

# ZCS-PFM Series Resonant High Frequency Inverter for Electromagnetic Induction Eddy Current-Heated Roller

Sang-Pil Mun<sup>(1)</sup>, Sang-Hwa Jung<sup>(1)</sup>, Chang-Il Kim<sup>(3)</sup>, Sang-Don Kim<sup>(2)</sup>, Mutsuo Nakaoka<sup>(1)(4)</sup>

<sup>(1)</sup>Kyungnam University/Dept. of Electrical Engineering, Masan, Korea

TEL : +82-55-249-2835, FAX : +82-55-249-2839, E-mail : mun2630@kyungnam.ac.kr

<sup>(2)</sup>Gyeongnam Animation High School, Korea

<sup>(3)</sup>Gyeongnam Provincial Namhae College/Dept. of Electricity, Korea

<sup>(4)</sup>Yamaguchi University/Dept. of Electrical and Electronics Engineering, Yamaguchi, Japan

**Abstract** - This paper presents a novel prototype of ZCS-PFM high frequency series resonant inverter using IGBT power module for electromagnetic induction eddy current-heated roller in copy and printing machines. The operating principle and unique features of this voltage source half bridge inverter with two additional soft commutation inductor snubber are presented including the transformer modeling of induction heated rolling drum. This soft switching inverter can achieve stable zero current soft commutation under a discontinuous and continuous resonant load current for a widely specified power regulation processing. The experimental results and computer-aided analysis of this inverter are discussed from a practical point of view.

## I. INTRODUCTION

In recent years, the global warming due to a great consumption of electrical energy becomes a social serious problem from an environmental point of view. In office automation fields, the copy machine is widely used together with information and telecommunication electronics appliances. With the increase of the interest to worldwide global environment, the energy saving power electronics regulation technology has also attracted special interest in office automation field. In the laser printer, after its toner is processed for copying paper, the process supplying a heat to the toner for fixing is indispensable for copying machine. At present, most of system in which the toner is designed to fix using the halogen heated fixing scheme is conventionally introduced in the copy machines. However, there are some problems to be solved such as heating speed, a lot of energy consumption for this consumer application.

In this paper, a high frequency inverter type electromagnetic induction-heated roller for toner fixing process is proposed in place of the conventional halogen heater type, which is based on eddy current induced in the cylindrical rolling drum. The induction heating technology has widely applied in home electronic and household appliances such as electromagnetic induction-heated cooker and hot water producer, since it has some remarkable advantages such as clean, rapid heating, temperature control easiness and efficient energy conversion. Therefore, the electromagnetic induction-heated processing scheme is actively considered for the high-frequency inverter type induction-heated rolling drum in copy machine. A voltage source lossless inductor-assisted half bridge zero current soft switching high frequency inverter with PFM control scheme for commercial utility power supply 200[Vrms] is implemented for this application, and its operation principle and performances are originally evaluated and discussed for induction heated roller drum in the copy machine.

In the first place, the induction-heated roller load of high frequency load resonant inverter is represented using a magnetic flux based transformer circuit model, and the computer-aided simulation analysis of this inverter is developed including circuit parameter measurement. In the second place, it is verified that the proposed high frequency ZCS-PFM inverter such as the voltage source series resonant inverter circuit topologies: half bridge type, center tapped type, full bridge type and boost half bridge type have

particular effectiveness and practicability for toner fixing processing from an experimental point of view. Finally, the operating principle is described and the operating performances is evaluated and discussed on the basis of simulation and experiment.

## II. ZCS-PDM CONTROLLED HIGH FREQUENCY INVERTER

### A. Induction Heating Load Technology

The induction heating of conductive metal and semiconductor materials is based on non-contact direct heating using the electromagnetic eddy current induction principle. Fig. 1 shows a basic principle of electromagnetic induction heated cooking appliances with a pancake type spiral planer coil as litz wire-based working coil for generating high frequency magnetic flux. The pancake type working coil (see Fig. 1) connected the quasi-resonant zero voltage soft switching high frequency inverter using IGBTs generates high frequency magnetic flux. And then, high-frequency magnetic field produced from the working coil makes eddy current in the bottom portion of vessel or pan. As a result, in principle, the bottom portion of this vessel is able to be directly heated on the basis of Joule's law. The Joule's heat is to be specified by resistivity of the vessel material due to eddy current heating. The electromagnetic eddy-current induction heating has excellent unique features such as rapid heating, clean, local part heating and safety. In this paper, induction heating roller drum load composed of litz wire based cylindrical type work coil and cylindrical heating element depicted in Fig. 2 is newly used for a load of the inverter.

