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Razvoj uporabnih termografskih metod

The Development of Applied Thermographic Methods

Mladen Andrassy - Srečko Švaić - Ivanka Boras *

Termografija je nestična metoda za merjenje temperature in njene porazdelitve po površinah na predmetih. Temelji na infrardečem (IR) sevanju. Moderne termografske naprave podajajo časovno temperaturno porazdelitev, ki je poleg nestika glavna prednost metode. To daje termografiji zelo pomembno orodje, ki ga uporabljajo na vseh tehničnih področjih in tudi v medicini, biologiji itn.

Naslednji pregled daje osnove termografije in nekaj primerov kakovostne in kolikerostne termografije, ki pokriva velik spekter različnih uporab teh merskih tehnik na področju testiranja, razvoja izdelkov in znanstvenega raziskovanja.

(Ključne besede: termografija, razvoj metod, naprave termografske, uporaba termografije)

Thermography is a contactless method for the measurement of temperature and its distribution on the surfaces of objects. It is based upon the registration of infrared (IR) radiation from the object. Modern thermographic devices give the real-time surface temperature distribution, which combined with the absense of any contact is the basic advantage of the method. This makes thermography a very useful tool which has applications in all technical areas including medicine, biology etc.

The following review provides the basics of thermography and a couple of examples from qualitative and quantitative thermography indicating the wide spectrum of possible applications of this measuring technique in the field of surveillance, product development and scientific research.

(Keywords: termography, method developments, termographic equipment, termography applications)

0 UVOD

IR sevanje je znano skoraj 200 let in ga je odkril sir William Herschel (1738 do 1822) in ugotovil, med merjenjem toplotnih učinkov sončnega sevanja, da sevanje obstaja tudi nad rdečo svetlobo zunaj vidnega področja. IR je elektromagnetno sevanje v obsegu valovnih dolžin λ = 0,8 do 1000 μm, kar pomeni, da se širi v okolico vidne svetlobe (0,4 do 0,8 μm) (sl. 1). Kot preostala sevanja, je IR sevanje izpostavljeno osnovnim zakonom sevanja črnega telesa [1]:
1. Planckov zakon porazdelitve energije:

0 INTRODUCTION

IR radiation has been known for almost 200 years. Sir William Herschels' (1738 to 1822) measurements of thermal effects in the solar radiation spectrum revealed that light exists beyond red, outside the visible region. IR is an electromagnetic radiation in the range of wavelengths λ = 0.8 to 1000 μm, which means that it extends close to the range of visible light (0.4 to 0.8 μm), as shown in Fig. 1. Like all other radiation, IR is subject to the basic laws of black-body radiation [1]:
1. Planck's law of spectral energy distribution:

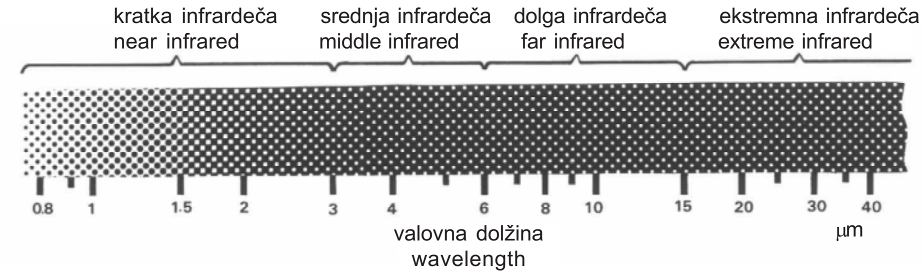
$$dE_c = \frac{c_1}{\lambda^5 \exp(c_2 / \lambda T) - 1} d\lambda \tag{1}$$

glede na kar je del energije povezan z valovno dolžino $d\lambda$ in je odvisen od same valovne dolžine in absolutne temperature T.
2. Wienov zakon

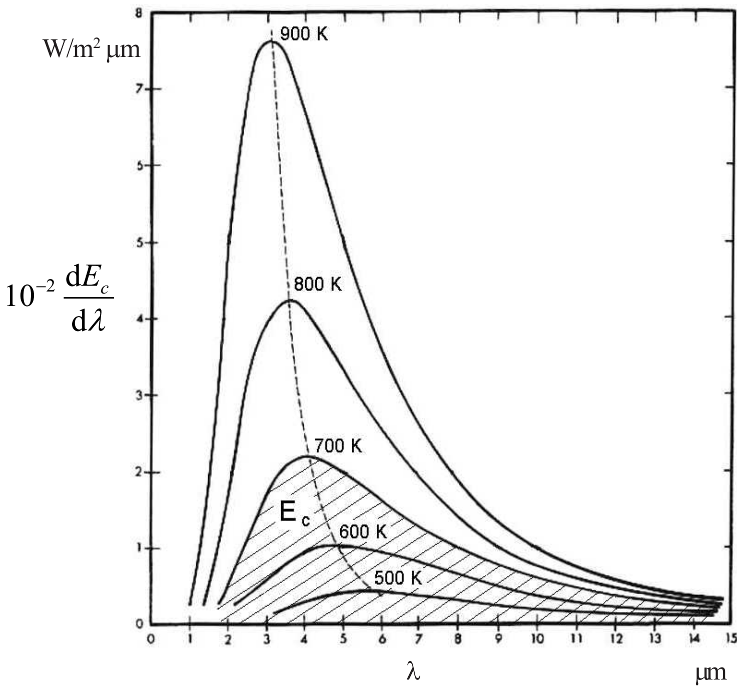
according to which the amount of energy radiated at a band of wavelengths $d\lambda$ depends on the wavelength itself and the absolute temperature T.
2. Wien's law:

