EXPERIMENTAL ANALYSIS AND OPERATING OPTIMIZATION OF SOLAR ELECTRIC MOTORS

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REZUMAT. Lucrarea de faţă prezintă contribuţii în legătură realizarea şi experimentarea unui motor electric solar 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. În acest sens, a fost dezvoltat un studiu experimental referitor la dimensiunea unghiului fantei discului obturator (β), în vederea determinării poziţiei optime a acestuia în raport cu elementele de comutaţie din structura fototraductorului de poziţie.

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 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. In this respect, was developed an experimental study on the size of the disk shutter angle (β), in order to determine its optimal position in relation to the switching elements of the position phototransducer structure.

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

1. INTRODUCTION

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, 10].

Therefore, developing new solution in solar motors category that works on helio-electromechanical conversion are based on the following analogies: analogy with the DC motor with static commutation; analogy with the selfdriving synchronous servomotor with permanent magnets and analogy with stepper motor with permanent magnets [8].

Theoretical and experimental contributions presented in this paper are related to an solar electric motor achievement and experimentation. A particular interest is represented by the position transducer of the rotor. Basically, it is composed of an opaque disk, provided with a slot mounted on a motor shaft, and a light source directed towards sensitive elements of the transducer, path of the light beam being interrupted or released by the disk, depending of the angle of rotation of the rotor. The photosensitive elements (phototransistors etc.) is mounted to the motor stator.

It should be noted that the position transducer, due to dependence on solar radiation received from the Sun, has a character of an position phototransducer. Thus, have been preserved the main characteristics of the position transducer identified in the DC motor with static commutation, as follows [9, 11]: to allow easy adaptation in the switch circuit, so that it can operate safely and economically; ratio between the maximum and minimum signal must be large; energy consumption must be as low as possible; to provide robustness in corosive environments at high temperatures and safe operation under vibrations.

2. CONSTRUCTIVE AND FUNCTIONAL FEATURES

In the present design, DC motor consist of an heteropolar inductor and of an induced. In the case analysed, heteropolar inductor, in most of the cases, is plased on the rotor and induced winding is placed on the stator.

This situation is encountered in the solar motors cases, where solution with the inductor on the rotor,

especially encoutered for low power, is illustrated in figure 1. In the both cases, the induced is connected to the power supply through an electronic switch controlled by an position phototransducer provided with shutter disk slot.

The power supply consists of a battery of photovoltaic cells placed on a fixed support, mounted on the stator and exposed to solar radiation. Through a shutter disk slot, mounted on the rotor shaft end, are exposed, successively, to the sunlight, swiching elements (phototransistors) (figure 1).

In the case of the analysed solar electric motor, the switching system is materialized in a phototransducer that consists of an disk shutter with an angular size slot characterized by *angular dimension „β" of the sector signal of position transducer* and is calculated with:

$$\beta = \frac{2\pi}{pN_s}, \qquad (1)$$

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

Path of the light beam is interrupted or released depending on the „β" angle of the slot and the rotor position. In the case of analyzed position phototransducer, the light sourse is represented by sunlight. Characteristic is that power supply opperation, position phototransducer and electronic switch are subject to the existence of sunlight, thus underlining the *solar motor* character for analyzed solution.