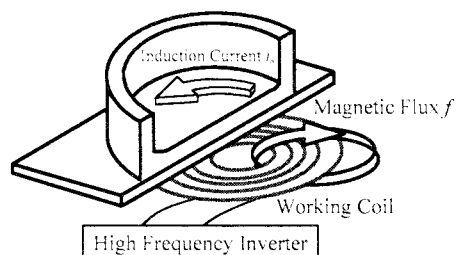


Fig. 1. Induction heating principle

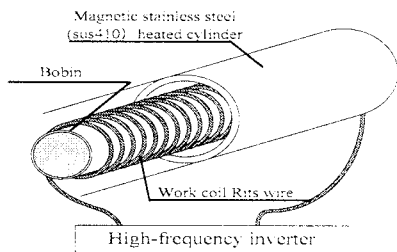


Fig. 2. Induction heating roller with working coil

### B. Circuit Modeling Induction Heating Roller

Fig. 3 shows the structure of heating roller load as a load of this high frequency inverter. In the copy and print machine, toner image adheres to decalcomania paper in the unstable condition, after decalcomania paper separates from the photoreceptor. This toner image is dried by the fixing equipment in which the heating roller consists of the working coil and the fixing roller, and toner image becomes an eternal image. At present, the fixing equipment widely spreads from the low speed to high-speed copy machine and color copy machine for industrial use is heat fixing system, and also halogen lamp system in Fig. 3(a) is introduced in conventional copy machine. The induction heating roller drum which Fig. 3(b) demonstrates is newly adopted as induction heat fixing roller equipment.

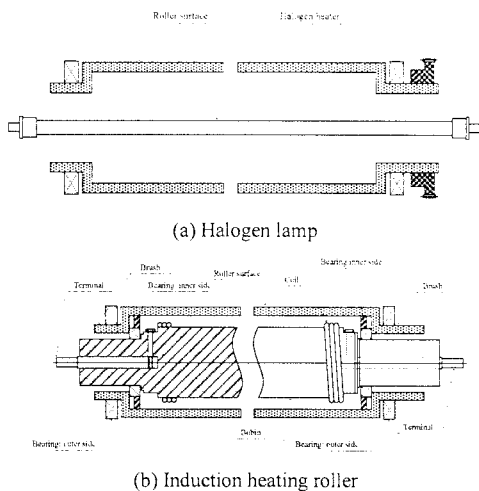


Fig. 3. Sectional view of fixing roller

### C. System Description & Circuits Operation

The proposed lossless inductor snubber-assisted high frequency zero current soft switching inverter using IGBT power module is depicted in Fig.4. The series resonant capacitors  $C_1$  and  $C_2$  are used for the series compensation resonant capacitors, and two lossless inductor snubbers:  $L_{S1}$  and  $L_{S2}$  are respectively connected in series with the active power switching blocks:  $Q_1(S_1/D_1)$  and  $Q_2(S_2/D_2)$ . In this application-specific inverter, both active power switches can respectively operate under stable ZCS commutation in spite of pulse frequency modulation (PFM) scheme. The

output power of this inverter is continuously regulated on the basis of the PFM scheme. The mode transition of this high frequency inverter circuit and its equivalent circuit are shown in Fig.5.