$$\lambda_{max} T = c_3 \tag{2}$$

* Termogrami / Thermograms by: Kruno Petrović



Sl. 1. *Elektromagnetni spekter*
Fig. 1. *The electromagnetic spectrum*



Sl. 2. *Porazdelitev spektralnega sevanja*
Fig. 2. *Distribution of spectral radiation*

pravi, da se največja valovna dolžina sevanja λ_{max} v Planckovi porazdelitvi premika v del z manjšimi valovnimi dolžinami pri naraščanju temperature.

3. Integracija Planckove enačbe (1) vodi do obrazca za celotno sevano energijo iz 1 m² površine s temperaturo *T*, ki sta jo empirično dobila Stefan in Boltzmann:

stating that the maximum radiation intensity wavelength λ_{max} in Planck's distribution shifts to the range of shorter waves with an increase in the temperature.

3. Integration of Planck's equation (1) yields the formula, obtained empirically by Stefan and Boltzmann, for the total energy radiated by 1 m² of a surface at the temperature *T*:

$$E_c = 5{,}67 \cdot 10^{-8}\, T^4 \qquad (3).$$

Slika 2 predstavlja omenjene zakone.

Za praktično uporabo postane zelo pomemben Kirchoffov zakon. Pravi, da telesa v toplotnem ravnovesju oddajajo ravno toliko svetlobe, kolikor jo absorbirajo, kar pomeni, da je sevalni koeficient ε enak absorpcijskemu koeficientu α. Sevalni koeficient je razmerje med oddano energijo površine in oddano energijo črnega telesa pri enaki temperaturi:

Fig. 2 represents the cited laws.

For practical applications of thermography, the Kirchoff rule becomes specially important. It states that bodies in thermal equilibrium emit as much energy as they absorb, which means that the emissivity coefficient ε of their surface equals the absorption coefficient *a*. The emissivity coefficient, on the other hand, is the ratio of the emitted energy of a surface to the emitted energy of a blackbody at the same temperature:

$$0 \le \varepsilon = E / E_c \le 1 \qquad (4).$$

Tako za črno telo velja $\varepsilon_c = \alpha_c = 1$, kar pomeni, da absorbira samo sevano energijo brez zrcaljenja ali prepustnosti. Po drugi strani telesa, ki nimajo lastnosti črnih teles, absorbirajo del α sevane energije, zrcalijo del r in prepuščajo del d:

Thus, for a blackbody $\varepsilon_c = a_c = 1$, i.e. it only absorbs the irradiated energy without reflecting or permeating it. Bodies not having blackbody properties, absorb the part a of the irradiated energy, reflect the part r and permeate the part d, thus:

$$a + r + d = \varepsilon + r + d = 1 \quad (5).$$

Glavnina fizikalnih teles je neprepustna za IR sevanje ($d = 0$), toda zaradi $r > 0$ je koeficient sevanja ε manjši od ena. Taka telesa imenujemo siva telesa, njihovo sevanje pa je sestavljeno iz njihovega lastnega sevanja, ki je določeno z njihovo temperaturo glede na (3), in odbojnim sevanjem, ki je določeno z okoliškimi telesi.

Z merjenjem sevalne energije telesa in z upoštevanjem omenjenih zakonov, je mogoče določiti temperature teles brez dotikov. Te meritve so osnova termografske metode.

The majority of physical bodies are untransparent for IR radiation ($d = 0$), but because of $r > 0$ their emissivity coefficient ε is less than unity. Such bodies are called gray bodies, and the radiation from their surfaces consists of their own radiation determined by their temperature according to (3) and of the reflected radiation determined by the temperature of the surrounding bodies.

By measuring the radiated energy from a surface, and by taking into account the mentioned laws, the determination of surface temperatures becomes possible without the need to make contact with it. Such measurements are the basis of thermographic methods.

