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RESEARCH ARTICLE OPEN ACCESS

NON-STATIONARY THERMAL CONDUCTIVITY IN ELECTRONIC DEVICES

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ABSTRACT

In large number of engineering tasks, heat transfer takes place over time, i.e., physical bodies are in non-stationary (transient) conditions.We will use an implicit numerical method for calculating the temperatures at fixed time intervals for certain nodes of the studied body.

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INTRODUCTION

Theproblems for thermal conductivity are solved not only by analytical methods but also by numerical methods.We will use an implicit numerical method which is stable for all values of the steps in space and time.The smaller the steps, the more accurate are the temperatures, because the errors are reduced with finite differences in approximating the derivatives. The method of finite differences has significant advantages - repeated same mathematical operations, creating favorable conditions for implementation in modern computing.The rapid development of electronic machines decreases the cost of operations and when applying a simple method of finite differences, it is gaining more and more applications.

FINITE DIFFERENCES METHOD

For numeric calculation of temperatures in non-stationary thermal conductivity, the device is divided into cells with centers called nodes.

The energy balance for a solid body is:

$q(t) = -\rho.V.c\frac{dT(t)}{dt} = \overline{h}_c.A_x(T(t) - T_\infty),$ where:

ρ – density of the body (device)
c - relatively warm absorption of the material
A_s- body surface
c - body volume
h_c- convective heat transfer coefficient$W/(m.°C)$

$$B_i = \frac{h_c.L}{k}$$

B_i - Bio's coefficient
k -thermal conductivitycoefficient$W/(m^2.°C)$

$L = \frac{V}{A_s}$, $F_0 = \frac{\alpha.t}{L^2}$

α - thermal conductivity coefficient
F_0 – Fourier number

One-dimensional case:

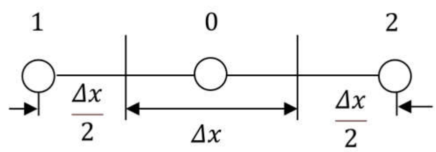


Fig. 1.

Using the law of conservation of energy located between the two nodes, we have for node 1 and 2:

$$q_{1\to0} + q_{2\to0} = \frac{\partial U_0}{\partial t}$$

where U_0 is the is the internal energy in node 0, i.e., for node 0 we get:

$$kA\frac{T_1^t - T_0^t}{\Delta x} + kA\frac{T_2^t - T_0^t}{\Delta x} = \rho A\Delta x.c.\frac{T_0^{t+\Delta t} - T_0}{\Delta t}$$

In this equation we will express the temperature t by the temperature at a moment $t+\Delta t$, i.e.,we are approximating with directed back difference in time (called implicit method) then the equation for node 0 is:

$$kA\frac{T_1^{t+\Delta t} - T_0^{t+\Delta t}}{\Delta x} + kA\frac{T_2^{t+\Delta t} - T_0^{t+\Delta t}}{\Delta x} = \rho A\Delta x c\frac{T_0^{t+\Delta t} - T_0^t}{\Delta t}$$

Simplifying the equation, we will get:
$[1+2F_0]T_0^{t+\Delta t} - F_0(T_1^{t+\Delta t} + T_2^{t+\Delta t}) - T_0^t = 0,\ F_0 = \frac{\alpha\Delta t}{(\Delta x)^2}$

2. For inner node 0:

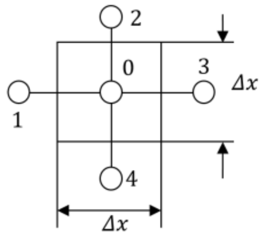


Fig. 2.

