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Measurement system for SSRF pulsed magnets

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Abstract This paper describes the magnetic field measurement system for pulsed magnets in SSRF. The system consists of magnetic probes, analog active integrator, oscilloscope, stepper motor and a controller. An application program based on LabVIEW has been developed as main control unit. After the magnetic field mapping of a septum magnet prototype, it is verified that the test results accord with the results of theoretical calculation and computer simulation.

Key words Magnetic probe, Integrator, Pulsed magnetic field, LabVIEW

CLC numbers TL503.8, TL506

1 Introduction

The injection and extraction of electron beam in Shanghai Synchrotron Radiation Facility (SSRF) need 15 pulsed magnet systems, which include two kicker magnets, four septum magnets and three bump magnets for the booster injection and extraction[1], and four kicker magnets and two septum magnets for the storage ring injection[2]. High performance of the pulsed magnets is crucial for efficient beam injection and extraction.

Because of demands on high performance accelerators and especially the adoption of top-up injection model, pulsed magnetic field becomes a necessity. Therefore, one has to find ways to measure the magnet parameters, such as field strength, field uniformity, field integral, etc. At present, pulsed magnetic field measurement systems include mainly a magnetic probe, an integrator to convert induced electromotive force to magnetic field signal and a data acquisition system. Generally, The integration is achieved with the passive RC integral circuit[3,4] or the digital integral function of a digital oscilloscope[5-7], while the data acquisition is done by a fast sampling digital oscilloscope[3-7].

On the basis of studying measurement systems for pulsed magnets at home and abroad, a fast, reliable, precise and automatic measurement system has been developed in order to meet the project schedule of SSRF and technical requirements of measuring the pulsed magnetic field. It comprise (1) a mechanical motion bench and motor controller to do the measurement fast and automatically, (2) a precise analog active integrator[8] to convert magnetic field signal, and (3) a digital oscilloscope with cutting and amplifying function[8] to improve the vertical resolution and precision (within ±0.1%) of the measurement system.

2 Hardwares

A testing platform was assembled in order to measure magnetic field distribution in the magnet aperture of the pulsed magnets (Fig.1). It consists of a septum power supply, a septum magnet prototype, magnetic probes, the Agilent 54810A oscilloscope (2-Channels 500MHz, 1 Giga-Samples/second (GSa/s)), an Agilent 82350 PCI GPIB card, the integrator, a Pearson-101 current transformer, the motion bench, a motor motion controller, etc.

The pulsed current and magnetic field are queried simultaneously by the oscilloscope. The pulsed current is measured by the current transformer. The magnetic

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probe is used to pick-up the induced electromotive force, which is converted to magnetic field signal by the integrator. A computer is used, and it communicates with the motion controller via an RS232 to control movement of the measuring bench, and interfaces with the oscilloscope via GPIB for data reading.

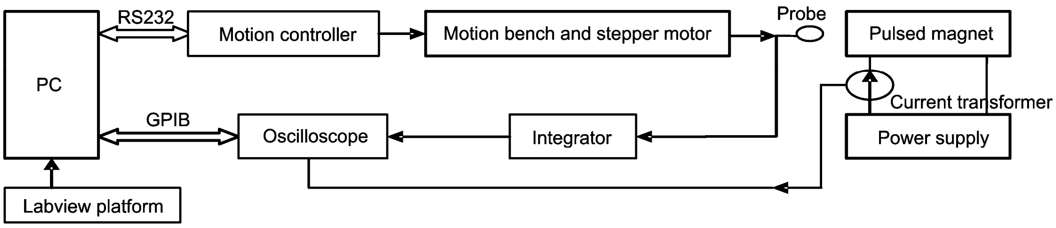

Fig.1 Schematic diagram of the pulsed magnets measurement system.

2.1 Magnetic probe

Since the septum delivers a pulsed magnetic field of 60 μs half-sine base, two kinds of field probes, namely long coil probe and point coil probe, were developed. The long coil probe has measured the integral field with a strip of double sided Printed Circuit Board (PCB) and it is 1.6 mm wide and 1 meter long. The point coil probe is a 20 turn coil of 4 mm diameter made with enameled copper wire for the beam motion mapping. The probes have not been calibrated precisely, i.e. there are some errors for measuring the area of coils, but the error is a constant by using the same probe for measurement. Since what we concern most is the relative magnetic field distribution, the relative value of magnetic field measured as such is accurate.

