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A HIGH LEVEL, LOW FREQUENCY RF SYSTEM FOR THE ACCELERATION OF LIGHT IONS IN THE AGS*

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Abstract

A high level, low frequency rf system for accelerating light ions is described. This system accelerates ions from typically 7 to 8 MeV/nucleon to 200 MeV/nucleon. It operates at the 12th harmonic of the AGS rotation frequency, in a nominal range of 0.5 to 2.5 MHz. It preaccelerates the beam so that a synchronous "bucket-to-bucket" transfer can be made to the present AGS proton rf system for further acceleration up to energies of about 14 GeV/nucleon, covering the frequency range of 2.5 to 4.5 MHz. An existing pre-conversion AGS two-gap cavity was rebuilt to cover the low frequency range and to accommodate gap voltages as high as 8.5 kV (magnetic field rise rate of 1.2 kG/sec). The cavity is driven by a push-pull tetrode power amplifier and driver chain capable of delivering over 100 kW.

Introduction

In recent years there has been a growing interest in the acceleration of ions in addition to protons in the AGS. Studies and planning over several years brought about a viable solution that would start to fulfill experimental needs in a short time by initially providing light ions to AGS users.

Some of the main ingredients of high energy light ion acceleration already existed at BNL. These included a Tandem Van de Graaff source, an almost usable accelerating cavity, and the AGS itself. Two major missing parts were a 2000-foot long beam transfer line and a low frequency rf system.

The additional low frequency rf system would accelerate ions from typically the 7 to 8 MeV/nucleon to 200 MeV/nucleon range, the normal proton injection energy of the AGS. The ion beam, now bunched and correctly phased for bunch-to-bunch transfer, would be accelerated to its final energy by the existing AGS high level, high frequency rf system. A new low level rf system would also be required. It is discussed in a paper by V. Kovarik, found elsewhere in these proceedings.

RF Parameters

Using an AGS magnetic field at injection of 90 Gauss, and a rate of rise of 1.2 kG/sec, a realizable set of parameters for a high level rf system were obtained. They are as follows:

Number of rf cavities	1
Number of accelerating gaps	2
Rf peak voltage per gap	8.5 kV
Frequency range	0.5-2.5 MHz

A block diagram of the system is shown in Figure 1. The various parts of the system are described in the following sections.

Cavity

The cavity is a rebuilt AGS pre-conversion, two-gap accelerating cavity. It was originally built to tune over a frequency range of 1.4 to 4.5 MHz, with a corresponding saturating bias current range of 50 to 1000 amperes. It has an average power rating of 25 kW. In order to tune from 0.5 to 2.5 MHz, both gaps were padded with 4750 pF vacuum capacitors. For the frequency swing factor of 5:1, the new tuning current range is 100 to 3000 amperes. All original buswork was replaced with water-cooled bus and gap connections. The original internal structure of the cavity and 4H ferrite material were retained.

