A Special Case of Electronic Power Control of Induction Heating Equipment

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Abstract: Although electronic power control of induction equipment, as the title refers to a specific device, in the present paper, we will show that the method is commonly used for every band-pass characteristics loads at alternating current. Being aware of the benefits of the proposed solution with respect to the conventional power control electronics procedures we can also find a specific solution that is carried out using an embedded microcontroller in the varying conditions of a certain value power control. The proposed control has been applied to an induction heating device, which yields strong results.

Keywords: embedded microcontroller; band- pass behaviour AC load; induction heating; power control

1 Induction Heating and Conventional Control

This method is often used in creating fine-textured metallic materials. Here the heat treatment is important to soak homogeneous smooth gradients. The induction heating then heats up the entire volume of metal so that during the cooling the required heat treatment is performed.

This process is used in the installation of certain mechanical structures as well. In this case, heat (from?) the component that expands the assembled structure [7].

During the induction heating process the target is placed in a coil of an oscillating circuit (Figure 1). The coil is driven with alternating current; the magnetic field induces a current in the target, in which the eddy current is generated. This, in turn, causes the heating of the work piece [4].

The above procedure has two weak points in terms of electronics. The work piece itself as an iron core detunes the resonant frequency of the resonant circuit. This will change the inductive power, thus yielding poor power and temperature control [1].

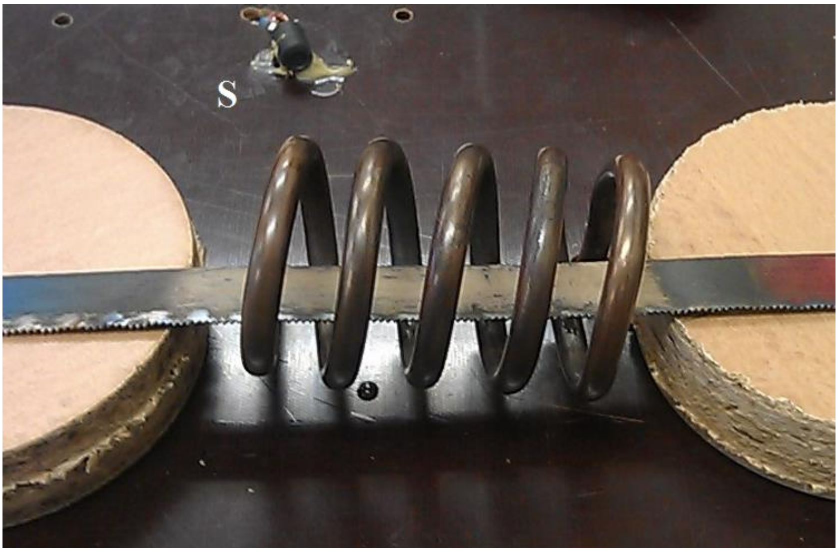

Figure 1
The metal target inside the water-cooled coil. Above a ferrite core sensor coil (S) for sensing the intensity of electromagnetic field is seen

2 Conventional Electrical Power Control

Most of the electrical power regulation changes the value of the load (R_t) voltage (U_R). The formula can be described in equation (1)

$$U_{out} = f(\tau), \tag{1}$$

where the input parameter τ is a control signal and U_R=U_{out}. In precision electrical engineering applications, the output voltage is controlled by a precise value holder operating the power supply voltage and in most events is a constant value.

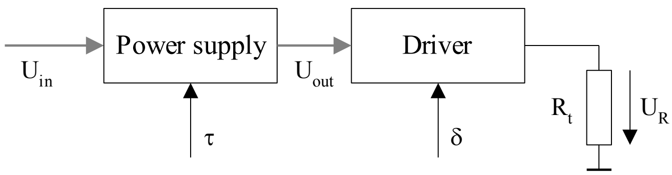

Figure 2
The structure of conventional electrical power control

In this case, the load voltage, electrical power can be determined according to equation (2)

$$U_R = f(U_{out}, \delta), \tag{2}$$

where δ is an relevant parameter in determining the value (power) of output [5]. Thus, a two-stage, often duplicated redundant control is created, which depends on two parameters according to equation (3)

$$U_R = f(\tau, \delta). \tag{3}$$

In case of power supply, with the advent of modern semiconductors two different solutions are commonly used: the phase-fired and pulse width modulation (PWM) power control [6].

3 Traditional Structure of Induction Heaters

The advanced semiconductor induction heating equipment essentially consists of a power supply and a high-power oscillator (Fig. 3). The coil (L_i) and a parallel connected capacitor (C_i) form a resonant circuit. The oscillator frequency is equal to the resonance frequency of the oscillating circuit [7].

