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APPLICATION OF THE MONTE CARLO METHOD TO SIMULATE SOLAR ENERGY USE PROCESSES

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Abstract. The article discusses the features of the application of the Monte Carlo method to simulate the processes of using solar energy. In particular, a computer simulation of the operation of a solar-based laser device is considered. The Monte Carlo method is used to simulate the geometry of the stochastic distribution of the movement of photons inside a device, as well as to study the efficiency of a laser as a function of light absorption.

Keywords: Monte Carlo method; solar energy laser; laser model; absorption of light; laser efficiency.

Annotatsiya. Maqoqolada quyosh energiyasidan foydalanish jarayonlarini simulyatsiya qilish uchun Monte-Karlo usulini qo'llash xususiyatlari ko'rib chiqiladi. Xususan, quyosh nuriga asoslangan lazer qurilmasining ishlashini kompyuter simulyatsiyasi ko'rib chiqiladi. Monte-Karlo usuli qurilma ichidagi fotonlar harakatining stoxastik taqsimotining geometriyasini simulyatsiya qilish, shuningdek, lazerning yorug'lik yutilish funktsiyasi sifatida samaradorligini o'rganish uchun ishlatiladi.

Kalit so’zlar: Monte-Karlo usuli; quyosh energiyali lazer; lazer modeli; yorug'likni yutish; lazer samaradorligi.

Аннотация. В статье рассматриваются особенности применения метода Монте-Карло для симуляции процессов использования солнечной энергии. В частности, рассматривается компьютерная симуляция действия лазерного устройства на основе солнечной энергии. Метод Монте-Карло используется для симуляции геометрии стохастического распределения движения фотонов внутри устройства, а также для изучения эффективности лазера в зависимости от абсорбции света.

Ключевые слова: Метод Монте-Карло; лазер на основе солнечной энергии; модель лазера; абсорбция света; эффективность лазера.

Introduction

The processes of transformation and use of renewable energy are characterized by the influence of stochastic factors due to local infrastructure. Therefore, traditional analytical methods cannot be applied to such systems. One of the widely used numerical methods based on stochastic principles for choosing parameters is the Monte Carlo method. This method was developed at XVII century and takes its name from the famous Monte Carlo’s casino in Monaco. Casino’s plays pushed further development of the theory of the probabilities and its applications. Let consider the use of the Monte Carlo method to numerical computation of the geometric probability. Suppose, for given region on geometric coordinate plane divided by several subregions we want to compute the areas of each part. Arbitrary point of the region we can denote by $P(x,y)$, where x and y are the two coordinates of the point according to X and Y axis. Using computer generator of random numbers for the x and y coordinates respectively we can get sequence of the randomly distributed points falling on the parts of the region. Using frequencies of these points according to each subregion one can compare the areas of the parts and define their areas.

Research methodology

The article discusses the application of the Monte Carlo method to study the principles of building simulation models for studying processes in laser devices based on solar energy. We use the Monte Carlo method to simulate the operation of a solar-powered laser. Such device converts the solar radiation energy into the laser light energy. The effectiveness of device depends on active element that absorb the solar light and transform it into the laser light. To develop a computer simulation the model proposed in [1, 2] is considered. Configuration is shown below.

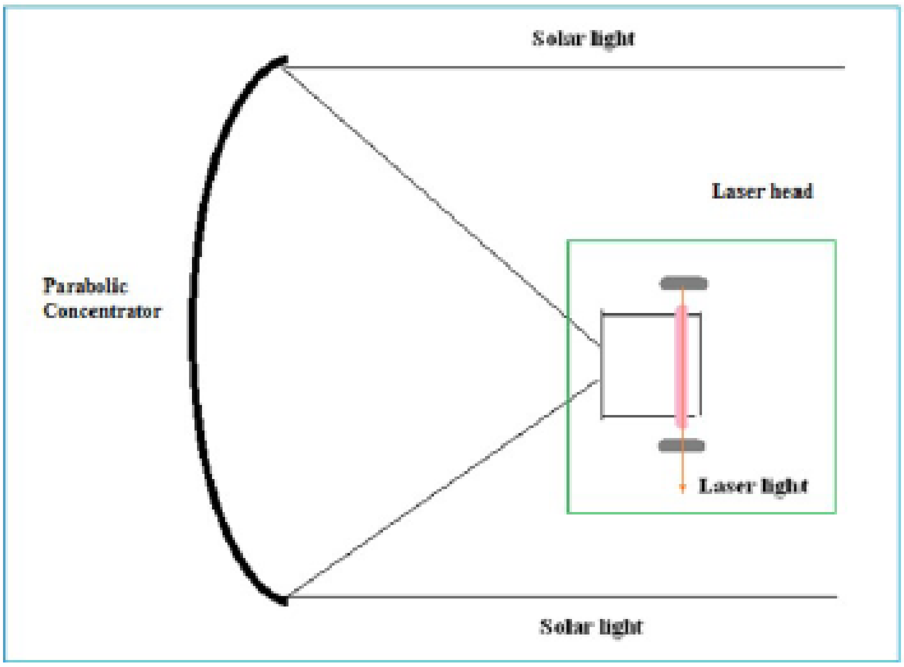

Figure. 1. General scheme of the solar laser system

The core part of the model consists in determining the sequence of intersection points by using geometrical optics and modeling the elementary processes such as reflection, refraction, absorption, and emission by Monte-Carlo method. In the following, we will describe the basics of the used model.

