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Series Capacitor Compensated Resonant High Frequency Inverter with ZCS-Pulse Density Modulation for Induction Heating Fixing Roller in Copy Machine

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Abstract - This paper presents the voltage source type half bridge lossless auxiliary inductor snubber assisted series capacitor compensated resonant high frequency inverter for induction heated fixing roller in copy machines. This high-frequency inverter treated here can completely achieve zero current soft switching (ZCS) commutation for wide power regulation range under its constant frequency pulse density modulation (PDM) scheme. Its transient and steady-state operating principle is originally presented for a constant frequency PDM control strategy under a ZCS operation commutation, together with its output effective power regulation characteristics-based on the PDM strategy. The experimental operating performances of this ZCS-PDM high frequency inverter using IGBTs are illustrated as compared with computer simulation ones. Its power losses and actual efficiency are evaluated and discussed on the basis of simulation and experimental results.

Keywords - Voltage source type series load resonant inverter, Half bridge topology, Lossless inductive snubbers, Zero current soft switching, Pulse density modulation time ratio control, Induction heated roller in copy machine, Consumer power electronics.

I. INTRODUCTION

In recent years, much interest to environmental-friendly technologies has grown greatly and energy saving regulations relating to the office automation (OA) equipment in next generation has become more and more significant.

The heat-based fixing process of a toner in a copy and printing machine is required after transferring a toner on moving paper from a rolling drum for a copying machine or a laser printer. At present, the toner fixing process equipment using the indirect radiant heat by the sheathed heater or the halogen lamp is applied widely. In practice, this fixing process usually takes 90% of all energy needed for printing devices operation in new generation.

Therefore, the effective development of more energy-saving toner fixing process is a significant task for a great demand. This new method being developed will lead to the improvement of the overall processing system speed and efficiency. The direct heating of the roller by electromagnetic induced currents has attracted an interest recently as an alternative to the light heating by the halogen lamp, however; only a few numbers of publications on this issue have been presented yet. In general, the electromagnetic induction heating scheme is safe, highly efficient, faster heating response that allows controlling temperature more simply and precisely. Therefore, this can lead to reducing the physical size of the printing devices and their performances enhancement. Hence, development of the efficient power supply for the induction-heating (IH) roller in such power applications is a very important task.

The authors have already developed high-frequency PDM inverter for ozone generation and evaluated its performances previously and the PDM control strategy has been considered effective solution of the mentioned above problem for induction heating applications. As a further development, in this paper, half-bridge series resonant voltage-source inverter is introduced, which operates under a high frequency and ZCS operation conditions by two auxiliary inductances connected in series with the active power switches. The power regulation characteristics of the developed power conversion scheme are presented in this paper, together with the comparative evaluations of the power losses analysis based on experiments and simulation.

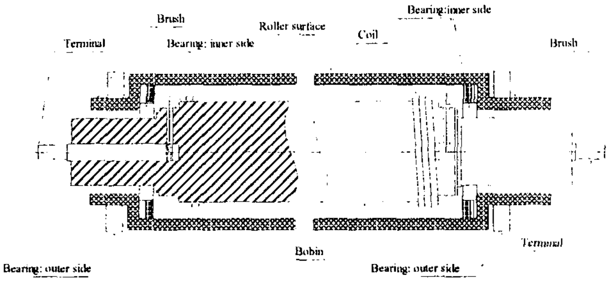


Fig.1. Sectional view of toner fixing roller

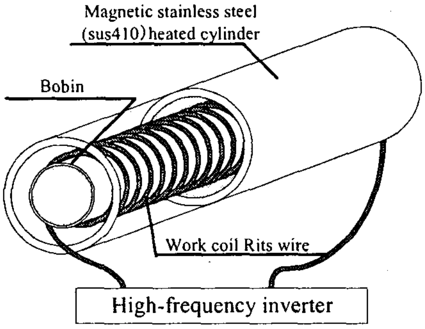


Fig.2. Induction heating roller

Ⅱ. INDUCTION HEATED ROLLER

The physical structure of the experimental induction heated roller used actually as a load of the developed high-frequency inverter is schematically shown in Fig.1. At present, the main heating method for the fixing roller is introduced by light emission from the halogen lamp and the structure of light heated roller. On the other hand, the fixing roller made of stainless steel with an induction-heating coil inside is depicted and it is schematically represented in Fig.2.

