OPERATING ANALYSIS OF SOLAR ELECTRIC MOTORS

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REZUMAT. Lucrarea de faţă prezintă contribuţii în legătură realizarea şi experimentarea unui motor electric solar cu inductorul pe rotor a cărui funcţionare se bazează pe conversia helio-electromecanică a energiei solare. Caracterul particular imprimat motorului electric solar analizat, se referă deopotrivă la traductorul de poziţie, care datorită dependenţei de radiaţia luminoasă primită de la Soare, are caracterul unui fototraductor de poziţie. Este analizată influenţa unghiului fantei discului obturator din structura fototraductorului de poziţie asupra fenomenului de comutaţie al motorului.

Cuvinte cheie: motor electric solar, bloc solar, celule fotovoltaice, fototraductor de poziţie.

ABSTRACT. This paper present contributions regarding the achievement and experimentation of an solar electric motor with inducer on rotor of which operation is based on helio-electromechanical conversion of solar energy. The particular character transferred to the analyzed solar electric motor, refers to the position transducer which due to dependence of light radiation received from the Sun, has a position phototransducer character. Is analysed the value of the shutter disk angle from position phototransducer structure on the switching phenomenon of the motor.

Keywords: solar electric motor, solar unit, photovoltaic cells, position phototransducer.

1. INTRODUCTION

This paper present contributions regarding the achievement and experimentation of an solar electric motor of which operation is based on helio-electromechanical conversion of solar energy [3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16]. The interest for solar electric motor was encouraged by the unprecedented development of microtechnologies and power electronics, the miniaturisation of electronic components and their price, increasing efficiency and photovoltaic cells price decrease. Appearance of the solar electric motors is due to the techniques and intuitive methods of technical creation [1, 2].

The operating block diagram of the DC motor with static commutation (MSC) is presented in figure 1.

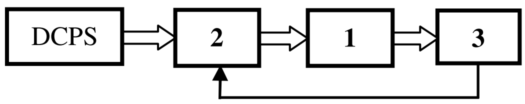


Fig. 1. The operating block diagram of the DC motor [15, 17, 19]: 1- synchronous motor; 2- switching device; 3- position phototransducer of the rotor; DCPS- DC power source.

Operation, at the appropriate time to switch, without contacts, is controlled by the position transducer 3 of the rotor. When it is necessary to ensure a constant rotational speed, DC motor with switching device is equipped with a speed stabilization element.

Typically, the DC motor has on the stator three winding sections connected in star or delta, which provides starting torque at all rotor positions. A motor with an winding consists of a large number of sections will have lower torque pulsations and a uniform rotational speed, but the cost of electronic switching scheme will be higher.

Therefore, the DC motors with static switching, of magnetoelectric type, present the following specific elements:

- on the stator is the inducer winding, and the rotor present an permanent magnet;
- moments at which are perform the switching in the induced winding are determined by the rotor position sensor;
- the switching are made without contacts, using a switch with semiconductors controlled by impulses provided by the rotor position sensor.

2. THEORETICAL AND STRUCTURAL FEATURES OF THE MOTOR

There are two ways to achieve an motor based on solar helio-electromechanical conversion [5, 18]:

-by associating a solar cell panel with a typical DC motor (equipped with collector and brushes);

-using static switching and include the power supply, consisting of solar cells, in engine construction.

Solar electric motor with static switching solution is less known in the specialty literature. The use of this solution is justified at this stage, for the following applications:

-the development of vehicles and equipments for outer space;

-the development of systems and installations that require high safety in operation, in particular environmental conditions (temperature, humidity, wind, precipitation, etc..) and which installations do not have supervisory staff, as appropriate for the Sun tracking systems, for the solar concentrator collectors, photovoltaic cell panels and solar heliostats.

