Lossless Inductor Snubber-Assisted ZCS-PFM High Frequency Series Resonant Inverter for Eddy Current-Heated Roller

Y.L. Feng, M. Ishitobi, A. Okuno and M. Nakaoka,
Department of Electrical and Electronic Engineering
Yamaguchi University
Yamaguchi, Japan

H. W. Lee,
Division of Electrical Electronics Engineering
Kyungnam University
Masan, Korea

***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.**

***Keywords;* High Frequency Series Resonant Inverter, Lossless Inductor Snubber, Induction Heated Roller**

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 200Vrms 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.

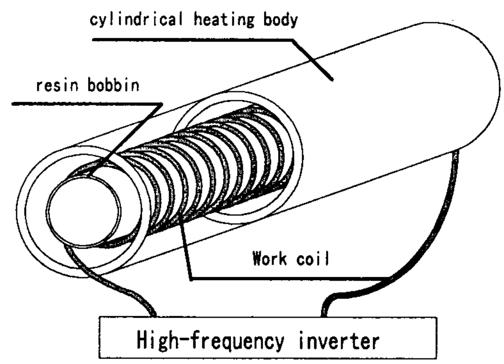


Fig.1. Induction-heated roller

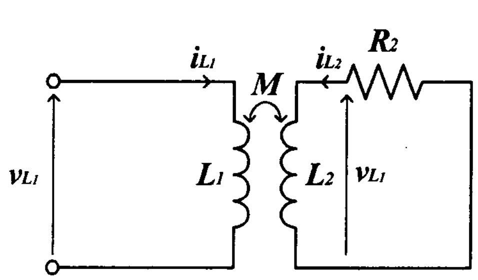


Fig.2. Transformer circuit model of induction-heated roller

II . EQUIVALENT CIRCUIT MODEL OF INDUCTION-HEATED ROLLING DRUM LOAD

The electromagnetic induction-heated roller structure of new conceptual copy machine composed of inner cylindrical work coil assembly connected to a high frequency load resonant inverter and rolling drum to be heated is shown in Fig.1. The induction-heated roller load in Fig.1 is represented using transformer circuit model circuit as Fig.2. The circuit parameters featured for this heating roller are defined as the self-inductance L_1 of the working coil, coupling coefficient of the transformer model; $k = M / \sqrt{L_1 L_2}$, the time constant in the secondary side in induction heated roller; $\tau = L_2 / R_2$, these circuit parameters are measured with a frequency domain procedure by using high frequency amplifier on the basis of alternating circuit theory.

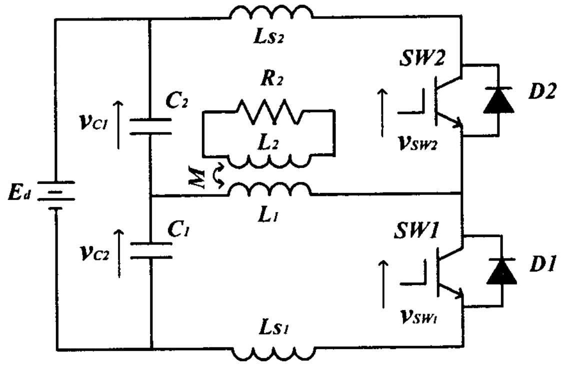


Fig.3. ZCS-PFM high frequency inverter using IGBTs

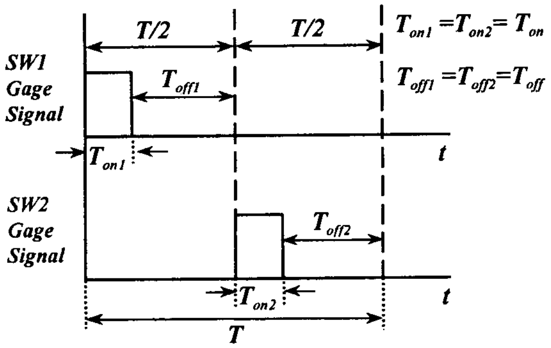


Fig.4. Gate pulse voltage signal timing sequences

III . ZCS-PFM HIGH FREQENCY LOAD RESONANT INVERTER

A. Main circuit configuration description

The proposed lossless inductor snubber-assisted high frequency zero current soft switching inverter using IGBT power module is depicted in Fig.3. The series resonant capacitors C1 and C2 are used for the series compensation resonant capacitors, and two lossless inductor snubbers; Ls_1 and Ls_2 are respectively connected in series with the active power switching blocks; $Q_1(SW1/D1)$ and $Q_2(SW2/D2)$. 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.

