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A study on frequency control of the medium - frequency furnace using PLC and siemens inverter

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Abstract— **Nowadays, the electric furnace equipment in general and the medium frequency induction furnace in particular are being widely applied for steel production. Power semiconductor induction steel furnaces have many outstanding advantages such as flexible control, fast response, economic efficiency, small size and volume, reliable working and high accuracy, especially applied the advances of other science and technology disciplines such as cybernetics, information technology in order to improve production efficiency, reduce the loss of energy, the cost of products and free labor. Therefore, the study of medium frequency induction furnace is essential. In which the issue of frequency control of the furnace while maintaining the head power is mentioned in this article. The paper suggests a solution to use PLC S7-200 controller of Siemens.**

Index Terms **— Medium frequency furnace, induction furnace, frequency control, PLC controller.**

I. INTRODUCTION

The medium frequency furnace is a medium frequency electric heating device. It works based on the phenomenon of electromagnetic induction. When we give an alternating current with frequency *f* through a coil, there will be a reciprocal magnetic field in the coil. If we place a metal block into the variable magnetic field, there will be a vortex (called Fuco) in the metal mass. The Fuco currents also vary with the frequency of the current flowing through the coil and closed circuit in the metal block.

This causes the metal to be heated. The larger the value of the eddy current, the greater the heat generated and the hotter the mass of metal. So if neglecting negligible losses on the coil, the energy of the current through the coil has been completely converted into heat energy on the metal block.

When alternating current through a copper primary winding with an inner cooling layer will generate variable magnetic flux through the metal (secondary coil) to generate electromotive force:

$$E_2 = 4,44.\phi.f.n_2.10^{-8}\ (V)$$

And the electric current I_2 generates a great deal of heat to melt the metal.

We have:

$$I_2 = I_1.n_1$$

$$W = (I_1.n_1)^2.\phi.\pi^2.\frac{d}{h}.\sqrt{\rho.\mu.f.10^9}\ (w)$$

Inside:

I_1: Electric current in the coil.

n_1: Number of induction coils.

d: Average diameter of metal ladle (cm).

h: Height of liquid metal contained in the furnace (cm).

f: Frequency (Hz).

ρ: Resistivity of metals

II. OVERVIEW OF THE MEDIUM FREQUENCY FURNACE

2.1. The factors influence furnace heat

+ The heat generated in the metal block is due to the short circuit of the Fuco currents. It also depends on the following factors:

- Resistivity ρ and permeability coefficient μ of metal.
- Magnetic field strength H:

$$W_{nhiệt} \sim H^2 \sim I^2$$

- Induction current frequency:

$$W_{nhiệt} \sim \sqrt{f}$$

Thus, to increase the heat generated in the metal mass increase the value of the current through the coil or increase the frequency of this current.

+ Increasing the current through the coil: Since the coil has a resistance, when increasing the current, the loss of the coil will increase, this loss is the heat loss of coil: $Q = I^2.R.t$. This is the unwanted heat that not only causes loss but also shortens the life or damages the coil. Therefore, depending on the furnace capacity, the current value is accordingly selected. For large-capacity ovens, cooling is usually carried out to increase the life of the coil.

+ Increasing the frequency of the current flowing through the coil: Medium frequency furnaces usually take the frequency at about 500 ÷ 10000 Hz. Increasing the frequency of the current can reduce the heat loss on the coil, but source circuits require very complex, depending on the purpose of the furnace. It can be done by changing frequency with Siemens inverter in the system.

Although the medium frequency furnace is a very useful device in the steel industry, the design problem is not simple and there are a number of other issues. Two issues of concern are: the first, increasing the temperature increase the resistivity and thus increases total resistance of the material. This significantly consumes the energy of the supply. The second,

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when the material temperature reaches the Curie point the permeability (μ) decreases. This leads to a decrease in inductance value (L) and changes in the resonant frequency. The process of changing the furnace's energy from supply again reduces and increases the firing time. In addition, heat loss occurs during extended periods of time to reach the desired temperature point.