1 TERMOGRAFASKE NAPRAVE

Termografske metode delajo IR sevanje vidno, po drugi strani pa omogočajo določevanje temperaturne porazdelitve po površinah teles. Razvite so bile (večinoma v vojski) za omogočanje “vidnosti v temi” in v zadnjih tridesetih letih so na voljo tudi za množično uporabo. Termografske naprave so majhne kot video kamere in omogočajo snemanje temperaturnih porazdelitev v dejanskem času z ločljivosti, ki je boljša od 0,1°C. Rezultat meritev je termogram, ki predstavlja površinsko temperaturno porazdelitev v sivi skali ali v barvah. Termogram je viden na zaslonu naprave in ga lahko shranimo v pomnilnik za kasnejšo uporabo.

Termografski sistem je iz treh glavnih delov: optični del, preoblikovalni del in zaslonski del. Optični sistem je iz leč, ki so prosojne za IR sevanje (običajno iz germanija ali silicija, ki so prosojne za valovne dolžine nad 1,8 μm oziroma 1μm). Starejše naprave imajo mehanski sistem z rotirajočimi prizmami ali poševnimi ogledali. Prizme morajo biti tudi IR prepustne, medtem ko morajo ogledala odbijati IR sevanje (polirano zlato ali s silicijem obložen aluminij).

Osrednji del spremembe signala je IR sevalno iskalo, do katerega vodimo sliko objekta. Moderni sistemi uporabljajo fotonska iskala, narejena iz sintetičnih polprevodniških kristalov (In-Sb, Hg-Cd-Te), v katerih se nosilci nabojev (elektroni) sprostijo pod vplivom IR sevanja različnih valovnih dolžin. Imajo zelo majhen odzivni čas, toda morajo biti v kriogenskih temperaturah, da se jim zveča občutljivost in da so zaščiteni pred toplotnimi motnjami okolice. Za hlajenje je bil najprej uporabljen tekoči dušik; sodobne naprave pa uporabljajo Peltierjeve celice. Glede na njihovo sestavo je

1 THERMOGRAPHIC DEVICES

Thermographic devices make IR radiation visible, and they enable the determination of the temperature distribution on the surfaces of bodies. They have been developed (mostly by the military) to enable “sight in the dark”, and not until the last thirty or so years have they been available for public use. Contemporary thermographic devices are as small as video cameras and permit recording of temperature distributions in real time with a resolution better than 0.1 °C. The measurement result is a thermogram, which depicts the surface temperature distribution in gray scale or in a colored code. The thermogram is visible on the display of the device, and it may be saved to the memory for later evaluation.

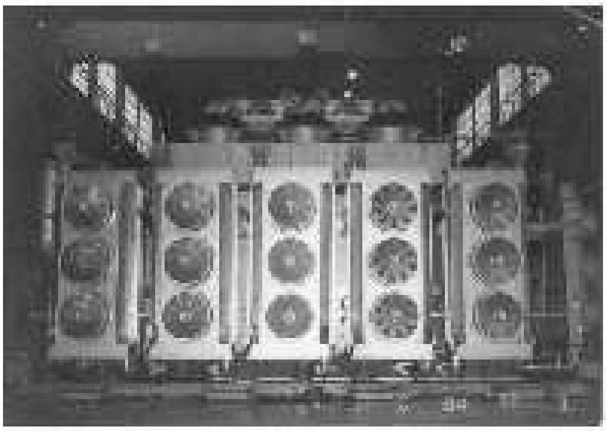
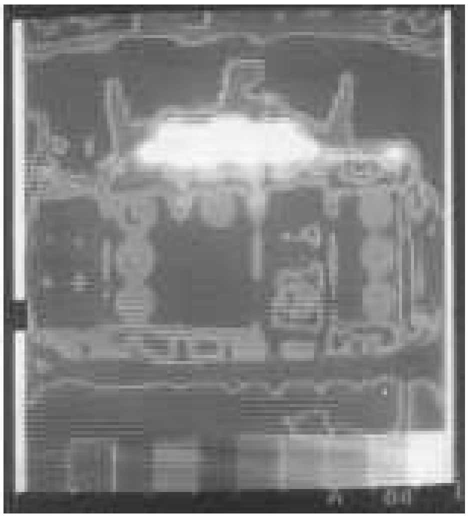
The thermographic system normally consists of three major parts: the optical, the converting and the displaying parts. The optical system consists of lenses transparent to IR (usually germanium or silicon, which are transparent to wavelengths above 1.8 μm or 1 μm respectively). Older devices had mechanical scanning systems with rotating prisms or tilting mirrors. Here the prisms also had to be IR transparent, while the mirrors had to reflect IR radiation (polished gold or silicon-coated aluminum).