Timing sequences of the gate voltage pulse signals supplied to two active power switches; Q_1 and Q_2 for driving the high frequency inverter is shown in Fig.4. It is possible that its output power can be continuously adjusted by varying switching frequency under a condition of fixed on-time; $T_{on} = T_{on1} = T_{on2}$. Series compensation resonant capacitors; C1, C2 and roller load parameters (L_1, k , τ) including two lossless inductor snubbers configure a load resonant tank circuitry.

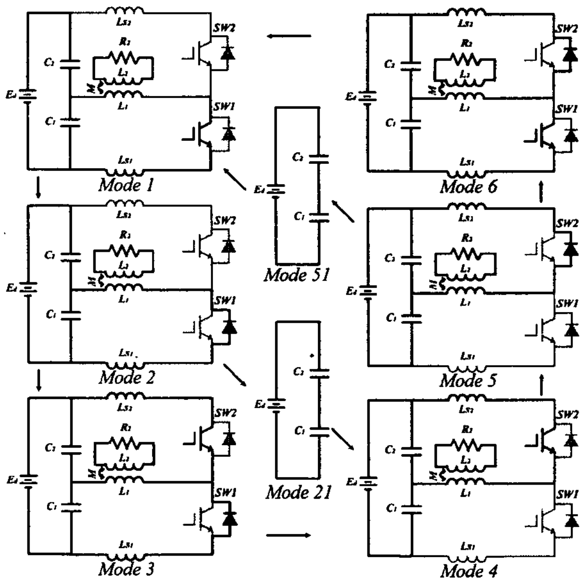


Fig.5. Mode transitions and equivalent circuits

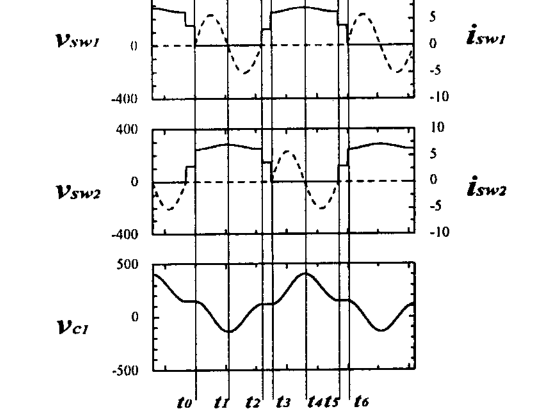


Fig.6. Steady state operation waveforms in the discontinuous current mode

The switching frequency fs is designed to be less than natural oscillation frequency fd of the resonant tank. When the inverter switching frequency fs becomes smaller than half of load resonant frequency fd, the discontinuous current mode appears in which the load current becomes zero and active power switches can completely achieve zero current soft commutation. By inserting the lossless inductor snubbers, the zero current soft switching can be realized in the continuous mode.

B. Circuit operation

The mode transition of this high frequency inverter circuit and its equivalent circuit are shown in Fig.5.

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.

