A Simple Induction Heating Design for the Steel Molds of Aluminum Extrusion Presses

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ABSTRACT

Induction heating is a widely preferred method for heating metals. However, its initial investment can be costly for simple processes. In this work, an affordable heating system has been developed for use in induction heating. Steel molds used in aluminum extrusion presses can be heated up to the extrusion temperatures by using this system.

KEYWORDS

Induction heating, aluminum extrusion

I. INTRODUCTION

Induction heating is used in several applications such as melting, annealing, welding, shrink fitting and plasma.

The heat energy obtained in induction heating is given as

$$Q = 860.R.I^2 \quad (1)$$

Power supplies intended for this application has to provide the necessary power, frequency and physical conditions. Investment cost of these power supplies is high, and therefore, for simple applications these induction heating systems are not preferred.

Heating the steel molds used in aluminum extrusion presses is one of these simple applications. These molds are preheated up to the press temperature (450 – 500 °C) for approximately 30 minutes in resistive ovens. This process has to be repeated every morning when starting the first press and anytime when a new mold is placed. Since the mold hardness may deteriorate, it is not proper to keep the molds in these ovens for prolonged periods.

Heating period may be considered as a lost time. Moreover, the energy loss is higher since the efficiency of resistive ovens is less than that of the induction ovens.

There have been some work in which a metal strip was heated by using a coil placed on a yoke or inside in a pack of laminated steel (magnetic yoke.) Medium frequency has been used in these applications, and temperatures as high as 900 °C have been reached on aluminum and steel work pieces [1-4].

This work suggest a simple and cheap system utilizing the basic principles of induction heating to quickly heat the steel molds used in aluminum extrusion presses. Low power consumption is also aimed.

II. METHOD

Figure 1 shows the system designed for the heating process. It is connected to three-phase 50 Hz power grid. The 3-phase power transformer is rated 150 kVa, and has several taps. The balance inductor also has a tapped structure. There are also a balance capacitor and a resonance capacitor in the system. All the components are connected on the secondary of the transformer in delta.
Component values are given as follows so that balance is achieved: Balance inductor, 11.74 mH, balance capacitor 863 μF, heating inductor 2.66 mH, resonance capacitor 3795 μF. The 3rd terminal of the 13-tap transformer is used. The no-load voltage at this terminal is measured to be 160 V.

The winding is made by using a 15x17 mm cross-section conductor and it has 2x15 turns. This coil is placed around a core with a cross-section of 140x200 mm. The arm height is 300 mm, and the window opening is 110 mm. Two yokes with a cross-section of 140x200 mm are at the top, and the mold is placed between these two yokes. The inductor design is pictured in Figure 2.

The parameters for the balance inductor are as follows: core cross-section= 120x170 mm, arm height= 310 mm, window opening= 80 mm. There are two windings with 34 turns of 10x10 mm conductor on each one.

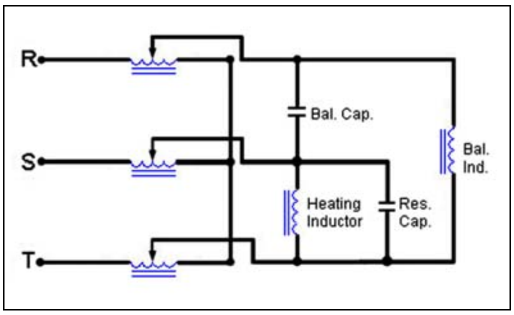


Figure 1. Connection diagram of the system

III. EXPERIMENTAL RESULTS

Experiments aiming to reach to 450-500 °C in 120 seconds were performed. Figure 3 shows some data and waveforms related to the heating section. Figure 3a shows the voltage and current variations of the heating inductor for 120 seconds. Mold temperature was measured to be t_0=20 °C at the beginning of the experiment, and t_{120}=470 °C at the end.

