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DEVELOPMENT OF AN IGBT PULSER FOR TPS LTB KICKER

C.L. Chen#, C.S. Fann, H.P. Chang, K.L. Tsai, Y.S. Cheng, S.Y. Hsu, K.T. Hsu, K.K. Lin
National Synchrotron Radiation Research Center, Hsinchu, Taiwan

Abstract

The Linac to Booster (LTB) injection kicker for Taiwan Photon Source (TPS) was first commissioned using Pulse Forming Network (PFN) pulser equipped with a thyratron switch. Although its bench-testing results fulfilled all specifications, the performance was degraded due to a couple of unavoidable integration difficulties. After evaluating several improving options in hand, an alternative pulser using IGBT switch is proposed for off-the-bench beneficial purpose. The results of the upgraded pulser satisfy the overall specifications with comfortable margins. Some major performance parameters, such as flattop and tail ringing, are emphasized concerning their influence on beam injection. This report describes the field-testing result of this new IGBT pulser.

INTRODUCTION

TPS LTB kicker pulser was installed for system test in 2014 using PFN- thyratron switch. This PFN pulser was designed and constructed in house, and it fulfils all the performance specifications, such as flattop width, pulse-to-pulse stability, and current pulse fall time with respect to the designed inductive load. The overall bench tested performance of the kicker pulser is listed in table 1. However, due to hardware design constrains, the load inductance (4.4 μH) exceeded the existing circuitry tuning limits of compromising margin, so the overall performance of PFN pulser was degraded, as illustrated in figure 1.

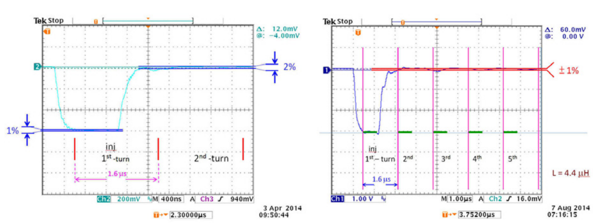

Figure 1: current pulse at (L) bench test; and (R) field test.

The contents in Table 1 indicate that the flattop, its ripple, and fall time, are consequently influenced. Several improving attempts have been studied in order to eliminate the postpulse oscillation, which has tail ripples and could induce extra kick, while the injected beam is circulating around in the booster ring. The urgent improvement attempt by modifying the electrical circuit and reducing the field inductance was made in time for booster injection system test in 2014 [1]. Yet, for the modified PFN circuitry, the available flattop region is reduced to 200 ns due to the unavoidable prolonged fall time. This reduction in the flattop duration does not only limits the bunch train tuning capability in the MB (multi-bunch) operation, but also restricts the bunch pattern manipulation flexibility in the MB+SB (single bunch) hybrid mode operation [2].

The initiation of this IGBT study is to improve TPS injection pulser by using an alternative approach. After evaluating several improvement options in hand, a pulser using IGBT switch is introduced. Comparing its performance with the modified PFN pulser [3] using same inductive load, the IGBT pulser provides a couple of advantages in this particular application, as follow:

1. Fall time can be reduced;
2. Flattop duration can be increased;
3. Small postpulse oscillation can be achieved;
4. Installation space is greatly reduced in the accelerator tunnel.

Some disadvantages are to be considered before implementing the IGBT pulser. There are: i) limitation of reducing fall time due to the existing inductive load; ii) noise interference with the low triggering threshold of IGBT switch. After examining the corresponding bench tested countermeasures, the results indicate that the performance of this IGBT pulser satisfies the specifications with comfortable margins. This report describes the field-testing result of this IGBT pulser in details.

Table 1: LTB Kicker Pulser Tested at Bench and Field

Booster Injection Kicker			
Parameter	**specifications**	**bench-test**	**field-test**
Pulse Shape	flat-top	flat-top	flat-top
Type	PFN	PFN	PFN
Pulse Length (μs)	1	1	0.7
Nominal Current (A)	280	280	280
Inductance (μH)	1.6	1.6	4.4
Fall Time (μs; 5-95%)	0.4	0.4	0.9
Pulse-to-pulse Stability (%)	0.1	0.1	0.1
Flatness (%)	± 1	± 1	± 2
Postpulse ripple (%)	± 1	± 1	± 1.5
Repetition Rate (Hz)	3	3	3

IGBT PULSER LAYOUT

The upgraded injection pulser consists of two parts: an IGBT switching unit and a DC charging power supply (DC-PS). Choosing the IGBT switch is primarily based on its capability of high delivery power and rapid switch-off ability [4]. A functional block diagram of using IGBT switch for the LTB kicker PS is shown in figure 2. A DC-PS charges the capacitor bank to a designated value. Then IGBT trigger is switched on by a control unit according to

#clchen@nsrrc.org.tw

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the requirement of booster injection sequence. The gated current passes through the inductive load, i.e. kicker, to produce the beam deflection force. The current is terminated as soon as the IGBT switches off.

