A 64 kHz Frequency Control Using BRM for Induction Heating

K.Jamjan * , P.Thepsatorn **, A.Charean *** and V.Tipsuwanporn ****

* Dept. of Electrical Engineering ,Faculty of Engineering , Saint's John University, Bangkok,Thailand.
** Dept. of Electrical Engineering ,Faculty of Engineering , Srinakarinwirot University, Nakornnayok ,Thailand.
*** Dept. of Electrical Engineering ,Faculty of Engineering , Kasem Bundit University, Bangkok,Thailand.
***** Faculty of Engineering , King Mongkut's Institute of Technology Ladkrabang , Bangkok,Thailand.
Tel: (66-2) 326-7347 : Ext. 102; E-mail : ktvittay@kmitl.ac.th

Abstract: This paper proposes a method for controlling energy distribution to 1 phase induction heating coil by using the Binary Rate Modulation (BRM) Technique. Such method provides proper frequency to the heating coil's requirement by control the frequency at the resonance point, that is, 64-kHZ frequency band. System design are classified to 2 parts. The first part determines main frequency , and the second part generates the frequency from the 8-bit BRM derived from IC no. PAL22V10 in order to control the frequency for Full-bridge connected inverter when supplying the energy required by the 1 phase induction heating coil. Therefore, efficiency of the energy supply can be increate.

Keyword: Resonance frequency , Introduction Heating coil

1. INTRODUCTION

Generally, the introduction heating coil is controlled by using Half-Bridge or Full-Bridge Inverter which employs thyrister through the following control techniques :

- Frequency Control Based Power Control
- Pulse Width Modulation Based Power Control
- Duty Control Based Power Control

Employing the thyrister causes the circuit large, energy waste and high cost. Therefore , this research will apply the BRM technique [1-3] to control electrical energy distribution for the induction heating coil. Such technique can use the 1 ϕ or 3 ϕ AC signal to determine he control signal as required by supplying main control frequency signal deriving from MCS-51 to the heating coil, resulting the main frequency to be reduced when comparing to the PWM control [4] . The method can be applied to control adjustment of the resonance position for the heating coil by using the MCS-51 automatically.

2. PRINCIPLE

2.1 Induction Heating

Induction heating occures from electrical and heating phenomenon based on electromagnetic Induction , Skin Effect , and Heat Transfer. When supplying the AC signal to magnetic coil which specimen is installed inside. The AC signal will induce magnetic field crossing the induction coil, so that , if the specimen is magnetise the magnetic field crossing the specimen will induce current flow. Mostly , specimen in skin deep level while the flowing paths are closed loops conducting heat on the specimen's skin. Such heat which depends on the induction current and equivalent resistance of the flowing paths will be transferred to neighborhood through radiation , convection , and conduction at the Skin.

Fig.1 demonstrates simple induction heating method. If the specimen is installed inside or near the induction coil , the specimen will be induce and the heat will occur. Considering the system as a transformer unit , the induction coil performs as primary coil whose turn equal to the turn of induction coil and the specimen perform as one-turn secondary coil connecting to a load like short circuit due to the equivalent resistance of the specimen is relatively low.

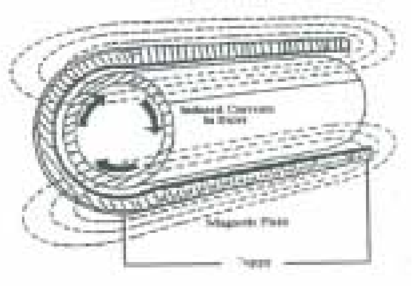

Fig. 1 Simple introduction heating.

