LED-Photoresistor Polaroid Optocouplers

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Abstract— **Transducers are indispensable devices to perform a connection between two physical systems operating with different types of signals. LED-photoresistor Polaroid optocoupler is a device which combines the advantages of transducers with those of optocouplers. This is possible by introducing a system of Polaroid filters into the way of the beam light, to allow the opto-couplor's modification of the electrical resistance at the exit, as a result of an axial rotation movement of the receiving module towards the emitting module. Such a device can be used both as a mechanic-electrical transducer and as a mechanic-electrical modulator. The device is designed to be applied in the field of mecatronix automations and robotics.**

Index Terms — **Optocoupler, Photo-Interrupter, Photoresistor, Polaroid optocoupler, Transducer**

I. INTRODUCTION

Optocouplers are optoelectronics devices which have been designed to optical coupling two systems with different tensions, to perform their galvanic separation.

In the case when the user has access to the optical length of the light beam, optocouplers can accomplish different functions: the commutation of some circuits by means of the optical way, signals' filtration through the optical way, the optical multiplexation/demultiplexation of signals, and the detection of the electrical signals through the optical way. [1]

Such an optocoupler is the photo-interrupter.

As the intensity of this optocoupler's outlet current of can have only two values, one corresponding to the obturated beam light and the other one to the unobstructed beam light, one needs a device to change the signal emitted by this one.

This inconvenient can be overcome if the mechanic system for the obstruction of the beam light is replaced with a Polaroid filter system. Such an optocoupler is named *Polaroid optocoupler.*

II. THE DESCRIPTION OF THE DEVICE

LED-photoresistor Polaroid optocoupler is an optoelectronics device of circuit, comprising: the transmitting module, the receiving module and a mechanic system which allows the axial assembly of these modules' compounds, as well as their setting into action.

The transmitting module (T_x) is made of a light source and a P-polarizing Polaroid filter whereas the receiving module (R_x) is made of an A-analyzing Polaroid filter and a photoresistor.

As light sources, one can use lamps with reduced incandescence, super bright LEDs and LASER diodes.

One can make two kinds of Polaroid optocouplers: Polaroid optocouplers with remote control and Polaroid optocouplers without remote control.

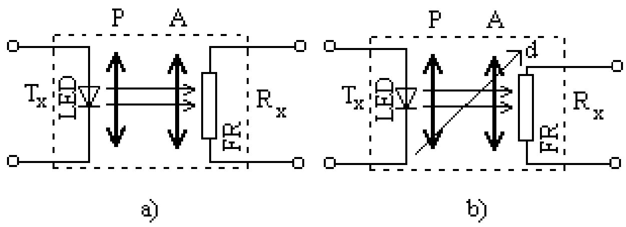

Fig. 1 LED-photoresistor Polaroid optocoupler:
(a) without remote control, (b) remote control.

In Fig. 1 are represented the circuit symbols of the two types of LED-photoresistor Polaroid optocouplers.

III. OPERATING PRINCIPLE

The main trait of the Polaroid optocouplers consists in the possibility to modify the electrical signal at the receiver's exit, as a result of two processes: one of beam light's polarization by which it's performed the coupling between the transmitter and the receiver and another one of reorientation of the light radiation's polarization plan.

If on a filter which in-line polarizes light radiation falls a wave group, coming from the source of an optocoupler, so as the intensity vector of the electric field **E**, forms an angle with the plane of vibration, the emergent radiation will be characterized only by the component $\mathbf{E_y}$ of the wave group. The component $\mathbf{E_x}$ of the emergent wave group will be absorbed by the filter, (Fig. 2). [4]

If E_m represents the maximum value of the vector's intensity of the electric field, according to Fig. 2 the relation (1) is true.

$$E_{my} = E_m \cdot \cos\gamma \qquad (1)$$

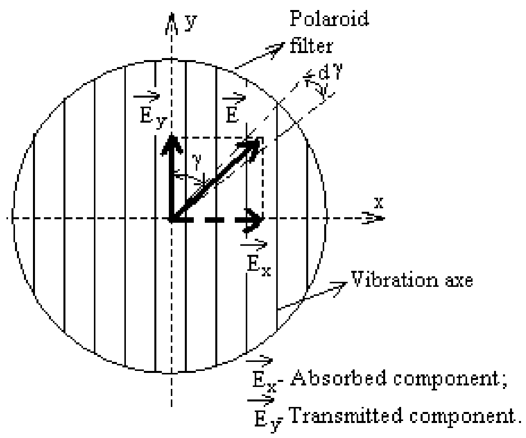

Fig. 2 A wave group where **E** is the equivalent of two wave groups' components $\mathbf{E_y}$ and $\mathbf{E_x}$. By in-line polarization, only the component $\mathbf{E_y}$ is transmitted

