

THE CEBAF RF SEPARATOR SYSTEM*

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Abstract

The 4 GeV CEBAF accelerator at Thomas Jefferson National Accelerator Facility (Jefferson Lab) is arranged in a five-pass racetrack configuration, with two superconducting radio-frequency (SRF) linacs joined by independent magnetic transport arcs. The 1497 MHz continuous electron beam is composed of three interlaced variable-intensity 499 MHz beams that can be independently directed from any of the five passes to any of the three experimental halls. Beam extraction is made possible by a system of nine warm sub-harmonic separator cavities capable of delivering a $100 \mu\text{rad}$ kick to any pass at a maximum machine energy of 6 GeV. Each separator cavity is a half-wavelength, two cell design with a high transverse shunt impedance and a small transverse dimension. The cavities are powered by 1 kW solid state amplifiers operating at 499 MHz. Cavity phase and gradient control are provided through a modified version of the same control module used for the CEBAF SRF cavity controls. The system has recently been tested while delivering beam to Hall C. In this paper we present a description of the RF separator system and recent test results with beam.

Introduction

The 4 GeV CEBAF accelerator is arranged in a five pass racetrack configuration, with two superconducting radio-frequency (SRF) linacs joined by independent magnetic 180° transport arcs. The continuous electron beam is composed of three interlaced variable intensity beams that can be independently directed from any of the five passes to any of the three experimental halls. This allows three simultaneous experiments at the same or different energies and currents. Electrons are emitted through a thermionic cathode or a polarized laser cathode that is being commissioned. Presently only one experimental hall is fully operational, Hall C, with Hall A in the final commissioning stages.

To develop the three independent beams the CEBAF accelerator uses a chopping cavity system in conjunction with separator cavities operated at the third subharmonic (499 MHz) of the accelerating cavities. The separator cavities are positioned in each of the five passes and allow for different combinations of energy to be delivered to the experimental halls. The accelerator can deliver only a single lower energy (845, 1645, 2445, 3245 MeV) to any one hall at a time or the maximum energy (4 GeV) to one, two or all three experimental halls. Each pass has been designed to deliver the $100 \mu\text{rad}$ kick necessary to extract the beam. The separator

phase arrangements for the first through fourth pass and fifth pass are shown in Fig. 1.

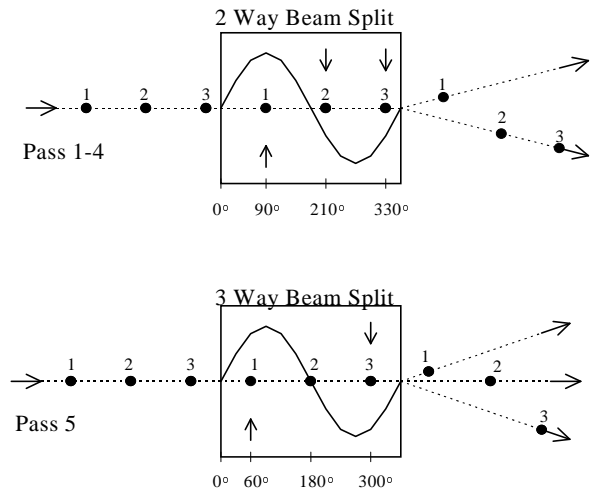


Fig. 1: Separator Cavity Phasing.

The nine cavities are arranged in the following fashion: pass one and two each have one cavity, pass three and four each have two cavities and the final fifth pass has three cavities (Fig. 2). The reason is that it was more economical to build cavities than to buy high power amplifiers. In addition the arrangement allows for energy upgrade in the future without the addition of hardware.

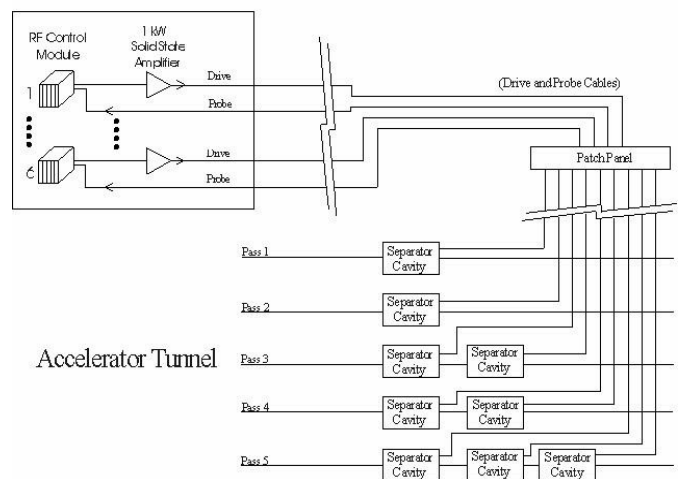


Fig. 2: RF Separator System.

