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ELECTRONIC ENGINEERING

Design and Implementation of 2kHz Inverter for Induction Hardening Machine

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***Abstract*— Induction hardening machine is to change the structure of chemical and physical properties of materials, usually metals, in order to improve their properties in relation to a particular application. This machine is based on the high frequency induction heating, electrical and electronic technologies. The use of electronic controls in induction hardening machine is a new area industrial electronics. From the electronic point of view, induction hardening machines are composed of rectifier, inverter and protection system. In this project, SCRs are selected as electronic switching devices for inverter circuits. By controlling the SCRs, the desired high frequency and power to harden the materials can be obtained. This paper concentrates on designing and implementing of medium frequency inverter circuit for induction hardening machine aiming to be a good local product considerably comparable with foreign counter-parts in terms of cost. Design has been approached by surveying the induction hardening machines installed at No.4 Farm machinery industry, Kyaikkalo in Yangon and theoretical concepts are described in detail in this paper.**

***Keywords*— Induction hardening, chemical and physical properties of materials, a new area industrial electronics, SCRs, electronic switching devices**

I. INTRODUCTION

Induction hardening machines are widely used in industrial applications. They can harden the shafts, gears, bots and nuts, engine cylinders etc. by using a very large amount of electrical power at high frequency. The two main portions of induction hardening machines are high frequency generation and load coil. Only high frequency generation portion will be emphasized in this article. The main frequency conversion process uses motor generator sets, spark-gap converters, electron-tube oscillators and thyristorised power supplies. Choosing the best strategy is the challenging matter and the optimized design for this strategy is essential to the success of project implementation in an efficient and economical way. The thyristoried method, the latest technique, is applied to this system. The solution to get the required frequency and power are the focuses of this article. The basic block diagram of an induction hardening machine is shown in Fig. 1.

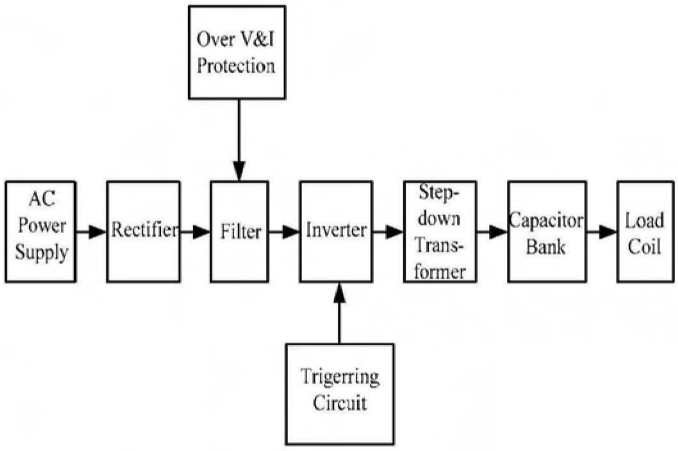

Fig. 1 Block diagram of induction hardening machine

Firstly, the 50 Hz single-phase AC power supply is rectified by single-phase full-controlled rectifying circuit which contains four diodes. The rectified output voltage contains ripple. So, filter circuit (induction coil) is used to eliminate the ripple. The filter coil has two functions: to eliminate the ripple and to provide the constant DC output power. The output of filter is nearly pure DC and is fed to the single-phase bridge parallel connection inverting circuit which is composed of four SCRs with triggering control. Using this inverter circuit, the filter output power can be converted to single-phase 2 kHz, 1kW AC power.

This output power is sent to load coil by passing through the step-down transformer and capacitor bank. The capacitor bank has two functions. One is to provide force commutation of SCRs. And another is to compensate power factor of the machine. The lagging effect of power factor due to the inductor coil is compensated by means of a compensating capacitor bank. The output frequency is tuned by capacitor bank and load coil. Step-down transformer is used to increase the output current passing through the load coil. Finally, the output frequency with high current is passed through the load coil and makes the work-piece to harden the required depth.

