

OPTIČKI NAPONSKI PRETVARAČI

OPTICAL VOLTAGE TRANSDUCERS

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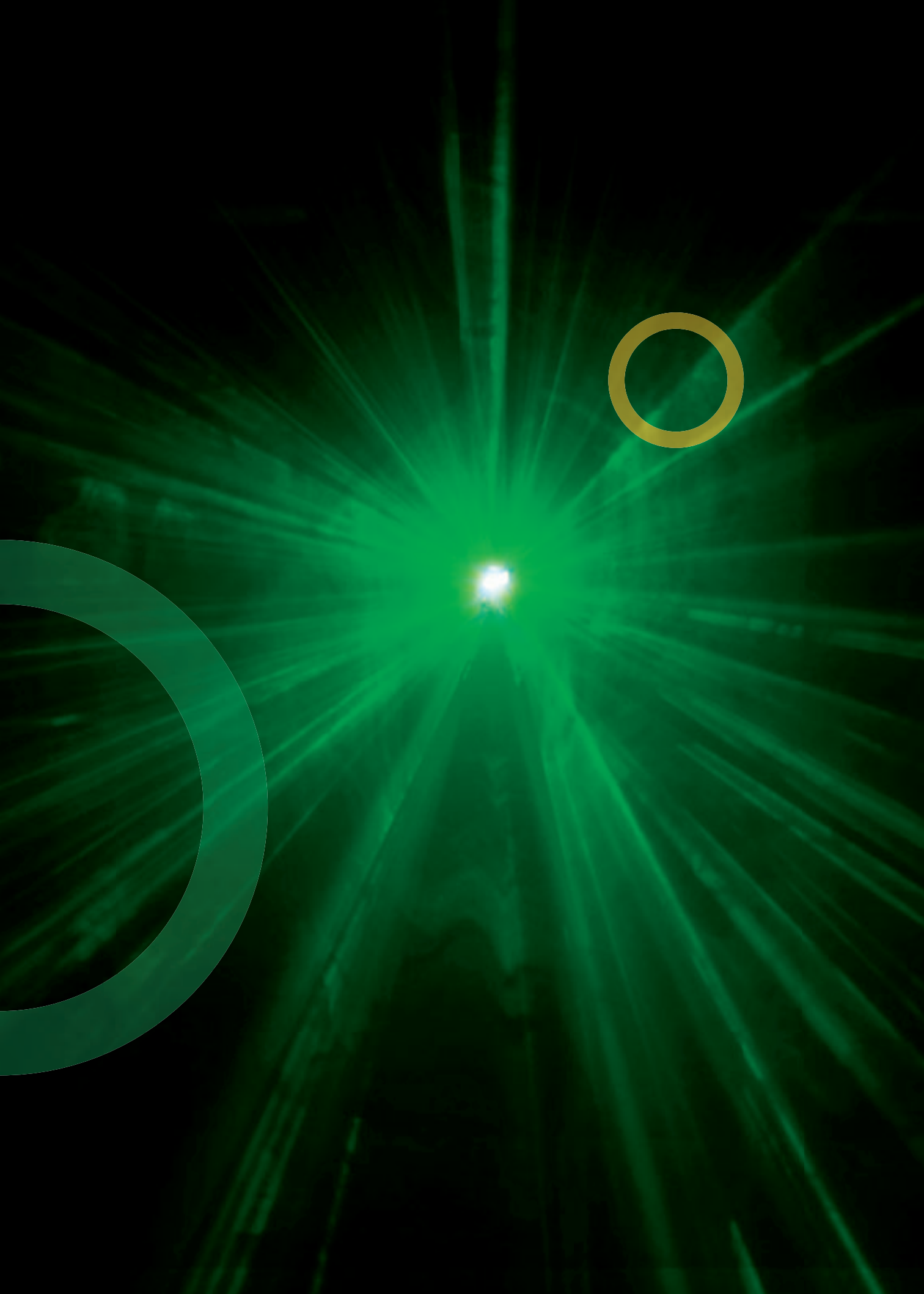
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U članku su opisana osnovna načela rada optičkih pretvarača za mjerenje visokog napona. Pockels je primijetio da je nastajanje razlike indeksa loma u nekim kristalima proporcionalno narinutom električnom polju. Glavni dijelovi osjetila zasnovanih na Pockelsovom učinku su: polarizator, Pockelsov kristal i analizator. To su pasivni elementi, u koje se svjetlost dovodi i odvodi optičkim nitima iz elektroničkog uređaja koji se nalazi na potencijalu zemlje.

Polarizirana svjetlost koja titra u dvije međusobno okomite ravnine prolazi kroz kristal različitim brzinama, a pod djelovanjem električnog polja brzine se mijenjaju, a to se detektira u elektroničkom sklopu. Prema ulazu svjetlosti u odnosu na narinuto električno polje razlikuje se uzdužni i poprečni učinak.

