INVESTIGATII ALE REZULTATELOR TESTARII NEDISTRUCTIVE IN INFRAROSU FOLOSIND FORMULAREA PROBLEMEI INVERSE

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Rezumat: *Aceasta lucrare are ca scop sa dezvolte o metoda analitica ce permite proiectarea experimentala pentru testarea in infrarosu nedistructiva active. Aceasta este alcatuita din predeterminarea unei frecvente necesare a semnalului termal de intrare, data fiind adancimea de interes pentru investigarea posibilelor defecte in materiale.*

Cuvinte cheie: problema inversă, metodă, infraroşu

1. Introducere

Aceasta metoda este cunoscuta pentru abilitatea de a oferi imagini termice care sunt influentate de defecte interioare, de exemplu sub suprafata, dar nu foarte adanc. Din acest motiv, modelul folosit pentruproiectarea experimentala a testarii in infrarosu nedistructiva active a materialelor poate fi redusa din tridimensional intr-o singura dimensiune, stiind ca rezultate relevante pot fi obtinute inainte ca undele termale reflectate dinspre mai multe limite mobile sa ajunga. Investigatia incepe cu formularea si solutia problemei directe pentru problema conductiei caldurii in tridimensional, apoi continua cu solutia Fourier a problemei intr-o singura dimensiune si sfarseste cu simularea rezultatelor care permit determinarea frecventei semnalului termic de intrare pentru investigarea unor posibile defecte in materiale.

INVESTIGATION OF NON DESTRUCTIVE INFRARED TESTING ISSUES USING INVERSE PROBLEM FORMULATION

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Abstract: *This paper has the final goal to develop an analytical method that permits experimental design for active non-destructive infrared testing. This consists in the predetermination of the required frequency of the input thermal signal given the depth of interest for the investigation of possible defects in materials*

Keywords: inverse problem, method, infrared

1. Introduction

This method is known for the ability to give thermal images that are influenced by inner defects, i.e. under the surface, but not too deep. For this reason, the model used for the experimental design of non-destructive infrared active testing of materials can be reduced from full three-dimensional (3D) to one-dimensional (1D) given that the relevant results can be obtained before reflected thermal waves from more remote boundaries arrive. The investigation starts with the formulation and the solution of the direct problem for three-dimensional (3D) heat conduction problem, then continues with the Fourier solution of the one-dimensional (1D) problem and ends with simulation results that permit the determination of the frequency of the input thermal signal needed for the investigation of possible defects in materials.

2. Formularea problemei directe pentru fluxul de caldura

Problema directa este formulata pentru problema conductiei caldurii tridimensionale prin ecuatia neomogena

$$u_t = k \cdot \nabla^2 u + F \quad (1)$$

unde
u(x, y ,z ,t) este temperature intr-un corp solid in punctele x, y, z la timpul t.
k este difuzia data de k = K / (σ · τ)
σ este caldura specifica a corpului solid care conduce caldura
τ este densitatea de volum [kg/m^3]
F(x, y, z, t) este densitatea de caldura (sau fluxul de caldura) dintr-o sursa interna de caldura
Problema direca se refera la efectele densitatii de caldura sau un flux de caldura distribuit F(x, y, t) ca sursa pentru temperature sistemului cu parametri distribuiti.
Conditiile la limita sunt specifice fiecarui caz particular. De exemplu, pentru o suprafata izolata, conditiile la limita sunt date de ∇u · n = 0, unde n este vectorul normal la acea suprafata.
Conditiile initiale iau forma u(x, y, z, 0) = ϕ(x, y, z).
Metoda separarii variabilelor conduce la solutia propusa u(x, y, z, t) = X(x) · Y(y) · Z(t) · T(t)
Solutia este data aici pentru cazul bidimensional [1]

$$u(x,y,t) = \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} \left(\frac{F_{mn}}{a_{mn}}\right) \cdot (1 - e^{a_{mn} t}) \cdot \sin(n \cdot \pi \cdot x) \cdot P_{mn} \cdot \sin(m \cdot \pi \cdot y) \quad (2)$$

Solutia acestei probleme directe nu este in forma inchisa, din aceasta rezultand dificultati majore in rezolvarea problemei inverse de a determina pe F(x, y, t) pentru a atinge un u(x, y, t) dorit.

