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PRIMJENE STROBOSKOPA
APPLICATIONS OF STROBOSCOPES

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Sažetak: *Stroboskopi su uređaji za promatranje predmeta u brzom periodičnom gibanju stvaranjem optičke iluzije zaustavljenog ili usporenog predmeta, a oslanja se na tromost ljudskog oka kako bi se postigao željeni učinak. Osim za promatranje predmeta u brzom gibanju stroboskopi se primjenjuju na mnoge raznovrsne načine: od ispitivanja strojeva do podešavanja broja okretaja gramofona.*

Ključne riječi: - stroboskop
- stroboskopski efekt
- stroboskopsko promatranje

Summary: *Stroboscopes are devices for observation of cyclically moving high-speed objects by creating an optical illusion of stopped or slowed motion. The stroboscopic effect relies on the persistence of vision in the human eye to achieve the desired effect. In addition to the observation of fast moving objects, stroboscopes can be used in a variety of applications ranging from machinery inspection to turntable pitch control.*

Keywords: - stroboscope
- stroboscopic effect
- stroboscopic observation

1. UVOD

Stroboskop je uređaj za mjerenje frekvencije i promatranje jednostavnih gibanja koja se periodično ponavljaju stvaranjem optičke iluzije usporenoga ili zaustavljenoga gibanja.
Princip rada stroboskopa vrlo je sličan načinu na koji radi filmska kamera, u kojoj zatvarač dijeli pokret u niz statičnih slika bez vidljiva kretanja. Zbog tromosti ljudskog oka niz prikazanih slika daje privid kontinuirana kretanja prilikom projekcije slika. Zatvarač filmske kamere može stvoriti stroboskopski efekt u sinkronizaciji s periodičnim gibanjem. Pri promatranju kotača koji se okreće frekvencijom 24 s^{-1} kroz zatvarač kamere koji radi na frekvenciji od 24 s^{-1}, kotač će se nalaziti na istom položaju u svakom trenutku vidljivosti, pa će se činiti da je zaustavljen.
Povećanjem brzine zatvarača na 25 s^{-1} svaki trenutak vidljivosti događa se 1/25 sekunde ranije, no kotač još uvijek radi puni krug za 1/24 sekunde. Kotač se tako vidi u nešto ranijem dijelu svojega kretanja, što stvara iluziju polagana kretanja kotača unatrag.
Usporavanjem zatvarača na 23 s^{-1} kotač postaje vidljiv u kasnijem dijelu svojega gibanja, što stvara iluziju polagana kretanja kotača naprijed.
Isti bi se učinak postigao osvjetljavanjem kotača izvorom svjetlosti odgovarajuće brzine bljeskanja pa se može reći da mijenjanjem brzine prekidanja vidljivosti nastaje privid gibanja unaprijed ili unatrag bilo kojom

1. INTRODUCTION

A stroboscope is a device which permits measurement of the frequency and observation of cyclical movement by creating an optical illusion of stopped or slowed motion.
The basic operating principle of a stroboscope is quite similar to a motion picture camera, where a shutter breaks up the action into a series of static frames with no apparent motion. Due to persistence of vision in the human eye, the series of projected frames takes on the appearance of continuous motion.
The shutter of a movie camera can produce a stroboscopic effect at or near synchronism with a cyclic motion. When observing a wheel rotating at 24 s^{-1} through a camera shutter operating at the same frequency, the wheel will be at the same position at each glimpse, and appear to stand still.
Increasing the shutter speed to 25 s^{-1} causes each frame to occur 1/25 of a second earlier than before, but the wheel still needs 1/24 of a second to return to the original position. Therefore the wheel is observed in a slightly previous part of its motion, creating an illusion of the wheel slowly turning backwards.
Reducing the shutter speed to 23 s^{-1} will cause the wheel to be observed in later parts of its cycle, creating an illusion of slow forward motion.
The same effect would have been achieved by pointing a light source flashing at the appropriate frequency

željenom brzinom. Vidljivost se može prekidati mehanički zaklanjanjem predmeta, ili prekidanjem osvjetljenja promatranog predmeta.
Prema osnovnom principu stroboskopije, objekt u pokretu osvijetljen izvorom svjetlosti frekvencije jednake frekvenciji gibanja predmeta prividno se zaustavlja, pa je moguće i odrediti brzinu gibanja predmeta mijenjanjem frekvencije bljeskova izvora svjetlosti sve do prividnoga zaustavljanja predmeta. Ta mogućnost mjerenja bez izravnog dodira s mjerenim predmetom predstavlja osnovnu prednost stroboskopije nad konvencionalnim metodama mjerenja kod kojih je potreban mehanički dodir s predmetom.
Stroboskopski efekti na frekvencijama od 2 do 55 Hz mogu izazvati fotosenzitivnu epilepsiju kod oko 95 % ljudi koji pate od nje [1], stoga zakonski propisi o zaštiti na radu ograničavaju trajanje stroboskopskih efekata na pola minute. Zbog toga su stroboskopi namijenjeni kazalištu i glazbenoj produkciji konstrukcijski ograničeni na 12 Hz [2].
Promatranje predmeta koji se kreću relativno sporo, tj. kod kojih frekvencija bljeskova ostaje ispod ili blizu granice razlučivosti ljudskog oka (16-25 Hz), izaziva naprezanje vida. U takvim slučajevima, gdje izravno promatranje predmeta izaziva zamor vida (npr. ispitivanje šivaćih strojeva) ili predstavlja opasnost za promatrača (npr. ispitivanje zrakoplovnih propelera s promjenjivim korakom), slika se prenosi sustavom kabelske televizije do promatrača. Osim uklanjanja vidljivih bljeskova tim se načinom postiže i povećanje slike promatranoga predmeta.

2. PRIMJENA STROBOSKOPA

2.1. Regulacija brzine vrtnje gramofona

Brzina vrtnje gramofona regulira se pomoću titranja svjetla fluorescentne cijevi. Zbog karakteristika generatora visokog napona potrebnog za njezin rad svjetlost cijevi titra frekvencijom dvostruko većom od mrežne, što kod mrežne frekvencije od f = 50 Hz iznosi 100 Hz.

LP-ploča okreće se brzinom od $33\frac{1}{3}\,\text{min}^{-1} = 0{,}55\dot{5}\,\text{s}^{-1}$.