2.2 Analog active integrator[8]

The integrator is used to convert the induced electromotive force to magnetic field signal. The magnetic field B can be calculated by

$$B = \frac{RC}{NS} V_o \tag{1}$$

where N and S is respectively the turns and area of the probe, RC is the time constant of the integrator, and V_o is the output voltage.

Eq.(1) shows a linear relation between the magnetic field and output voltage of the integrator. An analog active integrator was designed and the circuit experiment and test revealed that errors of the active integral circuit were within ±0.1%, which well meets the precision requirement of the measurement system.

2.3 Motion bench and controller

The motion bench and controller (WN-SC400), from Beijing Winner Optical Instruments Co., Ltd.[9], are integrated in a chassis. The motion bench is driven by a two axis stepper motor, which is capable of providing microstep movements and two axis close-loop operation.

3 Softwares

The system is fully automatic. The data acquisition and instrument commands are controlled by the computer through LabVIEW software. A high resolution color control panel (Fig.2) provides friendly communication for the operator.

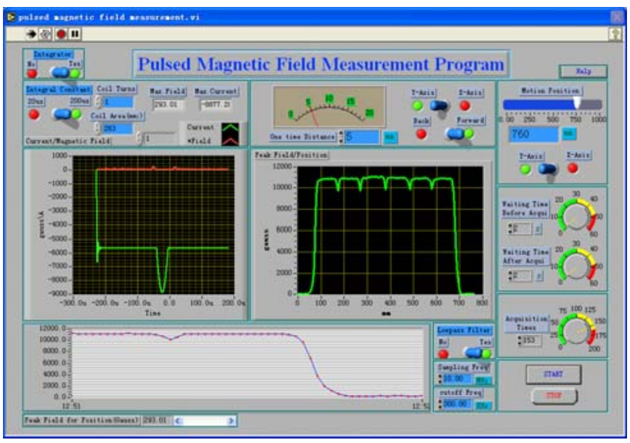

Fig.2 Operating page of main field measurement of the septum magnet.

Settings in the operating page of measurement include parameters of the coil, constant of the integrator, parameters of the low pass filter, and control step of the motor. The system is programmed to move the probe to desired location, take the data and treat them once it stops. After the data acquisition, the coil moves automatically to next location to get the data there. The time and interval of of the data acquisition loop can be pre-set.

The data is logged to a hard disk in format of a text file. It is convenient to use other software (e.g. Matlab) to process the data after the measurement. The data include the time, pulsed current, pulsed magnetic field and peak of the field along the coil.

4 Test results

As mentioned above, the measurement error shall be within ±0.1% to meet design requirements of the pulsed magnets. Therefore, measuring precision of components of the system shall be better than ±0.1%. However, with only an 8-bit resolution (8 bit ADC), the oscilloscope we used can detect at best a 0.4% signal change. To improve the resolution, we put different offset voltages on signal waveform respectively to cut and amplify part waveform area (especially the peak value area). The amplitude of waveform was about 500 mV, and measuring scale of the oscilloscope after part amplification was 10 mV/div. In this way sampling precision of the oscilloscope could be better than 0.1%.

After assembly and test of the measurement system, a prototype system of the magnetic field measurement of septum magnet was established. A 3-D schematic layout of the magnet for field mapping is shown in Fig.3(a). The septum thickness is 2.3 mm at the entrance and increases gradually to 10 mm at the exit along the *z* axis. Cross section of the septum magnet is shown in Fig.3(b). The design requirements of the septum magnet are given in Table 1. The data were processed by Matlab software.