Knowing that the intensity of the beam light is proportional with the square of the maximum value of the electric field intensity, relation (1) becomes[1]:

$$d\mathcal{J}_\gamma = d\mathcal{J}_{\gamma o} \cdot \cos^2 \gamma , \qquad (2)$$

where:

$d\mathcal{J}_{\gamma o}$ - the intensity of a unpolarized radiation light beam, incident on the surface of a Polaroid filter, characterized by a **E** vector whose orientation is situated within an infinitesimal $d\gamma$ angular interval, whose bisecting line forms angle γ with the vibration plan, (fig.2);

$d\mathcal{J}_\gamma$ - the intensity of the emergent radiation beam light.

If the surface of the Polaroid filter is uniformly illuminated by a beam light of $\mathcal{J}_o$ intensity, by integrating relation (2), it's obtained the capacity of the linear polarized beam light at the exit from the polarizer:

$$\mathcal{J} = 4 \cdot \int_0^{\frac{\pi}{2}} \frac{\mathcal{J}_0}{2 \cdot \pi} \cdot \cos^2 \gamma \cdot d\gamma = \frac{\mathcal{J}_0}{2} \qquad (3)$$

If this radiation passes through the second filter (analyzer), so as the angle between the polarizing plans of the two filters can be α, according to the relation (3) and to Malus's law, the beam light at the exit from the analyzer will have the intensity:

$$\mathcal{J}' = \frac{\mathcal{J}_0}{2} \cdot \cos^2 \alpha \qquad (4)$$

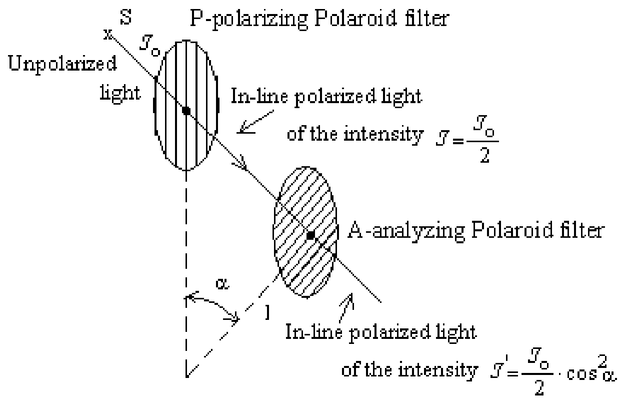

Fig. 3 Group of Polaroid filters

Observation:

Relation (4) is true in the case when the Polaroid filters are ideal (the emission coefficient in the vibration plan is T=1, and in any other plan, the absorption coefficient is A=1).

As the intensity of the light beam at the exit from the analyzer depends on the angle formed between the polarizing plan of the analyzing filter and that of the polarizing filter, for a constant value in time of the radiant sterance of the light source, the relative rotation of the analyzer-receiver system towards the transmitter-polarizer system will determine the modification of the radiant flux, incident on the receiver's surface.

This modification of radiant flux will lead to the modification of the current from the receiver's exit.

In the case when the angle between the polarizing plans of the two filters doesn't get modified in time, but when the distance between the two systems varies, the transducer changes a translation movement into a variable electrical current.

The translation movement of a system towards the other one can be also used to adjust the mechanic-electrical characteristic of the optocoupler used to turn the translation movement into a variable electrical current.

IV. THE STUDY OF THE EXIT RESISTANCE'S DEPENDENCE OF THE LED-PHOTORESISTOR POLAROID OPTOCOUPLER ON THE DIHEDRAL ANGLE (A) AND ON THE DISTANCE (D) BETWEEN T_X AND R_X MODULES

The analyzed optocoupler uses a white super bright LED as transmitter, whose light intensity on the direction of the longitudinal axis is (10365±226) mcd for a current of (19±0.01) mA.

