

# Flat Facet Parabolic Solar Concentrator With Support Cell for One and More Mirrors

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*Abstract:* - Parabolic dish solar concentrators are very expensive devices with a cost of up to a half of the total cost of a solar power station. The specific technology of parabolic mirror manufacturing makes the decrease of the cost very problematic. Even in mass production the cost of a parabolic mirror is estimated as \$500 per square meter. There is another way to make a parabolic concentrator by approximating a parabolic surface with large number of small flat mirrors. We created a small prototype of this type of solar concentrator which contains 24 flat mirrors in the form of equilateral triangles with side length of 50mm. This prototype has special nuts to adjust the positions of the nodes in the points of connections of the apexes. These nuts make it possible to approximate the parabolic shape in an easy and inexpensive way.

*Key-Words:* - Solar Concentrator, Flat Mirrors, Recognition System

## 1 Introduction

It is possible to reduce the cost of a parabolic dish approximating the parabolic shape with a number of small flat mirrors (facets). This approach was tested in 1982 in Australia where 14 parabolic dishes of 20 square meters each were created [1]. Each dish consisted of approximately 2300 rectangular flat mirrors. The concentration rate of 970 suns was obtained. Unfortunately, the parabolic surface for those dishes was made of an expensive fiber glass material which had thickness of 6 mm. Moreover, those dishes needed an expensive heavy support frame. We propose micromechanical technology for assembly of support devices from small bars and nodes. The cost estimation of a flat facet parabolic concentrator based on the proposed technology is approximately \$50-60 per square meter [2].

We created a small prototype of this type of solar concentrator which contains 24 flat mirrors in the form of equilateral triangles with side length of 50mm. This prototype has special nuts to adjust the

positions of the nodes in the points of connections of the apexes. These nuts make it possible to approximate the parabolic shape in an easy and inexpensive way. This prototype was created manually. The time estimation of manual assembly gives approximately 30 hours per square meter of parabolic dish. Therefore, it is necessary to develop a fully automated assembly process to obtain low cost concentrators. We have developed several image recognition systems [3], [4] that may be used for this purpose.

Solar energy is one of the most promising sources of energy for use in the future. The main drawback of modern solar plants is high initial cost of the installations. Approximately half of the cost is due to the solar concentrators, especially if parabolic dish solar concentrators are used. The main reason of the high cost is utilization of the specific technology of parabolic glass mirror manufacturing. There are different estimations of the cost of such mirrors. For the world's largest project for a solar dish plant ([5], [6]) solar concentrators with diameters of 37 feet

which corresponds to a surface area of 100 square meters will be used. At present, the cost of one dish prototype is \$150,000. The manufacturer hopes to obtain a cost of approximately \$50,000 per prototype in the near future. Therefore, one square meter will cost approximately \$500. Regardless of the gradual reduction of this cost with time, in our opinion, it will stay above the cost of one square meter of flat mirror because of the well developed and very cheap technology of manufacturing of the latter.

In this paper we propose to approximate a large parabolic surface with small flat mirrors. This idea was realized for the first time in 1982 in Australia [1] using 2300 rectangular flat mirrors of 100x100 mm<sup>2</sup>. The concentration rate of 970 suns was obtained. The resulting parabolic dish is presented in Fig. 1.



Fig. 1. Solar concentrator “White Cliffs” [1]

The main drawback of this concentrator was its support frame manufacturing. It was made of rather expensive fiberglass with thickness of 6 mm. Moreover, this support frame required precise handling of the 20 m<sup>2</sup> parabolic surface, because flat mirrors were glued directly to the fiberglass surface with no option of adjustment of their positions. We propose a support frame that is less expensive and allows adjustment of the positions of small flat mirrors. We suppose that for practical applications all the procedures of support frame assembly and mirror position adjustment will be automated.

## 2 The Proposed Flat Facet Parabolic Dish Concentrator

The structure of the proposed support frame is presented in Fig. 2.

It consists of a lower layer triangular grid, an upper layer triangular grid, triangular mirrors, and bars that connect upper and lower layer triangular grids. An example of a triangular cell of the support frame is presented in Fig. 3. Each cell is used to support one triangular mirror and contains three adjusting screws (Fig. 3). The complete support

frame is presented in Fig. 4.

The prototype of the support frame demonstrated good rigidity and relatively low material consumption. The prototype was made of aluminum bars and its weight is 0.5 kg. It is possible to decrease this weight 3-4 times substituting the aluminum bars by thin wall aluminum tubes. In a large scale prototype the number of bars or tubes to support one triangular mirror is approximately 7.

