THE ACTIVE FILTER VOLTAGE RIPPLE CORRECTION SYSTEM OF THE BROOKHAVEN AGS MAIN MAGNET POWER SUPPLY*

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I. INTRODUCTION

The Brookhaven AGS is a strong focussing accelerator which is used to accelerate protons and various heavy ion species to an equivalent proton energy of 29 Gev. Since the late 1960's it has been serving high energy physics (HEP - proton beam) users of both slow and fast extracted beams. Since the late 1980's slowly extracted heavy ion beams have been added for fixed target physics experiments (HIP). Beginning in 1996 fast extracted beams will be commissioned in preparation for injection into the RHIC accelerators.

This paper, and a companion paper [1], describe the improvements to the Main Magnet Power Supply (MMPS) so that it enables a more flexible operation of the AGS, enhances its reliability, and also improves the MMPS's ultimate performance specifications. One of the major areas for the latter is the fixed target program operating off the AGS slow extracted beam lines. The active filter, by improving the MMPS output ripple, is instrumental in the improvement of the ultimate duty factor of the extraction beam spill.

II. PARAMETERS

The AGS MMPS consists essentially of two power supplies connected in parallel (the actual implementation is in 2 stations). One PS is a high voltage unit (P type) that is typically used for fast ramping during acceleration and energy recovery. The other is a lower voltage unit (F type) that is used for slow ramping or for flattop operation. Even though the F units are operated as 24-pulse controlled rectifiers, the ripple requirement at flattop is very stringent. The key parameters for the AGS are shown in Table 1.

Table 1

Voltage dc max	±10 kV (P type)
Voltage dc max	±1.5 kV (F type)
Current dc max	6.0 kA
Current rms	4.0 kA
Magnet Resistance (R)	0.26 Ohms
Magnet Inductance (L)	0.75 Henry
Nominal Pulse Rep. Rate	3.0 Sec
Nominal Flat top	1.5 Sec
Fundamental Ripple Freq.	720 Hz (P type)
Fundamental Ripple Freq.	1440 Hz (F type)

Slow extraction from the AGS is accomplished on the third-integer resonance. A set of four sextupoles arranged in a +,-,+,- configuration excites the resonance just after the AGS Main Magnets are flattoped at the desired energy. The beam horizontal and vertical tunes, average radius, chromaticity and skew parameters are set to nominal values. The beam momentum spread is adjusted by RF phase-back and at RF turn-off the beam is effectively debunched. The debunched beam is brought to extraction radius by slightly sloping the flattop of the MMPS. The extracted beam orbit is set by local orbit deformations and by three (3) stages of septa comprised of electrostatic, thin copper magnetic, and thick copper magnetic ejection. Extraction is accomplished in the horizontal plane. Once extracted beam is established, an SEC (secondary emission chamber) intensity signal is used for measurement and for feedback to a slow spill servo loop that dynamically adjusts the MMPS flattop.

Since the AGS MM time constant is 3.0 seconds, it has a corresponding load breakpoint frequency of 0.05 Hz and thus can do a good job of average spill rate and length control. The spill generally has modulation components in the 60-720 Hz sub-harmonic ripple range mainly due to the MMPS and to the 10, or so, other PS's that are utilized during the extraction process. The spill servo cannot correct these. An effort has been underway for some time to reduce these troublesome components by improving individual PS's. However, as the spill from the AGS is increased in length, the sensitivity to these effects also increases. Thus, an active filter approach has been applied to the AGS MMPS.

III. ACTIVE FILTER DESIGN AND RESULTS

One of the most critical contributions to spill modulation is due to the MMPS. Its basic ripple at flattop is 1440 Hz, ±25 Hz, which is the slip frequency of the motor-generator system. This presents both good and deleterious effects. The frequency variation makes it easier to measure, however it prevents synchronized corrections and can beat with the line frequency to create other more complicated harmonics. The damped passive filter at the output of the MMPS attenuates the raw ripple to about 20 volts peak-to-peak. The requirement by the spill is an order of magnitude less, or 1-3 volts peak. Due to the high peak voltages of ±10 kV and the high currents of 6 kA, series or parallel regulators or filters become very difficult schemes to implement physically. It was decided therefore that in order to create a filter with the robustness required by the continuous and flexible operation of the AGS, to use a series transformer/choke as the coupling element to the MMPS circuit. We implemented two different techniques of correcting the AGS MM ripple. One using a wide band feedback

