COMMON MODE PHENOMENA IN THE MAGNET POWER SUPPLY SYSTEM OF THE KEK PS 12 GeV MAIN RING

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Abstract

Common mode phenomena have been observed in the magnet power supply system of the KEK PS 12 GeV main ring. The bending magnet power supply system is a series connection of the power supply "BI", the chain of magnets "B′ ", the power supply "BII" and the chain of magnets "B". A dummy magnet which is inserted between the B chain and the BI power supply makes the system asymmetric and causes difference between the current of the B chain and that of the B′ chain. Common mode currents have also been observed to be the order of 10^{-4} or less of the normal mode current using high precision DC current measuring systems. The phenomena are well explained with a simulation.

1 INTRODUCTION

The KEK PS main ring employs 48 bending magnets to form closed orbits of protons of the injection energy of 500 MeV to the flattop energy of 12 GeV in the circumference of 340 m. The total resistance is 0.76 Ω. The total inductance at the injection energy is 1.2 H and less at the higher energy. The current is 202 A at the injection energy and 2850 A at the flattop energy. The current is ramped in the acceleration time of 0.79 s. The necessary voltage is up to 5500 V to achieve the ramping speed. The power supply, including the Q magnet system, has a power capability of 20 MW at the peak and 8 MW in average for the repetation period.

Ideally the current should be exactly same for all of the magnets. Unavoidable noise sources and asymmetries in the circuit, however, could create common mode noises which make undesirable difference in current for each magnet.

The bending magnet power supply system [1] is a series connection of the power supply "BI", the chain of magnets "B′ ", the power supply "BII" and the chain of magnets "B" as shown in Fig. 1. The voltage output of BI with a DC filter that is to reduce normal mode ripples has been noted as "VBLF". The voltage output of BII with a DC filter has been noted as "VBRF". Each power supply has been equipped with a common mode filter of two 50 μF capacitors, shown as C1, C2, C3 and C4 in Fig. 1, with the middle point ground. The parameter has been optimized to minimize common mode noises originated at the power supply.

Output voltage patterns of BI and BII are same and a same number of magnets are in the B chain and B′ chain.

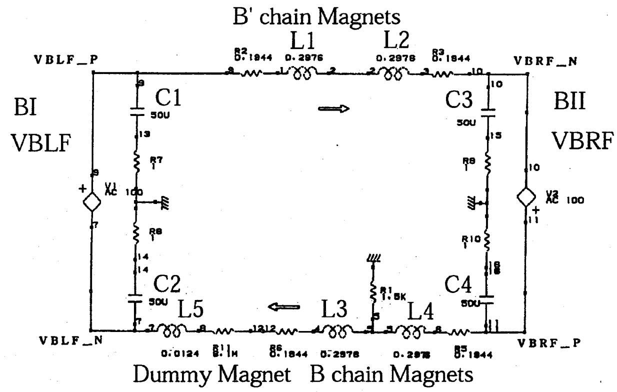

Figure 1: A schematic circuit of the bending magnet power supply system of the KEK PS 12 GeV main ring.

The system is then symmetric. The circuit is grounded at the middle point of the B chain to minimize the system voltage with respect to the ground. The 1.5 kΩ resistor for the ground has been inserted empirically to reduce common mode noises.

A half size bending magnet has been used for monitoring the magnetic field and called a "dummy magnet". The dummy magnet is inserted between the B chain and the BI power supply. The system becomes then asymmetric. We observed common mode phenomena due to the asymmetry in measurement of signals of backleg coils of the magnets and high precision DC current measuring systems. A simulation analysis was also performed.

2 BACKLEG COIL SIGNALS

All magnets have backleg coils to monitor the magnetic field, and most of the signals are available in a substation building. All of the available signals were recorded with a 14 bit recorder at the sampling rate of 10 kHz. The data of all the magnets were subtracted from the data of one magnet in the B chain, I-1B′ , as a reference. The subtracted signals of the B chain are shown in Fig. 2 and those of the B′ chain are shown in Fig. 3.

Ripples of about 40 Hz is significant at the beginning period of 200 ms for the B′ chain magnets, but not so for the B chain magnets. The difference of the backleg signals from the two chain magnets indicates the existence of the common mode component.

The resonant frequency of an LC circuit made with the B′ chain magnets, L1 + L2 in Fig. 1, and the common mode capacitor, C1 + C3, is 40 Hz. Another LC circuit made with the B chain magnets and the dummy magnet, L3 + L4 + L5, and the common mode capacitor, C2 + C4, has slightly different resonant frequency from the previous LC circuit because of mostly the dummy magnet inductance. The slight difference in the resonant frequency would probably be the cause of the difference in backleg coil signals between the B chain magnets and the B′ chain magnets.