The central part of the signal conversion is the IR radiation detector to which the object is focused by the optics. Modern systems use photon detectors made from synthetic semiconductor crystals (In-Sb, Hg-Cd-Te) in which the charge carriers (electrons) are set free under the influence of IR radiation of certain wavelengths. They have very short response times, but they have to be at cryogenic temperatures, in order to increase the sensitivity and to shield the thermal noise of the surroundings. For the cooling, liquid nitrogen was first used; modern devices use Peltier cells. Depending on their občutljivost zaznaval omejena na relativno ozke trakove valovnih dolžin (nekaj 5 μm), običajno v srednjem IR območju (2,5 do 50 μm). Občutljivost na krajše valovne dolžine so prednost pri višjih temperaturah in obratno. Sistem snemanja ima točkovna zaznavala, snemanje pa traja določen čas, za kolikor se izvedba termograma za določen časovni interval zakasni. Moderne naprave uporabljajo FPA tehniko (Focal Plane Array) z množico zaznaval. Standardna iskala FPA imajo 244 vrstic s 320 zaznavali, na področju 8 x 6 mm. Taka zaznavala so veliko hitrejša in omogočajo termografijo v dejanskem času. Ojačen in moduliran električni signal, ki ga daje zaznavalo, se prenese na zaslon termografske naprave.

Termogrami se običajno prikazujejo na zaslonu (katodna cev ali zaslon na tekočih kristalih) (sl. 3). Termogram je slika predmeta, ki predstavlja površinske temperature v lestvici sivih odtenkov. Moderne naprave lahko spremenijo sivo skalo v barvno, kar pomeni, da različne barve pomenijo različna temperaturna področja. Osnovna razlika med termogramom in fotografijo je, da termogram predstavlja sevano energijo poleg odbite energije. To je eden od največjih problemov temperaturnih meritev s termogrami. Če termogram naredimo na objektu z lastnostmi črnega telesa ($\varepsilon = \varepsilon_c = 1$), bi to pomenilo stanje telesa pri njegovi lastni temperaturi. Dejanski objekti pa so siva telesa, kar pomeni da njihovi termogrami vsebujejo delež, sorazmeren s koeficientom odboja $r = 1 - \varepsilon$ (za $d = 0$ - neprosojno telo), zrcalnega sevanja, ki prihaja iz okoliških teles z različnimi temperaturami. Koeficient oddaje je odvisen od površinskih lastnosti in kota oddaje glede na pravokotnico. To naredi stanje bolj zapleteno za nenavadne geometrijske oblike. Nekatere termografske naprave so prilagojene za sevanje črnega telesa, kar pomeni, da moramo izračunati natančno temperaturo telesa z uporabo podatka za sevalnost površine. Moderne naprave

composition, the detector sensitivity is bound to relatively narrow wavelength bands (some 5 μm), usually in the medium IR range (2.5 to 50 μm). Detectors sensitive to shorter wavelengths are preferred for higher temperatures and vice versa. Scanning systems have point detectors, and scanning takes a certain time, thus slowing the realization of the thermogram. Modern devices use Focal Plane Array (FPA) detectors with a multitude of detectors. Standard FPA detectors have 244 lines with 320 detectors each, with an area of 8 x 6 mm. Such detectors are much faster and enable real-time thermography. The amplified and modulated electrical signal produced by the detector is transferred to the display unit of the thermographic device.

The thermograms are usually displayed on a screen (cathode-ray tube or LC display) - Figure 3. A thermogram is a picture of the object, reproducing the surface temperature distribution in gray scale grades. Modern devices can convert the gray scale into a colored code, which means that different colors are associated with narrow gray scale regions. The basic difference between a thermogram and a photograph is that the thermogram represents the radiated energy of the object besides the reflected energy. This indicates one of the biggest problems of thermographic temperature measurements. If the thermogram was taken of an object with blackbody properties ($\varepsilon = \varepsilon_c = 1$), it would represent the state of the object determined by its own temperature. Real objects however, are graybodies, meaning that their thermograms contain a share, proportional to the objects' reflection coefficient $r = 1 - \varepsilon$ (for $d = 0$ - untransparent body), of reflected radiation coming from neighboring objects at different temperatures. The emissivity coefficient depends upon the surface properties and the emission angle to the surface normal. This makes the situation more complicated for complex geometrical shapes. Some thermographic devices are adjusted to blackbody radiation, thus making it necessary to calculate the exact temperature values by using data for the emissivity of the surfaces. Mod-

Sl. 3. *Fotografija in termogram istega objekta*
Fig. 3. *Photograph and thermogram of the same object*

so prilagojene za katerokoli sevalnost, toda to velja za celo področje snemanja.

Opisane lastnosti dokazujejo, da je termografija idealno sredstvo za kakovostno določanje temperaturne porazdelitve po objektnih površinah, toda merljivost rezultatov je povezana s številnimi problemi.

2 UPORABA TERMOGRAFIJE

Termografijo lahko razdelimo, glede na način merjenja, na pasivno in aktivno termografijo.

Pri aktivni termografiji je posneti objekt pri temperaturi, ki je različna od okolice, kar omogoča neposredno izdelavo termogramov brez posebnih priprav.

