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INTENSE PULSED NEUTRON SOURCE (IPNS-I) ACCELERATOR RF SYSTEM*

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Abstract

RF equipment constructed for the IPNS-I accelerator system, formerly called the Zero Gradient Synchrotron (ZGS) Booster II, is described in this report. The accelerator is a first harmonic rapid cycling machine intended to accelerate 3×10^{12} protons from 50 MeV to 500 MeV, 30 times per second. The RF system produces a peak accelerating voltage of 22 kV over a 2.2 MHz to 5.3 MHz frequency band. Two single gap ferrite loaded cavities are located 180° around the accelerator and operated 180° out of phase to provide the desired voltage. High level equipment, low level subsystems and control equipment are covered as well as modifications incorporated after start-up.

General Description

The IPNS-I accelerator[1] accelerates up to 3×10^{12} protons from 50 MeV to 500 MeV, 30 times per second. Guide magnets are powered by a resonant type power supply producing a sinusoidal $\dot{B}$ function. A harmonic number of 1 has been chosen so all the accelerated beam is contained in a single bunch approximately filling half of the 1691 in machine circumference. The accelerating system operates at the revolution frequency of 2.2 to 5.3 MHz. Figure 1 displays the frequency function, accelerating voltage and B field.

Figure 2 shows the location of equipment in a typical RF section. There are two such sections diagonally opposite each other each containing a 52½ in long accelerated cavity, cavity bias filter, and power amplifier. An enclosure above the cavity houses the bias filter and the power amplifier is located beneath the cavity. Cavity bias is applied through ports near the top center of the cavity. Removable bridge members support the cavity from the ceiling and a trolly mechanism is available for maintenance. Driver stages, power supplies and local controls are located above the RF sections outside the radiation shield.

Figure 3 is a block diagram of the accelerating system showing major components as well as signal flow and various control loops. $\dot{B}$ information obtained from windings included in a guide field magnet (ring magnet) serve as the frequency program source. The field monitor ("B" monitor) accepts $\dot{B}$ information, performs analog integration and provides a calibrated B field signal (1 V = 1 kG). Since $\dot{B}$ signals do not include the dc field component this must be reinserted. Normal operation is achieved with a simple dc reference, summed with ΔB information, but a dc current signal is available to provide a tracking offset when desired. An analog function generator accepts B field data and provides quadratic terms to produce the B field to frequency function of Fig. 1. The resulting function contains no discrete breakpoints so filtering is unnecessary.

The master oscillator output is split and feeds two separate amplifier channels. Each channel contains its own AGC loop and cavity tuning equipment. An electronic phase shifter provides 180° ±90° out of phase signals to these amplifier channels and functions in conjunction with a feedback loop to maintain the desired cavity phasing.

RF amplitude information is obtained from capacitive dividers at each final amplifier output. The RF envelope is detected, compared to reference and applied as input to a current ratioing gain controlled RF amplifier. A multibreakpoint function generator is summed with $\dot{B}$ to provide the desired reference function of Fig. 1.

A frequency to voltage converter sampling the master oscillator output provides the drive signal for cavity tuning. Independent function generators produce third order polynominal fits to compensate for ferrite linearity effects and accurately match the cavity resonant frequency to the operating frequency. A phase detector is included to monitor cavity tuning and close a slow feedback loop to remove long term drift.

Cavity

Two single gap accelerating cavities are used to provide the 22 kV peak RF potential required for proper acceleration. The cavities are ferrite loaded coaxial structures originally used in the Brookhaven AGS Accelerator. Since our frequency range and required gap voltages are close to the AGS values, only minor modifications are required. The AGS used a two gap configuration with 4 core stacks of 20 Phillips type 4H ferrite rings in a structure that measured 97-3/4 in in length. We simply split a single AGS cavity in half, reconstructed the beam pipes and vacuum flanges and added bias windings and an end cover.

The saturating field required to tune the cavity over the entire 2.2 to 5.3 MHz band varies from 1.5 Oe to 11 Oe. Single turn "figure eight" wound RF field canceling bias conductors provide this saturating field. A small amount of leakage field (60+ G at the outer edge of the beam pipe) may be seen by the proton beam. To reduce this undesirable feature, type 430 magnetic stainless steel is used for the beam pipes. This forms a good magnetic shield and causes no observable eddy current loading of the bias system. A 0.02 in layer of copper is flame sprayed over the stainless steel to provide a low impedance RF path for the cavity.

Addition of bias windings and connection to the bias RF filter can cause undesirable resonances within the cavities' operating band. A search for resonances was carried out to ensure that no high impedance resonances occurred in the passband or any harmonically related regions. A number 20 copper wire was strung through the cavity and terminated in 300 Ω, the characteristic impedance of a line thus formed. The tracking oscillator output of an Hewlett Packard Model 140T spectrum analyzer system was loosely coupled to this line. A high impedance broadband transformer connected across the accelerating gap coupled induced voltages through to the analyzer input providing a fairly accurate representation of gap impedance versus frequency. To achieve a realistic impedance plot at these low drive levels, a 4 kΩ

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swamping resistor was added across the accelerating gap. One high impedance resonance was observed at about 3 MHz. This was caused by bias winding inductance and its stray capacitance to ground. One thousand pF capacitors were added to the bias winding leads at the point where they leave the cavity to shift this resonance down below 2 MHz. The search was carried to 40 MHz with no other resonances being observed.