The paper presents basic operating principles of optical transducers for the measurement of high voltage. It was observed by Pockels that the change in refractive indexes in certain crystals is proportional to the applied electric field. The main parts of the sensor based on Pockels effect are: polarizer, Pockels crystal and analyzer. These are passive elements to and from which the light is taken by means of optical fibers from an electronic device at the earth potential. The polarized light that vibrates in two mutually perpendicular planes passes through the crystal at different speeds that change under the influence of the electric field, which is detected by an electronic circuit. The longitudinal and transverse effect are distinguished with respect to the applied electrical field.

Ključne riječi: optički naponski pretvarači, Pockelsov učinak
Key words: optical voltage transducers, Pockels effect



1 UVOD

Visoki napon se može mjeriti korištenjem elektrooptičkih učinaka, i to Pockelsovog ili Kerrovog učinka. Pockels je primijetio da je nastajanje razlike indeksa loma u nekim kristalima proporcionalno narinutom električnom polju. Polarizirana svjetlost koja prolazi kroz kristal, a titra u dvije različite ravnine, pod djelovanjem električnog polja različito mijenja brzinu širenja. Linearna ovisnost promjene indeksa loma o jakosti električnog polja naziva se Pockelsov, a kvadratna ovisnost Kerrov učinak. Elektrooptičke učinke pokazuju mnogi kristali, tekućine i plinovi. Različite tvari imaju i različitu, ali stalnu ovisnost promjene indeksa loma o električnom polju. Za elektrooptičke pretvarače koriste se kristali velike Pockelsove ili Kerrove konstante, određenog rasporeda kristalografskih osi.

Električno polje i svjetlosna zraka moraju ulaziti u kristal u strogo određenim pravcima. Zbog toga se koriste kristali s međusobno okomitim osima, i to oni iz kubične ili tetragonske kristalne građe. Prema ulazu svjetlosti u odnosu na narinuto električno polje razlikuje se uzdužni i poprečni učinak. Kod uzdužnog Pockelsovog učinka svjetlosna zraka, mjereno električno polje i optička os kristala su u istom pravcu. Poprečni Pockelsov učinak ima svjetlosnu zraku u smjeru optičke osi kristala, a mjereno električno polje je okomito. Na uzdužnom Pockelsovom učinku se zasnivaju pretvarači za mjerenje punog visokog napona, dok izvedbe s poprečnim Pockelsovim učinkom redovito koriste kapacitivno djelilo napona, to jest mjere niski napon.

1 INTRODUCTION

High voltage can be measured using electrooptical effects, i.e. the Pockels or Kerr effect. It was observed by Pockels that the change in refractive indexes in certain crystals is proportional to the applied electric field. The polarized light, which passes through the crystal and vibrates in two different planes, under the influence of the electric field effects has different changes of the propagation rate. The linear dependence between the change of the refractive index and the intensity of the electric field is recognized as the Pockels effect, while the square dependence is recognized as the Kerr effect. Numerous crystals, liquids and gases demonstrate electrooptical effects. Different substances exhibit different, but constant, relationships between the change of refractive index and electric field. For electrooptical transducers, crystals with specifically arranged crystallographic axes which have a high Pockels or Kerr constant are used.

The electric field and light ray have to intersect the crystal in strictly determined directions. For this reason, crystals of cubic or tetragonal structure with mutually perpendicular axes are used. The longitudinal and transverse effect are distinguished with respect to the applied electrical field. In the longitudinal Pockels effect, the light ray, measured electrical field and optical axis of the crystal are all in same direction. In the transverse Pockels effect, the light ray is in the direction of the crystal optical axis; the measured electrical field is perpendicular to it. Transducers for measuring the full high voltage are based on the longitudinal Pockels effect, while the configurations based on the transverse Pockels effect usually use a capacitive voltage divider, i.e. measure low voltage.

2 OPTIČKI NAPONSKI PRETVARAČ S UZDUŽNIM POCKELSOVIM UČINKOM

Širenje svjetlosti u vakuumu odvija se najvećom brzinom i u svim smjerovima jednako. U kristalima brzina svjetlosti, odnosno indeks loma ovise o smjeru njenog širenja i ravnini titranja. Indeks loma svjetlosti, n , definiran je kao odnos brzine svjetlosti u vakuumu, c , i brzine u nekoj tvari, v :

$$n = \frac{c}{v} \quad (1)$$

Postavi li se u točki ulaza svjetlosti u kristal koordinatni sustav X, Y, Z koji je paralelan s kristalografskim osima i nanese indeksi loma vala svjetlosti koja u tom smjeru titra dobit će se u krajnjim točkama prostorna ploha koja se zove optička indikatriksa ili indeksni elipsoid, dan izrazom:

$$\left(\frac{x}{n_x}\right)^2 + \left(\frac{y}{n_y}\right)^2 + \left(\frac{z}{n_z}\right)^2 = 1, \quad (2)$$

