Support Frame for Micro Facet Solar Concentrator

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Abstract: - The low cost micro facet solar concentrator is proposed. Large number of small flat mirrors is situated at parabolic surface to approximate large parabolic mirror. Low cost commercial flat mirrors can be used for manufacturing of such concentrator. The problems of production of micro mirrors, support components and automatic assembly of concentrator are discussed. Rough estimations show that the cost of the concentrator should be approximately $ 55 per square meter of concentrator surface.

Key-Words: - solar concentrator, flat micro mirror, automatic assembly

1 Introduction

At present interest in solar energy is growing [1] - [3]. Two main approaches are used to create solar power plants. One of them is connected with photovoltaic transformers of sunlight to electric current, and the other is connected with the heating of a work liquid or gas and its use in heat engines (turbines or Stirling motors). Both types of solar power plants use solar concentrators to improve efficiency of solar energy transformation. There are three main types of concentrators: parabolic trough concentrators, parabolic dish concentrators, and tower concentrators. Parabolic trough concentrators permit temperatures of 400^{o}C. Tower concentrators give temperatures of 600^{o}C, and parabolic dish concentrators give 750 ^{o}C. The higher temperature allows us to obtain higher efficiency of the solar power plant. In this article we will consider only parabolic dish concentrators. The main problem of the creation of parabolic concentrators is the high cost of their manufacture. There are projects, where the power cell based on a parabolic dish of 87.7 m^2 costs $ 150 000. The authors hope that an industrial version will cost $ 50 000 and will compete with conventional fuel technologies [4]. The cost of 1m^2 (approximately $500) is still very high. The main reason is that these parabolic reflectors are made from special mirrors. The glass of the mirrors has thickness from 0.7 mm to 1.0 mm [4]. Special technology is needed to make such glass and to obtain the parabolic shape. There are proposals to make the concentrators from smaller facets [5]. But in these proposals the facets are to be made from flexible mirrors to obtain a parabolic approximation in each facet, and conventional low cost mirrors (with thickness of 3 mm) cannot be used for this concentrator.

In this paper we will show that it is not necessary to make flexible facets. If the size of the facet is sufficiently small, it is possible to make them from conventional flat mirrors. It is possible to use for this purpose low cost commercial mirrors and obtain the concentration rate of some hundreds of suns due to the use of some thousands of flat facets in one concentrator. The cost of such concentrators can be made very low if production of its components and assembly processes will be fully automated.

2 Solar concentrator

There are two main types of solar concentrators: trough- and dish-shaped mirrors. Trough solar concentrators have a cylindrical shape and give a low value of concentration ratio. Concentration ratio can vary: if the light that falls on 100 cm^2 is focused onto 1 cm^2 of receiver, the ratio is considered as 100 suns. If the light from 10 cm^2 is focused onto that 1 cm^2, the ratio is 10 suns. Commercial concentration ratios are around 200 to 300 suns. In the future, as much as 1 000 suns are expected from concentrating systems [6]. Such a concentration ratio can be achieved with dish-shaped concentrators. At present this type of concentrators is however very expensive. For example, in 2005 the cost of 1 kW was approximately \$1 500 [7]. Solar-to-electric conversion efficiency η is approximately 0.3. Solar energy for 1 m^2 (P_A) is 1.0 kW [1]. So the area of concentrator for 1 kW of energy must be:

$$A = 1/(P_A \times \eta) = 1/(1.0 \times 0.3) = 3.333 \quad (1)$$

In this case the cost of 1 m^2 of dish concentrator will be approximately \$ 600. This cost can be explained by the complex technology of production of the dish concentrator mirrors. As a rule they are produced from thin (less than 1 mm) flexible glass covered with aluminum or silver film. The production of such mirrors is rather expensive. The method of parabolic shape formation is by bending the mirror according to the required shape.

In order to have a lower cost, we propose to use a large number of small pieces of flat commercial mirrors to approximate the parabolic shape concentrator. In this manner we can obtain sufficiently good concentrating ratio and achieve a low cost for the dish concentrator. The analysis of concentrator shape shows that it will have a good performance if it will be made from some thousands of small triangle flat mirrors as it is shown in Fig.1.