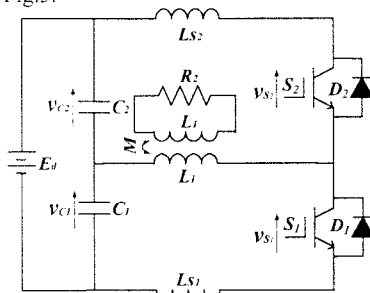


Fig.4. ZCS-PFM high frequency inverter using IGBTs

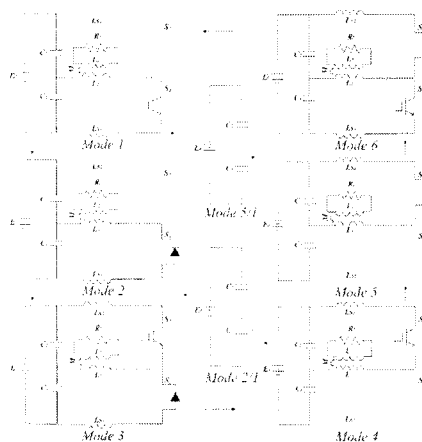


Fig. 5. Mode transitions and equivalent circuits

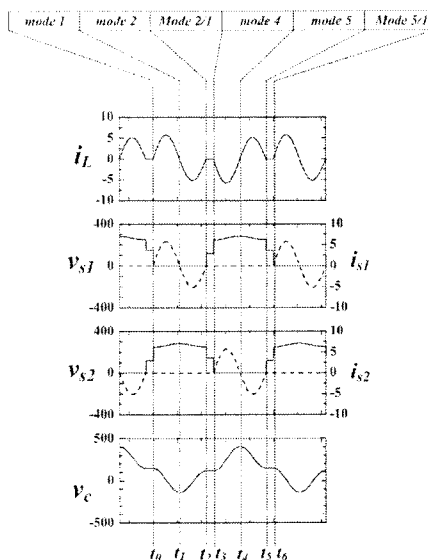


Fig. 6. Steady state operation waveforms in the discontinuous current mode

Periodic steady state voltage and current waveforms of

this inverter under the discontinuous current mode and continuous current mode are respectively illustrated in Fig.6 and Fig.7.

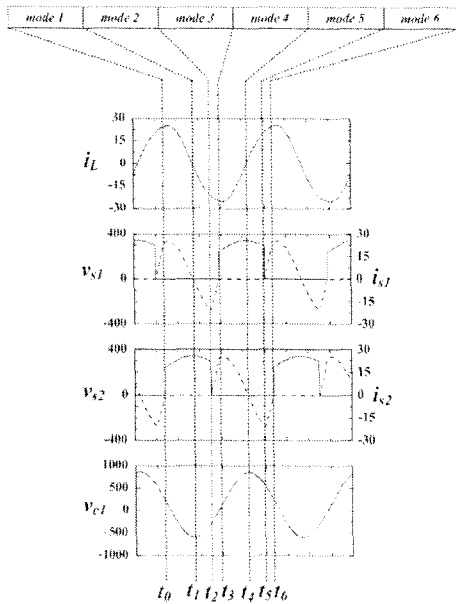


Fig.7. Steady state operation waveforms in the continuous current mode

### III. SIMULATION AND EXPERIMENTAL RESULT

The design specifications and circuit parameters of this inverter breadboard setup are indicated in TABLE. 1. The soft-recovery high-speed diode (USR30P produced by Origin Electric Co. Ltd.) is used in parallel with reverse blocking IGBT(CT75AM-12 produced by Mitsubishi Electric Co. Ltd.) of the TO-3P package for this high frequency inverter circuit. In the case of introducing active power switches; IGBTs in parallel with diode  $Q_1$  and  $Q_2$ , upper limitation of the switching operating frequency is designed as 45kHz, and the lowest operating frequency is designed so as to operate outside the audible frequency region.

The experimental operating waveforms and the simulation waveforms are respectively illustrated in Fig.8 and Fig.9.

TABLE. 1 DESIGN SPECIFICATION

Parameter	Symbol	Value
DC voltage supply	$E_d$	282.8[V]
Resonance capacitor	$C_1, C_2$	0.07[ $\mu$ F]
Lossless inductor	$L_{S1}, L_{S2}$	11.0[ $\mu$ H]
Inductance of work coil	$L_t$	80.0[ $\mu$ H]
Induction-heated roller load	$\tau$	6.0[ $\mu$ S]
	$k$	0.65
IGBT as active power switches	$V_{CE}$	600 [V]
	$I_C$	75 [A]
Reverse conducting diode	$V_{RM}$	600 [V]
	$I_0$	50 [A]