The model uses three Cartesian coordinates to determine the position of the photon on the surface of parabolic concentrator, along with three direction cosines to determine the direction of propagation inside the solid angle suspended by solar disk randomly. The initial start conditions will vary depending on application.

However, for the considered case, the initial position and direction cosines can be modeled by randomizing the initial direction of each photon:

Position:

$$x = rcos\varphi$$

$$y = rsin\varphi$$

$$z = (x^2 + y^2)/k$$

Direction cosines:

$$\mu_{x\psi} = sin\,\psi\,cos\,\theta$$

$$\mu_y = sin\,\psi\,sin\,\theta$$

$$\mu_z = cos\psi,$$

where *r* is random number uniformly distributed between *0* and *R* (radius of parabolic concentrator), φ - random number uniformly distributed over the interval [0, 2π], ψ - random number limited by the semi-angular diameter of the Sun which is equal to 0.0046 radians, θ - randomized azimuth angle limited by [0, 2π].

The wavelength is determined from the solar spectral intensity by solving following integral equation [3]:

$$\xi = \int_0^{\lambda_0} I_{AM1.5}\,(\lambda)\frac{\lambda}{c}d\lambda$$

where $I_{AM1.5}(\lambda)$ is the normalized spectral intensity [W/m^2/ nm] of the AM1.5 solar radiation at a given wavelength λ_0[nm], ξ is the random number uniformly distributed over [0,1] and

$$S = \int_0^{\infty} I_{AM1.5}\,(\lambda)\frac{\lambda}{c}d\lambda = 1$$

Absorption coefficient μ at a given wavelength is determined by using absorption spectrum of the active medium.

The absorption length *l* is the distance the photon travels until it is absorbed by the active medium:

$$l = -\frac{ln\,\xi}{\mu}$$

where ξ is random number and μ is absorption coefficient for the given wavelength.

Research results

As we consider a single photon, it can be either reflected or refracted. Therefore, to model these processes we use following approaches:

In principle, the reflection coefficient depends on the incident angle as well as on the polarization of the light. Since solar light is not polarized, we used average value of reflection coefficients for two polarization states (*s* and *p*) of solar light:

$$K_r = \frac{1}{2}\left[\frac{sin^2(\alpha-\beta)}{sin^2(\alpha+\beta)} + \frac{tan^2(\alpha-\beta)}{tan^2(\alpha+\beta)}\right] \quad ,$$

where α and β are the angles of incidence and refraction, respectively.

To determine which of the two processes is occurred, the random number ξ is generated and compared with the above reflection coefficient. If $\xi < K_r$, the reflection, otherwise the refraction is selected. Note that the reflection from the parabolic concentrator is independent of the incident angle as well as of the polarization of light, it is constant.

For the reflected photon the new direction cosines are determined as:

$$\boldsymbol{b} = \boldsymbol{a} - 2(\boldsymbol{a}\cdot\boldsymbol{n})\boldsymbol{n} \quad ,$$

where we use vector notation for simplicity, **a** is incident vector, **n** is unit normal vector to the considered surface and **b** is reflected vector. Note that normal vector is distinct for different parts (end sides, lateral surface of an active medium, the surface of parabolic concentrator and different surfaces of frequency converter) of the laser system considered.

Expressions used for refracted photon are as follows: when a ray travels from a medium with refractive index $n_1$into another medium with a refractive index n_2, some of the light is transmitted and bended. Snell's law tells us that

$$n_1 \sin\alpha = n_2 \sin\beta$$

$$\cos^2\beta = 1 - \frac{n_1^2(1-\cos^2\alpha)}{n_2^2} \ .$$

The bended photon direction cosines can be determined as:

$$c = \frac{n_1(a+n\cos\alpha)}{n_2} - n\cos\beta$$

$$= \frac{n_1(a+n(a\cdot n))}{n_2} - n\sqrt{1-\frac{n_1^2(1-(a\cdot n)^2)}{n_2^2}} \ ,$$

where we use the vector notation again for simplicity, **a** is incident vector, **n** is unit normal vector to the considered surface and **c** is refracted vector.

Conclusions and recommendations

Using this model, we can develop computer simulation of process by input randomly defined parameters. Then, depending on the active element characteristics efficiency of the laser device may be computed.

In [3] it's shown that for some choice of the active element effectiveness of the laser power vs solar power is linearly increased.

Literature and collections:

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