II. Theory of Induction Heating and Induction Hardening

Induction heating is a non-contact heating process. It uses high frequency electricity to heat materials that are electrically conductive. Since it is non-contact, the heating process does not contaminate the material being heated. It is also very efficiently since the heat is actually generated inside the work-piece.

In this process, the induced e.m.f is responsible for the production of heat. Low frequency heating was known as early as in the end of the 18^{th} century. The application of high frequency induction heating came gradually after the Second World War.

Induction heating is also known as eddy current heating because, the heat produced is due to the eddy current losses taking place in the system. This type of heating is used in melting, forging, surface hardening, brazing, and soldering operations.

A. Principle of Induction Heating

The principle of induction heating is explained with the help of a set-up shown in Fig. 2. The metallic job called charge is kept within the alternating magnetic field. When alternating voltage e is supplied across the job coil, as shown in Fig. 2 and alternating current I starts flowing in the job coil. This current produces an alternating magnetic field. The metallic job placed in this field cuts the alternating magnetic flux and produces an induced emf given by

$$e = \left\{ -N\frac{d\varphi}{dt} \right\} \quad (1)$$

Where,

N= the number of turns in the job coil (N is unity for a single turn)

φ = magnetic flux

$\frac{d\varphi}{dt}$ = rate of change of flux

The alternating currents produced by the induced e.m.f e, are known as the eddy currents. This eddy current will be responsible for generating the required amount of heat. In fact, the heat will be produced in the form of eddy current losses. As the supply frequency is increased the eddy current losses will increase which will cause more amount of heat to be produced. Thus for a large amount of heat, high frequency AC is used. Skin effect which is also dependent on the value of frequency has an important bearing on the process of induction.

Eddy current losses can be expressed by the equation.

$$W_e = K \times f^2 \times B_m^{\ 2} \times V \quad (2)$$

Where,

K= empirical property of the material

f= frequency

B_m= maximum flux density

V= volume of the core

It is clear from equation 2 that the watt loss in the form of heat produced is directly proportional to (1) the square of the supply frequency (2) the square of the maximum flux density and (3) volume of the object. The supply frequency has another important effect of depth of penetration of the heat due to skin loss called the hysteresis loss which is responsible for the total heat generated. Hysteresis loss is given by

$$W_h = K \times B_m^{\ 1.6} \times V \times f \quad (3)$$

It is seen from equation 3, the hysteresis loss varies in proportion to the supply frequency, the 1.6 power of maximum flux density and volume of the core. An important point to note is that hysteresis loss takes place only up to the curie temperature. Above that temperature this loss does not exist because the magnetic properties vanish. This loss only takes place in the case of materials.

