SOURCE AND EXTRACTION FOR SIMULTANEOUS FOUR-HALL BEAM DELIVERY SYSTEM AT CEBAF*

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Abstract

A new design for simultaneous delivery of the electron beam to all four 12 GeV CEBAF experimental halls requires a new 750MHz RF separator system in the 5th pass extraction region, a 250 MHz repetition rate for its beams, and addition of a fourth laser at the photo-cathode gun. The proposed system works in tandem with the existing 500MHz RF separators and beam repetition rate on the lower passes. The new 5th pass RF separators will have the same basic design but modified to run at 750 MHz. The change to the beam repetition rate will be at the photo-cathode gun through an innovative upgrade of the seed laser driver system using electro-optic modulators. The new laser system also allows addition of the fourth laser. The new RF separators, the new laser system and other hardware changes required to implement the Four-Hall operation delivery system will be discussed in this paper.

INTRODUCTION

The CEBAF accelerator at Jefferson Lab has been providing beam to three experimental halls in the past twenty years. This is achieved by creating three interleaving beams in the injector each at 500MHz, one third of 1500MHz [1], the main accelerating frequency. These beams are accelerated up to 5 passes through the main machine before they are separated to go to their respective halls. The separation is done using RF separators also operating at 500MHz. The detail of the extraction process is explained in the references. As a part of the 12GeV upgrade, a fourth experimental hall, Hall D, is being added to CEBAF [2] (Figure 1).

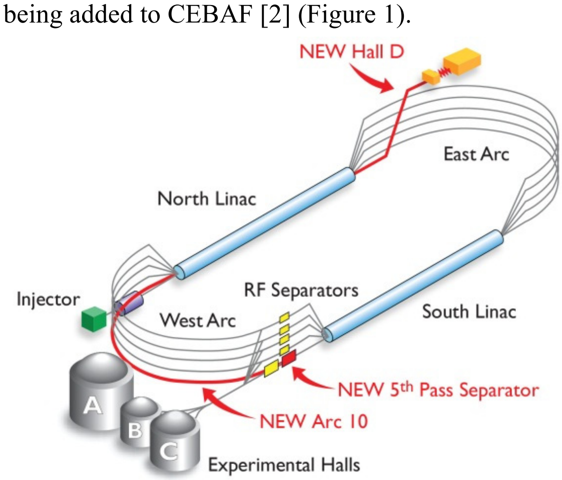

Figure 1: CEBAF12GeV upgrade with four Halls.

This new hall needs the highest energy beam of the accelerator which comes from the 5th pass extraction line. 500MHz RF separators can provide beam to at most three halls simultaneously. To add a fourth hall, a change to the extraction system and beam pattern is proposed [3]. The change for the extraction system requires the 500MHz separator cavities in the 5th pass to be replaced with 750MHz cavities. The separator cavities in the other passes will remain at 500MHz.

The change to the beam pattern requires each hall, including the new fourth hall, to have its own independent beam with each beam switchable to 250MHz structure from the present 500MHz repetition rate. The beam pattern is initiated at the injector. A new beam is created by adding a new laser to the photo-cathode gun and the beam structure is changed by changing the laser pulse structure.

The following sections discuss the two key topics for the new Four-Hall delivery plan: Design of 750MHz cavities for the new RF Separator and a simple upgrade to the electron gun laser system. The laser upgrade includes addition of a fourth laser plus the new beam patterns needed in four-hall delivery system. It also produces low repetition rate beams desired by some of our experiments.

RF SEPARATOR DESIGN

500MHz cavity design

The 500MHz CEBAF RF separator cavity design [4, 5] combines high transverse shunt impedance with smaller transverse dimensions. For example, with less than10kW of RF power, a combination of four cavities can deflect a 11 GeV beam by 150μrad, enough to provide the needed beam separation. The basic unit of the design consists of a cylindrical cavity with two rods attached to one end of the cavity (Figure 2).

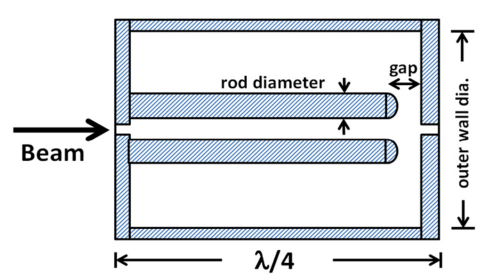

Figure 2: Basic unit of the deflecting structure.

There are gaps between the rods and the cavity wall on the other end. The cavity is a λ/4 resonator. The deflecting mode is the one in which the RF current runs in opposite directions on the rods and the rods have opposite voltages. The RF field between the rods is close to a TEM dipole mode and is concentrated near the axis. This

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concentration of field is the reason for the high transverse shunt impedance ($R_t=V_t^2/P$). The outer wall of the cylinder does not see much RF field and as a result, the outer diameter of the cavity can be as small and unrelated to the operating frequency.

