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DESIGN OF A RELATIVISTIC KLYSTRON TWO-BEAM ACCELERATOR PROTOTYPE

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Design of a Relativistic Klystron Two-Beam Accelerator Prototype*

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We are designing an experiment to study physics, engineering, and costing issues of an extended Relativistic Klystron Two-Beam Accelerator (RK-TBA). The experiment is a prototype for an RK-TBA based microwave power source suitable for driving a 1 TeV linear collider. Major components of the experiment include a 2.5-MV, 1.5-kA electron source, a 11.4-GHz modulator, a bunch compressor, and a 8-m extraction section. The extraction section will be comprised of 4 traveling-wave output structures, each generating about 360 MW of rf power. Induction cells will be used in the extraction section to maintain the average beam energy at 5 MeV. Status of the design is presented.

I. BACKGROUND

Relativistic klystron two-beam accelerator [1] research has reached a point where we are ready to construct and test components that have been specifically designed for linear collider applications. Our planned program will take advantage of recent technical advances in three related areas: the experimental program in relativistic klystrons at LLNL [2], a preliminary design report (PDR) by a joint LBL-LLNL team on the RK-TBA concept as a power source candidate for a large linear collider, and the development of related technologies in heavy ion fusion (HIF).

First, the experimental program at LLNL has provided a firm physics base for the key RK-TBA feasibility issues of rf extraction, reacceleration of a modulated beam, and suppression of transverse instabilities. Power conversion from electron beams to rf at 11.4 GHz has been demonstrated at the hundreds of megawatts level, and the phase and amplitude shown to be stable over a substantial portion of the beam pulse. The relationship between rf stability and energy flatness of the drive beam is well understood. Reacceleration experiments at ATA have successfully demonstrated the transport of a bunched beam through three rf extraction structures and two intervening induction cells. The critical issue of transverse instability was addressed experimentally, higher order mode damping techniques were demonstrated, and detailed comparisons with simulations were made. Overall, these experiments demonstrate the feasibility of the TBA concept, and add confidence to the predictive power of the computer codes.

Secondly, the RK-TBA PDR [3] investigated an rf power source for the NLC linear collider. This design would provide the rf power requirements for a 1-TeV collider using the NLC accelerating structures. A bottom-up cost estimate shows that providing the rf power for the 1-TeV NLC with technology based on this design could be cost competitive with conventional klystrons using pulse compression. Our estimate of the conversion efficiency of wall plug energy to rf energy is 40%. Theory and simulations show acceptable drive beam stability over the relativistic klystron, and no insurmountable technological issues were uncovered.

Thirdly, the new RK-TBA design borrows heavily from ongoing HIF technology development [4]. Recent advances in that field have direct impact on the technical feasibility of our design. Metglas™ cores, permanent magnet quadrupoles, and low-voltage pulsed power systems are important features of the induction accelerators used in both areas:

II. Proposed Layout of the Experiment

The rf power source described in the PDR consists of 50 units, each about 340 m in length. The cost of building even one unit for developmental studies is prohibitive. Instead, we propose to build a smaller (29 m) prototype unit to validate the required physics and engineering technologies. To be compatible with the rf parameters for the NLC, we need to produce 11.4-GHz rf power that has a 200-ns flat top with good phase and amplitude stability. A schematic of the beamline for the prototype is shown in Fig. 1. The experiment will be housed in the existing shielded vault area of Building 58 at LBL.

a. Injector/Accelerator

The SNOWTRON injector, used in early relativistic klystron experiments [5], will be modified for use as the electron source. The SNOWTRON was a linear induction injector comprised of twelve 150-kV induction cells. It has a triode electrode configuration with a stalk mounted 12.5-cm diameter dispenser cathode. Modifications will include replacing the ferrite induction cores with Metglas™ cores to increase the pulse length, and a new electrode package to minimize emittance. The injector will be operated at about

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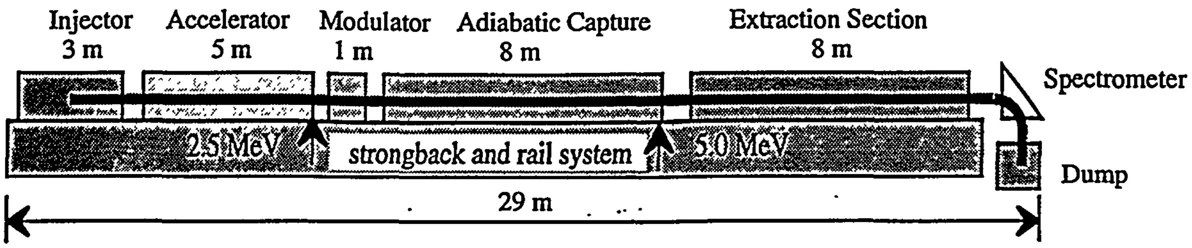

Figure 1. Schematic of the beamline for the RK-TBA Prototype experiment.

1 MV. Approximately 15 Experimental Test Accelerator (ETA) [6] induction cells will be used to accelerate the beam to 2.5 MeV prior to the modulator. The ETA cells will also have their ferrite cores replaced with Metglas™ cores.