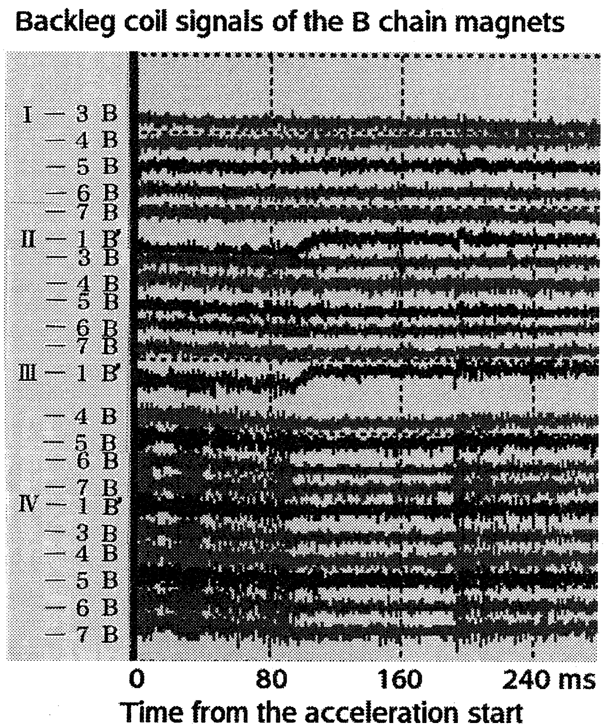

Figure 2: Backleg coil signals of the B chain magnets during the acceleration period.

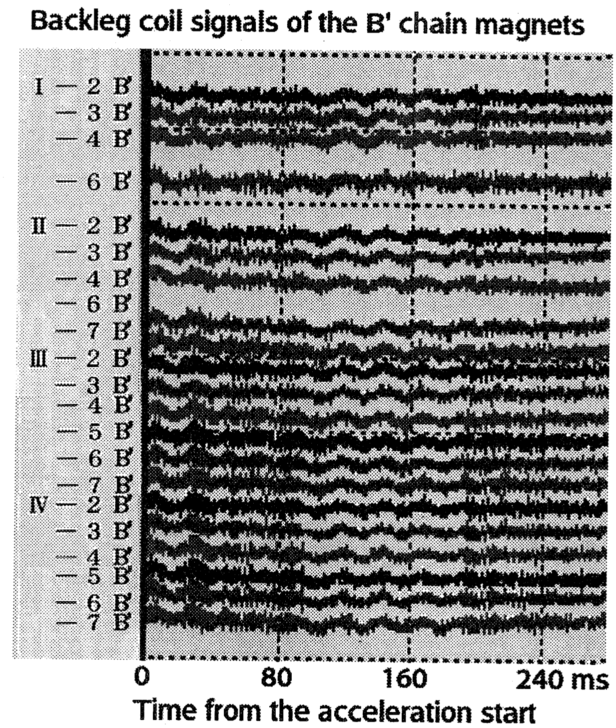

Figure 3: Backleg coil signals of the B′ chain magnets during the acceleration period.

Ripples of about 70 Hz was also significant at the end period of 100 ms for the B′ chain magnets, but not so for the B chain magnets. The inductance of the magnets becomes smaller at the end of the acceleration period. The resonant frequency is then higher than that at the beginning of the acceleration period.

The observable offset of two magnets, II-1B′ and III-1B′, at the beginning period of 100 ms can be explained by the size of vacuum chambers inserted in the magnets. The stainless steel vacuum chambers for the two magnets are specially wider than the normal vacuum chambers in the all other bending magnets because of the beam extraction acceptance. Difference of the eddy current effect causes the offset of the two magnets.

3 HIGH PRECISION DC CURRENT MEASUREMENT

Common mode currents of very low frequency of less than a Hz those can not be measured with backleg coil signals would also be inferred. Two DC current transformers (DCCTs) which can measure a maximum current of 3000 A with a precision of about a few ppm have been prepared. The DCCT has a wide frequency response of 0 to 500 kHz. One of them has been installed for the B chain current and another has been for the B′ chain current. Signals from the two DCCTs were sent to a differential amplifier. Output signals from the amplifier have been recorded with a 14 bit recorder with the sampling rate of 5 kHz with a 4 kHz filter. Obtained data have been processed with an offline analysis of a 41 point smoothing filter. The difference between the B chain current and the B′ chain current shown as the upper line in Fig. 4 is observable and about 20 mA. Because the normal mode current is 202 A at the injection period, the common mode current is a 10^{-4} order effect in the beginning of the acceleration. The effect is less than 10^{-5} in the end of the acceleration as the normal mode current is ramped. The lower line in Fig. 4 shows the current through the ground shunt resistor. The ground current is a similar order as the difference between the B chain current and the B′ chain current.