Ⅲ ZCS-PDM CONTROLLED HIGH FREQUENCY INVERTER

A. System description

The overall power processing system including newly developed ZCS-PDM controlled series resonant high frequency inverter is depicted in Fig.3. E_d is a DC voltage applied to the inverter after diode rectification of 200V/60Hz utility AC power source, $Q_1(SW_1/D_1)$ and $Q_2(SW_2/D_2)$ are the switching blocks composed of the power semiconductor switches (IGBTs) SW_1 and SW_2 with antiparallel diodes D_1 and D_2, C_r is a series resonant capacitor; L_{s1} and L_{s2} are an auxiliary ZCS-assisted inductive snubbers connected in series with SW_1 and SW_2. In this circuit, the power switches Q_1 and Q_2 operate completely under ZCS conditions for the commutation in both turn-on and turn-off transitions. The output power of the high-frequency inverter is able to be regulated by PDM control strategy. The circuit block enclosed by the dotted line is the transformer model (L_1, k, τ) of the IH load comprised of the working coil and induction heated fixing roller load displayed in Fig.2.

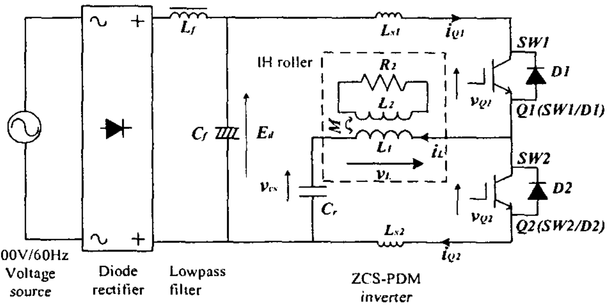


Fig.3. High frequency ZCS-PDM inverter system

B. Circuits features

Since the geometric placement of the heated rolling drum and working coil is loose coupling for the induction heating, the magnetic coupling between working coil and roller load is relatively poor. The high frequency inverter circuit topology with series resonant load with C_r and L_r is introduced.

The operation of ZCS-PDM high frequency inverter operation in this appliance can be mainly divided in two modes; continuous load current operating mode and discontinuous current operating mode in the case of the inverter working frequency f_s is smaller than resonance frequency f_r of the series capacitor compensated resonant load. Although ZCS commutation mode can be provided for the discontinuous current operation without the auxiliary inductive snubbers, extremely high peak currents on the active power switches and high peak voltage on the resonant capacitor become serious problem for high output power of this high-frequency inverter. Furthermore, to make the most of power semiconductor switching devices, continuous current operating mode had better be employed for this series resonant inverter.

Developed inverter is operating in continuous load current mode that provides the operation in ZCS&ZVS for turn-off mode transitions. As for turn-on mode transitions, hard switching would occur if no modifications are made. Therefore, two extremely small inductances are connected in series with the active power switches Q_1 and Q_2 that provide completely ZCS conditions for turn-on commutation. Thus, the soft switching commutation can be achieved both for turn-on and turn-off mode transitions. Furthermore, since the power losses caused by tail current and fall current of bipolar mode power semiconductor switches like IGBTs during turn-off is likely to disappear in the inverter circuit topology that operates on the principle of ZCS, the proposed PDM-ZCS resonant inverter is rather preferable to the ZVS scheme.

As shown in Fig.4, the power regulation can be achieved by varying of the time ratio between the period T_{on}, when the power is injected into the load and period T_{off}, when the power is non-injected into the load. In fact, with the changing the time ratio, the density of the applied pulses is changed, therefore, the pulse density modulation control scheme is taking place while the working frequency is kept constant under zero current soft switching transition commutation.