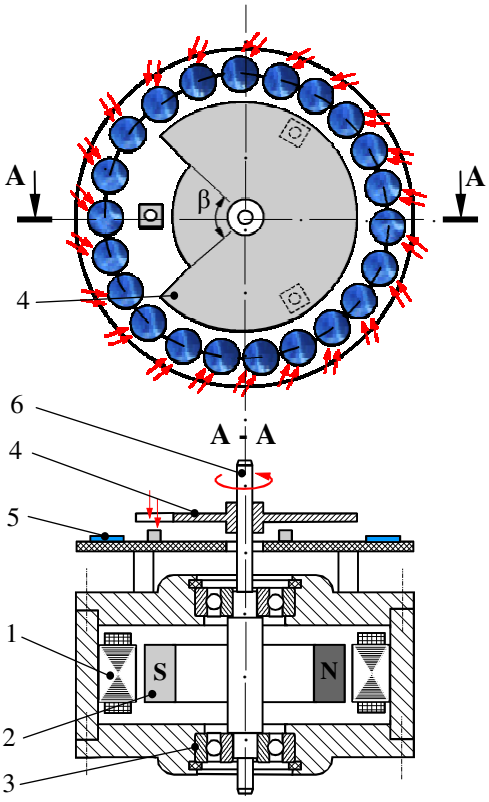


Fig. 1. Solar electric motor – longitudinal section [3, 5, 6, 10]:
1- stator; 2- rotor; 3- slide bearing; 4- shutter disk; 5- photovoltaic cells; 6- shaft.

The experimental results highlights the fact that solution with the inductor on the rotor is the best solution for the solar motor. The stator is a radial winding consisting of three sections with axes offset by 2π/3 radians, connected in „star" and provides the following advantages: simple design and easy start for any initial position of the rotor.

The switching circuit used in the analyzed motor is presented in figure 2.

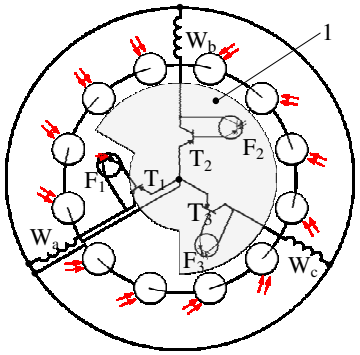


Fig. 2. Switching circuit [3, 5, 10]:
1- shutter disk; F_1, F_2, F_3- phototransistors; W_a, W_b, W_c- induced winding sections.

Photovoltaic cells battery feeds each induced winding sections W_a, W_b and W_c. The picture from figure 3, present the experimental design of the solar electric motor with phototransistor switching circuit.

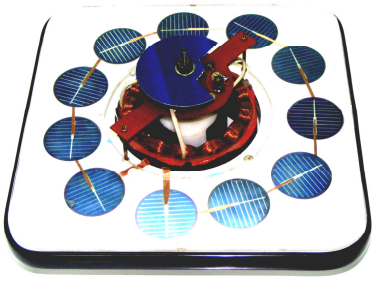


Fig. 3 Solar electric motor – experimental design [7, 10]

A first analysis of solar motor components leads to identifying the same elements as for an usual DC motor with static commutation: a synchronous motor, a switching device and a position phototransducer.

The constructive and functional features involved in analyzed solar electric motor are related by the following issues:

- the power source is included in the motor being established of several photovoltaic cells placed on an insulating support covered with protection transparent screen and which support is fixed to the motor stator, being constantly exposed to solar radiation;
- the power source supplies a system that consists of three circuits, each composed of a section of induced winding in series with a switching element (phototransistor);
- switching elements are disposed after an circular route, being exposed, successively, to solar radiation through the shutter disk slot.

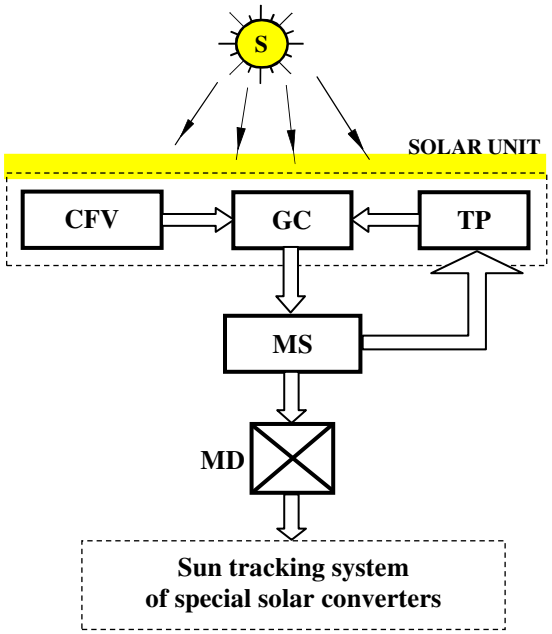


Fig. 4. Operating block diagram of the analyzed motor [10]: CFV – photovoltaic cells battery; GC – switching group; TP – position transducer; MS – synchronous motor; MD – reduction gear.

