THE AGS CONVERSION RF SYSTEM*

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Introduction

The conversion of the Brookhaven Alternating Gradient Synchrotron (AGS) to increase its intensity by an order of magnitude is to be accomplished as a two step process. The first step will be to increase the capacity of the present power supply to the extent that the cycling rate of the AGS can be doubled. The second step will be to replace the present 50 MeV injector with a new linac having an energy of 200 MeV. The basic requirement for the RF system conversion is for accelerating cavities which can cover the frequency range and can accommodate the increased voltage necessitated by the increased rate of rise of magnetic field. The following report outlines the specifications for the conversion RF system during the "Interim Phase" and "Final Phase" and describes the equipment necessary to meet these specifications.

System Requirements

The basic changes in the RF system parameters stem from the increased rise rate in magnetic field which will be available during the interim phase of the conversion and the higher injection energy during the final phase. The present rate of rise of magnetic field is 14 kG/s which requires an energy gain per turn $\Delta E = 96$ keV. During the interim phase this will be increased to 28 kG/s requiring an energy gain per turn $\Delta E = 192$ keV. To operate with the equilibrium particle at 30°, as is presently the case, would require a total accelerating peak voltage of 384 kV. The present AGS uses twelve ferrite loaded, double gapped accelerating cavities each developing 8 kV per gap. During the interim system the same number of gaps will be used. However, because of power limitations in the ferrites, the stable phase point will be slid above 30° allowing the peak voltage per gap to be reduced to 12 kV instead of 16 kV. Because of the increased power requirements in the ferrites, twelve new power amplifiers will be installed each capable of delivering 120 kW, although in the interim phase the power requirement per station will be only 70 kW.

During the final phase of the conversion the 50 MeV linac will be replaced by a 200 MeV linac and the number of accelerating stations will be reduced from 12 to 8. Because the present ferrites are power limited, new ferrites will be chosen to be compatible with 200 MeV injection. Sliding the stable phase point back to 30° will require that the peak voltage per gap be increased to 24 kV. Ferrites will be chosen to meet the following minimum specifications: Cavity voltage = 24 kV peak; frequency range 2.5-4.5 Mc/s; cavity impedance 9600 Ω minimum; station impedance 4800 Ω minimum; station power dissipation = 60 kW maximum.

To facilitate maintenance and minimize the radiation hazard attendant with the increased beam levels, a new RF building will be erected to house all the RF power equipment and the cavity tuning electronics. RF power will be delivered on a system of outdoor overland trays as shown in Fig. 1.

Accelerating Cavity

The existing ferrite cavities have been described[1] and will be used during the interim phase. However, because of increased power levels in the ferrites, a new water system will be installed having an increased parallel water feed to cool the ferrite. The current power level at 8 kV/gap is 18 kW/station. Estimated interim power level at 12 kV/gap is 60 kW/station.

The existing cavity impedance at resonance varies from 925 to 1200 Ω over the frequency range. To impedance match the cavities to the RF cables a capacitance matcher will be used having a step up capacitance ratio of 3.3 to 1. (Fig. 2). However care must be taken to keep the system tuned to the proper resonant frequency at which point the driving point impedance becomes $R\left(\frac{C}{C + c_1}\right)^2$. Off tuning to the wrong resonance results in a driving point impedance equal to $\frac{R}{Q^2}$ which for a high Q system results in very large standing wave ratios. The cavity bias system will be designed for a maximum tuning error of 10° in which case there will be no danger of tuning on to the wrong resonance. The beam loading is 2 kW max for 2×10^{12} protons/pulse/station which is negligible compared to the losses in the RF cavity.

The final phase requires that the present ferrite cavities be discarded in favor of new ones. The new ferrites should have $\mu \approx 120$ and materials are now available with higher μQ products than the Ferroxcube 4H now being used. Further investigation will have to be made to determine the final cavity configuration. Ferrite investigations will also continue. This final cavity will be installed during the installation of the new linac.

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Power Amplifier

The same series of final power amplifiers will be used in both the interim and final phases of the conversion. These will be similar in concept to the AGS ring amplifiers currently in operation. They will be located in a central building delivering power to their loads via a pair of high power 50 Ω coaxial cables. Each cavity pair will dissipate 60 kW, each cable pair 12 kW, and 45 kW beam loading in the final phase. Each power amplifier will then be rated for a power output of at least 120 kW or a ring total of 1.44 MW. There will be fourteen such modules. Each cavity is driven by one power amplifier and six PA's are driven by one PA. A new predriver chain of about 50 kW to drive the two driver PA's also will be built. The conversion power amplifiers are described in full detail in Ref. 2.