Fig. 2 demonstrates equivalent circuit of the induction coil and the specimen. Giving I_c as the current flowing in the induction coil and I_w as the current flowing in the specimen , these two currents are related as follows :

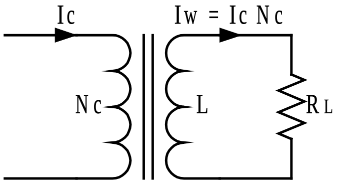

Fig. 2 Equivalent induction heating circuit.

$$I_w = N_c I_c \tag{1}$$

where N_c is the equivalent resistance of specimen

Heating losses , P_w , in the specimen equals to

$$P_w = N_c^2 I_c R_w \tag{2}$$

where $$K = 2\pi f \mu_o \left(\frac{N_c^2}{I_c} \right) \quad \Omega / m \tag{3}$$

Form equation (1) to (3) , property of the induction coil can be calculated as shown

Induction coil efficiency

$$\eta = \frac{R_w}{R_c + R_w} \qquad (4)$$

Induction coil power factor

$$Cos\phi = \frac{R_w + R_c}{Z_2} \qquad (5)$$

where

$$Z_2 = (R_w + R_c)^2 + (X_c + X_w + X_g)^2 \qquad (6)$$

Induction Coil Power

$$P = \frac{P_w}{\eta} \qquad (7)$$

Apperrent in induction coil power

$$coil\ VA, (VA) = \frac{P}{cos\phi} = I^2 Z \qquad (8)$$

Induction voltage per turn

$$\frac{E_c}{N_c} = \frac{(coil,VA)}{Total\ \ Ampere - Turn} = \frac{(VA)^2}{H_o I_c} \qquad (9)$$

$$coil\ \ Ampere - Turn, I_c\ N_c = H_o\ I_c \qquad (10)$$

2.2 Principle of BRM signal Generation

Principle of 8-bit BRM signal generation and related equation are derived from reference [1]and [3]. The reference [1] described the control of heating coil by the 1ϕ AC signal. The reference [3] described the control of 3ϕ induction motor speed .Therefore , this paper will demonstrate the 8-bit BRM signal as shows in Figure 3

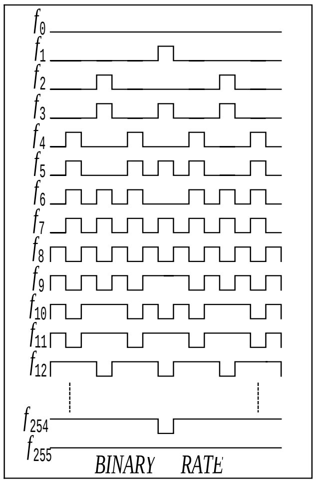

Fig. 3 8-bit BRM signal patterns.

3. HARDWARES OF SYSTEM CONTROL

3.1 Structure of System Control

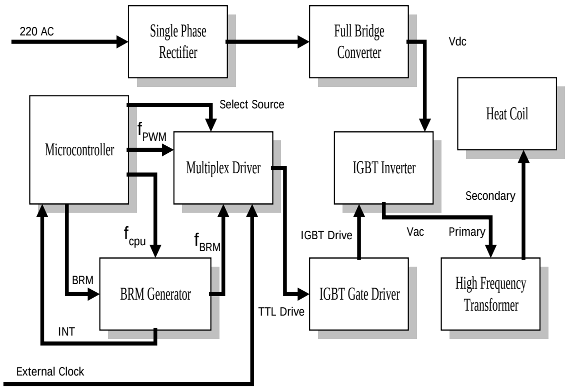

Fig. 4 hardwares of structure of system control.

Fig. 4 demonstrates structure of the 1ϕ induction coil control which can be divided into 7 parts as follows :

Main Controller Unit

Using microcontroller to receive instruction from user , control demonstrations on 7 segment , determine the BRM and PWM signal patterns , process the main frequency control values for the BRM and PWM signal generator , including control each trix timing of the BRM signal for the IGBT Driver through Multiplex Driver.

BRM Generator Unit

Using IC no. PAL 22V10 to generate the BRM signal whose trixing signal pattern are provided by the microcontroller. The unit has protection circuit for false phase trixing which may damage the IGBT Inverter.

IGBT Gate Drive Unit

Adjusting the signal derived from the Multiplex Driver to suitable for the IGBT Gate in the IGBT Inverter unit.

Rectifier Unit

Rectifying the 1ϕ AC signal to full wave form and then converting to be DC voltage.

