A Measurement of Ripple Current in the by-pass resistor of Synchrotron Magnets : New Method for Mode Separation Measurement

Takashi AOKI, Masayuki KUMADA*, Kazuto NISHIKIGOURI, Tsutomu GUSHIKEN,
Yoshinobu SANO, Tomohito TOGASHI, Eiichi TAKADA*, Koji NODA*, and Mitsutaka KANAZAWA*
Accelerator Engineering Corporation
2-13-1, Konakadai, Inage-ku, Chiba 263, JAPAN
*National Institute of Radiological Sciences
4-9-1, Anagawa, Inage-ku, Chiba 263, JAPAN

Abstract

We report a result of the ripple measurement in the by-pass resistor circuit of HIMAC synchrotron main magnet coils. The result shows clear separation of common- and normal- mode components in the frequency domain. An interpretation of the data and relevant characteristic of the method such as ripple sensitivity are discussed.

1 Introduction

In order to examine the validity of the design principle of the synchrotron power supply and magnet load circuits, current ripple ratio was measured and evaluated for common and normal mode of the output current. In HIMAC, magnet coils were separately connected for top and bottom pole piece, as shown in Fig. 1.[1] Since a ripple component of the magnetic field of main magnets can cause an instability and loss of the beam, it should be reduced as much as possible. We need to understand the mechanism of ripple formation and transmission. One important clue was pointed out to watch the common mode current of the power-supply magnet system. Although indirect compared with a magnetic field measurement, current measurement at by-pass circuit of the so-called bridging resistor is expected to be a clear demonstration of the mode separation and also a handy sensor of high frequency component. An initial result showed the components corresponding to both the normal and common modes. With an application of the technique of measuring sum and difference in leads of top and bottom coil by-pass resistor, two modes were indeed separated clearly.

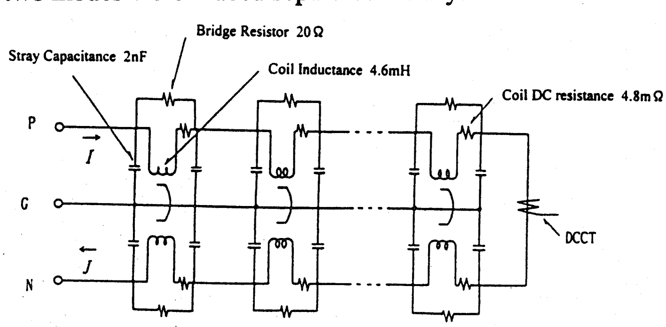

Fig. 1. Equivalent circuit of coil ladder of magnets.

Detail of the measurement and further analysis are discussed in the following sections.

2 Detection Method

Detection of a current ripple in the by-pass resistor lead was done by a single current probe. Figure 2 shows an illustration of the mode-separation method.[2] Common mode current is nothing but the in-phase component of the current that runs through schematic lines of upper and lower magnet coils in Fig. 1, while normal one is the component that flows from positive output to the upper coils and to the lower coils and returns to the negative port of the power supply. Thus, in the left picture of Fig. 2, only the normal mode component can be detected because of cancellation of common mode one. The right side of Fig. 2 depicts the case where only the common mode is measurable.

The current probe was a Sony Tektronics P6034, whose sensitivity and conversion ratio is 0.5 mA and 2 V/A, respectively. Background noise was found to correspond to -130 dBVrms, or 0.63 μA in current. A Hewlett Packard HP35670A four channel FFT analyzer was fed with the probe signal, and analyzed for 10 Hz to 52 kHz span. Calibration of the probe and analyzer was done with a small current source.

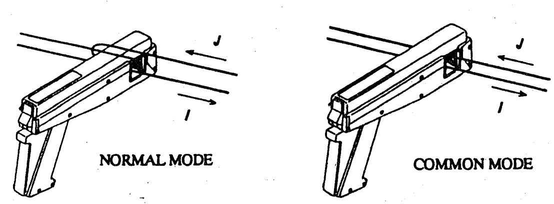

Fig. 2. Illustration of mode-separating detection by a single current probe. Left: I+J sensing configuration. Right: I-J sensing.

3 Result of Measurements

3.1 Mode Separation

A result of direct measurement is shown in Fig. 3, without mode separation. 1200 Hz (normal) and 600 Hz (common) components are visible in both coils.

When the ripple signal was measured with the mode separation, the result demonstrated the clear separation of normal and common mode components, as shown in Fig. 4.