The existing 500MHz separators cavities (Figure 3a) consist of the four basic units discussed above with two mirror imaged units in one half and two in the other. The two halves are coupled through two large off-axis holes in the center plate. Combining the units in this way makes a cavity one RF wavelength long that can be controlled and powered with a single input coupler.

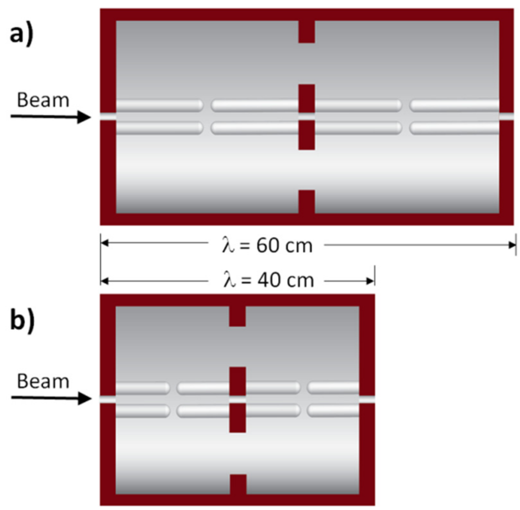

Figure 3: a) 500MHz cavity and b) 750MHz cavity. Both are one λ long and consist of eight rods.

750MHz cavity design

A goal of the design is to make the 750MHz RF structure similar to the 500MHz cavities that have worked successfully for the past two decades. Another goal is to keep mechanical parts of the new system the same to avoid redesign and retest of components. Since the basic unit of the design scales like a λ/4 resonator and the frequency is independent of the outer cylindrical wall diameter, the 750MHz cavity is roughly a shortened 500MHz cavity (Figure 3b). Therefore the outer diameter and flanges which hold the rods and tuners can be taken directly from the 500MHz design. What remained was the design of the rods themselves. The diameters of the rods were varied in a CST Microwave Studio model to optimize the shunt impedance and peak power density of the 8-rod cavity.

As determined previously, increasing the rod separation quickly reduces the shunt impedance [4]; therefore the beam 15 mm aperture diameter of the original design is retained. This aperture will not cause a beam interception problem with a deflecting angle of ±150μrad even with a reasonable aberration. Table 1 shows the cavity design parameters with different rod diameters. As can be seen from Table 1, the 2cm diameter rod's design provides the highest shunt impedance and low peak power loss density which is important for the water cooling.

Table 1: 750MHz Cavity Parameters vs. Rod Diameter

Rod diameter	**2cm**	**2.5cm**	**3cm**
Frequency (MHz, Calculated)	748.4	748.4	748.3
Cavity Length (cm)	40	40	40
R_t/Q (kΩ) Including time of flight	17.7	16.1	13.9
Q Calculated	7061	7497	7838
Q (expected)	6047	6420	6713
R_t (MΩ, expected)	107	104	93.1
Beam Energy (GeV)	11	11	11
Separation Angle (μrad)	300	300	300
Number of Cavities	4	4	4
Power/Cavity (kW)	1.59	1.64	1.83
Peak Power Loss Density (W/mm^2)	2.8e5	2.6e5	2.8e5

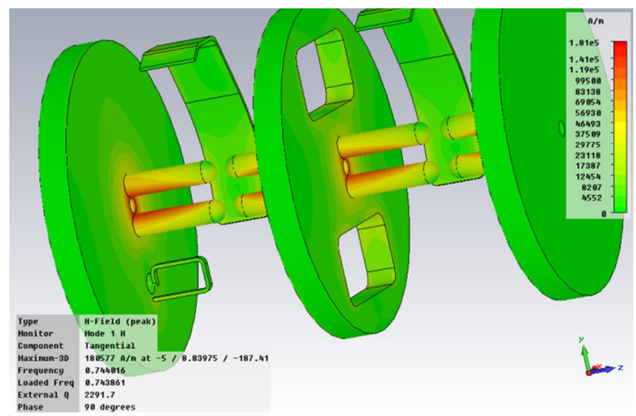

Figure 4: Surface magnetic field amplitude on 8-rod, 2cm rod diameter, 750MHz cavity simulated by CST MWS.

For RF coupling to the cavity, a copper strap-type loop design is used as shown in the lower half of Figure 4. This coupler has been previously tested up to 8kW without water cooling and should be work here. The loop dimensions are 45×25.4 mm^2. It provides Q_{ext} of 2292 and coupling β=2.64 when the loop and the rods are coplanar. By rotating loop out of the plane, a critical coupling can be achieved. The beam loading is not an issue for critical coupling because for a deflecting cavity the beam loading is zero when the beam is on the cavity axis.

