HIGH REPETITION BEAM KICKER WITH IGBT SWITCHING MODULES

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Abstract

A kicker power supply with repetition rate of 1 kHz was designed and constructed. Since a conventional thyratron switch cannot be operated with a sufficient lifetime in such a high repetition rate, a new type of a power supply has been developed that employs high power IGBTs as switching modules.

In order to realize a simultaneous turn-on of numerous IGBTs connected in parallel and in series, a new technology, a subordinated-driving method, is applied.

With this new type of the power supply, a kicker field with a repetition rate of 1 kHz is achieved. The power supply is proved to function with sufficient stability and its jitter is found to be small, within ±1nsec.

1 INTRODUCTION

In the existing kicker magnets for synchrotrons, the repetition rates generally range in the orders from 0.1 to 10 Hz, depending on the repetitions of synchrotrons. In this range of repetition rates, the kicker fields can be turned on by the use of thyratrons as switching elements.

In some recent applications, however, much higher repetition rates are demanded. It is especially the case when an FFAG synchrotron scheme is employed. Since the FFAG scheme does not require a ramping period for a particle acceleration, the accelerating cycle can be increased, in principle, by orders of magnitude. For example, in the 'PRISM/FFAG' project[1], the phase rotation ring project for the production of high quality muon beams, the kickers need to achieve a repetition rate of 1 kHz or even higher.

Conventional kicker power supplies with thyratron switches can not be used in such high repetition rates because of a thyratron's lifetime limit. Although the exact lifetime of a thyratron tube is difficult to predict, it can be estimated from 10**8 to 10**9 shots. When a thyratron tube is operated at 1 kHz, consequently, its lifetime becomes from 1 to 10 days. The use of IGBT modules is the key issue in order to overcome this lifetime limitation.

2 IGBT SWITCHING CIRCUIT

Contrary to a thyratron, which is a gas-filled discharge tube, an IGBT is a solid-state device that has virtually no limited lifetime. In order to prove a principle of the 1 kHz kicker, we started constructing a kicker power supply which is composed of IGBT modules, as is previously reported[2].

The basic design parameters of the power supply are summarized in Table 1. The IGBT module used is CM75DY-28H from Mitsubishi Elec. Co., which has maximum operating voltage and current of 1.4 kV and 150 A, respectively. The massive connections of the IGBTs, 36 modules in series and 4 series in parallel, achieve the designed specification of 35 kV and 700 A.

The key technology to achieve the synchronous switching of all those IGBT modules is the subordinated-driving method that is applied to the multi-stage gating circuit[3]. Its principle is summarized in Figure 1. In the figure, numbers of IGBT modules are connected in series. The gating signal is supplied only on the module nearest to the ground, which is called the master-stage.

