Modeling of printed circuit boards separation by cutting

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Abstract: - In the paper we deal with the printed circuit boards recycling problem. We focused on study of a cutting as an alternative method of conductive ways from plastic board separation as one of stages of the printed circuit board recycling procedure. For this purpose we formulated mathematic model of the cutting process and next we used its analytical solution for its modeling by mathematic software Maple. The obtained results confirm energy intensity of the cutting process.

Key-Words: - Cutting, Mathematical Modeling, Printed Circuit Board, Recycling, Heat Transfer

1 Introduction
The printed circuit boards (PCBs) that represent a significant part of electronic waste is potential significant source of material and energy. Therefore possibilities of PCBs reuse are searched in the whole world at present. Material composition of PCBs is highly heterogeneous. They are made from plastic boards covered by one or more metal layers with moulded electronic components. They can contain not only precious metals (gold, silver and copper), but also a large quantity of other materials as are plastics, ceramics, glass etc. which should be recycled [3]. Suitability of the above mentioned materials for their reuse strongly depends on economy cost. In our workplace we would like to make antinoise panels based on crushed plastic boards of PCBs sticked by special adhesive mixture [10]. For this purpose, we search energy-saving technological method of the conductive ways from plastic boards separation. In general, there are many problems by PCB recycling at this time. The mechanical-physical processes are attracting more attention than chemical operations in that considerable chemical waste water polluted by hazardous chemical substances is produced [10]. By reason of an effective recycling of precious metals and other valuable raw materials, melting and electrolysis are preferable than mechanical recycling methods. Furthermore, the polluting matters are removed from PCB by melting and electrolysis. On the other hand, the thermic methods seem as most suitable [4].

In this paper we focused on study of a cutting as an alternative method of conductive ways from plastic board separation as one of stages of the printed circuit board recycling process. For this purpose we formulate mathematic model of the cutting process and next we used its analytical solution for its modeling by mathematic software Maple.

2 Describing of cutting process
In practice, the cutting process can be realized by using of an band saw. The process course depends on many factors. Non-stationary temperature field in PCB and cutting belt can be described by Fourier-Krchhoff’s equations (1), (2) with appropriate initial and boundary conditions (3) – (6) [6, 1].

\[
\frac{\partial t_1(x, \tau)}{\partial \tau} = a_1 \frac{\partial^2 t_1(x, \tau)}{\partial x^2} \quad \tau > 0, \quad 0 < x < \infty \tag{1}
\]

\[
\frac{\partial t_2(x, \tau)}{\partial \tau} = a_2 \frac{\partial^2 t_2(x, \tau)}{\partial x^2} \quad -\infty < x < 0 \tag{2}
\]

\[t_1(x, 0) = t_2(x, 0) = t_p\tag{3}\]

\[t_1(\infty, \tau) = t_2(-\infty, \tau) = t_p\tag{4}\]

\[q + \lambda_1 \frac{\partial t_1(0, \tau)}{\partial x} - \lambda_2 \frac{\partial t_2(0, \tau)}{\partial x} = 0\tag{5}\]
\[
\frac{\partial t_1(x, \tau)}{\partial x} = 0, \quad \frac{\partial t_2(x, \tau)}{\partial x} = 0
\]  
(6)

Equation (1) represents heat transport in the plastic board. Equation (2) represents heat transport in the band saw. Initial temperature distribution in the belt and in the board is given by equation (3). Final temperature distribution in the belt and in the board is given by equation (4). Heat transport in the touch point of both materials is given by relation (5). Equation (6) determines change of temperature in infinite points of the belt and in the board. We supposed that total heat flow divides equally among \( q_1 \) and \( q_2 \)

\[
q_1 = q_2 = 0.5q
\]  
(7)

Under these conditions we obtained analytical solution given by temperature field \( t_i(x, \tau) \) in plastic board

\[
t_i(x, \tau) = \frac{2q}{\lambda_i} \sqrt{a_i \tau} \left\{ \frac{e^{-\frac{x^2}{4a_i \tau}}}{\pi} - \frac{x}{2\sqrt{a_i \tau}} \text{erfc}\left(\frac{x}{2\sqrt{a_i \tau}}\right) \right\}
\]  
(8)

3 Software application for modeling temperature fields of cutting process

3.1 Computer simulation of the cutting process course

For this purpose we programmed special application for calculation and visualization of temperature field \( t_i(x, \tau) \) in PCB during cutting by mathematic software Maple interface (figure 1) [9]. Because we need prompt basic information about the process course, we programmed application for automatic computing of the temperature fields as a Maplet form defined by source code

```maple
> with(plots):
> with(plottools):
use Maplets:-Elements
maplet := Maplet( onstartup = RunWindow( W1 ),
Window[W1](...),
Window[W2](...),
Window[W3](...)
); end use:
Maplets:-Display( maplet );
```

Fig.1. Window of the software application for modeling of cutting process course
The commands Window[W1](...), Window[W2](...) and Window[W3](...) contain text fields, boxes and graphics tools for computing, display and export of the required data.

Parameters [7, 10]:
- Thermal conductivity: 0.88 W.m⁻¹.K⁻¹
- Heat flow: 40 kW.m⁻²
- Time of the process: 60 s
- Density: 1900 kg.m⁻³
- Specific thermal capacity: 800 J.kg⁻¹.K⁻¹
- Specific times of the process: 1 s, 5 s, 10 s, 20 s, 30 s, 60 s

**Fig. 2.** 3D Temperature field in during cutting in PCB - thickness 1 mm

**Fig. 3.** 2D Temperature field in during cutting in PCB - thickness 1 mm for variable time

**Fig. 4.** 3D Temperature field in during cutting in PCB - thickness 2 mm

**Fig. 5.** 2D Temperature field in during cutting in PCB - thickness 2 mm for variable time

### 4 Design of cutting machine
This machine will be used to cut the electronic components from the surface of PCB. The machine is designed as a band saw. The practical part of the force ratios were determined for cutting PCB [11].

3D model of the cutting machine was created in Autodesk Inventor 11 Professional.
5 Conclusion

By modeling of the cutting process by mathematic software Maple we determined friction coefficient, thrust pressure and frequency of the belt rotation as major factors that affect generated heat flow. The obtained results confirm energy intensity of the cutting process. In consequence of so much of heat generation during the process, the plastic material can agglomerate with metals, which complicates the process.

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