NEW DEVELOPMENT OF COMPACT FAST PULSED POWER SUPPLY SYSTEM IN THE SPring-8

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Abstract

We have developed a compact fast pulsed power supply system as a part of the development of the fast kicker magnet system in the SPring-8 storage ring since 2007. The initial required pulse width and current was 800 ns which is sufficiently short time less than 4.8 μs of the revolution time and more than 250 A for 0.8 μH load respectively. The volume of the power supply system was required less than 0.03 m^3 to install the power supply system to be anywhere without changing the existing main accelerator components. We chose a Si-MOSFET as a switching device of pulsed current generation circuit. The output current is increased by parallel or parallel-series connecting of MOSFETs. We started the development of a test system whose output current was a 67 A with a pulse width of 1.0 μs in 2008. In 2012, by using the parallel-series connecting of MOSFET, we confirmed the output current of 232 A with a pulse width of 0.4 μs, whose case volume is less than 0.01 m^3.

INTRODUCTION

The fast kicker magnet system is needed for following purposes of electron beam control in the SPring-8. The first is the 1 ps short pulsed X-ray generation by a vertical kick scheme [1] [2] [3]. The second is the suppression of the fast beam oscillation by counter kick [4].

In the installation of the kicker magnet system in the accelerator ring, it is very important to select the install location which give the optimum phase advance in order to maximize the kick efficiency. There are two restrictions to install the kicker magnet: 1) not to change the arrangement of the existing main accelerator magnet components and 2) to put the kicker magnet in the small space in the straight section. In the SPring-8 accelerator ring, according to the restriction, the allowed space for the installation is less than 30 cm long in the mean. That is all of our motivation to develop the compact, fast rise time and large output pulsed power supply system as putting it anywhere.

At first of the development, we started from the development of power supply system whose pulse width is from 1.0 μs to 2.4 μs; target values of the required pulsed width and the output current was 2.4 μs in the half of the revolution time of 4.8 μs and 320 A, corresponding to 71 μrad kick angle, to make an isolated single electron bunch to excite 2.0 mm vertical oscillation. Under the success of that development, we started the development of faster rise time power supply system whose pulse width is less than 1.0 μs; target value of the required pulsed width and required output current was 0.8 us and 250 A, corresponding to 37 μrad kick angle, to agree with the beam oscillation width. In the latest development, we have succeeded in the improvement of the output current in the pulse width region less than 0.7 μs by the MOSFET parallel-series configuring for the output stage.

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POWER SUPPLY SYSTEM AND CIRCUIT

To fulfill the the required fast rise time pulse and the large output current in the allowed small space, we build up the following concept designs: 1) putting the power supply system near to the kicker magnet to reduce the load to the power supply system and 2) using the Si-MOSFET solid-state device to make a compact power supply system. The power supply system was divided two parts under the concept designs, driving circuit part and the main voltage power supply part. Two driving circuits were placed close to the kicker magnet and connected to each one turn air-core coil (see figure 1). By system dividing, the load to the

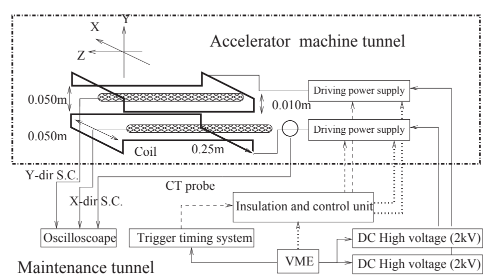

Figure 1: Overview of the kicker magnet system.

power supply system is reduced to less than 0.8 μH with the feeder line which is made by the optimized Litz-wire. In addition to the reduction of the occupied volume, an advantage of separating the power supply by two parts is easy protection from scattered X-rays of synchrotron radiation.

The driving circuit is composed of an LC resonant circuit to generate a half sine waveform (see figure 2). To generate the fast rise time pulse with large output current, a high voltage was supplied to the driving part and switched to the load with Si-MOSFETs. The MOSFET has two capabilities of the fast switching and high-voltage resistance. And the size of the MOSFET is smaller than an IGBT and thyratron. The driving circuit has two special features of polarity changeover and output pulse-width changeover. They are controlled via control and ground-insulation unit from the VME remote system. The output current is linearly controlled by changing the supplied high voltage.

Table 1: The historical progress of developed driving circuit.

