# HIGH PERFORMANCE ACTIVE FILTER FOR THE POWER SUPPLY OF THE HIMAC SYNCHROTRON MAGNET

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*Abstract*

The relative ripple amplitude of the HIMAC synchrotron power supply was at a few ppm level during an initial commissioning period. The beam spill however, was not uniform enough. Since the commissioning, we have been upgrading the power supply and finally arrived at a level which is thirty times less than that of the commissioning stage, which is far below ppm. Addition of the band pass filter to the existing high pass filter greatly improved the performance of the active filter. With this improvement, ripple component was completely removed and the beam spill is now almost free from the ripple without using any other means such as spill feedback system. This paper describes the electric circuit design and its performance.

## 1 HIMAC SYNCHROTRON POWER SUPPLY

The HIMAC synchrotron power supplies are now almost ripple-less power supply compared to existing synchrotron power supplies[1]. In previous EPAC report, the relative rms ripple amplitude was reported to be a few ppm[2]. This is due to the introduction of a common and normal mode concept in a synchrotron power supply system. We found a common mode can not be neglected in the power supply and a magnet load. Furthermore, the magnet load should be regarded as a ladder circuit or transmission line where resonant property of a ripple or a spike can not be avoided.

In conventional synchrotron power supply system, no effective measures against the resonance have not been taken. The effect of the common mode ripple was overlooked in any previous designs of the power supply. These frequencies of these ripples and spike are rather high and can be suppressed by low-pass filter or bridge resistor connected in parallel to the magnet coil. With the low-pass filter the major residual component is 100 Hz ripple. However, this can not be suppressed by these method. Active filter is employed for this purpose. Table 1 and Figure 1 shows a major parameter of the power supply system and a total system configuration.

Table 1:

| | Bending-Magnet | Quadrupole |
|---|---|---|
| output power (MW) | 5.15x2 | 0.538x2x2 |
| voltage (kV) | 2.26x2 | 1.68x2x2 |
| current (kA) | 2.26 | 1.68x2x2 |
| Inductance(mH) | 51.6 | 4.89 |
| Resistance(m$\Omega$) | 19.3 | 9.73 |

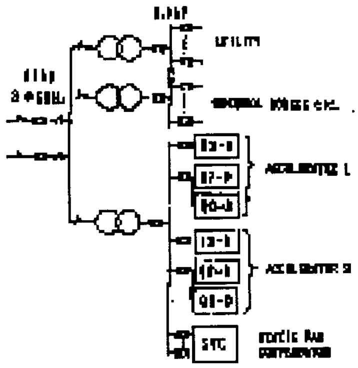

Figure 1: HIMAC power supply system

## 2 CARACTERISTIC FEATURE OF THE HIMAC POWER SUPPLY

Following characteristic features are main reason of the HIMAC low ripple synchrotron power supply.

1. Stabilization of primary AC voltage variation by Static Var Controller(SVC) where reactive power generated by the power supply system. Figures 2 and 3 shows a pattern of reactive power of the system. A magnitude of the reactive power is suppressed by a pair of 24 pulse thyristor convertor and invertor operation. SVC is also useful for reducing imbalance among line voltages which causes illogical ripples.
2. The whole system was made symmetric with respect to the ground line where the switching noise of the turning-on and -off of the thyristor convertor flows as shown in Figure 4.
3. The active filter is feed-forward type and made so that it does not respond to the pattern voltage as shown in Figure 5.

In addition, as Automatic Pulse Phase Shifter(APPS), Phase Lock Logic (PLL) is used to reduce an error of the triggering phase among the thyristors.

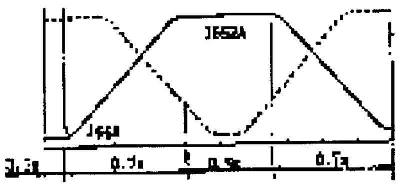

Figure 2: Control circuit of the HIMAC power supply.

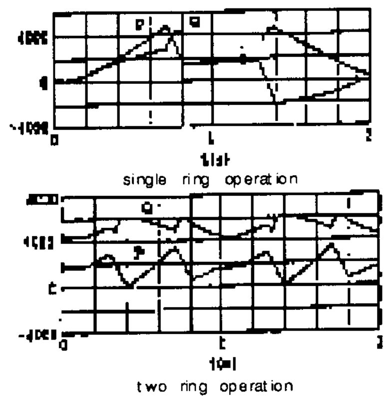


Figure 3: Pattern of a reactive power.