In the case of studied solar engine, switch function, which performs sliding contact between brush and commutator segments for DC motor, is taken from semiconductor devices, able to work in the switching mode. Because, in this case, the switching is performed with static elements, is not necessary that the switching device to rotate. This fact becomes possible, placing the armature winding on stator and making rotor to rotate. Using a rotor with permanent magnets is possible to eliminate any sliding contact.

To perform the static switching to solar engine is necessary to have a device to detect the rotor position and transform this information as a signal, applied to a second device of the position phototransducer structure.

A first analysis of solar electric motor components leads to identify the same elements as for a DC motor with regular switching: synchronous motor, a switching device and a position phototransducer.

Constructive and functional particularities involved in the analyzed solar engine are related by issues presented below:

■ the power source is included in the motor and consists of a battery with solar cells placed on an insulating support covered with transparent protection screen and which support is fixed to the motor stator, being constantly exposed to solar radiation;

■ said power source comprises a *main part* that supplies an assembly consisting of three parallel connected circuits, each consisting of a section of induced winding in series with a switching group into which two solar cells are connected in series;

■ switching groups are arranged as a circular route being exposed, successively, to solar radiation through the disk shutter slot; as described, the main source is permanently connected in series with one group of switching, which is the *secondary part*, resulting, finally, a increase with corresponding switching voltage.

The indus of the motor is a radial winding, consisting of three sections, with the axis shifted by $2\pi/3$ radians, connected in "star" and which provides the following advantages: simple design, easy start for any initial rotor position, a small number of photovoltaic cells used for switching.

The switching is achieved via a shutter disk fixed to the upper end of motor shaft and provided with a slot size characterized by *angular dimension „β” of the sector signal of position transducer* and is calculated with:

$$\beta = \frac{2\pi}{pN_s}, \tag{1}$$

where p is the number of poles pairs and N_s is the sections number of the induced windings.

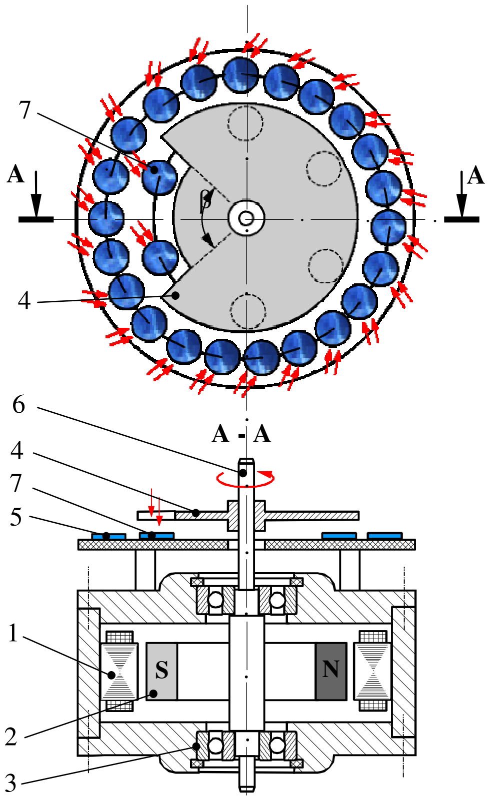


Fig. 2. Longitudinal cross section of the solar electric engine [18]: 1- stator; 2- rotor; 3- slide bearing; 4- disk shutter; 5- photovoltaic cells; 6- shaft; 7- photovoltaic switching group.

It should be noted that encoder position, due to dependence on illumination received from the Sun, has a phototransducer position character. Thus, were preserved the main features of the classic position transducer identified to DC motor with static switching, as follows [9, 11]: to allow easy adaptation in switching scheme, in order to work safely and economically; the ratio between the maximum and minimum signal to be large; energy consumption should be as low as possible to provide robustness in corrosive environments at high temperatures and safe operation under vibration.

The power supply operation, the transducer position and the electronic switch are conditioned by the existence of sunlight, thus underlining the solar engine character for the test solution.

