Edge effect of load in transverse flux induction heating systems

A. Zenkov[1], A. Ivanov[1], V. Bukanin[1] and V. Nemkov[2]

[1]St. Petersburg Electrotechnical University (LETI), 5, Prof. Popov Str., St. Petersburg, Russia, 197376
[2]Fluxtrol, Inc., 1388 Atlantic Blvd, Auburn Hills, Michigan, USA, 48326

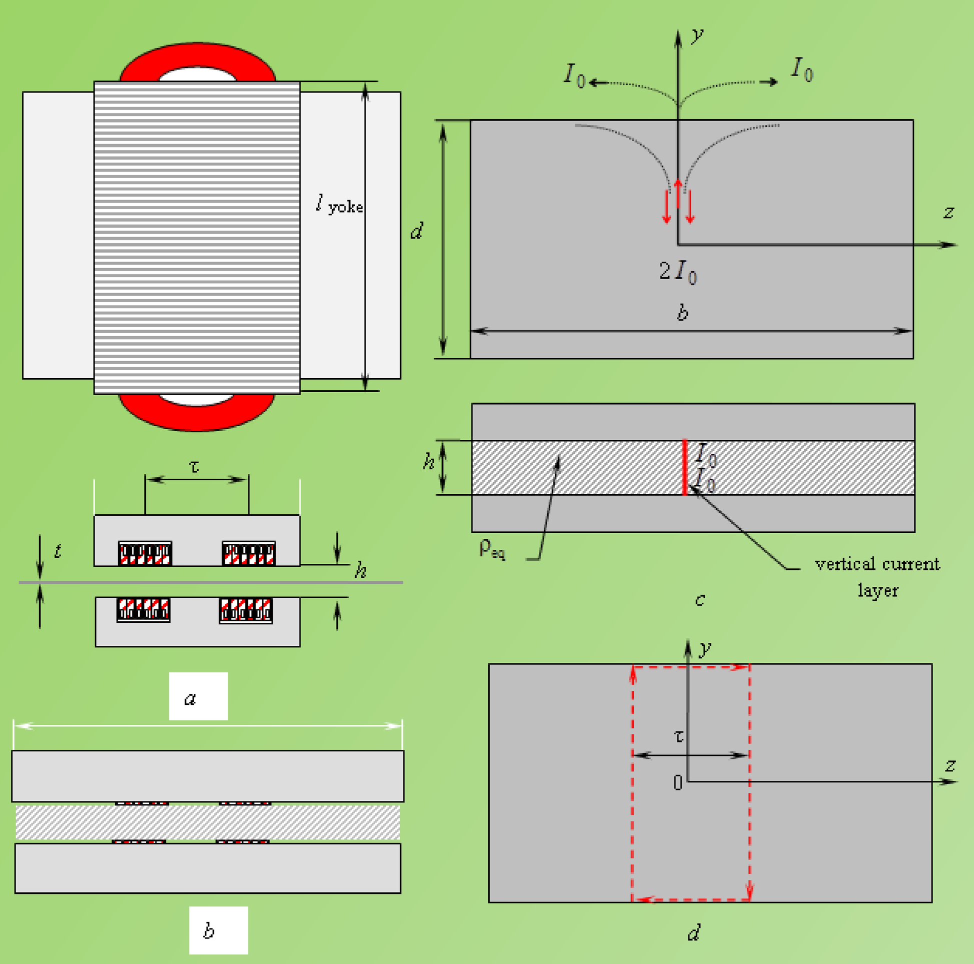
Introduction

Induction heating in transverse flux can be economically effective for thin workpieces from aluminum, copper, gold, silver and other metals with low resistivity. One thing for sure is that obtaining of temperature uniformity is never easy, because a strong edge effect of the load plays determining role in quality of heating. Multiple studies since the beginning of 1960s showed that it is a very serious problem for this type of heating.

Methods of calculation

Analytical method

The analytical solution of TFIH system (a) can be obtained, assuming that the metallic strip is located between two large and flat poles of electromagnet without poles and slots (b).