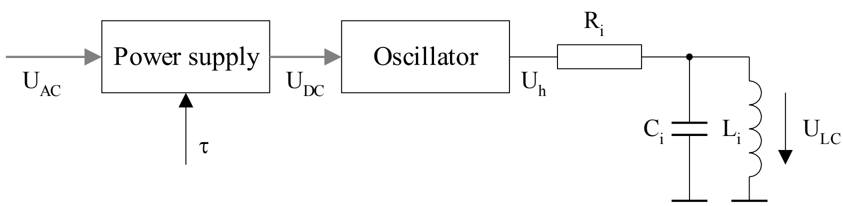

Figure 3

The generally used construction of induction heating equipment

The output of power supply, denoted by U_{DC}, and coil-voltage, U_{LC}, the heating power is only a function of the parameter τ.

This method has the disadvantage that the target placed in the coil changes its impedance. Thus, the coil voltage changes according to equation (4)

$$U_{LC} = U_h \frac{1 - \omega^2 L_i C_i}{1 + j\omega R_i L_i - \omega^2 L_i C_i}, \tag{4}$$

where R_i denotes the internal resistance of high power oscillator circuit.

Therefore it is necessary to tune the oscillator again after inserting the object in the coil. Thus, maximum power is again on the coil, with significant heating power on the work piece.

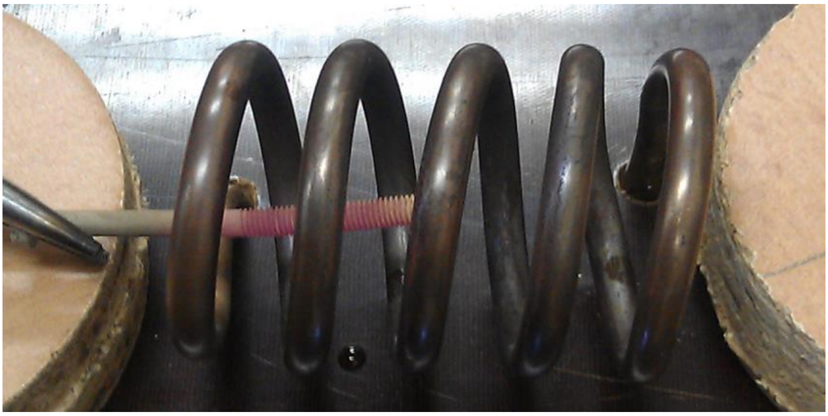

Figure 4
One incandescent screw in the coil

4 A New Method for Induction Power Control

In the proposed arrangement (Fig. 5) the microcontroller (μC) generates the high frequency signal (U_{osc}), which matches the power amplifier with the resonant circuit. In case of resonance frequency the heating power only depends on the voltage supply (U_{DC}).

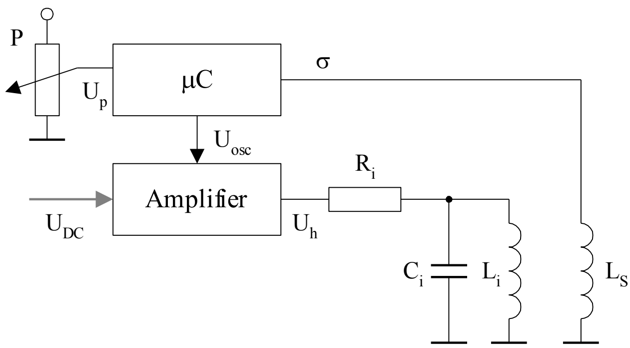

Figure 5
The proposed structure of the induction heating equipment

The system is an important part of the coil that is fed back into the value of the radiated magnetic field, by a sensing coil, onto the appropriate input (σ) of a microcontroller [12]. The sensing coil of the constructed equipment can be observed in the upper part of Fig. 1 denoted by 'S'.

With this hardware it is possible to determine the frequency of the off-tuned oscillating circuit [13]. The sensor coil (L_s) detects the magnetic field strength. The inserted target makes radiated signal changes because the resonant circuit is off tuned [14] [15]. On the other hand, the work piece consumes power from the magnetic field [16].

