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Earth Sciences**MODELLING OF THE AMOUNT OF SOLAR ENERGY FALLING ON THE PANEL OF SOLAR CAR ALONG THE ROAD****Corresponding Member of NAS of Azerbaijan R.G.Gardashov, Academician of ANAS
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The model developed for calculation of the amount of the solar energy falling on the panel of solar car is presented. The input parameters of the model are characteristics which: 1) define the Sun position in the sky (instant of time and geographical coordinates: latitude, longitude and height from the sea level to the point at road); 2) determine the road tilt; 3) define the optical state of the atmosphere. Main output of the model is the amount of solar energy falling on the solar car for any instant of time and position of the car. The program packet which realizes this model will be the basis part of the navigation system of solar cars and will provide their optimal managing.

Keywords: solar energy, solar car, solar panel, solar zenith and azimuth, relief, meteorological conditions, road tilt

Introduction

At present the use of solar energy increases rapidly year after year and according to the prognosis of the International Energy Agency (IEA) in 2050 the solar energy will occupy the first place in production of electric power. There is no doubt that in the near future the era of vehicles working with petroleum products will come to an end and the transition to the electric vehicles moving by the solar energy (solar cars) will gradually begin. Such optimistic forecast is based on the background that the photoelectric cells of the new generation with high efficiency become a reality.

Now at the different leading research centers and universities of the world the intensive investigations in the direction of creation of solar cars working with solar energy and having suitable characteristic for mass production are carried out. Within the last years the permanent competitions of solar cars have been holding and the average speed about 90 km/h has already been reached. Mass production of solar cars will be realized if their technical characteristics (overall dimensions, mass, speed, body capacity, etc.) are close to conventional cars. The obtained results and intensity of investigations in this field give us the confidence in reaching the necessary characteristics soon. The weak side

of solar cars is that they can normally move only in availability of a sufficient amount of solar energy.

But this imperfection can be removed by using accumulator, which supplies the car's electromotor and is charged either by solar radiation energy, produced by panel (when it is in abundance), or at the "solar electric station" (which will replace the oil filling station).

Thus, existence of enough amount of solar radiation is necessary for efficient working of solar cars. It is known that the amount of solar radiation is maximal when sunbeams fall perpendicularly on the panel of the car. If solar panel has no flexibility then satisfy this condition continuously along the road is impossible because it needs the variation of orientation of the panel. Construction of a flexible solar panel following the Sun, similar to sunflower, seems unreasonable because the shape of the car must have the aerodynamic feature.

The amount of solar radiation falling on the panel of the car, at the given point and fixed instant of time, depends on several factors. Some of those factors have a deterministic character but others – random. The deterministic factors are the followings:

1. The zenith and azimuth of the Sun. At the given point of observation and fixed mo-

ment of time those angles determine the position of the Sun in sky and are calculated by using formulas of astronomy.

2. The relief of territory surrounding the given point. During some period of time the Sun may be shaded by relief (hills, mountains, etc.) and the amount of radiation falling on the panel will be essentially small.

3. The tilt of the road at the given point. The angle between the sunbeam and the normal to panel, thereby the amount of radiation, depends on tilt.

The random factors acting to the amount of radiation are the followings: clouds, aerosol, dust, mist, smoke, rain, snow etc.

The objective of this work is to develop the mathematical model for calculation of quantity of solar radiation falling on the panel of car in any point of road and in any moment of time. The algorithm based on this model and the FORTRAN program package for calculation was also realized.

The input parameters of the program are:

1. The time t , which is given on Greenwich; 2) the geographical coordinates (latitude

θ , longitude φ) and height h from the sea level to considered point M on the road; 3) the zenith and azimuth angles of the normal to the road surface at the point M , which determine the road tilt; 4) the shadow function $f(\gamma)$, determining the shading of sky and Sun; 5) optical thickness of atmosphere; 6) cloud amount.

Meteorological parameters (optical thickness of the atmosphere and cloud amount) which have a random character are entered to the program for two cases: first – according to weather forecast and second – as a scenario.

Outputs of the program are: the amount of the solar energy falling on the solar car in the any point of the road and for each moment of the time. For the first case this means that the forecast of the solar energy amount is given. It is clear that the accuracy of this forecast depends on precision of the weather prognosis.