The switching mode proposed refers to using three commutation groups each consisting of two solar cells in series. Proposed switching system is composed of the main power supply, made up of several photovoltaic cells and which is connected to a set of three parallel connected circuits. Each circuit consists of a section W_A, W_B, W_C in series with one switching group B_A, B_B, B_C in composition of which enter two photovoltaic cells arranged on a circular route, every angle of $2\pi/3$ radians. They are exposed, successively, to solar radiation through the disk shutter slot. Light source, consisting of sunlight, is guided to the solar cells by the disk shutter, the beam path being interrupted or released, depending on the angle β of the slot and the rotor position. The longitudinal cross-section of the analysed motor is presented in figure 2.

The electrical scheme of the solar electric motor presented in Figure 3 represents, in our opinion, the best solution, based on the following statement: *the current established through a consumer connected to a power source, made up of several photovoltaic cells, always record a decrease if one or more photovoltaic cells from the source are blocked.*

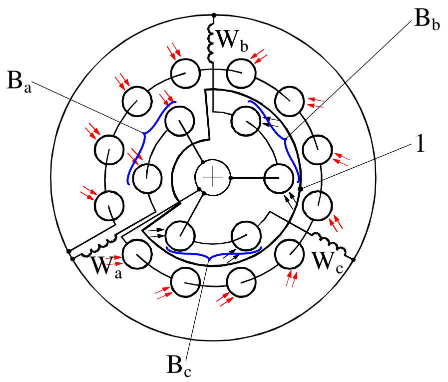


Fig. 3. The electrical operation scheme of the solar electric motor [4, 18]: 1- shutter disk; B_a, B_b, B_c- photovoltaic switching group; W_a, W_b, W_c- induced windings section.

Figure 4 illustrates the experimental model of the analyzed motor having the switching made by special groups of photovoltaic cells, connected in series with induced winding sections and with power supply.

Fig. 4. Solar electric motor – experimental design

The main power source, the switching groups and position sensor are dependent as regards the operation, by solar radiation, which leads to the consideration of an *sun block*.

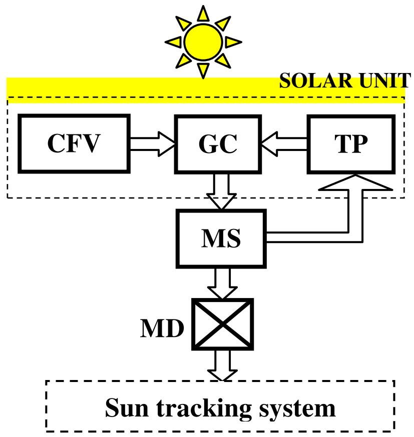


Fig. 5. Operating block diagram of the analyzed motor [18]: CFV- photovoltaic cells battery; GC- switching group; TP- position transducer; MS- synchronous motor; MD- reduction gear.

About the possibility of using solar electric motor to the development of the Sun tracking systems, the equivalent configuration scheme, which has many differences from that used in the case of a DC motor with static switching, usually takes the form shown in figure 5.

3. POSITION PHOTOTRANSDUCER WITH PHOTOVOLTAIC CELLS ANALYSIS

Contributions set out below starts from the finding that, regardless of adopted phototransducer type, it is important that the signal generated by him to depend only by rotor position and not by speed of rotation, the direction of rotation or environmental conditions [17, 19].

Theoretical explanations linked to the achievement of position phototransducer with photovoltaic cells is based on the existence of two currents identified, explaining the effect of a photovoltaic solar cells (Figure 6).

In operation, through the junction appear a current I_s caused by photovoltaic conversion of direct component of solar radiation. Through the mentioned junction, appear a direct current I_d, which is opposite to the current by photovoltaic nature. The current through the junction will be given by:

$$I = I_s - I_d = I_s - I_0[\exp(U/U_T) - 1], \qquad (2)$$

where I_0 is the saturation current on the reversed polarity of junction, and U_T is the thermal voltage, equivalent to the operating junction temperature.