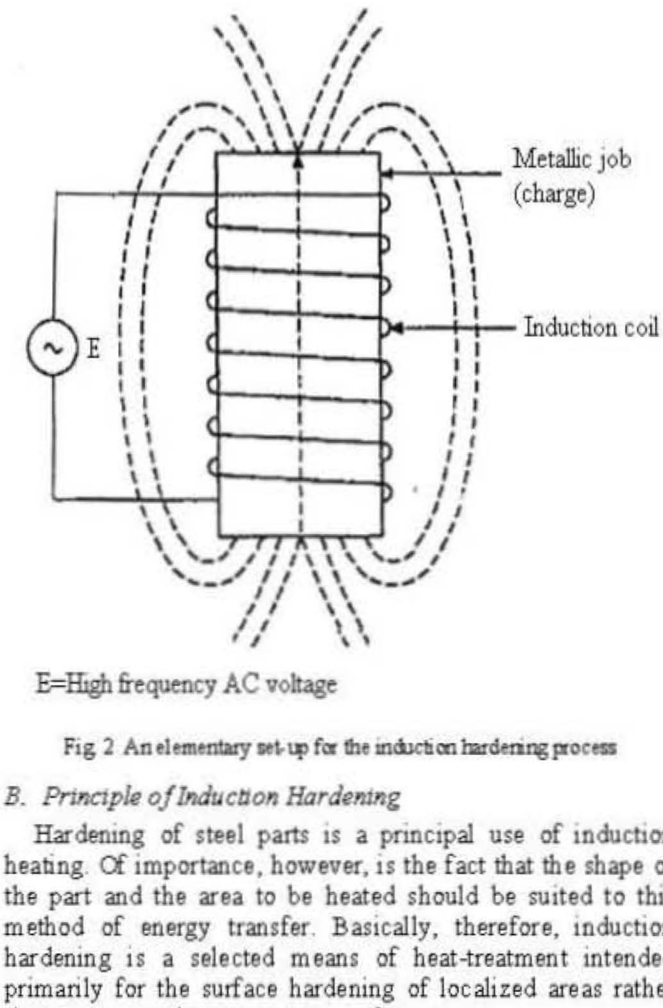

Fig 2 An elementary set-up for the induction hardening process

B. Principle of Induction Hardening

Hardening of steel parts is a principal use of induction heating. Of importance, however, is the fact that the shape of the part and the area to be heated should be suited to this method of energy transfer. Basically, therefore, induction hardening is a selected means of heat-treatment intended primarily for the surface hardening of localized areas rather than as a general-purpose means of treatment.

Essentially, there are two forms of hardening. A steel part can be "through hardened", that is heat-treated in such a way that the inside of the component is as hard as the outside. Or it can be "surface hardened", in this case, the core of the component remains malleable whilst the outside surface attains the desired hardness value.

Where induction hardening can be applied, it has definite advantages. These are (1) rapid heating with large production possibilities, (2) uniform control so that rejections are reduced or eliminated, and, as a rule, (3) economical heating costs, especially where only localized areas are treated.

The speed at which a metal part is heated depends on several factors, the most important being the relation of the available power to the area being heated referred to as kilowatts per square inch, the type of work coil used and its location in respect to the work's surface, and the resistively of the metal being heated. Since the resistively of most steels is fairly equal, power output and coil characteristics the basic considerations for induction hardening. There must be enough electrical energy flowing through the coil to generate the desired amount of heat in the surface of the work. For case-hardening steel parts, where a fast heat rise is necessary so that heating is restricted almost entirely to the surface, a value of from 5 to 10 kW per sq- in of surface may be needed. In some instances, where a restricted case hardness is desired, higher concentrations may be satisfactorily heated for hardening at about 2 to 3 kW per sq-in. At this value, however, unless the part is small a greater amount of thermal heat conduction below the surface will results, and the overall heating time will be increased somewhat proportionately.

III. Design Consideration for Inverter and Triggering Circuits

Inverters are static circuits (that is, they have no moving parts) that convert DC power into AC power at a desired output voltage or current and frequency. The output voltage of an inverter has a periodic waveform that is not sinusoidal but can be made to closely approximate this desired waveform. These are many types of inverters, and they are classified according to number of phases, use of power semiconductor devices, commutation principles, and output waveforms.

A. Current Source Inverter (CSI) with Parallel Resonant Load

High-frequency power is required for induction heating and melting. The load in this case can be regarded as a variable inductance compensated by a capacitor. A current-fed bridge inverter as shown in Fig. 3 with a parallel-resonant load is taken for analysis.

