HV TRAPEZOID 1 μS-PULSE SWITCHING USING SI-THYRISTOR FOR KICKER MAGNET SYSTEMS

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Abstract

The R&D on the fast rise/fall switching of high voltage and large current trapezoid wave has been started for the power supplies of kicker magnet using SI-thyristors instead of thyratrons. Test experiment was demonstrated using the prototype SI-thyristor pulse module, which is made for the klystron driver, connected to the pulse forming line (PFL) with an end-clipper. Rise time of 0.3 μs was observed for ~ 27 kV . It is possible to introduce the SI-thyristors into the kicker system for a large lepton accelerator ring at least. It is expected to improve the current rise time less than 100 ns with optimum surrounding circuit elements, and to establish a stacking technique to produce higher voltage and larger current for hadron kicker systems finally.

1 INTRODUCTION

In order to improve the reliability and lifetime of a pulsed power supply and a high voltage switching, semiconductor-switching devices have been desired to replace the thyratron tubes. Recently, pulse and switching operations of several tens kV using IGBT and MOSFET have been developed [1]. We notice the turn on characteristics of the SI-thyristor (SITh). SITh is attractive of the attention for its large current gradient dI/dt ~ 100 KA/μs as equivalent to a thyratron and it has been attempted to use as a klystron modulator [2] and a high repetition modulator [3] for an induction accelerator[4] recently. We have started to develop for the kicker system as one of its application.

Kicker magnet systems are commonly used for an injection/extraction of particle accelerator rings to produce a rectangle wave of magnetic field with a fast rise/fall and sufficient flatness. Those kicker magnets are divided into two types: one is a lumped magnet, which is often used for larger rings with a long pulse width of 1 ~ 30 μs; the other is a transmission type, used for smaller rings with 20 ns ~ 1 μs pulses. Table 1 shows the several kicker magnets around KEK under operating and designing now. All the kicker systems are operated and designed with a thyratron switch. However, such a vacuum tube has a drawback of limited lifetime, so it should be replaced to an all-solid-state element with a longer lifetime as possible.

This paper describes the preliminary demonstration results using SITHs.

Kicker Magnets	Current width [μs]	Current rise [ns]	Field rise [ns]	Field strength [KG]	PFL Voltage [KV]	Impe-dance [Ω]
BK1-4	0.2	50	92	0.40	65	25
MK1, 2	0.2	50	120	0.63	65	25
MK3 - 5	0.2	50	85	0.32	65	25
AIK	0.2	50	85	0.32	65	25
AEK	1.4	80	150	1.00	65	12.5
FX2 - 8	1.1	80	145	0.96	63	12.5
PFK	0.9	80	400	-	10	6.25
BIK	3.0	-	1000	-	35	lumped
K1 - 11	1.2	80	240	~ 0.5	60	10
MIK	1.2	80	250	-	60	-
MEK	6.0	80	1000	-	60	lumped
KLHC	25.0	80	1000	-	80	lumped

Table 1 : Parameters of kickers.

BK	KEK-PS-BR-extraction
MK, FX	KEK-PS-MR-injection & -ext.
AIK, AEK	KEK-PS-AR-inj. & -ext. (designed)
PFK	KEK-PF-inj.
BIK	KEK-B-inj.
K	JAERI/KEK-BR-ext. (designed)
MIK, MEX	JAERI/KEK-MR-inj. & ext. (designed)
KLHC	CERN-LHC (designed)

2 CHARACTERISTICS OF THE SI-THYRISTOR

SITh has a low on state voltage drop characteristics by means of thyristor action followed by the high carrier injection effect around the gate channel. It has the high-speed switching and low loss characteristics and has high tolerance for electronic noise. These features are especially remarkable at the high blocking voltage area, over 3 kV or so. For these high voltage applications, buried gate type SITh is just suitable comparing with another structures, because of the easiness to get high voltage and high conduction characteristics. Especially for the Pulsed Power Application, the high blocking voltage, high current rise rate and high current characteristics are quite necessary to get the high power and high efficiency.

On the other hand, pulse turn-off characteristics is now under consideration. In order to get the superior Pulsed Power characteristics, the gate control technique is the most important invention.

