52 MHz RF Systems for HERA

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Abstract

The rf system for the acceleration of protons in the main HERA ring is a contribution from Canada to the construction phase of HERA. With the 52 MHz rf system for PETRA II [1], it is being built by CRNL under contract to the Institute of Particle Physics, with funding by the Natural Sciences and Engineering Research Council and DESY. We will review system design and present a progress report on construction.

Introduction

The HERA proton storage ring [2] will have two rf systems [3], one at 52 MHz for capture and storage of the beams transferred from PETRA, and one at 208 MHz for acceleration from 40 GeV/c to 820 Gev/c and storage. The specification for the 52 MHz rf system in HERA calls for a total circumferential voltage of 15-30 kV during capture, and up to 290 kV continuously during transfer of the beam to the 208 MHz system and subsequent acceleration and storage. The system must tune by approximately 20 kHz during acceleration, to match the particle velocity variation. Maximum average design beam currents are 0.17 A, so that the rf system must cope with large reactive beam-loading effects. Also specified are an rf feedback system with an open-loop gain of 50, a significant reduction of higher-order cavity mode impedances, stringent limits on allowed rf noise and a feedforward system capable of cancelling out 90% of the beam-induced voltage. The total system of cavities and rf amplifiers must be operable from the DESY central control computer, and at the same time be capable of operation in a stand-alone mode for commissioning and testing during manufacture at CRNL.

One notable difference from the requirements for PETRA II is that the cavities and rf amplifiers will be located in the HERA tunnel, about 145 m north of the interaction point in Halle West, while computers, power supplies and some other control equipment will be located in an equipment room in that hall, at a distance of some 250-300 m.

Cavity Design

The Fermilab Debuncher Ring rf system [4] was chosen as the starting point for the design of the HERA 52 system, as its operating characteristics closely match the specification given above. The cavity (Figure 1) can be likened to two half-wave resonators placed back to back, or to a TM-010-like cavity loaded by an intermediate cylinder supported at the zero-field symmetry point in the centre of the cavity. Relative to PETRA II, the aspect ratio of the cavity has been changed somewhat to permit the construction of the outer cylinder using a standard size of aluminum sheet, minimize weld joints and provide higher Q and shunt impedance. The increase is estimated to be about 20%. The calculated R/Q is 162 Ω. As for PETRA II [1], fabrication from aluminum was chosen for reasons of cost and ease of manufacture. Unlike the PETRA II cavities, the entire cavity volume will be evacuated. As a result, considerable attention has been paid to the potential problem of multipactor during operation at low voltage. The primary defence against this problem will be careful titanium coating of all parts of the cavity likely to be affected.

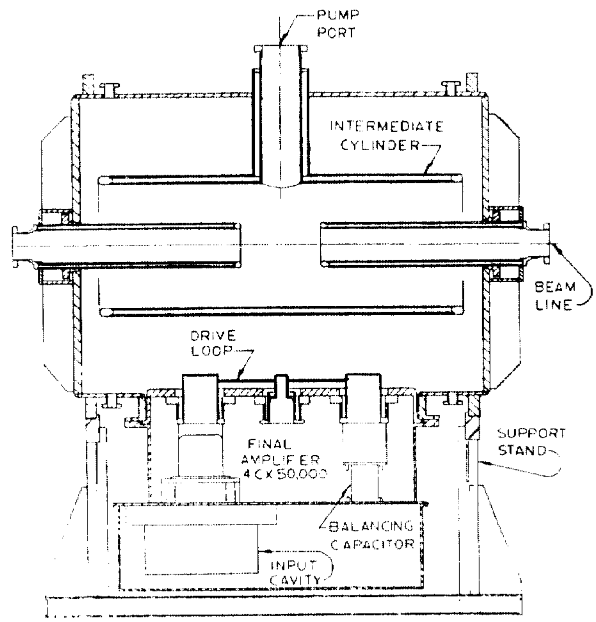

Figure 1. HERA 52 MHz cavity cross-section.

Extra access ports have been provided to facilitate this process. The inner conductor, intermediate cylinder, portions of the cavity outer wall, tuner and higher-order mode dampers will be water cooled. Double-wall construction for the intermediate cylinder and inner conductor allows cooling tubes to be attached to the cylinder walls in the annular volumes, providing an effective cooling system that can easily withstand the operating pressure of 2 MPa, but with no water-to-vacuum joints.

Two cavities are sufficient to meet the requirements of HERA 52,and provide flexibility for future changes in operating procedures.

Cavity tuning is achieved by variation of the resonant frequency of a partially external coaxial half-wave resonator loop-coupled into the main cavity (Figure 2), as was done for PETRA II [5]. Although the frequency swing required is only about 10% of that for PETRA, the coupling loop size will not be reduced proportionately, since the HERA 52 cavity has lower magnetic fields near the cavity wall. The volume of ferrite will be about half that used for PETRA II. The volume of ferrite per unit of frequency variation is greater for HERA so that the magnitude of the rf current in the tuner can be kept down, in spite of the higher cavity fields. The higher-order mode damper (Figure 3) is identical in concept to that of PETRA II [6], and the coupling loop is the same, although the cavity design changes will result in a somewhat different length for the external, resistor-loaded line.