Cavity Bias System

The tuning terminals of the RF accelerating cavities will be connected in series and powered from a programmed current source. In shunt with the individual cavity terminals will be a servo driven transistor trimming circuit whose purpose it is to correct for differences in cavity tuning requirements and small errors in the program as shown in Fig. 3. In order to keep all electronics out of the ring, the power supply, transistor shunts and tuning servo elements will be located in the RF building. Directional couplers in the high power RF cables will provide the phase detector with input output phase information necessary for the tuning servos.

The maximum current necessary in the main tuning loop in both the interim and final phase is approximately 1000 amperes. However, the $\frac{di}{dt}$ at 50 MeV required for the interim system is 12500 A/s whereas the final system will require a $\frac{di}{dt}$ at 200 MeV = 37200 A/s. For the long lengths of conductor necessary from the RF building to the cavities the inductive drops become appreciable. The total inductance of a parallel pair of 1000 MCM conductor 3000 ft. long plus the 12 cavity inductances is approximately 1 mH. The toal resistance of this combination is about 48 milliohm. The power source for the main tuning will be capable of at least 60 V at 1200 amperes.

The current in the main tuning loop must be correct within the limits of the trimming circuits for all operating conditions. This implies that it automatically correct for different cycling modes of the accelerator. The current program must then be based on the instantaneous rotational frequency of the beam. The program generator consists of a linear frequency discriminator whose input is derived from the low level RF system and whose output is filtered and used to drive a diode network. The diode network is used as a control element to derive the transfer function between frequency discriminator output voltage and cavity tuning current. The main tuning current will be held to ± 1% of the correct value.

Each cavity must have its individual tuning system. A review of the cavity tuning variations from unit to unit indicates that a correction of the order of ± 10% should cover all reasonable needs. In the completed system a tuning current of 1000 amps will be needed, therefore the vernier system must accommodate a ± 100 amp. swing. The dc loop gain of the vernier system will be 80. This loop gain is sufficient to hold the maximum phase error to 10 degrees while delivering a full offset current of 100 amps. The small signal bandwidth is 20 kc/s.

Phase Detector

By means of directional couplers located at the output of the power amplifier oupling transformer, the forward and backward waves on the coaxial lines are sampled. The forward wave is then delayed by twice the electrical length of line. A small fraction of the forward delayed wave is then added to the reflected wave. By measuring the phase difference between the forward and composite backward wave in a zero crossover type phase detector, a signal proportional to the phase angle of the cavity impedance is derived. This signal is used as a reference signal for the cavity bias vernier system. The phase detectors has a maximum error at ± 30° of ± 2% over the frequency range from 750 kc to 5 Mc with a phase modulation response of 100 kc. The phase detector block diagram is shown in Fig. 4.

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The RF amplitude at each cavity will be measured by using directional couplers. By adding the delayed forward wave to the backward wave, a signal proportional to the cavity voltage is obtained. A summing device will add the amplitudes of all the cavities. This summed signal will be rectified and applied to the power amplifier predriver to produce the correct amplitude control of the entire RF system.

Low Level System

The low level RF system has been described in Ref. 1. In principle, no major changes are contemplated. However, two changes are necessary. For the interim system, the phase compensating cable must be changed to compensate for the increased lengths of RF cable. For the final system, the starting oscillator and its program must be changed to accommodate the new starting frequency of 2.5 Mc/s. The location of the low level system will remain in the main control room.

Status

Tests are currently being performed on the spare AGS cavity in order to determine its ultimate operating parameters in the interim system. Ferrite evaluation programs are currently being conducted in order to make an optimum choice for the final system. A prototype of the final power amplifier is being built and will shortly be tested. The power amplifier predriver is in the design stage and construction will be started shortly. The main tuning current driver in the cavity bias system is in the design stage and will be built shortly. The vernier portion of the cavity bias system has been designed and portions of it have been successfully tested. The phase detector has been built and successfully tested.

Acknowledgment

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References

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2. "The AGS Conversion Radio Frequency Power Amplifier". R.H. Rheaume and R.T. Sanders. IEEE Transactions on Nuclear Science. June, 1967. Proceedings of the Second National Particle Accelerator Conference.