2. Direct problem formulation for heat flow

Direct problem is formulated for three-dimensional (3D) heat conduction problem by the non-homogenous equation

$$u_t = k \cdot \nabla^2 u + F \quad (1)$$

where
u(x, y ,z ,t) is the temperature in a solid body in the point x, y, z at time t.
k is diffusivity given by k = K / (σ · τ)
σ is the specific heat of the solid body conducting the heat
τ is the volume density [kg/m^3]
F(x, y, z, t) is heat density (or heat flux) from an internal heat source.
Direct problem refers to the effects of heat density or a distributed heat flux F(x, y, t) sources on the distributed parameters system temperature u(x, y, z, t).
Boundary conditions are specific to each particular case. For example, for an insulated surface, the boundary condition is given by ∇u · n = 0, where n is the vector normal to that surface.
Initial conditions take the form u(x, y, z, 0) = ϕ(x, y, z)
The method of separation of variables leads to the proposed solution u(x, y, z, t) = X(x) · Y(y) · Z(t) · T(t)
The solution is given here for two dimensional case [1]

$$u(x,y,t) = \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} \left(\frac{F_{mn}}{a_{mn}}\right) \cdot (1 - e^{a_{mn} t}) \cdot \sin(n \cdot \pi \cdot x) \cdot P_{mn} \cdot \sin(m \cdot \pi \cdot y) \quad (2)$$

This direct problem solution is not in closed form and this results in major difficulties in solving the inverse problem of determining F(x, y, t) for achieving a desired u(x, y, t).

3. Inverse Problem Solution for Remote Temperature Monitoring

In this section remote sensing issues will be

3. Solutia problemei inverse pentru monitorizarea temperaturii de la distanta

In aceasta sectiune, vor fi analizate subiecte legate de simtirea la distanta, tinand cont ca monitorizarea in acest caz poate duce la probleme inverse care sunt puse gresit. In cazul simtului, vor fi investigate solutiile problemelor puse gresit de a estima variabilele interne ale unui sistem din masuratori asupra limitelor sistemului. Aceste dificultati sunt subiecte intalnite in detectia temperaturii de la distanta in timp real [2].
In aceasta sectiune, atentia este asupra detectiei temperaturii in timp real, departe de locatia sursei de caldura. Masurarea temperaturii si estimarea fluxului de caldura au mai fost analizate pentru alte aplicatii cu parametri distribuiti si dificultatile rezolvarii probleme inverse a caldurii au fost identificate si investigate [3]. Solutiile rezultate ale problemelor puse gresit de estimare a variabilelor interne ale unui sistem din masuratorile la limita ale sistemului sunt investigate in [2, 9]. Evenimente catastrofice locale sau distribuite se intind in cateva secunde pana la cateva ore si mediul de propagare lucreaza ca un filtru trece-jos care elimina componentele semnalelor de frecventele inalte folositoare, inainte ca acestea sa ajunga la senzorii la distanta. Acest efect al filtrului trece-jos fizic este cauza principala pentru ca problemele inverse sa devina gresit puse. In propagarea semnalelor in camp, doua cauze pot fi luate in considerare:
A) Sursa de caldura initiata local (de exemplu, explozii care produc unde de caldura care se intind in spatiu)
B) Unde infrarosii asociate cu generarea caldurii care se propaga mai repede pe distante lungi in spatiu si cu o atenuare mai putin semnificativa, in asa fel incat mediul lor de propagare se comporta cu o extensie mai mica decat un filtru trece-jos. Masurarea temperaturii de la distanta este mai eficienta cu senzori pe baza radiatiilor infrarosu, insa acest lucru nu este posibil in cazul analyzed taking into account that monitoring in this case can lead to inverse problems that are ill-posed. For the case of sensing the solutions of the resulting ill-posed problem of estimation of internal variables of a system from measurements on the boundary of the system will be investigated. These difficulties are typical issues in real-time remote temperature sensing [2].
In this section the focus is on real-time temperature sensing, away from heat source location.
Temperature measurement and heat flow estimation has been analyzed for other distributed parameters applications and the inverse heat problem solving difficulties were identified and investigated [3]. The solutions of the resulting ill-posed problem of estimation of internal variables of a system from measurements on the boundary of the system are investigated in [2, 9]. Local or distributed catastrophic events are spreading in seconds to hours and the propagation medium operates as a low pass filter that filters out useful high frequency signal components before reaching remote sensors. This physical low pass filter effect is the main cause for inverse problems to become ill-posed. In field propagation of signals, two cases can be considered:
A) Locally initiated heat source (for example, explosions producing heat waves that spread in space)
B) Infrared waves associated with the heat generation that propagate faster over longer distances in space and with less significant attenuation such that their propagation medium acts to a much lesser extend as low pass filters. Remote temperature sensing is more efficient with infrared radiation sensors, but this is not possible in the case of solid or liquid propagation fields.

