PHOTOELECTRIC MOTOR
WITH STATIONARY AXIAL DIAPHRAGM

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ABSTRACT

The present paper deals with the photo-commutation effect that can be described most easily by means of elementary photoelectric motor construction. The elementary photo-commutation cycle has been analysed as well as theoretical quantitative relations. Analysis of properties of solar energy powered motor has been performed based on relations between light intensity and functional parameters of the motor. The aim of the research was to examine effect of illumination intensity on photoelectric commutator parameters, motor start-up conditions, and rotor rotational speed. In the paper is proposed the mathematical model of proposed and made by as elementary DC photomotor. As the power source of this motor are photodiodes in armature coil which are supplied by light. The commutation of photodiodes realizes by light and shade. The mathematical model consists from ordinary differential equations in normal Cauchy form of electromechanical state. The results of computation are given.

Keywords: photoelectric motor, photoelectric commutator, photovoltaic cells, contactless commutator.

INTRODUCTION

As demand for energy coming from ecological sources increases, researchers pay more attention to possibility of construction of small electric machines powered with solar energy. One of possibilities consists in application of semiconductor photovoltaic cells to drive direct current electric motors. In such motors, the photocells represent integral part of construction. The elementary photoelectric motor, which will serve here for demonstration of the photo-commutation effect, is an electromechanical device that transforms electric pulses coming from photovoltaic cells into mechanical motion. It is realised as a direct current machine containing a photocommutator. Figure 1 represents schematic diagram of the photoelectric motor.

Rotor of the photoelectric motor (4) rotates in magnetic field of a permanent magnet (3) in small angular steps induced by electric signals, supplied in proper sequence from the photocells (2). Photovoltaic cells rotate together with the rotor and are connected to its windings. Sequence of signals is forced by photoelectric commutator, of which a fixed diaphragm (1) is an integral part (in case discussed here). Sense of rotor rotation is related directly to the supply voltage depending on polarity of cells. First designs of photoelectric motors with one pair of photovoltaic cells determine a new trend in direct current motor design development, closely related to continuous progress in construction of new and still more efficient photovoltaic cells. In order to optimize parameters of photoelectric
Motors, it is necessary to test them by means of specially designed measurement setups.

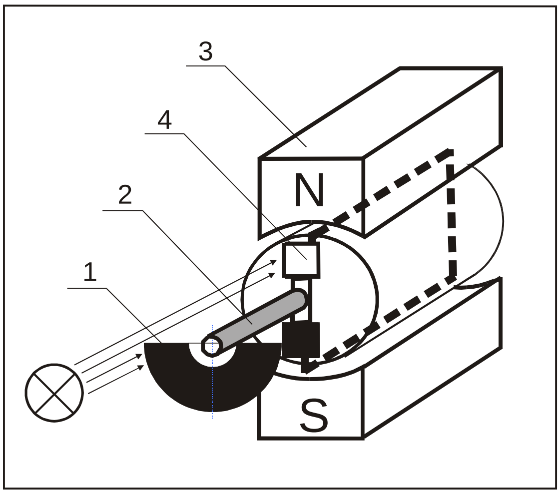


Fig. 1. Diagram of the photoelectric motor with stationary axial diaphragm (see text for description)

The measurements cover basic parameters of photo-commutator and dependence of rotor's rotational speed on illumination conditions.

THE PHOTO-COMMUTATION EFFECT

The principle of operation of photoelectric commutators is as follows. The light beam illuminating currently exposed cell(s) connected to motor windings results in voltage pulse, duration of which depends on diaphragm's window width, photovoltaic cell surface area, and rotational speed of the rotor. Occurrence of the pulse results in feeding of the motor's windings with proper voltage or configuration of voltages. The voltages are there until occurrence of the next driving pulse coming from next photocell(s) exposed by the diaphragm. This results in change of current distribution in the winding, causing change in magnetic field direction, which consequently results in rotor turn by certain angle. Number of configurations of driving voltages, after which they start to repeat, can be called (just like in the case of a stepping motor) the commutation cycle. There are two fundamental types of photoelectric commutators:

– axial, with rotating or fixed diaphragm,
– radial, with rotating or fixed diaphragm.