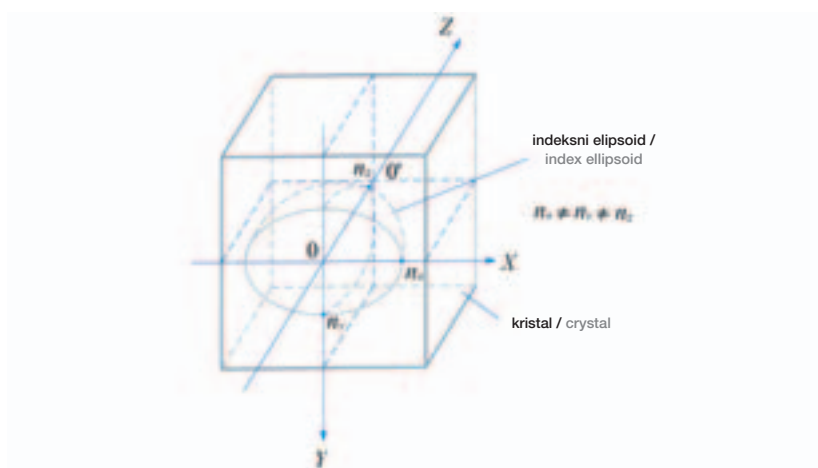
gdje su, n_x, n_y, n_z indeksi lomova u smjeru koordinatnih osi X, Y, Z , slika 1.

2 OPTICAL VOLTAGE TRANSDUCER WITH LONGITUDINAL POCKELS EFFECT

In a vacuum, light propagates at the highest speed, equally in all directions. In crystals, the speed of light, i.e. the refraction index, depends on the direction of propagation and the vibration plane. The index of light refraction index, n , is defined as the ratio between the speed of light in vacuum, c , and the speed of light in a certain substance, v :

If at the point of the light's incidence on the crystal a coordinate system X, Y, Z , is set, which is parallel to the crystallographic axes and denote the wave refractive indexes of the light vibrating in that direction, at the boundary points a spatial plane is obtained called the indicatrix or index ellipsoid, as per the equation:

where, n_x, n_y, n_z are refractive indexes in the direction of coordinate axes X, Y, Z , Figure 1.



Slika 1
Kristalografske osi i
indeksni elipsoid
Figure 1
Crystallographic axes
and indeks ellipsoid

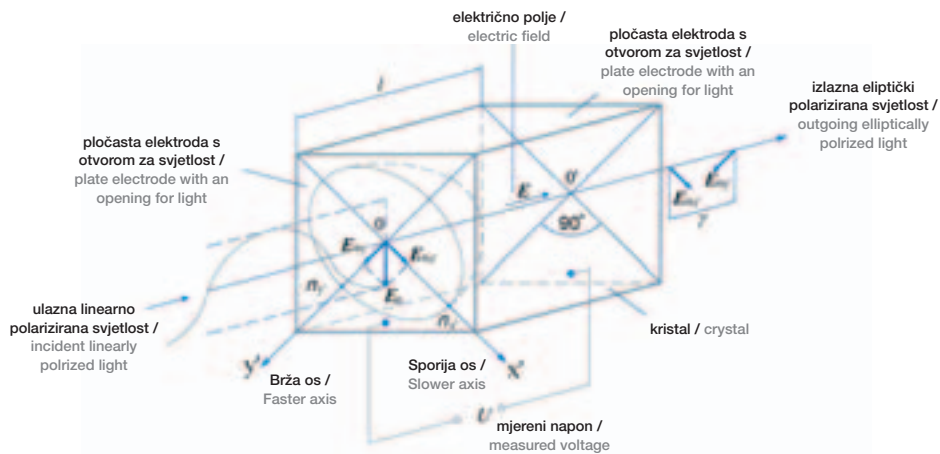
Kada se narine električno polje E u smjeru osi kristala Z , dolazi do zakretanja osi indeksnog elipsoida na x' i y' i do promjene indeksa loma n_x i n_y . Promjenom jakosti električnog polja mijenja se vrijednost indeksa loma.

Linearno polarizirana svjetlosna zraka, predočena svjetlosnim vektorom E_0 , koja ulazi u kristal u smjeru osi Z , može se rastaviti u dvije komponente E_{0x} i E_{0y} . One titraju u kristalu u ravninama s različitim indeksima loma, slika 2.

When the electric field E is applied in the direction of the Z axis of the crystal, the axes of the index ellipsoid will shift to x' and y' , the refractive indexes will change into n_x and n_y . Changing the intensity of the electric field will change the refractive index value.

A linearly polarized light ray, represented by a light vector E_0 , which intersects the crystal in the direction of the Z axis, can be decomposed into two components E_{0x} and E_{0y} . They vibrate in the crystal, in planes which have different refractive indexes, Figure 2.