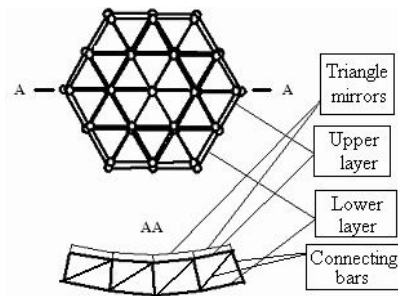


Fig. 2. Structure of a flat facet parabolic dish concentrator

The concentration rate of this type of flat mirror solar concentrator depends on the number of triangular flat mirrors. In [7] we presented the equations for calculations of the concentration rate and approximate cost of this solar concentrator. To calculate the concentration rate we divided the solar concentrator into several zones (Fig. 5). Examples of solar concentrator parameters are presented in Table 1.

Table 1. Examples of flat mirror solar concentrator parameters

Number of zones	Number of mirrors	Triangular side (meters)	Focal distance (meters)	Concentration ratio (suns)
3	54	0.05	0.28	11.5
10	600	0.05	0.933	122
20	2400	0.05	1.866	377
25	3750	0.05	2.332	522
30	5400	0.05	2.8	666.5
40	9600	0.05	3.732	954.2
50	15000	0.05	4.665	1238.6

The cost estimation was made assuming that thin wall steel tubes will be used instead of aluminum bars. This estimation gave us \$55 per square meter assuming that the labor cost is approximately equal to the material cost.

To avoid expensive precision treatment of a large parabolic surface we use adjustment nuts, a gauging plate with holes that correspond to the adjustment nuts, and indicator for distance measurement (Fig. 6). To adjust a nut it is necessary

to insert the indicator into the corresponding hole of the gauging plate and turn the nut until the moment the indicator shows the distance that was calculated for a parabolic surface in this point.

### 3 Advances in Image Recognition for Automatic Assembly

To obtain a low cost solar concentrator it is necessary to produce and assemble all the components automatically. We developed several image recognition methods to facilitate the automatic production and assembly of micro components. These methods were tested in the following tasks:

- recognition of the relative pin-hole position [8],
- micro work piece shape recognition [3],
- mechanically treated metal surface texture recognition [9].

The proposed methodology for recognition of the relative pin-hole position [8] utilizes four light sources and one web-camera. Four light sources produce the shadows of the pin that allow us to

obtain 3D displacements of the pin relative to the hole.

For tolerances of 0.1 mm the pin-hole displacements were recognized with a recognition rate of 99.5% for the horizontal coordinate and 89.9% for the vertical coordinate [8].

The proposed micro work piece shape recognition methodology [3] was tested in the task of recognition of micro screws. 40 screws with a diameter of 3 mm were produced with a computer numerical control (CNC) lathe. Ten screws were produced with the correct position of the cutter (Fig. 8, *b*) and thirty with the incorrect one (Fig.8, *a, c, d*). A mean recognition rate of 92.5% was obtained in recognition of cutter position [3] and was improved to 96.88% [4]. This methodology may be used for intermediate inspection of the work piece during the manufacturing process.