PLC has large memory, special functions such as PWM, basic data communication as well as excellent features of modules.

Using PLC in the medium frequency furnace, the location, temperature, pressure and voltage control and overcurrent protection becomes easier. In addition, the power supply can be adjusted as desired. All PLC features can help facilitate the production, control and automation of the frequency furnace. Therefore, in this study, the PLC control system has been chosen for the frequency furnace - a system with continuous and appropriate power at the resonant frequency achieved.

2.2. Resonance frequency

When the system had a working resonance frequency, the researchers came up with a number of resonant frequencies defined in the loop phase (PLL). However, these systems are complex, difficult to calibrate, and sensitive to noise. So we have to find the way to simplify the system and operate it reliably.

When the furnace is operating at frequencies lower than the resonant frequency, the current flowing through the furnace coil I_L is also larger than the capacitor current (I_C). On the other hand, when the furnace is operating at a frequency higher than the resonant frequency, the current flowing through the furnace coil I_L is higher than the capacitor current (I_C). If I_C equals I_L there is the resonant frequency. This case is described in Figure 1. In particular, the amplitude of the current in the furnace coil and the current passing through the capacitor are considered to be a function of frequency.

To achieve the desired properties, the simulation using MATLAB Simulink software is performed. Figure 2 describes the controller's operation as follows: initially, the frequency adjustment (f_s) is higher than the resonant frequency (f_0). Therefore, the current through the capacitor is higher than the current through the furnace coil. Therefore, adjust so that the frequency characteristic of the furnace is close to the resonant frequency. During the simulation, the parameters of the furnace are allowed to change linearly. As seen in the figure, after some point, the controller decides to increase the frequency so that the system reaches the resonant frequency.

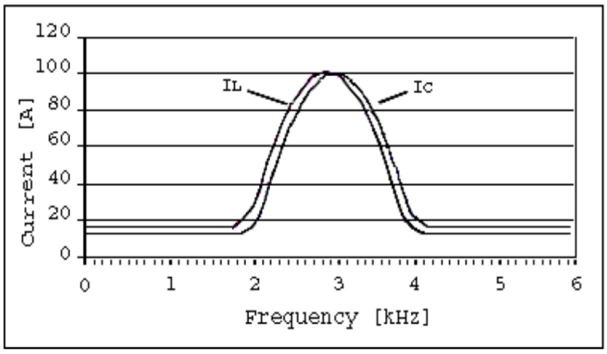


Figure 1: Characteristics of currents when the furnace works at resonant frequency