Slika 2
Zakretanje i deformiranje indeksnog elipsoida zbog električnog polja i zaostajanje svjetlosnog vektora u ravnini x' .
Figure 2
Rotation and deformation of an index ellipsoid due to the electric field and lagging of the light vector in an x' plane



Pod djelovanjem električnog polja dolazi na izlazu iz kristala do faznog pomaka među tim komponentama za kut γ , odnosno za duljinu δ [1]:

Under the influence of the electric field, the phase shift between the components at the crystal's exit will be γ angle, i.e. length of δ [1]:

$$\delta = (n_x - n_y) \cdot l, \tag{3}$$

gdje je l duljina kristala u smjeru širenja svjetlosti.

where l is the length of the crystal in the direction of light propagation.

Prema Pockelsovim zapažanjima:

In accordance with Pockels' observations:

$$(n_x - n_y) = K_p \cdot E, \tag{4}$$

gdje je K_p Pockelsova konstanta za dati kristal.

where K_p is the Pockels constant for the relevant crystal.

Fazna razlika γ u radianima iznosi:

Phase difference γ , in radians, is:

$$\gamma = 2\pi \cdot \frac{\delta}{\lambda} = 2\pi \cdot \frac{K_p}{\lambda} \cdot E \cdot l = 2\pi \cdot \frac{K_p}{\lambda} \cdot U. \quad (5)$$

Fazni pomak γ u kristalu kod uzdužnog Pockelsovog učinka ne ovisi o duljini kristala l , već o narinutom naponu U .

Za mjerenje treba imati slog kao na slici 3, koji se sastoji redom od: izvora svjetlosti, polarizatora, Pockelsovog kristala, analizatora i fotodetektora. Svjetlosni izvor može biti svjetleća dioda (LED) uskog spektra zračenja, velike životne dobi oko 10^5 sati. Polarizator je optička prizma ili pločica od sintetičkih materijala polaroida, a daje svjetlo koje titra samo u jednoj ravnini. Ravnine titranja u polarizatoru na slici 3 označene su crticama. Iza polarizatora je Pockelsov kristal ili ćelija na koji je narinut mjereni napon. Analizator je ista naprava kao i polarizator. PIN fotodetektor je fotodioda kod koje su P i N tip poluvodiča razdvojeni vrlo tankim prozirnim izolatorom. Struja kroz fotodiodu razmjerna je broju svjetlosnih čestica, fotona, koji upadnu na izolator, to jest jakosti svjetlosti. PIN fotodetektor je pouzdan i ima dug životni vijek. Pravci propuštanja polarizatora i analizatora su okomiti ili pod kutom od 45° zavisno od izvedbe. Fotodetektor mjeri samo jakost svjetlosnog vektora, koji se prema Malusovom [2] zakonu mijenja s kvadratom amplitude svjetlosnog vektora. Svjetlosna jakost iza polarizatora jednaka je onoj ispred analizatora bez obzira na međusobni fazni pomak komponenta svjetlosnog vektora. Tek kada te dvije komponente svjetlosnog vektora prođu kroz analizator dat će jakost svjetla ovisno o njihovom faznom pomaku γ .

Integral električnog polja E duž nekog puta l između točke a (fazni vodič) i točke b (zemlja) daje napon između tih točaka:

The phase shift γ in a crystal with a longitudinal Pockels effect does not depend on the length of the crystal l , but on the applied voltage U .

For measuring, the configuration as per Figure 3 is required, consisting of: a light source, polarizer, Pockels crystal, analyzer and photodetector. The light source can be a light emitting diode (LED) of the narrow emitting spectrum, whose lifetime is reaches about 10^5 hours. The polarizer is an optical prism or a plate made from polaroid synthetic materials, and it gives a light that vibrates in one plane only. The vibration planes in the polarizer, Figure 3, are marked with an intermittent line. After the polarizer, there is a Pockels crystal or a cell where the measured voltage is applied. The analyzer is the same device as the polarizer. The PIN photodetector is a photodiode where P and N semiconductor types are separated from each other by a very thin transparent insulator. The current through the photodiode is proportional to the number of light particles, photons, that impact the insulator, i.e. it is proportional to the intensity of light. The PIN photodetector is reliable and has a long lifetime. The transmission axes of the polarizer and analyzer are either perpendicular to each other or inferior to an angle of 45° , depending on the arrangement. The photodetector measures the intensity of the light vector only, which, in accordance with Malus' law [2], changes in relation to the square of the amplitude of the light vector. The intensity of light after the polarizer is equal to the intensity of light before the analyzer, regardless to the mutual phase shift of the light vector components. After these two light vector components have passed through the analyzer, they will provide an intensity of light in relation to their phase shift γ .