The cavities are powered by six solid state amplifiers that can be manually switched to any cavity in any pass. The most

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amplifiers that will be needed at any one time is five, so one acts as a hot spare. Eventually it is envisioned to have an electromechanical switch matrix for drive and probe cables so that one can switch remotely between passes.

Cavities

The CEBAF separator cavity is a new design which achieves a high transverse shunt impedance in a package with compact transverse physical dimensions [1]. Two B field coupled $\lambda/2$ cells make up each separator cavity. Each cell is a resonant cylindrical cavity with four internal coplanar field perturbing rods that are parallel to the cavity axis (Fig. 3). As reported in other papers the cavity is operated in a TEM dipole type mode at 499 MHz and the beam path is along the cavity axis [1, 2]. The frequency of each cell is adjusted by a manually operated capacitive frequency tuner. Power is delivered to the separator cavity by a critically coupled inductive copper loop probe mounted to a 1 5/8" coaxial EIA adapter. Cavity gradient is measured by a small highly undercoupled monitor loop probe.

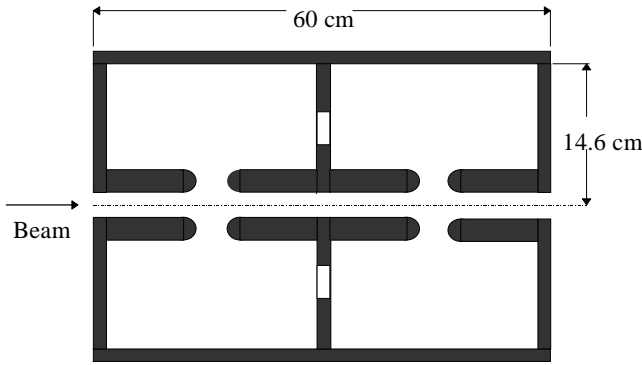


Fig. 3: Two Cell Separator Cavity.

The separator cavity is constructed from two cylinder body assemblies, one center flange/rod assembly and two end flange/rod assemblies. These parts are then joined together using Conflat vacuum hardware.

The flange/rod assemblies are quite intricate [3]. The rods are made from a tellurium copper alloy for strength and are brazed into an OFHC copper end slug. The end slug is brazed to a stainless steel collar which is then electron beam welded to a stainless steel Conflat flange (Fig 4). The entire assembly is then copper plated. Water channels in each flange assembly deliver coolant to the rods, which are hollow and fitted with septum plates. A water channel also surrounds each cylinder body.

An interesting feature of the cavity is that the stainless steel cylinder body does not require copper plating. The fields and therefore the currents are very weak at the cavity perimeter, making plating irrelevant. Tests made during prototyping showed that copper plating the cylinder body resulted in less than a 5% increase in the intrinsic Q . This amounted to a substantial cost savings in manufacturing the cavity.

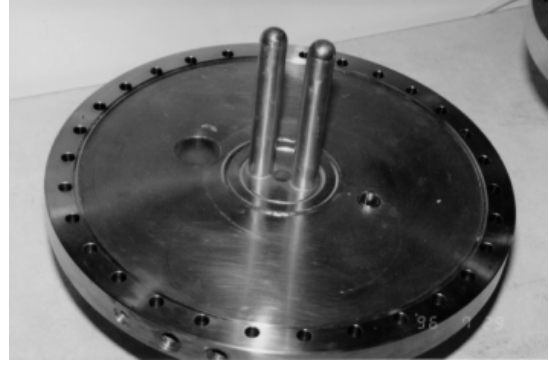


Fig. 4: End Flange and Rod Assembly.

CEBAF Separator Cell	
Length	27.6 cm
Radius	14.6 cm
Beam pipe diameter	1.43 cm
Rod diameter	2 cm
Rod gap longitudinal	2 cm
Rod center transverse spacing	3.5 cm
Cavity resonant frequency	499 MHz
Cavity loaded Q	2500
Transverse shunt Impedance	350 M Ω /m

Separator Cavity Transverse Shunt Impedance

The transverse shunt impedance is an important figure of merit for a deflecting cavity, and we have determined this value through three separate means. The first method was to perform a MAFIA code simulation of the cavity. Next we conducted a beam test with an installed separator in the accelerator, where we measured the beam deflection. Finally, a bead pull measurement was conducted in the lab [4]. Given the complicated geometry we believe the MAFIA results are in fairly good agreement with the other two methods.