Essence of mathematical model

In the case of clear atmosphere the amount of direct solar radiation reaching the car panel is defined by the formula (Fig. 1)

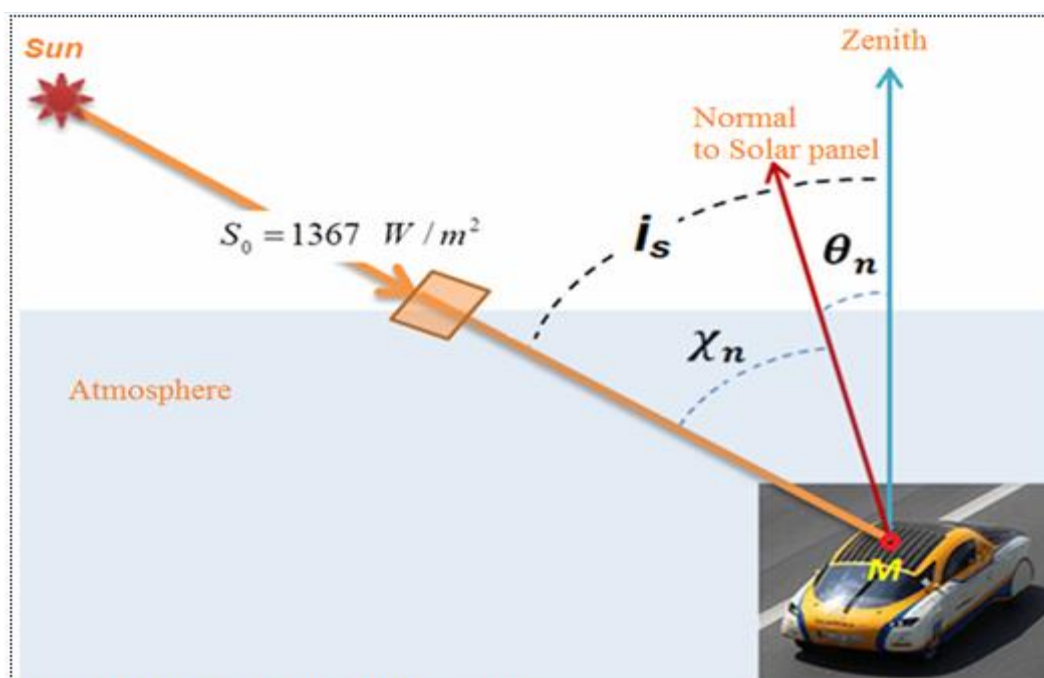


Fig 1. On formulation of the problem

$$S_p = S_0 \cos \chi_n \exp \left(-\frac{\tau}{\cos i_s} \right), \quad (1)$$

where, $S_0 = 1367 \text{ W/m}^2$ – solar constant (i.e. the amount of incoming solar electromagnetic radiation per unit area that would be incident on a plane perpendicular to the rays, at upper boundary of atmosphere);

τ – optical thickness of atmosphere (for clear atmosphere $\tau = 0.3$);

i_s – zenith angle of the Sun;

χ_n – angle between the sunbeam and normal to the panel.

The angle χ_n is defined through the zenith i_s , azimuth ϕ_s of the Sun and zenith θ_n , azimuth ϕ_n of normal to panel (or to road tilt), by the equation of spherical trigonometry

$$\begin{aligned} \cos \chi_n = & \cos i_s \cos \theta_n + \\ & + \sin i_s \sin \theta_n \cos(\phi_s - \phi_n) \end{aligned} \quad (2)$$

The zenith i_s and azimuth ϕ_s of the Sun depend on point M on the road and instant of time t and are defined by the formulas of astronomy. To define those angles, methods having different degree of accuracy have been developed. We calculate those angles on the method which is based on solution of Kepler equation and have more accuracy (Emegen G. and others, 2006, Gardashov and Eminov, 2013).

To calculate the diffuse sky radiation falling on the panel, the method taking into account of optical parameters affecting the brightness of the sky and the shadow effect of the relief has been developed.

The shadow effect, caused by mountains or other obstacles, which substantially reduce falling solar radiation will be taken into account by using “shadow function”. This function is included in the general formula and is determined by measuring with the theodolite (Fig. 2).