The loaded cavity Q, without feedback, is expected to be 5500.

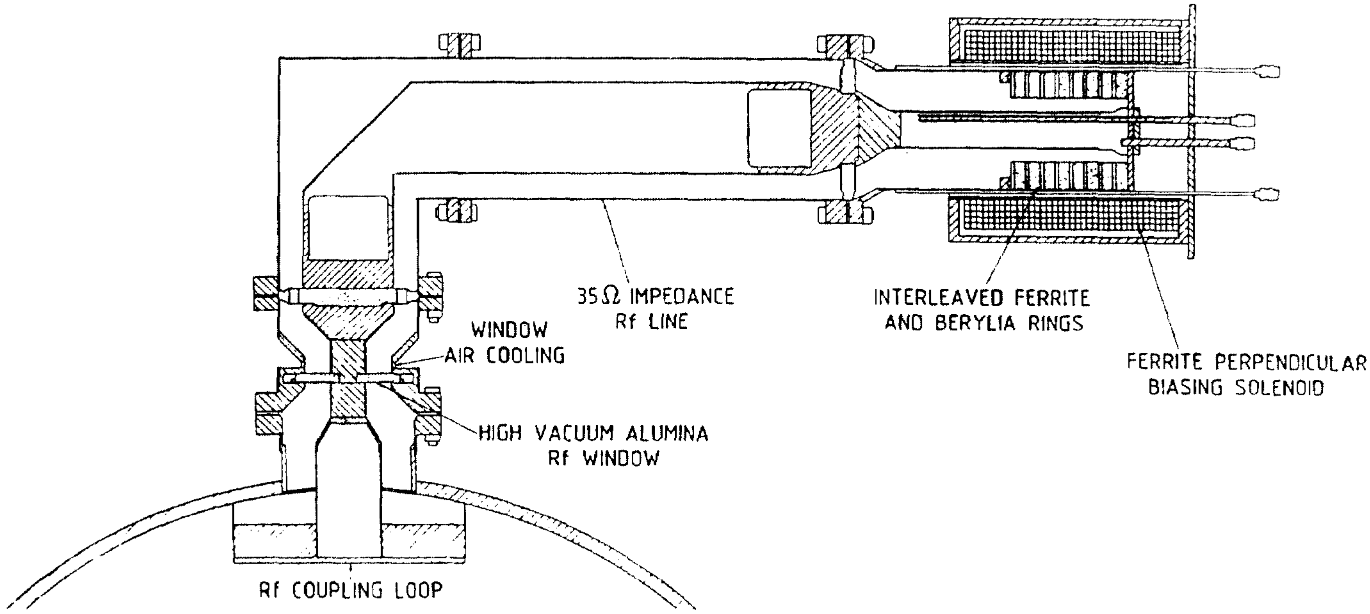

Figure 2. Cross-section of HERA 52 MHz tuner.

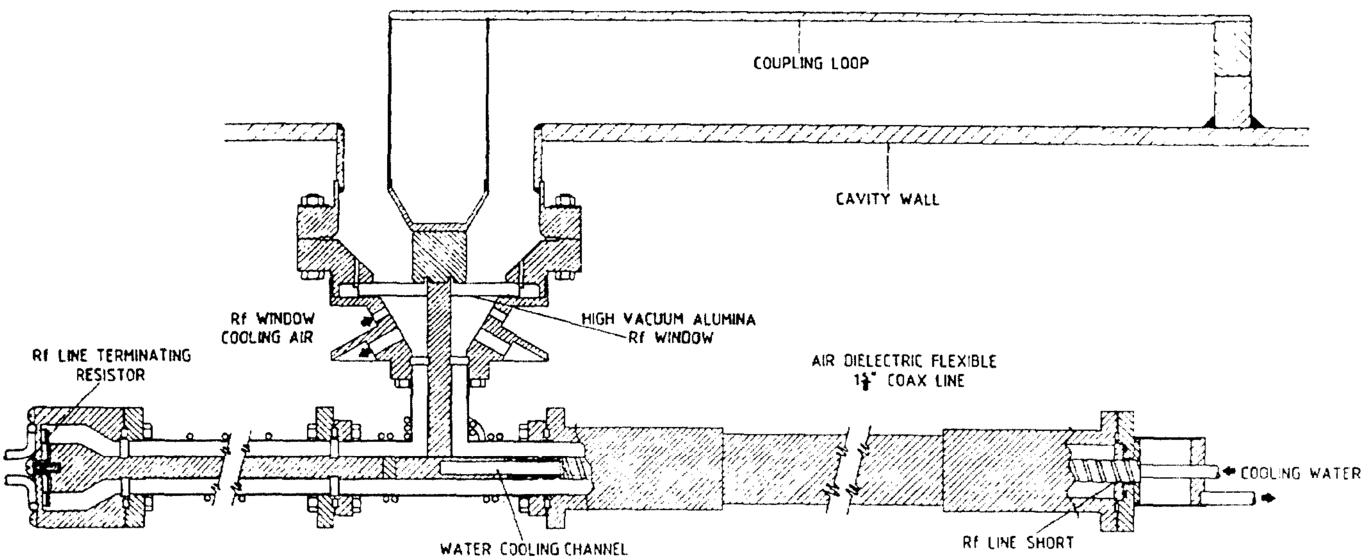

Figure 3. Cross-section of HERA 52 MHz higher order mode damper.