U tih $0{,}55\dot{5}$ okretaja, ili u jednoj sekundi, svjetlo bljesne 100 puta, što znači da za jedan puni okretaj tanjura svjetlo mora bljesnuti 180 puta. Zbog toga je na obodu tanjura gramofona napravljeno 180 međusobno jednako udaljenih oznaka i ako se gramofon vrti točnom brzinom, čini se da oznake stoje, jer svaki bljesak hvata sljedeću oznaku na mjestu prethodne. Slično tome, za brzinu od 45 min^{-1} stavljaju se 133 oznake.
Suvremene izvedbe gramofona koriste sinkrone elektromotore pogonjene putem pretvarača frekvencije [3]. U takve je gramofone obično ugrađen vlastiti stroboskop kojem pretvarač frekvencije služi kao izvor

against the wheel. Visibility can be interrupted mechanically by blocking the object from view or by interrupting the illumination of the observed object.
According to the basic principles of stroboscopy, a moving object illuminated by a light source flashing at the same frequency at which the object is moving appears to stop, so it is possible to determine the speed at which the object is moving by varying the frequency at which the light source flashes until the object appears to stop. This possibility of measurement without mechanical contact with the object represents the basic advantage of stroboscopy over conventional measuring methods.
Stroboscopic effects at frequencies ranging from 2 to 55 Hz can induce photosensitive seizures in about 95 % of affected persons [1], so work safety regulations limit the duration of stroboscopic effects to half a minute or less. Because of this, stroboscopes for theatrical and stage producition are limited to 12 Hz by design [2].
The observation of relatively slow moving objects, where the flashing frequency remains at or near the flicker threshold (16-25 Hz), causes eye strain. In such cases, where direct observation presents annoyance (inspection of sewing machines) or danger (inspection of variable pitch aircraft propellers) to the observer, a closed circuit television transmits the picture to the observer. Apart from the removal of visible flashes, this system delivers a magnified image of the observed object.

2. APPLICATION OF STROBOSCOPES

2.1. Turntable pitch control

Turntable pitch adjustment is achieved using the flicker of fluorescent lighting. Due to the characteristics of the high voltage generator required for its operation, fluorescent lighting flickers at 100 Hz, twice the mains frequency of f = 50 Hz.
A LP record spins at the speed of $33\frac{1}{3}\,\text{min}^{-1} = 0{,}55\dot{5}\,\text{s}^{-1}$.

In those $0{,}55\dot{5}$ revolutions, or one second, the light flashes 100 times, or 180 flashes in a full revolution of the turntable platter. Therefore, 180 equally spaced markings are made on the edge of the platter, and the markings will appear to be stationary if the turntable is spinning at the correct speed, because each flash catches the following marking at the place of the previous one. Similarly, 133 markings are used for the speed of 45 min^{-1}.
Modern turntables use synchronous electric motors driven by frequency converters [3]. Such turntables usually have built-in stroboscopes triggered by the frequency converter (Figure 1).

impulsa za aktiviranje (Slika 1).
Svjetiljka toga stroboskopa (Slika 2) osvjetljava oznake postavljene na obodu tanjura, pri čemu zaustavljena slika pojedinoga prstena odgovara određenom broju okretaja tanjura.

The lamp of that stroboscope (Figure 2) lights the markings on the platter rim, and the stationary picture of a ring corresponds to a particular turntable platter speed.

Slika 1. Stroboskop na gramofonu
Figure 1. Turntable mounted stroboscope

Slika 2. Podešavanje broja okretaja gramofona
Figure 2. Turntable pitch control

2.2. Primjena na remenskim prijenosima

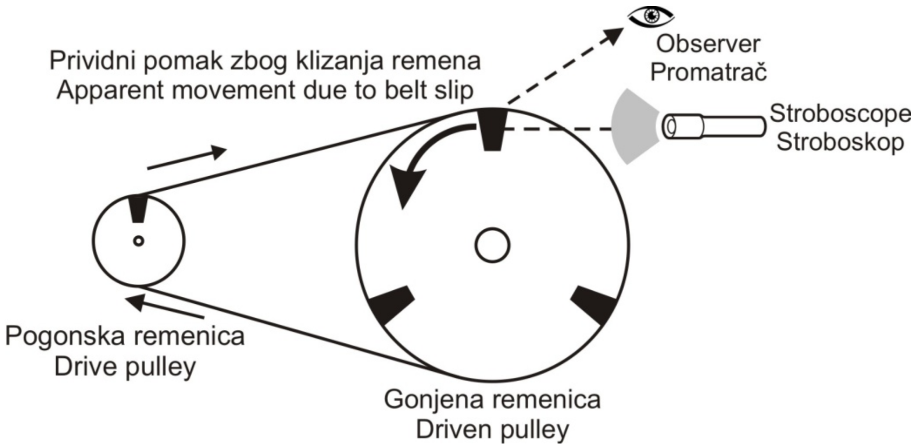
Stroboskopija se primjenjuje za ispitivanje klizanja remena te mjerenje prenesene snage. Klizanje remena ispituje se mjerenjem razlike brzina pogonjene i pogonske remenice pomoću stroboskopa. Pri tom se postupku stroboskop sinkronizira s pogonskom remenicom te se promatra pogonjena remenica i traže znakovi klizanja [4].
Prilikom mjerenja uobičajeno je spojiti stroboskop na fotoelektrični okidač usmjeren na reflektirajuću oznaku na pogonskoj remenici. Stroboskop se usmjerava na pogonjenu remenicu na koju je postavljena referentna oznaka, pa je klizanje moguće izravno uočiti putem prividnoga gibanja oznake.
Pri pogonu s promjenom broja okretaja postavljaju se na pogonjenu remenicu jednoliko raspoređene oznake,

2.2. Application on belt drives

Stroboscopes are used to check for belt slip and to measure transmitted power. Belt slip is checked by measuring the difference in drive and driven pulley speeds using a stroboscope. In order to perform this procedure, the stroboscope is synchronized to the drive pulley, after which the driven pulley is observed for signs of slippage [4].
It is customary to connect the stroboscope to a photoelectric trigger pointed at a reflective marking on the drive pulley. The stroboscope is pointed against the driven pulley with a reference mark on it, and any slippage is detected by the apparent motion of the marking.
On drives with a transmission ratio different from one, equally spaced markings are placed on the rim of the

čiji je broj jednak prijenosnom omjeru remenskog prijenosa.

driven pulley, the number of which is equal to the transmission ratio of the belt drive.