Circuit type(FY)	R&D(2007)	TestI(2008)	TestII(2009)	Development(2010)	Improvement(2011)
Current(A/coil/V)	67/400	141,397/500	187,260/850	270,555,740/950	232,282,383/1950
Pulse width(μs)	1.1	1.2,2.5	0.8,1.2	0.8,1.8,2.4	0.4,0.5,0.7
Repetition(Hz)	1	1	10	150	10
# of MOSFET	2	4	4	6	6×2
MOSFET type	2SK3131	STY60NM60Z	STY30NK90Z	IXFB44N100P	IXFB30N120P
Vol. Resistance(V)	500	600	900	1000	1200

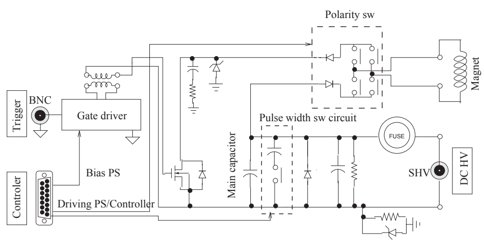

Figure 2: Schematic view of a driving circuit.

HISTORICAL PROGRESS

We started the development of a R&D circuit whose output current was a 67 A with a pulse width of 1.0 μs in 2007 (see table 1). At that year, the maximum voltage resistance of the available MOSFET was 400 V. From 2008 to 2010, the voltage resistance of the MOSFET increased up to 900 V. The current rise time also improved with the progress of the voltage resistance. For the required large current, the current is enhanced by increasing the number of MOSFETs connected parallel. We achieved an output current of 270 A with a pulse width of 0.8 μs. Responding

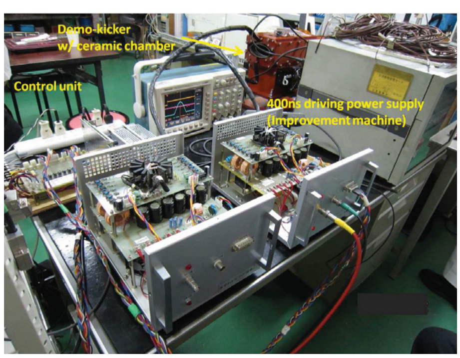

Figure 3: Test bench view of the improvement circuit (made by TEXIO TECHNOLOGY Co. and SEKINE ELECTRIC Works Co., LTD.).

to the above development success, we started improving the output current at the rise time region less than 800 ns. The Si-MOSFETs with 1200 V voltage resistance became available as of 2011. We increased the circuit voltage resistance and output current by connecting the MOSFETs in parallel-series. In 2012, by using the total of 12 MOSFETs, we confirmed the output current of 383 A, 282 A, 232 A with a pulse width of 0.7, 0.5 and 0.4 μs respectively, whose case size is a just 210(W) x 160(H) x 260(D) mm (see figure 3). The output current is measured by a search coil (S.C.) under the condition that the power supply was connected to the dummy-kicker magnet which has same inductance as the actual kicker magnet (see figure 4). The S.C. was calibrated by CT probe, and the error associ-

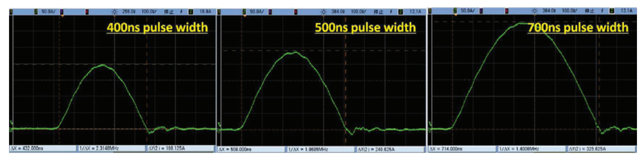

Figure 4: The CT probe signals of the output current. The calibration factor of CT probe was 10 mA/mV. The measured current was reduced by about -8.0 % by CT probe inductance.

ated with the calibration was estimated to be 1.3 %. When the ceramic chamber is inserted into the magnet, the output current reduced by about -9.4 % by the eddy current flowed on the metal coating on the inside wall of the chamber.

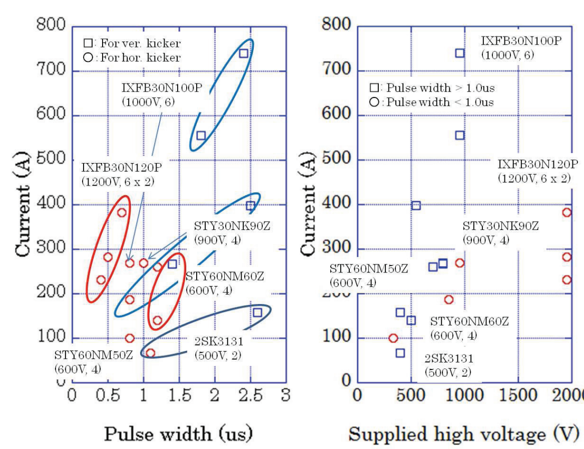

Figure 5: The output current improvement for the pulse width and supplied voltage.