The equation is:

$$[1+4F_0]T_0^{t+\Delta t} - F_0(T_1^{t+\Delta t} + T_2^{t+\Delta t} + T_3^{t+\Delta t} + T_4^{t+\Delta t}) - T_0^t = 0$$

3. For inner nod with boundary convection

$$[1+2F_0(2+B_i)]T_0^{t+\Delta t} - 2F_0\left[\frac{T_2^{t+\Delta t}}{2} + \frac{T_3^{t+\Delta t}}{2} + T_1^{t+\Delta t} + (B_i)T_\infty^{t+\Delta t}\right] - T_0^t = 0$$

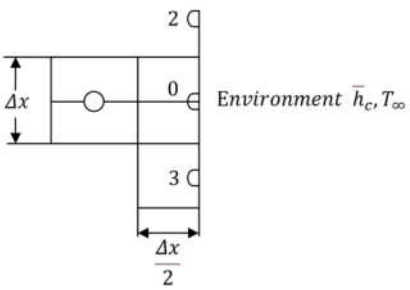


Fig. 3.

4. For external corner with boundary convection:

$$[1+4F_0(1+B_i)]T_0^{t+\Delta t} - 4F_0\left[\frac{T_1^{t+\Delta t}}{2} + \frac{T_2^{t+\Delta t}}{2} + (B_i)T_\infty^{t+\Delta t}\right] - T_0^t = 0$$

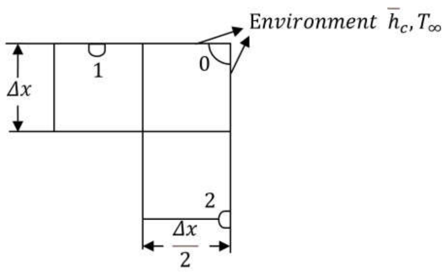
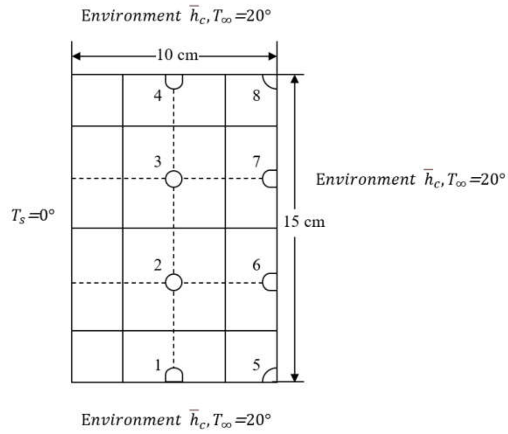


Fig. 4

We will get the temperature distribution in the device bysolving the resulting system of equations for all nodes in the body:



Example: An electronic device has the shape of a long parallelepiped with a rectangular cross section (10 *см*, 15 *см*, $\Delta x = 0{,}05$ *м*)

$k = 20W/m.°C$ - thermal conductivity coefficient
$h_c = 80\ W/(m^2.°C)$ -heat dissipation coefficient
$\alpha = 5.10^{-5}m^2/s$ - thermal conductivity coefficient

We will divide the body into squares with $\Delta x = 0{,}05\ m$

The temperature of the 3 surrounding walls is$T_\infty = 20°C$
The body temperature (due to an internal source) has risen to $65°C$.

On the fourth wall a temperature-maintaining fan is switched on to 0°, i.e., $T_s = 0°$

Calculating the temperatures in the nodes 1 ÷ 8, so that the temperature of the device becomes less than 20 ° C (ambient temperature) at intervals $\Delta t = 20°C$

The equations for inner nods 2 and 3 are:

$$i=2: [1+4F_0]T_2^{t+\Delta t} - F_0\left(T_1^{t+\Delta t} + T_3^{t+\Delta t} + T_6^{t+\Delta t} + T_s\right) - T_2^t = 0$$
$$i=3: [1+4F_0]T_3^{t+\Delta t} - F_0\left(T_4^{t+\Delta t} + T_2^{t+\Delta t} + T_7^{t+\Delta t} + T_s\right) - T_3^t = 0$$