Bearing in mind that the principle of operation for both types of photoelectric commutators is the same, in the following we discuss only the case of axial photoelectric commutator with fixed diaphragm.

ELEMENTARY PHOTO-COMMUTATOR

Elementary photoelectric commutator with fixed axial diaphragm has two single photovoltaic cells installed axially directly on the rotor. The fixed diaphragm is installed on the stator. The cells are interconnected so that exposure of both of them at the same time would result in a short-circuiting (Fig. 2).

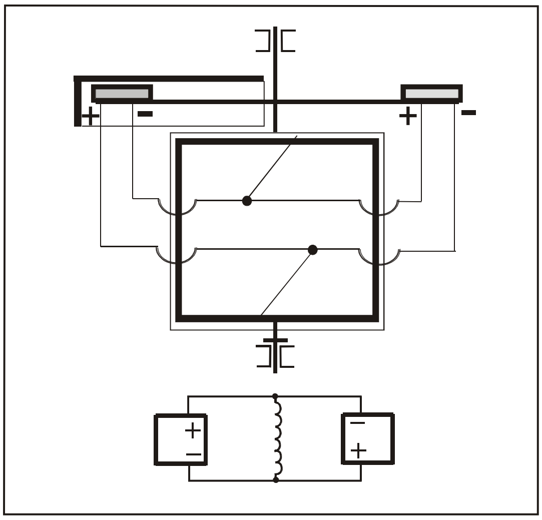


Fig. 2. Diagram of commutator photocells' connections with rotor windings

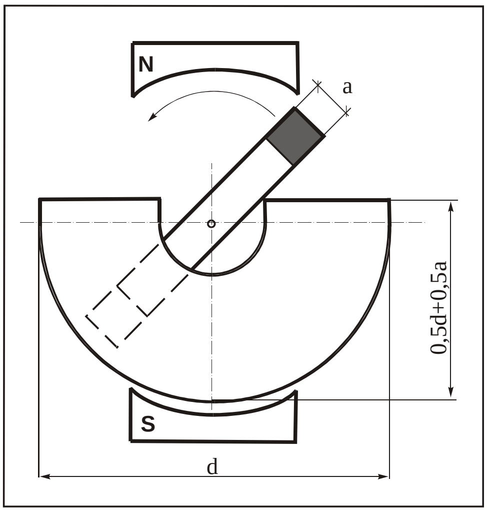


Fig. 3. Diagram of the photoelectric commutator (see text for description)

Rotor of construction described above constitutes one segment of the photo-commutator. To obtain the photo-commutation effect, the fixed diaphragm must fulfil the fundamental conditions: firstly, one of the photocells must be completely shaded; secondly, the diaphragm must be properly situated with respect to the stator. It has to make possible for rotor to rotate by angle of 180 degrees. Diagram of the elementary photo-commutator and its theoretical dimensions are shown in Figure 3.

Dimensions of the diaphragm are selected depending on size of photocells so that they are prevented from short-circuiting. The diaphragm causes momentary complete shading of both cells. Thanks to inertia of the rotor, the second cell is being exposed. Theoretically, in case of shading of both cells, autonomous start-up of the motor is impossible. In practice this is not the case, because perfect shading of both cells is impossible, and usually more than two segments of the photo-commutator are used. The voltage pattern in single cell (before short-circuiting and connection with the rotor) in the course of photo-commutator operation is shown in Fig. 4.

