RTA GUN PERFORMANCE

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Abstract

The technical challenge for making two-beam accelerators into realizable power sources for high-energy colliders lie in the creation of the drive beam and in its propagation over long distances through multiple extraction sections. This year we have constructed a 1.2-kA, 1-MeV, electron induction injector for the RTA accelerator. The electron source will be a 8.9 cm diameter, thermionic, flat-surface cathode with a maximum shroud field stress of approximately 165 kV/cm. The injector's pulse length should be over 120-ns flat top (1% energy variation) with a normalized edge emittance of less than 300 π-mm-mr. Details of the design and performance of the injector, beam line, and diagnostics will be presented.

1 INTRODUCTION

Induction accelerators are a unique source for high-current, high-brightness, electron beams. A collaboration between the Lawrence Livermore National Laboratory (LLNL) and Lawrence Berkeley National Laboratory (LBNL) has been studying rf power sources based on the Relativistic Klystron Two-Beam Accelerator (RK-TBA) concept for several years [1, 2]. Demanding beam parameters are required of the electron source, an induction injector, to achieve the transport goals. A test facility, called the RTA, has been established at LBNL [3] to verify the analysis used in the design study. The primary effort of the facility is the construction of a prototype RK-TBA subunit that will permit the study of technical issues, system efficiencies, and costing. In this paper, we will discuss the development of the RTA electron source and it's pulsed power system, which has recently been constructed and is now undergoing testing. Figure 1 is a photograph of the gun undergoing initial tests. Beam tests will be performed this fall.

2 RTA GUN

A major part of our effort during the past year has been towards the design of a low emittance electron source for RTA accelerator. We expect to produce an electron source with a much lower emittance than typical induction guns. The electron source will be a 8.9-cm-diameter, thermionic, flat-surface M-type cathode with a maximum shroud field stress of approximately 165 kV/cm. An emission density of 20 A/cm^2 is required from the cathode to produce a 1.2 kA beam.

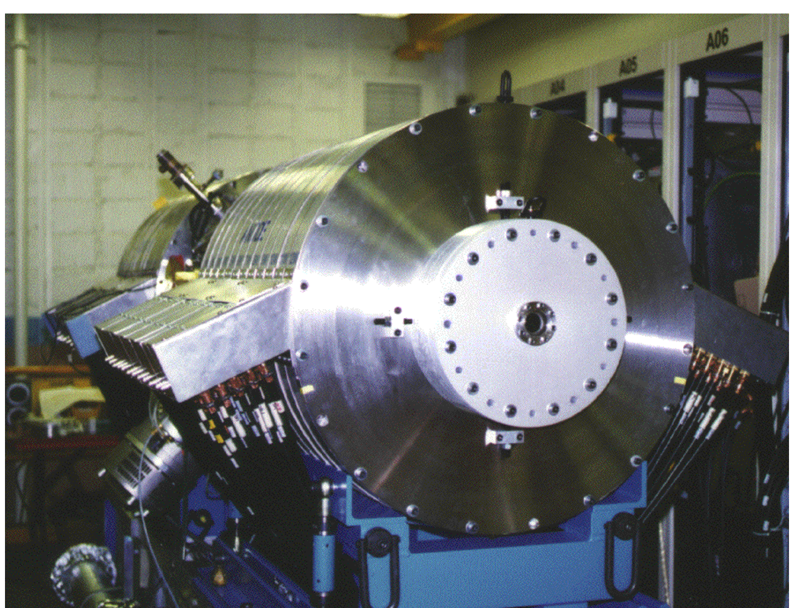

Figure 1. RTA Gun during pulsed power test.

The RTA gun has 72 induction cores, each driven at 14 kV. The voltage from the cores are summed across the A-K gap to produce 1 MV. The cells are segmented radially to reduce the individual aspect ($\Delta r/\Delta z$) ratio of the cores. The lower aspect ratio reduces the variation in core impedance during the voltage pulse simplifying the pulse forming network (PFN) design.