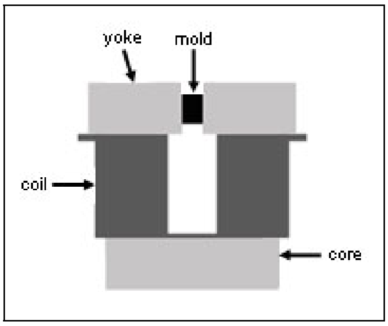


Figure 2. Inductor structure

Balance inductor and balance capacitor currents were measured to be I_b=44.57 A and I_c= 44.20 A, respectively, while the heating inductor current was 66.1 A at 158.1 V, as seen in Figure 3b. Therefore, the apparent power is

$$S = VxI = 158.1x66.1 = 10.45 \;\; kVA \qquad (2)$$

Since the power factor was PF=0.87 as seen in Figure 3c, the active power can be calculated as

$$P = SxPF = 10450x0.87 = 9091.85 \;\; W \approx 9.1 \;\; kW \qquad (3)$$

The displacement factor during this operation is measured to be Cos φ=0.97. Therefore, the apparent power for the fundamental component is

$$S_1 = \frac{P}{Cos\varphi} = \frac{9.1}{0.97} = 9.4 \;\; kVA \qquad (4)$$

and the reactive power is

$$Q_1 = \sqrt{S_1^{\,2} - P^2} = \sqrt{9.4^2 - 9.1^2} = 2.4kVAR \qquad (5)$$

This value is seen as 2.5 kVAR in Figure 3c. This is due to the rolling effect of the instrument.

The mass of the mold is G= 4.5 kg, the temperature difference is Δt=470-20=450 °C, and the specific heat for the steel is c=0.1-0.15 kcal/kg.°C. Therefore, the required amount of heat to obtain a temperature difference of Δt=450 °C in 120 seconds is

$$Q = m\,c\,\Delta t = 4.5x\;0.1x450x\frac{60}{2} = 6075 \;\; kcal \qquad (6)$$

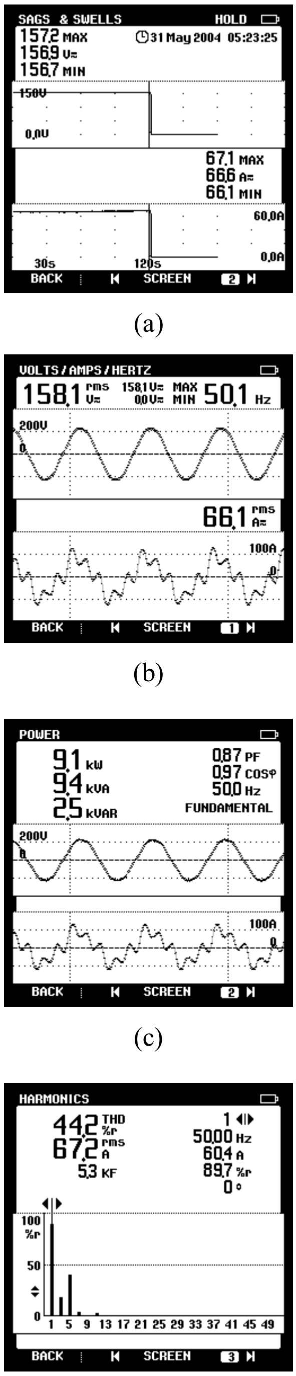
This corresponds to an hourly electrical energy of

$$E_h = \frac{6075}{860} = 7.064 \;\; kWh/h \qquad (7)$$

It should be noted that this value is obtained by using the lowest possible value of specific temperature for the steel. This yields the minimum required energy to heat the steel mold.

Since the power consumed by the load is 9.1 kW, the minimum efficiency of the heating unit is

$$\eta = \frac{7064}{9092}x100 = 77.69\% \qquad (8)$$



(a)

(b)

(c)

(d)

Figure 3. Heating unit: (a) voltage and current rms value variations (b) voltage and current time variations (c) power measurements (d) harmonic measurements

Figure 3d shows the harmonic component values of the heating inductor current. The main harmonic constitutes 89.7% of the total current. The third and fifth harmonics are also considerably high.

Figure 4 shows the power values drawn by all three phases during the heating process. The total drawn power is

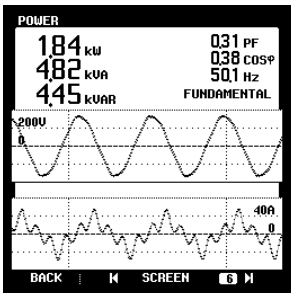
$$P_T = P_R + P_S + P_T = 1.84 + 3.88 + 5.15 = 10.87 \quad kW \quad (9)$$

As the minimum power required by the heater is 7.06 kW, the minimum efficiency for the total power transfer can be found as

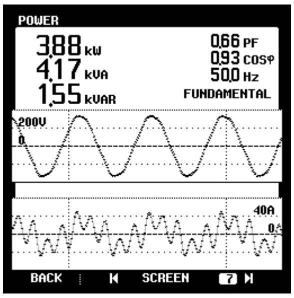
$$\eta = \frac{7{,}06}{10{,}87} x100 = 64.98\ \% \qquad (10)$$

Since the maximum efficiency for the medium frequency induction steel annealing and melting ovens is 60%, it is obvious that a considerably better value of efficiency is obtained with the developed system.

