BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, L.I.N.Y.

BNL 6922

HJH-6

Internal Report

RIPPLE FILTER FOR AGS MAIN MAGNET POWER SUPPLY

H.J. Halama

April 3, 1963

MASTER

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission, makes any warranty, representation, or guarantee, or assumes any liability with respect to the accuracy, reliability, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

3. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or

invent with such contractor.

The proposed electronic filter will be used during flattop at energies between 10 and 30 Bev. The change in position of the proton beam produced by current ripple during the acceleration cycle is small due to smaller ripple voltage as well as to the correcting action of the closed loop rf system.

Filtering could be used during the whole accelerating cycle with the proposed system if it became necessary.

The position error of the proton beam (Δr) during the flattop caused by fluctuations in the magnetic field in the AGS is given by Eq. 1.

$$\Delta r = -\alpha r \frac{\Delta B}{B} \approx -\alpha r \frac{\Delta I}{I} \quad (1)$$

α = momentum compaction factor $\approx \frac{1}{75}$

r = radius of AGS $\approx 120\text{m}$

I = main magnet current

$$\Delta I = \frac{Vr}{\omega L_m}$$

Vr = ripple voltage across magnets

ω = ripple frequency (fundamental ≈ 720 c/s)

L_m = inductance of magnet ring

From Figs. 1, 2 and 3*, we see that the worst condition for the design of the electronic filter occurs when we want to operate at 10 Bev energy. The ripple voltage

*graph #3 was calculated from data calculated and plotted in Fig. 4 by E. Rutan.

Facsimile Price \$	<u>1.10</u>
Microfilm Price \$	<u>.80</u>
Available from the Office of Technical Services Department of Commerce Washington 25, D. C.	

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

is approximately 3.5 kv peak to peak with ~ 1 kv negative swing and $\frac{\Delta I}{I} = 3.5 \cdot 10^{-4}$. The above numbers are quoted for normally adjusted ignitron triggers. Poorly adjusted triggers would raise the numbers about 25%. Another drawback of 10 Bev operation is the low dc voltage across the magnets.

$$V = IR \approx 2.500 \times .25 \approx 625 \text{ volts.}$$

From Fig. 5, we see that by connecting a shunt voltage regulator between the saturable reactor and magnet ring we can reduce the ripple voltage to a very low value. The inductance of the reactor was measured at 1, 2 and 3 ka dc and found to be approximately 18 mh. If we also use an existing magnet in series with the saturable reactor, the reactance into which the shunt tube has to work is

$$X_L = \omega L \approx 90 \Omega,$$

and the maximum current

$$I_{\max} = V_r \frac{\max}{X_L} \approx 45 \text{ amp peak to peak.}$$

It follows from the above parameters that a system capable of supplying ± 25 amp into the reactor will do the job.

Fig. 5 shows the high level circuit components of the ripple filter:

1. 2.5 kv 50 amp power supply with low impedance to > 720 cycles. It should be a 12 phase rectifier (2 three-phase full wave branches) so that its ripple is kept low.

2. Two F-6398 triodes, selected because of their low price (\$3,000) and a very high anode stand-off voltage (~ 65 kv). These tubes will be conditioned for high voltages before being operated in the filter, and should not arc over at ~ 8 kv which is a maximum for this application. As seen from Fig. 5, the shunt triode is driven by another F-6398. It operates as a cathode follower and has to deliver only 7 amp peak drive. No grid current is drawn for this operation and a swing of ± 500 v can be provided by one or two smaller tubes in parallel such as 4-1000 A.

3. Biasing supplies with their current limiting resistors and relays (Jennings, vacuum types). The relays will close for "ripple filter on" condition.

4. A crowbar spark gap and its circuitry (for example, a 10 ka model made by Radiation at Stanford) to protect the tubes and power supply in case of a tube arc.

5. A conventional 4-1000 A amplifier with the power supply (2.5 kv at 1.5 amp) This stage requires only $\pm 45\text{v}$ grid drive and is therefore supplied by a low level operational amplifier A_1 (Fig. 6).

Since the ripple filter is a closed loop system, the use of RC networks is avoided wherever practical and all amplifier stages have a wide bandwidth. This gives us freedom to shape the gain-phase characteristics according to the requirements of the complicated transfer function of the load.

The ripple voltage extraction from the main magnet voltage is accomplished by a differentiator-integrator combination (Fig. 6), and since $R_d C_d = R_i C_i$, the phase lead is cancelled by the phase lag.

The waveforms of the voltages at various points are shown in Fig. 6, and the operation of the circuit is as follows:

Shortly after beginning of the flattop, S_1 (a mercury relay) opens and applies the voltage to A_3 .

The rise time of this voltage is $R C_D \approx 5 \mu\text{sec}$. The differentiated output of this step input will be a narrow spike, and when S_2 closes about 1 msec later ($200 R C_D$), this spike will have decayed to zero. The integrated output at A_2 thus shows an ac component of magnet voltage only, and the ac coupling has been achieved without adding any time constants to the closed loop.

The relays which bias the F-6398 triodes for the ripple filtering operation are closed at the same time as S_2 .

When S_1 and S_2 are first closed, the ripple voltage would be too large and would saturate A_1 as well as 4-1000 A stage, thus producing a large transient in the system. A variable resistor R_x (Raysistor) is therefore used to program the gain in the loop, and the resistance of the raysistor is decreased from many megohms to a few hundred ohms in several milliseconds.

The bias voltages on F-6398 are sampled during the invert time of the acceleration cycle, and if they are not correct, the main breaker will disconnect the ripple filter from the main magnet power supply and indicate a fault.

Acknowledgments

The author is indebted to H.C. Praddaude and several members of the Accelerator Department staff for helpful discussions.

HJH/hm

Distribution: AD,B1,B2.

KV peak to peak

- 5 -

Accelerator Department
AGS-Int. Rpt. HJH-6
4/3/63

FIG. #1

Magnet Voltage Ripple

Fig.1

KV negative peak

- 6 -

Accelerator Department
AGS Int. Rpt. HJH-6
4/3/63

FIG. #2

Negative Swing of Magnet Voltage Ripple

Fig. 4

The energy scale shown on the top of Figure 4,
should be disregarded.

FIG. 5
HIGH LEVEL CIRCUITRY FOR THE RIPPLE FILTER.

A₁, A₂ AND A₃ STABILIZED OPERATIONAL AMPLIFIER
BW > 10 KC
S₁ S₂ MERCURY RELAYS (CLARE)

FIG. 6
LOW LEVEL CIRCUITRY FOR THE RIPPLE FILTER