The induced current densities can be written in the following Fourier series

$$\dot{j}_z = \frac{\dot{E}_z}{\rho_{eq}} = j\dot{H}_e \frac{8}{\pi\Delta^2} \sum_{n=1,3,\ldots}^{\infty} \frac{(-1)^{\frac{n-1}{2}} Sh p_d y}{n p_d Ch(p_d \frac{b}{2})} \cos\frac{n\pi(z-\frac{b}{2})}{d},$$

$$\dot{j}_y = \frac{\dot{E}_y}{\rho_{eq}} = -j\dot{H}_e \frac{8}{\pi\Delta^2} \sum_{n=1,3,\ldots}^{\infty} \frac{(-1)^{\frac{n-1}{2}} Sh[p_b(z-\frac{b}{2})]}{n p_b Ch(p_b \frac{d}{2})} \cos\frac{n\pi y}{b},$$

The current densities will be the two-dimensional arrays of the complex values with fixed d/Δ.

$$\dot{j}_y = \varphi(\frac{d}{\Delta},\frac{y}{\Delta},\frac{z}{\Delta}), \quad \dot{j}_z = \psi(\frac{d}{\Delta},\frac{y}{\Delta},\frac{z}{\Delta}),$$

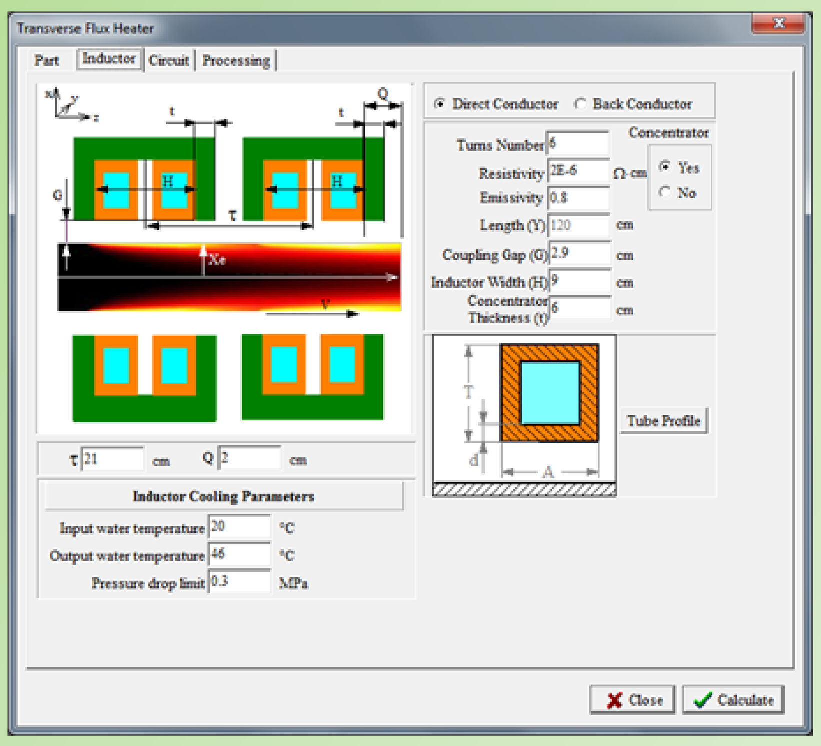
The specific power is calculated as $p_v(y,z) = \rho_{eq}\left[\left|\dot{j}_{y\Sigma}\right|^2 + \left|\dot{j}_{z\Sigma}\right|^2\right].$