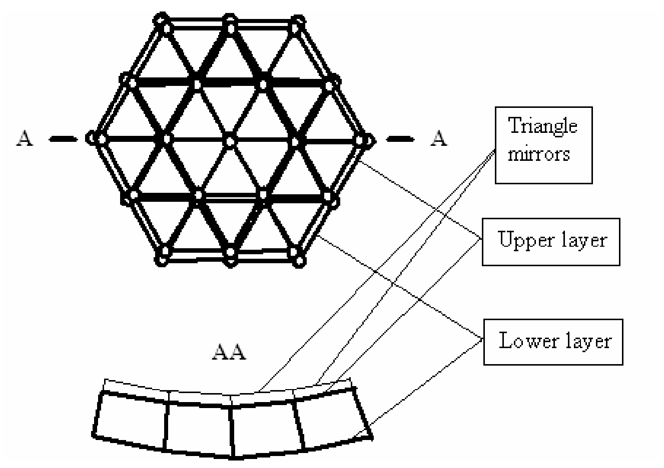

Fig. 1. Design of a flat facet parabolic dish concentrator

We will subdivide this concentrator onto different zones (Fig.6) and denote the number of the zones by letter *n*.

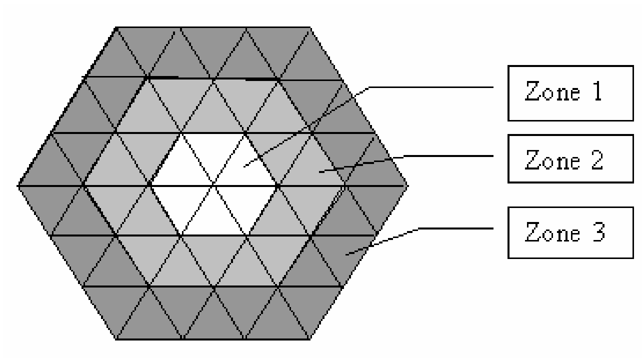

Fig. 2. Zones of triangle mirrors of solar concentrator

3 Manufacturing and assembly of flat mirror solar concentrator

Commercial flat mirrors are very cheap. It is relatively easy to cut them for small triangles. But it is not so easy to manufacture and assembly the support frame for these triangle mirrors. Let us consider a support frame which is based on joint bars and connection elements. The example of a cell that supports one mirror is presented in Fig. 3.

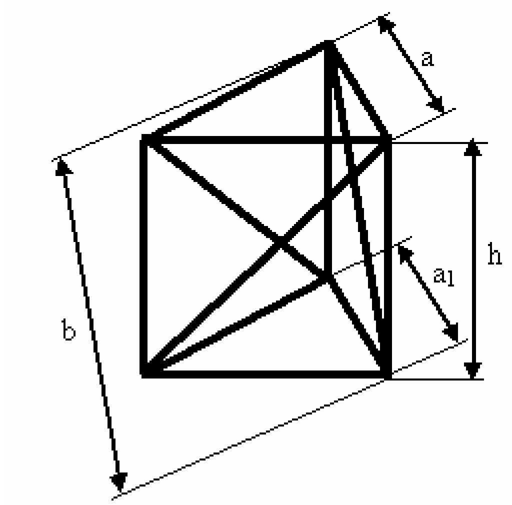

Fig. 3. Support cell for one mirror

It consists of upper and lower triangles and three faces of almost rectangular shape. The upper triangle side is slightly smaller than the lower triangle side to permit us to assemble the parabolic support frame (Fig. 1).

To assemble zone 1 of the solar concentrator (see Fig. 2) it is possible to use one vertical bar and six parts of the support cell (subassembly of the first type) shown in Fig. 4.

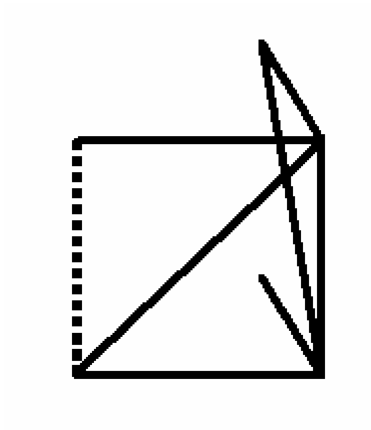

Fig. 4. Subassembly of the first type

Rotating the subassembly of the first type by 60° and connecting them to each other and to a central vertical bar we can assemble zone 1 of the solar concentrator. To assemble other zones of the concentrator we need, as well as the subassembly of the first type (Fig. 4), also the subassembly of the second type (Fig. 5).