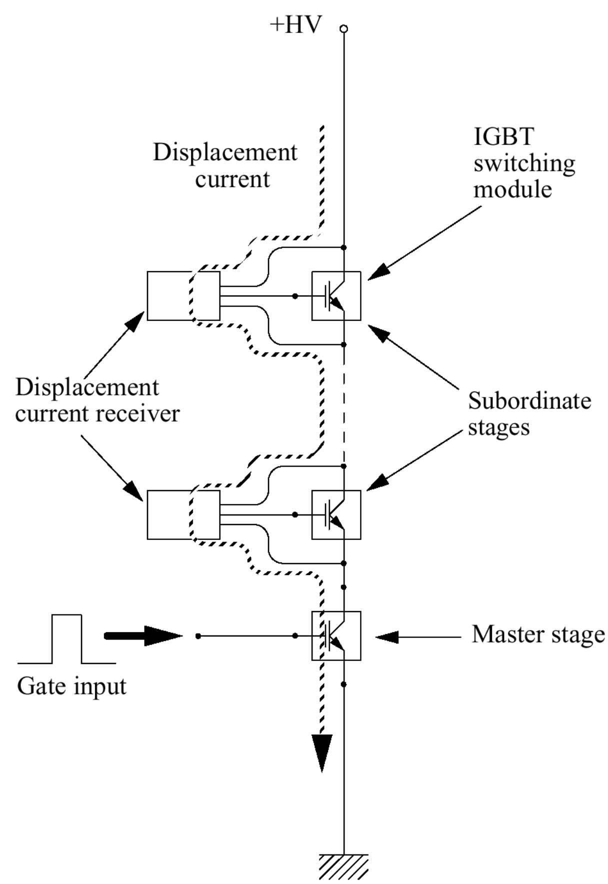

Figure 1: Principle of the subordinated gating system. Numbers of switching modules (in the figure, IGBTs) are connected in series. The gating signal is supplied only on the module closest to the earth potential, called the master-stage. The other stages are turned on subordinately to the master-stage.

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Table 1: 1 kHz Kicker Power Supply Specifications

Maximum PFN Charging Voltage	35 kV
Maximum Kicker Current	700 A
PFN Impedance	25 Ω
Rise Time	300 nsec
Flat Top Width	200 nsec
Flat Top Accuracy	±2.5%
Jitter	±5nsec
Maximum Repetition Rate	1 kHz

The other modules are called the subordinated stages.

Before the gating signal is put in, all the IGBTs are open and the equal voltage distribution of +HV/n is applied on all the stages, where n is the number of the stages. When the gating signal is applied to the master-stage, the potential difference of the master stage disappears, and the voltage applied on all the subordinate stages increases from +HV/n to +HV/(n-1). This increase of the voltage leads to the flow of the 'displacement current' (Figure 1). The current is picked-up by the displacement current receivers on all the subordinate-stages, which gives the gating-signals onto all the subordinate-stages. Thus the simultaneous turning-on is assured without any complicated line connections.

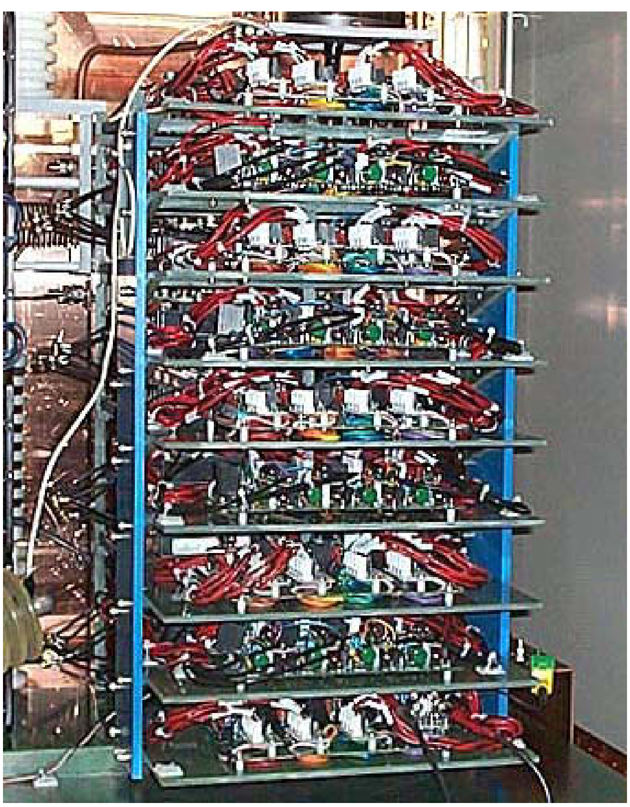

Figure 2: The subordinated-driving switching unit in the 1 kHz repetition power supply. The unit consists of nine layers of circuit boards, where each layer contains 16 IGBTs, 4 in series x 4 in parallel. The maximum switching voltage and current with this unit are 35kV and 700A. The height of the unit is about 60cm.

Figure 2 shows the photograph of the subordinated-driving switching unit built for our 1 kHz power supply. The unit is composed of nine layers, and each layer contains IGBT modules and a displacement-current receiver.