The performance largely depended on the MOSFET property especially on voltage resistance as shown in figure 5. The output current in the pulse width less than 1.0 μs was improved by high voltage-resistance MOSFET coming out. From this figure, we can easily expect to achieve the output current over 1 kA by improvement circuit at the pulse width more than 2.0 μs with 1.95 kV.

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PRACTICAL USE AND TECHNICAL ISSUES

For the practical use, trouble free operation during the user experiment run is required. There are following technical issues in long stable operation: 1) ensuring the synchronized switching of the multi parallel-connected MOSFETs, the protection circuit for the overload generated by a little time lag in accidental asynchronous switching of MOSFET, and the thermal reduction system for the MOSFET heat load by using the MOSFET with 90 % supplied voltage for its voltage resistance, 2) improving the impedance mismatch between the power supply system and magnet coil, 3) reducing the high frequency electromagnetic wave noise from the beam wake field generated when beam passes through the kicker chamber, 4) reducing the reverse high voltage induced by the kicked beam, and 5) reducing the scattered X-rays of the synchrotron radiation.

In the region of pulse width less than 1.0 us, the issues of 1) and 2) are needed to treat carefully to avoid the unexpected MOSFET breaking down by the over-voltage and over-current. To overcome the issues, the MOSFET was screened by strict level less than 10 % for the on-resistance, the floating inductance in the circuit was reduced, and the lengths of the timing distributing line were uniformed. About the temperature rise on the elements by 7∼14 degrees, the heat-sink was cooled by a fan. After solving the 1) and 2) issues, at the factory test of power supply, the operation period more than 2 weeks was ensured. In the operation with electron beams, the running period was reduced to less than 5 days. The break down process of the driving circuit strongly depended on the beam filling mode and beam current. The figure 6 shows S.C. signals

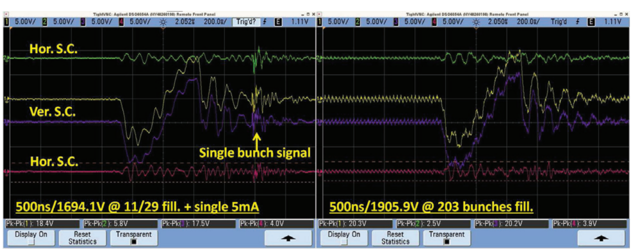

Figure 6: The vertical and horizontal search-coil signals for each magnet coil at beam operation. The right figure shows the S.C. signals at 203 bunch filling mode. The left figure shows the S.C. signals at 11/29 filling + single 5 mA 1 bunch mode. In these cases, the driving circuit was operated with 500 ns pulse width.

at the typical beam filling mode with high current single bunch and high frequency noise.

To solve the issues of 3), 4) and 5), first of all, we shut out the noise from the ground-line by floating the system from the ground level and the radiation and noise shield was installed. After the installation of the noise shield and noise protection circuit to prevent the MOSFET from false switching by external noise and the protection circuit of reverse voltage induced by the kicked beam, we achieved the long practical operation stability of more than 1 month. An actual setup in the SPring-8 storage ring is shown in figure 7.

Figure 7: Actual setup of the driving circuits stored in the radiation and noise shield boxes. Two driving circuits are connected to each coil. The one is standby driving circuit.

CONCLUSION AND FUTURE PROSPECT

By using the improved circuit, it became to be possible to suppress a 500∼800 ns fast rise time beam oscillation at an injection and to excite a beam tilt, which was able to generate the ∼3 ps pulsed X-ray by 50 μm slitting, for electron bunches stored in the 400 ns time region. Its case size made it possible to put the kicker magnet in any place of just 30 cm free space. In the future, to generate the 1 ps short pulse radiation light by bunch by bunch, we need the faster current rise time less than 400 ns and larger output current of ∼ 1 kA. From a point of view of the future light source ring, comparing with the existing pulsed power supply system, it will be required to be compact as much as possible in order to increase the flexibility of the pulsed magnet arrangement for the high density of accelerator components.

To increase the output current based on improvement circuit, we are planning following approaches for keeping compact size: a) parallel-series stacking of the power supply module by using transformer coupling, b) increasing the number of using MOSFET and c) using the SiC-MOSFET instead of the Si-MOSFET, which has higher voltage resistance and lower switching resistance than Si-MOSFET. We will develop the compact fast pulsed power supply system continuously to reach 1 kA region in the output current with a 200 ns pulse width and 1 kHz repetition in the next step.

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