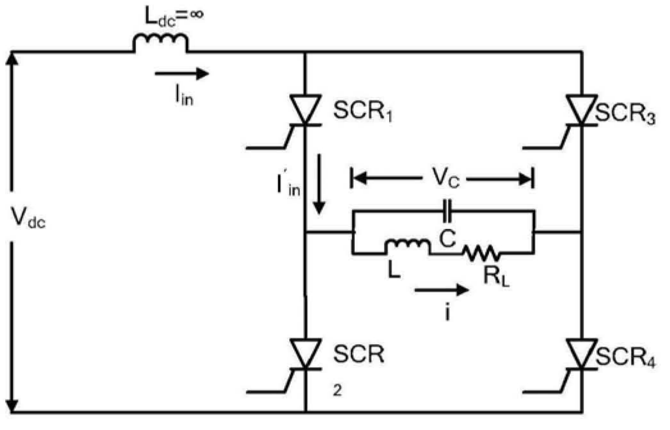

Fig. 3 Current-fed bridge inverter with parallel resonant load

In the above circuit, the inductance L_{dc} is so large that the input current remains constant and a square-wave current is impressed on the resonant-load circuit. The load voltage is nearly sinusoidal. The SCRs are turned off by the reactive power supplied by the load itself, provided the inverter operating frequency is equal to the resonance frequency of the load. In this circuit, no separate turn-off arrangement is required.

B. Oscillator (Starting Circuit for Inverter Triggering Circuits)

Design Requirement: 2 kHz oscillation signal

Based on NE555 IC specifications operating in astable mode,

$$t_H = 0.693\,(R_A + R_B)\,C \quad (4)$$

Where,

t_H= on time

$$t_L = 0.693\,R_B C \quad (5)$$

Where,

t_L= off time

$$f = \frac{1.44}{(R_A + 2R_B)C} \quad (6)$$

Where,

f = frequency

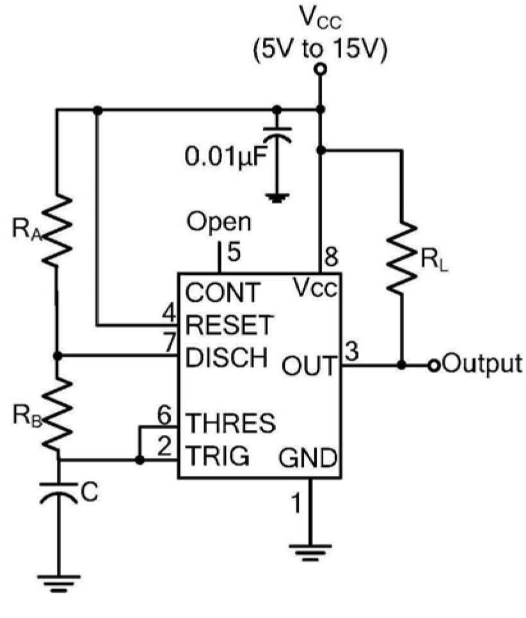

Fig. 4 Starting circuit for inverter triggering circuit

C. Dual Timer Circuit for Inverter Triggering Pulses

Design Requirement: Producing pulses to feed the SCR gates

Based on NE556 dual timer operating in monostable Mode, R_A and C can be calculated from this equation.

$$\text{Delay Time, } T = 1.1 R_A C_1 \quad (7)$$

$$f = \frac{1}{T} \quad (8)$$

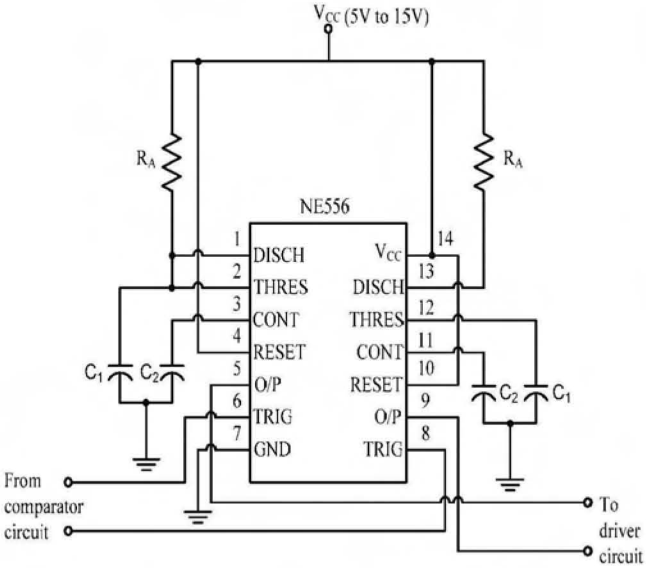

Fig. 5 Dual timer circuit for inverter triggering pulses

IV. Configuration of the Implemented Circuits

The implemented circuit can be classified into sub-circuits and can be represented with the block diagram shown in Fig. 6. Schematic overall circuit diagram is shown in Fig. 8. It uses linear ICs and these ICs are NE555, LM339 and NE556.