LASER SYSTEM UPGRADE

The existing laser system for the CEBAF photo-cathode gun consists of three lasers, each producing ~ 40ps pulses at a 500MHz pulse repetition rate with independently controlled phase and amplitude [6]. The laser pulses strike the photo-cathode to produce three independent 500MHz pulse structure electron beams which also have independent phase and current control. When the three lasers are properly phased 120 degrees apart, every RF bucket of the 1500MHz machine

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fundamental frequency is filled. A schematic of one of the existing lasers is shown in Figure 5.

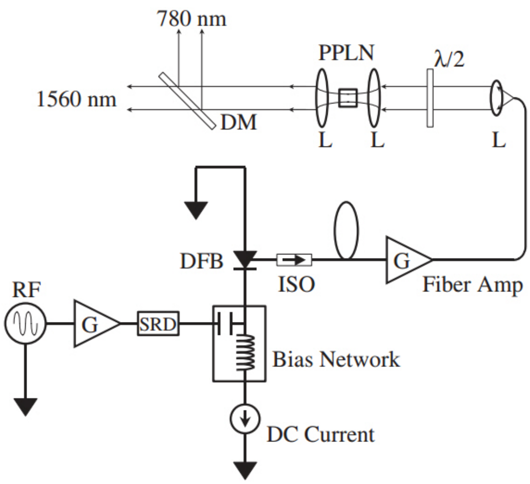

Figure 5: Schematic of the fiber-based laser system. DFB, distributed feedback Bragg reflector diode laser; ISO, fiber isolator; SRD, step recovery diode; L, lens; PPLN, periodically poled lithium niobate frequency doubling crystal; DM, dichroic mirror [6].

The 500MHz RF energy is applied to a 1560nm distributed feedback Bragg reflector diode (DFB) to gain-switch the laser at the fundamental frequency of the applied RF. The pulses produced are amplified by a 5W Erbium-Ytterbium fiber laser amplifier. The output of the 5W amplifier is launched into a periodically-poled lithium niobate frequency doubling crystal to up-convert the 1560nm light to the 780nm light needed to extract circularly polarized electrons from our photocathode.

An upgrade to the laser system is needed to produce beams which are independently switchable between 500MHz and 250MHz structure. Although 500MHz and 250MHz can be achieved by simply changing the fundamental frequency of the applied RF, this would cause undesirable changes to the laser pulse shape that would negatively impact electron beam optics. It is much more desirable to keep the 500MHz structure on the DFB laser and cut-away every other laser pulse. This can be achieved by adding a high extinction lithium niobate optical modulator to the existing system between the DFB laser output and the 5W laser amplifier input. The optical modulator is driven by a divide-by-N circuit that can choose several subharmonics of 500MHz. This system can switch between 500MHz laser pulses and 250MHz and its subharmonics, 125MHz, 62.5MHz, and 31.25MHz (Figure 6). With proper phasing, the pulses produced at any of these frequencies will cleanly pass into any desired RF bucket of our 1500 MHz fundamental machine frequency.

The upgraded laser system must also produce an independent beam for the new experimental hall while simultaneously delivering beam to any of the existing halls. This requires a fourth laser to be added specifically dedicated to Hall D. This new laser system is a copy of the laser systems used for the existing halls including the upgrade discussed above. Therefore, the Hall D laser can also run at any of the subharmonics, (250, 125, 62.5, 31.25MHz).

The plan is to test this new laser system with beam during the machine commissioning in 2014. The critical issue is to demonstrate that the "cut-away" pulses are truly turned off and do not produce electrons at the cathode.

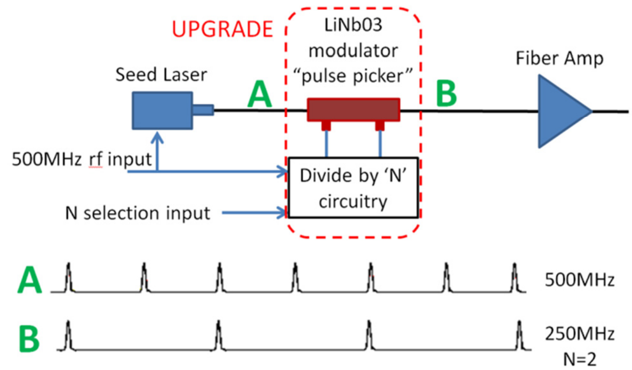

Figure 6: The proposed upgrade to the existing lasers system selecting 1 out of N pulses. At the bottom, an example of pulse structure for N=2 at points A and B.

CONCLUSION

Central to achieving simultaneous Four-Hall operations at CEBAF accelerator are the 750MHz RF separators and new laser system capable of providing a new beam pattern. The designs for these systems were presented. Since the changes to the extraction and injector are made so that the new Hall D beam integrates within the existing accelerator system, only a few other systems need alterations. Among the systems are: the personnel and machine safety systems, the beam accounting system, and the beam operations procedures. These systems will be modified to accommodate the presence of four beams in accelerator.

REFERENCES

[1] For simplicity the RF frequencies have been rounded to the nearest 10Hz value; CEBAF fundamental frequency is 1497MHz.

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