Numerical method

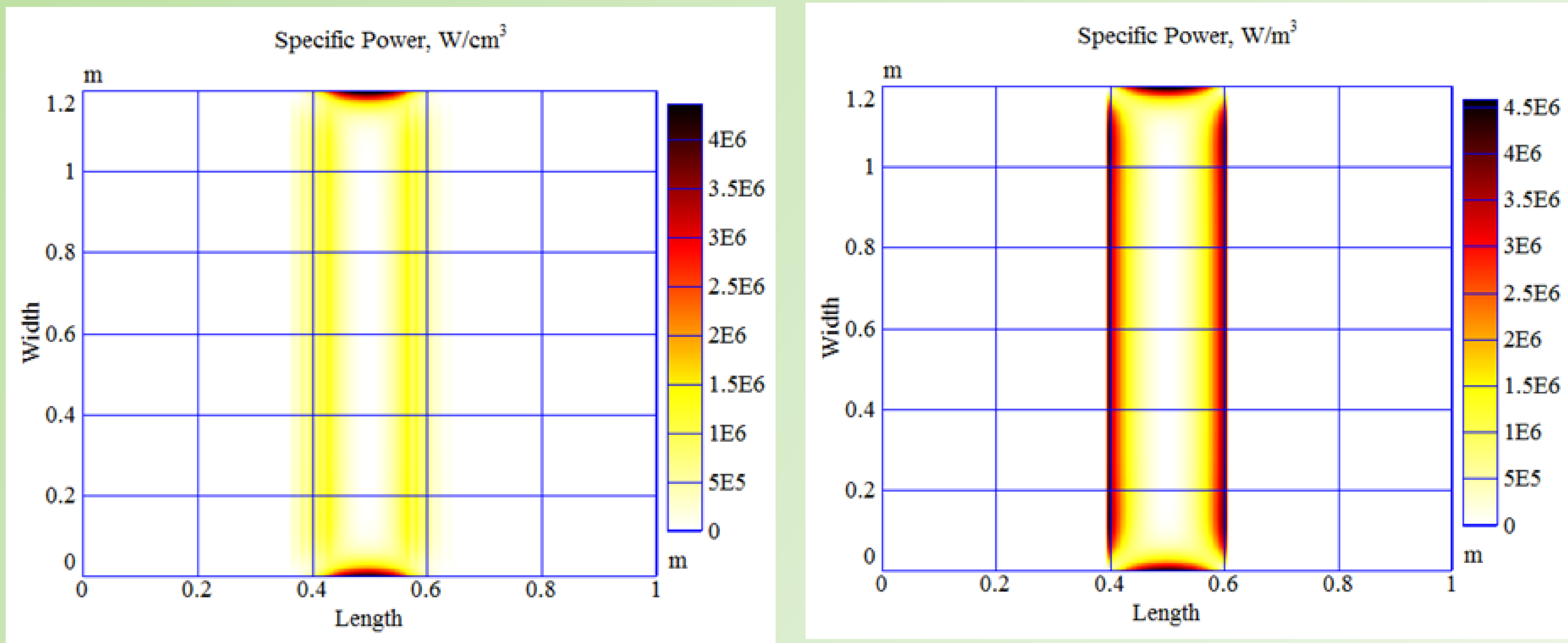
Equation in numerical method of calculation for magnetic field in a rectangle body has the form

$$\frac{\partial}{\partial y}(\rho_{eq}\frac{\partial \dot{H}}{\partial y}) + \frac{\partial}{\partial z}(\rho_{eq}\frac{\partial \dot{H}}{\partial z}) = j\omega\mu\mu_0\dot{H}. \quad p'(y) = \int_\tau p_v(y,z)dz \quad p_v = \rho\left(\frac{\partial \dot{H}}{\partial y}\frac{\partial \overset{*}{H}}{\partial y} + \frac{\partial \dot{H}}{\partial z}\frac{\partial \overset{*}{H}}{\partial z}\right)$$

New program of Transverse Flux Heating is inserted in ELTA 6.0 to make simulation and predict temperature distribution in the width of thin strips.