The test operation was carried out with the power supply connected to the existing kicker test-bench with a magnetic-alloy (MA) return yoke. The output pulses from the power supply were delivered to the kicker test-bench through a transmission line with 100m length. The line was composed of 25 Ω coaxial cables (2 parallel of 50 Ω cables).

3 TEST OPERATION RESULTS

The 1kHz operation has been successfully achieved with up to the maximum charging voltage (Figure 3). On the figure, the total voltage applied across the switching unit (lower waveform) oscillates between zero and the maximum voltage in synchronization with the master-stage voltage oscillation (upper waveform).

In this test operation, the triggering pulse is supplied in a burst mode with a 10% duty factor, which means, within 1000 cycles in one seconds, the first 100 cycles are turned on and the rest 900 cycles are left without switching. This limitation is mainly due to the current ability of charging and cooling of the power supply. If a power supply with an increased charging and cooling ability is built, it will enable the CW 1 kHz operation.

The resulting kicker fields in the 1 kHz operations are measured as are shown in Figure 4. The kicker current

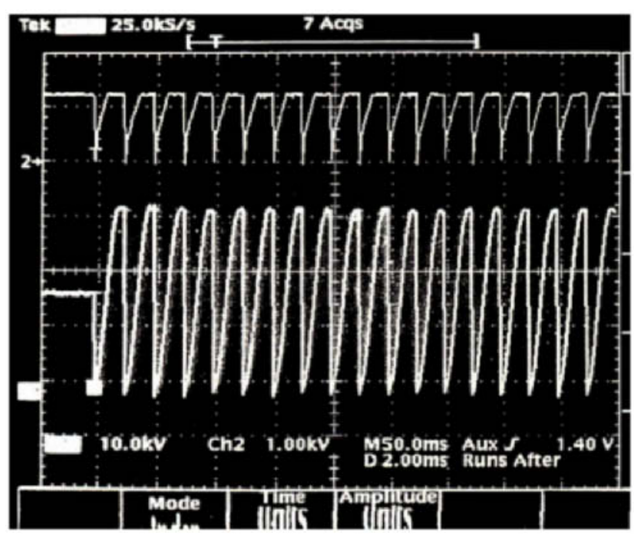

Figure 3: A confirmed result of the 1 kHz operation. The upper waveform is the master-stage voltage (1kV/div) and the lower waveform is the voltage across the switching unit in Fig. 2 (10kV/div). The applied DC voltage is 34 kV. The abscissa denotes 2msec/div.

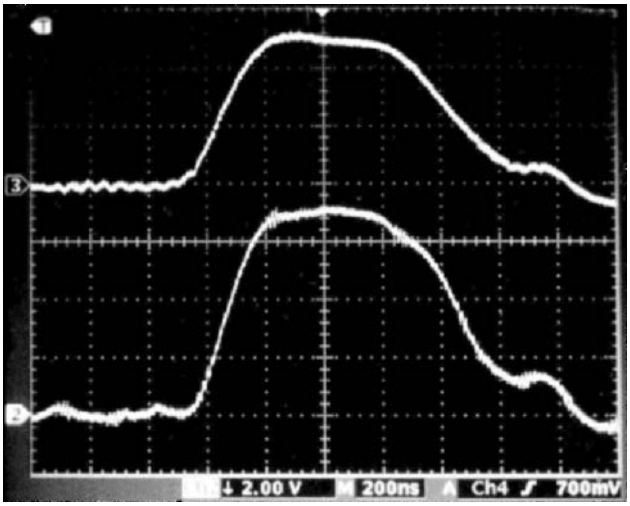

Figure 4: Observed kicker fields. The kicker current (lower, 200A/div) is measured with a current transformer The current reaches its designed maximum value, 700A, within a 10-90% rise-time of 240nsec. The kicker field (upper, 500 mV/div) is measured with a search coil placed at the center of the kicker gap. The abscissa denotes 200nsec/div.