Table 1 The design requirements of the septum magnet

Parameters	Value
Magnet length /mm	600
Aperture (H×V) /mm^2	26×10
Deflection angle /mard	51.1
Magnetic field /T	1
Repetition rate /Hz	2
Septum thickness (at entrance) /mm	2.3
Current waveform	Half sine
Pulse width /μs	60
Uniformity	2%
Stray field on bump orbit	0.1%

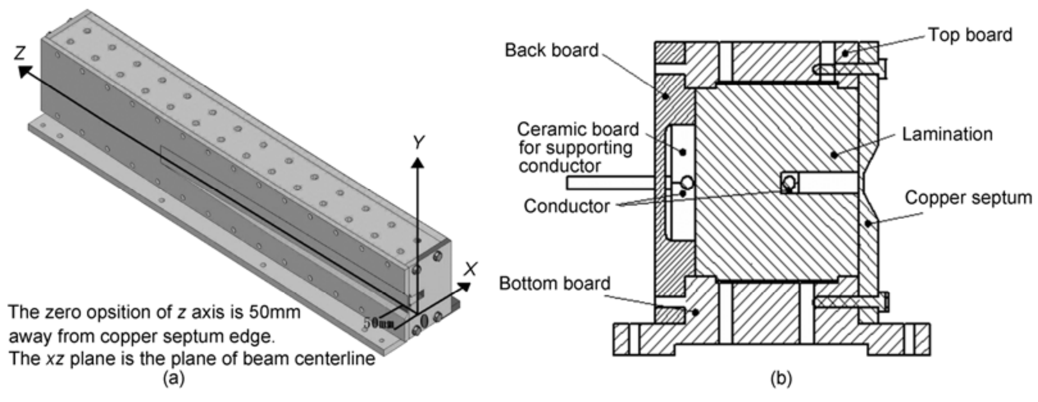

Fig.3 Layout of the septum magnet for field mapping.
(a) The 3-D schematic, (b) Cross section of the septum magnet.

4.1 Main magnetic field

4.1.1 Measurement of the point coil

The typical current signal and main magnetic field signal are shown in Fig.4(a). The coil was moved along a 3mm×5mm gird in *x*-*z* plane, measuring 4×153 (=612) points. Coil center of the first measured line along *z* axis was 3.5 mm to the copper septum in the gap. The main field distribution along *z* axis is shown in Fig.4(b). The five sags in Fig.4(b) correspond to the position of five ceramic boards which support the conductor.

4.1.2 Measurement of the long coil

The main field integral along the *x* axis is shown in Fig.4(c). Coil center of the first measured line was 1mm to the copper septum in the gap and the step of measurement was 1 mm. The uniformity of the main field integral in the measured range was 0.9%.