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loop and another using a tuned filter feedback loop with adjustable gain and phase. The schematics of the circuits as well as the signal flow graphs are shown in Figures 1, 2A, and 2B. The parameters of figures 1,2 are the following. V1(s), V2(s) are the station 1 and 2 voltage ripple of the AGS MM power supply. VM(s) is the AGS magnet voltage ripple. VAF(s) is the coupled ac voltage from the active filter. L1=0.25 mH, R1= 0.1 Ohms. G1(s), G2(s) are compensated amplifiers. G3(s) is the active filter power supply closed loop transfer function. G4(s).K4 is the transformer/choke transfer function. G5(s) is the tuned filtered transfer function. It can be seen that each of the 2 MMPS station voltages are sensed, summed, filtered and compared to the instantaneous waveform. The error is used to drive the primary of the transformer which induces and cancels the ripple from the magnet voltage. The power driver is a commercial, bipolar, 4-quadrant, switch mode PS which has a wide voltage bandwidth. The switching frequency is ~44 kHz, which results in a constant voltage full power bandwidth of 1 kHz. The loop response (gain and phase) of the power supply (G3(s)) and the active filter choke (G4(s)) is shown in Fig. 3. The open loop response of the active filter from Fig. 2A is shown in Fig. 4. The tuned filter (G5(s)) was tuned to correct 120 Hz, 180 Hz, 240 Hz, 360 Hz, and 720 Hz. The response is shown in Fig. 5. The results of the ripple correction utilizing the two different techniques are shown in Figures 6A and 6B. Using the tuned filter feedback scheme we were able to correct more because we could control the phase and the gain of every frequency component separately.

