NRIAG Journal of Astronomy and Geophysics (2015) 4, 249–255

National Research Institute of Astronomy and Geophysics

NRIAG Journal of Astronomy and Geophysics

www.elsevier.com/locate/nrjag

Simulation model of a new solar laser system of Fresnel lens according to real observed solar radiation data in Helwan of Egypt

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Received 23 November 2014; revised 28 August 2015; accepted 21 September 2015
Available online 20 October 2015

KEYWORDS

Solar laser;
Solar concentrator;
Fresnel lens;
Compound Parabolic Concentrator (CPC)

Abstract A new simulation model of a new solar pumped laser system was tested to be run in Helwan in Egypt (latitude $\varphi = 29°52'$N, longitude $\lambda = 31°21'$E and elevation = 141 m) as an example of an industrial polluted area. The system is based on concentrating the solar radiation using a Fresnel lens on a laser head fixed on a mount tracking the sun during the day and powered by a DC battery. Two cases of this model are tested; the first one is the model consisting of a Fresnel lens and a two-dimensional Compound Parabolic Concentrator (CPC), while the other is the model consisting of a Fresnel lens and a three-dimensional Compound Parabolic Concentrator (CPC). The model is fed by real actual solar radiation data taken in Helwan Solar Radiation Station at NRIAG in the various seasons in order to know the laser power got from such a system in those conditions. For the system of Fresnel lens and 2D-CPC, an average laser output power of 1.27 W in Winter, 2 W in Spring, 5 W in Summer and 4.68 W in Autumn respectively can be obtained. Accordingly, the annual average output power for this system is 3.24 W. For the system of Fresnel lens and 3D-CPC, an average laser output power of 3.28 W in Winter, 3.55 W in Spring, 7.56 W in Summer and 7.13 W in Autumn respectively can be obtained. Accordingly, the annual average output power for this system is 5.38 W.

1. Introduction

One of the most interesting applications of solar energy is to generate the laser beam directly. Using the idea of concentrating the sun light, one can get the optical energy needed to excite the laser material in order to generate the laser beam. This kind of application is called *Solar Laser*.

The idea of the solar laser depends on concentrating the solar radiation in order to obtain a pumping intensity greater

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Peer review under responsibility of National Research Institute of Astronomy and Geophysics.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.nrjag.2015.09.004
2090-9977

than the threshold level needed to generate the laser. For such purposes, optical concentration devices are used such as the three-dimensional parabolic concentrator (paraboloidal concentrator (3D-PC)), spherical concentrator (SC), Fresnel lens (FL), solar towers, and solar mirror arrays. With the help of the two- or three-dimensional non-imaging concentrators e.g. compound parabolic concentrators, conical concentrator, and V-trough concentrator, one can increase the concentration level to a higher one to attain the approximately the theoretical energy level.

Abdel-Hadi (2006) developed a solar concentration system consisting of a Fresnel lens and a Compound Spherical Concentrator (CSC). The concentrated radiation was 267.14 W which equals 6.8×10^6 W/m^2. This power could generate a laser beam of 2.552 W which could be translated into an intensity of 6.458×10^4 W/m^2 with a slope efficiency of 0.028 according to the simulation model developed for this concentration system.

Ohkubo (2009) developed a solar-pumped 100 W class laser that features high efficiency and low cost owing to the use of a Fresnel lens and a chromium co-doped neodymium YAG ceramic laser medium. A laser output of about 80 W was achieved with combination of a 4 m^2 Fresnel lens and a pumping cavity as a secondary power concentrator. This output corresponds to 4.3% of conversion efficiency from solar power into laser, and the maximum output from a unit area of Fresnel lens was 20 W/m^2, which was 2.8 times larger than previous results with mirror-type concentrator.

Liang and Almeida (2011) developed a solar pumped laser system irradiated by a Fresnel lens using a Cr:Nd:YAG ceramic medium. The incoming solar radiation from the sun was focused by a 0.9 m diameter Fresnel lens. The output power produced from this system was 12.3 W of cw laser corresponding to 19.3 W/m^2 of intensity.