Slika 3. Promatranje klizanja remena, omjer prijenosa i = 3
Picture 3. Belt slip observation, drive ratio i = 3

Klizanje se lako uočava u obliku prividnoga polaganog kretanja oznake unatrag.
Odnos napetosti remena i frekvencije kojom on vibrira koristi se u stroboskopskom ispitivanju sile u remenu [4]. Remen u pogonu promatra se stroboskopski u pobuđenom stanju, te se mjeri frekvencija kojom on vibrira. Zaustavljeni remenski prijenos može se pobuditi laganim udarcem čekića, a sila u promatranom kraku remena dana je jednadžbom (1):

Slippage is easily noticed as apparent slow backward motion of the marking.
The relation of belt tension to its vibrating frequency is used to stroboscopically determine the belt tension [4]. An operating belt is stroboscopically observed, and its vibrating frequency measured. A stopped belt drive can be made to vibrate with a light hammer blow, and the force in the observed section of the belt is given by the equation (1):

$$T = Kf^2 L^2 W \quad (1)$$

Nakon određivanja sile u oba kraka remena može se izračunati prenesena snaga *P* jednadžbom:

After determining the tension in both sections of the belt, the transmitted power *P* can be calculated using the equation:

$$P = KL^2W(f_t^2 - f_s^2) = (T_t - T_s) \cdot v \quad (2)$$

2.3. Mjerenje linearne brzine

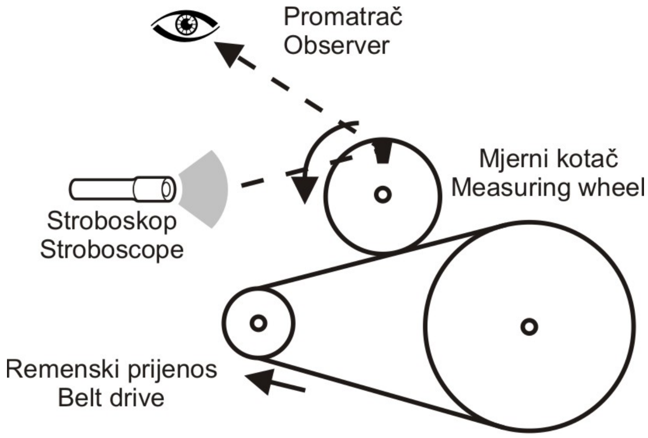
Moguće je mjeriti linearnu brzinu gibanja simetričnoga strojnog elementa (valjak, bubanj, kotač, remen…) koristeći mjerni kotač (Slika 4).
Mjerni kotač prislanja se na površinu mjerenog predmeta, tako da se obod kotača kreće brzinom površine predmeta, dok na kotaču postoji mjerna oznaka za stroboskopsko mjerenje. Promjer kotača određen je na način da se postigne jednostavan omjer broja okretaja kotača i mjerene brzine, npr. kotač se može okretati brzinom od 10 s^{-1} u trenutku kada mu je obodna brzina jednaka 1 ms^{-1}. Takav je disk u praksi potrebno pravilno namjestiti u odnosu na mjereni element te izbjeći trenje koje bi nastalo zbog pretjeranog pritiska. Vanjski promjer diska povremeno

2.3. Measurement of linear speed

It is possible to measure the linear movement speed of a symmetrical machine element (roller, drum, wheel, belt etc.) by using a measuring wheel (Figure 4).
The wheel is placed on the surface of the measured object, so that the rim of the wheel spins at the exact speed of the object, and the wheel has a marking for stroboscopic observation. The wheel diameter is determined in a way such as to give a simple relation between the number of wheel revolutions and the measured speed, e.g. the wheel could be spinning at 10 s^{-1} at the moment in which its rim speed equals 1 ms^{-1}. Such a disk must be carefully aligned in relation to the measured element, and any drag due to excessive pressure and friction must be avoided. The outer disk

se mjeri kako bi se izbjegao utjecaj trošenja na rezultate mjerenja [4].

diameter is subject to occasional measurement to avoid the effect of wear and tear on measurement results [4].



Slika 4. Mjerenje linearne brzine
Figure 4. Linear speed measurement

2.4. Istraživanje rada zvučnika

Zvučnici se ispituju priključivanjem na audiooscilator. Stroboskop dobiva impuls za bljesak od toga istog oscilatora priključenog preko frekvencijskog djelitelja koji snižava frekvenciju na ulazni pojas stroboskopa, no zadržava harmonički omjer potreban za stroboskopsko promatranje.
Promatrač može promatrati različite faze ciklusa rada zvučnika dodavanjem sklopa za vremenski pomak između frekvencijskog djelitelja i stroboskopa.
Eventualne nepravilnosti membrane zvučnika ispituju se lijepljenjem radijalnih linija tankih umjetnih vlakana na membranu zvučnika, a pri ispitivanju stroboskop bljeska frekvencijom neznatno različitom od cjelobrojnog manjekratnika frekvencije pogonskog oscilatora, kako bi se mogle uočiti čvorne točke i vibracije membrane zvučnika promatranjem slobodnih krajeva umjetnih vlakana. Ta se ispitivanja obično provode pod povećalom ili mikroskopom [4].

2.5. Nadzor kvalitete proizvodnje olovne sačme

Olovna sačma manjih promjera proizvodi se skrutnjivanjem rastaljenog metala u slobodnom padu. Rastaljeno olovo ulijeva se u posudu s kalibriranim otvorima u dnu nakon čega posuda vertikalno vibrira pod utjecajem elektromagneta spojenih na električnu mrežu. Kapljice rastaljenog olova zbog površinske napetosti poprimaju oblik kuglice prilikom slobodnog pada, nakon čega se hvataju u posudu s vodom.
Stroboskop se postavlja tako da daje horizontalan snop svjetlosti oko 50 cm ispod posude, pri čemu se padajuće kuglice olova vide kao obrisi. Ako elektromagneti rade na frekvenciji električne mreže, moguće je promatrati veličinu i oblik kuglica koristeći frekvenciju mreže kao okidač stroboskopa [4].