The optocoupler's receiver is a photoresistor type LDR07. Its resistance to darkness is $R_d = (4.40 \pm 0.44) G\Omega$.

To study the resistance's dependence of the LED-photoresistor Polaroid optocoupler on the dihedral angle (α) and on the distance (d) between T_x and R_x modules, there have been used these characteristics: $R=R(\alpha)_{d=const}$ and $R=R(d)_{\alpha=const.}$

The circuitry used to establish these characteristics is show in Fig. 4.

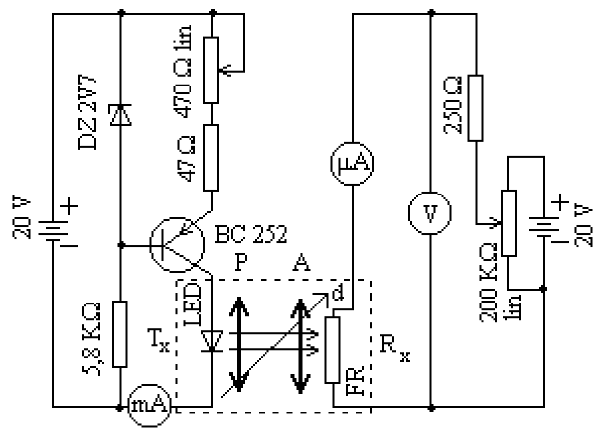

Fig. 4 Circuitry used to study the LED-photoresistor Polaroid optocoupler with distant control

The supply voltage of the photoresistor is V=(3± 0.01)V.

The driving circuit of the LED is a constant current generator. The intensity of the current through the LED is adjusted with the help of linear potentiometer of 470 Ω resistance.

[1] Malus's Law

IV.1. Tracing the family of the characteristics $R=R(\alpha)_{d=const.}$

TABLE I. TABLE WITH THE VALUES OF THE RESISTANCE'S DEPENDENCE OF THE LED-PHOTORESISTOR POLAROID OPTOCOUPLER FOR DIFFERENT VALUES OF THE ANGLE BETWEEN THE POLARIZING PLANS, WHEN THE ISTANCE BETWEEN THE T_X AND R_X MODULES IS CONSTANT

Nr. det.	α (DEG)	R (KΩ) 73mm	R (KΩ) 83mm	R (KΩ) 88mm	R (KΩ) 93mm	R (KΩ) 98mm	R (KΩ) 103mm	R (KΩ) 108mm	R (KΩ) 113mm
1	0	6.7	7.7	8.8	9.8	10.4	11.3	12.4	13.5
2	10	6.8	7.8	8.9	9.5	10.6	11.5	12.5	13.8
3	20	7.4	8.4	9.5	10.0	11.3	12.3	13.8	14.9
4	30	8.4	9.5	10.0	11.2	12.3	13.8	15.3	17.2
5	40	9.8	10.4	11.5	12.8	14.1	15.7	17.7	20.2
6	50	11.3	12.3	13.8	15.3	16.6	18.9	20.9	24.5
7	60	13.8	15.3	16.6	18.9	20.9	23.5	26.8	31.1
8	70	17.7	19.5	21.7	24.5	28.1	31.1	37.0	42.4
9	80	23.5	26.8	29.5	32.8	37.0	42.4	49.5	54.1
10	90	32.8	37.0	42.4	45.7	49.5	54.1	59.5	66.2

The characteristic $R=R(\alpha)_{d=const.}$, represents the resistance's dependence of the LED-photoresistor Polaroid optocoupler on the dihedral angle formed between the plans of the polarization of the Polaroid filters attached to the T_x and R_x modules, when the distance between these ones is constant.

As the ammeter isn't ideal, the value of the determined resistance with the circuitry in figure (4) is accompanied by a big systematic error.

If instead of the relation, R=V/I it's used the relation:

$$R = \frac{V - R_a \cdot I}{I}, \tag{5}$$

where R_a represents the microammeter resistance, then the value of the illuminated photoresistor's resistance will be affected by accidental errors.

The values of experimental determinations are specified in table I.