The power source, switching elements and position phototransducer are dependent, as regard the operation, by solar radiation which leas to taking into account the concept of *solar unit* (figure 4).

3. SOLAR ELECTRIC MOTOR OPERATION ANALYSIS

In figure 5 is presented the test bench to develop the expected experimental study. In figure 6 is an explanation for the definition of β and γ angle values involved in the experimental study. The angle β is the angular size of the phototransducer signal and cause during the excitation period of each sensitive element of the phototransducer. For operation of the motor is necessary that:

$$\beta = 2\pi / (p \cdot N_s) \text{ [rad]}, \quad (2)$$

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

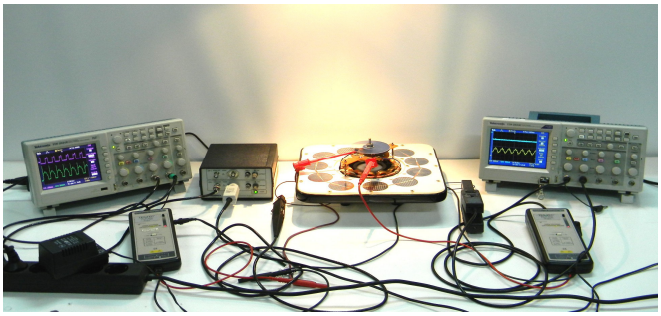


Fig. 5. The test bench used in the experiment

In the case of the position phototransducer used in motor structure, β is the angle of the shutter disk slot (figure 6). Considering the axis of each sensitive element and shutter disk slot axis, γ angle value is defined as the angle measured between the two axes in the opposite direction of rotation of the motor. To highlight the influence of angles β and γ, the experiment was developed in stages, changing the value of angle γ for various values of angle β, all considered for a constant voltage source provided by photovoltaic cells, included in engine construction.

The study highlights the influence of angle β and γ values on: motor start position, influence on the speed of rotation and influence on the torque.

From the analysis carried, there is a decrease in performance, for values of the angle β of 80^0, 60^0 and 40^0 and the angle γ of 0^0 and 10^0. This decrease in performance is reflected in the low speed of the shaft, of a few revolutions per minute, with unfavorable influences on starting torque. For the motor running at high speed and torque it is recommended that control of the pulse duration, provided the photosensitive elements, to be minimized, which is equivalent to $\beta = 120^0$ and $\gamma = 40^0$.

The characteristics n = f (β) for different values of the angle γ are presented in Figure 7. Solar electric motor speed variations depending on the angle γ at different values of angle β are shown in Figure 8.

Therefore is obtained a reduction in motor speed when γ angle is kept at low levels and at the same time, an increase of the current absorbed by the photovoltaic source. Must be highlighted the increasing trend of motor speed, when the angle γ increases, regardless of the evolution of angle β. It should be noted that there is a limit for angle β, below which the motor performance, resulting in torque and speed, is greatly reduced.