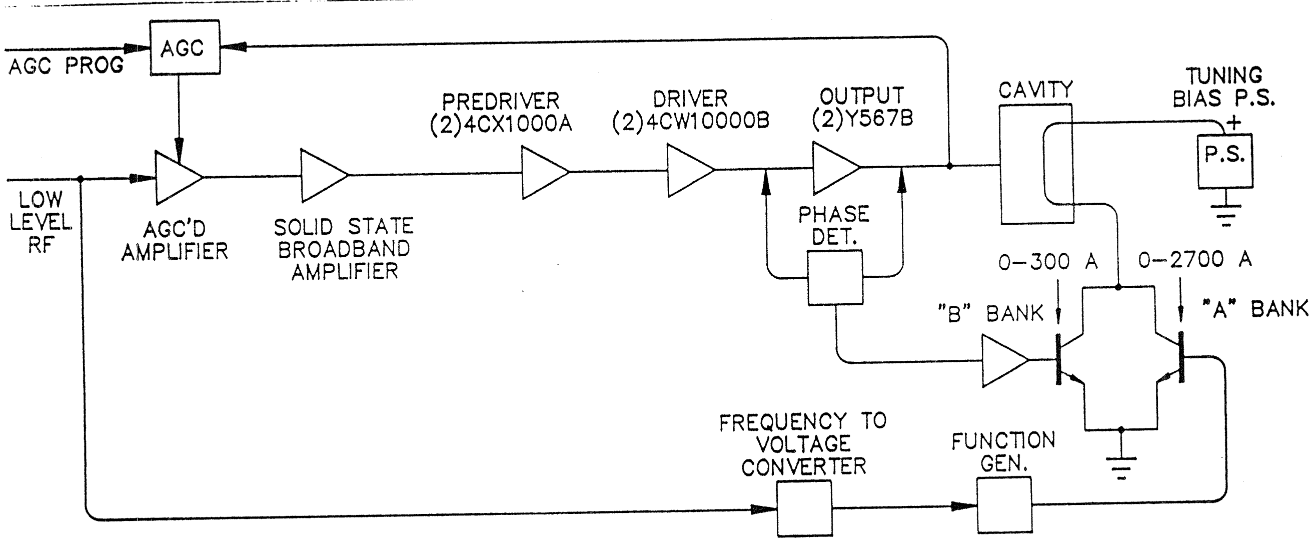

Fig. 1. System functional block diagram.

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Ferrite dissipation exceeded the estimates extrapolated from small sample measurements. These were projected to be 70 kW at 0.5 MHz, decreasing to 30 kW at 2.5 MHz, with a gap voltage of 8.5 kV peak. During early testing, peak ferrite dissipation was found to exceed 200 kW at 0.5 MHz. The gap voltage was then programmed to stay within a safe operating area (SOA) of less than 110 kW dissipation. The choice of SOA was made to keep the average cavity dissipation below the rated value and also to allow the power amplifier to operate more conservatively. This SOA did require the gap voltage to ramp up from less than 6.8 kV at 0.5 MHz to 8.5 kV at 1.1 MHz. The cavity was tested at its maximum average power level for a life test before installation. It was scanned with a heat detecting (IR) television camera but no hot spots were detected.

Cavity Tuning System

The power output requirements of the power amplifier are kept within reasonable bounds by tuning the cavity to resonance throughout the total frequency sweep. Tuning is accomplished by varying the cavity ferrite saturating current in response to two signals. The first of these is an open loop program obtained from the output of a function generator which is driven by a frequency-to-voltage converter (Fig. 1). The second is the output of a phase detector which compares the phases of the output stage grid and plate voltages. Together they regulate the cavity tuning to within ± 10 degreees of resonance with gap voltages of over 7 kV.

The coarse tuning open loop program function generator is adjusted so that a transistor bank, called the "A" bank, keeps the saturating current within 200 Amperes of its correct value for resonance. The initial value of this current is under 100 Amperes at 0.5 MHz and rises to over 2700 Amperes at 2.5 MHz. It can be driven up to 3000 Amperes. The "A" bank consists of 62 parallel-connected, "Hockey Puck" transistors. They are Powerex type D62T259010, mounted in pairs on water-cooled heat sinks. The output transistors are driven by eight parallel transistors of the same type.

The fine tuning or vernier regulator is capable of adjusting the tuning current up to 300 Amperes using the "B" bank. This bank consists of 14 output transistors and two drivers of the type described above.

The frequency response of the current loop ("A" bank) has been made slower than the phase loop ("B" bank) to minimize loop interaction effects. Both loops share the same load, cables, and d.c. voltage supply as shown in Figure 1. The gain-bandwidth product of the tuning loop varies strongly with the rf gap voltage level and the tuning current. No attempt has been made to dynamically vary the compensating networks to optimize the response over the range of these variables. Instead, compensation and loop gain settings were made for the worst combination of gap voltage and operating fequency. With these limitations, the gain-bandwidth product of the phase loop at 6 kV peak rf, from 1 to 1.5 MHz, is about 2 kHz. Under these same conditions, the current loop's unity-gain bandwidth is approximately 700 Hz.

The gap voltage program shown in Figure 2 was chosen not only to keep ferrite dissipation in a safe region, but also to keep the effects of nonlinearities at a minimum.[1] Because of this change of incremental permeability, μ_o, with the change of rf flux density at low saturating bias levels, the gap voltage is increased at constant frequency. During this rise in gap voltage, the slope of the operating path on the B-H curve changes, tuning the cavity to a lower frequency. The phase loop then calls on the "B" bank to retune the cavity to resonance. When the gap voltage has reached its level necessary for acceleration, only then is the frequency swept. Only small gap voltage changes are made during the frequency sweep. The demands on the phase loop are lessened with this mode of operation. This is especially noticeable at the points of gap voltage program slope change.

RF Power Amplifier

The high power output stage consists of a push-pull pair of EIMAC type Y567B water cooled tetrodes operating class AB_1 in a grounded cathode configuration. Their anodes are directly coupled (with appropriate blocking capacitors) to the accelerating cavity.