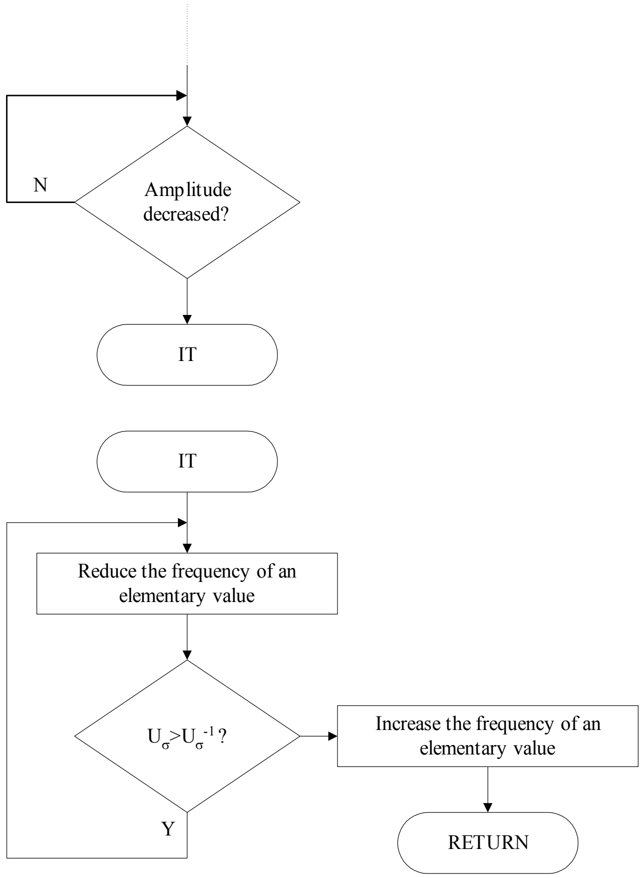

Figure 6
The most important part of the flowchart of the embedded microcontroller generating appropriate frequency

4.1 Automatic Frequency Tuning

The relevant part of the frequency generation of the embedded microcontroller's control program flowchart is shown in Fig. 6. If the sensed field strength changes, the main program will generate an interruption. In the interruption subroutine it starts to reduce the frequency [9].

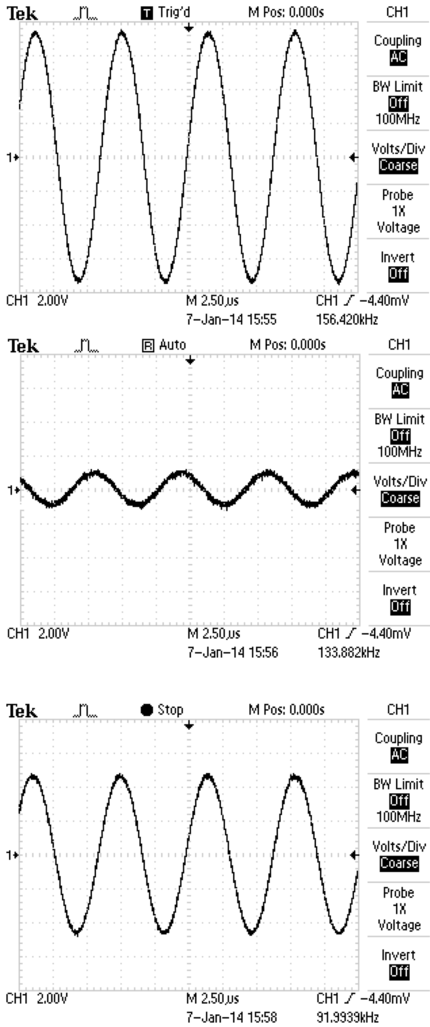

Figure 7
Oscilloscope images of the measured sensor coil signals

The reduction step size is 1 kHz. The intensity of the radiated magnetic field (U_σ) is continuously measured. If the amplitude decreases ($U_\sigma > U_\sigma^{-1}$), it steps back and sets a new resonance frequency value [8].

The tuning process can be used to speed up the successive approximation procedure [11].

In Fig. 7, during the tuning process, voltage and frequency signals are observed. The upper image shows the empty heating coil and its sensed amplitude at ~156 kHz resonance frequency. The middle image shows amplitude and frequency at the target insertion. A significant decrease is observed in the amplitude. With the start of the tuning, the current frequency is ~134 kHz. The increased amplitude found by new resonance frequency can be seen in the bottom oscilloscope image.

The relevant part of the embedded microcontroller and high power electronic is shown in the schematic of Fig. 6.

The high power semiconductors, IGBTs (Q1, Q2), are driven by optocouplers from the microcontroller digital outputs, utilizing the internal pull-up resistors on RBO and RB1. The resonant circuit (L1, L2) of the impedance matching is realized by a transformer (TR1.) Thus, the driving of the half bridge utilizes the full potential of the HW SW abilities of the microcontroller.