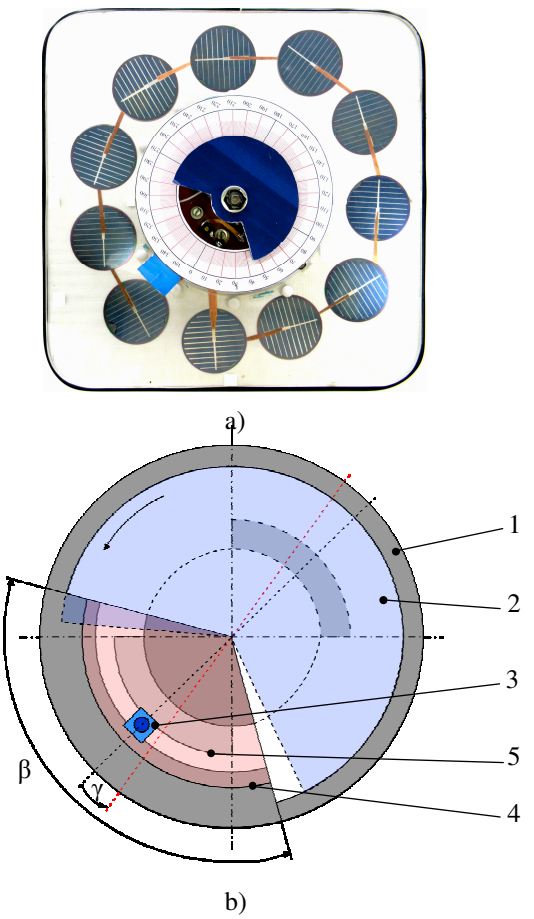


Fig. 6. Explanatory on verifying the solar electric motor switching by changing the angles *β* and γ:
a- experimental design; b- β and γ angle definition.
1- stator; 2- shutter disk slot; 3- sensitive element;
4- position phototransducer support; 5- rotor poles.

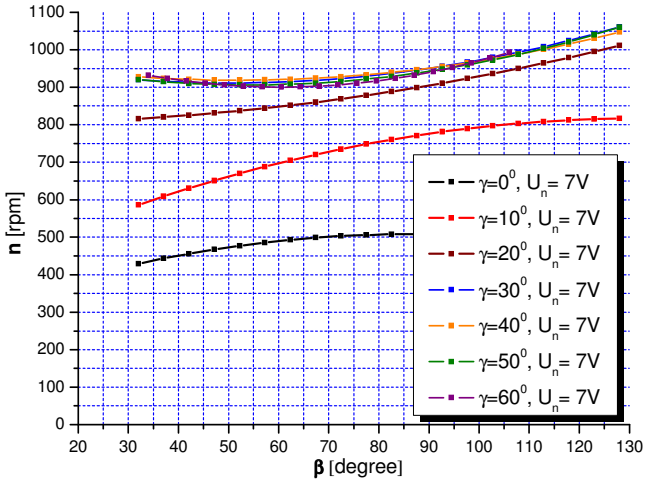


Fig. 7. Solar electric motor speed variation on the angle β at different values of the angle γ, U_n= 7V

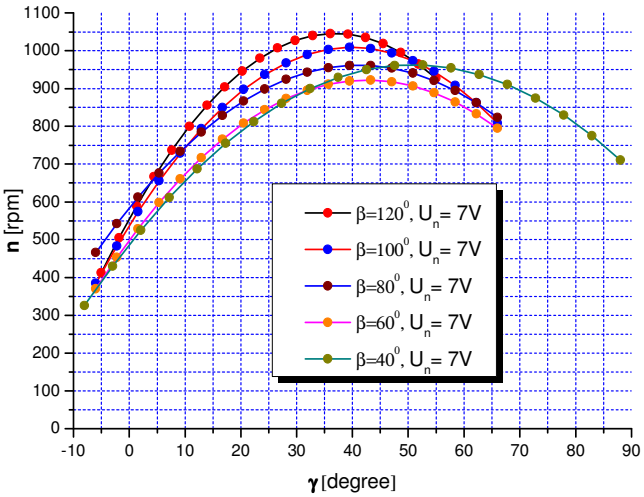


Fig. 8. Solar electric motor speed depending on the angle γ at different values of the angle β, U_n= 7V

In Figure 9 are shown the waveforms of the current and voltage, for switching phase, for $\beta = 120^0$ and γ in $0^0 \div 50^0$ range, for a constant voltage of 7V.

3. CONCLUSIONS

The solar electric motors presented in this paper, characterized by novelty and remarkable modernity, opens a wide field of activity for many researchers in the field of heliotehnics. Integration of solar motors, especially those based on helio-electromechanical conversion in Sun tracking systems is undoubtedly a first step. From this perspective, future developments, interest and concerns of researchers will be open to numerous discoveries and technological innovations.

The experimental results confirm the final conclusions, expected by a theoretical analysis of the analyzed motor:

- speed of rotation, torque and starting position are influenced by the angle values β şi γ;
- for $\beta=120^0$ and $\gamma = 40^0$ is obtained the maximum speed of rotation and for the angle values of β of 80^0, 60^0 and 40^0 and γ of 0^0 and 10^0 is obtained a decrease of motor performance found in the low speed of rotation, of a few revolutions per minute, with unfavorable influences on starting torque.