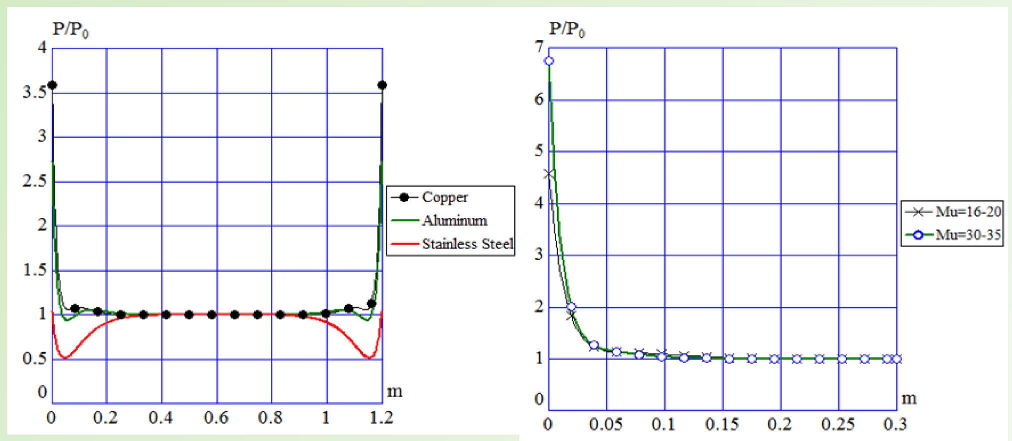


Investigation of TFIH edge effect

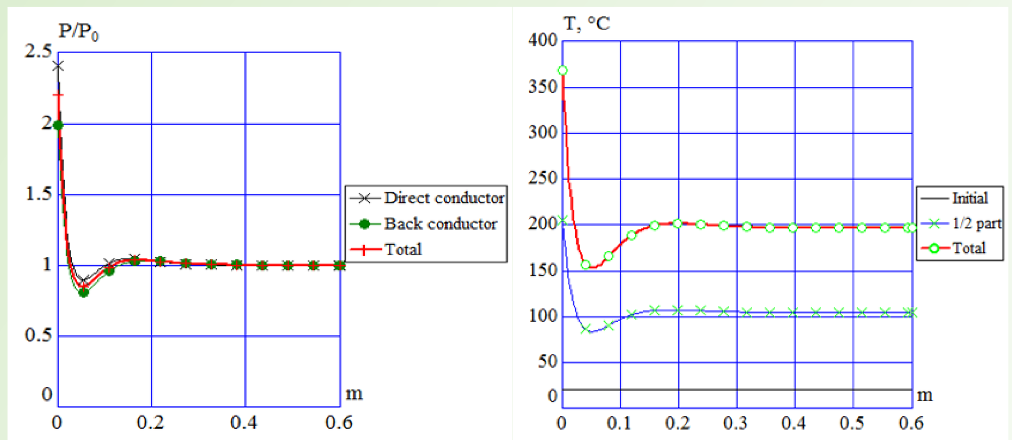


Results of simulation

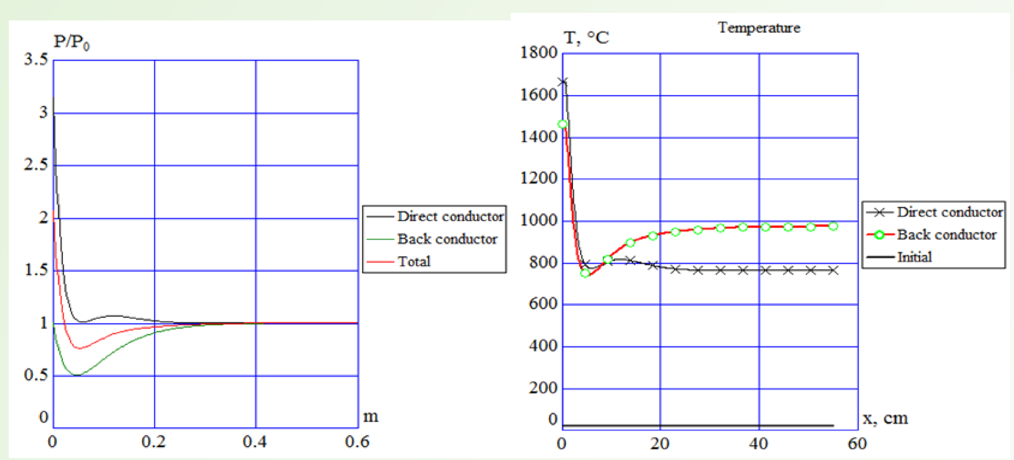
Strip parameters: thickness t = 2.5 mm, width d = 1200 mm, materials – copper, aluminum, stainless steel and ferromagnetic steel.
Parameters of E-type TFIH system: direct and back conductor – inductor width 90 mm, turns number 6 from copper tube, coupling gap 29 mm (total window opening h = 60.5 mm), pole pitch τ = 210 mm. Processing: continuous heating.