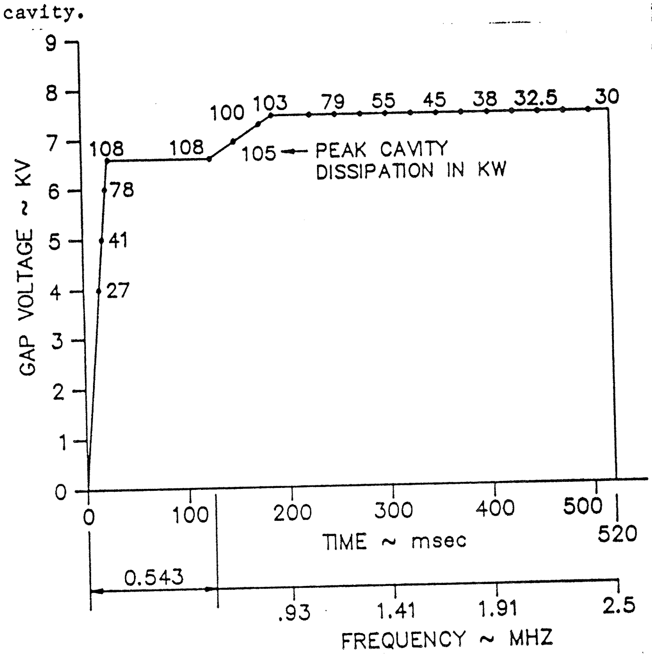

Fig. 2. Rf gap voltage program.

Figure 2 shows a typical gap voltage program used for this system during light ion acceleration. Also shown on this figure is the corresponding measured peak cavity dissipation with levels as high as 108 kW. The amplifier is designed to deliver 110 kW, conservatively, but can be operated continuously at 150 kW. There is essentially no beam loading so almost all power delivered to the cavity goes into ferrite dissipation.

The stage voltage gain varies from 29.5 db to 22.5 db as frequency is increased. This corresponds to an increase in load (cavity) impedance from about 330 Ohms at 0.5 MHz to over 1100 Ohms at 2.5 MHz. At these low impedance levels, the stage operates without instabilities or parasitics. Cross neutralization was not necessary. The d.c. anode voltage (8 kV d.c.) is brought to the power tubes through the cavity, eliminating the need for a plate choke.

Driver Stage

The driver stage is a push-pull voltage amplifier. It uses a pair of type 4CW10,000B water-cooled tetrodes. The stage is coupled both input and output by broadband filter networks. The tubes are operated in class AB_1 with their anode voltages supplied by means of a ferrite core crosscoupling choke. The stage operates as a voltage amplifier with a stable gain of 10.25 ± 0.5 db across the passband. The relatively low gain is dictated by the low network input impedance of its output interstage coupling network and, in turn, the final stage input capacitance.

Predriver Stage

The predriver stage is a push-pull voltage amplifier similar to the driver stage. It incorporates a push-pull pair of 4CX1000A tetrodes operating class A. Instead of an input filter network, it has an input transformer to provide phase inversion from an unblanaced 50 Ohm drive cable. The stage gain is 20 ± 0.5 db across the passband.

All three power tube stages are built into an industrial-type control equipment enclosure. The enclosure was modified with the addition of internal decks, RFI shielding, and contact finger door gaskets. Adjacent compartments contain grid bias power supplies, controls, and cooling equipment. The cabinet assembly measures 84-inches high, 103-inches wide, and 24-inches deep. It is mounted on casters and can be disconnected and moved (in less than one hour) to a low radiation area during high intensity proton acceleration.

AGC System

The rf gap voltage that is shown in Figure 2 is regulated by an automatic gain control (AGC) system so that it follows a programmed function (reference). A pair of capacitive voltage dividers are used to monitor the voltge at one gap. The stepped down signals are detected, filtered, and summed. The gap voltage envelope is monitored and also compared with the reference to generate an error signal. The error signal controls the gain of the AGC'd rf amplifier (Motorola type MC1590) shown in Figure 1.

Operational Experience and Conclusions

The high level, low frequency rf system was designed, built, and operated in just over two years. It was built as a prototype that was to become the final model. It was designed conservatively with an eye toward simplicity.

The system has operated without failure during two commissioning periods and one high energy physics run. Part of this success was due to the use of high speed overload relays and crowbar circuits in the final amplifier anode and screen power supplies. Also, all components were rated with comfortable safety margins.

Acknowledgments

The transistor bank design was adapted from an earlier design by R. Lockey, for the AGS F-10 SEB ejection magnet regulating system. The tuning system's overall design was influenced by the AGS ring conversion design described in Reference 2. The authors are indebted to P. Warner, J. Woods, and the rf technician staff for their efforts in building the system and untiring assistance during commissioning.

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