Pri aktivni termografiji je objekt enake temperature kakor okolica, kar pomeni, da moramo objekt toplotno stimulirati, da dobimo potrebni toplotni kontrast. To povzroča, da lahko aktivno termografijo uporabljamo predvsem v laboratorijskih prilikah.

2.1 Pasivna termografija

Uporaba pasivne termografije je zelo široka. Poleg industrijskih merjenj jo uporabljamo v medicini, biologiji, gradbeništvu, meteorologiji, varstva pred ognjem in pri iskanju izgubljenih ljudi v divjini. Pasivna termografija daje večinoma kakovostne termograme, ki so ugodni za primerjavo. Oblika temperaturnega področja termograma kaže na možnost nezveznosti.

Ena najpogostejših uporab termografije je nadzor in vzdrževanje industrijskih naprav. Značilen primer je ogled električne opreme. Slika 4 prikazuje grafično termografsko pripravo in termogram, ki označuje pregrevanje zaradi kratkega stika. Namestitev takega sistema povzroča

ern devices may be adjusted to any given emissivity, but this is constant for the entire recording area.

The described circumstances indicate that thermography is an ideal means for qualitative determination of the temperature distribution on object surfaces, but the quantification of the measurement results may be associated with serious problems.

2 APPLICATION OF THERMOGRAPHY

Thermography may be divided, according to the measuring approach, into passive and active thermography.

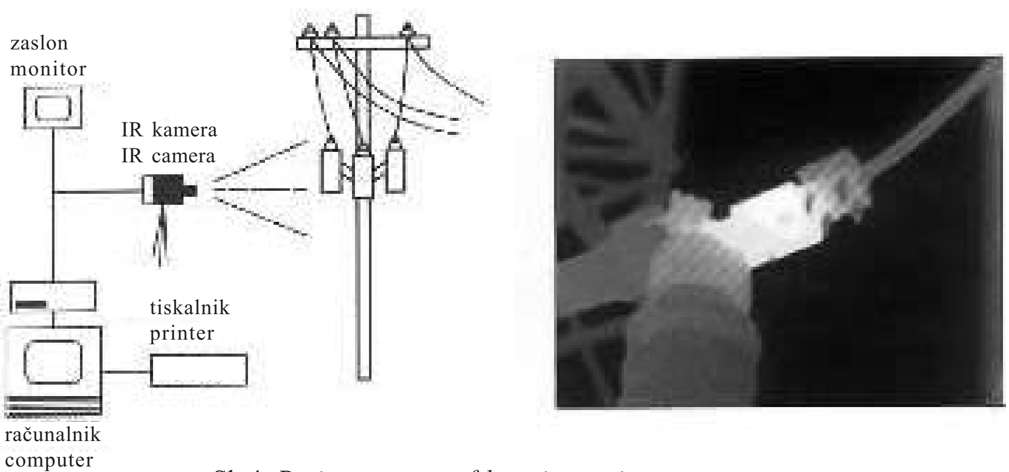
In passive thermography the recorded object is at temperatures that are different from the ambient, thus enabling direct taking of thermograms, without special preparations.

With active thermography the objects are at the ambient temperature, thus making necessary a thermal stimulation of the object in order to obtain the required thermal contrast. This makes active thermography possible mostly in laboratory applications.

2.1 Passive thermography

The application of passive thermography is very wide. Along with industrial measurements, it is used in medicine, biology, civil engineering, meteorology, fire protection, for the detection of people lost in the wilderness etc. Passive thermography gives mostly qualitative thermograms which are suitable for comparisons. The shape of the temperature field on the thermogram indicates the possible cause of the discontinuity.

One of the most frequent applications of thermography is in the supervision and maintenance of industrial facilities. A characteristic example is the inspection of electrical switching equipment. Fig. 4 shows a schematic of the thermographic inspection gear and a thermogram indicating overheating due to a short cir-



Sl. 4. *Pasivna termografska priprava in termogram*
Fig. 4. *Passive thermography arrangement and thermogram*

naraščanje produktivnosti in učinkovitosti obrata, ker omogoča odstranitev nenačrtovanih motenj in skrajša čas popravil.