The auxiliary lossless inductive snubbers; L_{s1} and L_{s2} (, $L_{s1} = L_{s2} = L_s$) provide ZCS operation for Q_1 and Q_2 in continuous load current mode based on the overlapping current in the loop of SW_1, D_2 and SW_2, D_1.

Since the complete ZCS operation for Q_1 and Q_2 is provided in whole power regulating range, the electromagnetic conductive and radiative noise and the switching losses are kept low. Furthermore, as compared with the resonant inverters driven by the other control methods like PFM, PWM and PAM for the light load condition, almost no power losses is absorbed during the power non-injected period in this series resonant inverter, therefore. The inverter efficiency is almost the same as well as heavy load.

C. Circuits operation

The operation modes of the series resonant inverter circuit shown in Fig.4 are illustrated in Fig.6 for the power injection period.

The circuit parameters of the ZCS-PDM high-frequency inverter using IGBTs are indicated in Table1. The auxiliary inductance L_s is adjusted to 12μH to provide switch peak voltage 350V that includes some tolerance to the limit reference parameters of the chosen IGBTs. In this case, the switch current $di/dt_{\max}$ stress becomes 12.5A/μs and current overlapping time t_u becomes 3.8μs.

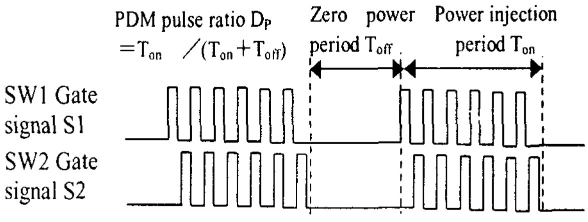


Fig.4. Principle of PDM control

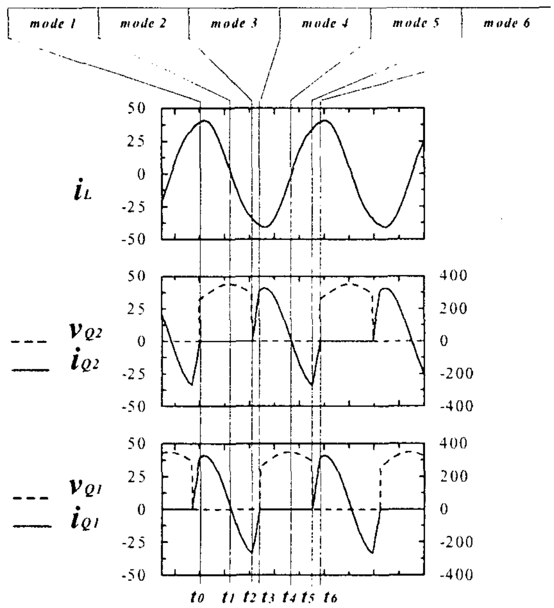


Fig.5. Voltage and current waveforms in steady state

IV. EXPERIMENTAL RESULTS AND THEIR EVALUATIONS

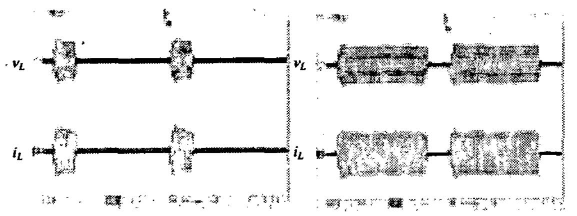
A. Experimental results

In the developed high-frequency inverter we use IGBTs (Mitsubishi Electric Co. Ltd, CT75AM-12) with soft-recovery diodes (Origin electric Co. Ltd, US30P) as the antiparallel fast recovery diodes. For pulse density ratio $D_p = 0.2$ and 0.8, the experimental waveforms of the current i_L and the voltage v_L are shown in Fig.6. Observed voltage and current waveforms for the active power switches Q_1 and Q_2 are shown in Fig.7. The validity of the transformer models parameters of IH fixing roller load is proven on the basis of these experimental results.

The voltage and current waveforms of Q_1 and Q_2 for the beginning of the power injection period are shown in Fig.8. It is clear that Q_1 and Q_2 can operate under the principle of ZCS conditions.