The integral of the electric field E along the distance l between point a (live lead) and point b (earth) gives the voltage between these points:

$$U_{ab} = \int_a^b E \cdot dl. \quad (6)$$

Napon kod koga fazni pomak γ dosegne vrijednost π naziva se poluvalni napon. Za većinu kristala s uzdužnim Pockelsovim učinkom fazni pomak $\gamma = \pi$ postiže se već pri naponu 11 kV do 40 kV,

The voltage value at which the phase shift γ achieves the value π is called a half-wave voltage. For majority of crystals with the longitudinal Pockels effect, the phase shift of $\gamma = \pi$ is achieved

ovisno o kristalu [3] i [4]. Kako je fazni napon visokonaponskih vodova znatno viši fazni pomak γ će višestruko prekoračiti vrijednost π . Budući da se kut određuje preko trigonometrijskih funkcija, iste će se vrijednosti funkcija javljati za različite kutove γ , odnosno različite napone. Za otklanjanje te višeznačnosti koriste se elektronički sklopovi (signalni procesori) koji registriraju osim same vrijednosti signala i broj ekstremnih vrijednosti, odnosno koliko je puta prekoračen poluvalni napon. Za Pockelsovo osjetilo najčešće se koriste kristali bizmut-germanijev oksid ($\text{Bi}_4\text{Ge}_3\text{O}_{12}$), ili amonij-dihidrogen fosfat ($\text{NH}_4\text{H}_2\text{PO}_4$).

Izvedba Pockelsovog osjetila prikazana na slici 3 [5] koristi dva svjetlosna puta da bi jednoznačno odredila vrijednost kuta γ unutar raspona od π radijana.

at a voltage value ranging from 11 kV to 40 kV, depending on the crystal [3] and [4]. As the phase voltage of the high voltage lines is significantly higher, the phase shift γ will many times exceed the value of π . As the angle is determined by trigonometric functions, the same function values will be obtained for different γ angles, i.e. different voltages. In order to eliminate this ambiguity, use is made of electronic circuits (signal processors) that, besides the signal value itself, register the number of extreme values (i.e. how many times the half-wave voltage has been exceeded). The crystals that are most used for the Pockels sensor are bismuth-germanium oxide ($\text{Bi}_4\text{Ge}_3\text{O}_{12}$) and ammonium-dihydrogen phosphate ($\text{NH}_4\text{H}_2\text{PO}_4$).

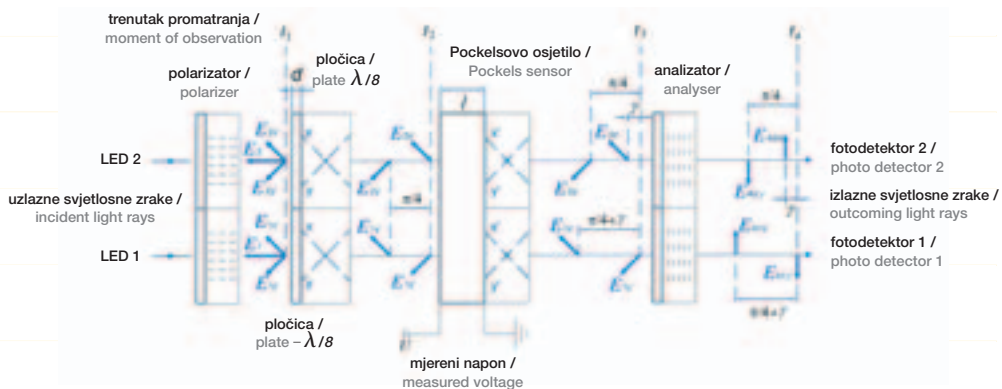
The Pockels sensor configuration as presented by Figure 3 [5] uses two light paths in order to unambiguously define the γ angle value within the range of π radians.

Slika 3

Pockelsovo osjetilo s dva svjetlosna puta

Figure 3

Pockels sensor with two light paths



Svjetlosni vektori E_1 i E_2 , koji su prošli kroz polarizator, rastavljaju se na međusobno okomite komponente E_{1x}, E_{1y}, E_{2x} , i E_{2y} . Njihove ravnine titranja paralelne su sa zakrenutim osima indeksnog elipsoida Pockelsovog osjetila. Na prvom svjetlosnom putu nalazi se kristalna pločica $-\lambda/8$, a na drugom $\lambda/8$. Kristalna pločica $-\lambda/8$ propušta komponentu E_{1x} , s manjom brzinom nego E_{1y} . Debljina pločice d , odabrana je tako da se dobije fazni pomak $-\pi/4$. Prolaskom svjetlosti kroz Pockelsovo osjetilo, koje je pod naponom U , dolazi do daljnjeg pomaka među komponentama za kut γ . Pravci propuštanja polarizatora i analizatora su međusobno okomiti. Na izlazu iz analizatora amplitude svjetlosnog vektora komponente svjetlosnih zraka su:

The light vectors E_1 and E_2 , after having passed through the polarizer, are decomposed to mutually perpendicular components E_{1x}, E_{1y}, E_{2x} , i E_{2y} . Their vibration planes are parallel with the shifted axes of the index ellipsoid of the Pockels sensor. In the first light path there is a crystal plate $-\lambda/8$, while in the second light path there is a crystal plate $\lambda/8$. The crystal plate $-\lambda/8$ transmits the component E_{1x} , at a lower speed than E_{1y} . The thickness of plate d was selected in order to get the phase shift of $-\pi/4$. Passing the light through the Pockels sensor, which is below the voltage U , contributes to a further shift between the components, by an angle of γ . The transmission lines of the polarizer and analyzer are perpendicular to each other. At the analyzer exit, the amplitudes of the light vector of light ray components are:

$$E_{A1x'}(t) = E_{A1x} \cdot \sin(\omega t - \frac{\pi}{4} - \gamma), \quad (7)$$

$$E_{A1y'}(t) = -E_{A1y} \cdot \sin \omega t, \quad (8)$$

$$E_{A2x'}(t) = E_{A2x} \cdot \sin(\omega t - \gamma), \quad (9)$$

$$E_{A2y'}(t) = -E_{A2y} \cdot \sin(\omega t - \frac{\pi}{4}), \quad (10)$$

gdje su:

E_{A1x} , E_{A1y} , E_{A2x} , E_{A2y} – amplitude svjetlosnih vektora na ulazu u analizator,

$E_{A1x'}(t)$, $E_{A1y'}(t)$, $E_{A2x'}(t)$, $E_{A2y'}(t)$ – trenutni iznosi u smjeru propuštanja.

Analizator propušta dio komponenti svjetlosnog vektora u smjeru njegove osi, te se zbrajaju na fotodetektoru. Jakost svjetlosti na fotodetektorima je:

where:

E_{A1x} , E_{A1y} , E_{A2x} , E_{A2y} – amplitudes of the light vectors at the analyzer input,

$E_{A1x'}(t)$, $E_{A1y'}(t)$, $E_{A2x'}(t)$, $E_{A2y'}(t)$ – momentarily values in the conducting direction.

The analyzer passes part of the light vector components in the direction of its axis, they are summed up by the photodetector. Intensity of light at the photodetectors is:

$$I_1 = I_0 \cdot \sin^2(\frac{\gamma}{2} + \frac{\pi}{8}), \quad (11)$$

$$I_2 = I_0 \cdot \sin^2(\frac{\gamma}{2} - \frac{\pi}{8}), \quad (12)$$

gdje je I_0 jakost svjetlosti na izlazu iz polarizatora. Iz para mjerenih vrijednosti fotodetektora (11) i (12) može se odrediti kut γ , odnosno mjereni napon (5).

where I_0 is the intensity of light at the polarizer exit. From the measured photodetector values (11) and (12), the angle γ , i.e. measured voltage (5) are determined.

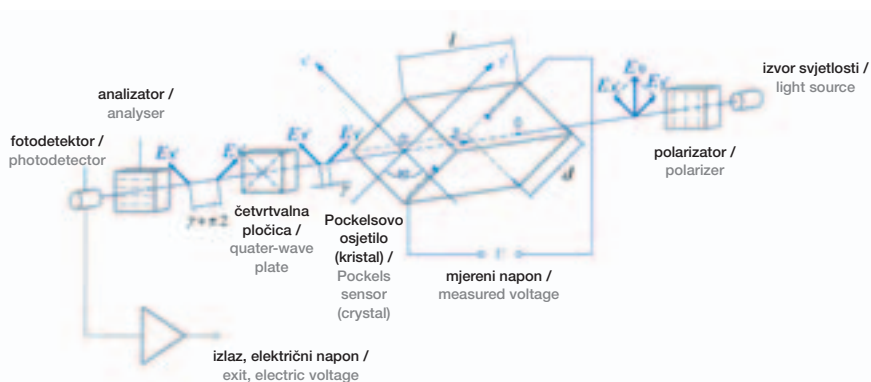
3 OPTIČKI NAPONSKI PRETVARAČ S POPREČNIM POCKELSOVIM UČINKOM

Kod osjetila s poprečnim Pockelsovim učinkom okomito na pravac širenja svjetlosti narinuto je električno polje. Mjereni napon je nekoliko kilovolta pa se osjetilo koristi u sprezi s kapacitivnim djeliteljem napona. Na slici 4 prikazana je izvedba pretvarača koji se sastoji od izvora svjetlosti, polarizatora, osjetila od kristala litij-niobata (LiNbO_3), analizatora i fotodetektora. Iza fotodetektora nalazi se elektronički sklop za obradu električnog signala. Pri tome se redovito koristi amplitudna detekcija [5] i [6].