Inverse problem for heat flux input remote estimation from temperature measurements

This section presents the analytical solution campurilor de propagare solide sau lichide.

Problema inversa pentru estimarea la distanta a intrarea flux de caldura din masuratori de temperatura

Aceasta sectiune prezinta solutia analitica pentru identificarea dificultatilor in estimarea la distanta a intrarii flux de caldura necunoscut bazat pe iesirea de la senzorii localizati pe limite date ale campului termic. Mai intai este analizata problema invera sa conductiei caldurii luand in considerare ecuatia conductiei caldurii, ca o linie dreapta intr-o dimensiune, 1D, pentru x > 0 si pentru t > 0

$$\frac{\partial^2 u(x,t)}{\partial x^2} = \frac{\partial u(x,t)}{\partial t} \qquad (3)$$

unde u(x, t) este temperatura (adimensionala) in punctul x la timpul t.
Masuratorile temperaturii $u(x_m, t)$ rezulta din iesirea temperaturii $T_m(t)$, a senzorului localizat la $x = x_m$, $u(x_m, t) = T_m(t)$
Conditiile la limita sunt:
$u(x, t) < \infty$ pentru un corp semi-infinit
$u(0, t) = T(t)$ in cazul in care temperatura la x = 0) este necunoscuta
$u_x(0, t) = - q(t)$ in cazul in care nu se cunoaste fluxul de caldura pe suprafata q(t) intrand la x = 0.
Abordarea cu transformata Fourier este folosita pentru studiul efectului frecventei in cazul intrarii de temperatura nelocalizate [3]. Ecuatia $q = - k \cdot \nabla u$, la suprafata (x = 0), q(0, t) poate de asemenea fi rezolvata folosind abordarea seriei infinite propusa de Burggraf [2].
Solutia timp-domeniu a ecuatiei 1D pentru estimarea de la distanta a fluxulu de temperatura $q_{est}(0, t)$ de la masuratorile de temperatura T, este obtinuta folosind abordarea seriilor infinite dupa cum urmeaza [1-3]

$$q_{est}(0, t) = q(x_m, t) + \sum_{n=1}^{\infty}\{x_m^{2n-1} / [k^n \cdot (2n + 1)!]\} \cdot (d^nT / dt^n) + \sum_{n=1}^{\infty}\{x_m^{2n} / [k^n \cdot (2n)!]\} \cdot (d^nq(x_m, t) / dt^n) \qquad (4)$$

for the identification of the difficulties in remote estimation of the unknown heat flux input based on the output from sensors located on given boundaries of the thermal field. Inverse heat conduction problem is first analyzed considering straight line 1D heat conduction equation for x > 0 and t > 0

$$\frac{\partial^2 u(x,t)}{\partial x^2} = \frac{\partial u(x,t)}{\partial t} \qquad (3)$$