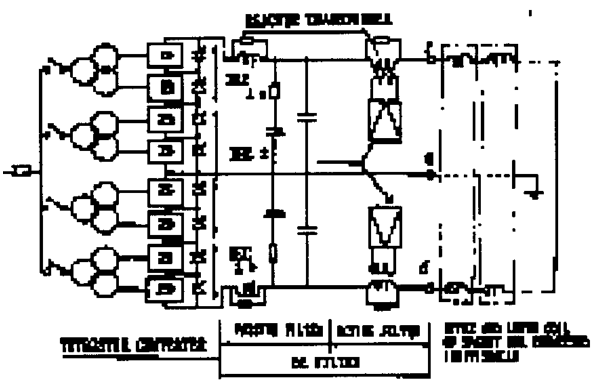

Figure 4: Main circuit

## 3 UPGRADE OF THE ACTIVE FILTER

We have upgraded the active filter which consists of High-pass filter and phase compensation circuit to the with band-pass filter of harmonics of the illogical component and also the fundamental normal mode harmonic of 1200Hz. The block diagram of the old circuit and the new circuit is shown in Figure 6. The frequency characteristic of these filters are shown in Figure 7.

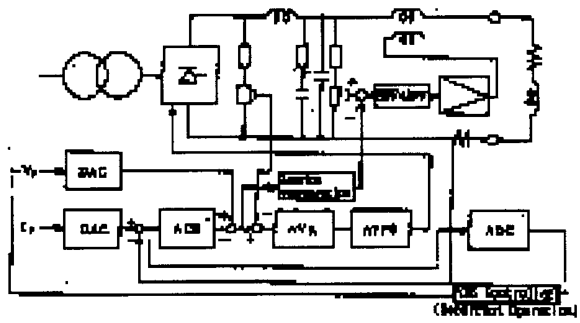

Figure 5: Control circuit

The resultant performance of the ripple is shown in Figure 8. The reduction of 100 Hz is 40 dV and 1200 Hz is 41 dB which is a satisfactory result.

Further reduction of the common mode ripple of 600 Hz is under consideration. Detection method of more sensitive measurement of the ripple is also under development.

## 4 ACKNOWLEGEMENT

The authors would like to express their thanks for sharing a oportunity for the develoment and the study of this research to the director Dr. K. Kawachi.

## 5 REFERENCES

[1] M.Kumada et al., proceeding in this conference.