(lower waveform) is measured with a current transformer. The upper waveform is the kicker field measured with a search coil. The search coil was fixed at the center of the 50mm-width gap of the kicker test-bench. The two waveforms show almost the same property of the field's rise-up and fall-down. The field strength at the flattop can be roughly estimated as 300-400 Gauss. Since the field strength is weak, no saturation is observed (Figure5).

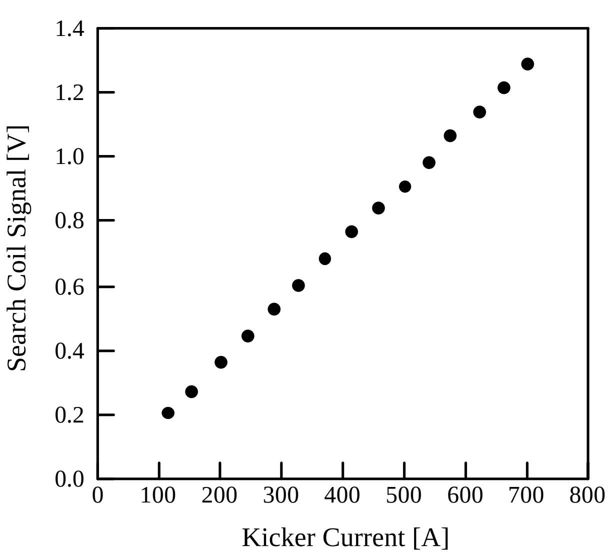

Figure 5: The output signal of the search coil with respect to the kicker current. The linear rise of the search coil signal indicates, as far as the measured range, there is no saturation within the MA (magnetic alloy) core by the magnetic field.

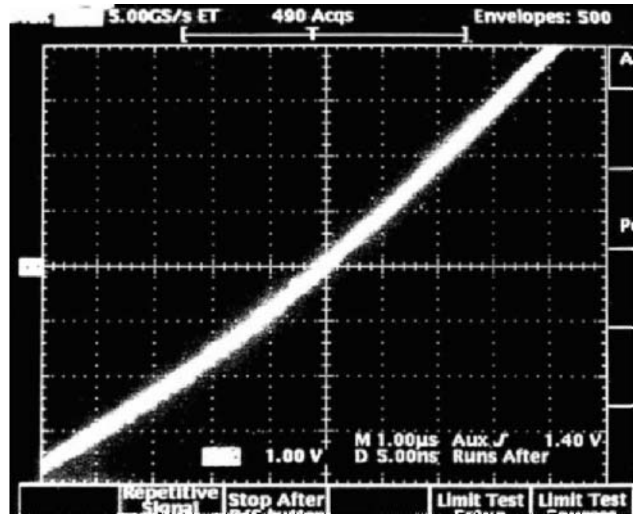

Figure 6: A measured result of the jitters in the output pulses. 500 pulses are overlapped in the above waveform The charged voltage is 33 kV and the output current is 660 A. Both values are close to the designed maximum, 35kV/700A. The measurement is done at the output current of 100 A, which is at the center of the above figure. The jitters are found to stay within 1nsec. The abscissa denotes 5 nsec/div.

Figure 6 shows the jitters of the output pulses. 500 waveforms are overlapped in a single line. It can be observed that the jitters stay within ±1nsec, which means that the simultaneous switching by the subordinated-driving system is satisfactorily functioning.

4 SUMMARY

The kicker power supply with a 1 kHz repetition rate is constructed and tested. The switching modules used are high-power IGBTs and they are connected massively both in parallel and in series. In order to assure the synchronous switching of all the IGBTs, the subordinated driving method is applied.

Test operations so far indicate that the 1 kHz repetition rate is achieved as in the designed intention. The resulting kicker fields are measured and the observed small jitter implies that the satisfactory level of synchronous switching is realized.

5 REFERENCES

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