2.4. Investigation of loudspeaker operation

Loudspeakers are investigated by connecting them to an audio oscillator which gives the flash signal to the stroboscope through a frequency divider which lowers the frequency to the input range of the stroboscope while maintaining the harmonic ratio required for stroboscopic observation.
The observer can observe various stages in the operating cycle of the loudspeaker by adding a time delay circuit between the frequency divider and the stroboscope. Eventual irregularities of the loudspeaker membrane are investigated by glueing radial lines of fine rayon fibers on the speaker membrane, and the stroboscope is operated at a frequency slightly different from an integer submultiple of the driving oscillator frequency in order to observe nodal points and membrane vibrations by observing the free ends of the fibers. Such investigation is usually carried out using a microscope or magnifying glass [4].

2.5. Lead shot manufacturing inspection

Small gauge lead shot is manufactured by solidification of molten lead in free fall. Molten lead is poured into a container with calibrated openings in the bottom, after which the container is vibrated vertically by electromagnets connected to the mains. Molten metal drops assume a spherical shape in freefall due to surface tension, and are caught in a water tray.
The stroboscope is adjusted to give a horizontal beam of light about 50 cm under the container, with falling lead pellets visible as contours. If the electromagnets are mains operated, it is possible to observe the size and shape of the pellets by using the mains as a stroboscope trigger [4].

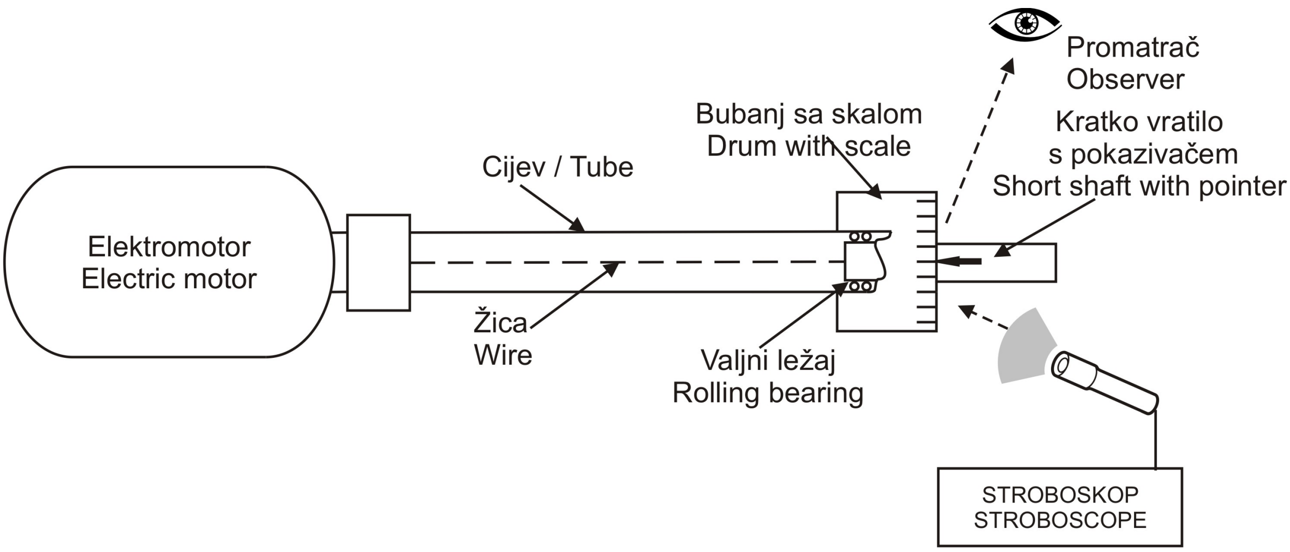
2.6. Stroboskopsko mjerenje okretnog momenta

Dva vratila spojena elastičnom spojkom međusobno se zakreću u ovisnosti o prenesenom momentu. Elastična spojka zapravo je torzijska opruga definirana jednadžbom:

2.6. Stroboscopic torque measurement

Two shafts connected by an elastic coupling twist in relation to each other according to the transmitted torque. An elastic coupling is in fact a torsion spring defined by the equation:

$$M = -k\varphi \quad (3)$$



Slika 5. Stroboskopsko mjerenje okretnog momenta
Figure 5. Stroboscopic torque measurement

te je stoga dovoljno dodati baždarenu skalu i pokazivač kako bi se mogao mjeriti preneseni moment. Stroboskop bljeska frekvencijom koja odgovara broju okretaja motora kako bi se dobila zaustavljena slika skale i pokazivača. Takvim se mjeračima mjere gubici u pogonima mehaničkih tahometara i ostalim preciznim prijenosnicima [4].
Na izlazno vratilo elektromotora postavlja se cijev duga 50 cm, dok se bubanj sa skalom postavlja na drugi kraj cijevi, blizu ležaja. Unutar cijevi nalazi se komad klavirske žice, čvrsto pričvršćen za cijev na strani elektromotora, dok je na drugoj strani pričvršćen za kratko vratilo koje se okreće u ležaju postavljenom na drugom kraju cijevi. Na tom se vratilu nalazi oznaka koja pokazuje zakretanje u odnosu na bubanj postavljen na kraju cijevi, dok se sklop kojem se mjeri gubitak snage spaja na slobodan kraj kratkog vratila.
Pri zakretanju malog vratila dolazi do torzije klavirske žice, zbog čega se pokazivač pomiče u odnosu na bubanj. Zakretanje kratkog vratila ograničeno je graničnicima na 180°.
Pri pokretanju motora žica prenosi vrlo velik moment, pa se zakreće do kraja, a snaga se prenosi izravno putem cijevi koja se oslanja na graničnike. Međutim, nakon što se postignu stacionarni uvjeti opterećenja, žica se polagano odvija, a pokazivač se zaustavlja na