We have done high-voltage tests on the gun. In operation a 500 kV potential is developed across each of the two 30-cm-ID PYREX insulators producing a 5.1 kV/cm average gradient along the insulator. The maximum fields at the triple points, the intersection of insulator, vacuum, and metal, is less than 3.5 kV/cm. Maximum surface field in the cathode stalk of the gun is about 85 kV/cm. The maximum field is about 116 kV/cm on the anode stalk.

Initial beam focusing in the gun is accomplished by large-bore air-core solenoids installed on the central pumping spool. The first solenoid is operated to null the magnetic field from the other solenoids at the cathode front surface. With a flat cathode a high dB/dz is needed to prevent the beam from hitting the anode surfaces. The magnetic field at a distance of 20 cm from the cathode is about 650 gauss. There are seven smaller solenoids located within the anode stalk to provide additional focusing to transport the beam to the end of the gun.

2.1 Pulsed Power System for the RTA Gun

The pulsed power system for the gun consists of a 20-kV High-Voltage Power Supply, 6-kJ Energy Storage Bank, two Command Resonant Charging (CRC) Chassis, 24 Switched Pulse Forming Networks, and four Induction Core Reset Pulsers. Each PFN will drive a single 3-core induction cell of the gun.

Segmenting the core in the induction cell and driving the individual core segments avoids a high-voltage step-up transformer. This reduces the developmental effort needed to achieve a "good" flattop pulse (minimal energy variation) with fast risetime and improves the efficiency of the overall pulsed power system. Our system of low-voltage PFNs driving multiple core induction cells is similar to the system envisioned for the full scale RK-TBA design. For the gun core material we choose 20-μm-thick 2605SC METGLAS. In the RTA main extraction section we will use a lower loss 2714AS METGLAS for the induction cores.

Design of the switched PFNs follows easily from published METGLAS core loss data [4]. For the RTA induction cells, a flux swing of 2.6 T in 400 ns (FWHM) results in a magnetization rate of 6.5 T/μs. At this rate, a loss density of 1800 J/m^3 translates into 30 J lost in a cell with 16.7×10^3 cm^3 of 2605SC METGLAS. For a cell input voltage of 14 kV applied for 400 ns, these losses require that 5900 A be supplied to the three radial cores. An additional 3600 A is required to supply beam current (1200 A x 3 cores/cell), resulting is a total current of 9 kA. The required drive impedance for a cell is then 1.5 Ω, which is provided by the PFN module.

An area of concern was the variation of the energy loss for different METGLAS cores. Experience [5] with the 72 cores in the gun leads us to believe that for a large RK-TBA, matching cell cores should permit acceptable energy loss variation.

2.1 Gun Voltage Waveform

Achieving the fast risetime necessary to minimize the volt-seconds required for the injector cores presented a challenge. Budget constraints coupled with the large availability of EEV CX1538 thyratrons from the ATA program at LLNL made these tubes an attractive option. However, their poor time rate of current change (4 kA/μs rating) made them questionable for this application, which requires about 40 kA/μs. A variety of techniques were tried to decrease the risetime. In a 1.5 Ω system, stray circuit inductances must be maintained at or below 100 nH to achieve a 10-90% risetime of 150 ns. This was accomplished by placing the thyratron between two current sheets connecting the PFN output to the output cables. The ionization time of the thyratron was substantially reduced by applying a 1-2 A pre-pulse to the keep-alive grid 300-400 ns prior to the arrival of the main control-grid pulse. Faster risetimes were achieved with Triton F-130 ceramic thyratrons. An upgrade of the current thyratrons in the gun pulsed power system should allow us to achieve the design 100-ns risetime.

At the 1-MV, 1.2-kA operating conditions we hope to produce a ±1% gun voltage flat waveform for 120 ns. We will need to adjust the number of turns in appropriate sections of individual PFNs to achieve this goal. Insertion of ferrite material in the center of the inductors coils will allow additional small corrections to the waveform.