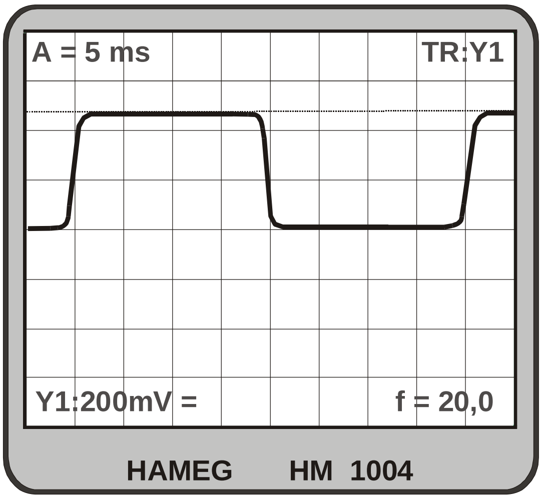


Fig. 4. Characteristics of a single photocell obtained by means of hameg hm 1004

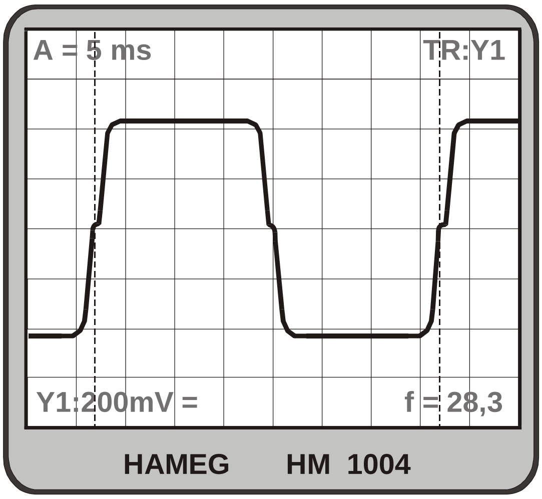


Fig. 5. Characteristics of pair of photocells obtained by means of hameg hm 1004 oscilloscope

The presented characteristics was taken at rotational speed of 1200 rpm and illumination intensity of 10 000 Lx. Determination of cells voltage is possible from this figure, equalling about 0.44 V. Figure 5 shows the resultant characteristics of the short-circuited pair of cells before connection to the rotor taken at the same illumination as above and at 1700 rpm.

One full period of photo-commutation is visible. After exposure of the first cell, voltage increases until a maximum value depending on actual conditions and remains the same until the moment of shading. Temporary drop of the voltage occurs (both cells are shades). After exposure of the second cell, the voltage reaches the same value, but of the opposite sign. Then the voltage decays. The maximum voltage value depends on intensity of light illuminating the surface of the cell. Comparing the two plots, one can note that voltage produced by pair of cells is slightly lower than the value for single cell which is a result of imperfection of the diaphragm. The period of total shading of the pair of photocells decreases with increasing rotational speed.

Mathematical model of photoelectric motor with two segments of the photo-commutator

As an object of research, a silicon photovoltaic cell has been used of the following parameters: I_{max}=1,1mA, U_{max}=0,5V, dedicated for military applications. The active area of the cell equaled 10 mm ^{2} The motor under investigation has been equipped with two-segment commutator. Fig. 6 represents rotational speed of the rotor versus illumination intensity in artificial light conditions. It can be seen from the plot that motor start-up occurs only after the intensity exceeds the value of E = 1,500 Lx. Together with increasing light intensity, rotor speed increases and stabilizes at intensity of E = 20,000 Lx. Further increase of light intensity does not cause increase of rotational speed (the solid line). With light intensity decreasing, rotor speed decreases down to its minimum value of n = 150 min^{-1} at E = 1,000 Lx (dashed lined, point A representing a limit of characteristics consistency).