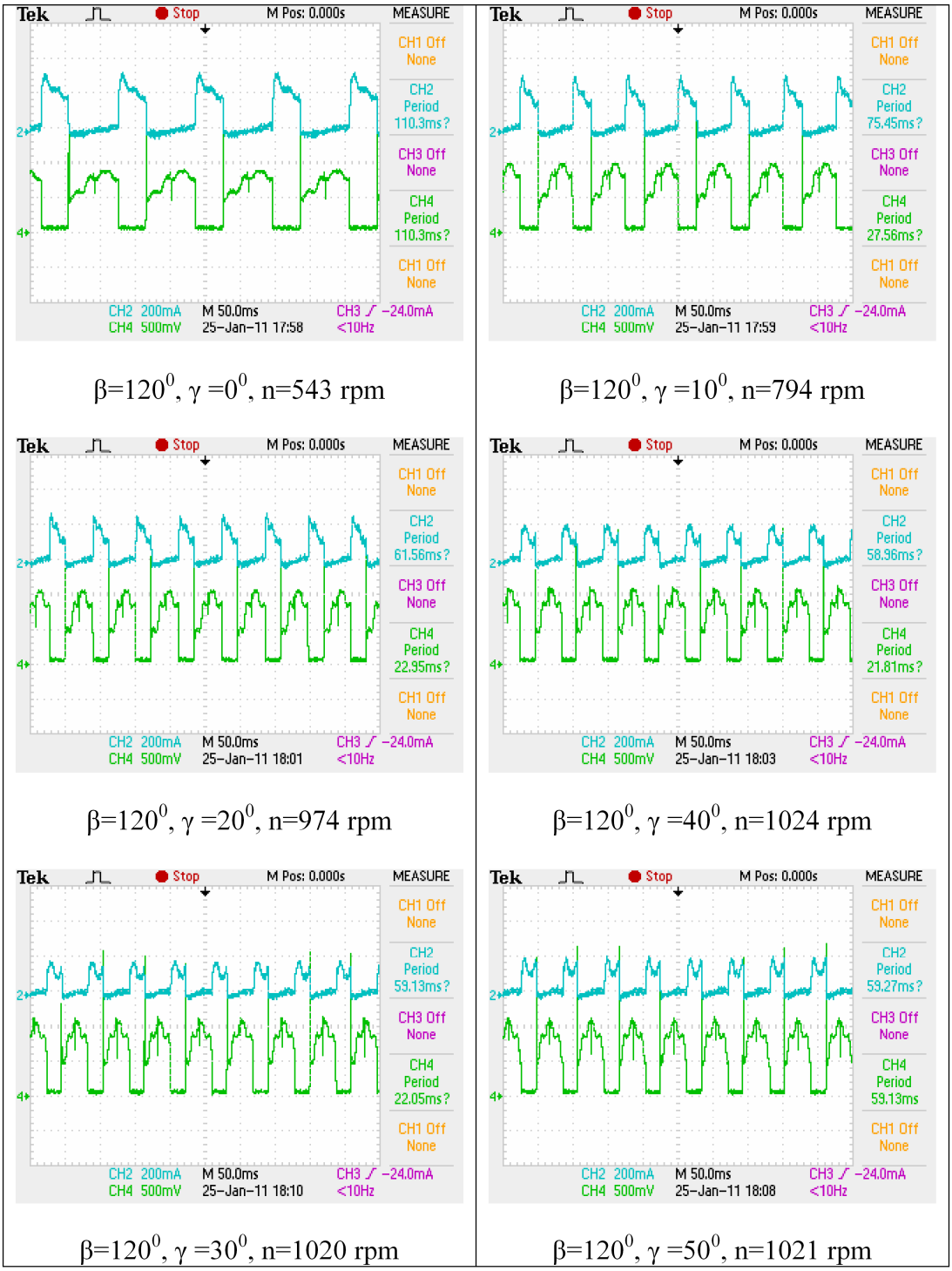


Fig. 9. Waveforms (current and voltage) taken during the switching moment in a section of induced winding, for $\beta = 120^0$ and $\gamma = 0^0 - 40^0$, U_n=7V

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