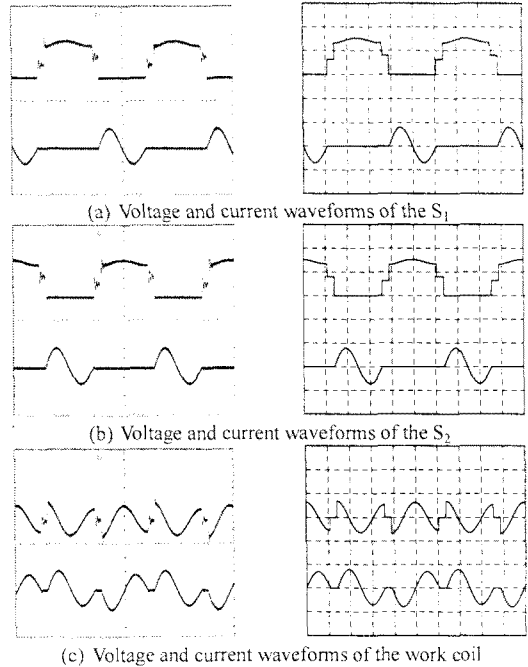
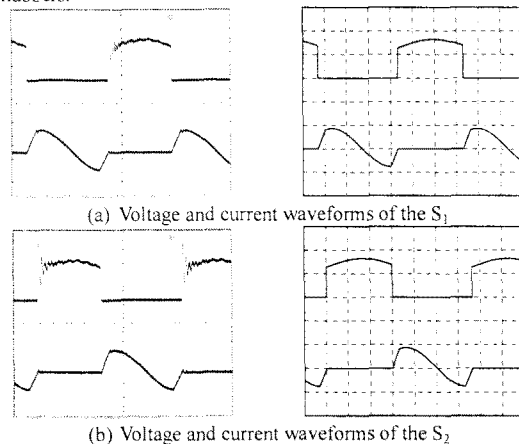


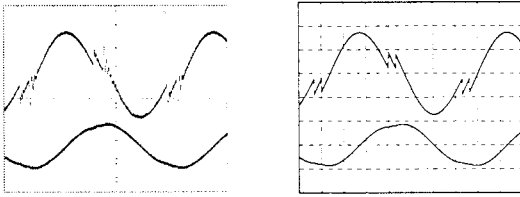
Fig.8. Steady state operation waveforms in the discontinuous current mode(200[V/div], 8[A/div], 10[usec/div])

Fig.8 and Fig.9 display steady state operation voltage and current waveforms in discontinuous current mode under switching frequency  $f_s=20.5$ kHz as well as continuous current mode at an inverter switching frequency  $f_s=37.5$ kHz. The voltage and current waveforms of the active power switching block:  $Q_1$  and  $Q_2$  as well as the working coil depicts the upper traces. The operating waveforms in the left side are observed ones. The operating waveforms in the right side are comparative simulation ones. In addition, voltage and current waveforms are respectively illustrated in upper trace and under trace.

Observing all experimental and simulation operating waveforms, the simulation and experimental results have good agreements, for high frequency load resonant inverter with the induction-heated roller load. It is proven that the power semiconductor switch can completely achieve the ZCS commutation operation even at the current continuous mode with the aid of two lossless inductor snubbers.



(b) Voltage and current waveforms of the  $S_2$



(c) Voltage and current waveforms of the work coil

Fig.9. Steady state operation waveforms in the continuous current mode (200[V/div], 20[A/div], 4[usec/div])