Amplifier System

Accelerating voltage for IPNS-I is supplied directly to the accelerating gaps by two separate amplifier chains each composed of a 100 kW final stage, a 20 kW driver stage, two 1 kW predriver units and several low level stages. The final amplifier stage consists of a pair of Amperex 8752 triodes used in a conventional grounded grid class AB1 push pull configuration. The triodes are fed from a 10 kV anode supply and biased for an idle current of about 4 A per tube. Voltage is supplied to the anodes through air core RF chokes in a shunt feed approach. A ferrite loaded transmission line transformer is used at the input with swamping resistors added to minimize reflected beam loading effects and to reduce the amplifier's input impedance. The final stages are housed in RFI shielded enclosures 48 in wide by 42 in high by 44 in deep designed to be inserted beneath the cavities. Honeycomb ventilating panels in the cabinet sides and top allow for convection cooling with the final filaments and input swamping resistors water cooled. Final drive power is supplied by a pair of 4CW25000 class AB1 grid driven tetrodes located some 50 ft away outside the radiation shield.

Master Oscillator System

An EXAR Systems SR200 integrated circuit module containing a voltage controlled oscillator and some analog waveform conditioning circuitry forms the heart of the master oscillator system. The VCO is operated at the accelerator revolution frequency and exhibits adequate linearity and stability to make heterodyning unnecessary. All external frequency determining components are low temperature coefficient units and a proportional controlled oven is used to isolate the oscillator chip and associated components from ambient temperature fluctuations. A separate power supply provides necessary voltages to the oscillator system and the oscillator output is transformer coupled to the remainder of the system to prevent ground loop difficulties. VCO input information is obtained from a function generator module that provides the terms of a third order polynominal with beam position feedback providing fine adjustment. Beam phase information is obtained from a RF mixer based phase detector operating at the revolution frequency. The low frequency components are filtered out and summed with the function generator and position feedback signals. A multibreakpoint function generator is available for beam parking and steering operations.

Controls

The IPNS-I accelerator RF system contains some interesting control features. The two amplifier chains are fed from common power supplies but independent control of each station is available. Protection and sequencing controls are provided at control locations on the equipment deck over each RF station. Solid state relays (SSR) controlled by dual-in-line packaged relay based logic units[2] provide the primary sequencing and control features. Inputs such as "water flow," "door interlock," and "grid bias on" complete the common return connection to 5 V relay coils with their contacts utilized to enable the SSR. SCR memory circuits hold fault information until manually cleared. The entire interlock system is operated at 5 V integrated circuit logic compatible levels retaining the reliability and noise immunity inherent to relay systems and the possibility of utilizing standard logic control equipment. Remote trip relays included in the main circuit breakers prevent uncontrolled startup after a power down condition and remove power upon a serious interlock violation. Panic buttons located near all equipment locations are hard wired to the remote trip relays to remove all power irregardless of interlock status. Separate fast acting overcurrent sensors and vacuum contactors are installed at the driver and final anode supplies to isolate one station upon fault conditions without affecting the operation of the other. Local protection is included in the anode supplies and each independent piece of equipment.

System Improvements

A few changes have been incorporated into the system since the accelerator was commissioned. (1) A modified RF voltage program has been incorporated (Fig. 1). The initial program was essentially $\dot{B}$ with an added offset, but we found by experimentation that more voltage at the end of the acceleration cycle is desirable and that the amount of captured beam is very dependent on the voltage program at injection. Elevated RF voltage late in the acceleration cycle is required to allow for beam phase fluctuations and we expect to return to a lower level when beam phase feedback is improved. (2) Beam phase feedback alterations have been under development. The original phase detector is sensitive to changes in bunch shape since raw beam data forms one of its inputs. A heterodyning filter arrangement has been assembled and will be incorporated when testing is complete. (3) The $\dot{B}$ windings used to generate the RF frequency program were unusable at commissioning time. Noise transients were coupled in from the Ring Magnet Power Supply (RMPS) and extra windings included in the resonating chokes were utilized instead. Recent improvements in the RMPS filtering have allowed us to utilize the original pickup coils with only the addition of a differential input ground loop isolation amplifier. (4) Improvements in power amplifier dynamic range, increased bandwidth for the automatic gain control system and closing the slow cavity tuning feedback loop have also contributed to improved overall systems performance.