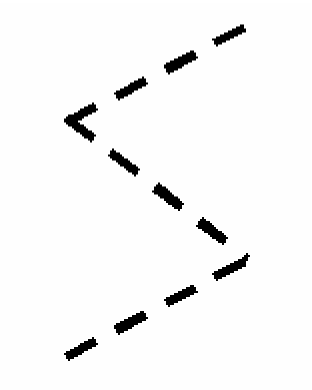

Fig. 5. Subassembly of the second type

To create one sector of zone 2 (1/6 part of the total zone 2) it is necessary to connect two subassemblies of the first type and one subassembly of the second type as it is shown in Fig. 6. Rotating the assembly by 60° and repeating this process 6 times we will obtain two zones of the solar concentrator.

For each sector of zone 3 it is necessary to connect 3 subassemblies of the first type and two subassemblies of the second type. Each sector of zone i needs $(6 \times i)$ subassemblies of the first type and $6 \times (i-1)$ subassemblies of the second type. So in total we need the number of the subassemblies of the first type:

$$n_1 = 6 \times n \times (n-1)/2 = 3 \times n \times (n-1), \qquad (2)$$

and the number of the subassemblies of the second type:

$$n_2 = 6 \times (n-1) \times (n-2)/2 = 3 \times (n-1) \times (n-2). \qquad (3)$$

The subassembly of the first type contains 7 bars and the subassembly of the second type contains 3 bars. So the total number of bars for the solar concentrator:

$$\begin{aligned} N_B &= 7 \times n_1 + 3 \times n_2 + 1 = \\ &= 21 \times n \times (n-1) + 9 \times (n-1) \times (n-2) + 1 \end{aligned}. \qquad (4)$$

For a solar concentrator which has n=50 we need 51 450+21 168+1=93 786 bars. It is clear that for manufacturing and assembly of such a number of bars we need special low cost technology. We have developed such a type of technology during the last decade. This technology is based on sequential generations of micromechanical equipment [8], [9].