Therefore it is enough to add a calibrated scale with a pointer in order to measure transmitted torque.
The stroboscope flashes at a frequency which equals the number of revolutions of the drive motor in order to achieve a stationary image of the scale and pointer. Such devices are employed to measure the losses in drives of mechanical tachometers and other precision gears [4].
A 50 cm tube is attached to the motor output shaft, while the drum with the scale is placed at the opposite end of the tube, close to the bearing. Inside the tube there is a piece of piano wire, well fastened to the tube on the motor side, while its other side is attached to the short shaft revolving in the bearing placed at the other end of the tube. That short shaft carries a marking which shows the amount of twist in relation to the drum, while the gear with losses to be determined is connected to the free end of the short shaft.
Twisting of the short shaft causes torsion in the piano wire, and the pointer moves in relation to the drum. Limiters limit the movement of the short shaft to 180°.
The wire is subject to a high torque on motor startup and twists to its fullest extent, so power is transmitted directly through the tube resting on limiters. However, once stationary loading conditions are achieved, the wire slowly unwinds, and the pointer stops at the

položaju koji odgovara prenesenom okretnom momentu. Stroboskop se podešava koliko je potrebno za dobivanje stacionarne slike skale i pokazivača.
Mjerač okretnog momenta baždari se opterećivanjem poznatim okretnim momentom i promatranjem pomaka pokazivača u odnosu na bubanj, a rezultirajuća skala je obično linearna.
Snaga *P* računa se jednostavno kao produkt okretnog momenta *M* i kutne brzine vratila ω:

position which corresponds to the transmitted torque. The stroboscope is adjusted enough to obtrain a stationary image of the scale and pointer.
The torque meter is calibrated by loading it with a known torque and observing the movement of the pointer in relation to the drum, with the resulting scale usually being linear.
The power *P* is easily calculated as the product of torque *M* and shaft angular velocity ω:

$$P = M \cdot \omega \, . \quad (4)$$

Točnost i mjerno područje takva mjerača određuju promjer i materijal žice, a moguće je izmjeriti male snage reda veličine od 0,5 W.

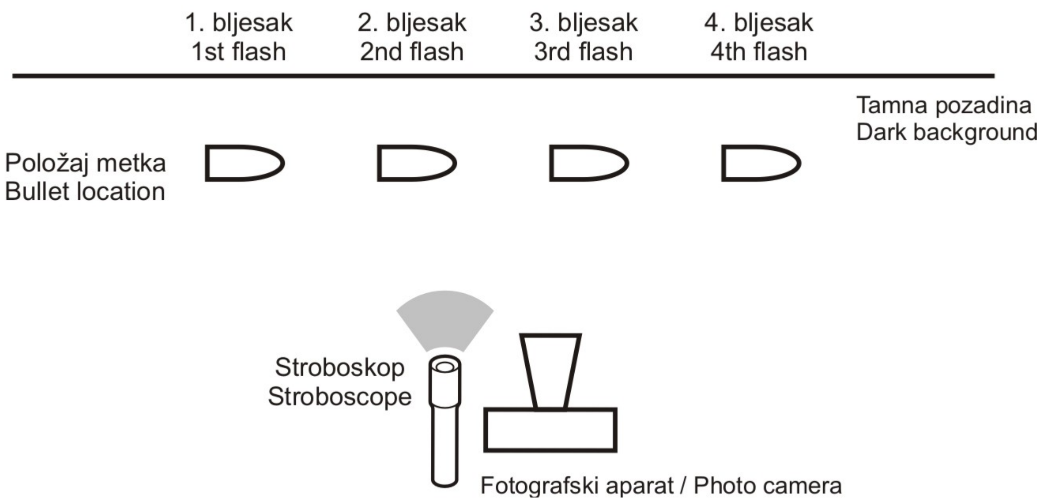
The accuracy and measuring range of such a torquemeter are determined by wire diameter and material, and small powers of the magnitude of 0,5 W can be measured.

2.7. Mjerenje brzine metka

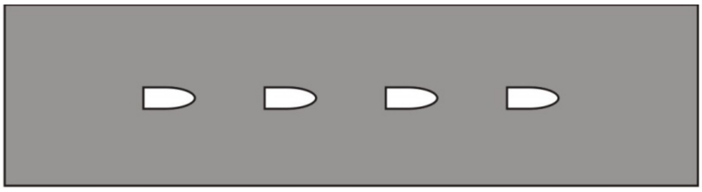
Metak u letu može se jasno fotografirati, budući da se pomiče za nekoliko milimetara između dvaju bljeskova stroboskopa.
Fotografiranjem pod svjetlom uzastopnih bljeskova dobivaju se snimke s jasno određenim vremenskim odmakom iz kojih je moguće izračunati brzinu i ubrzanje, budući da se na uzastopnim snimkama prikazuje metak u poznatim vremenskim i prostornim razmacima (Slika 6). Mjerenje se provodi u zamračenoj prostoriji uz potpuno otvoreni zatvarač fotografskog aparata. Metak se oboji živom bojom, a fotografija se snima ispred tamne pozadine (Slika 7).
Poznata frekvencija bljeskanja stroboskopa određuje vremenski razmak (npr. ako stroboskop bljeska sa 6000 min^{-1}, slike su razmaknute 0,01 s), a prijeđeni put određuje se koristeći poznatu duljinu metka [4].

2.7. Measurement of bullet speed

A bullet can be easily photographed in flight, as it travels several millimeters between two stroboscope flashes.
Photographing using the light of consecutive flashes provides pictures with clearly defined time lapses, which enable the calculation of velocity and acceleration data, as the bullet is photographed in clearly defined time and space intervals (Figure 6). Measurement is carried out in a darkened room with a fully opened camera shutter. The bullet is painted in a bright colour, and the photograph taken in front of a dark background (Figure 7).
The known flashing frequency of the stroboscope determines the time lapse (e.g. if the stroboscope flashes at 6000 min^{-1}, the pictures are 0,01 s apart), while the distance travelled can be determined using known bullet length [4].



Slika 6. Fotografiranje metka u letu
Figure 6. Photographing a bullet in flight



Slika 7. Snimka metka u letu
Figure 7. Photograph of a bullet in flight

2.8. Strobofotografija

Strobofotografija se smatra visokobrzinskom fotografijom, budući da su vremena ekspozicije kraća od onih koja je moguće postići mehaničkim zatvaračima [5]. Kod klasične fotografije to se događa pri 0,001 sekundi, dok se kod filma ta granica dostiže pri 250 ili više sličica u sekundi (primjerice konvencionalna kinematografska oprema radi na 16 ili 24 sličice u sekundi). Za razliku od konvencionalne fotografije, vrijeme ekspozicije kod visokobrzinske fotografije kontrolira se na izvoru svjetlosti, dok zatvarač aparata ostaje otvoren, što znači da izvor svjetlosti mora dati kratak i snažan bljesak usmjeren na predmet.

