RF POWER SOURCE DEVELOPMENT AT THE RTA TEST FACILITY*

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Abstract

The RTA Test Facility has been established at LBNL to demonstrate key concepts related to both physics and technical issues of a proposed two-beam accelerator 1.5-TeV c.m. upgrade of the NLC collider design (TBNLC). A prototype two-beam accelerator rf power source will be constructed at the RTA Test Facility which will allow testing of the major components of the TBNLC rf power source. The proposed test facility and its current status are described. Performance of the induction accelerator pulsed power system, including the induction cores, is a key issue affecting both cost and efficiency of the rf power source. Recent test results on the RTA pulsed power system are presented.

1 INTRODUCTION

For several years a Lawrence Berkeley National Laboratory (LBNL) and Lawrence Livermore National Laboratory (LLNL) collaboration has studied rf power sources based on the RK-TBA concept [1]. This effort has included both experiments [2] and theoretical studies [3]. Last year, a preliminary design study for a rf power source suitable for the NLC was published [4]. The design specifically addressed issues related to cost, efficiency, and technical issues. For a 1-TeV center of mass energy design, the rf power source is comprised of 50 subunits, each about 340 m in length with 150 extraction structures generating 360 MW per structure. Estimated conversion efficiency of wall plug energy to rf energy for this source could be >40%. Theory/simulations showed acceptable drive beam stability through the relativistic klystron, and no insurmountable technological issues were uncovered.

We have established a test facility at LBNL to verify the analysis used in the design study. The principle effort is constructing a TBNLC rf power source prototype, called the RTA [5]. All major components of the TBNLC rf power source will be tested. However, due to fiscal constraints, the RTA will have 8 rf extraction structures, with a possible upgrade to 12. See Fig 1. Table 1 is a comparison between the pertinent parameters for TBNLC and the RTA. The pulsed power system and induction cells in the extraction section will be similar for both machines, allowing a demonstration of efficiency and establishing a basis for costing. Other features shared between the two machines include transverse chopping for initial beam modulation, adiabatic compression to increase the rf current while accelerating the beam, PPM quadrupole focusing, and detuned rf extraction structures.

Issues to be addressed by the RTA are drive beam dynamics, efficiency, emittance preservation and rf power quality. Efficiency can be separated into the conversion efficiency of wall plug power into beam power and beam power into rf power. The conversion of wall plug power into beam power can be fully measured in the RTA. High conversion efficiency of beam to rf power is only realized in a system with many extraction structures. For TBNLC, the number of extraction structures is limited by beam stability and transport issues. The direct study of beam dynamics involving transport over tens of extraction structures will not be possible with the RTA. The reduced beam energy in the RTA extraction section does allow the observation of almost an entire synchrotron period. This should be sufficient for the beam to approach a steady state condition that can be extrapolated to a full scale system. Verification of simulations used to model beam dynamics in RK-TBA’s is a high priority. Beam dynamics issues such as focusing magnet misalignments, transverse modulation, and adiabatic compression can be studied.

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TABLE 1. Comparison between RTA and the TBNLC.

Parameter	RTA	TBNLC
Pulse Duration	200 ns	300 ns
Rise Time	100 ns	100 ns
Current		
Pre-Modulation	1.2 kA	1.2 kA
Extraction Section	600 A dc 1.1 kA rf	600 A dc 1.1 kA rf
Beam Energy		
Injector	1 MeV	1 MeV
Modulator	2.8 MeV	2.5 MeV
Extraction	4.0 MeV	10.0 MeV
Bunch Compression	240° - 110°	240° - 70°
Extraction Section PPM Quadrupoles		
Betatron Period	1 m	2 m
Lattice Period	20 cm	33.3 cm
Phase Advance	72°	60°
Occupancy	0.5	0.48
Pole Tip Field	870 G	812 G
Beam Diameter	8 mm	4 mm
RF Power		
Frequency	11.4 GHz	11.4 GHz
Power/Structure	180 MW	360 MW
Structures	Standing & Traveling-Wave	3 cell Traveling-Wave
Output Spacing	1 m	2 m

2 PULSED POWER SYSTEM

Conversion of wall plug power into induction drive beam power is a significant factor in the rf power source efficiency. The efficiency of a TBA induction accelerator depends on several factors. Beam transport dynamics will determine the size of the beam pipe. The rf power requirement determines the pulse duration, beam current,