IGBT Inverter Unit

Supplying power to primary side of High frequency transformer according to frequency value and pattern determined by the microcontroller.

High Frequency Transformer Unit

Supplying driving power from the IGBT Inverter to the induction coil.

Heating Coil Unit

Generating high frequency magnetic field at Resonance position for distributing heat to the metal.

3.2 Calculation of Main Control Frequency between BRM and PRM

The main control frequency generated by the microcontroller can be derived from the following equation:

$$f_{CPU} = \frac{f_{OSC}}{2\times D_{OCR}} \qquad (11)$$

where f_{CPU} is the main control frequency generated by the microcontroller

f_{OSC} is Microcontroller clock signal

D_{OCR} is Divided frequency value in the microcontroller

From equation (11) , PWM frequency is given as follow:

$$f_{PWM} = \frac{f_{CPU}}{256\times 2} \qquad (12)$$

where f_{PWM} is the PWM frequency in the induction coil

f_{CPU} is the main control frequency generated by the microcontroller

From equation (11) the BRM frequency is calculated from

$$f_{BRM} = \frac{f_{CPU}}{256\times 2}\times(255-P_{BRM}) \qquad (13)$$

Where f_{BRM} is the BRM frequency in the induction coil

P_{BRM} is the BRM energy supply pattern

So that, equations of induction coil BRM and PWM frequency are obtained as follow :

$$f_{PWM} = \frac{f_{OSC}}{1024\times D_{OCR}} \qquad (14)$$

$$f_{BRM} = \frac{f_{OSC}}{1024\times D_{OCR}}\times(255-P_{BRM}) \qquad (15)$$

And equation for calculating the divided frequency value in the microcontroller are

$$D_{OCR} = \frac{125}{16\times f_{PWM}} \qquad (16)$$

$$DCR_x = \frac{125\times(255-P_{BRM})}{16\times f_{BRM}} \qquad (17)$$

Where $f_{OSC} = 8\ MHz$

According to the equation (4) and(5) the frequency generated from f_{BRM} and f_{PWM} are shown in Table 1. Results from the Table shows that by using the PWM principle the frequency are determined between 0.03-15.69 kHz By using the BRM principle the Frequency are determined between 0.03-2007.84 kHz.

Table 1 Limits of f_{BRM} and f_{PWM}

Range	fpwm	fbrm							
		f127	f191	f223	f239	f247	f251	f253	f254
Max(kHz)	15.69	2007.84	1003.92	501.96	250.98	125.49	62.75	31.37	15.69
Min(kHz)	0.03	3.94	1.97	0.98	0.49	0.25	0.12	0.06	0.03

In this paper , the 1ϕ induction coil is controlled by mean of frequency control at resonance frequency ; e.g. 64 kHz , however , the PWM principle could not perform at high frequency as shows in Figure 5. The figure illustrates relation of f_{PWM} when varing the OCR_x value for controlling fundamental frequency.

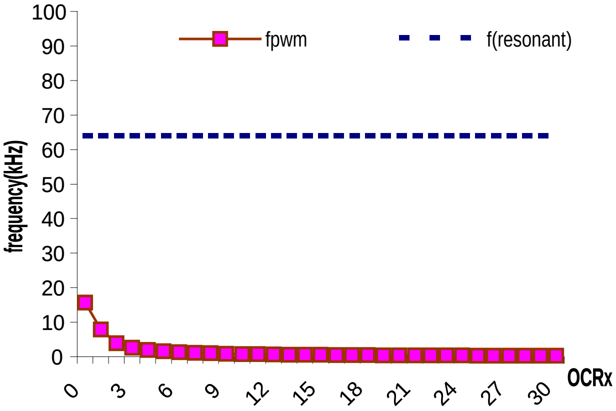

Fig. 5 Relations between f_{PWM} and OCR_x .

