APPLICATION OF A GTO THYRISTOR
TO A DUAL RESONANT FREQUENCY CIRCUIT FOR EXCITATION OF SYNCHROTRON MAGNET

H. Someya, T. Adachi, Y. Irie, Y. Yano and H. Sasaki

National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 305, Japan

Abstract

In order to confirm the possibility of a dual resonant circuit using a gate-turn-off thyristor (GTO), a model circuit is constructed and investigated. The result is described.

Introduction

A rapid-cycling synchrotron with repetition rate of 50 Hz is proposed as the intense pulsed neutron and meson sources, which is named GEMINI[1]. The guide magnets in this accelerator are divided into twelve meshes each of which contains a capacitor resonating with the magnet. Since the RF accelerating voltage increases with the excitation frequency of the magnet, the RF acceleration system is constrained to operate in a hard condition, especially, for this type of the rapid-cycling accelerator.

In order to reduce the accelerating voltage, a dual frequency operation of the resonant magnet system is adopted. This method was first proposed by M. Foss and W. Praeg[2]. According to the original idea, the frequency is changed from f_a of the acceleration period to f_r of the reset period or from f_r to f_a by switching a part of the resonant capacitor with a inverter type thyristor. In our circuit, f_a and f_r are assigned to 33 Hz and 100 Hz respectively, and the inverter type thyristor in the original circuit is replaced by a gate-turn-off thyristor (GTO). This improvement simplifies the circuit. In order to confirm the dual frequency operation with the GTO, a model of a dual resonant frequency circuit is constructed and investigated. Parameters of the model circuit are listed in Table 1.

Table 1 Parameters of the model circuit

Pulse power supply		
Capacitor C_f	Capacity	17.0 μF
	Peak voltage	1400 V
Inductor L_f	Inductance	11.2 H
Inductor Lp	Inductance	77.8 mH
Thyristor SCRp		SKT16/16C (SEMIKRON)
Dual resonant frequency system		
Capacitor C_1	Capacity	253 μF
	Peak voltage	700 V
	Peak current	120 A
Capacitor C_2	Capacity	2560 μF
	Peak voltage	233.3 V
	Peak current	107 A
Inductor L_m	Inductance	10 mH
	Peak voltage	700 V
	Peak current	120 A
Diodes D_1 and D_2		101F12S (NEC)
Gate-turn-off thyristor (GTO)[3]		GFF90A6 (HITACHI)
	Peak off-state voltage	600 V
	RMS on-state current	42 A
	Controllable on-state current	
	in repetitive case	90 A
	in non-repetitive case	120 A
	Peak on-state voltage	2.3 V at 90 A
Snubber circuit		
Capacitor C_s	Capacity	0.4 μF (1.5 kV)
Resistor R_s	Resistance	10 Ω (5 W)
Diode D_s		1S2719

Circuit description

The diagram of the model circuit is illustrated in Fig. 1. Fig. 2 shows the voltage and current waveforms of a dummy magnet L_m in a typical operation of the model circuit. The reference of time ($t=t_0$) is taken at the end of the acceleration when the magnet current begins to decrease. The capacitor C_1 with the inductance L_m of the dummy magnet is in resonance at the frequency of 100 Hz ($t_0<t<t_2$), and C_1 and C_2 are at 33 Hz ($t_2<t<t_4$). The behavior of the circuit is as follows.

- $t=t_0$: The magnet current is at its peak and the voltage across capacitors C_1 and C_2 is zero.
- $t_0<t<t_1$: The capacitor C_1 is changed and reaches the peak voltage at $t=t_1$.
- $t_1<t<t_2$: The capacitor C_1 discharges through the inductance L_m until the diode D_1 turns on.
- $t_2<t<t_3$: The diode D_1 turns on at $t=t_2$ when the capacitor current of C_1 is at its peak, and capacitors C_1 and C_2 are thereafter charged in the opposite direction.
- $t=t_3$: The capacitor voltages on C_1 and C_2 reach their maximum and the diode D_1 turns off.
- $t_3<t<t_4$: The GTO is now turned on at $t=t_3$ to maintain the 33 Hz oscillation and the capacitors C_1 and C_2 are charged through the path containing GTO and D_2. Their current reaches its peak at $t=t_4$. Finally, the GTO is turned off at this moment and the circuit comes back to the initial state.

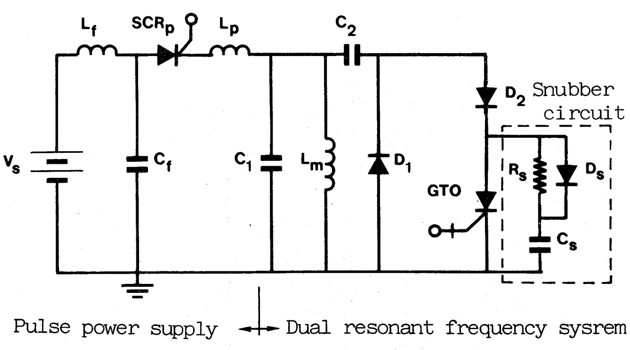


Fig.1 The diagram of the model circuit

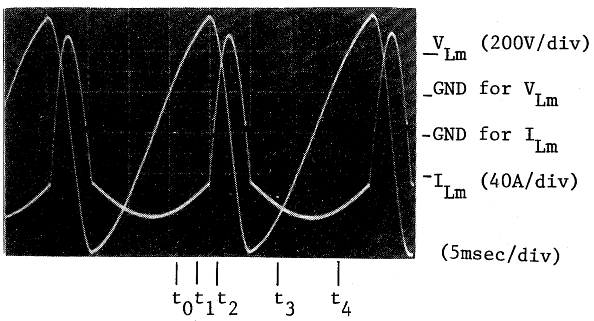


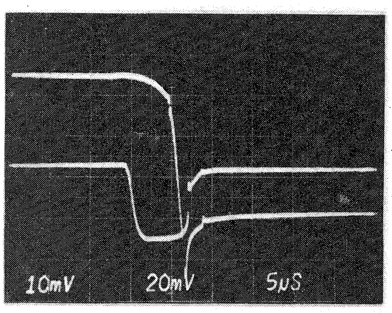
Fig.2 Voltage and current waveforms of the dummy magnet