FIG 1

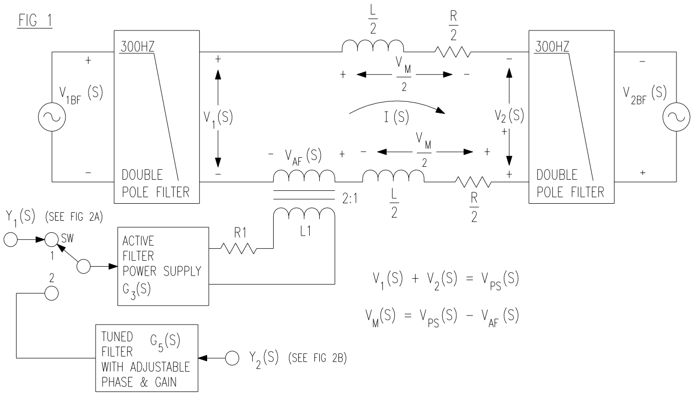


FIG 2A

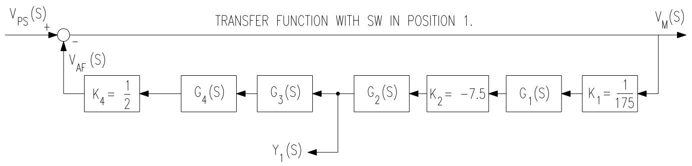


FIG 2B

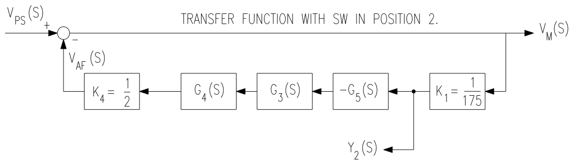


Fig. 3
G3(s)*G4(s) TRANSFER FUNCTION

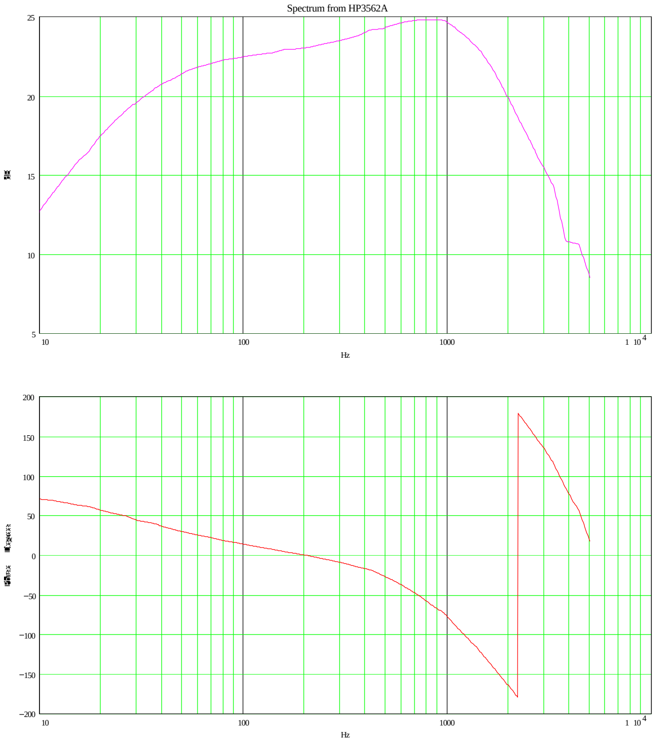


Fig. 4
K2*G1(s)*G2(s)*G3(s)*G4(s) TRANSFER FUNCTION

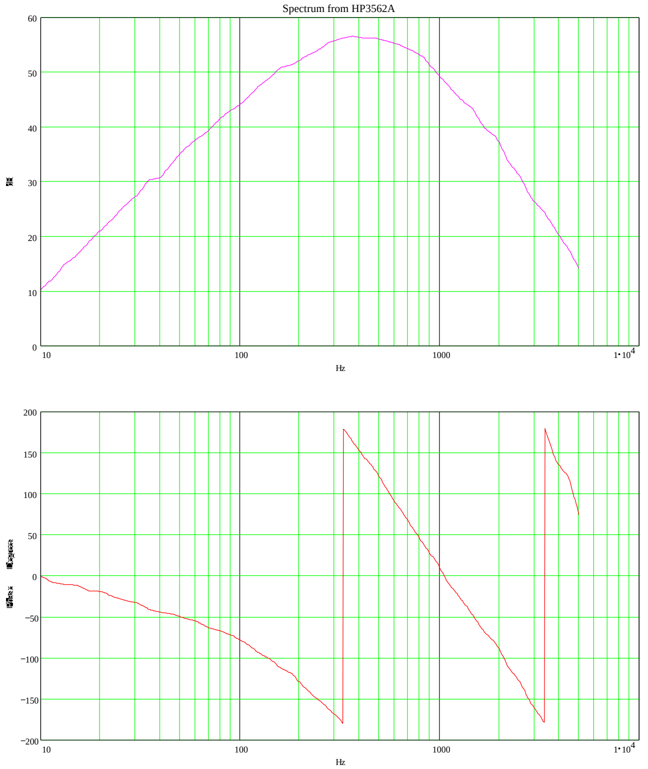


Fig. 5
G5(s) TRANSFER FUNCTION

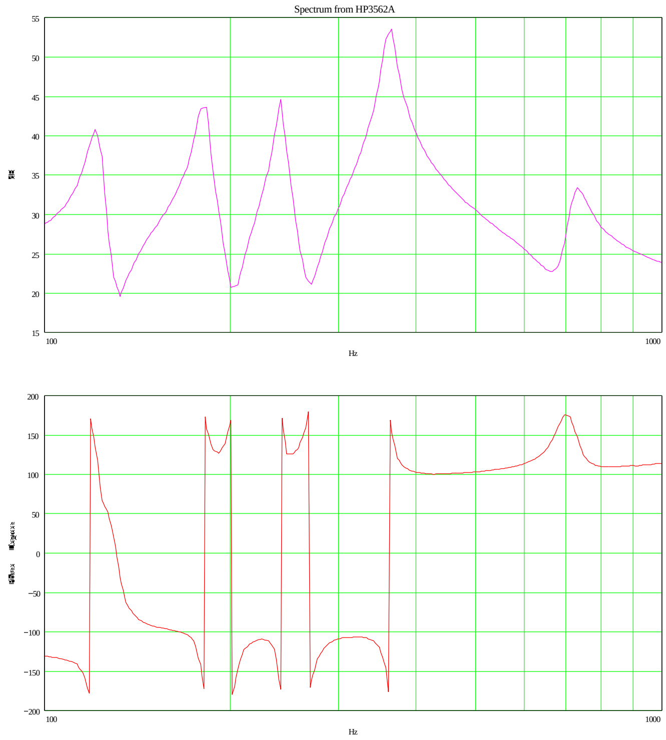


FIG. 6B

AMPLITUDE OF AGS MAIN MAGNET VOLTAGE RIPPLE COMPONENTS
(VOLTS PEAK)