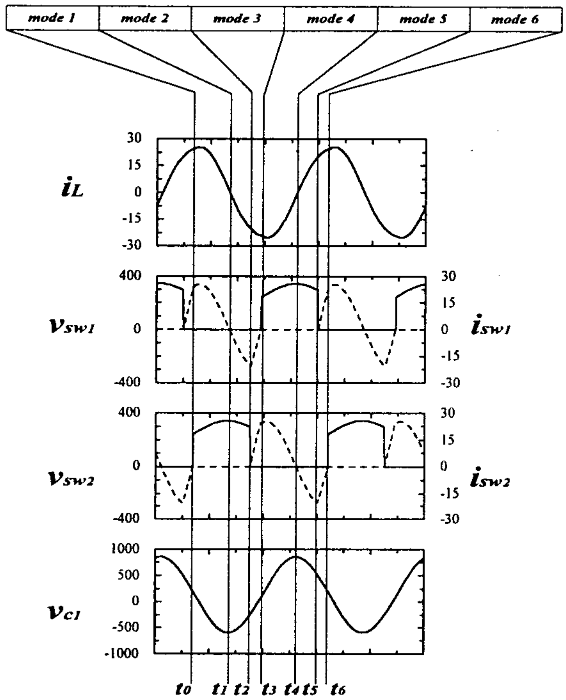


Fig.7. Steady state operation waveforms in the continuous current mode

IV. EXPERIMENTAL RESULTS AND EVALUATIONS

A. Parameter design of breadboard setup

The design specifications and circuit parameters of this inverter breadboard setup are indicated in TABLE. I . 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.

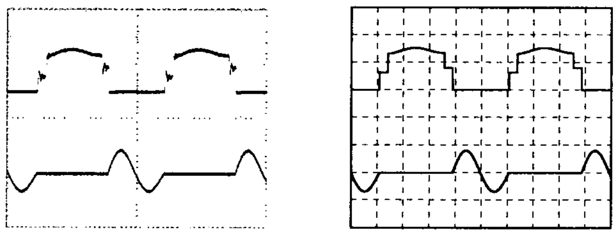
TABLE. I DESIGN SPECIFICATION

Parameter	Symbol	Value
DC voltage supply	E_d	282.8 [V]
Resonance capacitor	C_1 C_2	0.07 [μF]
Lossless inductor	L_{s1} L_{s2}	11.0 [μH]
Inductance of work coil	L_1	80.0 [μH]
Induction-heated roller load	τ	6.0 [μs]
Induction-heated roller load	k	0.65
IGBT as active power switches	V_{CE}	600 [V]
IGBT as active power switches	I_C	75 [A]
Reverse conducting diode	V_{RM}	600 [V]
Reverse conducting diode	I_O	30 [A]

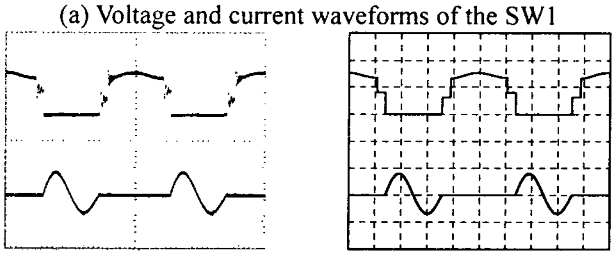
In the case of introducing active power switches; IGBTs in parallel with diode Q_1 and Q_2, upper limitation of the switching operating frequency is designed as 45kHz, and the lowest operating frequency is designed so as to operate outside the audible frequency region.

B. Steady state opration performances

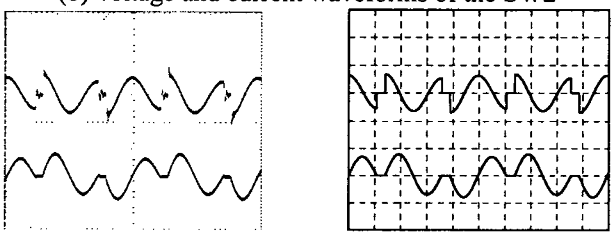
The experimental operating waveforms and the simulation waveforms are respectively illustrated in Fig.8 and Fig.9.