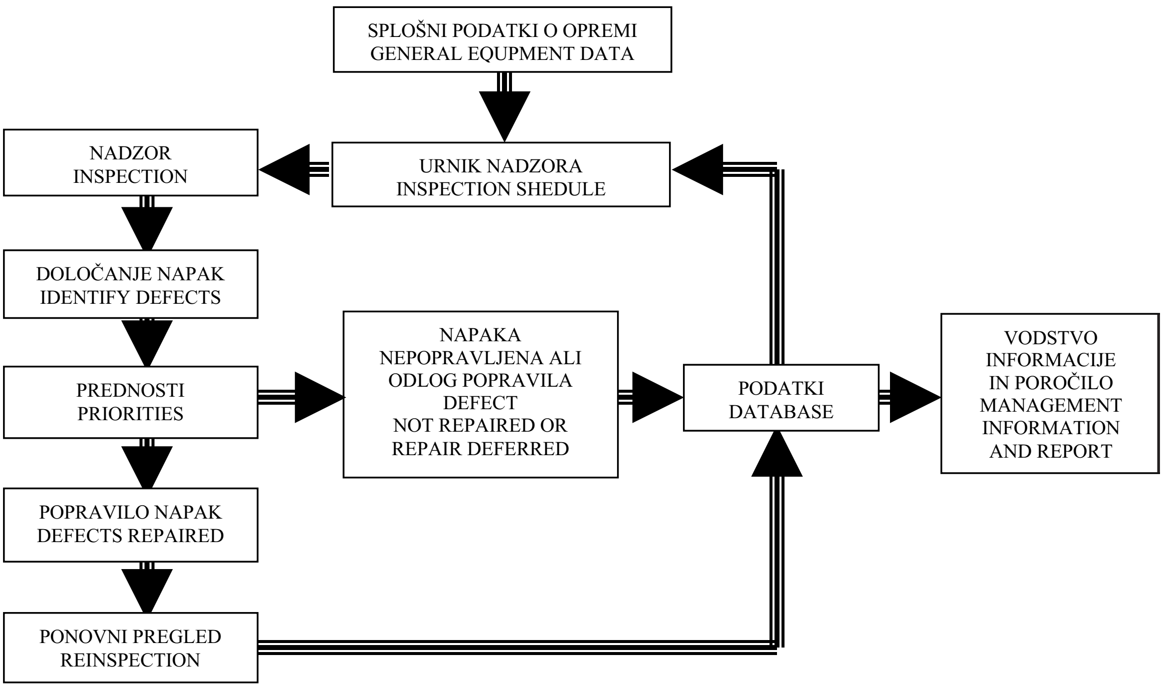
Nadzor nad večino proizvodnih naprav lahko organiziramo glede na pretočni diagram na sliki 5. Podatki vsebujejo seznam delov, ki jih nadzorujemo, z opisom pomena, razpoložljivosti nadomestnih delov, pričakovane dobe trajanja, vprašanj o varnosti in njihove lege v sistemu. Urnik nadzora je narejen na podlagi domnev in začetnih pregledov, medtem ko se nezadostnosti določajo in razvrščajo glede na izločitveno teorijo (takojšnje popravilo, načrtovano popravilo v prihodnosti ali podaljšano nadzorstvo).

To je opravljeno na podlagi razpoložljivih rezervnih delov, postopkov vzdrževanja in ocene nenačrtovanih zastojev. Odločitve in podatki o napakah se shranijo v bazo. Urnik nadzorov in baza podatkov sta tako stalno dopolnjevana s podatki iz nadzorov. V tem postopku se lahko zgodi, da nekaterih pomanjkljivosti ne moremo odpraviti zaradi nedostopnosti opreme itn., nepopolnosti sekundarnega izvora, napak v instalacijah, napačnih ureditev in izvedb napak. Urnik mora prav tako vsebovati informacije, ki jih potrebujemo za nadzor v prihodnosti, npr. poraba časa, tipi popravil in število rezervnih delov. Te podatke potrebujemo tudi za shranjevanje rezervnih delov in kot informacijo za časovno dobo komponent. Po prvih uvajalnih obdobjih opisani sistem dosega zmanjšanje števila zlomov in napak, posebno najbolj nevarnih, podatki pa omogočajo razvoj službe vzdrževanja.

cuit. The installation of an inspection system in such cases results in increased productivity and efficiency of the facility, because it eliminates unplanned operation interruptions and shortens the repair period.

The supervision of most production facilities may be organized according to the flow diagram in Fig. 5. The equipment data contains the list of the system parts under supervision, with the description of their importance, availability of spare parts, expected life time, security requests and their position in the system. The inspection schedule is prepared on the basis of prediction and initial inspection, where deficiencies are identified and sorted according to elimination priority (immediate repair, planned repair in the future or extended surveillance).

This is done on the basis of disposable spare parts, maintenance procedures and an estimation of unplanned standstill. The decisions made and the data on failures are loaded to the data base. The inspection schedule and the data base are thus permanently updated with data from successive inspections. In this procedure it may occur that some failures may not be eliminated because of inaccessibility of the equipment etc., and imperfections of secondary origin, due to faulty installation, wrong adjustment or manufacturing errors, may be indicated. The schedule must also contain a series of information needed for future inspections, such as time consumption, types of repair and the number of spare parts. This data is also used for the spare part storage and gives information on the life time of components. After the initial running-in period, the described system results in a decreased number of breakdowns and failures, especially the most dangerous ones, and the data base yields elements for the development of the maintenance service.