The minimum period required for stabilization of rotational speed was established as equal to

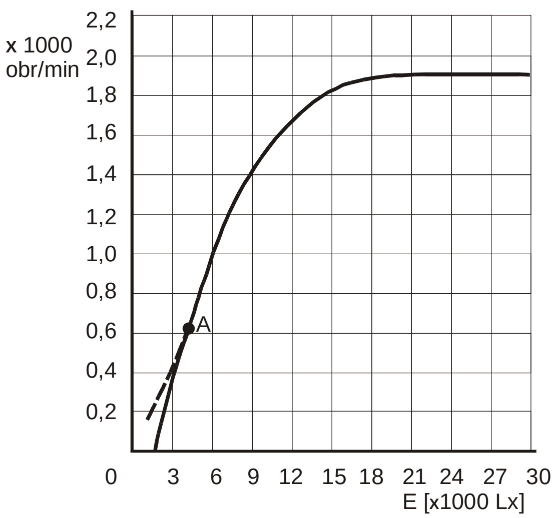


Fig. 6. Rotor rotational speed versus light intensity

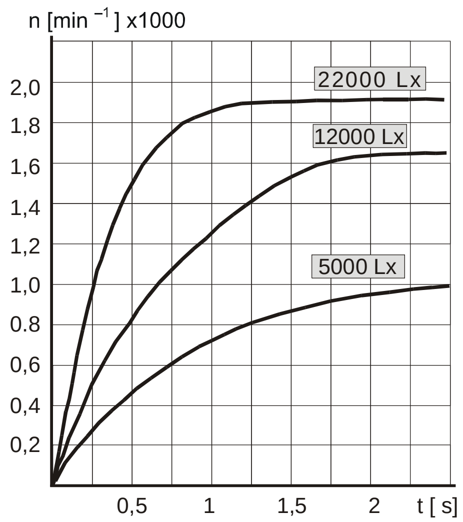


Fig. 7. Motor start-up characteristics at different light intensity values

Fig. 7 represents rotational speed of the rotor versus illumination intensity in artificial light conditions. That motor start-up occurs only after the intensity exceeds the value of E = 1,500 Lx. The next step consist in finding the period of time after which the rotor will reach its maximum rotational speed at given value of illumination intensity. Fig. 4 represents the start-up characteristics at E = 5,000, 12,000, and 22,000 Lx

Mathematical model of photoelectric motor.

The equation of armature winding has ordinary form

$$u(\lambda,t) = L\frac{di}{dt} + (r + r(\lambda))i + e,. \tag{1}$$

where:

$u(\lambda,t)$ is photocell voltage as function of illumination λ and time t;

i is current;

e is EMF of rotation;

r is winding resistance;

$r(\lambda)$ is photocell resistance.

EMF we look for according to Faraday's law

$$e = -w\frac{d\Phi}{dt}, \tag{2}$$

where:

Φ is magnetic flux;

w is number of armature winding coils.

Magnetic flux we look for determination:

$$\Phi = \int_S \mathbf{B}d\mathbf{S} = BS\cos\gamma, \tag{3}$$

where:

B is module of magnet induction vector **B**;

S is averaged area of armature winding window;

γ is angle of rotor turn.

Having placed (3) into (2), we receive:

$$e = w\omega BS\sin\gamma, \tag{4}$$

where ω is angular velocity of rotor.

Having placed (4) into (1), we receive:

$$\frac{di}{dt} = \frac{1}{L}\left(u(\lambda,t) - (r + r(\lambda))i - w\omega BS\sin\gamma\right). \tag{5}$$

The differential equation (5) we must add by movement equation

$$\frac{d\omega}{dt} = \frac{1}{J}\left(T - T_m(\omega,t)\right); \qquad \frac{d\gamma}{dt} = \omega, \tag{6}$$

where:

M is internal torque;

$M_m(\omega,t)$ is impressed mechanical moment (given).

The expression of internal torque we obtain from magnetic energy of coil w_m

$$T = -\frac{\partial w_m}{\partial\gamma} \tag{7}$$

why

$$w_m = w\Phi i = wBSi\cos\gamma. \tag{8}$$

Having placed (9) into (6), we have

$$T = wBSi\sin\gamma \tag{9}$$

Having placed (9) into (6), we have

$$\frac{d\omega}{dt} = \frac{1}{J}\left(wBSi\sin\gamma - T_m(\omega,t)\right); \qquad \frac{d\gamma}{dt} = \omega \tag{10}$$