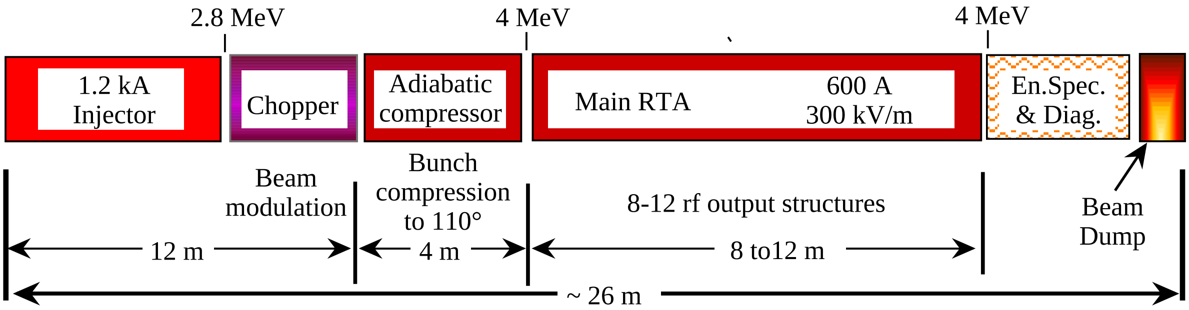

FIGURE 1. Schematic of the proposed RTA showing major components.

accelerating gradient, and repetition rate. Once these factors are established, the outer radius and material of the core can be calculated from: $\Delta V\ \Delta t = \Delta B\ A\ F_p$, where ΔV is cell voltage swing, Δt is pulse duration, ΔB is core flux swing, A is core cross section, and F_p is core material packing factor. The core volume increases nearly as the radius squared, so smaller, more efficient and lower cost induction cells can normally be obtained by using higher ΔB materials and minimizing the inner radius.

Several core materials have been tested at the RTA Test Facility [6]. Two METGLAS® alloys, 2605SC and 2714AS, have been selected for use in the RTA. The alloy 2605SC has a ΔB of ~ 2.5 T with a core loss of ~ 2 kJ/m^3 for a 400 ns pulse and 20 µm thick ribbon. The alloy 2714AS has a lower ΔB, ~ 1.1 T, but a much lower core loss of ~ 150 J/m^3 with 18 µm ribbon. It is important that core tests are performed with the expected pulse shape and duration for accurate loss measurements. For our TBNLC geometry, the low core loss 2714AS can achieve a conversion efficiency of wall plug power to drive beam power of 59%, a substantial improvement over 2605SC.

The modest repetition rate (120 Hz) and current rise time (100 ns) envisioned for the NLC permit the use of a simple, and cost effective thyratron driven modulator. The total induction cell core is segmented longitudinally into smaller cores each individually driven at 20 kV or less. Driving at this voltage level avoids a separate step-up transformer. Length of the induction cell, thus number of cores per cell, is set by geometrical constraints due to extraction structures, magnet positions, etc. The TBNLC design in Fig 3 has 5 cores per cell while the RTA has 3.

Beam energy flatness is an important issue affecting beam transport and rf phase variation. The current drive to the cores is nonlinear for a constant amplitude voltage pulse since the core saturates outward from the inner radius. This effect is shown in Fig 4 where the voltage pulse has ~ 200 ns of flat top during which the current increases non-linearly. The generated voltage amplitude can be kept constant, within bounds, during the initial stages of core saturation by tapering the impedance of the PFN stages. Our PFN will consist of many coupled L-C stages. Lower aspect ratio ($\Delta r/\Delta z$) cores saturate more uniformly, thus requiring less impedance tapering.

3 INJECTOR

The injector consists of two sections, a 1-MV, 1.2 kA induction electron source, referred to as the gun, followed by several induction accelerator cells to boost the energy to 2.8 MeV. Two goals of the design are minimizing

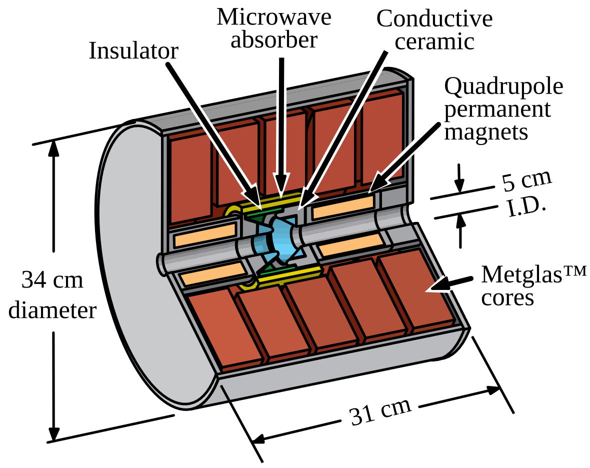

FIGURE 3. A proposed RK-TBA induction cell design illustrating longitudinal core segmentation.