The equations for boundary nods (i = 1, 4, 6, 7), which are not in the edges of the body are:

$$i=6;\ [1+2F_0(2+B_i)]T_6^{t+\Delta t} - 2F_0\left[\frac{T_7^{t+\Delta t}}{2} + \frac{T_5^{t+\Delta t}}{2} + T_2^{t+\Delta t} + B_iT_\infty\right] - T_6^t = 0$$

$$i=7;\ [1+2F_0(2+B_i)]T_7^{t+\Delta t} - 2F_0\left[\frac{T_8^{t+\Delta t}}{2} + \frac{T_6^{t+\Delta t}}{2} + T_3^{t+\Delta t} + B_iT_\infty\right] - T_7^t = 0$$

$$i=1;\ [1+2F_0(2+B_i)]T_1^{t+\Delta t} - 2F_0\left[\frac{T_5^{t+\Delta t}}{2} + \frac{T_S^{t+\Delta t}}{2} + T_2^{t+\Delta t} + B_iT_\infty\right] - T_1^t = 0$$

$$i=4;\ [1+2F_0(2+B_i)]T_4^{t+\Delta t} - 2F_0\left[\frac{T_8^{t+\Delta t}}{2} + \frac{T_S^{t+\Delta t}}{2} + T_3^{t+\Delta t} + B_iT_\infty\right] - T_4^t = 0$$

The equations for boundary nodes 5 and 8 at the edges of the body are:

$$i=5;\ [1+4F_0(1+B_i)]T_5^{t+\Delta t} - 4F_0\left[\frac{T_1^{t+\Delta t}}{2} + \frac{T_6^{t+\Delta t}}{2} + B_iT_\infty\right] - T_5^t = 0$$

$i = 8;\ [1 + 4F_0(1 + B_i)]T_8^{t+\Delta t} - 4F_0\left[\frac{T_4^{t+\Delta t}}{2} + \frac{T_7^{t+\Delta t}}{2} + B_i T_\infty\right] - T_8^t = 0$

The coefficients of Bio and Fourier are:

$$B_i = \frac{h_c \Delta x}{k} = \frac{80.0{,}05}{20} = 0{,}2$$
$$F_0 = \frac{\alpha \Delta t}{(\Delta x)^2} = \frac{5.10^{-5}.20}{(0{,}05)^2} = 0{,}04$$

Due to the symmetry, we have: $T_4 = T_1, T_3 = T_2, T_8 = T_5, T_7 = T_6$

We will replace $B_i = 0{,}2$ and $F_0 = 0{,}4$ for $i = 2, 1, 6, 5$ in the equations:

$$i = 2;\quad 2{,}6T_2^{t+\Delta t} - 0{,}4\left[T_1^{t+\Delta t} + T_2^{t+\Delta t} + T_6^{t+\Delta t}\right] - T_2^t = 0$$
$$i = 1;\quad 2{,}76T_1^{t+\Delta t} - 0{,}8\left[\frac{T_5^{t+\Delta t}}{2} + \frac{T_S}{2} + T_2^{t+\Delta t} + 4\right] - T_0^t = 0$$
$$i = 6;\quad 2{,}76T_6^{t+\Delta t} - 0{,}8\left[\frac{T_6^{t+\Delta t}}{2} + \frac{T_5^{t+\Delta t}}{2} + T_2^{t+\Delta t} + 4\right] - T_6^t = 0$$
$$i = 5;\quad 2{,}92T_5^{t+\Delta t} - 1{,}6\left[\frac{T_1^{t+\Delta t}}{2} + \frac{T_6^{t+\Delta t}}{2} + 4\right] - T_5^t = 0$$

If $T_1^{t+\Delta t} = x, T_2^{t+\Delta t} = y, T_5^{t+\Delta t} = u, T_6^{t+\Delta t} = v$ then the resulting system of equations will be:

$$\left|\begin{array}{l} i = 2; 2{,}6y - 0{,}4[x + y + v] - T_2^t = 0 \\ i = 1; 2{,}76x - 0{,}8\left[\frac{u}{2} + y + 4\right] - T_1^t = 0 \\ i = 6; 2{,}76v - 0{,}8\left[\frac{v}{2} + \frac{u}{2} + y + 4\right] - T_6^t = 0 \\ i = 5; 2{,}92u - 1{,}6\left[\frac{x}{2} + \frac{v}{2} + 4\right] - T_5^t = 0 \end{array}\right.$$