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

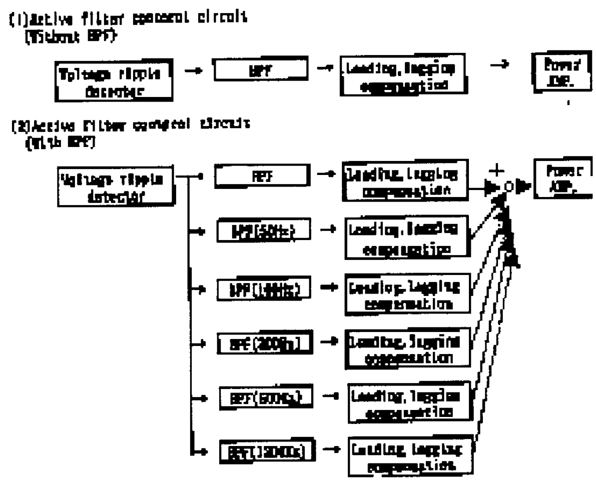

Figure 6: Active filter control circuit

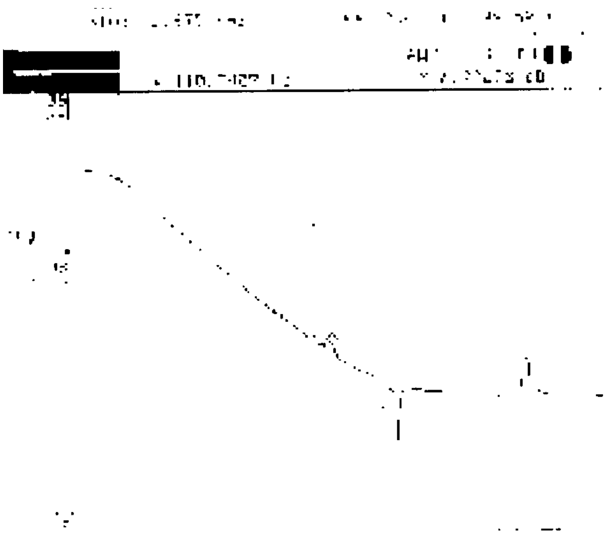

Figure 7: Frequency characteristic of the High-pass and Bandpass filter

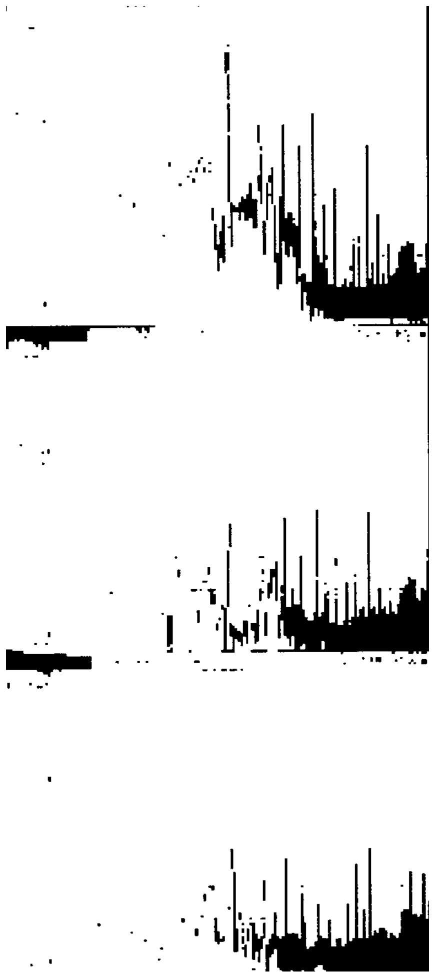

Figure 8: Ripple voltage without and with HPF, and with BPF

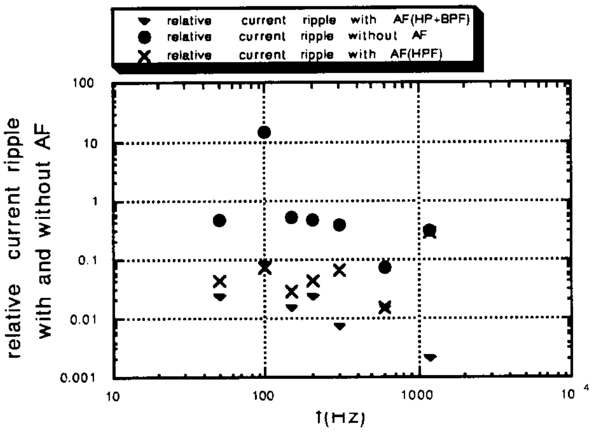


Figure 9: Relative current ripple with and without Active filter (normalized by the maximum current, rms)

Table 2: Relative current ripple with and without Active filter (normalized by the maximum current, rms)

(i) without AF

| f(Hz) | dBV | V | I(mA) | dI/I(ppm) |
|---|---|---|---|---|
| 50 | -67 | 0.02 | 0.6 | 0.44 |
| 100 | -31 | 1.44 | 20 | 15 |
| 150 | -56 | 0.08 | 0.7 | 0.51 |
| 200 | -55 | 0.09 | 0.6 | 0.44 |
| 300 | -53 | 0.11 | 0.5 | 0.37 |
| 600 | -62 | 0.04 | 0.1 | 0.07 |
| 1200 | -43 | 0.36 | 0.4 | 0.29 |

(ii) with AF(HPF)

| f(Hz) | dBV | V | I(mA) | dI/I(ppm) |
|---|---|---|---|---|
| 50 | -90 | 0.002 | 0.06 | 0.044 |
| 100 | -77 | 0.007 | 0.1 | 0.074 |
| 150 | -83 | 0.004 | 0.04 | 0.029 |
| 200 | -76 | 0.008 | 0.06 | 0.044 |
| 300 | -68 | 0.020 | 0.09 | 0.060 |
| 600 | -75 | 0.009 | 0.02 | 0.015 |
| 1200 | -44 | 0.36 | 0.37 | 0.27 |

(iii) with AF(HPF+BPF)

| f(Hz) | dBV | V | I(mA) | dI/I(ppm) |
|---|---|---|---|---|
| 50 | -95 | 0.001 | 0.03 | 0.022 |
| 100 | -76 | 0.008 | 0.11 | 0.081 |
| 150 | -88 | 0.002 | 0.02 | 0.015 |
| 200 | -81 | 0.005 | 0.03 | 0.022 |
| 300 | -89 | 0.002 | 0.01 | 0.007 |
| 600 | -75 | 0.007 | 0.02 | 0.015 |
| 1200 | -85 | 0.003 | 0.003 | 0.002 |