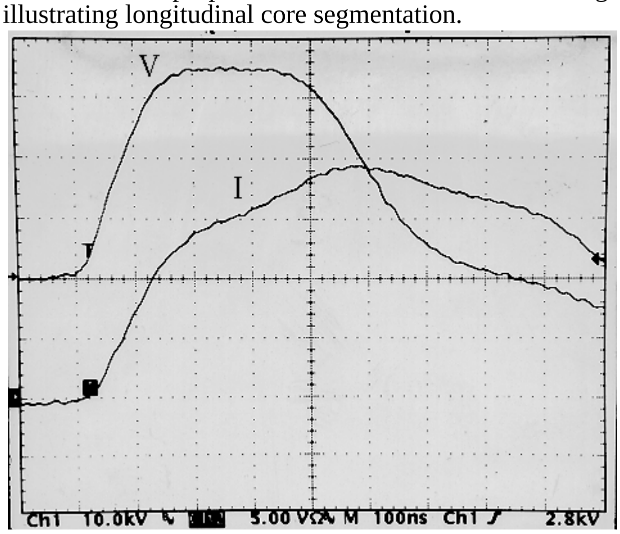

FIGURE 4. Oscilloscope traces of pulsed power system test on a mockup induction cell for the RTA gun. Time scale: 100 ns/div. V is cell voltage (1 kV/div), I is PFN current (50 A/div).

electrical field stresses in the gun and realizing the lowest possible emittance growth. Gun induction cores are segmented radially to reduce the individual aspect ratios with each driven separately at about 14 kV. Components of the induction cells for the gun are in fabrication.

A novel feature of the gun design is the insulator, a single, 30 cm ID, PYREX® tube with no intermediate electrodes. Average gradient along the insulator at the operating voltage of 500 kV is ~ 5.1 kV/cm. Maximum fields at the triple points, intersection of insulator, vacuum, and metal, are less than 3.5 kV/cm. Maximum surface fields in the cathode half of the gun are about 85 kV/cm. The rational for using PYREX® is to explore cost reduction methods for induction injectors. PYREX® is less expensive than ceramic, and additional savings are realized by avoiding intermediate electrodes. Our design allows for the addition of intermediate electrodes and/or substitution of a ceramic insulator to minimize the increased risk associated with this approach.

The focusing solenoidal field profile must be optimized for the injector to control beam radius while minimizing emittance growth. A new electrode package and larger dispenser cathode will likely be required for the desired low-emittance 1.2-kA, 1-MeV electron beam. The design goal is for beam radius < 5 mm and horizontal normalized edge emittance < 250 π-mm-mr at the end of the injector. Alignment of the solenoids is critical to avoid corkscrew motion and emittance growth. Incorporating homogenizer rings [7] with the solenoids could reduce the need for correction coils and simplify alignment.

Experience operating other induction accelerators has shown that careful alignment of the solenoids may not be sufficient to reduce the amplitude of the corkscrew motion [8] to the 0.5 mm desired for the RTA injector. We plan to use a time independent steering algorithm [9] developed at LLNL to control steering coils on the solenoids. The algorithm corrects for the Fourier component at the cyclotron wavelength of the field error.

4 BEAM DYNAMICS ISSUES

Beam dynamics issues related to longitudinal and transverse stability, modulation, and transport have been presented in detail elsewhere [3, 4, 10, 11]. A brief description of these issues is given here. Initial beam modulation is accomplished with a transverse chopping technique. After this modulator section, an adiabatic compressor, a system of idler cavities and induction accelerator modules, is used to bunch the beam and further accelerate it to an average energy of 4 MeV. The lower frequency component of the transverse beam breakup instability is controlled by Landau damping. Control of the higher frequency component, excited in the rf cavities, is accomplished with the focusing system in a technique that we refer to as the “Betatron Node” scheme. The rf extraction structures are appropriately detuned to compensate for space charge and energy spread effects so that the longitudinal current distribution is stable.

5 RF POWER EXTRACTION

After the adiabatic compressor, the beam enters the extraction section. where beam energy is periodically converted into rf energy (via extraction cavities) and restored to its initial value (via induction modules). Both traveling wave (TW) and standing wave (SW) structures are being considered for the extraction section of the RTA. The TBNLC design uses TW structures to reduce the surface fields associated with generating 360 MW per structure. RTA is designed to generate 180 MW per structure. Thus, inductively detuned SW cavities are a practical alternative. An interesting design variation is based on Shintake’s choke mode cavity [12].

6 SUMMARY

Construction has started on the RTA, a prototype rf power source based on the RK-TBA concept. Testing of material for the induction cores is completed and two METGLAS® alloys selected. The pulsed power system for the gun is based on driving individual cores at ~ 14 kV using glass thyratron tubes switched at 28 kV. The pulsed power system design for later portions of the RTA will continue to develop during testing of the gun. A novel feature of the gun is the use of PYREX® tubes as 500 kV insulators. Satisfactory performance of these insulators would demonstrate an inexpensive alternative to the more standard graded, ceramic insulator.

The RTA will be used to study physics, engineering, and costing issues involved in the application of the RK-TBA concept to linear colliders. All major components of a rf power source suitable for the NLC can be studied, e.g. the pulsed power system, current modulating system, ppm quadrupole focusing, and detuned rf extraction cavities. Some of the more important issues that will be address are efficiency, longitudinal beam dynamics, beam stability, emittance preservation, and rf power quality.

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