Because the asymmetry due to the dummy magnet was suspected to be the cause of common mode currents, We disconnected the dummy magnet from the circuit and repeated the measurement. The results are shown in Fig. 5. Because the circuit should be symmetry except for variations of magnets and capacitors, no common mode current is expected. The difference between the B chain current and the B′ chain current shown as the upper line in Fig. 5 is smaller than the previous measurement and it may mostly be the variations of the two DCCTs. The ground shunt current shown as the lower line in Fig. 5 is also smaller than the previous measurement.

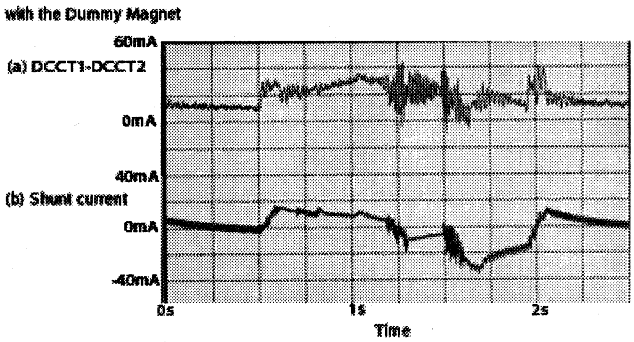

Figure 4: The difference between the B chain current and the B′ chain current (upper line) and the ground shunt current (lower line) with the dummy magnet in the circuit.

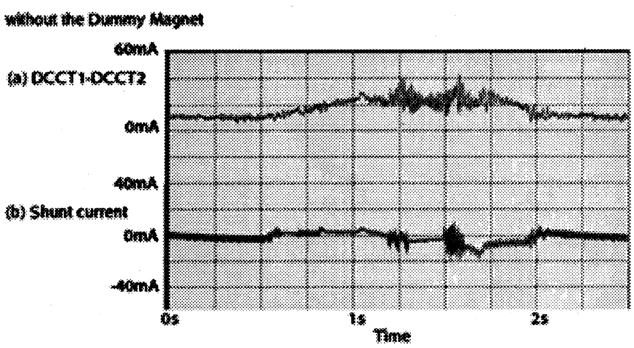

Figure 5: The difference between the B chain current and the B′ chain current (upper line) and the ground shunt current (lower line) without the dummy magnet in the circuit.

4 SIMULATION ANALYSIS

A circuit simulation has been performed with parameters shown in Fig. 1. The results are shown in Fig. 6. The upper figure shows the difference between the B chain current and the B′ chain current. The lower figure shows the ground shunt current. They are in a good agreement with the measurement with the dummy magnet. The simulation without the dummy magnet has also been done. No difference appeared between the B chain current and the B′ chain current. The ground shunt current was also zero.

5 CONCLUSIONS

Common mode phenomena have been observed in the magnet power supply system of the KEK PS 12 GeV main

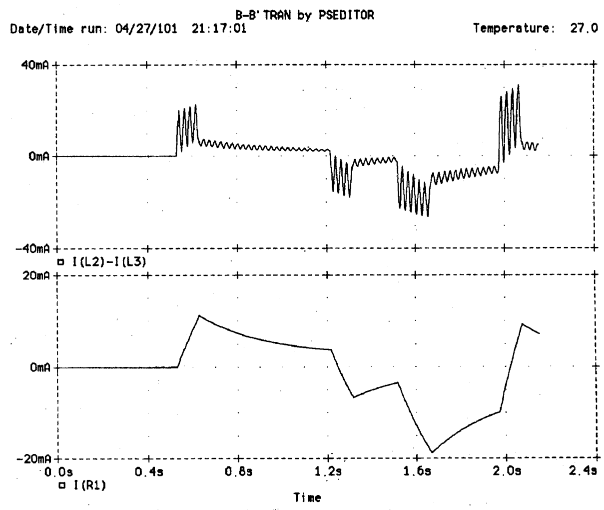

Figure 6: Circuit simulation results for the difference between the B chain current and the B′ chain current (upper figure) and the ground shunt current (lower figure).

ring. A dummy magnet provided to monitor the magnetic field makes the circuit asymmetry and causes common mode phenomena. Common mode currents have been observed to be the order of 10^{-4} or less of the normal mode current from the measurement of backleg coil signals of the bending magnets and high precision DC current measuring systems. The phenomena are well explained with a circuit simulation.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

[1] T. Sueno et al., "Variations of the Magnetic Fields of the KEK-PS Main Ring Bending Magnets", Proc. of the 5th Symp. on Power Supply Technology for Accelerators, Tsukuba, 1999, p.155 (in Japanese).