According to equation (1) we get:

- at short-circuit operation (U = 0):

$$I_{sc} = I_s; \qquad (3)$$

- at no-load (I = 0):

$$U_g = U_T \ln (I_s/I_0 + 1), \qquad (4)$$

and if $I_s \gg I_0$ - which usually happens when the light level is high enough, we have:

$$U_g \approx U_T \ln (I / I_0). \qquad (5)$$

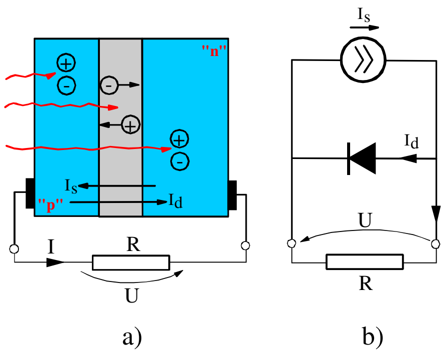


Fig. 6. Photoelectric conversion of solar energy [18]: a- explanatory of internal photovoltaic effect; b-simplified equivalent circuit of a photovoltaic cell.

In the absence of illumination of the photovoltaic cell is obtained:

$$I_I = - I_d = - I_0 [\exp(U/U_T) - 1], \qquad (6)$$

which justifies the name given to the current I_d by "*dark current*" of the photovoltaic cell (Figure 6a and Figure 6b).

The possibility of using a position phototransducer with photovoltaic cells is due, therefore, to "*dark current*", phenomenon made possible through obstruction of one or more solar cells connected in series, in the group of cells that form the photovoltaic power source.

The effect produced by the "*dark current*" is highlighted by reducing short-circuit current value for photovoltaic module that can be highlighted further, by adopting the term by *equivalent internal resistance* which is increased when the blocked number of photovoltaic cells rising.

Experimental checking of this theoretical solution, suggested above, was made possible by the experimental test bench shown in Figure 7.

Fig. 7. Experimental test bench to establish the possibility to optimize the position phototransducer with photovoltaics cells

In the experiment has been used a number of 27 photovoltaic cells. Photovoltaic panel was exposed to solar radiation in biaxial orientation system, to follow the apparent motion of the Sun.

For determining the optimal number of photovoltaic cells necessary for the commutation, was supervised the shortcircuit current and internal resistance of the photovoltaic panel in conditions of the growing number of blocked photovoltaic cells. Thus, consider the following reports:

-the ratio $\mathbf{I_{sc}/I_{sco}}$, where I_{sc} is the shortcircuit current of photovoltaic module exposed to solar radiation without blocked cells and I_{sco} is the shortcircuit current obtained to photovoltaic module after obstruction of a number of photovoltaic cells;

-the ratio $\mathbf{R_i/R_{io}}$, where R_i is the internal resistance of photovoltaic module without obstructions of the cells and R_{io} is the equivalent internal resistance of photovoltaic module with blocked cells.

Considering the time interval in July, between 8.00 a.m. and 18.00 p.m., were represented the curves

I_{sc}/I_{sco} = f (h) respectively R_i/R_{io} = f (h), during a solar day.

The analysis of two representations (Figure 8 and Figure 9) shows that the favorable situation, related to variation of solar irradiation, is obtained when the number of obstructed photovoltaic cells is lower.

This observation is important because, using the solution with small number of blocked cells, leads to the decrease of position phototraductor dimensions, in the present case, of the disk slot shutter which obviously entails an optimization in terms of startup, operation and speed control of the solar engine.