3 OPTICAL VOLTAGE TRANSDUCER WITH THE TRANSVERSE POCKELS EFFECT

At the sensors with the transverse Pockels effect, perpendicularly to the direction of light propagation an electric field is applied. The measured voltage is at the level of several kilovolts, therefore the sensor is used with a capacitive voltage divider. Figure 4 shows a transducer configuration consisting of a light source, polarizer, sensor from the lithium niobate (LiNbO_3) crystal, analyzer and photodetector. After the photodetector, there is an electronic circuit for processing the electrical signal. Amplitude detection is normally used [5] and [6].

Slika 4
Mjerenje napona
korištenjem
poprečnog
Pockelsovog učinka
s amplitudnim
detektiranjem
Figure 4
Voltage
measurement
using transverse
Pockels effect with
amplitude detection



Svjetlosni vektor E_0 se razlaže na komponente E_x i E_y , koje titraju u međusobno okomitim ravninama. Narinuto električno polje mijenja brzine svjetlosti u tim ravninama. Nastala fazna razlika γ prema izrazu (5), ako se uvrsti za jakost polja $E = U/d$, jednaka je:

The light vector E_0 is decomposed into the components E_x and E_y , which vibrate in mutually perpendicular planes. The applied electric field changes the speeds of light in these planes. The resulting phase difference γ in accordance with (5), if the value of $E = U/d$ is taken for the electric field intensity, is equal to:

$$\gamma = 2\pi \frac{K_p \cdot U}{\lambda \cdot d} \cdot l. \quad (13)$$

Potrebna osjetljivost na promjenu napona može se postići izborom dimenzija kristala l i d . Kad nema narinutog napona fazni pomak γ je nula, te projekcije vektora E_x i E_y u ravninu propuštanja analizatora daju komponente svjetlosnih vektora koje se poništavaju. Da bi područje rada bilo u linearnom dijelu sinusne funkcije umetnuta je četvrtvalna pločica koja pravi dodatni fazni pomak

The required sensitivity to the change of voltage can be gained by selecting the crystal's dimensions, l and d . When there is no applied voltage, the phase shift γ is equal to zero, the vector projections E_x and E_y pass the components of light vectors into the analyzer transmission plane; these components cancel each other out. In order to keep the operation range in a linear part of the sine function, a quarter-

$\pi/2$. Time se dobije ukupni fazni pomak od $\gamma + \pi/2$ među svjetlosnim vektorima, čije su projekcije u ravnini propuštanja analizatora, slika 4:

wave plate has been inserted; the plate produces an additional phase shift of $\pi/2$. This results in a total phase shift of $\gamma + \pi/2$ between the light vectors whose projections are in the transmission plane of the analyzer, Figure 4:

$$E_{Ax'}(t) = E_{Ax} \cdot \sin \omega t, \quad (14)$$

$$E_{Ay'}(t) = -E_{Ay} \cdot \sin(\omega t + \gamma + \frac{\pi}{2}), \quad (15)$$

gdje su:

where:

E_{Ax} , E_{Ay} – amplitude svjetlosnog vektora ispred analizatora,

E_{Ax} , E_{Ay} – amplitudes of the light vectors at the analyzer input,

$E_{Ax'}(t)$, $E_{Ay'}(t)$ – trenutne vrijednosti u smjeru propuštanja.

$E_{Ax'}(t)$, $E_{Ay'}(t)$ – momentarily values in the conducting direction.

Uz jednake amplitude geometrijski zbroj daje:

With the same amplitudes, the geometrical sum is:

$$E_{rez}(t) = 2 E_A \cdot \sin\left(\frac{\gamma + \frac{\pi}{2}}{2}\right) \cdot \cos\left(\frac{2\omega t + \gamma + \frac{\pi}{2}}{2}\right). \quad (16)$$

Ako se s I_0 označi jakost svjetlosti iza polarizatora, jakost svjetlosti I na fotodetektoru je:

If I_0 is the intensity of light after the polarizer, the intensity of light I at the photodetector is:

$$I = \frac{1}{2} I_0 (1 + \sin \gamma). \quad (17)$$

Istosmjerni član se može izlučiti pa se dobije:

A direct member is extracted, hence:

$$I = k \cdot I_0 \cdot \sin \gamma. \quad (18)$$

Konstanta k uzima u obzir i gubitke svjetlosti. Polazna jakost svjetlosti I_0 je stalna, a na kristal se dovode niži naponi da kut γ bude mali. Tada je vrijednost sinusa kuta približno jednaka samom kutu, pa je γ u linearnoj ovisnosti o mjerenom naponu.

The constant k takes into consideration losses of light. The starting intensity of light I_0 is constant, rather low voltages are brought to the crystal, in order to keep the γ angle low. Then, the sine value of the angle will be close to the angle value itself, therefore γ is linearly dependent on the measured voltage.

Shema optičkog naponskog pretvarača primijenjenog u plinom SF_6 izoliranom postrojenju dana je na slici 5. Ovdje je kapacitivno djelilo sastavljeno od kapaciteta C_1 između visokonaponskog vodiča i njegovog zaslona, dok kapacitet C_2 predstavlja kapacitet između zaslona i uzemljenog oklopa.