Fig.9 illustrates the pulse density modulation ratio vs. output power and pulse density modulation ratio vs. efficiency characteristics for this series resonant inverter.

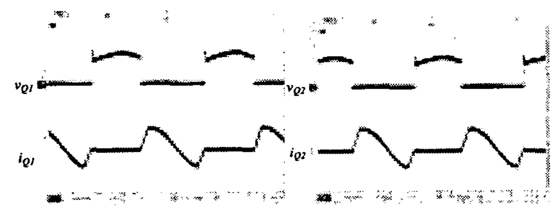
The output power of the series resonant inverter treated here can be regulated and linearly by changing the pulse density modulation time ratio. For output power regulation ranges from 5% to 100% of the maximum output power, the actual power conversion efficiency more than 94% can be achieved by the setup. Especially, it is important that actual efficiency more than 94% is able to be achieved even for both pulse density modulation ratio $D_p = 1.0$ in printing operating mode and $D_p = 0.05$ in stand-by mode, that make the proposed series resonant ZCS-PDM high-frequency inverter more effective for IH fixing roller application in next generation copy machine.



(a) Dp=0.2 (b) Dp=0.8

v_L:500[V/div], i_L:40[A/div], t: 400[μsec/div]

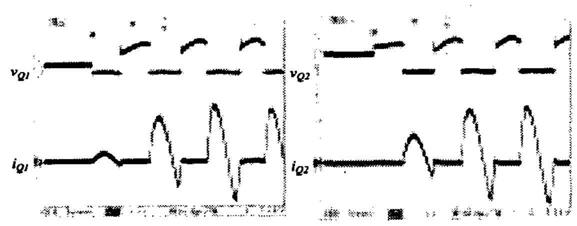
Fig.6. Experimental waveforms of v_L and i_L



v_{Q2}:250[V/div], i_{Q2}:40[A/div], t: 10[μsec/div]

(a) Voltage and current on Q1 (b) Voltage and current on Q2

Fig.7. Experimental waveforms of switch voltage and current



v_{Q2}:250[V/div], i_{Q2}:20[A/div], t: 20[μsec/div]

(a) Voltage and current on Q1 (b) Voltage and current on Q2

Fig.8. Experimental waveforms of switch voltage and current at the beginning of the power injection period

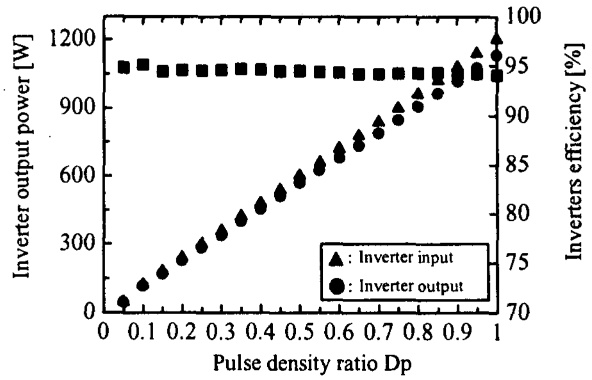


Fig.9. Power regulation characteristics in experimence

V. CONCLUSIONS

In this paper, the voltage-fed high-frequency half-bridge series load resonant soft switching inverter with ZCS-assisted auxiliary inductive snubbers has been introduced for IH fixing roller in the copy machine and its steady state operation under a principle of PDM control scheme has been evaluated and discussed.

The power regulating characteristics and operating performances of this lossless snubber-assisted series resonant inverter for steady state operation has been evaluated in simulation and experiment. For these power losses estimation, the transformer model of the IH fixing roller has been used from a practical point of view.

The actual high efficiency more than 94% has been observed for all the output power ranges from 50W to 1200W with stable operation and linear output power control property under a condition of ZCS commutation. The series resonant ZCS high frequency inverter, which is based on a PDM control scheme, has verified its effectiveness for the stand-by operating mode. Furthermore, the power losses analysis of this inverter with a PDM scheme has been analyzed using the approximated $v-i$ characteristics of IGBTs and diodes used here.

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