where u(x, t) is the temperature (in dimensionless units) in point x at time t.
Measurements of the temperature $u(x_m, t)$ result from the temperature output $T_m(t)$, of the sensor located at $x = x_m$, $u(x_m, t) = T_m(t)$
Boundary conditions are:
$u(x, t) < \infty$ for a semi-infinite body
$u(0, t) = T(t)$ in case that the temperature at x = 0) is the unknown
$u_x(0, t) = - q(t)$ in case of unknown surface heat flux q(t) entering at x = 0.
Fourier transform approach is used for the study of frequency effect in the case of the non-collocated temperature input [3]. The equation, $q = - k \cdot \nabla u$, at the surface (x = 0), q(0, t) can also be solved using infinite series approach proposed by Burggraf [2].
The time-domain solution of the 1D equation for remote estimation of heat flux $q_{est}(0, t)$ from temperature measurements T, is obtained using infinite series approach as follows [1-3]

$$q_{est}(0, t) = q(x_m, t) + \sum_{n=1}^{\infty}\{x_m^{2n-1} / [k^n \cdot (2n + 1)!]\} \cdot (d^nT / dt^n) + \sum_{n=1}^{\infty}\{x_m^{2n} / [k^n \cdot (2n)!]\} \cdot (d^nq(x_m, t) / dt^n) \qquad (4)$$

It can be observed that the higher the derivatives d^nT / dt^n the larger the values of the multiplicative coefficients $\{x_m^{2n-1}/[k^n \cdot (2n+1)!]\}$ and $\{x_m^{2n} / [k^n(2n)!]\}$ for larger distances between sensor location $x = x_m$ and the surface x = 0. This exact non-closed form result consists in a series expansion for higher derivatives d^nT / dt^n and corresponds to the multiplicative coefficient function of frequency ω, $\exp\{-\sqrt{(|\omega| / 2)}[1+ i \cdot \mathrm{sgn}(\omega)]\}$.
Similar difficulties appear in the case of other

Poate fi observat ca cu cat sunt mai mari derivatele d^nT / dt^n, cu atat mai mari vor fi si valorile coeficientilor de multiplicare $\{x_m^{2n-1}/[k^n \cdot (2n+1)!]\}$ si $\{x_m^{2n} / [k^n(2n)!]\}$ pentru distante mai mari intre locatia senzorului $x = x_m$ si suprafata $x = 0$. Acest rezultat de forma exacta neinchisa consta dintr-o expansiune a seriei pentru derivate mai mari, d^nT / dt^n si corespunde functiei coeficient de multiplicare a frecventei ω, $\exp\{-\sqrt{(|\omega| / 2)}[1+ i \cdot sgn(\omega)]\}$.

Dificultati similare apar in cazul altor probleme inverse pentru sisteme cu parametri distribuiti descrise de PDE eliptic, pentru alte cazuri de folosire a masurarii acustice sau a vibratiilor [3].

Ecuatia de deasupra pentru estimarea fluxului de caldura $q_{est}(0, t)$ ia in considerare efectul distantei x_m de la intrarea fluxului de caldura catre locatia senzorului si arata ca estimarea pentru componente de frecventa mai mare, care caracterizeaza semnale cu variatie mare, devine din ce in ce mai dificila pe cat creste distanta x_m.

Problema inversa a conductiei caldurii este ilustrata pentru cazul unui corp semi-infinit simetric unidimensional, unde intrarea caldura q(t) este aplicata la limita x = 0, ca in Fig.2.

inverse problems for distributed parameters systems described by elliptic PDE, i.e. for other cases of using acoustic or vibration sensing [3].

The above equation for the estimation of the heat flux $q_{est}(0, t)$ takes into account the effect of the distance x_m from the heat flux input to the location of the sensor and shows that the estimation for higher frequency components, that characterizes fast varying signals, becomes more and more difficult as the distance x_m increases.

Inverse heat conduction problem is illustrated for the case of a one-dimensional symmetric semi-infinite body, where the heat input q(t) is applied at the boundary x = 0, as shown in Fig.2.