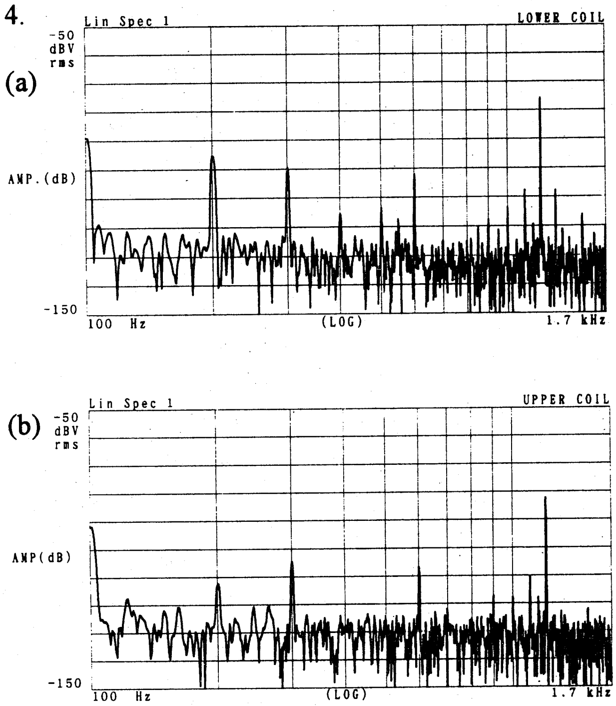

Fig. 3. The ripple spectrum before the mode separation is shown for (a)upper coil, and (b)lower coil of a QF magnet.

Further, the higher frequency region was also surveyed and is shown in Fig. 5. Again, the frequency relation between normal and common is seen clearly.

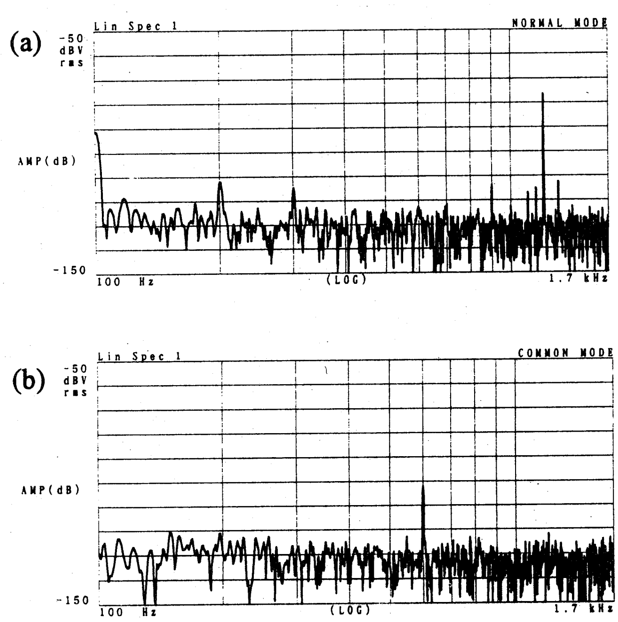

Fig. 4. The ripple spectra of (a)normal and (b)common mode current. In (a), 1200 Hz component is clearly seen, while (b) shows 600 Hz dominantly.

3.2 Spatial Distribution of the common-mode ripple

In Ref.[2], it is calculated that the normal mode amplitude does not show the spatial dependence (at least up to 1200 Hz), while the common mode, by construction, varies amplitude along the position in the load magnet ladder; largest at the nearest to the power supply, and null at the farthest. The common mode spectrum of Fig. 5 supports the calculation.

3.3 Comparison with result of conventional method

A conventional method is the voltage measurement at the output point of the power supply, where positive and negative output can be monitored simultaneously. The mode separation was by an internal function of FFT analyzer. The comparison of the normal mode result is shown in Fig. 6. It is noteworthy that the normal mode ripple spectrum in kHz range is similar at the by-pass resistor current and the power supply output, which indicates that the most of kHz region ripple is by-passed to the resistor as intended.

3.4 Ripple amount evaluation

The result must be evaluated in terms of relative ripple of the main coil current. In the present work, detected current was multiplied by the by-pass resistor resistance, and the obtained voltage was divided by the inductance of the main coil as measured in a cold test, to give the amount of ripple current in the main circuit. This current was then normalized to the full excitation specification value of the current. The inductance evaluation is problematic in this procedure, and is tested with BM case for up to 1800 Hz that the cold measurement value can be applied as a constant value.

Quadrupole (Focusing) Magnets

The result was 0.5 ppm for normal mode (both 100 and 1200 Hz), while for common mode 0.1 ppm at 600 Hz. These values are consistent with the result from the conventional method.

Dipole (Bending) Magnets

The normal mode was measured when active filter was turned off. The resultant value was about 4 ppm. As for the common mode, the design features the suppression of this mode, and indeed the observed value was 0.05 ppm at 50 Hz, which arises from the error and imperfection of the power supply construction.