Sl. 5. *Diagram poteka nadzora dejavnosti*
Fig. 5. *Flow diagram of inspection activities*

2.2 Aktivna termografija

Z aktivno termografijo (sl. 6) objekt izvzamemo iz toplotnega ravnovesja z okolico s številnimi toplotnimi spodbudami (sunkovitimi, ponavljajočimi, zaprtimi, vibracijskimi) z namenom, da naredimo sklepe v zvezi z mehanskimi in fizikalnimi lastnostmi ali njihovo notranjostjo, medsebojnimi vplivi med objektom in okolico zaradi spremembe temperature.

Tipični primer aktivne termografije je aplikacija pri neporušnih testiranjih. Slika 7 prikazuje enega od številnih termogramov površine jeklene plošče s krožnimi nevidnimi vdolbinami. Temperaturna porazdelitev na površini je bila posneta za več določenih časov z zaprto termografijo, velikost vdolbin pa je bila izračunana z ustreznimi numeričnimi postopki [2].

V takih primerih je odločilna natančnost merjenja temperature. Določiti je treba sevanje površine telesa in poznati temperaturo okolice. Zato je treba opisan primer in podobne naloge izvajati v laboratoriju, kjer lahko nadziramo vse parametre.

V laboratorijskih razmerah lahko določimo tudi koeficient sevanja. To naredimo s termogrami površin pri znanih temperaturah, ki jih dosežemo z natančnim merjenjem temperature ali s puščanjem predmeta na znani temperaturi okolice daljši čas. Da se izognemo problemom določanja sevanja, v nekaterih primerih, kjer je to mogoče, predmet oblečemo s plastjo znane sevalnosti.

Aktivna termografija je tudi zelo uporabno orodje na področjih razvoja izdelkov, raziskovanja prenosa toplote, vizualizacije tokov in številnih drugih primerov.

2.2 Active thermography

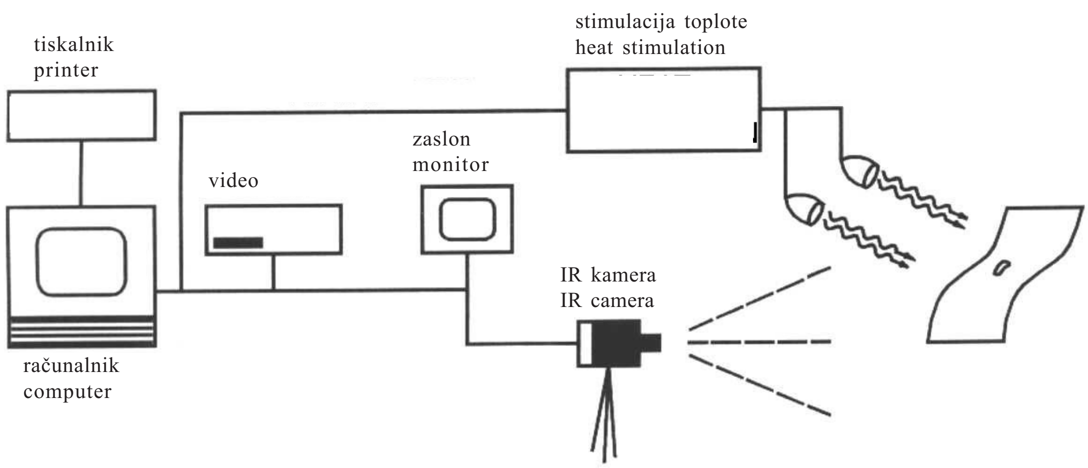
In active thermography, Fig. 6, the object is brought out of thermal balance with the ambient by various means of thermal stimulation (impulse, periodical, lock-in, vibration), in order to make conclusions on material and physical properties of its interior or on the patterns of interactions with the ambient, due to the induced temperature change.

A typical example of active thermography is its application in nondestructive testing. Fig. 7 shows one of a series of thermograms of the surface of a steel plate with circular recesses of variable depth on the invisible side. The temperature distribution on the surface was recorded for several defined time instants by means of lock-in thermography, and the size of the recesses was calculated using appropriate numerical procedures [2].