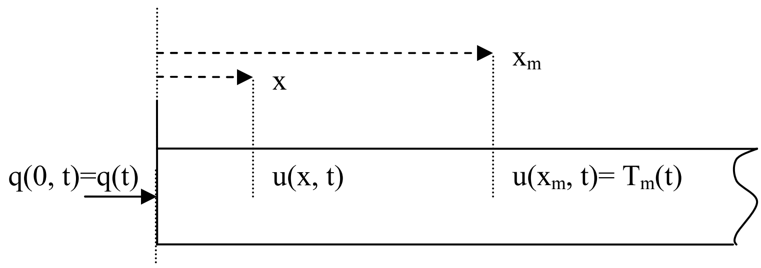


Fig. 2 Corp incalzit semi-infinit simetric si unidimensional

Fig. 2 One-dimensional symmetric semi-infinite heated body

Acesta poate fi modelat intr-o formulare adimensionala de catre ecuatia PDE 1D a conductiei caldurii pentru $x > 0$ si $t > 0$ [6, 7], $u_{xx}(x, t) = u_t(x, t)$, unde $u(x, t)$ este temperatura (adimensionala) in punctul x la timpul t. Ecuatia de iesire pentru masurarea exacta a temperaturii $u(x_m, t)$ de la iesirea

This can be modeled, in non-dimensional formulation, by the heat conduction 1D PDE equation for $x > 0$ and $t > 0$ [6, 7], $u_{xx}(x, t) = u_t(x, t)$, where $u(x, t)$ is the temperature (in dimensionless units) in point x at time t. Output equation for exact measurements of the temperature $u(x_m, t)$ from the temperature

senzorului de temperatura $T_m(t)$, localizat la $x = x_m$, este data de $u(x_m, t) = T_m(t)$.
Conditiile la limita sunt date pentru un corp semi-infinit cu temperatura finita a partii din dreapta
$u(x, t) < \infty$ pentru $x \to \infty$ si
a) $u(0, t) = T(t)$ in cazul in care temperatura suprafetei din partea stanga ($x = 0$), ca in Fig. 2, este necunoscuta. Aceasta este o problema de monitorizare a temperaturii de la distanta, pentru masuratoarea $u(x_m, t) = T_m(t)$.
b) $u_x(0, t) = - q(t)$ in cazul in care fluxul de caldura al suprafetei q(t) la intrarea partii din stanga a suprafetei corpului ($x = 0$) este necunoscuta. Atat a) cat si b) sunt probleme inverse.
Conditia initiala este data de $u(x, 0) = 0$.
Transformata Fourier cu privire la timp ne da $U_{xx}(x, \omega) = U_t(x, \omega)$
Pentru cazul conditiilor la limita initiale de deasupra, o problema de monitorizare a temperaturii de la distanta, soltuia transformatei Fourier de deasupra a temperaturii este $U(x_m,\omega) = \tau_m(\omega)$, masurata in interiorului corpului la locatia senzorului $x = x_m$, data fiind transformata Fourier a temperaturii necunoscute $U(0, \omega)$ la partea stanga a suprafetei ($x = 0$) corpului din Fig. 2, [7]

$$\tau_m(\omega) = U(0, \omega) \cdot \exp\{-\sqrt{(|\omega|/2)} \cdot [1 + i \cdot \mathrm{sgn}(\omega)]\} \quad (5)$$

Aceasta arata componentele de frecventa inalta ale suprafetei temperaturii $U(0, \omega)$ sunt multiplicate printr-un termen $\exp\{-\sqrt{(|\omega|/2)} \cdot [1 + i \cdot \mathrm{sgn}(\omega)]\}$ care descreste exponential cu cresterea ω, de exemplu un termen care se comporta ca un filtru trece-jos.
Inversa solutiei de mai sus ofera transformatei Fourier a temperaturii $U(0, \omega)$ in partea stanga a suprafetei ($x = 0$) corpului data fiind transformata Fourier a temperaturii masurate $\tau_m(\omega)$ in interiorul corpului la locatia senzorului $x = x_m$ [7]