Due to the existing high inductive load of the kicker magnet, it induces a large reflection oscillation signal in the circuit loop. This reflected interference signal causes the IGBT has difficulty switching off as expected. A filter technique is introduced to eliminate all possible noises and only allows clean triggering source arriving IGBT. Therefore, IGBT can be switched on and off properly according to the demanding triggers. The output current of the pulser is monitored by a current transformer, which is installed between IGBT switch and inductive load. This pulser is carefully examined at test bench before installation to the booster ring. A typical example of the measured output current signal is given in Figure 3.

Since the upgraded IGBT kicker pulser has to deal with a relative high inductive load, the circuitry needs to be pre-tuned at the bench before installing in the accelerator tunnel. An inductive load of tuning range between 1 to 3 µH is employed at the test bench for system optimization purpose. The purpose is to study and characterize this new IGBT pulser in dealing with various possible inductive loads in the field. Moreover, this helps to specify the operational range with the guiding specifications, such as fall time, pulse length and its achievable ripples.

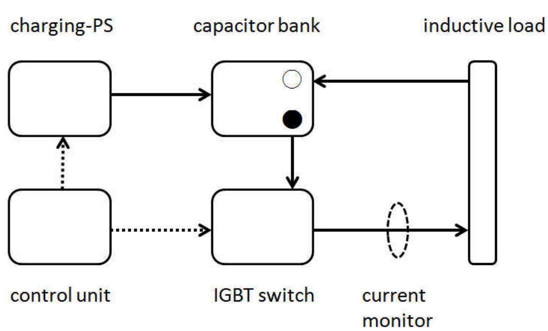

Figure 2: Functional block diagram of the IGBT-pulser.

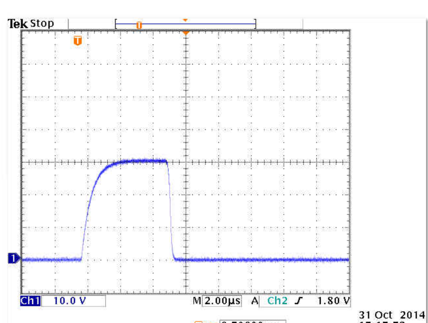

Figure 3: Typical current signal of the IGBT switch pulser.

As illustrated in Figure 3, the rise time of the delivering current is constrained by the load inductance. It gives a charge-up time of about 2.5 µs. The electron beam is injected at the region where stability and flat-top requirements are met. Then, the delivering current is shut off by command trigger. During the test, it was observed that the ringing noise caused by the large inductive character in the current loop induces unavoidable interference to the triggering command. Consequently, the IGBT switch was off-and-on as the interference is dominating over the command source leaving unwanted current leak-tail behind. This is one of the major issues which have to be solved before IGBT can be used as the switch in the injection kicker system. After coping with the phenomena, the IGBT pulser is put into testing.

TEST RESULTS FOR IGBT INJECTION KICKER

Figure 4 shows the installed circuitry for this IGBT pulser. The circuit consists of capacitor bank, IGBT module, control unit, current monitor and the supporting accessary. Its overall dimension is a 1U height 19 inches case with (W×D×H) 46×48×17 cm^3. Comparing with a PFN kicker PS, the IGBT system can save much installation space required in the accelerator tunnel. This compact IGBT unit can reduce not only the total material cost, but also the maintenance time, if the system is to be swapped with a backup unit during trouble shooting.