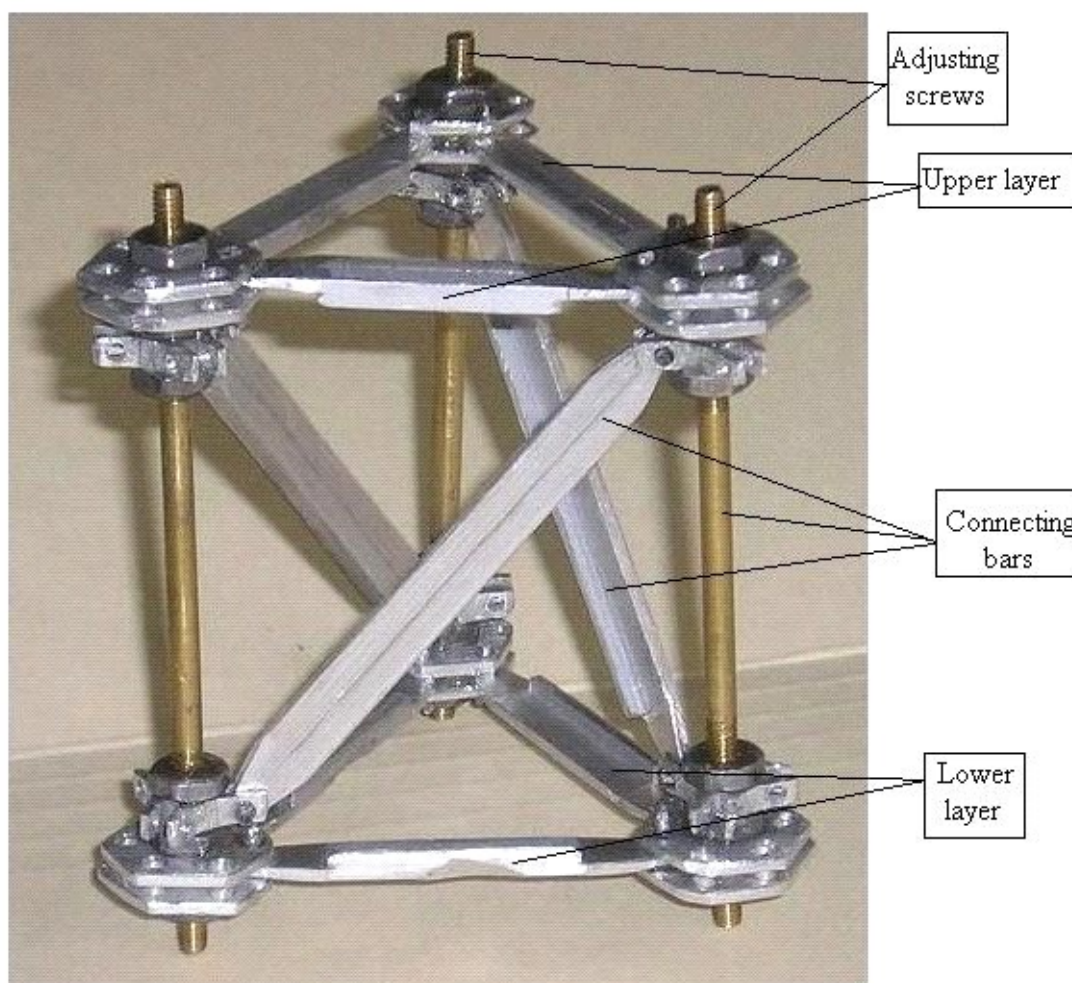


Fig. 3. Example of a triangular cell of the support frame

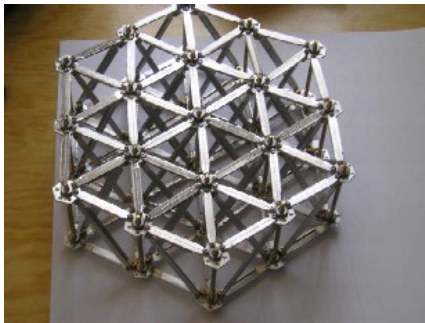


Fig. 4. Complete support frame

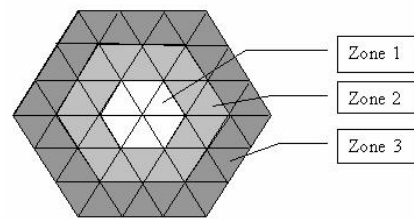


Fig. 5. Division of the solar concentrator into three zones

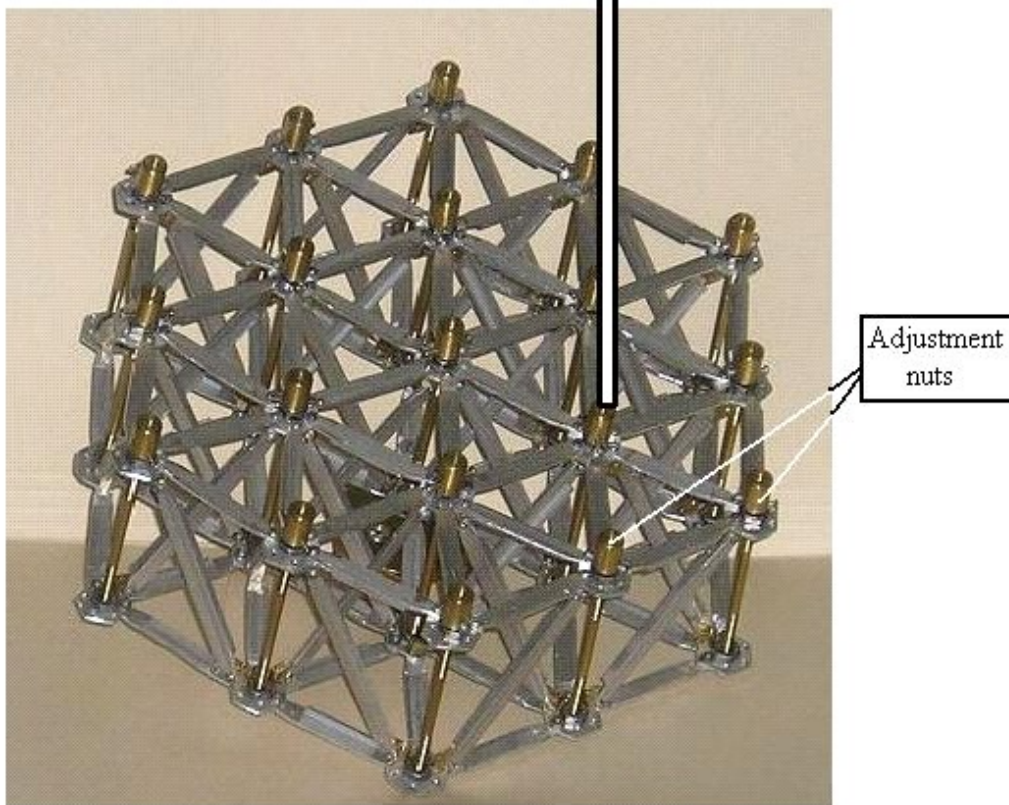
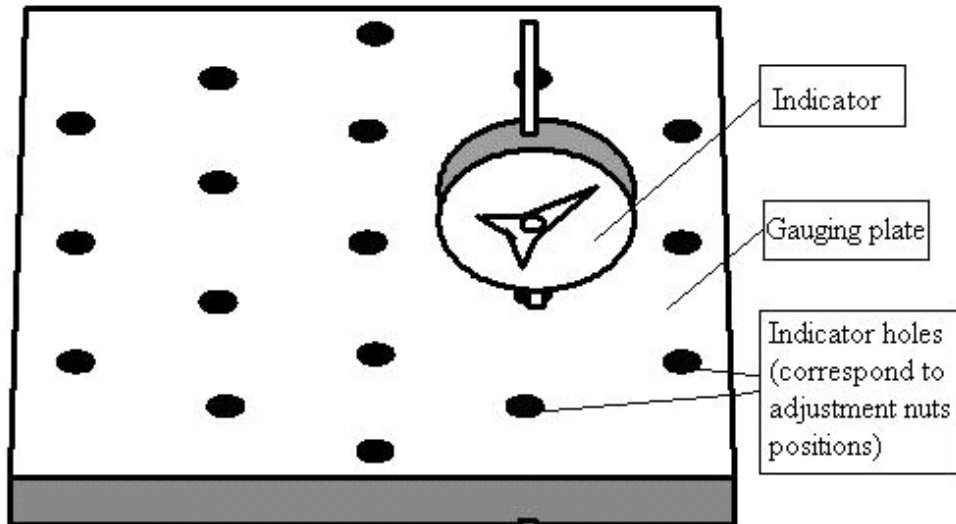


Fig. 6. Parabolic surface adjustment



The proposed mechanically treated metal surface texture recognition methodology [9] was tested in recognition of four texture types that corresponded to metal surfaces after: milling, polishing with sandpaper, turning with lathe and polishing with file.

The promising recognition rate of 99.7% was obtained for this task [9]. This methodology may be used for recognition of position and orientation of complex work pieces in the task of assembly of micromechanical devices as well as for surface quality inspection systems.

Many other recognition methods have to be developed to achieve fully automated processes of manufacturing and assembly of the solar concentrator components.

#### 4 Prototype of Flat Mirror Solar Concentrator

We have created a small prototype of a solar concentrator that contains 24 triangular flat mirrors with the side of 0.05 m (Fig. 7). Each triangular mirror is cut from a commercial flat glass mirror with a reflection factor of 0.9. The focal distance is equal to 0.5 m. Using equations presented in [2] we calculated the theoretical concentration rate of 7.5 suns for this prototype. Measurements made with a light meter gave us a concentration rate of 9.0 suns.

A large number of components of the solar concentrator prototype have dimensions of several millimeters. To manufacture low cost small components we have developed the methodology that has been called Micro Equipment Technology (MET) [10], [11].

The idea of this methodology is to use the equipment which has dimensions comparable to the components to be manufactured. For example, a screw with a diameter of 2 mm (which was used for our prototype) is to be manufactured by a lathe with dimensions of 20x20x20 mm. This lathe requires small floor area, has low energy consumption, and may have low cost. To obtain microequipment of these dimensions we proposed manufacturing sequential generations of micro equipment where each subsequent generation is manufactured using the micro equipment of previous generations.