As shown in Fig.1, the snubber circuit contains the diode D_s, the capacitor C_s and the resistor R_s. When the GTO is turned off, the capacitor C_s begins to absorb the main current through the diode D_s. And after the capacitor voltage reaches its maximum, it discharges through the resistor. This action suppresses the rapid rise of the voltage across the GTO and ensures its safety operation.

GTO gate pulses

Turn-off pulse

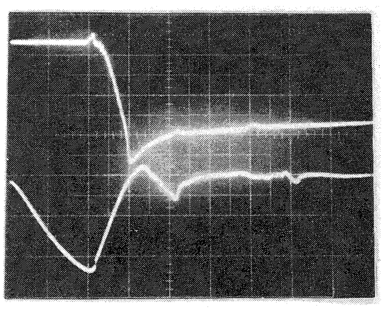
A turn-off gate pulse must have sufficiently high current. This condition affects the safety performance of the GTO severely. As shown in Fig. 3, a main current of the GTO (I_{GTO}) begins to fall slowly when the turn-off gate current (I_G) is low. It takes about 10 μsec to turn off the main current. In this case, the full operation breaks the GTO. On the other hand, as shown in Fig. 4, the main current begins to fall quickly as fast as 2 μsec when the turn-off gate current is sufficiently high. With the gate current of 24 A, the GTO safely operates even in the full operation condition, where the maximum main current is 107 A. This result also means that the gate pulse should be as fast as possible in the rise time since the long turn-off time was found to break the GTO.



I_G (2A/div)

I_{GTO} (4A/div)

Fig.3 The main current and the gate pulse of the GTO in the case of low current



I_{GTO} (50A/div)

I_G (10A/div)

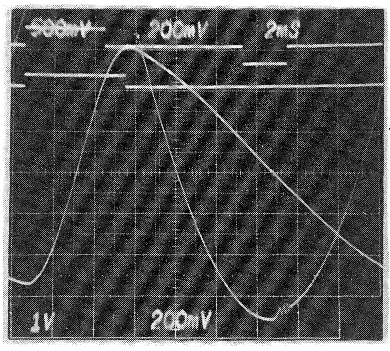
(2μsec/div)

Fig.4 The main current and the gate pulse of the GTO in the case of high current

Turn-on pulse

In the case of a resistive load, the gate pulse with narrow width may turn on the GTO. However, in our case of the inductive load, the narrow pulse fails to turn on the GTO since the rise rate of the main current is limited by the inductance. As shown in Fig.5, the voltage V_{Lm} of the dummy magnet is disturbed like a sawtooth wave around the bottom. This waveform implies that the GTO repeats on/off state, which depends on the construction of the gate circuit. We use 'UCZ90C12A2', which is made in HITACHI, Ltd., as the gate circuit. It controls the gate current by monitoring the anode voltage during the existence of the turn-on signal.

The control sequence is as follows. If the GTO is in on-state, the gate current is suppressed to avoid unnecessary power dissipation. In order to remove the above-mentioned disturbance, we improved the circuit by disconnecting the part which detects the anode voltage. We also keep the gate current during the on-state of the GTO. Finally, as shown in Fig. 2, the disturbance is removed out successfully.



V_{Lm}

I_{Lm}

Fig.5 Voltage and current waveforms of the dummy magnet

Conclusion

The behavior of the dual resonant frequency circuit has been understood in terms of the small scale model. However, in order to extend it to the GEMINI magnet, there remains the problem due to the high voltage in GEMINI magnet system[1]. The maximum ratings of the GTO, which is available at present, are listed in Table 2. For the purpose of the realization of the dual resonant operation in full scale, both parallel and serial connection of elements is necessarily required. And also protection circuits are needed. The development is now under investigation.

Table 2 Ratings of GFP1000B[3]

Repetitive peak off-state voltage	2500 V
RMS on-state current	400 A
Controllable on-state current	
in repetitive case	1000 A
in non-repetitive case (surge)	7000 A
Peak on-state voltage	2.5 V

Acknowledgement

We would like to thank Prof. H. Baba and Prof. S. Matsumoto for useful discussions on design of this dual resonant frequency circuit. In addition, we would like to thank Mr. H. Amano, Mr. S. Sugayama and Mr. H. Takahashi of Hitachi, Ltd. for fundamental informations of the GTO.

References

1) H. Sasaki et. al., elswhere in this proceedings
T. Adachi (ed.), Proc. of the Meeting on BSF Future Prospects, KEK, Int. 82-6 (1982)
T. Adachi and Y. Masuda (ed.) Proc. of the Meeting on BSF Future Prospects-II, KEK Int. 83-7 (1983)
2) M. Foss and W. Praeg, IEEE Trans. Nucl. Sci. NS-28, 2856 (1981)
3) Hitachi, Ltd., HITACHI POWER AND INDUSTRIAL SEMI-CONDUCTOR DATA BOOK, 4th ed. (1982)