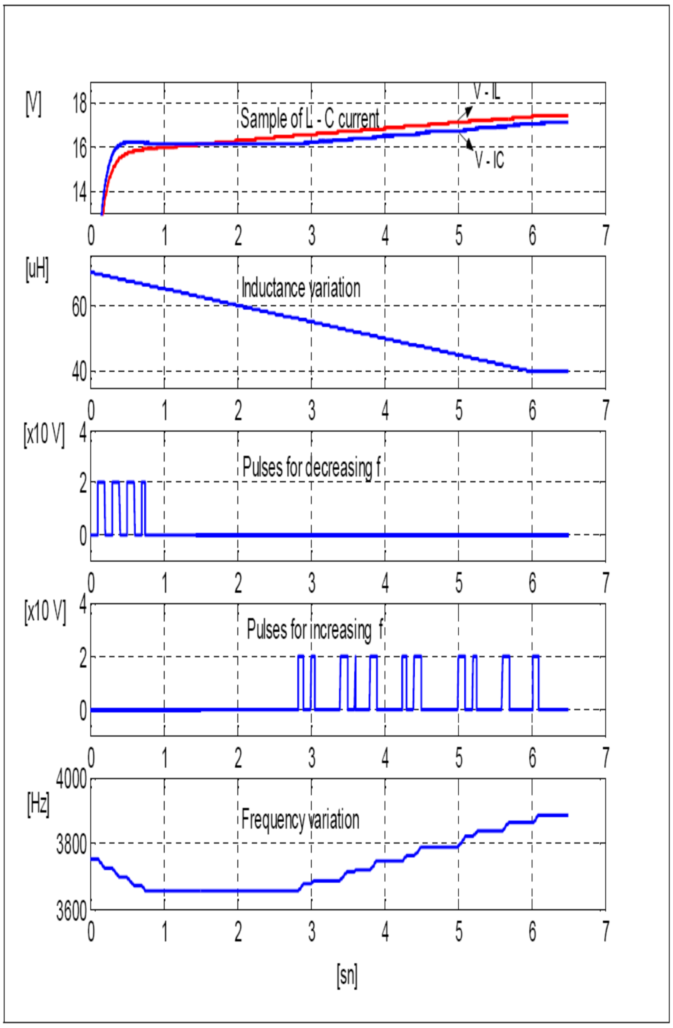


Figure 2: Resonance frequency characteristic

III. Algorithm Flowchart, Programming Program for PLC and Settings for the Inverter

3.1. Algorithm flowchart

Siemens S7-200 / CPU 214 was the PLC model that was chosen for hardware. This PLC has 14 inputs, 10 outputs, PWM, PTO pulse generator. These pulse generators may be directed to outputs Q0.1 and Q0.2. The inputs and outputs have several functions such as setting and changing temperature, pressure and position control. For overcurrent protection, overvoltage is equipped with additional short-circuit protection. The program has two main parts: the first part is to generate the necessary impulses for the inverter, the second part is to control the operation of the furnace.

The program can automatically determine time and cycle depending on the feedback signals sent to the PI controller. Moreover, the adjustment of pressure, temperature, overcurrent, over-voltage and short-circuit protection as well as switching system operate easily in accordance with the adjustment process. The schematics of the program are shown in Figure 3. The modules work through main programs and subroutines.

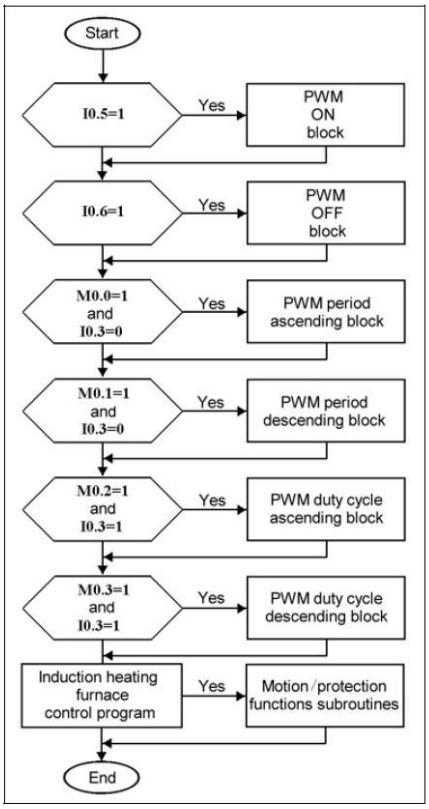


Figure 3: PLC program

3.2. System structure diagram

The block diagram of the system is seen in Figure 4 including: rectifier, source, high frequency generator (MFT), inverter and block diagram of the furnace (load).

- *Electricity supply*

Power source is AC / DC / AC converter. It has a capacity of up to 60 kW of electricity at any frequency from 5 Hz to 10 kHz. At the input of the inverter is a three-phase bridge rectifier, and the input is taken from the inverter can adjust the voltage and frequency.

- *Rectifier*

Three-phase bridge rectifier uses Diodes.

- *Inverter and controller*

Single-phase inverter with two inputs leads to IGBT GB123D. The value of the current of the module is 200A, 1200V. Siemens S7-200 / CPU 214 has been used as PWM pulse generator. The outputs of the PWM pulse generator are directed to the Semikron SKHI26 /W device port.

