FEM analysis of a induction heating micro system into a nozzle of a printing device

Gheorghe AMZA¹, Adrian MILICĂ²
Tehnologia Materialelor si Sudare
University “POLITEHNICA” of Bucharest
Splaiul Independentei, 313, 060042
ROMANIA
adrian_milica@yahoo.com

Abstract: In the current paper, the authors simulate a micro system that could be used in printing industry. The model contains a print head with thousands of nozzles, which every single nozzle is equipped with micro devices. One of the integrated devices is the micro heating inductor. The integrated micro heating inductor has the ability to melt the metal micro wire and to form a droplet. The droplet will be released by the heating induction system immediately and because of the gravity force, the droplet will fall to the end of the nozzle channel. The end of the channel is equipped with an ultrasound device that has the ability to slow down the molten metal droplet and release it immediately in the desired shape, in order to obtain a precise display circuit diagram on the synthetic paper.

Key-Words: Printing paper display, micro heating induction system, printing pixel circuits.

1 Introduction
Due to current technological progress in the near future we can use in the printing industry, flexible displays with own memory and energy at very low cost. To produce displays it needs different technologically advanced systems. Therefore we simulate a device that is similar with the ordinary printing heads but with the ability to print on the synthetic paper the circuits of the display. The integrated micro induction heating system that is placed in each nozzle of the print head has the ability to melt the metal micro wire and to form a droplet. The droplet will be released by the heating induction system immediately and because of the gravity force, the droplet will fall to the end of the nozzle channel. The end of the channel is equipped with an ultrasound device that has the ability to slow down the molten metal droplet and release it immediately in the desired shape, in order to obtain a precise display circuit diagram on the synthetic paper.

The importance of this device is that the drop has no contact with the interior walls of the nozzle and the droplet will have a high quality. In principle the induction coils are travelled by alternating electric current and produce a magnetic field that is varying in time. Due to Eddy current induction, by the Joule-Lenz effect, will cause the wire melting into a micro drop.

2 Principle of operation
The parts that generate the droplet from the micro wire are composed by two copper induction heating coils. A source of high frequency electricity is used to drive a large alternating current through the induction coils. These induction heating coils are known as the work coils. The passage of current through these work coils generates a very intense and rapidly changing magnetic field in the space within the work coils. The tin micro wire is placed within this intense alternating magnetic field. The alternating magnetic field induces a current flow in the conductive micro wire. The arrangement of the work coils and the micro wire is thought of as an electrical transformer. The work coils are like the primary where electrical energy is fed in, and the micro wire is like a single turn secondary that is short-circuited. This causes tremendous currents to flow through the micro wire. These are known as eddy currents. The high frequency used in induction heating applications gives rise to a phenomenon called skin effect. This skin effect forces the alternating current to flow in a thin layer towards the surface of the micro wire. The skin effect increases the effective resistance of the metal to the passage of the large current. Therefore it greatly increases the induction heating effect of the induction heater caused by the current induced in the micro wire.
3 Computational algorithm

The micro induction heating system consists of two copper induction coils with a diameter of 4 μm and tin micro wire with a diameter of 4 μm and height of 60 μm. The distance between the inductor and the micro wire is 2 μm. The driving frequency of the system is 7 MHz and the current intensity is 80 A. At the start of heating induction radiation, air temperature in the nozzle is 19°C. The induced current flows through the conductor of the micro wire forming a spiral cage on the surface of the cone and have $4\pi$ length and $60\delta$ section. Therefore the electrical resistance of the conductor is

$$R = \rho \frac{4\pi}{60\delta}$$

$\delta$ is the surface thickness of the micro wire where the whole energy of heating induction is transmitted.

Power losses in the micro wire occur through Joule-Lenz

$$P = \rho \frac{4\pi}{60\delta} (NI)^2$$

where $N$ is the number of coils and $I$ the current intensity.

The equation for current intensity flowing through the depth of penetration is

$$I = J\delta \left(1 - \frac{1}{e}\right)$$

where $J$ is the current density at the surface.

Figure 2: The drop temperature radiation into the nozzle.

Power dissipation can be increased by increasing the intensity of magnetic field in other words by increasing the number of ampere-turns in it. Increasing the number of turns can be limited by the space available and the size of the droplet that will be obtained.

4 Modeling

Following mathematical calculations the modeling was done between the interior walls of the nozzle.

The system to be solved is given by

$$j\omega \sigma(T)A + \nabla \times (\mu^{-1} \nabla \times A) = 0$$

$$\rho C_p \frac{\partial T}{\partial t} - \nabla \cdot k \nabla T = Q(T,A)$$

where $\rho$ is the density, $C_p$ is the specific heat capacity, $k$ is the thermal conductivity, and $Q$ is the inductive heating.

The electrical conductivity of micro wire, $\sigma$, is given by the expression

$$\sigma = \frac{1}{\rho_0 (1 + \alpha(T - T_0))}$$

where $\rho_0$ is the resistivity at temperature $T_0$, and $\alpha$ is the temperature coefficient of the resistivity. $T_0$ is the temperature 19 °C, and $T$ is the actual temperature in the domain.

The time average of the inductive heating over one period, is given by

$$Q = \frac{1}{2\sigma |E|^2}$$
5 Results and discussions

This model has been studied in frequency of 7 Mhz and current intensity at 80 A. The result diameter of the droplet released was at 6 μm.

The time radiation of the micro wire with induced currents is between 0 and 0.00005 seconds. During this time the temperature of the micro wire will increase from 19°C to 249.7°C.

In figure 7 is represented the last time of the irradiation with induced currents. After melting the part of the wire that was irradiated, the droplet formed will fall along the canal because of the gravity.
6 Conclusions

The benefit is that the currents that heat the micro wire and melts it are induced by means of electromagnetic induction. This means that no physical contact is required between micro wire and induction coils. This method can also improve efficiency by avoiding heat losses from the irradiated surfaces and it does not affect other systems inside the nozzle channel.

On the reached saturation, despite increasing magnetic field, magnetic flux density in the material will remain limited and so, although there is an increase in power density transferred from the inductor, the system performance will decrease.

Growth rate of the frequency does not lead to a significant increase in power dissipation and, in addition, brings a downside where increasing the inductance of the inductor and thus and thus might be a limitation of power.

References:

Figure 8: Micro wire temperature isosurface plot at time 0.00005.