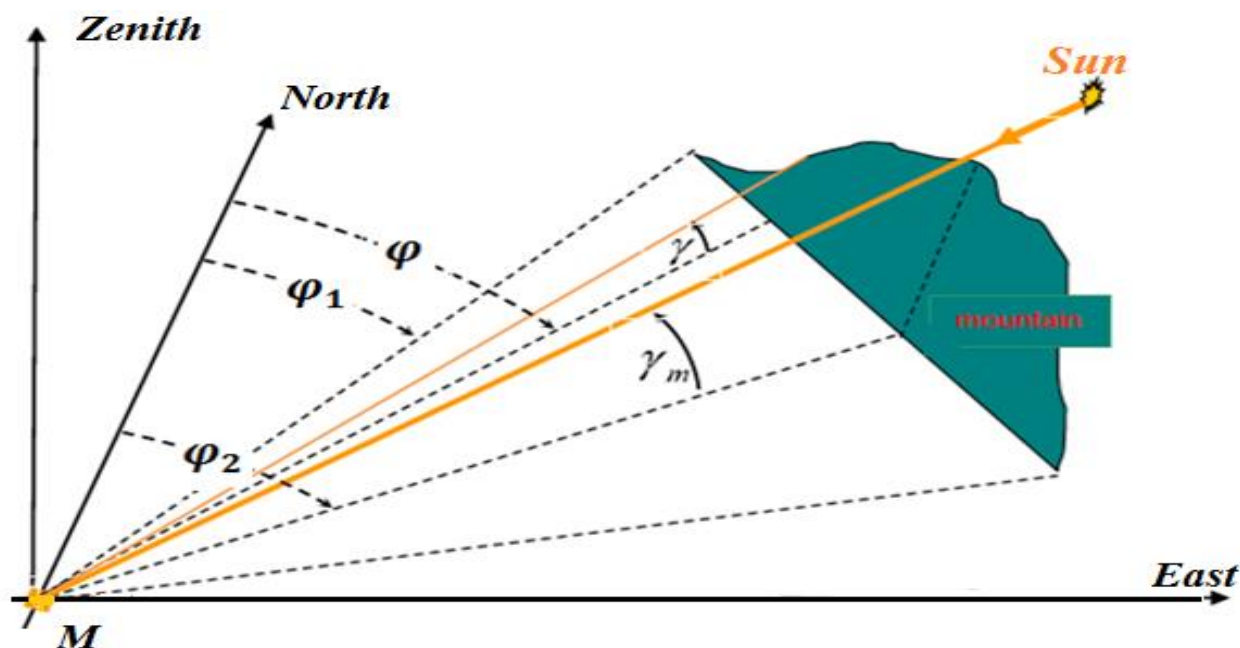


Fig 2. Determination of the “shadow function” $\gamma = \gamma(\varphi)$,
($\varphi_1 \leq \varphi \leq \varphi_2$) in the point M

Scheme of application of the model

An application of the developed mathematical model may be realized for any highway. The necessary information about the road parameters must be captured from the in situ measurements.

The following studies should be carried out:

1. Along the road with the interval of 5-500 m the points of measurement are selected and in those points the angles defining the road tilt are measured. The distance between points is chosen according to the degree of tilt and turning left and right. In places where they are changed rapidly the points must be taken closely, and vice-versa.

2. In the point of the road, where relief forms the shadow, the shadow function is measured by theodolite.

The results of measurements in the selected points will be noted in the tables shown below as an example (the number of points depends on the length of the road, tilt fluctuations, sharpness of turning).

The model should be verified by measuring with the pyrometer the amount of solar radiation falling into the road flat (in other words on the solar panel) and by recording the road characteristics (Table 1) and meteorological parameters (Table 2) simultaneously.

Table 1

Road characteristics

Point №	Latitude	Longitude	Height above sea level (m)	Distance from the previous point (m)	Azimuth of the road tilt, ϕ_n	Zenith of the road tilt, θ_n
1	40°41'34"	48°27'16"	452		96°41'	14°43'
2	40°41'34"	48°27'16"	489	120	125°23'	16°32'
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Table 2

Sun position and atmosphere conditions

Point №	Time Day.Month. Year Hour: minute	Sun azimuth ϕ_s	Sun zenith i_s	Cloud amount	Other meteo parameters	Identification of the point in photo
1.	12.10.2014 12:34	165°37'	45°28'	0		
2.	12.10.2014 13:54	175°45'	46°34'			
...	...	...	...	...	...	...