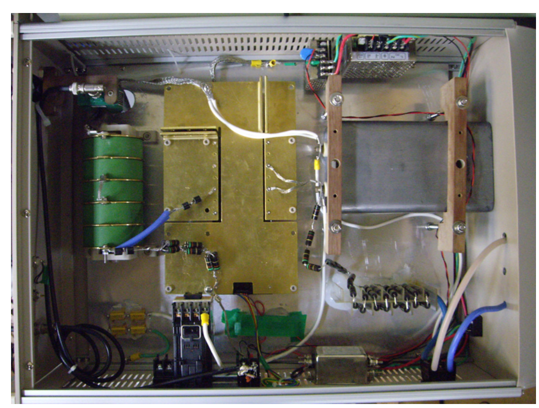

Figure 4: The layout of IGBT test unit circuitry.

The IGBT pulser is installed in the booster ring and connected to the in-vacuum injection kicker. The measured inductance of the kicker is 3.0 µH. A photo of the IGBT pulser and the in-vacuum kicker is shown in figure 5. On-site measurement result of IGBT pulser, operating at nominal value of 280A, is shown in Figure 6. It is capable of providing the beam manipulation power as required. Detailed analysis of the current waveforms, shown in Figure 7, indicates that the variation is within ±0.4% at both flattop and postpulse regions. The measured characteristics of the IGBT pulser are summarized in Table 2 for evaluation purpose.

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Figure 5: The field testing LTB kicker pulser and magnet.

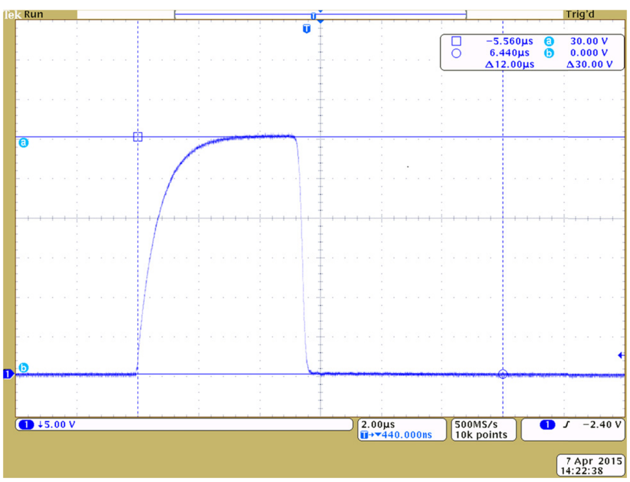

Figure 6: Comparison of current waveforms between (a) original PFN pulser; and (b) new IGBT pulser.

Table 2: The Modified PFN Pulser and IGBT Pulser

LTB Kicker Pulser		
Parameter	**PFN***	**IGBT**
Pulse Shape	flat-top	flat-top
Pulse length (µs)	0.2	1
Nominal Current (A)	280	280
Inductance (µH)	3	3
Fall Time (µs; 5-95%)	1.5	0.6
Pulse-to-pulse Stability (%)	0.1	0.1
Flatness (%)	± 0.2	± 0.25
Postpulse ripple (%)	± 0.2	± 0.4
Repetition Rate (Hz)	3	3

*modified PFN pulser

As shown in Table 2, the measured results show that the IGBT pulser is able to provide a current pulse at nominal output with 1 µs flattop and 0.6 µs fall time. The pulse-to-pulse stability and pulse flatness are are also well improved.

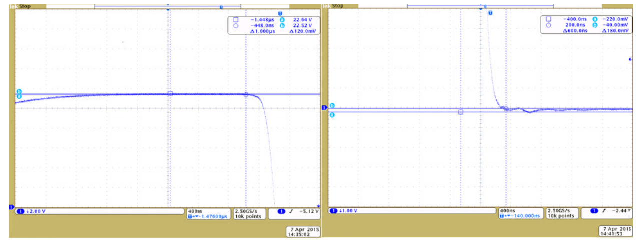

Figure 7: The measured flatness of flattop and postpulser.

SUMMARY

A test unit of IGBT switch based LTB kicker pulser has been built to verify its capability in operating under an electrically noisy environment. This test unit has provided encouraging information that it is potentially feasible to improve the overall field performance on its flat-top width, stability, and fall time of the current pulse. The field tested results indicate that the performance has been improved drastically. It could provide beneficial injection efficiency and bunch length manipulation capability for both MB operation and for the future MB+SB hybrid modes operation as well. Its safety control circuit, enforced noise resistivity, and system reliability would require further investigation if routine operation is needed in the future.

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