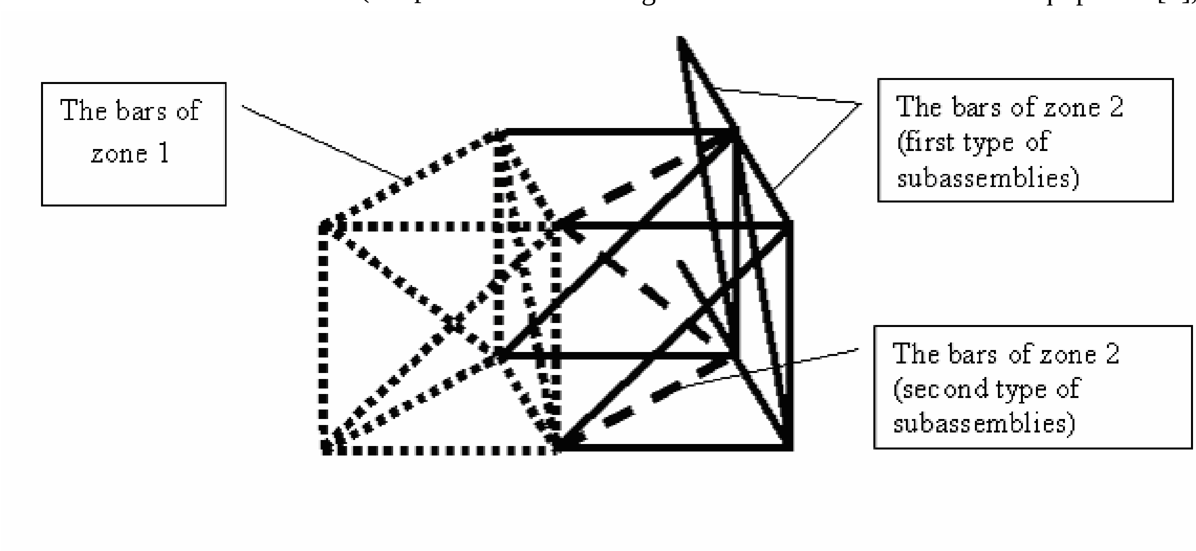

Fig.6. One sector of zone 2

The idea is to obtain micromachine tools and assembly devices comparable with the sizes of components to be produced. In our case the sizes of the bars have an order of 50-70 millimeters. These bars could be produced, for example, from steel tubes having length 50-70 mm, diameter 3-4 mm, and wall thickness near to 0.2 mm. To make these tubes from steel foil it is possible to use machine tools having overall sizes 100-200 mm. The connecting nodes of these parts will have the sizes of 3-5 mm. To produce such nodes it is possible to use micromachine tools with overall sizes of 10-20 mm. It was shown that such machine tools can give good tolerances without the use of super precise technology [10]. Such micromachine tools demand small space, have low energy consumption, and can be organized in desk top factories that realize mass parallel manufacturing process [8]. This process permits production which has costs comparable to the cost of the materials [9].

The assembly of the support frame will be made using micromanipulators with computer vision control [11] - [14].

At present we are developing microassembly devices with computer vision systems. For this purpose we have developed various algorithms for image recognition based on neural networks. The simplest algorithm LIRA was proved in a microassembly task [11], for shape recognition of micro screws [12], and for different tests, for example, texture recognition [13], handwritten digit recognition [14], etc. Another image recognition system PCNC [15] was proved in screw shape recognition, in texture recognition, face recognition, and handwritten digit recognition. All tests demonstrated good results. We intend to apply this adaptive control based on recognition systems for micro assembly devices including an assembly device for the support frame for solar concentrators.

4 Approximate cost estimation for solar concentrator

First let us estimate the cost of materials for manufacturing a solar concentrator with 50 zones (Table 1).

The cost of commercial mirrors is less than $ 20 for 1 square meter. The concentrator has an area A_c = 16.24 square meters. So the cost of the mirrors will be $ 324.8.

To estimate the cost of material for one bar we will calculate the weight of this bar. The weight of one bar is:

$$W_b = \pi \times d_b \times l_b \times t_b \times \rho_{st}\ , \qquad (5)$$

Table 1
Some examples of flat mirror solar concentrator parameters

Number of zones (n)	Number of mirrors (N)	Triangle side (a) (meters)	Focal distance (F) (meters)	Concentration ratio η (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

where d_b is the diameter of the bar, l_b is the length of the bar, t_b is the thickness of the bar walls, and ρ_{st} is a density of steel. In this article we take $d_b = 4\times10^{-3}$ m, $l_b = 7\times10^{-2}$ m, $t_b = 2\times10^{-4}$ m, ρ_{st} =7 800 kg/m^3. With these values we will have the weight of one bar 1.372×10^{-3} kg. This solar concentrator contains 93 786 bars. The weight of all the bars will be 128.7 kg. To estimate the weight of connecting nodes it is necessary to know their design. In this paper we will roughly estimate the weight of connecting nodes as 0.3 of the weight of the bars. So the weight of the connecting nodes will be 42.9 kg and the total weight of the support frame will be 171.6 kg. The cost of 0.2 mm steel foil at present is approximately $ 0.7 for 1 kg. The cost of materials for the support frame will be $ 120. The total cost of all materials is $ 444.8.

Here we will estimate the cost of micro manufacturing and micro assembly approximately equal to the cost of materials. In this case the cost of the solar concentrator can be estimated as $ 889.6. The cost of each square meter of solar concentrator surface will be about $ 55. To our knowledge this is much cheaper than the cost of existing parabolic solar concentrators.

5 Conclusion

A solar concentrator composed from a large number of small flat mirrors attached to a parabolic dish is proposed. A rough estimation of the solar concentrator cost is $ 55 per square meter. This solar concentrator can substantially reduce the cost of solar power plants and will permit application of these concentrators in solar systems for individual home energy service, breaks firing, etc. The support frame can be made using micro mechanical technology based on computer vision systems which is being developed by the authors.

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