By graphically representing data from table I, one obtains the family of characteristics $R=R(\alpha)_{d=const.}$

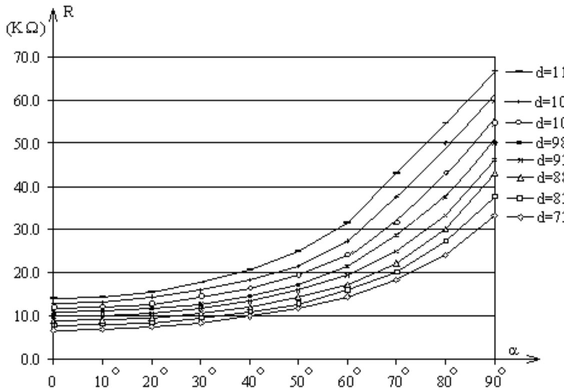

Fig. 5 Graphic representation of the LED-photoresistor Polaroid optocoupler's family characteristics, $R=R(\alpha)_{d=const.}$

IV.2 Tracing the family of the characteristics $R=R(d)_{\alpha=const.}$

The characteristic $R=R(d)_{\alpha=const.}$, represents the resistance's dependence of the LED-photoresistor Polaroid optocoupler on the distance between the T_x and R_x modules, when the dihedral angle formed between the polarization plans of the Polaroid filters attached to the two modules is maintained constant.

To trace the family of the characteristics $R=R(d)_{\alpha=const.}$, we grouped the data in table I, and re-grouped them in Table II.

TABLE II. TABLE WITH THE INTENSITIES OF THE ELECTRICAL CURRENT THROUGH THE PHOTORESISTOR FOR DIFFERENT VALUES OF THE DISTANCE BETWEEN T_X AND RX MODULES, WHEN THE ANGLE BETWEEN THE POLARIZING PLANS OF THE POLAROID FILTERS IS CONSTANT

Nr. det	d (mm)	R (KΩ) 0°	R (KΩ) 10°	R (KΩ) 20°	R (KΩ) 30°	R (KΩ) 40°	R (KΩ) 50°	R (KΩ) 60°	R (KΩ) 70°	R (KΩ) 80°	R (KΩ) 90°
1	73	6.7	6.8	7.4	8.4	9.8	11.3	13.8	17.7	23.5	32.8
2	83	7.7	7.8	8.4	9.5	10.4	12.3	15.3	19.5	26.8	37.0
3	88	8.8	8.9	9.5	10.0	11.5	13.8	16.6	21.7	29.5	42.4
4	93	9.8	9.5	10.0	11.2	12.8	15.3	18.9	24.5	32.8	45.7
5	98	10.4	10.6	11.3	12.3	14.1	16.6	20.9	28.1	37.0	49.5
6	103	11.3	11.5	12.3	13.8	15.7	18.9	23.5	31.1	42.4	54.1
7	108	12.4	12.5	13.8	15.3	17.7	20.9	26.8	37.0	49.5	59.5
8	113	13.5	13.8	14.9	17.2	20.2	24.5	31.1	42.4	54.1	66.2

The graphical representation of the data from Table II is shown in Fig. 6.

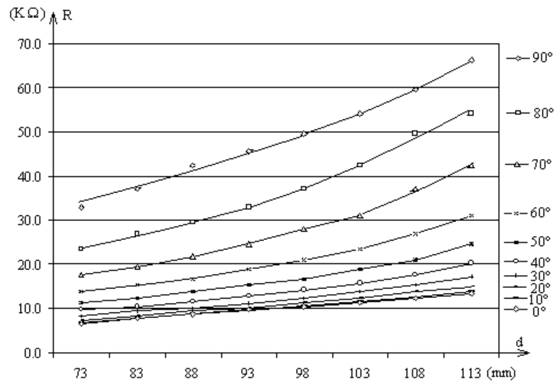

Fig. 6 Graphic representation of the family characteristics $R=R(d)_{\alpha=const}$

IV.3 Interpreting the traits of the led-photoresistor polaroid optocoupler $R=R(\alpha)_{d=const.}$ AND $R=R(d)_{\alpha=const.}$

In the case of photoresistors, the resistance (R)'s dependence on illumination is caused by the dependence of photoconductivity (Δσ) on illumination. [7]

In the case of LDR07 photoresistors, the resistance to darkness being of about some GΩ, one can make the approximation:

$$R = \frac{C}{\sigma} = \frac{C}{\sigma_d + \Delta\sigma} \cong \frac{C}{\Delta\sigma} = \frac{C}{k(\lambda)\cdot E_v^a} = \frac{C_1}{E_v^a} \tag{6}$$

where:

$$C_1 = \frac{C}{k(\lambda)} \tag{7}$$

This relation is valid in the stationary regime, in the case of generating and exclusively band-to-band recombination, for small thicknesses of the semiconductor layer.