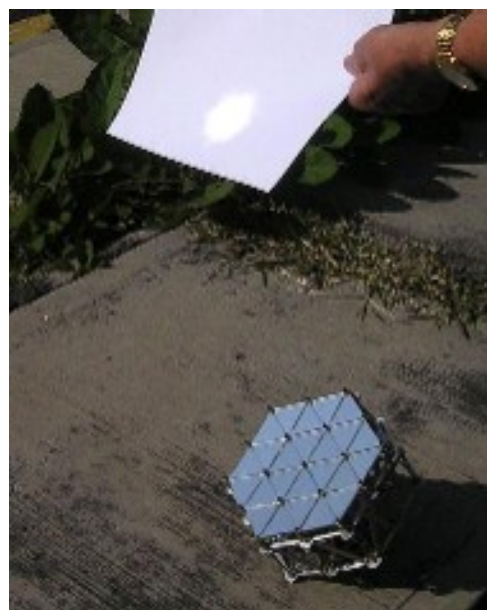


Fig. 7. Small prototype of flat facet solar concentrator

#### 5 Solar Concentrator with Four Mirrors for Each Support Cell

At present we have made improvements of the first prototype [12], [13]. We proposed to collocate four flat mirrors to one support cell.

This invention relates to solar concentrators, and consists of providing a technology that is used to concentrate solar energy, to be used as an alternative power plant.

A cell of the support device of the solar concentrator is presented in Fig.8. A solar concentrator with the proposed cell of the support device which is conformed by: a first superior bush (1), the second superior bush (9), the third superior bush (12), the fourth superior bush (5), the fifth superior bush (11), the sixth superior bush (25), the first inferior bush (22), the second inferior bush (18), the third inferior bush (20), the first superior bar (8), the second superior bar (10), the third superior bar (3), the first inferior bar (17), the second inferior bar (19), the third inferior bar (21), the first vertical bar (13), the second vertical bar (14), the third vertical bar (24), the first diagonal bar (16), the second bar diagonal (15), the third bar diagonal (23), the first mirror (2), the second mirror (7), the third mirror (4), the fourth mirror (6).