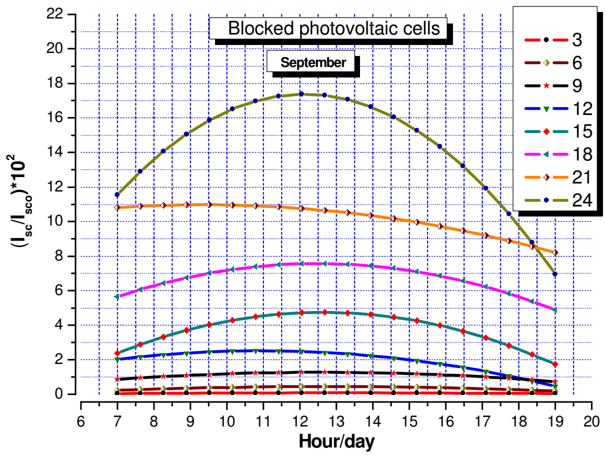


Fig. 8. The variation of I_{sc}/I_{sco} ratio depending on the blocked number of photovoltaic cells of the photovoltaic module

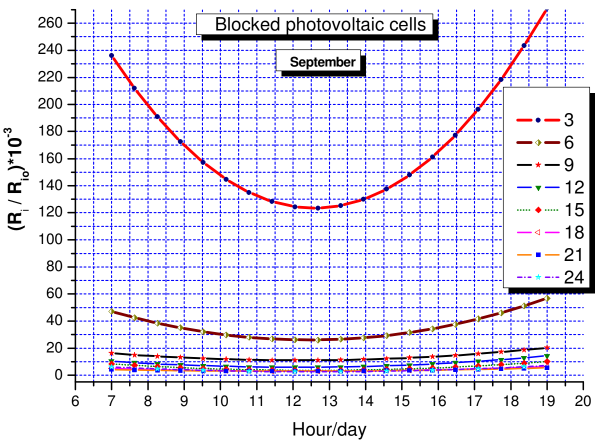


Fig. 9. The variation of R_i/R_{io} ratio depending on the blocked number of photovoltaic cells of the photovoltaic module

4. EXPERIMENTAL RESULS

The experimental test bench for the motor operating analysis is presented in Figure 10. The test bench developed for the study of the position phototransducer are presented in figure 11a. In this respect, in figure 11b is presented an explanation for the definition of angle β and γ involved in the experimental study. The angle β is the angular size of the disc shutter and is considered constant ($\beta = 120^0$) and which express the period of excitation of the phototransducer switching group.

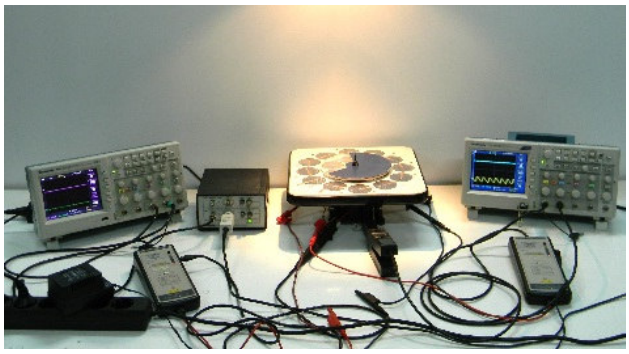
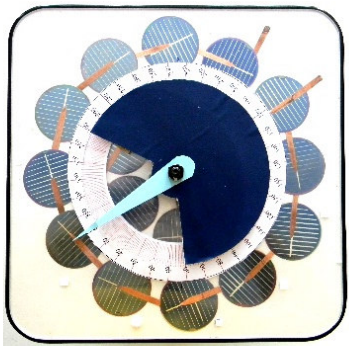
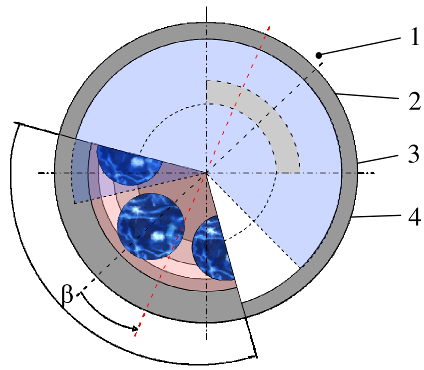


Fig. 10. The experimental test bench for the operating analysis of the solar electric motor with position phototransducer with photovoltaic cells

The experimental study was based on overlapping the rotor poles axis with the axis of the disk shutter slot, (the β angle).



a)



b)

Fig. 11. Explanatory for the β şi γ angle
1- stator; 2- disk shutter slot; 3- photovoltaic cells; 4- rotor poles.