Rf Amplifier Design

The 13 dB final amplifiers are designed for class AB1 operation of the Eimac 4CW50000E tetrodes in a grounded-grid circuit. Each amplifier chassis, mounted directly below the cavity and directly coupled into it with a drive loop designed for a 25:1 step-up ratio from the plate to gap voltage swing, will contain one tetrode and a balancing capacitor, attached to opposite ends of the loop. A 10 kV plate supply feed will attach to the mid-point of the drive loop. Design concerns being addressed include the provision of vacuum feedthroughs for high voltage and tube cooling water in a way which keeps the tube/drive loop resonant frequency sufficiently high to avoid stability problems while achieving the desired coupling to the cavity. The large input capacity of the tetrode fore-shortens the quarter-wave coaxial input resonator, which is doubly folded to fit in the available space under the anode/drive-loop compartment. Two plungers are provided to adjust resonator frequency and to match input coupling, made by a fixed wall tap at the 5 Ω point near the shorted end of the cavity. Preliminary designs for the final amplifier have been completed, and this subsystem is presently being prototyped.

The driver assembly will follow a design developed by TRIUMF using multiple 300 W MOSFET modules of the Granberg design [7,8]. A single module will drive the 10 module output stage for a total of 3 kW. The driver assembly must be located in the shielded electronics trench because of high radiation levels in the tunnel. The low output impedance of the 10 port output combiner requires that it be located close to the final input resonator. Specific advantages of this driver design include low (15 ns) propagation delay, compact design and ease of water cooling.

Analog Controls

The Analog Control System for HERA will be very similar to that used with PETRA [1]. As with PETRA, two feedback loops will be used: an rf loop with an open-loop gain of 50 will control the cavity voltage magnitude and phase, and a resonance control loop will keep the cavity tuned such that it appears as a resistive load on the rf amplifiers. Feedforward compensation will be provided in the same manner as for PETRA. Differences from the PETRA system fall into three categories:

- improved / extended performance,
- more convenient parameter adjustment,
- ~ 60% reduction in physical size.

The minimum operating gap voltage is 15 kV, during beam capture, a decrease from the 50 kV minimum in PETRA. In addition, the maximum required gap voltage is increased from the 100 kV level of PETRA to 150 kV. To accommodate this, the control loops are designed to operate over a 22 dB dynamic range; 9 dB greater than for PETRA.

Proportional and derivative action will be incorporated in the resonance controller, permitting the use of larger loop gains and reducing tuning response time. Computer simulation studies predict this improved controller will reduce the response time by a factor of three relative to that of PETRA.
During the system integration and testing phases of the PETRA project, it was recognized that adjustment of a number of parameters was inconvenient and was required more frequently than anticipated. The HERA design calls for additional variable attenuators and variable phase shifters so that all loops and monitoring circuits may be readily adjusted without opening circuit packaging.

To minimize control loop length, the "Fast Loop" circuits must be placed in the HERA electronics trench where space is very limited. Also, in this location, the radiation fields are strong enough to preclude the use of some materials, such as teflon, which are commonly used in rf components. Component selection, circuit layout, and construction are being planned so that radiation-sensitive components are not used and so that the overall system volume is reduced to about 40% of that for PETRA.

Digital Controls

The computer system to control each rf system is essentially the same as that used in the PETRA II RF system [1]. The main differences in hardware are the addition of a software bootstrap system from a floppy disk and a doubling of RAM to 256 kBytes. The bootstrap system will execute the software in ROM if no floppy disk is present, allowing proper default operation after initial power is applied. However, special configurations can be easily tested by booting the system from floppy based software.

Analog signal conditioning is also different. In PETRA the computer system is located adjacent to the rf system, thus a 0 - 5V standard was adopted for the analog signal levels since line losses are not significant. In HERA, the computer system is located approximately 250m from the rf amplifiers and cavity which are in the HERA tunnel. Thus all analog signal levels interfaced to the computer are 4-20mA current loops that have a much higher noise immunity.

Construction Status and Schedule

Fabrication of the cavity components is presently about 90% complete, and they will be delivered for initial assembly and tuning in June. Fabrication of tuners and higher-order mode dampers is well advanced, and these components, along with a prototype drive loop, are also expected to be available in June for initial cavity tuning. Final welding of the vacuum system is expected to take place in September, and first power to the cavities is scheduled for November. Dc power supplies for the rf systems and tuners have been ordered. Ferrite and beryllia for the tuners is on hand, as are most of the components for both analog and digital control systems. Completion of acceptance tests at DESY is scheduled for early summer 1989.

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