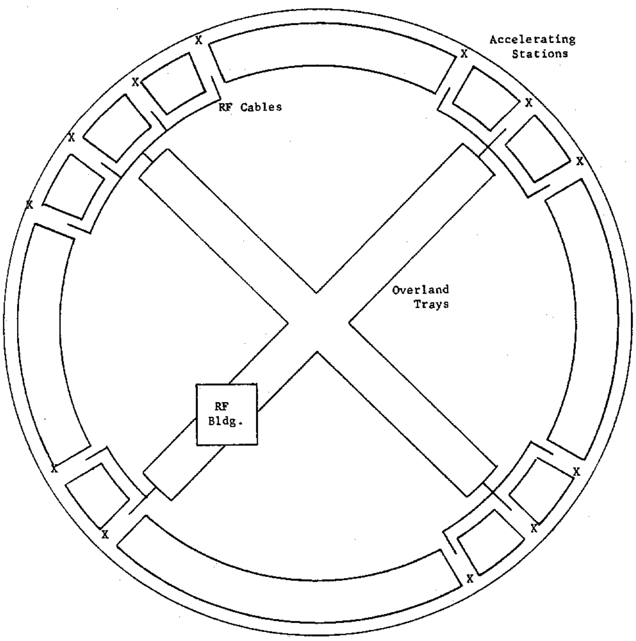

Fig. 1. RF Power Distribution.

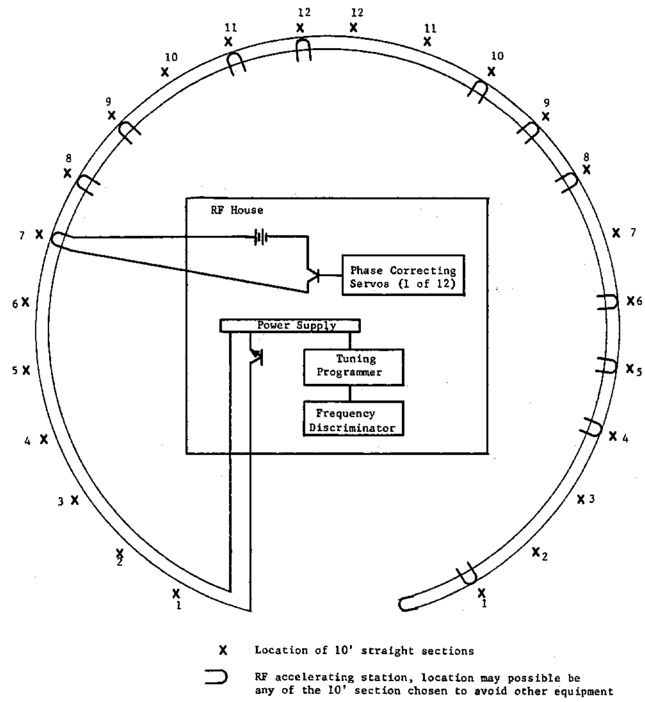

Fig. 3. Cavity Biasing System.

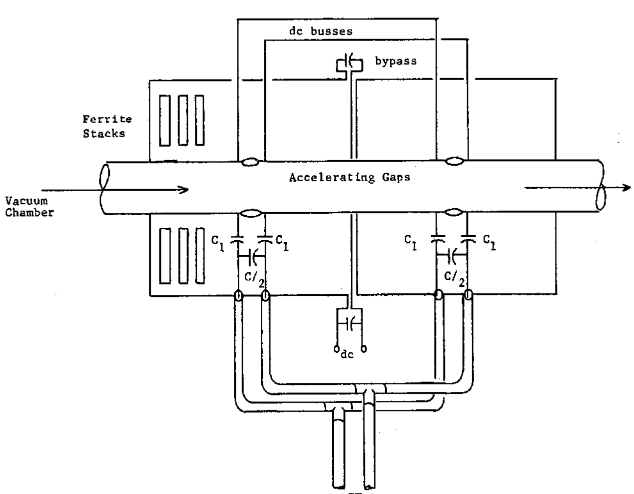

Fig. 2. Capacitive Matching.

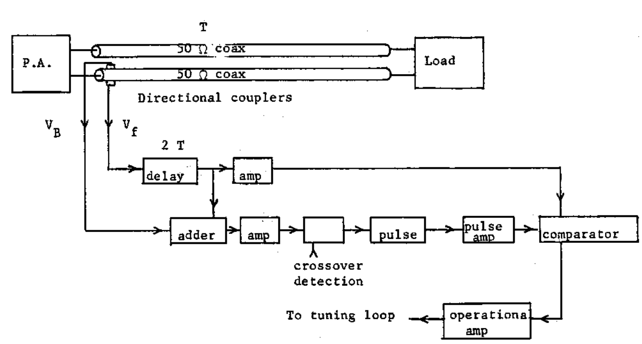

Fig. 4. Phase Detector.