THE HIMAC VERY LOW RIPPLE SYNCHROTRON - PART II

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Abstract

Ripples in the HIMAC synchrotron power supply are greatly improved since the presentation of the previous report[1]. As the high frequency ripple and spike were removed by a static method of the bridge resistor and the common mode filter, the improvement was focussed on the low frequency components of 50 Hz, 100 Hz and 1200 Hz of the normal mode of the Focussing Quadrupole and the Bending Magnet power supply. The major improvement was performed by a replacement of the DCCT and development of an active filter and a suppression of high frequency noises. During the upgrade, it was found that the ripple tolerance in the Bending magnet power supply must be a sub-ppm level in the HIMAC where a third order resonant extraction is employed. And the active filter were enhanced. Detail of the upgrade since the previous report in this conference is described in this report.

1 INTRODUCTION

In a synchrotron the current of the magnet string has a trapezoidal form. Because of the resonant beam extraction, the ripple content should be a few ppm or less at the flat top. The basic ripple frequency $f_b = 1200$ Hz of the power supply is given by the frequency of the power source($f_0 = 50$ Hz) multiplied by the number of thyristors(24). The Fourier analysis of the ripple voltage also gives multiples of f_b. Another ripple with the frequency of $2nf_0$ is caused by imperfections of the local transformers and by variations in the triggering of the thyristors. Furthermore oscillatory spike voltages are induced across each thyristor. In spite of various efforts, the reduction of spikes and ripples has been unsatisfactory for the requirement of the tolerance of the third order resonant extraction. In the HIMAC synchrotron power supply, a new approach is taken.

2 APPROACH OF HIMAC

We started from the proposition that the load of the synchrotron power supply is a cascaded string of the magnet inductance, its resistance and the capacitance between the excitation coil and the iron yoke. Typical magnitude of the capacitance of a Quadrupole magnet of a standard size is estimated to be a few nF. The iron yokes are assumed at a ground potential. At the HIMAC the yokes are connected by the earth line. The schematic diagram is depicted in Figure 1.

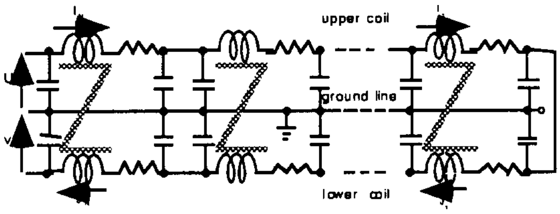

Figure 1: An equivalent circuit of the HIMAC magnet string.

This model circuit is a six terminal circuit that has parallel and series resonance. Due to a presence of the capacitance to the ground, the incoming current I to the load and the outgoing current J from the load may not necessary to be identical as contrast to the ordinary model of without the capacitance to the ground. The difference current I-J flows back to the neutral point of the thyristor bank. The potential at the neutral point develops and is known as a common mode voltage. In order to estimate the magnitude of the ripple current we need to know the resonance frequencies and the admittance. If the spike frequency or the ripple frequency overlap the resonance of the magnet string, the ripple current is enhanced. No previous analysis was done in the past. By applying eigen value technique, we found that six terminal circuit can be reduced to two set of orthogonal four terminal circuit. We found as a special case decomposition into the normal mode and the common mode is possible. The normal mode voltage and current is defined as U+V and I+J and the common mode voltage and current is defined as U-V and I-J respectively. With the mode separation, the normal and the common mode admittance Yp of the magnet string, which we model as a ladder circuit, can be written down simply as,

$$\frac{\mathcal{Y}_0}{\mathrm{Y}_{\mathrm{mn}}} = \frac{\prod_{k=0}^{N-1}\left[\cosh(\zeta_{\mathrm{mn}}) - \cos\left[\frac{2k+1}{2N}\pi\right]\right]}{\prod_{k=0}^{N-1}\left[\cosh(\zeta_{\mathrm{mn}}) - \cos\left[\frac{k}{N}\pi\right]\right]} \quad (1)$$

$$= 1 + \frac{1}{N}\sum_{k=0}^{N-1}\left[\frac{1+\cos\left[\frac{k\pi}{N}\right]}{1+Z_{\mathrm{mn}}Y_{\mathrm{mn}} - \cos\left[\frac{k\pi}{N}\right]}\right]$$

$$\frac{\mathcal{Y}_c}{\mathrm{Y}_{\mathrm{mc}}} = \frac{\prod_{k=0}^{N-1}\left[\cosh(\zeta_{\mathrm{mc}}) - \cos\left[\frac{k}{N}\pi\right]\right]}{\prod_{k=0}^{N-1}\left[\cosh(\zeta_{\mathrm{mc}}) - \cos\left[\frac{2k+1}{2N}\pi\right]\right]} \tag{2}$$

