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Recent Improvement of Ripple Performance in HIMAC Synchrotron Power Supply

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ABSTRACT

Ripples in the HIMAC synchrotron power supply and the admittance of the load were measured and confirmed to be small as 3 ppm for the Quadrupole Power Supply right after the commissioning. Further improvement was focused on the 50 Hz and 100 Hz ripples which were major component deteriorating the spill. By re-tuning the power supply, we could reduce the ripple to a level of 0.3 ppm[1)]. The study of the relation of the ripple and the beam spill revealed that the fluctuation of the beam spill is affected by the ripple in Bending magnet power supply in addition to that of the Quadrupole. After finding this fact, the beam spill became more uniform in routine operation by re-adjusting the Sextupole and Quadrupole strength. Encouraged by this performance, the Bending magnet power supply is upgraded by adding the active filter and the new DCCT. With this improvement the ripple became at a level of 0.2 ppm and the beam spill was improved.

I. 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 =50Hz) 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 transformers and by variations in the triggering of the thyristors. Furthermore oscillatory spike voltages are induced across each thyristor. The spikes are modulated by low frequencies and can also contribute ripple at frequencies as low as 100 Hz. Other problem associated with them is the production of noise spikes in equipment located in the neighborhood. 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. To fulfill the requirement for beam extraction, in most of the accelerator in operation, additional mean such as spill feedback controller must be applied.

In the HIMAC synchrotron power supply, a new approach is taken.

II. HIMAC approach

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 Fig.1.

This model circuit is a six terminal circuit that has parallel and series resonance. Due to

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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. Lowering the cut off frequency helps in reducing the ripple but slowing the response of the trapezoid pattern and deteriorating the tracking accuracy between the Quadrupole and the Bending magnet. 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 bandpass filter the relative ripple content became at a level of 0.3 ppm for the time. The main frequency of the beam spill changed from 100 Hz to 50 Hz. We found that the 100Hz was a superposition of the 50 Hz ripple of two different sources whose phases are shifted, namely from the power supply of the Focusing Quadrupole and that of the Bending magnet. The remained 50 Hz originated from Bending magnet power supply. The change of tune of the beam is speculated to come indirectly through Sextupole magnet that compensate the chromaticity. This was verified that by reducing the Sextupole strength, the better quality of the beam spill is obtained. 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. Typical reduction of 25 dB at 100 Hz was achieved after an elaborate adjustment of the cut off frequency of the high pass filter that is incorporated in the active filter circuit. Typical example of the frequency spectrum at 600 MeV/u with and without active filter are shown in Fig.2. where 50 Hz is reduced by 28 dB and 100 Hz is 32 dB. The small 50 Hz ripple is also due to the installation of the Holec DCCT. Its linearity and the stability are checked and implemented into the ACR feedback circuit.

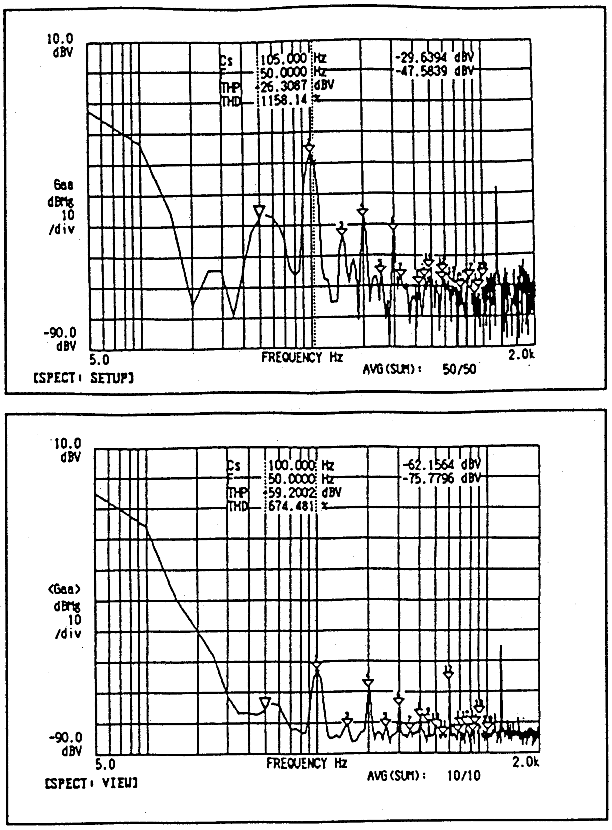

Fig.2 Ripple voltage spectrum of the Bending magnet at 600 MeV/u without (upper graph) and with (lower graph) active filter.

IV. ACKNOWLEDGMENTS

We gratefully acknowledge the support of the members of the division of accelerator physics and engineering and AEC. The author thanks the enlightening discussion with Prof.Y.Irie of KEK.

V. REFERENCES

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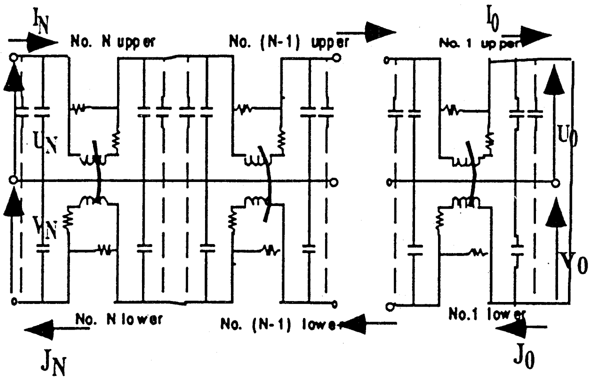

Fig. 1 An equivalent circuit of the HIMAC magnet string.

a presence of the capacitance to the ground, the incoming current I to the load and the outgoing current J from the load are not 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 the case of the grounded neutral as in the HIMAC this potential is small. 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. To avoid the overlap, the knowledge on frequency characteristic of the load is required. No previous analysis was done in the past. Computer simulation is time consuming. By applying eigenvalue 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 $Y_{n,c}$ of the magnet string, which we model as a ladder circuit, can be written down simply as,

$$Y_n = Y_{no} \coth(N\zeta_n) \qquad (1)$$

$$Y_c = Y_{co} \tanh(N\zeta_c) \qquad (2)$$

where Y_{no} and Y_{co} is the characteristic admittance of the ladder circuit. ζ_n and ζ_c and the are expressed by

$$\zeta_{n,c} = \cosh^{-1}(1 + Z_{n,c}Y_{n,c}). \qquad (3)$$

$Z_{n,c}$ is the mode impedance of the magnet and $Y_{n,c}$ 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[2)]. The analytic solution in time domain is possible by Inverse Laplace transformation[2)]. The admittance of the HIMAC magnet string was measured and the validity of the present model was verified. The current ripple is estimated using the admittance from the voltage ripple of the power supply. At the HIMAC the resonance can be suppressed by the bridge resistor parallel to the magnet. This resistor also helps to bypass the ripple and spike current of the magnet.

With a finding of the presence of two orthogonal mode in the load, the model of the mode separation is extended to the power supply side. Direct consequence of the preceding argument is the addition of the common mode low pass filter. Without this filter, the common mode ripple voltage is directly applied to the magnet string. Furthermore the common mode current in the HIMAC Bending magnet string is considerably reduced 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.

In this way, in the HIMAC, most of the ripple voltage of the normal and common mode is suppressed. The relative ripple current of the Quadrupole with active filter was 3 ppm and that of the Bending magnet without active filter was around 5 ppm right after the initial operation. It appeared that the beam spill did not reflect the small ripple content the study was continued.

III. Improvement at the 50Hz and 100 Hz ripples