Table 1 gives the current and harmonic values for each phase. It is clear from the table that, the currents are distributed to each phase very evenly although the line-to-line voltages are not balanced.



(a)



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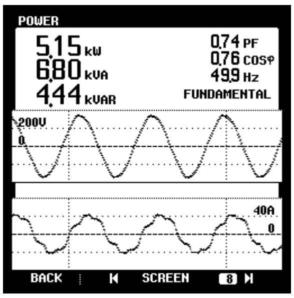


(c)

Figure 4. Power drawn by each phase: (a) Phase R, (b) Phase S, (c) Phase T

IV. CONCLUSION

A simple and low cost system to heat the steel molds for the aluminum extrusion presses was developed. The temperature was increased to 470 °C in 120 seconds. A picture showing the heating set-up is given in Figure 5. The temperature that is read on the instrument was obtained in 160 seconds.

The efficiencies of the heating unit and the total system were obtained as 77.69% and 64.98%, respectively. This is better than the maximum value of 60% for medium frequency induction steel annealing and melting oven.

The current harmonics exist at the 3rd and 5th frequencies, but since the total power drawn from the line is 10.87 kW, their effect on the supply is not important.

Table 1. Currents and their harmonics for each phase

(a) Phase R

	1^{st}	3^{rd}	5^{th}	7^{th}
	50 Hz	150 Hz	250 Hz	350 Hz
THD 48.3 %r	22.30 A	5.04 A	14.52 A	1.03 A
25.61 A	83.2 %r	18.3 %r	52.2 %r	3.5 %r
KF 6.3	0 °	-169 °	21 °	157 °

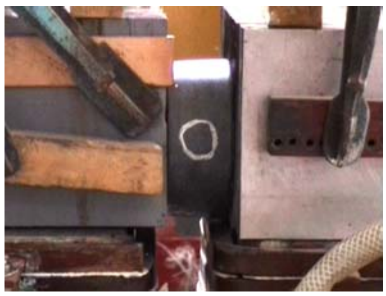
(b) Phase S

	1st	3rd	5th	7^{th}
	50 Hz	150 Hz	250 Hz	350 Hz
THD 72.1 %r	17.83 A	6.14 A	17.38 A	0.99 A
25.74 A	69.5 %r	24.3 %r	67.6 %r	3.7 %r
KF 12.7	0 °	-136 °	-124 °	-148 °

(c) Phase T

	1^{st}	3^{rd}	5^{th}	7^{th}
	50 Hz	150 Hz	250 Hz	350 Hz
THD 20.5 %r	29.64 A	1.97 A	5.56 A	0.56 A
30.28 A	98.0 %r	6.5 %r	18.3 %r	1.9 %r
KF 2.1	0 °	62 °	85 °	18 °

(a)



(b)

Figure 5. Pictures of the heating unit

REFERENCES

[1] S. Fukushima, K. Okamura, T. Krase, G. Prost, “A High-Performance Edge Heater for the Hot Strip Mill”, IEEE Transactions on Industry Appl., Vol 29, No. 5, Sep/Oct 1993.

[2] C. Guaneri, P. Masse, Y. Terrail, “Experimental Thermal Validation of Two Vector Potential Formulations in Industrial Transverse Flux Induction Heating Process“, IEEE Transactions on Magnetics, Vol 31, No, 3, May 1995.

[3] K. Tani, T. Yamada, “New Approach to Coupled Magnetic and Thermal Problem in Induction Heating System with Traveling Conducting Plate Using Cubic Interpolated Pseudo-Particle Method“, IEEE Transactions on Magnetics, Vol 33, No. 2, March 1997.

[4] N. Bianchi, F. Dughicro, “Optimal Design Techniques Applied to Transverse – Flux Induction Heating Systems“, IEEE Transactions on Magnetics, Vol. 31, No. 3, May 1995.