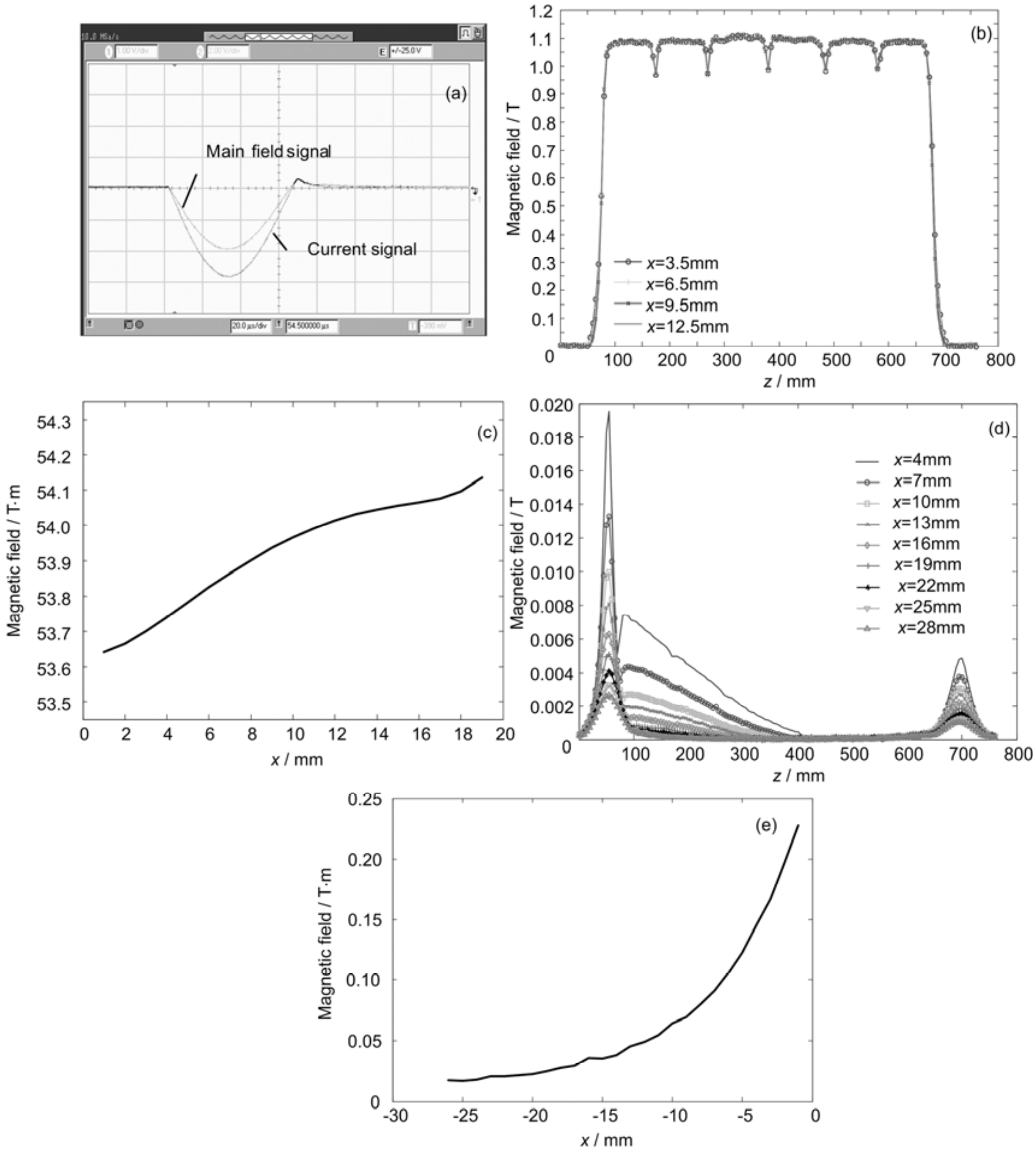

Fig.4 (a) Current signal and main field signal; (b) The main field distribution along *z* axis, *I*=8877A; (c) The main field integral along *x* axis, *I*=8953A; (d) The stray field distribution along *z* axis, *I*=8978A; (e) The stray field integral along *x* axis, *I*=8943A.

4.2 Stray magnetic field

4.2.1 Measurement of the point coil

The coil was moved along a 3mm×5mm gird in *x*-*z* plane, measuring 9×153 (=1377) points. Coil center of the first measured line along *z* axis was 4 mm to the copper septum out of the gap. The stray field distribution along *z* axis is shown in Fig.4(d). From Fig.4(d), one sees that the stray field peaks at the entrance of copper septum and decreases gradually along the *z* axis. The value of stray field is reciprocal of septum thickness. This agrees with the theoretical calculation and computer simulation.

4.2.2 Measurement of the long coil

The stray field integral along the negative *x* axis is shown in Fig.4(e). Coil center of the first measured line was 1 mm to the copper septum out of the gap and the step of measurement was 1 mm.

The amplitude of bump orbit in physical design was 14.5mm, and the center of bumped beam was 4 mm to the copper septum, i.e. the distance between the copper septum and the center of stored beam was 18.5mm. From Fig.4(c), the minimum main field integral was 53.6453T•m, and from Fig.4(e) the ratio of maximum stray field integral and minimum main field integral at -4 mm and -18 mm of x axis were 0.27% and 0.05%, respectively.

5 Conclusion

The test results indicate that the magnetic field performances of the septum magnet prototype accord with the results of theoretical calculation and computer simulation[10]. After this magnet test, we also finished the measurement of kicker magnet prototype for booster injection. The measured performances of the kicker magnet are satisfied with the design requirement. It is verified that the system is reliable, fast, precision and automatic for pulsed magnetic field measurement.

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