The measures which intervene in the relation (6) have the following significations:

- σ_d – it's the semiconductor's conductivity to darkness;
- E_v – represents the illumination;
- C – is a proportionality constant specific to the photoresistor. It doesn't depend on the illumination or the tension (V) applied to this one;
- $k(\lambda)$ - represents optical radiation's spectral luminous efficacy;
- a – is a positive constant which can be sub unitary, super unitary or equal with the unit. For instance, in the case of generating and exclusively band-to-band recombination and particularized for small thicknesses of the sample, if recombinations are linear a=1, and in the case of quadrangular recombinations, a=0.5.

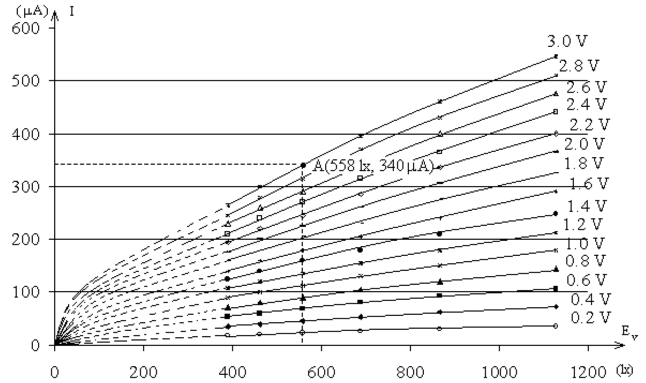

Fig. 7 The family of the luminous characteristics $I=f(E_v)_{V=const.}$ of the LDR07 photoresistor

In Fig. 7 is shown the family of the luminous characteristics $I=f(E_v)_{V=const.}$ of the LDR07 photoresistor.

From this figure one can notice that the photoresistor LDR07 is characterized by a<1 coefficient.

In Fig. 6 is rendered the family characteristics of $R=R(d)_{\alpha=const.}$ type of the LDR07 Polaroid optocoupler.

If the distance (d) between R_x and T_x modules increases, when the current's intensity through LED, the dihedral angle (α) and the supply voltage of the phototransistor are maintained constant, the optocoupler's resistance at the exit increases according to the law whose form is graphically represented in Fig. 6.

This variation has two causes:

a. the decrease of the photosensitive surface's illumination of the device from module R_x and of the light flux through this surface, at the same time with the increase of the distance (d) between R_x and T_x modules;
b. the dependence of the photoresistor's resistance on the ϕ_v light flux of the radiation (on the illumination of its photosensitive surface).

a) In the case of point light sources, when the beam light falls normally on the (A) surface, situated at distance (d) towards the source, the relation (8) it's true:

$$E_v = \frac{I_v}{d^2} \tag{8}$$

where I_v represents the radiation's light intensity.

In practice, this relation can be used if the rule of the ten diameters is respected, (the detector's diameter must be ten times shorter than the distance (d) source-detector). In this case, the obtained measure errors are lower than 1%.

Knowing that the intensity of the beam light which falls on the resistor's photosensitive surface, as well as its illumination are proportional with the square of the maximum value of the electrical field's intensity, from relations (4) and (8) results:

$$E_v = \frac{C_2 \cdot \mathcal{J}'}{d^2} = \frac{C_2 \cdot \frac{\mathcal{J}_0}{2} \cdot \cos^2 \alpha}{d^2} = \frac{C_3 \cdot \cos^2 \alpha}{d^2} \tag{9}$$

where: $C_3 = C_2 \cdot \frac{\mathcal{J}_0}{2}$

From relations (6) and (9) results:

$$R = \frac{C_1 \cdot d^{2a}}{C_3^a \cdot \cos^{2a} \alpha} \tag{10}$$

Expression (10) is a function showing the way in which the photoresistor's resistance depends on the α dihedral angle and on the (d) distance between T_x and R_x modules.