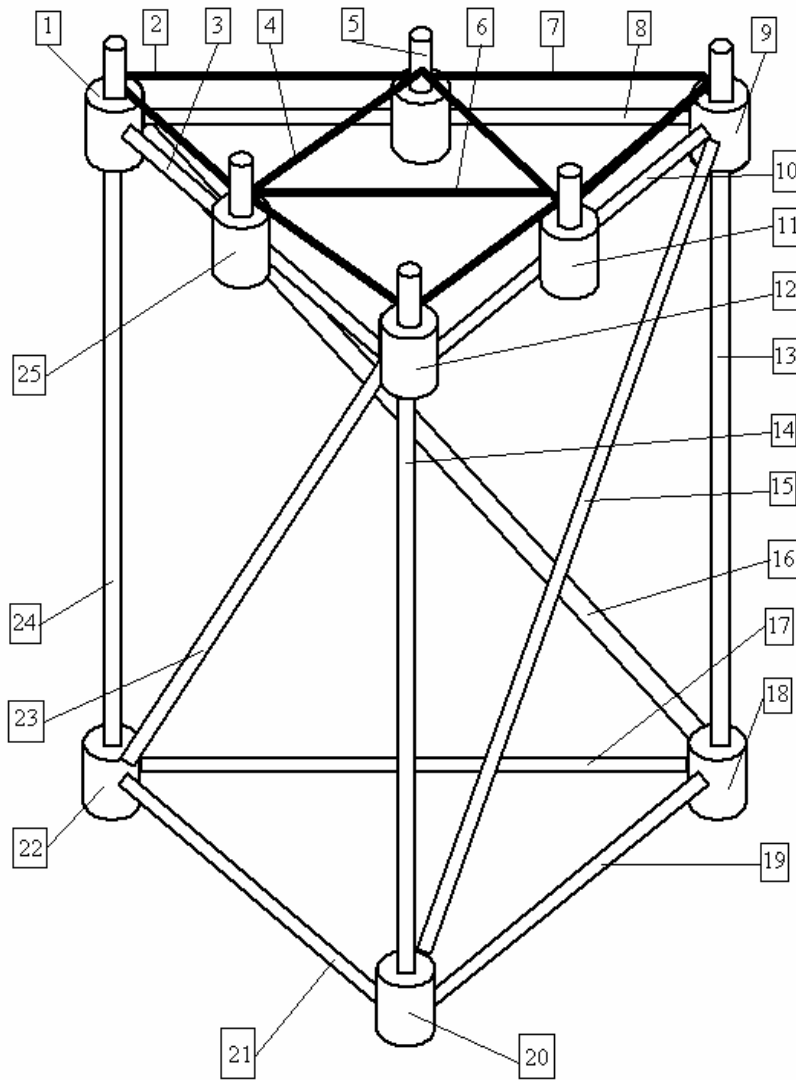


Fig.8. Support cell for four flat mirrors

This solar concentrator has a structure where each superior bar of a cell contains, in its center, an additional superior bush to support additional flat positions of the mirrors (Fig.9). These screws and nuts can be used for parabolic surface adjustment.

In order to adjust the mirrors' positions the solar concentrator with four flat mirrors contains bushes, each bush contains a screw and a nut (Fig.9). Screws and nuts have numbers 26, 27, 28, 29, 30, 31 (Fig.9).

The size of cell does not change; we obtain four mirrors smaller than in the known solution and have better adjustment of the parabolic surface and a better coefficient of solar concentration.

The main difference of the new solution is that

This solution is novel and allows the support of four flat mirrors instead of one of the known solution. This solution conserves the same amount of bars and nodes and allows an increase in the number of flat mirrors by a factor of four. This characteristic of the new solution allows an improvement of the factor of solar concentration conserving the cost, or, to reduce the cost conserving the concentration factor.