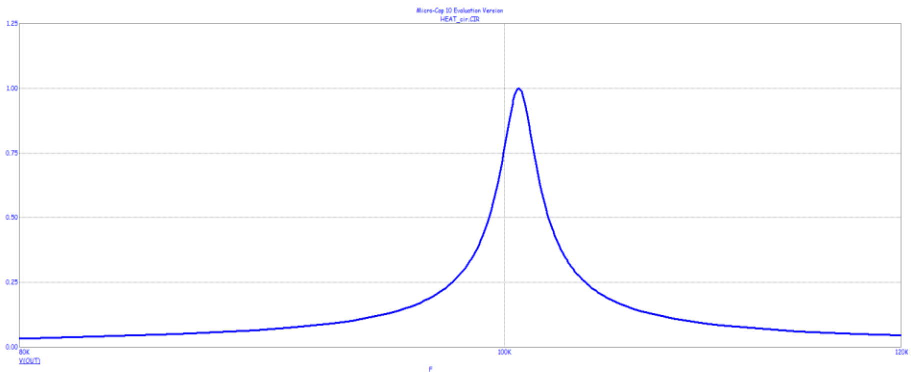

Figure 8

The frequency amplitude characteristic of the resonant circuit with an air-core coil

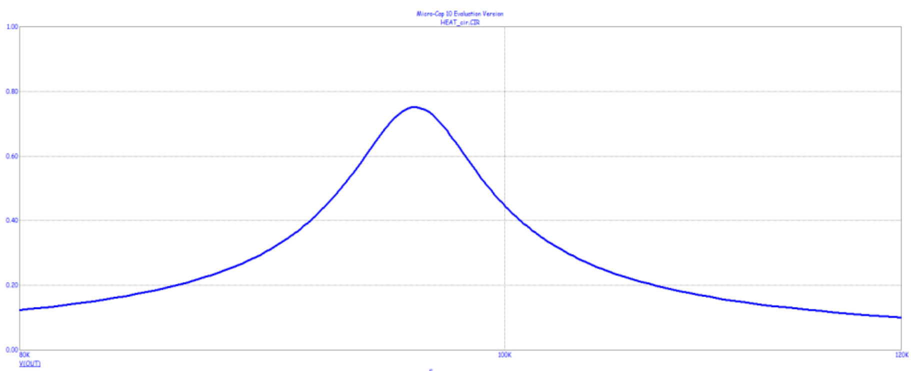

Figure 9

The frequency amplitude characteristic of the resonant circuit with an iron-core coil

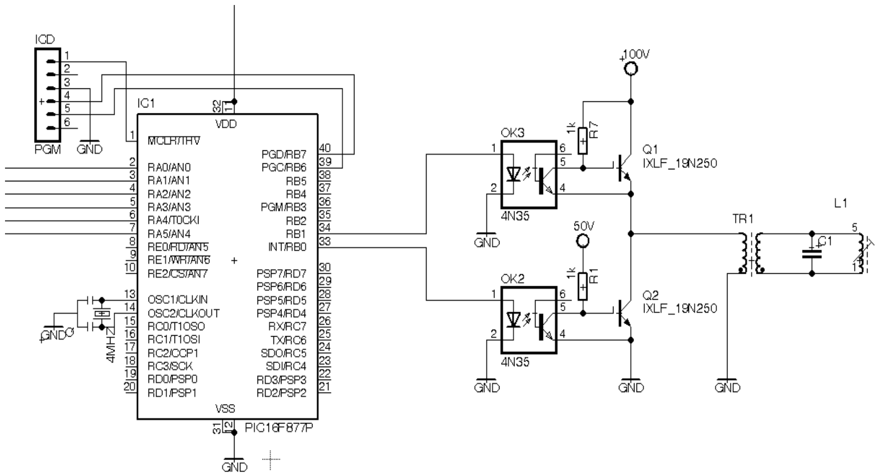

Figure 10
The power electronics fitting to the output of the microcontroller

4.2 Power Control

The heating equipment power depends on the parameters of the coupled resonant circuit (Fig. 5; R_i, L_i, C_i) and the excitation frequency value (f_{osc}). Fig. 8 shows that the R_i coupled resonant circuit behaves as a band-pass filter [3]. Thus, the magnetic energy of the coil (and?) the heating power is a function of frequency, as can be observed in figures 8-9 when the own frequency oscillating circuit is different. The voltage on the coil is reduced, together with the induction power, as described in the equation (4) as well. The *U-f* characteristic, Q factor of the resonant circuit due to the inserted object changes with the resonance frequency [2].

Fig. 9 also shows that the bandpass filter characteristic is flatter so the power control is finely influenced by varying the frequency. If it is known how much bigger the maximum power is than a given target, the frequency can be tuned and reduce the power. For practical reasons, the frequency is decreased. The reduction of power happens depending on the condition of an external control (Fig. 5 *P* potentiometer) or even on the basis of a look-up-table.