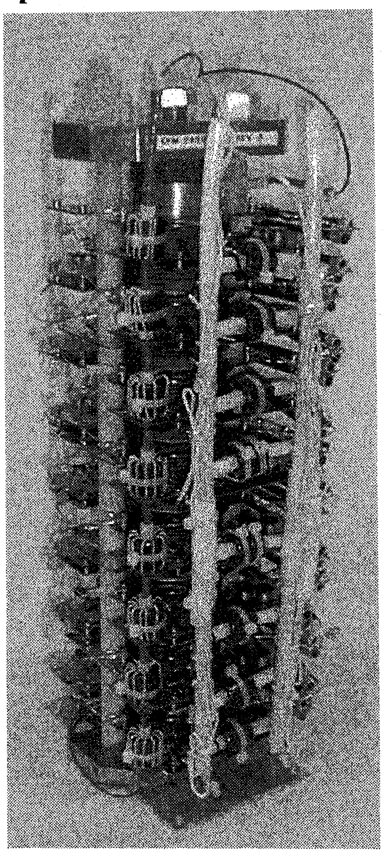

Figure 1: 15 series SI-thyristor stack for 40 kV operation.

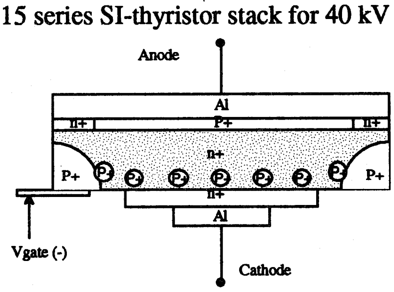

Figure : 2 SI-Thyristor RT103N.

3 EXPERIMENTAL SETUP

Fig. 1 shows the switch used for the test and figure 2 shows the structure. The switch has been assembled for a klystron driver [2]. Fifteen SIThs of type RT103N [5], which is reverse conducting with 4 kV hold-off voltage, are stacked in series to operate for 40 kV. Several diodes were connected in parallel with each thyristor to protect from the emergent large reflected current up to 12 kA. The trapezoid pulse was produced with the co-axial cables (Hitachi Cables type 20.0/6.0) of 130 m length with 50 Ω impedance. The end-clipper consists of the diodes (ORIJIN MD-O65SN1K) and resistors. The potential at PFL was observed with 5,000 : 1 probe and the anode current was measured with CT (Pearson model 110) through the 1/19.1 attenuator as shown in Fig. 3.

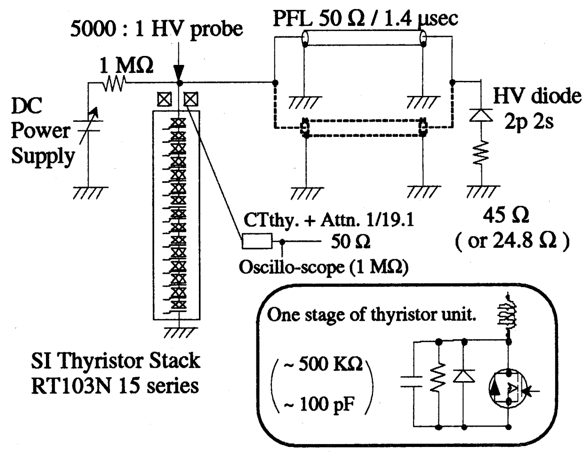

Figure 3: Single test line for a trapezoid pulse switching.

4 EXPERIMENTAL RESULT

The PFL is charged by the DC power supply through a 1 MΩ resistor. The potential at PFL is decided at a ratio of the resistances, 7.5 MΩ / (1+7.5) MΩ. Fig. 4 shows a typical wave form of a PFL potential, measured by the 5,000 : 1 probe in case of V_{PS} = 20 kV charging; bellow curve shows the same result but in [20 ms/div]. The measured maximum potential is 17.6 kV, and its ratio is equivalent to the resistance divider. The potential falls to the ground potential in 0.2 ~ 0.3 μs and is recovered as follows with an electrical time constant t_{CR} from a PFL capacitance.

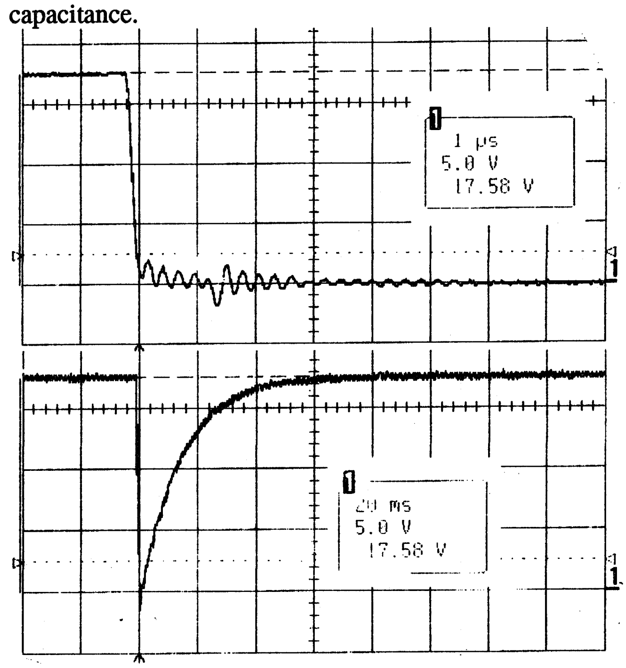

Figure 4 : Typical waveform of PFL potential.