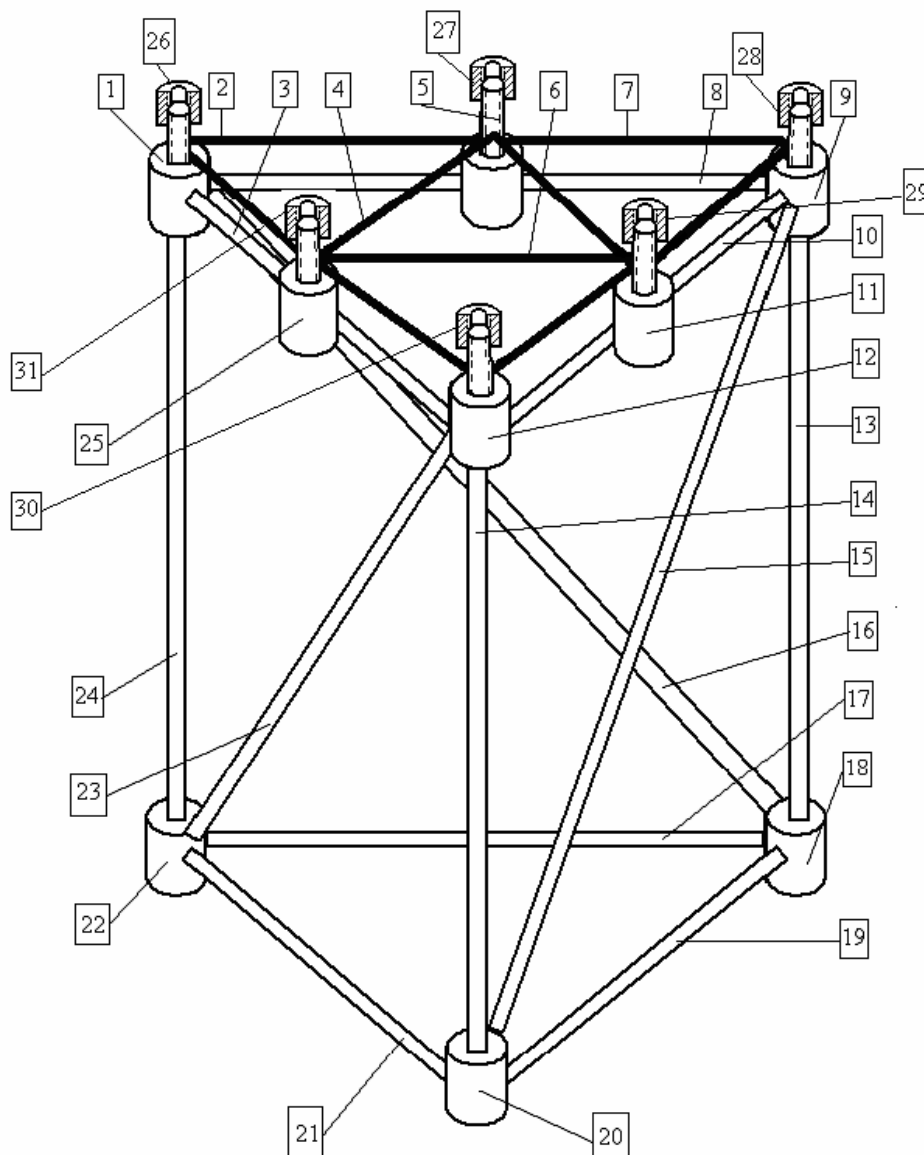


Fig.9. Support cell for four flat mirrors with screws and nuts

It is possible to increase the number of mirrors in a cell to 16 instead of 4. For this purpose we have added 3 additional bars (Fig.10). The bars that existed before have numbers 2, 3, 8 and the new additional bars have numbers 4, 6, 7.

Using these additional bars we added nine additional bushes in the positions marked with circles (for example, with number 10 in Fig.6) and we obtain the possibility of placing 16 flat mirrors in a cell.

With additional bars (Fig.10) the cell can support 16 flat mirrors. In the Fig.11 the support cell with 16 flat mirrors in the

proposed concentrator is presented. The nine bushes are presented in Fig.11 with the following numbers: 26, 27, 28, 29, 30, 31, 32, 33, 34.

## 6 Conclusion

A new type of flat facet solar concentrator is proposed.

The support frame of this concentrator is assembled with a large number of bars and nodes.

It has adjustment nuts which allow precise positioning of flat mirrors.

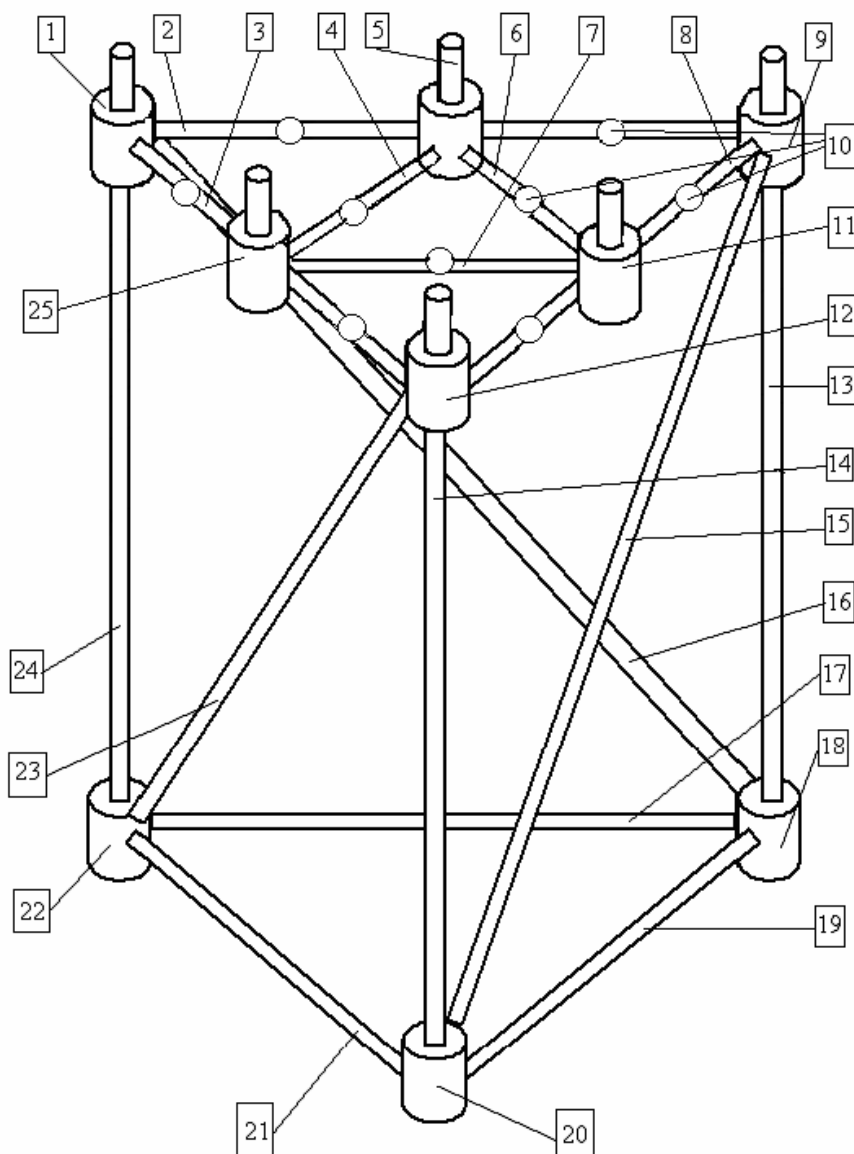


Fig.10. Support cell for 16 flat mirrors

Two variants of support frame were proposed: with support cell for one flat mirror and with support cell for four and 16 flat mirrors.