From this relation, one can notice that in point α=90°, photoresistor's resistance must be equal with zero. In practice, this thing isn't possible, because Polaroid filters aren't ideal. Although in the filter's polarization plan, at the exit from this one, the light flux should be null, in reality there is an emergent light flux different from zero.

In this case, expression (10) becomes:

$$R = \frac{C_1 \cdot d^{2a}}{C_3^a \cdot \left(\cos^{2a} \alpha + f\right)} \tag{11}$$

where (f) represents the fraction from the beam light's intensity which falls on the analyzer filter succeeding in passing through this one, in case of extinction.

If the distance between the T_x and R_x modules is constant, relation (12) can be written as:

$$R = \frac{C_4}{\cos^{2a} \alpha + f} \tag{12}$$

where C_4 is a constant value.

Relation (11) is a function of $R=R(\alpha)$ type.

Deriving relation (11), one obtains:

$$R' = \frac{2a \cdot C_4 \cdot \cos^{2a-1} \alpha \cdot \sin \alpha}{\left(\cos^{2a} \alpha + f\right)^2} \tag{13}$$

The first coefficient of the $R=R(\alpha)$ function is cancelled in the point α=0°. As in this point the second coefficient of the $R=R(\alpha)$ function is positive:

$$R'' = 2a \cdot C_4 \cdot (1+f)^{-2} > 0 \tag{14}$$

for the value α=0°, the function admits a minimum.

If the parameter a>0.5, the first coefficient of the $R=R(\alpha)$ function is cancelled in point α=90°, too. For this value of α angle, the function can admit a point of extreme and a point of maximum.

If the distance between modules T_x and R_x is modified, and the (α) dihedral angle is maintained constant, relation (10) can be written as:

$$R = C_5 \cdot d^{2a} \tag{15}$$

where C_5 is a constant.

From relation (15), one can notice that function $R=R(d)_{\alpha=const.}$ doesn't present extreme or inflexion points. If $d\to\infty$, $R\to\infty$ and $d\to 0$, $R\to 0$.

This dependence represented on the interval $d\in[73mm,113mm]$, can be observed in the graphic from figure (6).

IV.4 Graphic representation of the theoretical characteristics of the led-photoresistor polaroid optocoupler $R=R(\alpha)_{d=const.}$

In order to graphically represent function (11) one must determine the values of constants C_1, C_3 and f.

Although these constants are determined for one of the traits of the family of the LED-photoresistor Polaroid optocoupler $R=R(\alpha)_{d=const}$, their value is the same for the whole family characteristics.

Let's take the case of the characteristic for which d=73 mm.

If $\alpha = 0°$, from graphic (5) and relation (11) results:

$$R_{0^0} = \frac{C_1\cdot(73mm)^{2a}}{C_3^a\cdot(1+f)} = 6.7K\Omega \qquad (16)$$

If $\alpha = 90°$, relation (11) becomes:

$$R_{90^0} = \frac{C_1\cdot(73mm)^{2a}}{C_3^a\cdot f} = 32.8K\Omega \qquad (17)$$

From (16) and (17) the following values are obtained:
$f \cong 0.26$

$$\frac{C_1\cdot(73mm)^{2a}}{C_3^a} = 8.42K\Omega \qquad (18)$$

According to relation (6), for a given supply voltage of the photoresistor (V=3V), but for different illuminations, using the data of the graphic from Fig. 7, one can calculate the average value of the constant (a):

$$a = \left(\ln\frac{I_1}{I_2}\right)\cdot\left(\ln\frac{E_{v1}}{E_{v2}}\right)^{-1} \cong 0.7 \qquad (19)$$

If in relation (6) are replaced the corresponding values from graphic (7), A point as well as the value of the constant (a), one obtains the value of C_1.

$$C_1 \cong 7.38\ V^*\ lx^{0.7}/\mu A \qquad (20)$$

From relations (18) and (20) results:

$$C_3 \cong 3.18\ lx^*\ m^2 \qquad (21)$$

By replacing the values of the constants C_1, C_3, a and f from relation (11), one obtains the expression of the function $R=R(\alpha,d)$, of the LED-photoresistor Polaroid optocoupler equipped with LDR07 photoresistor:

$$R = \frac{7.38\frac{V\cdot lx^{0.7}}{\mu A}\cdot d^{1.4}}{3.18lx\cdot m^2\cdot\left(\cos^{1.4}\alpha + 0.26\right)} \qquad (22)$$

In Fig. 8 are shown the graphic representations of relation (22) for the following values of parameter (d): 73mm, 88mm and 98mm.