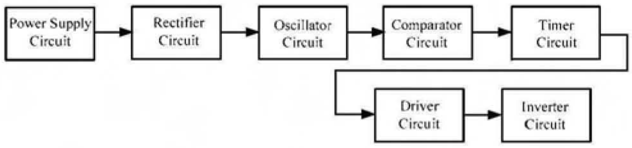

Fig. 6 Block diagram of implemented project

In this circuit, NE555 timer operated in astable mode is used as oscillator. And LM339 op-amp IC is used as zero-crossing detector. NE556 IC is used in monostable mode to produce the 20μs triggering pulse. The two MOSFET (IRF 830) comprises a driver for SCRs. And pulse transformers serve as electrical isolation between SCRs and drive circuits.

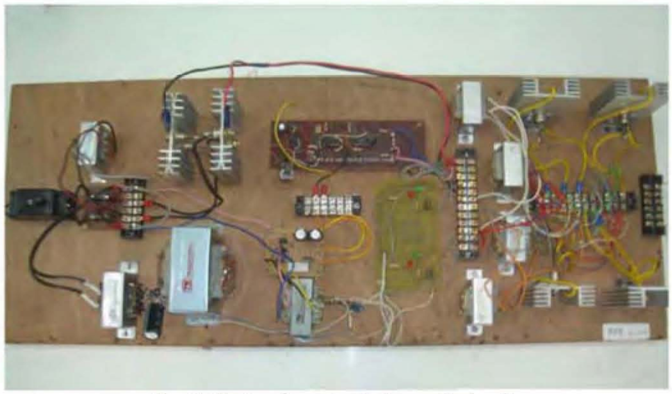

Fig. 7 Photo of constructed overall circuit

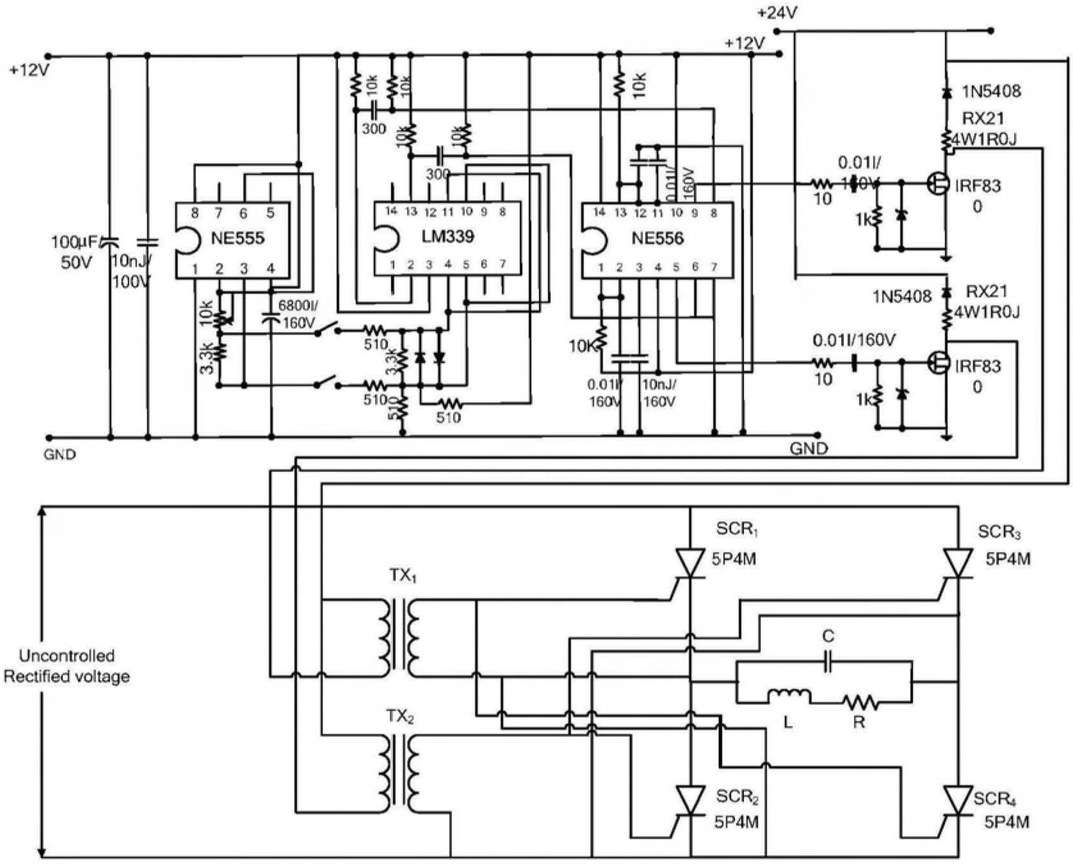

Fig. 8 Schematic circuit diagram of overall circuit

V. Experimental Testing

Prior to assembling the final product, testing has been done to make sure that required output signal waveforms are in the reasonable range. The final stage's output waveform, input to the SCRs, is shown in Fig. 9. This signal has been measured at the output terminals of the pulse transformer and it is the required triggering pulse for the current source inverter circuit. According to the adjusted settings of the oscilloscope, the reading shows that the measured signal is the 2 kHz pulse train which is the expected output.

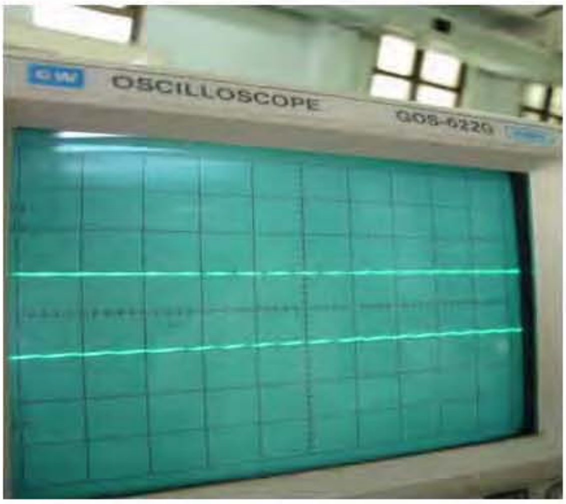

Fig. 9 Test result of SCR input waveform

VI. Conclusions

In this project, the implemented circuit has been designed based on surveying and theoretical approaching. It is mainly composed of rectifier, inverter and other circuits. Inverter portion is the main topic of this article, and it can generate the high frequency AC output for induction hardening and gives satisfactory result. In this paper, single-phase full-wave bridge rectifier is used to get constant DC power and single-phase full-wave parallel inverter is used to obtain the desired AC power. For inverter portion, current source inverter is selected to produce high frequency output and it can provide constant current to load coil. In this inverter, SCRs are selected as the switching devices because they can operate with the highest power among other switching devices. And so, this inverter is designed as a thyristorised inverter. Thyristors are triggered with pulse gating and triggering circuit is designed to generate the gate pulses at 2 kHz frequency. Three are two flexiblilites in designing triggering circuit. First is that it can easily change the operation frequency according to the load and the second preferable fact is that it is suitable for any types of SCR by adjusting the triggering pulse width. The pulse width transformer is used to isolate the SCRs and triggering circuit. In conclusion, this project has been designed with the locally available components to get the optimum performance.

Acknowledgment

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