A scheme of an optical voltage transducer used in a plant isolated by the gas SF_6 is presented by Figure 5. Here, the capacity divider consists of C_1 capacity between the high voltage conductor and its screen, while C_2 is the capacity between the screen and earthed shield. The capacity C_A is added to the

Kapacitet C_A dodan je kapacitetu C_2 tako da se na Pockelsovu osjetilu dobije dovoljno nizak napon. Izvor svjetlosti je LED, valne duljine $\lambda = 0,85 \mu\text{m}$, čija se svjetlost vodi optičkom niti (promjera $50 \mu\text{m}$) do polarizatora. Polarizator, Pockelsovo osjetilo, četvrtvalna pločica i analizator smješteni su na oklopu. Linearno polarizirano svjetlo dovodi se do PIN fotodetektora s optičkom niti (promjera $200 \mu\text{m}$) gdje se pretvara u električni signal, koji se dalje obrađuje amplitudnom detekcijom. Za priključak elektrodinamičkih brojila i releja [5] iz pojačala se može izvesti i analogni izlaz $100 / \sqrt{3} \text{ V}$, snage nekoliko desetaka voltampera.

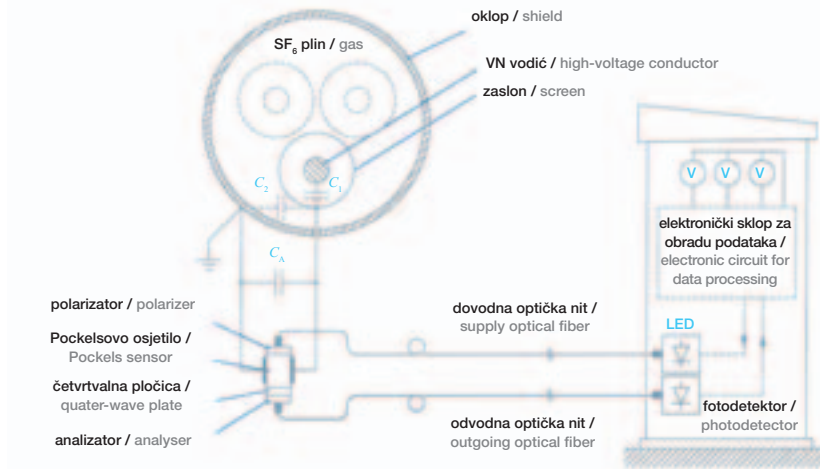
capacity C_2 in order to get a satisfactorily low voltage at the Pockels sensor. The light source is LED, of wavelength $\lambda = 0,85 \mu\text{m}$, whose light is by means of optical fibers (diameter of $50 \mu\text{m}$) conducted to the polarizer. The polarizer, Pockels sensor, quarter-wave plate and analyzer are placed on the shield. Linearly polarized light is taken to a PIN photodetector by means of optical fiber (diameter of $200 \mu\text{m}$) where it is converted into an electrical signal, which is further processed by amplitude detection. For connecting the electrodynamic counters and relays [5], an analogue output of $100 / \sqrt{3} \text{ V}$, whose power amounts to several tens VA, can be taken out at the amplifier.

Slika 5

Shema spoja optičkog naponskog pretvarača u oklopljenom postrojenju

Figure 5

Layout of the optical voltage transducer in a shielded plant



4 ZAKLJUČAK

Optički naponski pretvarači iskazuju dobra svojstva: postojanost, pouzdanost i točnost pri mjerenju i zaštiti [7], [8], [9] i [10]. Otporni su na elektromagnetske smetnje. Ne trebaju osigurače. Ne sadrže ulje te ne mogu eksplodirati. Naponski i strujni pretvarači mogu se izvesti korištenjem zajedničkih dijelova. To nadalje smanjuje njihovu masu, potreban prostor u postrojenju za njihovo postavljanje, dimenzije nosača i troškove postavljanja. Zbog jednostavnosti građe i dobre izolacije između dijelova koji se nalaze pod visokim naponom i uzemljenih dijelova za očekivati je manji broj preskoka, proboja i drugih kvarova, a time i pouzdaniji rad mreže na koju su priključeni.

4 CONCLUSION

Optical voltage transducers demonstrate favorable properties: stability, reliability and accuracy in measuring and protecting [7], [8], [9] and [10]. They are resistant to electromagnetic disturbances. No fuses are needed. They do not contain oil and cannot explode. The same parts can be used for voltage and current transducers. This will contribute to a reduction of their weight, the required installation space in the plant, the dimensions of the carrying elements and installation costs. Because of the simplicity of configuration and good insulation between the high voltage parts and earthed parts, one may expect fewer skips, breakdowns and other failures, which directly contributes to the higher reliability of the network they are connected to.

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