$$U(\omega) = \tau_m(\omega) \cdot \exp\{\sqrt{(|\omega|/2)} \cdot [1 + i \cdot \mathrm{sgn}(\omega)]\} \quad (6)$$

sensor output $T_m(t)$, located at $x = x_m$, is given by, $u(x_m, t) = T_m(t)$
Boundary conditions are given for a semi-infinite body with finite right hand side temperature
$u(x, t) < \infty$ for $x \to \infty$ and
a) $u(0, t) = T(t)$ in case that the temperature at the left hand side surface ($x = 0$), shown in Fig. 2, is the unknown. This is a distant temperature monitoring problem, for the measurement $u(x_m, t) = T_m(t)$.
b) $u_x(0, t) = - q(t)$ in case that the surface heat flux q(t) entering at the left hand side surface of the body ($x = 0$) is the unknown. Both a) and b) are inverse problems.
The initial condition is given by $u(x, 0) = 0$.
Fourier transform with regard to time gives $U_{xx}(x, \omega) = U_t(x, \omega)$
For the case of the above initial and boundary conditions, a distant temperature monitoring problem, the solution of the above Fourier transform of the temperature is $U(x_m,\omega) = \tau_m(\omega)$, measured inside the body at sensor location $x = x_m$ given the Fourier transform of the unknown temperature $U(0, \omega)$ at the left hand side surface ($x = 0$) of the body from Fig. 2, [7]

$$\tau_m(\omega) = U(0, \omega) \cdot \exp\{-\sqrt{(|\omega|/2)} \cdot [1 + i \cdot \mathrm{sgn}(\omega)]\} \quad (5)$$

This shows that high frequency components of the surface temperature $U(0, \omega)$ are multiplied by a term $\exp\{-\sqrt{(|\omega|/2)} \cdot [1 + i \cdot \mathrm{sgn}(\omega)]\}$ that decreases exponentially with increasing ω, i.e. a term that acts as a low pass filter.
The inverse of the above solution gives the Fourier transform of the temperature $U(0, \omega)$ at the left hand side surface ($x = 0$) of the body given the Fourier transform of the measured temperature $\tau_m(\omega)$ inside the body at sensor location $x = x_m$ [7]

$$U(\omega) = \tau_m(\omega) \cdot \exp\{\sqrt{(|\omega|/2)} \cdot [1 + i \cdot \mathrm{sgn}(\omega)]\} \quad (6)$$

where $\tau_m(\omega)$ is the Fourier transform of the temperature measurements $T_m(t)$ at $x = x_m$

unde $\tau_m(\omega)$ este transformata Fourier a masuratorilor de temperatura $T_m(t)$ at $x = x_m$ Aceasta arata ccomponentele inalte de frecventa ale temperaturii de suprafata U(0, ω) sunt multiplicate cu un termen $\exp\{\sqrt{(|\omega|/2)} \cdot [1 + i \cdot sgn(\omega)]\}$ care creste exponential cu ccresterea ω, de exemplu un termen care se comporta ca un filtru trece-sus care reduce latimea relativa a componentelor folositoare de joasa frecventa din semnalul masurat si amplifica componentele de inalta frecventa care contin zgomot, mereu prezente in semnalele de iesire a traductoarelor temperatura-tensiune. Aceasta amplificare a erorii de masurare face ca problema inversa a conductiei temperaturii sa fie una pusa gresit.