2.9. Baždarenje brzine zatvarača fotografskog aparata

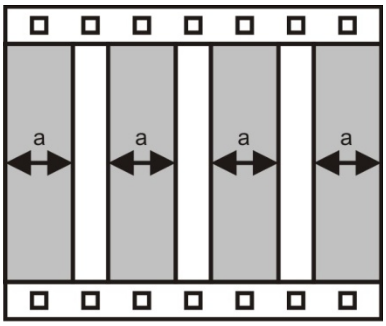
Ravninski zatvarač fotoaparata sastoji se od dviju tankih metalnih zavjesa koje se povlače jedna za drugom preko filma, a razmak među tim zavjesama određuje vrijeme trajanja ekspozicije [5].
Kada se takav fotografski aparat usmjeri prema stroboskopu koji bljeska velikom brzinom i eksponira film, na eksponiranom će se filmu nakon razvijanja vidjeti vertikalne trake progresivno tamnijih i svjetlijih područja u skladu s bljeskovima pri kretanju zatvarača (Slika 8) [4].

2.8. Strobophotography

Strobophotography is considered high speed photography, because exposure times are shorter than those that can be achieved using mechanical shutters [5]. This limit is reached at 0,001 s with conventional photography, while motion pictures reach the limit at 250 or more frames per second (conventional cinematographic equipment operates at 16 or 24 frames per second). Unlike conventional photography, exposure time in high speed photography is controlled at the light source, while the camera shutter remains open, meaning that the light source must give a short and bright flash directed at the object.

2.9. Focal plane shutter speed calibration

A focal plane shutter consists of two fine metal curtains which are pulled over the film one after another, and the spacing between the curtains determines exposure time [5].
When such a camera is pointed at a stroboscope flashing at high speed, and the film exposed, vertical stripes of progressively lighter and darker areas will be visible on the developed film, in accordance with the flashes during shutter travel over the film (Figure 8) [4].



Slika 8. Snimka nastala radom pravilno baždarenog zatvarača (pruge jednake širine a*)*
Figure 8. Image created by a properly calibrated shutter (stripe widths a *are equal)*

Za stroboskop postavljen na 18000 min^{-1} (300 Hz), s vremenom ekspozicije od 0,01 s, pojavit će se tri

With a stroboscope set to 18000 min^{-1} (300 Hz), and with an exposure time of 0,01 s, three light stripes will svijetle trake. Razmak među trakama mjeri se zato što jednolični razmaci među trakama znače ispravan rad zatvarača. Trajanje bljeska mora biti vrlo kratko kako bi se osigurala točnost toga postupka.

appear. Band spacing is measured, as equal spacing means proper shutter operation. The accuracy of this procedure is ensured by very brief flash duration.

2.10. Primjena u psihologiji i fiziologiji

Stroboskop je prepoznat kao koristan dijagnostički uređaj u fiziologiji i psihologiji. Stroboskopska stimulacija vrlo je važna u istraživanju moždanih valova i dijagnostici epilepsije. Također postoji veza između granice razlučivosti (frekvencije pri kojoj se trepćuće svjetlo doima stalno upaljenim) i nekih živčanih poremećaja, a ta se frekvencija lako određuje stroboskopom [4].
Stroboskop se u psihologiji koristi kao takistoskop, izvor kratkih bljeskova poznate boje, trajanja i intenziteta. Stroboskop se također koristi u medicini za promatranje i dijagnostiku glasnica.

2.10. Applications in psychology and physiology

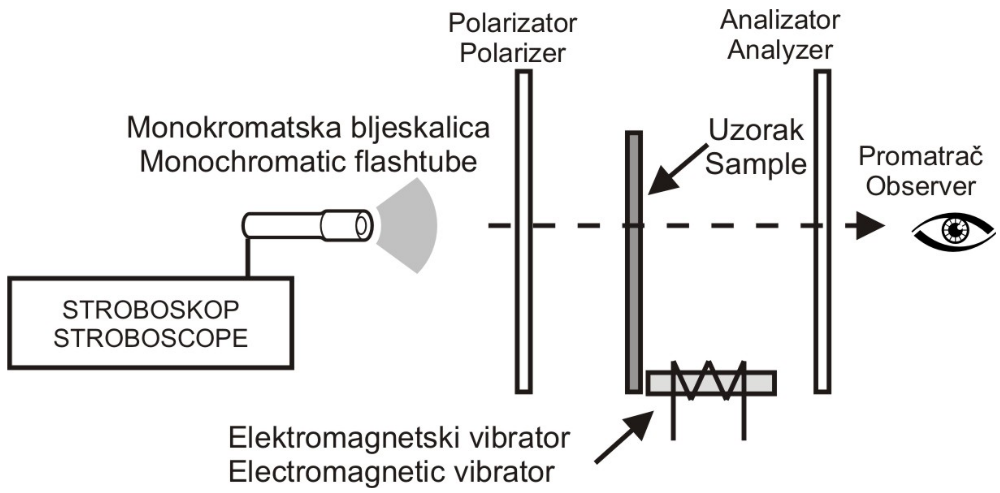
The stroboscope is recognized as a useful diagnostic instrument by psychologists and physiologists. Stroboscopic stimulation is very important for the study of brain waves and diagnosis of epilepsy. Also, a relation between flicker fusion frequency (the frequency at which a flashing light appears to be permanently lit) and certain nervous disorders has been established, and this frequency is easily determined by the stroboscope [4]. In psychology,the stroboscope is used as a tachistoscope, a source of brief flashes of known color, duration and intensity. Stroboscopes are also used in medicine for vocal cord observation and diagnosis.

2.11. Istraživanja fotoelastičnosti

Valovi udarnog naprezanja mogu se istraživati u prividno usporenom gibanju korištenjem elektromagnetskog vibratora, polariskopa i stroboskopa s monokromatskom bljeskalicom.
Ispitni uzorak montira se u polariskop, a vibrator se postavlja tako da kontinuirano udara u promatrani predmet. Podešavanjem frekvencije stroboskopa moguće je prividno ubrzati valove, usporiti ih, zaustaviti ih, ili im promijeniti smjer kretanja, što omogućuje istraživanje izoklina i vrhova valova. Mjesto udaranja vibratora i energija udara mogu se lako mijenjati kako bi se proučio njihov učinak na valove naprezanja, a moguće je i fotografirati pokus za jednostavnije istraživanje [4].