$$= 1 + \frac{1}{N}\sum_{k=0}^{N-1}\left[\frac{1+\cos\left[\frac{2k+1}{2N}\pi\right]}{1+\mathrm{Z}_{\mathrm{mc}}\mathrm{Y}_{\mathrm{mc}} - \cos\left[\frac{2k+1}{2N}\pi\right]}\right]$$

where Yno and Yco is the characteristic admittance of the ladder circuit. Zp, where p stand for normal and common, is expressed by

$$\cosh\zeta_{\mathrm{mp}} \equiv 1 + \mathrm{Z}_{\mathrm{mp}}\mathrm{Y}_{\mathrm{mp}} \tag{3}$$

$$\mathrm{Y}_{0\mathrm{p}} \equiv \frac{1}{\mathrm{Z}_{0\mathrm{p}}} = \frac{\sinh\zeta_{\mathrm{mp}}}{\mathrm{Z}_{\mathrm{mp}}} = \frac{\mathrm{Y}_{\mathrm{mp}}\sinh\zeta_{\mathrm{mp}}}{\cosh\zeta_{\mathrm{mp}} - 1} \tag{4}$$

Zp is the mode impedance of the magnet and Yp is the mode admittance expressed by the capacitance to the ground. Above equations are simple yet very powerful to fully describe the magnet string of resonant feature. The analytic solution in time domain is possible by Inverse Laplace transformation. At the HIMAC the resonance can be suppressed by the bridge resistor parallel to the magnet which is shown in section 4. This resistor also helps to bypass the ripple and spike current of the magnet. Direct consequence of the preceding argument is the addition of the common mode low pass filter. Furthermore the common mode current in the HIMAC in Bending magnet string does not appear as the magnetic field because of the separate connections of the upper and the lower coils due to the nature of the parallel direction of the current to the first order. In this way, in the HIMAC, most of the ripple voltage of the normal and common mode is suppressed. It appeared that, however, the beam spill did not reflect the small ripple content for the initial stage of the operation.

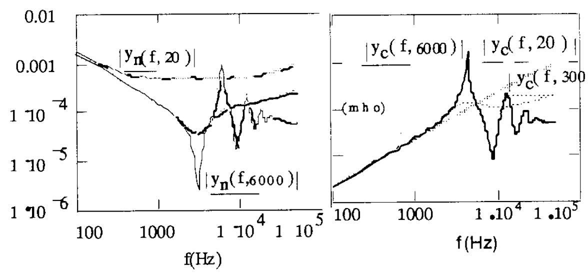

Figure 2: Admittance of the normal and the common mode with various magnitude of bridge resistor.

3 COMPARISON OF MEASURED ADMITTANCE AND CALCULATED ADMITTANCE-SMALL SIGNAL

The validity of the model is verified by comparing the actual admittance of the ladder circuit and that of the calculated one. Figure 2 show the admittance of the normal and the common mode with three kind of resistance. The comparison between the measurement of small signal and that of the calculation from the equations above are plotted in Figure 3.

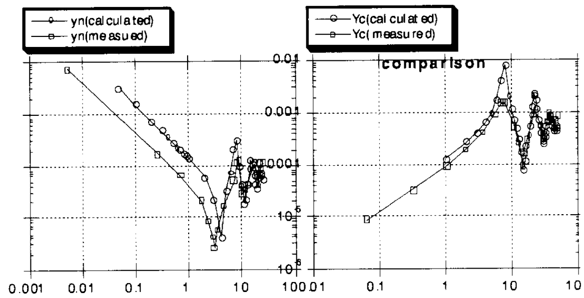

Figure 3: Admittance from the measurement and the calculation of normal and the common mode

4 RIPPLE AND BACKGROUND OF RESONANCE -LARGE SIGNAL-

By observing the signal of the search coil in the Quadrupole magnet gap, a strong modulation of the back ground was observed when the bridge resistor is of as shown in Figure 4 with the bridge resistor and without it. Apparently this indicates the resonance effect of the ladder circuit.