2.3 Diagnostics for the RTA Gun

A variety of diagnostics [6] will be used to determine the performance of the gun, both permanently installed monitors for general operations and temporary diagnostics specific to the injector commissioning and troubleshooting. Planned diagnostics include an isolated cathode with resistive divider for direct measurement of current emission, resistive-wall and magnetic probe current monitors for measuring beam current and centroid position, capacitive probes for measuring A-K gap voltage, an energy spectrometer, and a pepper-pot emittance diagnostic.

The majority of the diagnostics will be installed after the gun. The first 1.4 m of beam line after the gun will include two beam position and current monitors to allow the offset and angle of the beam at the exit of the injector to be measured. A pop-in probe will be incorporated in a pumping port to allow the beam profile to be viewed.

The current density profile will be measured using Cherenkov and/or optical transition radiation from intercepting foils. A primary concern with using foils is possible damage from beam energy deposition. Average heating of the foil can be controlled by adjusting the repetition rate of the injector. The difficulty is the single shot heating where material can be melted and ejected before the heat is conducted away. As an example, to avoid damage for a thin quartz foil, the beam diameter must be larger than 2 cm for a 1-kA, 300-ns, relativistic electron beam. The significant levels of energy deposited in the foil could affect the dielectric constant or generate a surface plasma that could be confused as a variation in beam parameters.

Three different methods may be used to determine the A-K voltage and beam energy. The first method involves measuring the applied voltage to the induction cores at the connection of the power feeds to the induction cells. Capacitive dV/dt pickup probes [6] are used for a more direct measurement of the A-K gap voltage and also to provide greater bandwidth with respect to the resistive dividers. We also hope to employ a conventional energy spectrometer comprised of an on-axis collimator, dipole magnet, scintillator, and viewing port to directly measure the beam energy.

2.4 Emittance measurement for the gun

We plan to use a pepperpot emittance diagnostic to help characterize the beam. Measuring the beam emittance is expected to be very difficult as the beam is highly space charged dominated. Our aperture plate will consist of a rectangular pattern of 121 (11x11) 250-μm apertures with 7 mm spacing on a 500-μm thick tungsten plate. The emittance term that is responsible for spot size growth of the beamlets after the aperture plate is approximately an order of magnitude larger than the space charge term.

Another serious problem concerns the effect of the conductive aperture plate on the beam. It has been demonstrated [7] that, while the local distribution in phase space can be determined, the global x–x' curve is dominated by the non-linear focusing of the aperture plate. EGUN simulations performed for our beam parameters indicate that the beam emittance determined from the pepperpot data will be as much as six times the actual emittance in the absence of the aperture plate. This effect can be accounted for in the analysis. However, the accuracy in the final emittance value will suffer.

3 ACCELERATOR SECTION DESIGN

Design of the full-scale RK-TBA system has an accelerator section after the gun that raises the beam energy from 1 MeV to 2.5 MeV before starting to bunch the beam at 11.4 GHz. In the full-scale RK-TBA system we expect to use a pulse power system similar to that demonstrated in the gun system for this section. The accelerator cells will be segmented to reduce the required drive. However, to reduce RTA's cost we are planning on using a 120-kV MARX spark-gap pulsed power system to drive 16 unsegmented accelerator cells in this section of RTA. The design is not acceptable for the full-scale machine because of the high gap erosion rates. The spark-gap system can provide a faster risetime than the thyratron system which will reduce the required cross sectional area of the induction cores. The volt-second rating of the accelerator cores (operated at 120 kV) will limit the flat top of the beam pulse in the RTA. Installation of additional cells (future upgrade), and operating all the cells at a lower voltage, will increase the useful duration of the current pulse. We also plan to test a High-Gradient Insulator [8] in the first of these accelerator cells. If successful we would like to construct the 16 cells for RTA accelerator section using High-Gradient Insulators.

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