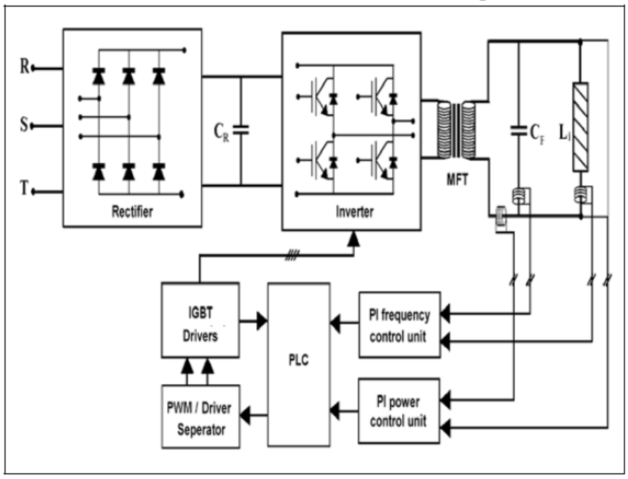


Figure 4: Block diagram of medium frequency steel furnace

The PI controller input signal is taken from the output signal of the PWM pulse generator and filter. Each signal is transmitted via PI regulator. As a result, the gain of the system is adjusted. Finally, the amplifier output is used to control the PLC. The control power supply also has a PI regulator. Voltage and current are generated, adjusted, filtered and amplified. It is then passed through the PI regulator. That amplified signal is used again to control the PLC.

3.3. Inverter

Medium frequency inverter has coefficient of 10/25, and be raised to the value 500V- 250V / 55kVA. The steel core of the machine is made of electrically engineering steel sheets which are insulated together, the thickness of steel sheets is 0,35mm.

IV. THE CALCULATION RESULTS

4.1. Supply

The calculation showed that the value of inductance L of the unburnt cylindrical material was 67,8 µH, and decreased to 63,17 µH when be heated. Similarly the resistance value increases from a value of 16,3 µΩ when not heated to 13 mΩ when heated. A capacitor of 28,82µF value is used at the resonance frequency of 3 kHz. The initial resonant frequency is:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{67,8.10^{-6}.28,82.10^{-6}}} = 3600\ (Hz) \qquad (1)$$

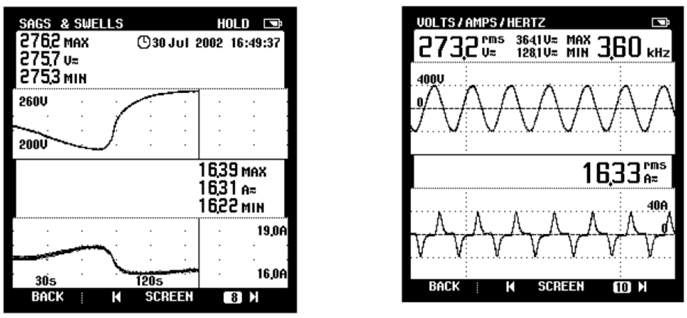
(The resonance frequency of 3600 Hz is obtained when the material temperature is 1250°C). Figure 5 shows secondary voltage and frequency obtained from (1) when no power supply or frequency adjustment is obtained. The values of the characteristic curves in Figure 5a are given in Table 1. In Figure 5b we see that the temperature difference is as high as 60°C and the system is still in progress. Because the temperature is stable at 1250°C for 25 seconds, it takes 160 seconds to reach 900°C. Figure 6 shows the test results when the controllers are used. In Figure 6a, the current input and the AC voltage are displayed. Measured power factors are 0,89 (tubular material) and 0,93 (solid material). The capacity in the furnace coils is calculated as follows:

$$P_P = UI\cos\varphi = 19,8\ (kW) \qquad (2)$$

Furnace capacity for a cylindrical solid material is:

$$P_S = UI\cos\varphi \approx 24,3(kW) \qquad (3)$$

Figures 6 - a, b show that the current and voltage responses are within the permissible limits (± 3%).