Assuming the automatic manufacturing and assembly of solar concentrator components this structure will reduce the cost

of solar concentrator production.

**7. Acknowledgement**

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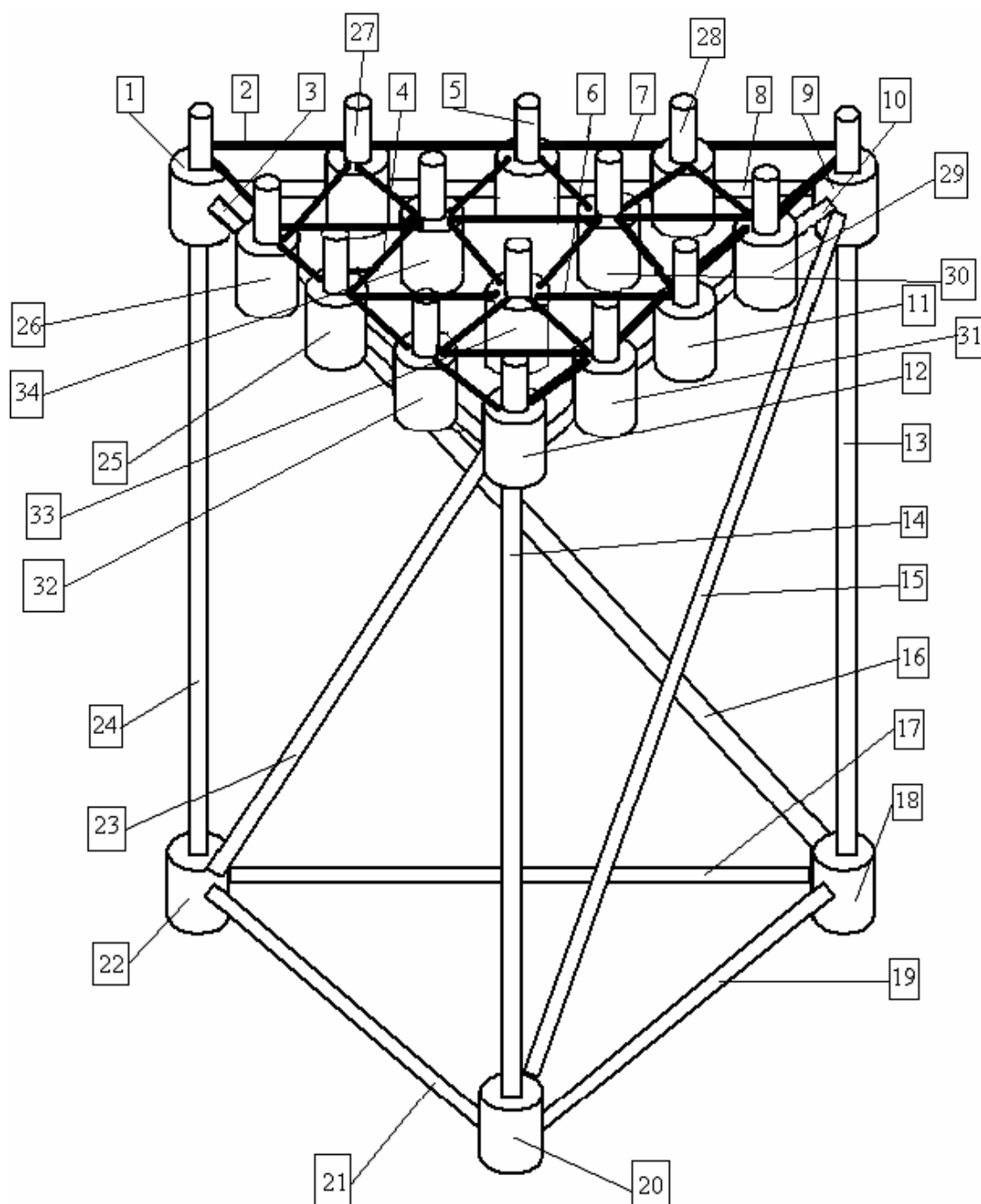


Fig.11. Support cell with 16 flat mirrors

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