(a) Voltage and current waveforms of the SW1



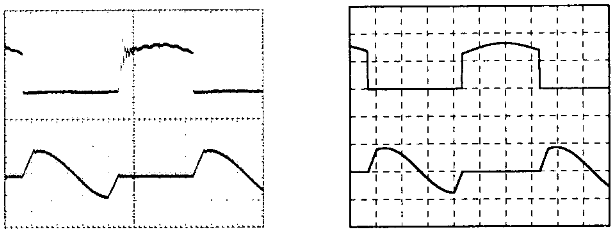
(b) Voltage and current waveforms of the SW2



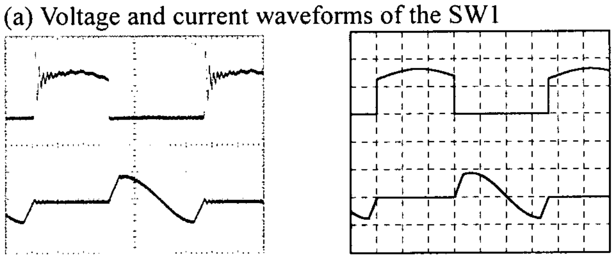
(c) Voltage and current waveforms of the work coil
v : 200[V/div], i : 8[A/div], *time:* 10[μsec/div]

Fig.8. Steady state opration waveforms in the discontinuous current mode

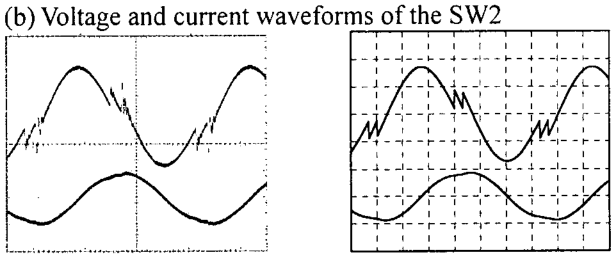
Fig.8 and Fig.9 display steady state opration voltage and current waveforms in discontinuous current mode under switching frequency fs=20.5kHz as well as continuous current mode at an inverter switching frequency fs=37.5kHz. The voltage and current waveforms of the active power switching block; Q_1 and 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.



(a) Voltage and current waveforms of the SW1



(b) Voltage and current waveforms of the SW2



(c) Voltage and current waveforms of the work coil

v : 200[V/div], i : 20[A/div], *time:* 4[μsec/div]

Fig.9. Steady state opration waveforms in the continuous current mode

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.

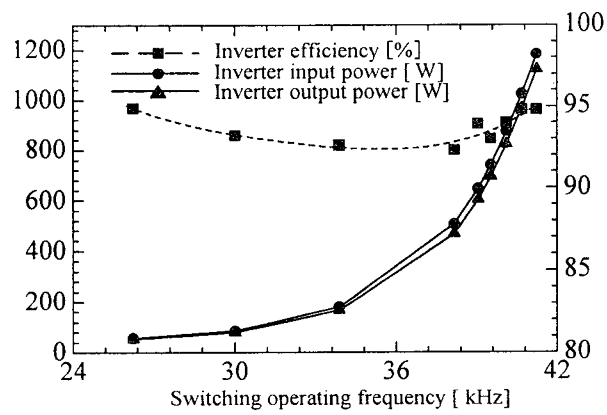


Fig.10. Power regulation characteristics

C. *Power regulation characteristics and evaluation*

Fig.10 shows the power regulation characteristics of the high freqency 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.

V. 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] H.Omori, M.Nakaoka :"Generic Circuit Topologies and Their Performance Evaluations of Single-Ended Resonant High-Frequency Inverter for Induction-Heated Cooking Appliances", Trans. IEE of Japan, Vol.117-D, No.2(1997-2)

[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, 1997

[3] I.Hirota, H.Omori, S.Muraoka, S.Hishikawa, K.Nishida,

E.Hiraki and M.Nakaoka :"Improved Quasi-Resonant ZVS-PWM Inverter with Active Voltage-Clamped Capacitor for Consumer Induction Heating", Proceedings of IEEE-IAS IATC, pp.111-116, May, 2000

[4] Monterde, Hernandez, R.Garcia, Martinez :"Comparison of Control Strategies for Series-Resonat Full-Bridge Inverter for Induction Cookers", Proceedings of The 8th European Conference on EPE, Vol.1～4, pp.1-8(CD-ROM), Sept, 1999

[5] Rafael Ordo.ez and Hugo Calleja, "Induction Heating Inverter with Power Factor Correction", Proceedings of IEEE CIEP, Oct, pp.90-95