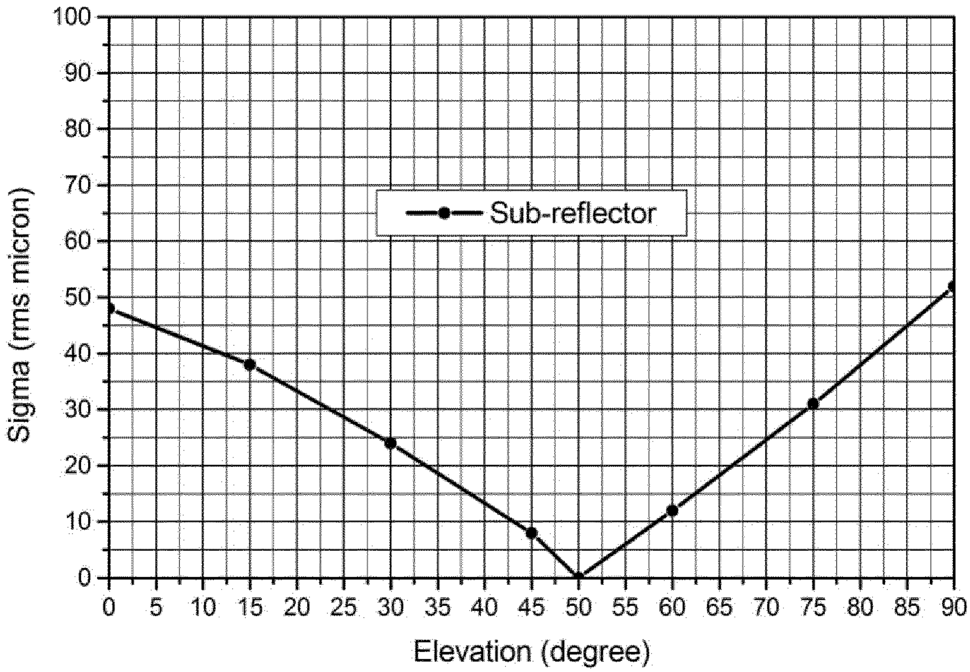

1.99-001
1.87-001
1.75-001
1.63-001
1.50-001
1.38-001
1.26-001
1.14-001
1.01-001
8.91-002
7.69-002
6.46-002
5.24-002
4.01-002
2.79-002
1.56-002

FIG. 17



100
90
80
70
60
50
40
30
20
10
0
Sigma (rms micron)
Sub-reflector
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
Elevation (degree)

FIG. 18

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2019/125478

A. CLASSIFICATION OF SUBJECT MATTER

H01Q 15/16(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01Q

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

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

CNKI; CNPAT; WPI; EPODOC: 副反射面, 天线, 位姿, 调整, 桁架, 定平台, 动平台, 杆, 球, 扇形, 三角, 网, secondary, reflecting, surface, antenna, posture, adjust, joist, moving, fixed, platform, pole, ball, sector, triangle, net

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 110289498 A (THE 54TH RESEARCH INSTITUTE OF CHINA ELECTRONICS TECHNOLOGY GROUP CORPORATION) 27 September 2019 (2019-09-27) claims 1-25	1-25
A	CN 202712431 U (THE 54TH RESEARCH INSTITUTE OF CHINA ELECTRONICS TECHNOLOGY GROUP CORPORATION) 30 January 2013 (2013-01-30) description, paragraph 7, and figure 1	1-25
A	CN 109301452 A (INST REMOTE SENSING & DIGITAL EARTH CAS) 01 February 2019 (2019-02-01) entire document	1-25
A	US 10241321 B1 (SCIPERIO INC.) 26 March 2019 (2019-03-26) entire document	1-25

☐ Further documents are listed in the continuation of Box C.

☑ See patent family annex.

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

Date of the actual completion of the international search	Date of mailing of the international search report
03 April 2020	**24 April 2020**

Name and mailing address of the ISA/CN	Authorized officer
China National Intellectual Property Administration (ISA/CN) **No. 6, Xitucheng Road, Jimenqiao Haidian District, Beijing 100088** **China**	
Facsimile No. **(86-10)62019451**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2019/125478

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	110289498	A	27 September 2019	CN	210040562	U	07 February 2020
CN	202712431	U	30 January 2013	None			
CN	109301452	A	01 February 2019	CN	208835260	U	07 May 2019
US	10241321	B1	26 March 2019	None			

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- CN 105226370 A **[0008]**
- CN 106450653 A **[0008]**
- CN 202004142 U **[0009]**
- CN 108172970 A **[0009]**
- CN 108155482 A **[0009]**