The angle γ is defined as the angle measured between the two axes in the counterclockwise direction. To highlight the importance of the angle γ, the experiment was developed in stages, changing the angle γ in the following range $0^0 \div 330^0$ for the same angle $\beta = 120^0$ and for a constant voltage from the power source, included in engine construction.

This experimental study is needed to determine, the influence of shutter disk slot position in relation to the photovoltaic cells used for commutation, the speed and starting torque. This suggests that the angle β, expose the photovoltaic cells from switching groups to solar radiation, partially or totally, due to the size of angle *γ*: 0^0, 30^0, 60^0, 90^0, 120^0, 150^0, 180^0, 210^0, 240^0, 270^0, 300^0, 330^0 (Table 1).

Table 1

Experimental study stages reflected in the degree of occlusion of each photovoltaic cell

Operating voltage **7 V**		Photovoltaic switching group					
		B_a		**B_b**		**B_c**	
The state in switching circuit		**PV cell 1**	**PV cell 2**	**PV cell 3**	**PV cell 4**	**PV cell 5**	**PV cell 6**
		in series		in series		in series	
The degree of occlusion of the photovoltaic cells, which form position phototransducer **0** – 100% blocked; **1/2** – 50% blocked; **1** – fully exposed to sunlight							
$\gamma[^0]$	0	1	1/2	0	0	0	1/2
	30	**1**	**1**	0	0	0	0
	60	1/2	1	1/2	0	0	0
	90	0	1	1	0	0	0
	120	0	1/2	1	1/2	0	0
	150	0	0	**1**	**1**	0	0
	180	0	0	1/2	1	1/2	0
	210	0	0	0	1	1	0
	240	0	0	0	1/2	1	1/2
	270	0	0	0	0	**1**	**1**
	300	1/2	0	0	0	1/2	1
	330	1	0	0	0	0	1

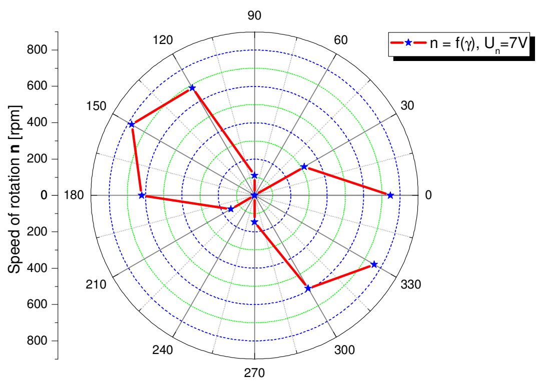


Fig. 12. Variation of the speed of rotation for different values of angle γ

Figure 12 show the evolution of rotational speed for different values of angular size *γ* and for a constant voltage provided by photovoltaics cell included in motor structure.

The solar engine rotational speed, measured for different angles *γ* shows that, starting and operating characteristics, are improved when the size of the angle *γ* have the following values: 0^0, 120^0, 150^0, 180^0, 300^0 and 330^0.

5. CONCLUSIONS

The operation of the position phototransducer with group switching with photovoltaic cell are based on the phenomenon of "*dark current*", identified in the case of a photovoltaic module, when one or more photovoltaic cells are blocked.

Regarding to the achievement of position phototransducer with photovoltaic cells solution is recommended a minimum obstruction of solar cells (one or two photovoltaic cells) because, in this case, the ratio of maximum and residual signal of phototransducer output is satisfactory and it is less dependent on solar radiation fluctuations.

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