Rezultatele simularii pentru Problema inversa 1D a conductiei temperaturii

Simularile din aceasta parte sunt bazate pe starea stabila a raspunsului termic a uneidale la variatiile unei temperaturi sinusoidale la intrare. Consideram conditiile la limita T (0, t) = T_0 cos (ωt). Cu amplitudinea de T_0=5[^{0}C] la intrare si cealalta limita x=L, dala este izolata. In [8], simularile au fost bazate pe frecventa sinusoidata adimensionala $\omega L^2/\kappa$, pe cand in aceasta lucrare am calculat solutia fazoare pentru T(x,t), propusa in [4], pentru ω=10 [rad/s], viteza impulsului V_0=10 [m/a], difuzia termala = 9.748*10-4 si factorul de disipare caldura H=0.001.
Simularile au fost facute pentru diferite valori ale lungimii dalei: L = 0.1 [m] ,0.5 [m] si 1 [m] pentru a arata efectele cresterii lungimii asupra propagarii caldurii in problema inversa a condictiei calduriil. T(x,t) functie de x pentru diferite valor ale lui t este aratat in Fig. 3; la cresterea lui L, masuratorile de temperatura in partea dreapta a limitei devine din ce in ce mai relevanta pentru intrare. Aceasta face ca problema sa fie mai aproape de o situatie a problemei inversa pusa gresit datorita cresterii lui L. Variatia T(x, t) functie de x pentru diverse perioade t pentru un subiect tip dala pentru o variatie de temperatura sinusoidala T(0, t) = T_0 cos (ωt)

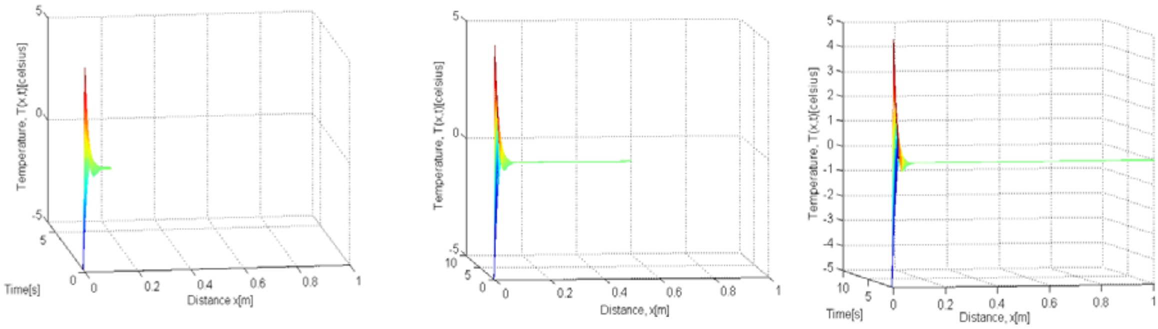
This shows that high frequency components of the surface temperature U(0, ω) are multiplied by a term $\exp\{\sqrt{(|\omega|/2)} \cdot [1 + i \cdot sgn(\omega)]\}$ that increases exponentially with increasing ω, i.e. a term that acts as high pass filter that reduces the relative weight of useful low frequency components from the measurement signal and amplifies the high frequency components that can contain noise, always present in the output signals of temperature to voltage transducers. This measurement error amplification effect makes the inverse heat conduction problem an ill-posed problem.

Simulation Results for 1 D Inverse Heat Conduction Problem

The simulations in this part are based on the steady-state thermal response of a slab to a sinusoidal temperature variation input. We considered the boundary condition T (0, t) = T_0 cos (ωt). With the amplitude of T_0=5[^{0}C] as the input, and at the other boundary x=L the slab is isolated. In [8] the simulations were based on dimensionless sinusoidal frequency $\omega L^2/\kappa$, while in this paper we calculated the phasor solution for T(x,t), proposed in [4], for ω=10 [rad/s], impulse velocity V_0=10 [m/a], thermal diffusivity= 9.748*10-4 and heat dissipation factor H=0.001.
The simulations were made for different values of the length of the slab L = 0.1 [m] ,0.5 [m] and 1 [m] to show the effect of increasing the length on heat propagation in inverse heat conduction problem. T(x,t) versus x for various values of t is shown in the Fig. 3; as L increases the Temperature measurement at the right hand side boundary becomes more irrelevant to the input. This makes the problem more close to ill posed situation due to increasing of L. The variation T(x, t) with x for various t for a slab subject to a sinusoidal temperature variation T(0, t) = T_0 cos (ωt) is shown in Fig. 4.
These results show that the response on the eight hand side, at x=L, (opposite to the side x=0, where the heat source is placed), are highly dependent on L for L < 0.1 [m] and

este prezentata in Fig. 4.
Aceste rezultate arata ca raspunsul la limita, x=L, (opus celui la x=0, unde sursa de caldura este plasata), sunt foarte dependente de L pentru L < 0.1 [m] si aceasta confirma ca testarea infrarosu activa nondistructiva poate fi folosita cu succes pentru identificarea defectelor interioare din materiale sub suprafata folosind termiviziunea la suprafata [10 -14].