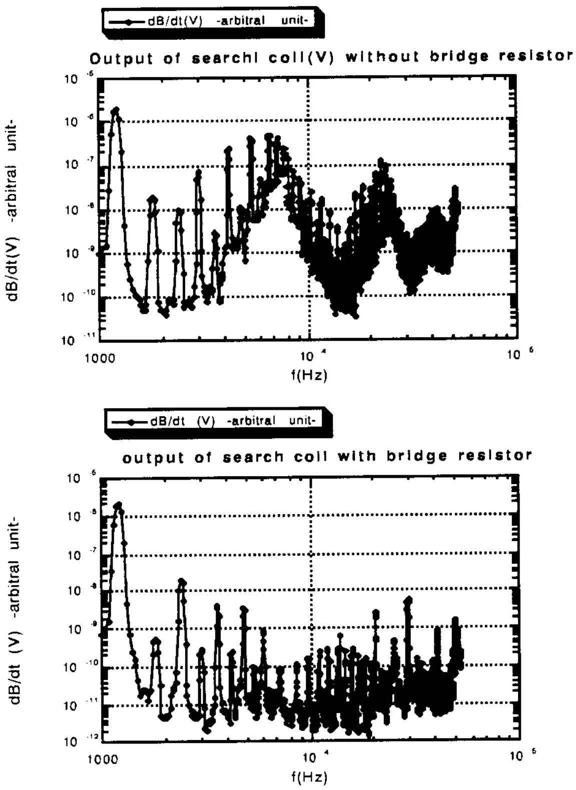

Figure 4: Ripple in search coil with and without bridge

5 SENSITIVE MEASUREMENT OF CURRENT RIPPLE

We found a simple method of very high sensitivity of the current ripple. This is done by measuring the current of the bridge resistor which is connected in parallel to the mail excitation coil and are shown in Figure 5. Complete separation between the normal and the common mode can be seen.

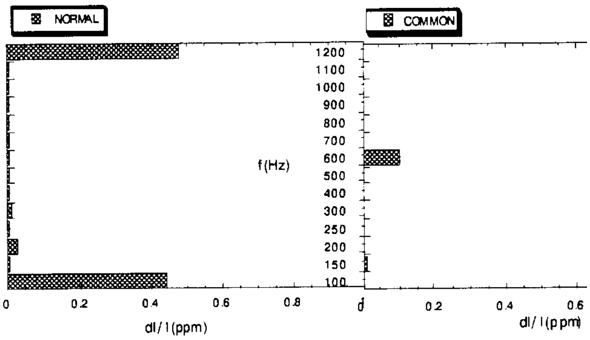

Figure 5: Current ripple measured in the bridge resistor

6 FURTHER IMPROVEMENT

The ripple component of 50 Hz and 100 Hz were the main component seen in the output of the power supply. The fluctuating component of the beam spill appeared to be 100 Hz. 100 Hz is caused by the imbalance of the phases of the AC power line. But 50 Hz can not be generated by the imbalance. These frequencies can not be damped by the low pass filter as the cut off frequency of both mode is chosen to be 75 Hz. We decided to strengthen the active filter of the Quadrupole by adding the bandpass filter of 50 Hz and 100 Hz for the individual fine tuning of the phase control. The bandpass filter worked fine as expected and the ripple was reduced. Through the careful study of the 50 Hz source, we found that the 50 Hz is originated from the DCCT. Although the relative amplitude of the DCCT was small as 50 ppm, it has been a performance limiting factor to go below ppm level.

With the evidence that the present beam spill is affected by Bending magnet, we decided to reduce the ripple current in the Bending magnet by adding the active filter of the similar type of the Quadrupole power supply. The inductance of the Bending magnet load is six times larger than that of the Quadrupole and supplying larger power is required.

7 ACKNOWLEDGEMENTS

The author thanks the enlightened discussion with profs. Y. Irie and K. Endo of KEK.

8 REFERENCES

[1] M.Kumada et al.,EPAC 94,London

[2] M.Kumada et al., in this conference

[3] M.Kumada et al., to be published in particle accelerator.

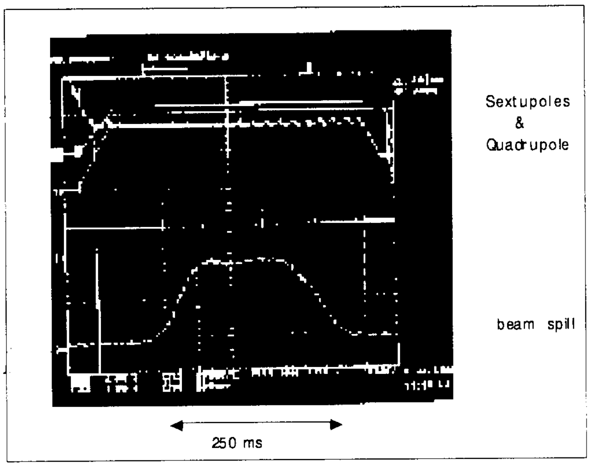

Figure 6: Figure 6 An example uniform beam spill