By comparison with experimental data, in these graphics are also represented the points corresponding to the family of the $R=R(\alpha)_{d=const.}$ characteristics of LDR07 photoresistor.

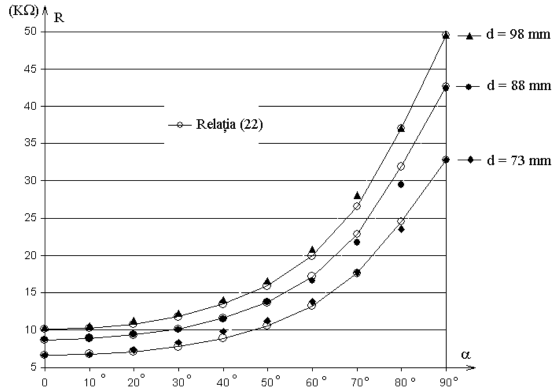

Fig. 8 The graphic representation of the family of the theoretical characteristics of the LED-photoresistor Polaroid optocoupler $R=R(\alpha)_{d=const}$, for a = 0.7 and d = 73 mm, 88 mm, 98 mm

The parameter's value a = 0.7, indicates the fact that the resistor's surface has been exposed to medium level of illumination, (for photoresistor's big illuminations a=0,5 and a=1 for low levels of illumination).

The fact that the value of the parameter depends on the illumination of the photosensitive surface, can be noticed in graphic (8).

In expression (6) we used a medium value of parameter (a). In reality, its value decreases at the same time with the increase of the light illumination of the receiver's photosensitive surface. That's why, for small (α) angles, (more intense illuminations), the experimental characteristic prevails over the theoretical one and for big values (illuminations of lower intensity), the relative position on their ordinate is reversed.

Observations:

- The comparison of the LED-photoresistor optocoupler's experimental characteristics with the theoretical ones can represent a method to analyze the way in which the photoresistor of R_X module reacts to different illumination levels.
- At the same time, this method can allow the experimental determination of some values specific to the semiconductor from which the photoresistor is made.

V. ADVANTAGES OF USING POLAROID OPTOCOUPLERS TOWARDS THE USE OF PHOTO-INTERRUPTERS

Unlike photo-interrupters, where we have a single way to modify the receiver's illuminations, (by obstruction), in the case of the Polaroid optocoupler, the radiant illumination of this one can be modified both as a result of the translation movement of a module towards the other one, and as a result of a rotation movement.

The way in which the relative rotation movement of a module modifies the receiver's illumination can be adjusted by modifying the distance between the two modules.

At the same time, the modification of the receiver's illumination as a consequence of a translation movement can be adjusted by a relative rotation movement of a module towards the other one.

Polaroid optocouplers allow the 'continuous reading' of the position of a mechanism's mobile component. This reading doesn't present intermittences like in the case of photo-interrupters.

A consequence of this advantage is the possibility to modulate the mechanic way of the electric signals with the help of the Polaroid optocouplers.

VI. CONCLUSION

The LED-photoresistor Polaroid optocoupler is an optocoupler circuit device whose exit resistance can be modified as a result of a translation and/or rotation movement of the receiver module towards the emitting module.

If the tension at the resistor's boundaries is maintained constant, the resistance's modification of this one will determine a modification of the current at the optocoupler's exit.

In this case, the device can fulfil the function of mechanic-electrical transducer or mechanic-electrical modulator.

In the case when it is used as a transducer, the optocoupler continuously turns the relative rotation/translation movement of the receiver module towards the emitting one, into a variable current.

If this movement is used to modulate an electric signal, then the device accomplishes the function of modulator.

If the Polaroid optocoupler is to belong to more complex systems, the command can be done both by rotation movements (the modification of α dihedral angle) and by translation movements (the modification of the distance between the receiver and the emitting modules d).

Polaroid optocouplers are designed to be applied in the field of mecatronix automations and robotics.

At the same time, they have the possibility to diversify the ways of designing consoles destined for games.

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