2.11. Photoelastic studies

Impact stress waves can be researched in apparently slow motion by using an electromagnetic vibrator, a polariscope, and a monochromatic flashtube stroboscope.
The test sample is placed inside the polariscope, and the vibrator set so that it continously strikes the sample. By adjusting the stroboscope frequency it is possible to apparently speed up, slow down, stop or reverse the motion of stress waves, which enables the study of isoclines and wave peaks. The point of impact and striking power of the vibrator can be easily varied to study their effect on stress waves, and the experiment can be photographed for easier study [4].



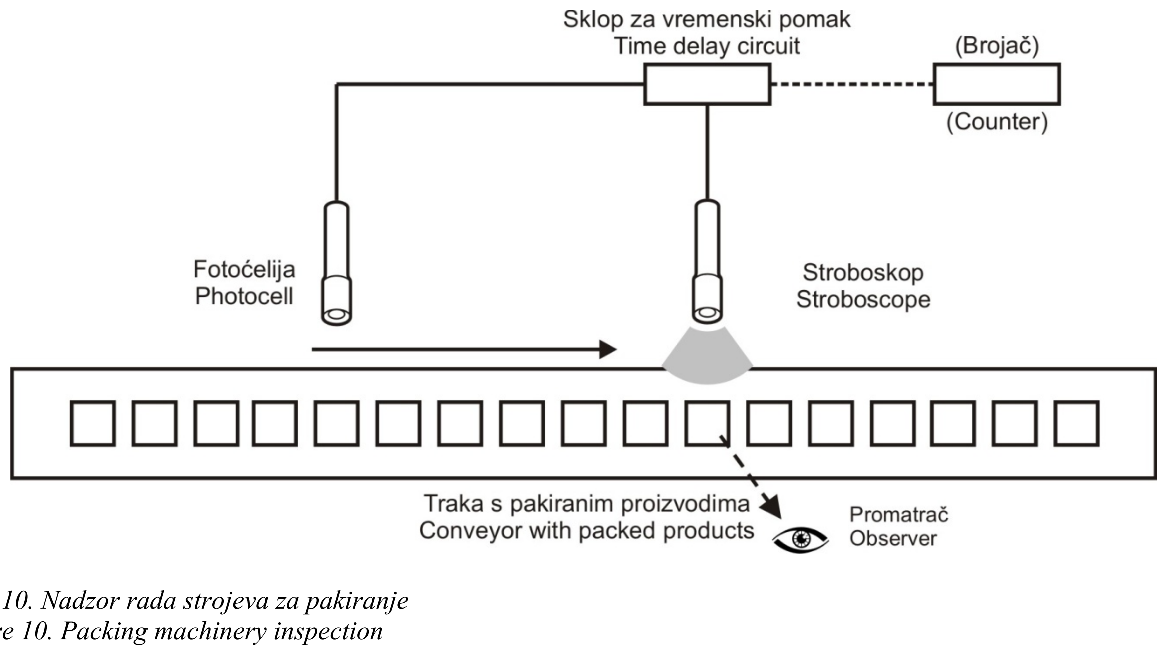
Slika 9. Fotoelastično istraživanje udarnog naprezanja
Figure 9. Photoelastic impact stress research

2.12. Nadzor ispravnosti rada strojeva

Stroboskopom je moguće lako kontrolirati ispravnost sustava za hlađenje. Strujanje zraka u unutrašnjosti uređaja učini se vidljivim dodavanjem kemijskog dima na usis ventilatora. Stroboskopskim promatranjem osigurava se da zrak dolazi do svih dijelova kojima je potrebno hlađenje, a mogući kvarovi lako se pronalaze.
Stroboskopom se kontrolira sinkronizacija boja tiskarskih strojeva u pogonu, čime je moguće i udvostručiti brzinu rada stroja. Promatranjem se uočava ne samo koja je boja izvan sinkronizacije, nego i koliko je potrebno korigirati pojedinu boju. Stroboskop se aktivira fotoelektričnim senzorom postavljenim nasuprot nekoj refleksivnoj površini, uz uređaj za vremenski odmak kako bi se kompenzirala udaljenost do mjesta promatranja [4].
Nadzor rada brzih strojeva za pakiranje proizvoda nije moguć bez stroboskopa. Naime nadzor rada bez stroboskopa zahtijevao bi usporavanje procesa pakiranja, što je vrlo nepraktično. U farmaceutskoj industriji vrlo je važan brz i pouzdan nadzor rada tih strojeva, budući da je potrebno uvijek znati točan broj pakiranih i zapečaćenih lijekova. Kao i pri kontroli tiskarskih strojeva, stroboskop se aktivira fotoćelijom usmjerenom na kutiju preko uređaja za vremenski odmak, a taj sustav ima i dodatnu pogodnost u obliku mogućnosti automatskog rada brojača spajanjem na izlaz fotoćelije (Slika 10).

2.12. Monitoring of machine operation

The correct operation of cooling systems can be easily verified by adding chemical smoke to fan intakes. Stroboscopic observation ensures that the air reaches all parts in need of cooling, and any malfunctions are easily detected.
A stroboscope is used to check color synchronization of running printing presses, enabling the print speed to be doubled. Observation does not just point to the color which needs synchronisation, but also to how much correction is required to a particular color. The stroboscope is activated by a photoelectric sensor set against a reflective surface, with a time delay circuit to compensate the distance to the observation place [4].
High speed packing machinery cannot be monitored without the use of a stroboscope. It is highly impractical to operate such machines at a reduced speed, and monitoring their operation without a stroboscope demands slowing down the packing process. The pharmaceuthical industry has a particular reason for quick and reliable monitoring of such machines, as it is necessary to know the exact number of packed and sealed products at all times. As with printing press inspection, the stroboscope is activated by a photocell pointed against a box through a time delay circuit, and the system offers the additional bonus of an automated counter by connecting to the photocell output (Figure 10).



Slika 10. Nadzor rada strojeva za pakiranje
Figure 10. Packing machinery inspection

Punionice boca, poput onih u pivovarama, koriste stroboskope za nadzor rada strojeva koji pune tisuću i više boca u minuti [4]. Ispravnost rada utvrđuje se količinom tekućine ili pjene koja se prelijeva preko grla boce. Uz pomoć stroboskopa koji bljeska

Bottling plants, such as those in breweries, use stroboscopes to monitor the operation of machines filling a thousand or more bottles per minute [4]. Correct operation is determined by observing the amount of liquid or foam spilling over from the bottle.

odgovarajućom brzinom, operator nadzire količinu tekućine koja se prelijeva i ispravlja pogreške u punjenju.