Distribution of power along the strip width for non-magnetic materials (left) and for steel 1040 (right)



Distribution of power (left) and predicted temperature (right) along the width of aluminum strip 2,5 mm thickness.



Distribution of power (left) and predicted temperature (right) along the width of steel 1040 strip 2,5 mm thickness.

Conclusion

This study confirmed existing and provided new information about edge effects of strips in TFIH system. New program Transverse Flux Heater based on a structure of ELTA has been developed to investigate edge effect. This program can simulate distribution of specific power along the strip width. Knowledge of edge effect is very important for understanding behavior, simulation, and optimal design of TFIH systems. Balancing proper selection of frequency and the coil position or length allows the designer to provide the required temperature distribution along the part.

More information may be found at:

www.nsgsoft.com www.fluxtrol.com

References

[1] Peysakhovich, V. A. (1961). To a question about the uniform heating of the moving metallic strip in the transverse magnetic field. Proceedings of NIITVCh, Industrial applications of high frequency currents in the electrothermics, Moscow-Leningrad, Mashgiz, Book 53, 40-52 (in Russian).
[2] Barglik, J. (1998). Electromagnetic and Temperature Fields in Induction Heaters for Thin Strips. // Proc. of the International Induction Heating Seminar, Padua, May 13-15, 95-102.
[3] Lupi, S. , Forzan, M. , Dughiero, F. , Zenkov, A. (1999). Comparison of Edge-Effects of Transverse Flux and Travelling Wave Induction Heating Inductors. INTERMAG '99, Kijoungiu, Korea, May 1999 and IEEE Trans. On Mag, Vol. 35, No 5, September 1999, 3556-3558.
[4] Bukanin, V., Dughiero, F., Lupi, S., Zenkov, A. (2001). Edge Effects in Planar Induction Heating Systems. Proceeding of the International Seminar on Heating by Internal Sources. Padua, September 12-14, 533-538.
[5] Nikanorov, A., Nauvertad, G., Shülbe, H., Nacke, B., Mühlbauer, A. (2001). Investigation, design and optimization of transverse flux induction heaters. Proc. of the International Seminar on Heating by Internal Sources. Padua, September 12-14, 553-558.
[6] Dughiero, F. , Lupi, S., Mühlbauer A., Nikanorov, A. (2001). TFH - transverse flux induction heating of non-ferrous and precious metal strips. Result of a EU Research Project. Proc. of the International Seminar on Heating by Internal Sources. Padua, September 12-14, 565-575.
[7] Zlobina, M., Nake, B., Nikanorov, A. (2010). Methods to control the temperature profile in transverse flux induction heaters. Proc. of the International Induction Heating Seminar, Padua, May 18-21, 465-471.
[8] S. Lupi, M. Forzan, A. Aliferov. (2015). Induction and direct resistance heating: Theory and Numerical Modeling, Springer, Switzerland, 370.
[9] Nemkov, V. S., Demidovich, V. B. (1988). Theory and Calculation of Induction Heating Devices. Energoatomizdat, 280. Leningrad, (in Russian).
[10] Nemkov, V., Bukanin, V., Zenkov, A., Ivanov, A. (2014). Simulation of induction heating of slabs using ELTA 6.0. Proc. of the Intern. Scientific Colloquium Modelling for Electromagnetic Processing, Hannover, 113-118.