Conclusion

It appears that, now the world is at the beginning stage of transition from cars with internal-combustion engine to electromobiles working simultaneously by the use of solar energy and accumulators. Evidently this transition will happen quickly. There are two main reasons to maintain this. First, the pollution of environment by exhaust gases from conventional cars becomes tragically dangerous for human life. Second, photoelectric cells with high efficiency have been discovered and their wide use is available. The main feature of solar cars which distinguish them from conventional cars is the reality that the origin of energy takes place outside of cars. If solar cars receive enough solar energy they will be able to continue motion regularly. This fact requires the optimum usage of the solar energy. Because, the amount of solar energy received by the panel depends on outside factors, the optimal managing of solar cars looks to be a main problem. To solve this problem we must be able to calculate the amount of received solar energy in any point of road and at any moment of time. Model explained here solves this problem. Among the input parameters of this model there are the tilt and shadow characteristics in the points of road. For the roads those characteristics must be measured and table 1 filled. Thus, for each road the de-

termination of those characteristics must be carried out and a data base created. The information from this database will give reality to the model described here. The program package which realizes this model will be an important part of navigation system of solar cars and will implement the optimal management (choosing the time of start of motion, speed which must be keeping along the road, instant of time of arriving to the mountain pass, where huge amount of solar radiation or fully charged accumulators are needed, choosing the time of start using of accumulator and its charging, and etc.) of solar cars.

REFERENCES

1. Emegen, G., Gokhan, K., Erdogan, F., Gardashov, R. 2006, The determination of sunglint location on the ocean surface by observing from the geostationary satellites.// Terrestrial, Atmospheric and Oceanic Sciences (TAO), Vol. 17, No.1, 253-261.
2. Gardashov, R.H., Eminov, M.Sh. 2013, The Determination of the Sun Glint Geographical Coordinates by Observing from Meteosat 9 Satellite.// Proceedings VII International Conference "Current Problems in Optics of Natural Waters", 10-14 September. St.-Petersburg. 154-158.

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YOL BOYUNCA GÜNƏŞ ELEKTROMOBİLİNİN ÜZƏRİNƏ DÜŞƏN GÜNƏŞ RADİASIYASI MİQDARININ MODELƏŞDİRİLMƏSİ

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Bu işdə günəş elektromobilinin panelinə düşən günəş enerjisinin miqdarını hesablayan model təqdim olunur. Modelin giriş parametrləri: 1) Günəşin göy üzündə yerini təyin edən, zaman anı və nöqtənin (elektromobilin) coğrafi koordinatları (en dairəsi, uz. dairəsi, dəniz səviyyəsindən yüksəkliyi); 2) yolun meyilliyini və nöqtənin kölgələnmasını ifadə edən kəmiyyətlər; 3) atmosferin optik vəziyyətini göstərən xarakteristikalarıdır. Modelin əsas çıxışı, zamanın hər bir anında və yolun hər bir nöqtəsində elektromobilin panelinə düşən günəş enerjisinin miqdarıdır. Bu modeli reallaşdıran proqram paketi elektromobillərin naviqasiya sisteminin əsasını təşkil edəcək və onun optimal idarəsini həyata keçirəcəkdir.

Açar sözlər: günəş enerjisi, günəş elektromobili, günəş paneli, günəşin zenit və azimutu, relyef, meteoroloji şərait, yolun meyilliyi

**МОДЕЛИРОВАНИЕ КОЛИЧЕСТВА СОЛНЕЧНОЙ ЭНЕРГИИ, ПАДАЮЩЕЙ НА ПАНЕЛЬ
СОЛНЕЧНОГО ЭЛЕКТРОМОБИЛЯ ВДОЛЬ ДОРОГИ****Р.Г.Гардашов, Р.М.Мамедов**

В работе предлагается модель для расчёта количества солнечной радиации, падающей на панель солнечного электромобиля. Входными параметрами модели являются: 1) момент времени и географические координаты (широта, долгота, высота над уровнем моря) точки (электромобиля), по которым определяется положение Солнца в небе; 2) величины, определяющие наклон дороги и затенения электромобиля; 3) оптические характеристики атмосферы. Основным выходным параметром является количество солнечной энергии, падающей на панель для любого заданного момента времени и точки нахождения. Пакет программ, реализующий эту модель, будет основной частью навигационной системы электромобиля, выполняя его оптимальное управление.

Ключевые слова: солнечная энергия, солнечный электромобиль, солнечная панель, азимут и зенит Солнца, рельеф, метеорологические условия, уклон дороги