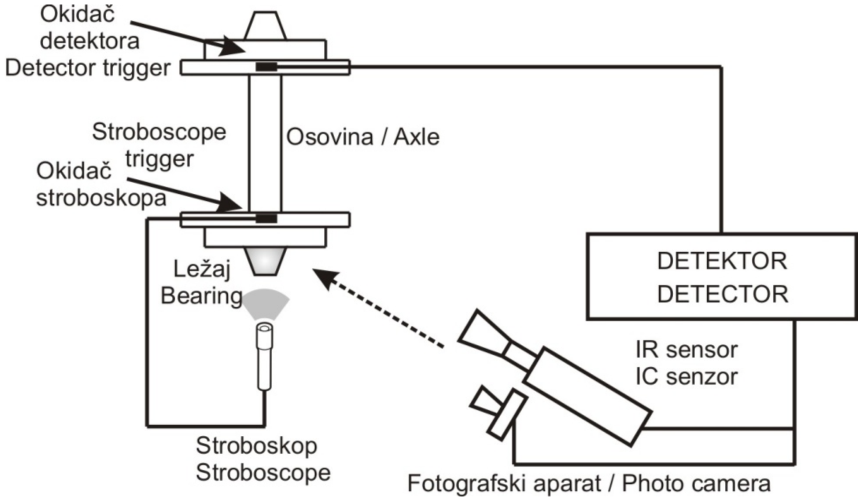
With the assistance of a stroboscope flashing at an adequate rate, the operator monitors the amount of the spilling liquid and compensates for filling errors.

2.13. Kontrola rada detektora pregrijanih ležajeva

Sigurnost željezničkog prometa jamče razni uređaji poput detektora pregrijanih ležajeva, brojača osovina, autostop-uređaja i sl.
Primjerice, pregrijan ležaj osovine može dovesti do blokade osovine, požara ili iskliznuća vlaka iz tračnica. Zbog toga detektor pregrijanih ležajeva mjeri infracrveno zračenje vlaka u prolazu, te obavještava osoblje vlaka ili prometnika da je sve u redu ili navodi broj osovine s pregrijanim ležajem (Slika 11) [6].

2.13. Control of Hotbox Detector Operation

Railway traffic safety is guaranteed by various devices such as hotbox detectors, axle counters, autostop devices etc.
For example, an overheated bearing (hotbox) can lead to a seized axle, fire or even derailment.
Because of that, a hotbox detector measures the infrared radiation of a moving train, and gives the train crew or the traffic controller an all clear signal, or specifies the number of the axle having a hotbox (Figure 11) [6].



Slika 11. Ispitivanje detektora pregrijanih ležajeva
Figure 11. Hotbox detector testing

Kotači vlaka u pokretu mogu se lako fotografirati uz pomoć stroboskopa, kao i bilo koji drugi predmet u pokretu. Na tračnice se postavlja mehanički ili magnetski okidač koji se aktivira prolaskom kotača, nakon čega stroboskop daje jedan bljesak. Istodobno kotač se snima fotografskim aparatom, a na snimci se kasnije provjerava položaj kotača vlaka u odnosu na detektor kako bi se provjerilo ispravno pozicioniranje detektora.

The wheels of a moving train can be photographed as easily as any other moving object. A mechanical or magnetic trigger is placed on the tracks, and the passing of a wheel activates the stroboscope to give one flash. The wheel is photographed at the same time, and the picture is later examined to check the position of the train wheel in relation to the detector in order to verify its correct operation.

3. ZAKLJUČAK

Stroboskopi imaju osiguranu budućnost čak i u dvadeset prvom stoljeću. Napredak u elektronici i proizvodnji bljeskalica omogućuje proizvodnju sve kompaktnijih i preciznijih uređaja, te stoga suvremeni model daleko nadmašuje mogućnosti prvih potpuno tranzistorskih uređaja iz pedesetih godina prošlog stoljeća, a dovoljno je malen i lagan da se može držati u ruci.
Zbog napretka u razvoju elektronike i senzora neki

3. CONCLUSION

Stroboscopes have a certain future even in the 21st century. The design of even more compact and precise stroboscopes has been made possible by progress in electronics and flashtube manufacture, so that the contemporary model exceeds the capabilities of the first fully transistorized models from the 1950s, yet is small and light enough to be hand-held.
Due to progress in the design of electronics and sensors, some machinery (e.g. printing presses and

strojevi (npr. tiskarski strojevi i strojevi za pakiranje) mogu raditi i bez pomoći stroboskopa, no stroboskop ostaje jednostavan i pouzdan dopunski alat za nadzor i provjeru ispravnosti trajno instaliranih senzora. Primjena u medicini i ostalim specifičnim primjenama vjerojatno će se nastaviti jer zamjenske tehnologije ne postoje ili su nepraktične za upotrebu.

packing machines) can operate wihout stroboscope assistance, yet the stroboscope remains a simple and reliable backup tool to verify the correct operation of permanently installed sensors.
The stroboscope will most likely continue to be used in medicine and other niche applications, as replacement technology either does not exist or is impractical for use.

4. POPIS OZNAKA

4. LIST OF SYMBOLS

napetost remena	T,	N	belt tension
konstanta remena	K,	$N \cdot m^{-3} \cdot s^2$	belt constant
frekvencija vibriranja	f,	Hz	vibrating frequency
duljina slobodnog remena	L,	m	length of free belt
širina remena	W,	m	belt width
snaga	P,	W	power
sila u kraku remena	T,	N	belt section tension
sila u pogonskom kraku	T_t,	N	tension of the tight belt section
sila u povratnom kraku	T_s,	N	tension of the slack belt section
frekvencija vibriranja pogonskoga kraka	f_t,	Hz	vibrating frequency of the tight belt section
frekvencija vibriranja povratnoga kraka	f_s,	Hz	vibrating frequency of the slack belt section
brzina remena	v,	$m \cdot s^{-1}$	belt speed
okretni moment	M,	Nm	torque
konstanta opruge	k,	$Nm \cdot rad^{-1}$	spring constant
zakretni kut opruge	φ,	rad	spring twist angle
kutna brzina	ω,	$rad \cdot s^{-1}$	angular velocity

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