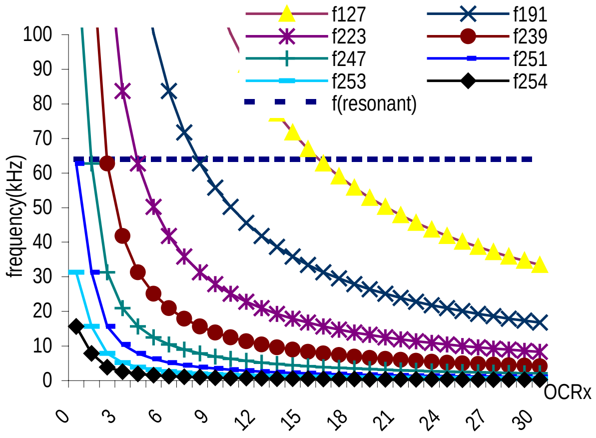

Fig. 6 Relations between f_{BRM} and OCR_x .

Fig. 6 demonstrates various patterns of the f_{BRM} such as 127 , 191 , 223 , 239 , 247 , 251 , 253 , and 254 which can see that each pattern can determine the resonance frequency for control the 1ϕ induction heating coil excepting the pattern 253 and 254 whose maximum frequency are 31.37 and 15.6 kHz , respectively.

4. EXPERIMENT RESULTS

4.1 Off-loading Energy Distribution to the Induction Heating Coil

Table 2 Performance in normal condition.

OCRx	BRM	I_{in}	V_{out} (Volt)		I_{out} (Amp)		F	Temp
Data	Pattern	Amp	Primary	Secondary	Primary	Secondary	kHz	$^{\circ}C$
1	251	7.0	102.4	10.2	5.1	51	64.23	-
2	247	7.2	103.2	10.7	5.4	54	65.78	-
3	239	7.1	101.7	11.1	5.0	50	65.37	-
5	223	6.0	104.5	10.2	4.2	42	64.11	-
9	191	4.2	106.8	10.5	3.3	33	64.90	-
16	127	1.5	100.5	10.1	1.3	13	65.87	-

4.2 Loading Energy Distribution to the Induction Heating Coil

At 100 V_{p-p} , f_{BRM} = 64 kHz , recording data after working 1 minute

Table 3 Performance in loading condition at 100 V_{p-p} .

OCRx	BRM	I_{in}	V_{out} (Volt)		I_{out} (Amp)		F	Temp
Data	Pattern	Amp	Primary	Secondary	Primary	Secondary	kHz	$^{\circ}C$
1	251	7.3	102.3	10.2	5.2	52	65.12	590
2	247	7.4	101.6	10.1	5.5	55	65.15	585
3	239	7.2	103.1	9.9	5.2	52	64.52	575
5	223	6.1	106.3	10.2	4.3	43	64.94	562
9	191	4.3	103.1	10.3	3.2	32	65.94	100
16	127	1.4	104.7	10.5	1.2	12	65.68	80

4.3 Loading Energy Distribution to the Induction Heating Coil At 256 V_{p-p} , f_{BRM} = 64 kHz recording data after working 1 minute

Table 4 Performance in loading condition at 250 V_{p-p} .

OCRx	BRM	I_{in}	V_{out}(Volt)		I_{out}(Amp)		F	Temp
Data	Pattern	Amp	Primary	Secondary	Primary	Secondary	khz	$^{\circ}C$
1	251	13.0	263.2	26.1	11.5	115	64.20	610
2	247	12.0	265.6	25.8	10.7	107	66.67	610
3	239	11.2	268.8	27.2	9.1	91	67.11	615
5	223	10.1	284.4	27.8	8.8	88	63.69	604
9	191	5.8	260.5	26.5	4.3	43	67.00	562
16	127	2.4	258.7	24.2	1.9	19	65.00	100

4.4 Demonstrations of Temperature change comparing to the time

At BRM pattern 247 , 250 V_{p_p} , f_{BRM} = 64 kHz

Table 5 Relation of temperature change and time in loading condition at 250 V_{p-p} .