Abdel-Hadi (2012) developed a simulation model of solar pumped laser system with a concentration system consisting of a Fresnel lens and a trough (2-dimensional) Compound Parabolic Concentrator (CPC). The Fresnel lens was in quadratic form and its dimensions were chosen to be 60 cm × 60 cm. The model was tested to the observed data of solar radiation in Helwan which is a town 35 km south of Cairo. The solar radiation records were taken by a manual solar radiation station and applied to this model. The results showed that for typical days representing each season, we can get an average laser output power of 6.2 W in spring, 6.8 W in Summer, 2.2 W in Autumn and 0.4 W in Winter.

In the present work, the same procedure has been adopted as in the work of Abdel-Hadi (2012). After constructing the automatic solar radiation station in October 2010 on the rooftop of the National Research Institute of Astronomy and Geophysics (NRIAG), it became easier to record more data of solar radiation. So, we applied the new recorded data on our model and got new results according to the actual solar radiation status. Then, we changed in the model itself by substituting the two-dimensional CPC by a three-dimensional CPC to test the increase of the output laser power obtained from this system.

2. Model scenario

The same model scenario adopted in the previous work is also adopted in this work (Abdel-Hadi (2012)). A Fresnel lens is fixed on an optical bench as shown in Fig. 1. The concentrated solar radiation will be focused on a compound parabolic concentrator (CPC). This system will direct the radiation into the Nd:YAG laser crystal. The crystal has total reflective coating from the side of contact while there is a high reflective mirror as an output coupler aligned to the system on the optical bench. A water-based cooling circulation is connected to the crystal in order to eliminate the heat caused by the concentration and the laser pumping process. The whole optical bench is set on a mount with a tracking motor which can let the system follow the position of the sun during the daytime.

Table 1 shows the parameters of the Fresnel lens chosen in this model.

Two cases of the Compound Parabolic Concentrator (CPC) were chosen in this model: 2D-CPC and 3D-CPC. The acceptance angle of both of them was chosen to be 45°. Figs. 2 and 3 show the geometry of the 2D-CPC and 3D-CPC used as secondary concentrators respectively, while Table 2 shows the parameters of both of them.

The Nd:YAG laser is by far the most commonly used type of solid-state laser. Neodymium-doped yttrium aluminium garnet (Nd:YAG) possesses a combination of properties uniquely favourable for laser operation. The YAG host is hard, of good optical quality, and has a high thermal conductivity. Furthermore, the cubic structure of YAG favours a narrow fluorescent linewidth, which results in high gain and low threshold for laser operation. In Nd:YAG, trivalent neodymium substitutes for trivalent yttrium in the lattice, so charge compensation is not required (Koechner 1992).

The threshold pumping power of the laser rod can be calculated from Eq. (1) (Weksler and Schwartz 1988):

$$P_{th} = \frac{A_a I_s}{\eta_q \eta_{ovp} \alpha} \left(\frac{2\gamma_l - \ln(R)}{2\varepsilon} \right) \tag{1}$$

where A_a is cross-sectional area of the crystal (rod) and γ_l is the loss per pass in the laser. The other parameters are shown in Table 3.

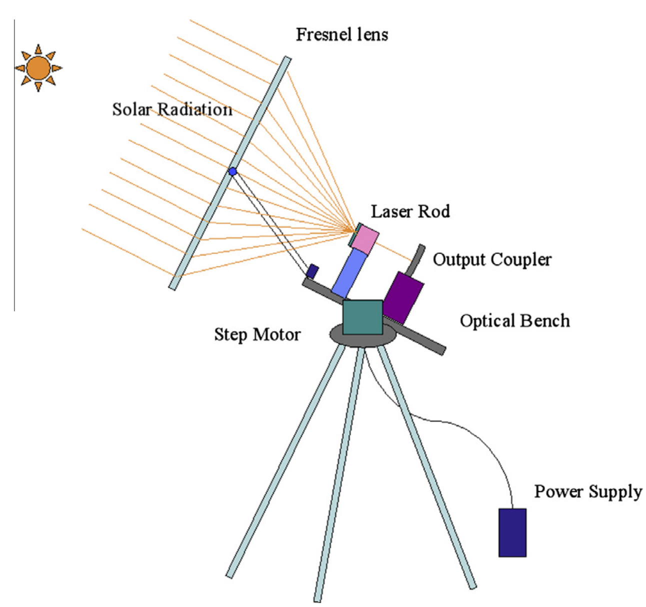

Figure 1 The total solar laser system (Abdel-Hadi (2006, 2012)).