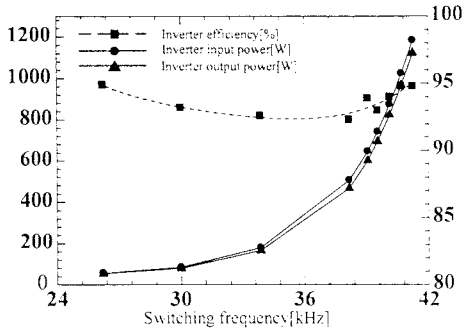


Fig.10. Power regulation characteristics

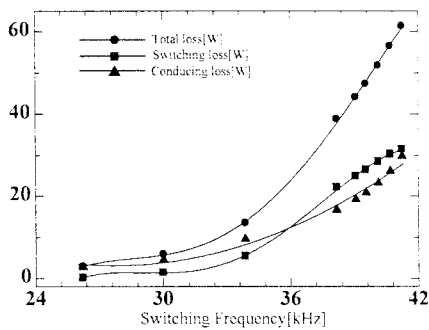


Fig.11. Power loss analysis

Fig.10 shows the power regulation characteristics of the high frequency ZCS-PFM inverter using IGBTs. The input electric power, the output power, power conversion efficiency of the inverter treated are illustrated graphically under a function of the switching operating frequency as a control variable. It is proven that the output power of this inverter can be continuously adjusted by varying switching frequency of this inverter. Over the full output power range, the power conversion efficiency of this inverter is 92% in experiment. In particular, the high efficiency over 94% can be also obtained in the copy mode and standby mode of copy machine using the induction heated fixing unit. It is verified the proposed high frequency load resonant inverter circuit operating under a principle of zero current soft switching is more effective for the future induction-heated rolling drum of the copy machine.

In this circuit, switching loss by fall current and tail current in the turn-off does not occur, because the switch is being turned off, when the current is flowing in the reverse conducting diode of the switch. The power loss are mainly conduction loss of the switch ( IGBT and diode for reverse conducting) and switching loss in the switch turn-on. Then, the switching loss of the inverter can be required using the total loss by test experiment and conducting loss. The power loss analysis result of this inverter is respectively shown in

Fig.11. In high power range (in the copying mode), the inverter power loss it tends to increase, while the switching frequency increases. The current stress  $di/dt$  in switching turn-on be alleviated employing lossless inductor and the switching loss can be reduced. On the other hand, in the lower power range (in the standing mode), the current discontinuous mode occurs, and the switching loss is very small, and it is proven that the conduction loss equals the inverter power loss almost.

#### IV. CONCLUSIONS

A novel prototype of lossless inductor snubber-assisted ZCS-PFM high frequency load resonant inverter using IGBTs for the induction-heated rolling drum for the fixing unit in copy machine was proposed originally, and the steady state operation principle of this inverter was clearly described from a practical point of view. In addition, the steady state operation and the power regulation characteristics of this inverter were quantitatively evaluated under varying switching frequency control implementation.

It was proven from an experimental point of view that inverter output power could be continuously adjusted and complete soft switching commutation of this inverter was effectively possible even in the higher output power range with continuous load current mode by inserting lossless inductor snubber in series with each active power switch. It was experimentally confirmed that this zero current soft switching inverter topology is more effective and acceptable for toner fixing process in copy machine. In the future, the comparative studies between ZCS-PFM and ZVS-PWM load resonant inverter should be investigated for induction heated rolling drum of the copy machine in next generation.

#### REFERENCES

- [1]Monterde, Hernandez, R. Garcia, Martinez; "Comparison of Control Strategies for Series-Resonant Full-Bridge Inverter for Induction Cookers", Proceedings of The 8th European Conference on EPE, vol.14, pp.1-8(CD-ROM), Sept, 1999
- [2]B. K. Lee, J. W. Jung, B. S. Suh, D. S. Hyun; "A New Half-Bridge Inverter Topology with Active Auxiliary Resonant Circuit Using Insulated Gate Bipolar Transistors for Induction Heating Appliances", Proceedings of IEEE-PESC, Vol.2, pp.1232-1237, June, 1999
- [3]P. R. Palmer, A. N. Githiari, "An MCT Based Industrial Induction Cooker Circuit Using Zero Current Switching," in Proc. of EPE, pp.2.677-2.682, September, 1995.
- [4]S. Kubota, Y. Hatanaka, "A Novel High Frequency Power Supply for Induction Heating," in Proc. of IEEE-PESC, Vol.1, pp.165-171, June, 1998.
- [5]Y. Hatanaka, H. Kifune and T. Shimada, "A Novel ZCS High Frequency Inverter with Complex Resonance and Design Procedure for High Amplitude of Output Current," in Proc. of IEEE-PEDS, Vol.1, pp.443-447, September, 2001.