Fig. 11 of the experimental device is shown during operation [10].

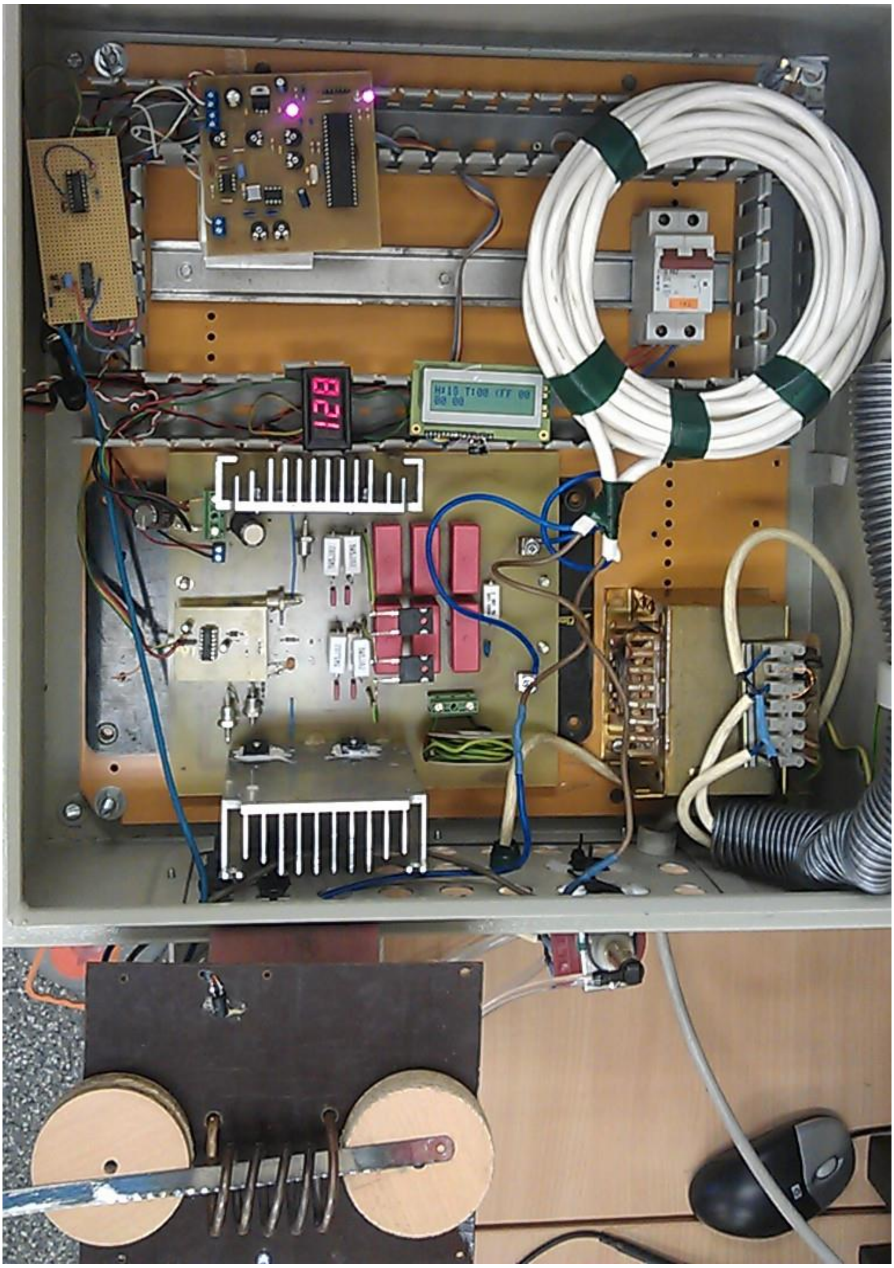

Figure 11
The view of the open induction equipment. The board of the microcontroller is seen below

Conclusions

In the third and fourth chapter we have shown the difference between the traditional and the proposed structure of induction heating equipment. We have shown that with a frequency-dependent load via changing the operating frequency, the electric power can be controlled.

The above applications have band-pass characteristic of the load, but it will be appreciated that in appropriate circumstances, low-pass, high-pass or band-stop filter characteristics can be used in the method.

In most cases, such a frequency-dependent transfer characteristics of the load can be implemented. To do this knowing the optimum operating frequency of the microcontroller, we should use external reactant elements to establish the desired filter characteristics.

The proposed procedure (and?) the desired performance stability can be achieved without the application of a precision power supply.

Acknowledgement

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