(a) (b)

Figure 5: Uncontrolled secondary voltage and current (a) variation of waveform RMS value (b)

Table 1: Numerical values for Figure 5a

t (s)	0	15	30	45	60	75	90	105	120	135	150	160
U (V)	226,9	220,7	212	209,2	197,8	194,6	233,8	258,6	268,8	273,2	275	275,7
I (A)	17,10	17,19	17,35	17,64	18,85	17,88	16,62	16,10	16,09	16,15	16,26	16,31
S (kVA)	3,88	3,79	3,68	3,69	3,73	3,48	3,89	4,16	4,32	4,41	4,47	4,50

(a) *(b)*

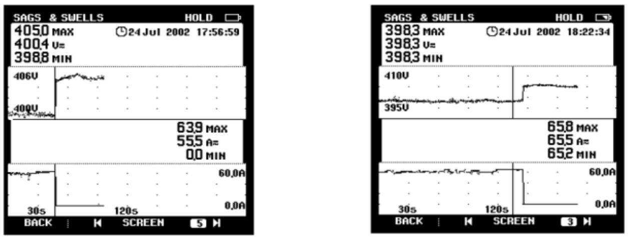


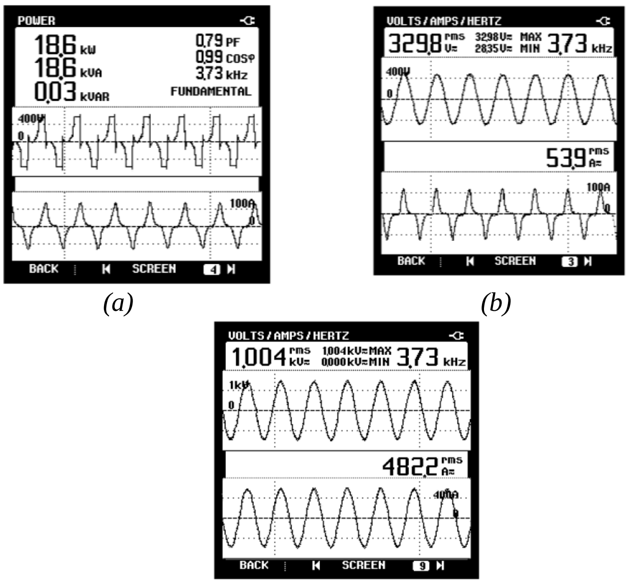
Figure 6: Controlled pressure currents with pipe material form (a) and solid form (b)

4.2. Frequency

Take the secondary side output of the high frequency transformer for frequency analysis. The waveforms are shown in Figure 7a-7c. Figure 7a shows the main energy transformation. The power factor is 0,79. The system's resonance frequency is 3,73 kHz. Figure 7b shows the secondary voltage. Current and voltage are apporoximately 330V and 54A. From that we can observe the waveform of voltage and current, and that is the condition resonating the frequency. With a power factor of 0,79, the total power found is:

$$P_P = UI\cos\varphi = 15,6\ (kW) \qquad (4)$$

The difference in power between input and output is mainly due to frequency change or loss of middle frequency. By adding an additional power transformer this reduction can be improved. Figure 7c shows the voltage, current and frequency when the system is operating at an initial power of 55 kW. The average power in this case is 48,4 kW.



(a) *(b)* *(c)*

Figure 7: Data of MFT (a) Power consumption; (b) voltage and current power; (c) secondary voltage and total furnace capacity

V. Conclusion

The system has been specifically designed for medium frequency steel furnaces. It has been tested with a high rigidity steel pipe and cylinder material, with different inductance and inductance values. While working, the system was made to follow resonant frequencies and electrical variations. In this paper, a system using PLC programmable logic controllers with very flexible modular structures has been developed. In addition, adaptive control, fuzzy logic, and intelligent control can be used in this system.

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