Figures 5 and 6 show the measured anode current in case of VPS = 10 kV, for Z = 50 Ω and R = 45 Ω (one line cable load) and Z = 25 Ω and R = 24.8 Ω (two lines parallel cable load), respectively. The current waveforms have a notable characteristic of two current rise tendencies. One is a former linear rise. This is dominated by the protection circuit elements around each SITh. Those parameters were chosen for a klystron driver as mentioned before. On the other hand, such large elements are not necessary for the power supply of the kicker magnet, so we can improve the former rise time by optimising these parameters of protection elements. The other tendency is a latter exponential rise. This is caused from a parasitic inductance and can be compensated by inserting speed-up capacitors.

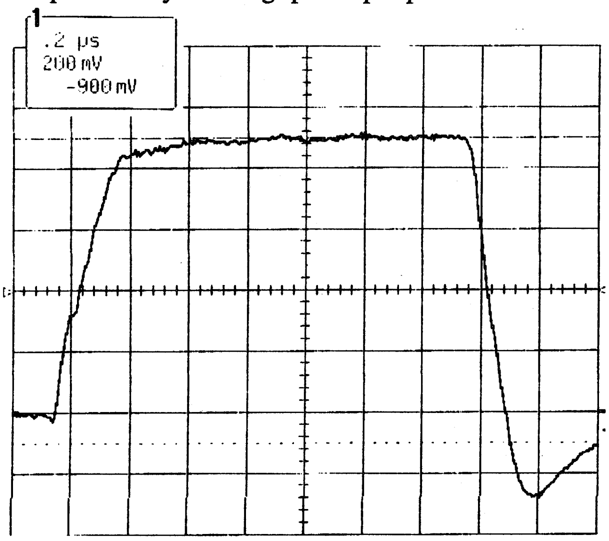

Figure 5: Measured current for Z = 50 Ω.

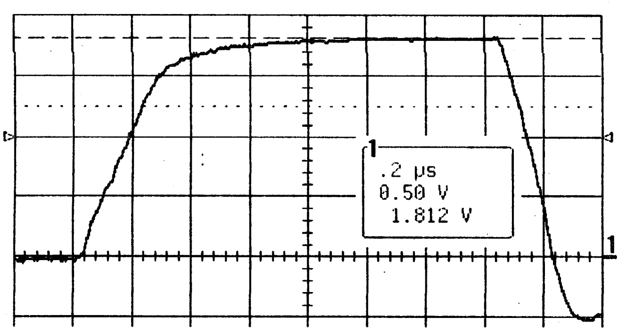

Figure 6: Measured current for Z = 25 Ω.

Impe-dance [Ω]	PS Voltage [KV]	PFL Voltage [KV]	Current rise at anode [ns]	Gradient dI/dt [KA/µs]
50	10	8.75	240 (0-95%)	1.0
	20	17.58	260 (0-95%)	1.3
	30	26.64	240 (0-95%)	2.0
25	10	8.75	280 (0-86%)	1.0
	20	17.58	280 (0-86%)	2.0
	30	26.64	260 (0-86%)	3.2

Table 2 : PFL potential and impedance dependence of Anode current rise time.

Measured results are summarized in Table 2 for Z = 50 or 25 Ω and V_{PS} = 10, 20, 30 kV.

5 SUMMARY

In order to confirm the feasibility for application of SITh to the kicker magnet power supply, demonstration experiment was performed using the prototype SITh pulse modulator, which is making for the klystron driver, connected to the pulse forming line (PFL) with an end-clipper. Rise time of 0.3 µs was observed for ~ 27 kV. It is possible to use the SITh in the kicker system for a large lepton accelerator ring at least. It is expected to improve the current rise time less than 100 ns with optimum surrounding circuit elements, and to establish a stacking technique to produce higher voltage and larger current for kicker systems in hadron accelerators at last. The more effort will be necessary to reduce the rise time less than 100 ns, due to the potential dependence of the SITh turn-ON. We will continue this experiment using the SITh stacking module for the exclusive use of the PFL.

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