1. Ax,1 IS THE RIPPLE WITHOUT THE ACTIVE FILTER CORRECTION
2. Ax,2 IS THE RIPPLE USING THE ACTIVE FILTER CORRECTION, WITH SWITCH (SW) IN POSITION 2 (SEE FIG. 2). TUNED FILTER WAS TUNED TO CORRECT 120 HZ, 180 HZ, 240 HZ, 360 HZ, 720 HZ.

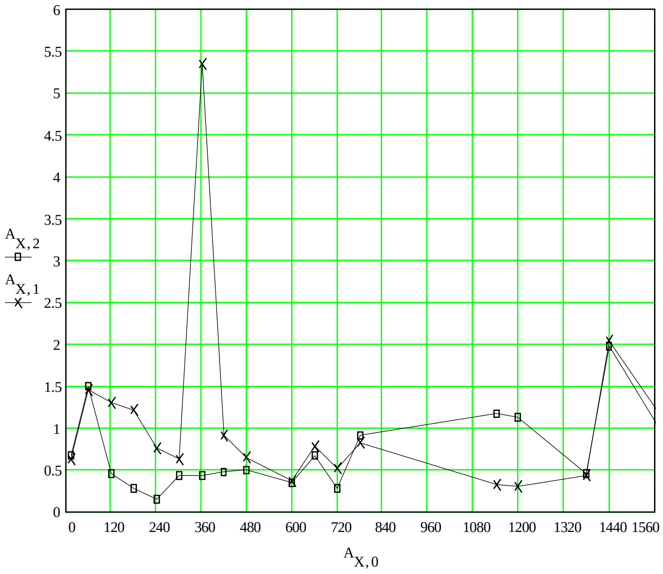
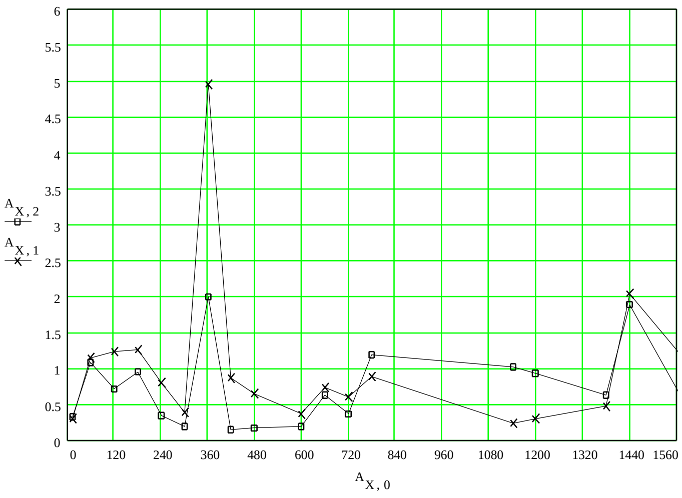


FIG. 6A

AMPLITUDE OF AGS MAIN MAGNET VOLTAGE RIPPLE COMPONENTS
(VOLTS PEAK)

1. Ax,1 IS THE RIPPLE WITHOUT ACTIVE FILTER CORRECTION
2. Ax,2 IS THE RIPPLE USING ACTIVE FILTER CORRECTION, WITH SWITCH (SW) IN POSITION 1 (SEE FIG. 1)



IV. FUTURE PLANS

The implementation in the future will be done digitally by a dedicated PC computer which will perform the data acquisition and manipulation, such as averaging. The output to the drive system will be through an arbitrary waveform generator. This scheme will be adaptive. Also, with a change in transformer ratio or a higher voltage power supply driver, we would like to apply the filter correction to the entire cycle. This will enable closer beam radius control, and aid in perhaps controlling other high intensity phenomena and instabilities.

V. ACKNOWLEDGMENTS

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