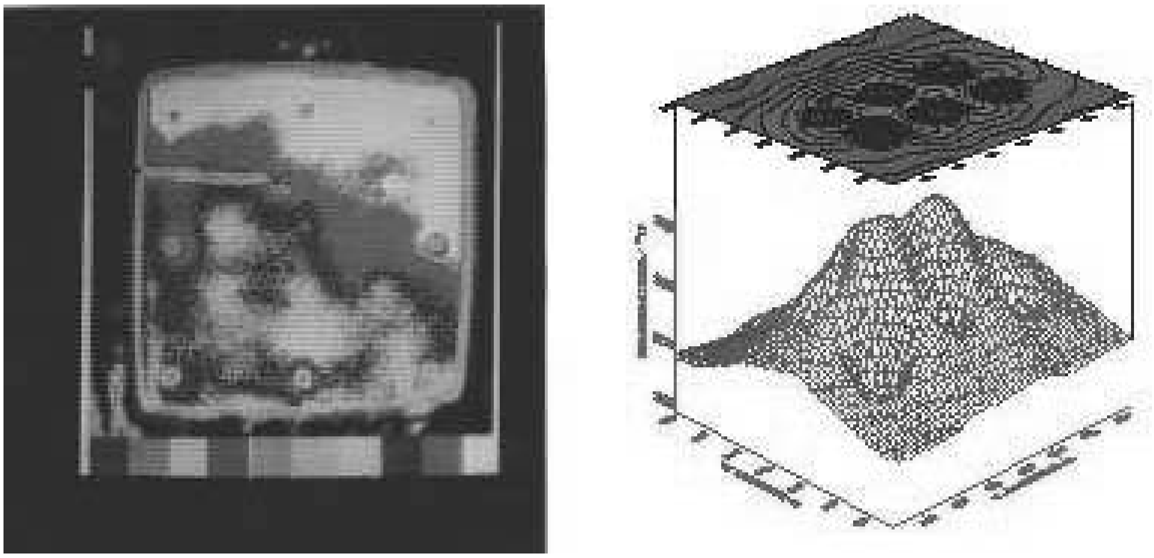
With such problems, the precision of the temperature measurement is crucial. As mentioned before, the emissivity of the object surface has to be exactly defined, and the temperature of the surrounding objects known. Therefore, the described example and similar tasks have to be carried out in the laboratory, where complete control of the relevant parameters is given.

In laboratory conditions even the emissivity coefficient may be determined by thermography. This is done by taking thermograms of surfaces at known temperatures, which is established by precise contact temperature measurements or by exposing the object to known temperature ambients for a long time. To avoid problems with unknown emissivity, in some cases, where it may be permitted, the object is coated with a layer of known emissivity coefficient.

Active thermography is also a very useful tool in other areas such as product development, research in heat transfer, flow visualization and many others.



Sl. 6. *Razporeditev pri aktivni termografiji*
Fig. 6. *Active thermography arrangement*



Sl. 7. *Termogram in tridimenzionalni prikaz izoterme plošče s presledki*
Fig. 7. *Thermogram and 3D isotherm presentation of plate with discontinuities*

3 SKLEP

Uporabnost termografije pri ekspertnih in znanstvenih dejavnostih je zelo široka. Zaradi njenih prednosti je termografija našla mesto v industriji, gradbeništvu, medicini, biologiji, meteorologiji itn. Glavne prednosti termografije so:

– merjenje temperature poteka brez stika s predmetom, s čimer se izognemo motnjam toplotnega stanja, kar je primer pri stikalnih meritvah;
– termogram je trajen posnetek temperaturnih vrednosti in porazdelitve na površini, ki jo zazna termografska naprava.

Seveda pa je treba omeniti tudi nekatere slabe strani termografije:

– natančnost meritev je odvisna od zanesljivosti podatkov o sevanju merjenih predmetov;
– če vzamemo termogram površine z nizkim sevalnim koeficientom, se lahko pojavijo motnje sevanja iz okolice, predvsem sončnega sevanja. Te težave postanejo izrazite pri kolikerostnih meritvah in jih lahko odpravimo samo v laboratorijih.

3 CONCLUSION

The applicability of thermography in expert and scientific activities is very wide. Due to its favorable features, thermography has found its place in industry, civil engineering, medicine, biology, meteorology etc. The basic advantages of thermography are:

– The temperature measurement is performed without contact with the object, thus avoiding the disturbance of the original thermal state, which is the case with contact temperature measurements.
– The thermogram is a lasting record of the temperature value and its distribution at the surfaces seen by the thermographic device.

However, some drawbacks of the thermographic method must be mentioned also:

– The quantitative accuracy of the measurements depends on the reliability of the emissivity data of the objects measured.
– When taking thermograms from surfaces at low emissivity coefficients, considerable disturbances from reflected radiation from surrounding objects may occur, especially from solar radiation. These difficulties become significant for quantitative measurements, and they may be overcome only in laboratory conditions.

4 LITERATURA
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Naslova avtorjev: prof.dr. Mladen Andrassy
prof.dr. Srečko Švaić
dr. Ivanka Boras
Fakulteta za strojništvo in ladjedelništvo
Univerze v Zagrebu
I. Lučića 5
10000 Zagreb, Hrvaška

Kruno Petrović
Kostelgrad Infrardeča Termografija
J. Gotovca 1/4
10000 Zagreb, Hrvaška

Authors' Addresses: Prof.Dr. Mladen Andrassy
Prof.Dr. Srečko Švaić
Dr. Ivanka Boras
Faculty of Mechanical Eng. and Naval Architecture
University of Zagreb
I. Lučića 5
10000 Zagreb, Croatia

Kruno Petrović
Kostelgrad Infrared Thermography
J. Gotovca 1/4
10000 Zagreb, Croatia

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