4 Discussion

The separation of normal and common modes in a

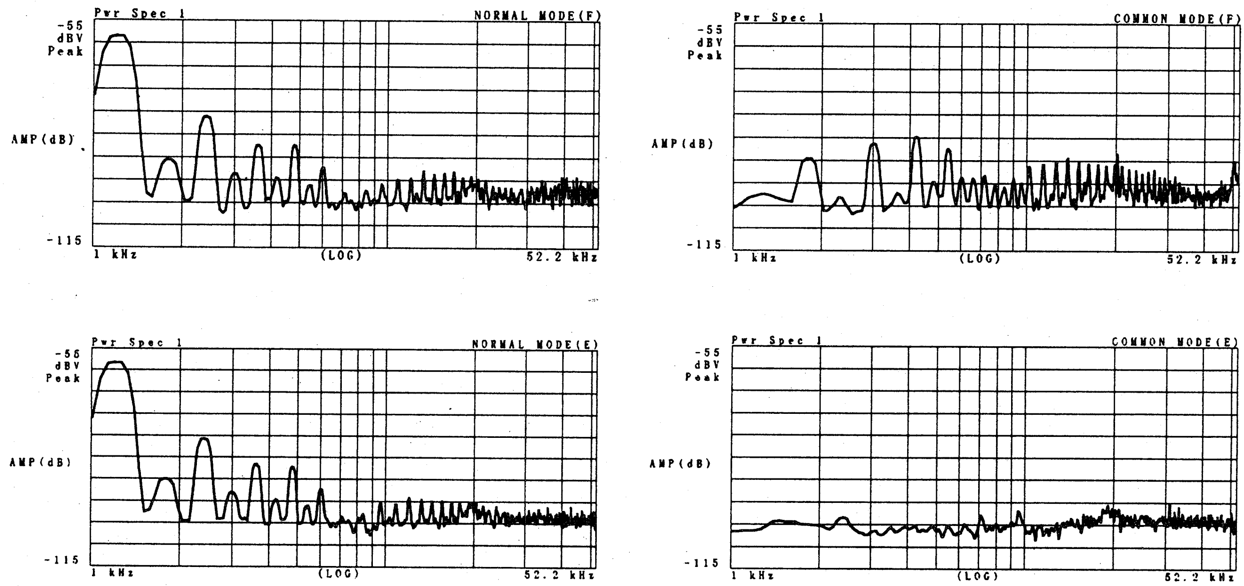

Fig. 5. Mode separated ripple spectrum of the QF magnet coils. Top pictures are for the coils nearest to the power supply. Bottom pictures are for the farthest. In both cases, the left panel shows the normal mode, and the right, the common.

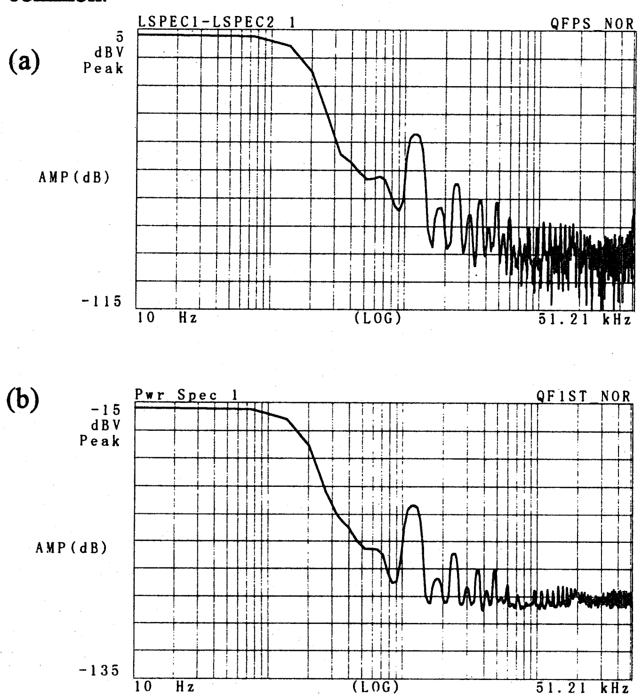

Fig. 6. The comparison of normal mode ripple measurement. (a)voltage measurement at the output terminal of the power supply, and (b)current measurement of the by-pass bridging resistors.

system of magnet coil and power supply was clearly observed. The normal to common attenuation is about 60 dB. The present result suggests the validity of the design guide line of treating the common mode component as applied to HIMAC power supply system.

To evaluate the frequency characteristic of the magnet coil, which strongly affects the result of present current ripple measurement, we have been studying a behavior of the (magnetic field) search coil output with and without by-pass resistor. Preliminary analysis of the ratio in frequency domain seems to be helpful to determine the frequency characteristic of the main coil.

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