Time(sec)	Temperature ($^{\circ}c$)
0	0
5	80
10	150
15	280
20	470
25	585
30	604
35	610
40	610
45	610
50	610
55	610
60	610

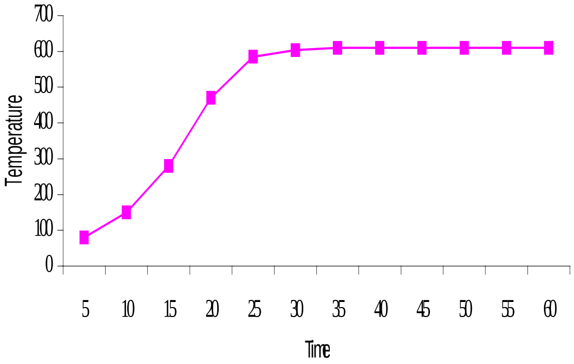

Fig.7 Temperature changer comparing to the time.

4.5 Demonstrations of Signal Patterns

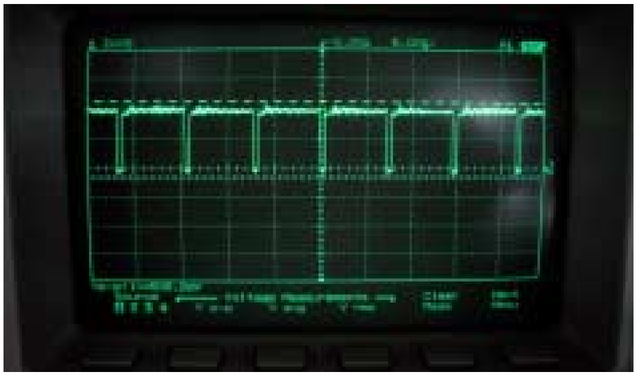

Fig. 8 BRM signal pattern 247 , 64 kHz.

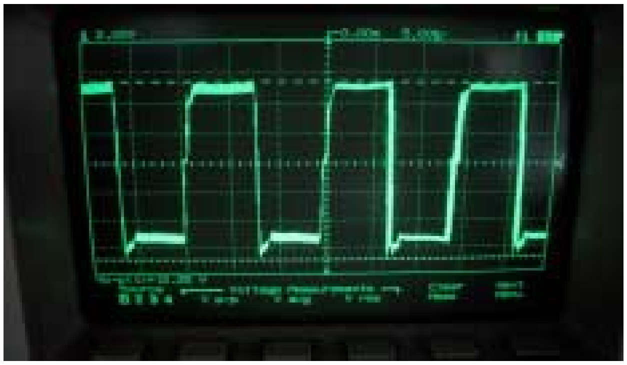

Fig 9 Driven signal of High Frequency Transformer at primary side (64 kHz).

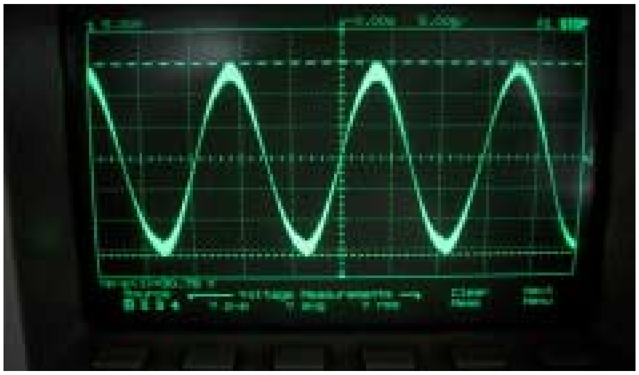

Fig. 10 Signal of the Induction Heating Coil (64 kHz).

Fig. 11 Energy Distribution at 250 V_{p-p} in Primary High Frequency Transformer BRM pattern 247.

5. CONCLUSION

Experiment results shown that energy distribution through BRM principle can supply energy at high frequency. Due to symmetric pattern transform of BRM , there were 8 patterns for determining the frequency at 8-bit BRM which each level doubles the load frequency while the main frequency is remained . Therefore , frequency control through the microcontroller is simple and practical frequency band are wider when comparing to application of 8-bit PWM principle which determine the supply frequency through only single main frequency and need very high main frequency causing automatic control at resonance for determining frequency to the load is difficult . Therefore , energy supply control by BRM principle is suitable to high frequency loading and automatic control through the microcontroller.

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