Imposing the condition of photocell commutation by light and shade the (5), (10) quire definitive form:

$$\begin{cases} \dfrac{di}{dt} = \dfrac{1}{L}\left(u(\lambda,t) - (r + r(\lambda))i - w\omega BS\,\mathrm{mod}(\sin\gamma)\right) \\ \dfrac{d\omega}{dt} = \dfrac{1}{J}\left(wBSi\,\mathrm{mod}(\sin\gamma) - T_m(\omega,t)\right) \\ \dfrac{d\gamma}{dt} = \omega \end{cases} \tag{11}$$

The proposed method of elementary photomotor my by generalized on real photomotor with arbitrary number of armature winding.

THE RESULT OF COMPUTATION

Fig. 8 represents the result of computation of some transient process particularly – the starting of unloaded photomotor by constant candlelight 22000 Lx.

In this case was integrated the ordinary differential equations (11) by concrete parameters:

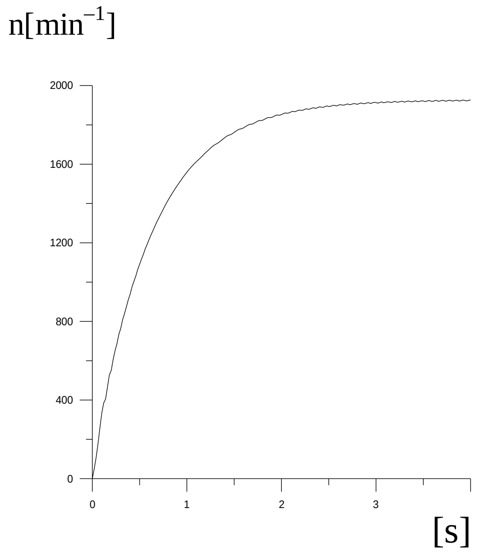
$$\begin{aligned} &\frac{di}{dt} = 385\left(0,212 - 338i - 0,1293nB\,\mathrm{mod}(\sin\gamma)\right); \\ &\frac{dn}{dt} = 2019200B\,i\,\mathrm{mod}(\sin\gamma); \qquad \frac{d\gamma}{dt} = 6,28n, \end{aligned} \tag{12}$$

where:

n is promptness of motor in turn/sec

$$n = \omega/(2\pi). \tag{13}$$

Calculated (A) and experimental (B) motor start-up transient characteristics



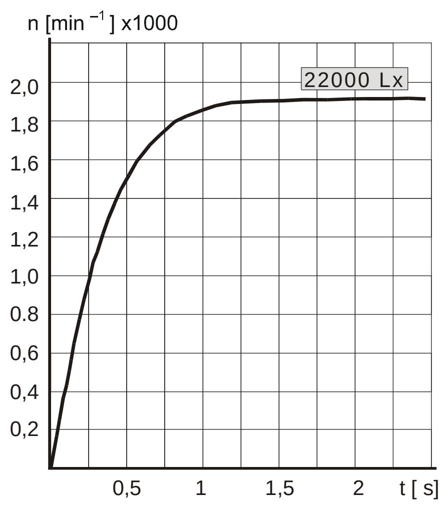


Fig .8. **A** - Calculated motor start-up transient characteristic by given light intensity values 22000 Lx: n = n(t) turn/min; **B** - Experimental characteristic

Comparing the calculation transient curve from fig. 8A with corresponding experimental curve (22000 Lx) from fig. 8B we see that they are equal with precision in all process diapason. The considered and described photomotor not exclude all possible construction of photomotors.

SUMMARY

In the photoelectric motor, photo-commutator serves for keeping the sense of force acting on rotor winding sides constant. Considering the principle of operation of the photoelectric commutator one has to bear in mind that it plays role of both the emitter of steering pulses and the power source. As a consequence, one has to keep the area of active surface as large as possible in each of its segments. One should also to minimise the period of total shading of the pair of cells. Important is also the fact that commutation is realised without contact.

Light intensity influences in a decisive way both start-up conditions and maximum rotational speed of the motor.

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