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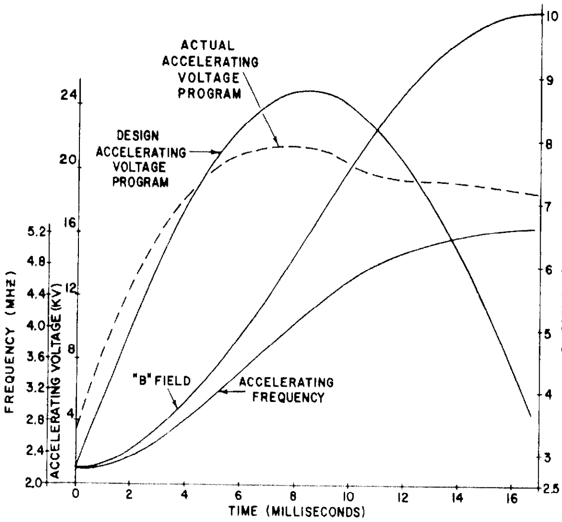

FIG. I IPNS-1 B FIELD, FREQUENCY, ACCELERATING VOLTAGE

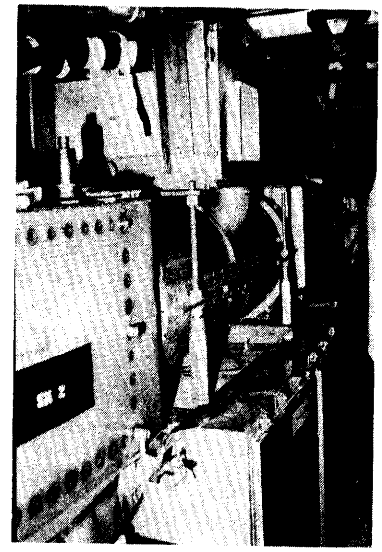

Fig. 2. Typical RF section

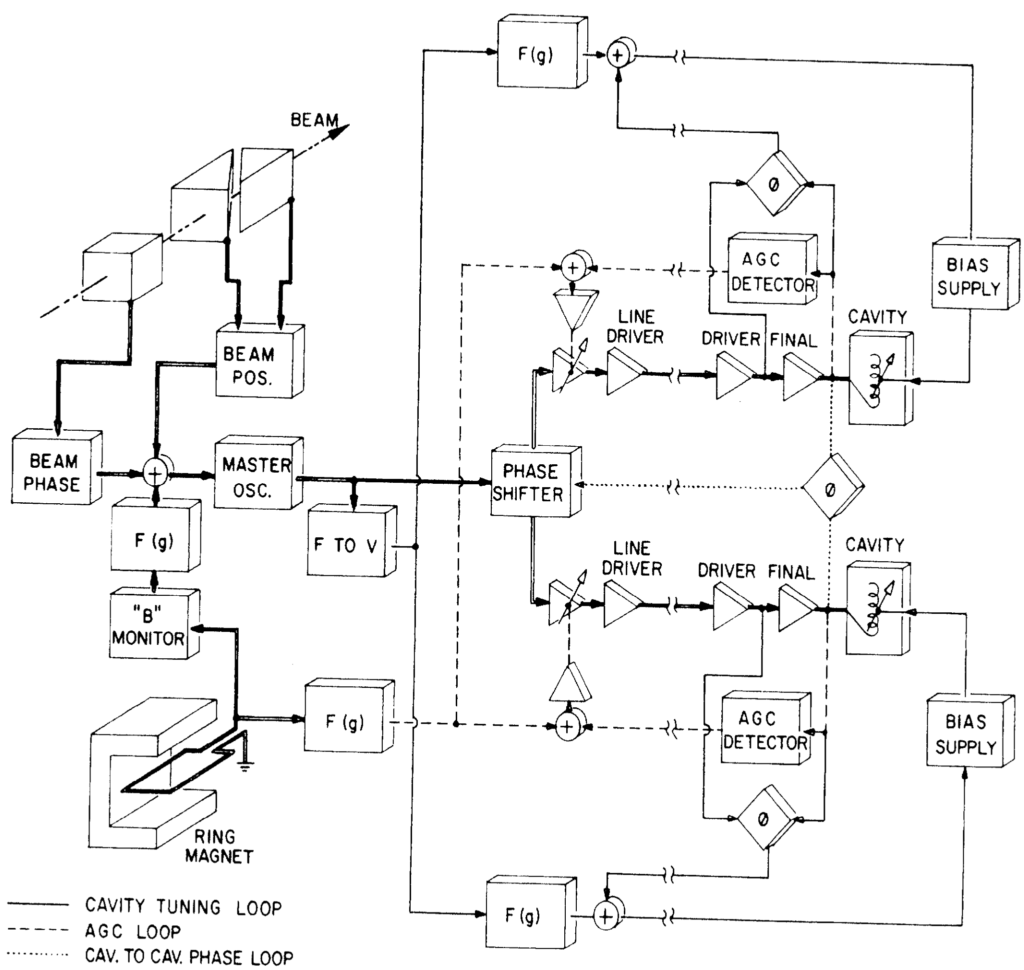

FIG. 3 IPNS 1 ACCELERATOR RF SYSTEM BLOCK DIAGRAM