*MAFIA**

$$R_{\perp} = \frac{V_{\perp}^2}{P_{\ell}} = 175 \text{ M}\Omega$$

*Beam Test**

$$R_{\perp} = \frac{V_{\perp}^2}{P_{\ell}} = \frac{(845 \text{ MeV} \cdot 131 \mu\text{rad} \cdot 2/3)^2}{26 \text{ W}} = 208 \text{ M}\Omega$$

*Bead Pull**

$$R_{\perp} = \frac{V_{\perp}^2}{P_{\ell}} = \frac{Q_0 \cdot \left(\int \sqrt{\Delta f} \cdot \cos \frac{\omega z}{c} \cdot dz \right)^2}{2\pi f^2 r^3 \epsilon_0} = 212 \text{ M}\Omega$$

Amplifiers

The amplifiers for the system were built by a private company on contract with Jefferson Lab. They are of a modular design that moves away from the traditional chassis

* includes transit time effects

style used by many high power solid state amplifiers. The amplifiers are capable of 1300 W of saturated power and 1 kW of linear power. The amplifiers are modeled after broadcast amplifiers where quick repairs are a necessity. Each amplifier has four (250 W) power modules that can easily be removed for repair. In addition the power modules can be removed and the amplifier operated with one, two, or three modules to reduce the power consumption. Each power module is identical and can be switched between amplifiers if necessary. The amplifiers can be controlled either locally for maintenance or remotely through the CEBAF control system during operation. Interlocks consist of a load-missing fault for personnel safety and over temperature to protect the unit.

Table 2
Amplifier Specifications

Power out (linear)	1 kW
Power out (saturated)	1.3 kW
Frequency	499 MHz +/- 5 MHz
Class	A
Gain	70 dB
VSWR (in/out)	1.3:1/1.5:1
Noise figure	< 8.0 dB

Cavity Control

Cavity control is accomplished through a modified superconducting (SC) cavity control module [5]. In a superconducting mode the cavity provides the first pole in the feedback system. In the normal conducting case that is not feasible since the cavity's bandwidth is 200 kHz. Therefore the control modules have been designed to include a removable artificial pole at 10 Hz. This allows high gain (30 dB) operation without the possibility of oscillation. The control system is based on a traditional phase and amplitude system that controls on each individually. The signal processing components were chosen to minimize AM to PM and vice versa. We have not had problems with the SC cavities and therefore do not foresee any problems with normal conducting cavities.

Calibration

The RF control modules are unique in that each is calibrated in an environmental chamber. The modules are completely characterized to remove offsets, phase shifts, and amplitude shifts. A complete record of temperature drifts is then downloaded into the control module where custom algorithms use the information to compensate for them. Local operational information such as cable attenuations and cavity coupling parameters are downloaded to the control module in situ.

Software control

The EPICs control platform provides the user interface in the form of control displays and state machine logic [6]. Because there are only six RF control modules and nine separator cavities, operators must have ability to switch RF controllers between the cavities. This posed a dilemma for the RF controls because each RF control module needs to have operational data (cable attenuations, cavity Q) specific for each cavity. To facilitate this a matrix database has been developed that allows operators to download any operational information to any RF control module.

Interlocks

The CEBAF accelerator is set up so that any experimental hall can have a number of different options of beam energy and current. Hall B in particular will require currents three to four orders of magnitude lower than the other halls. Any beam reaching this hall that is larger than $1\mu\text{A}$ could destroy the target; therefore an interlock is needed such that the separator phase cannot slip 120° . In addition directly downstream are very thin septa magnets that are susceptible to beam burn through. A phase slip of 20 degrees could put the beam onto one of the thin septa, causing a vacuum accident. Therefore a fast shutdown system that compares the chopping cavity phases to the separator cavity phase is being installed and tested.

Status

Presently all of the cavities are installed and have been tested to 1 kW. The phase slip interlock is undergoing beta testing and it is expected to be fully operational by January 1997. Operations with beam have also been successful. The system has been used to deliver 4 GeV, 70 μA beam to Hall C while concurrently delivering 845 MeV, 5 μA beam to Hall A. Multibeam delivery to all three experimental halls is planned for early 1997.

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