this confirm that active non-destructive infrared testing can be successfully used for the identification of inner defects in materials under the surface using surface thermo imaging [10 -14].



a) b) c)

Fig. 3 Raspunsul armonic termal cu stare stabila T(x, t) al unei dale la o variatie de temperature sinusoidala T(0, t) = T_0 cos (ωt)

Fig. 3 Steady-state thermal harmonic response T(x, t) of a slab to a sinusoidal temperature variation T(0, t) = T_0 cos (ωt)

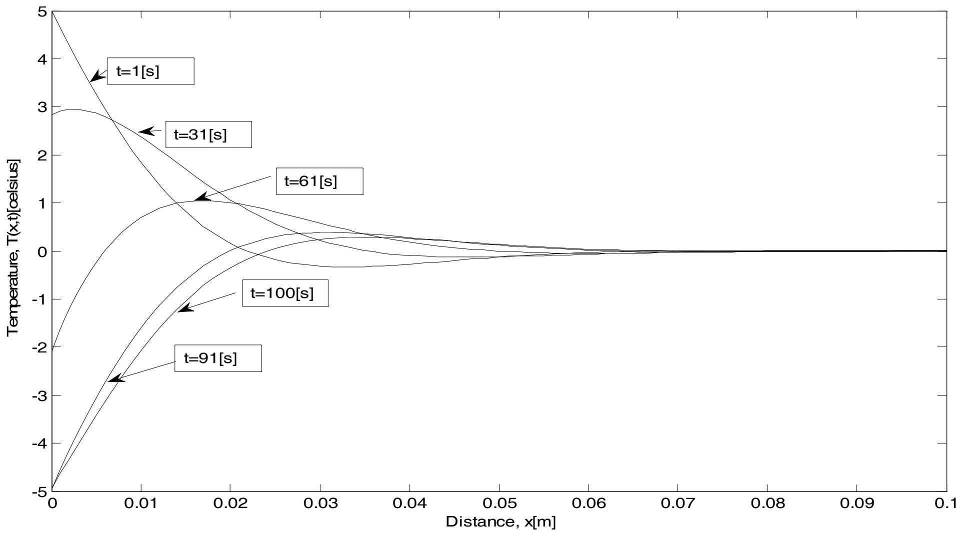


Fig. 4 Variatia T(x, t) cu x pentru t variabil pentru o dala la o variatie sinusoidala de temperatura $T(0, t) = T_0 \cos(\omega t)$

Fig. 4 The variation T(x, t) with x for various t for a slab subject to a sinusoidal temperature variation $T(0, t) = T_0 \cos(\omega t)$

Concluzii

Testarea activa nedistructiva in infrarosu folosind un puls sinusoidal sau raspuns armonic necesita predeterminarea frecventei semnalului de intrare caldura sinusoidal in functie de adancimea necesara a posibilului defect in materialul investigat. Lucrarea prezinta o abordare cantitativa pentru a gasi parametrii potriviti pentru testarea in infrarosu. Rezultatele simularii confirma ca metoda propusa poate identifica cu success defectele interioare din materiale, situate nu foarte departe de suprafata.

Conclusions

Active non-destructive infrared testing using a sinusoidal pulse or harmonic response requires the predetermination of the frequency of the sinusoidal heat input signal depending on the required depth of the possible defects in the material investigated. The paper presents a quantitative approach to finding suitable parameters for infrared testing. Simulation results confirm that the proposed method can successfully identify inner defects in materials situated not too far from the surface.

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