Simplifying the system, we will get:

$$\left|\begin{array}{l} -0{,}4x + 2{,}2, y - 0{,}4v = T_2^t \\ 2{,}76x - 0{,}8y - 0{,}4u - 3{,}2 = T_1^t \\ -0{,}8y - 0{,}4u + 2{,}36v - 3{,}2 = T_6^t \\ -0{,}8x + 2{,}92u - 0{,}8v - 6{,}4 = T_5^t \end{array}\right. \qquad (1)$$

I. If replacing $T_1^t = T_2^t = T_5^t = T_6^t = 65°$ in system (1) after Δt=20 sec. the temperature in nodes 1, 2, 5, 6 will be:

$x = 46{,}0496990° = T_1'$; $y = 47{,}7098907° = T_2'$
$u = 51{,}823132° = T_5'$; $v = 53{,}854733° = T_6'$

II. Again if we replace in the system (1) $T_1^t = T_1', T_2^t = T_2', T_5^t = T_5', T_6^t = T_6'$ after new $\Delta t = 20$ (in total 40 sec.), the temperature in nodes $1, 2, 5$ and 6 will be:

$x = 34{,}177060 = T_1''$; $y = 35{,}768873 = T_2''$
$u = 41{,}159719 = T_5''$; $v = 43{,}2769996 = T_6''$

III. If $T_1^t = T_1'', T_2^t = T_2'', T_5^t = T_5'', T_6^t = T_6''$ after $\Delta t = 20$ sec. (in total 60 sec.) in the system (1) then the temperature will be:

$x = 26{,}230465 = T_1'''$; $y = 27{,}306338 = T_2'''$
$u = 32{,}934884 = T_5'''$; $v = 34{,}5322126 = T_6'''$

IV. After $\Delta t = 20$ sec. (in total 80 sec) applying same procedure:

$x = 20{,}6851127 = T_1^{IV}$; $y = 21{,}210269 = T_2^{IV}$
$u = 24{,}536778 = T_5^{IV}$; $v = 25{,}95578 = T_6^{IV}$

V. The next $\Delta t = 20$ sec. (in total 100 sec.) from the system (1) we will get:
$x = 16{,}723061 = T_1^V$; $y = 16{,}779320 = T_2^V$
$u = 22{,}1072803 = T_5^V$; $v = 22{,}533786 = T_6^V$

VI. If $T_1^t = T_1^V, T_2^t = T_2^V, T_5^t = T_5^V, T_6^t = T_6^V$ substituted in the system (1) the results for the next $\Delta t = 20$ sec. (in total 120 sec.) are:

$x = 13{,}848345 = T_1^{VI}$; $y = 13{,}537002 = T_2^{VI}$
$u = 18{,}668304 = T_5^{VI}$; $v = 18{,}657694 = T_6^{VI}$

VII. The following iteration for the last $\Delta t = 20$ sec. (in total 140 sec) the results are:

$x = 11{,}748232 = T_1^{VII}$; $y = 11{,}157828 = T_2^{VII}$
$u = 16{,}127789 = T_5^{VII}$; $v = 15{,}777317 = T_6^{VII}$

The first 5 iterations logically note that $x < y,\ u < v,$ if the temperature of the device is greater than 20 ° C. For the last two iterations $x > y,\ u > v$, we have device temperature less than 20 ° C (ambient temperature).

CONCLUSION

When the temperature of the device becomes high (e.g. $65° = max$), then the fan the fourth surrounding wall will switch on and maintain constant temperature ($0° \equiv min$). Based on the research, the fan can be switched off after some time (e.g.,$7.\Delta t = 7\,.20$ sec. = 140 sec.), when the body temperature becomes lower than the ambient temperature (the temperature on the three walls is 20 ° C. If the temperature of the device rises again (65 ° = max), the fan is switched on again and the actions are repeated.This process ensures the stability of the devices. Temperature measurements performed along with physical variables measurements, are widely used in the nature study of processes and in conducting scientific and technical research.Temperature measurements are important for protection study of devices from thermal effects, control and regulation of technological processes, especially important in microelectronic circuits.

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