The primary design issue remaining to be resolved is the generation of the desired current profile with suitable energy flatness. The goal is to linearly increase the current from 0 to 1.5 kA over the first 100 ns and then maintain a constant 1.5 kA for another 100 ns. The energy profile of the beam exiting the injector can be corrected to a certain extent in the accelerator. However, the energy variation over the entire pulse must be less than 1% as the beam enters the modulator. Other solutions being studied include gated cathodes, ferroelectric cathodes, and photocathodes.

b. Modulator

The Choppertron modulator [7] will be refurbished close to its original design. A schematic of the modulator is shown in Fig. 2. The modulator operates by deflecting the beam in the horizontal plane with a 5.712 GHz TM_{110} cavity. This causes the B_z immersed beam to describe semi-helical trajectories along the $\lambda_\beta/4$ drift, and to scan in the vertical plane across an on-axis aperture of a water-cooled collimator. Emittance growth can be minimized by matching the B_z field to the energy, diameter, and emittance of the beam. The maximum transverse deflection of the beam at the aperture determines the harmonic content of the modulated beam. To lessen the impact of modulation on overall system efficiency, the 11.4 GHz component will not be optimized. The bunch length will extend over about 240° of longitudinal phase space at the exit of the modulator.

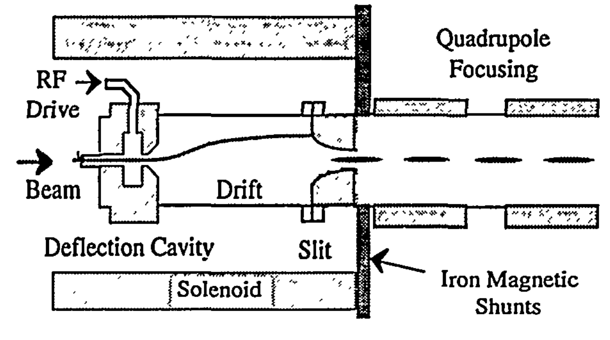

Figure 2. Schematic of the modulator.

c. Adiabatic Capture Section

The Adiabatic Capture Section will be comprised of four 2-m units similar to those in the Extraction Section. The modulated beam will be compressed in longitudinal phase space (240° ⇒ 107°) and accelerated to 5 MeV. Figure 3 shows simulation results of how the phase space and energy of the beam is changed in this section. Each unit will have six induction cells and one "idler" cavity. The "idler" cavity design is based on the traveling-wave output structure studied in the PDR, but without the extraction ports.

The compact, efficient induction cells described in the PDR are used in both the Adiabatic Capture and Extraction Sections. A drawing of one of these cells is shown in Fig. 4. Features of the cell that contribute to its high efficiency are the small inner diameter of the Metglas™ cores and periodic permanent quadrupole magnets. Each of the five cores in a cell will be pulsed at 20 kV producing 100 kV across the gap. This arrangement permits the use of a low-voltage, thyratron-switched, pulsed power system with no high-voltage step-up transformers.

d. Extraction Section

The Extraction Section will consist of four of the 2-m units shown in Fig. 6. About 360 MW will be extracted in each unit using a traveling-wave structure like that shown in Fig. 5. The output structures used for the prototype will vary somewhat from the PDR structures to compensate for differences in rf current between the two designs. Features of the output structures include two coupling ports, relatively large aperture, and a short rf cutoff section. The energy extracted from the beam is restored by the six induction cells in the unit.

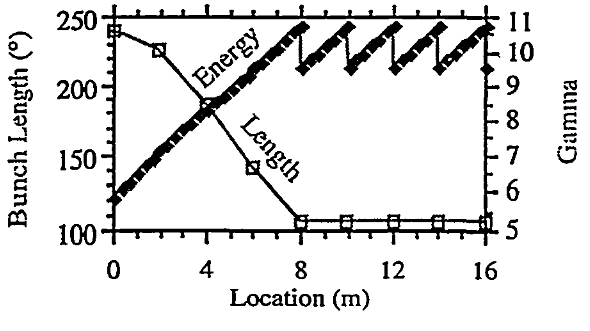

Figure 3. Simulation of Adiabatic Capture and Extraction.

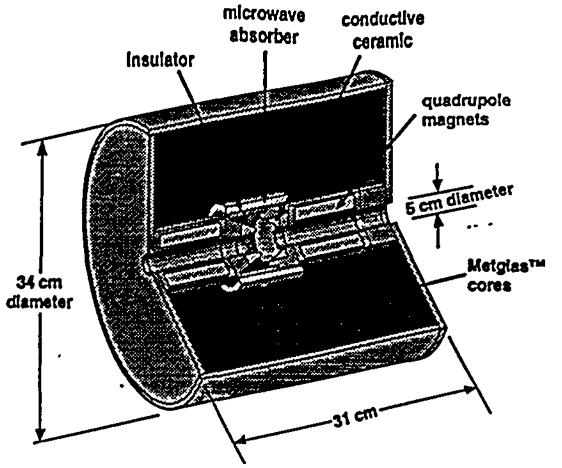

Figure 4. Drawing of the compact induction cell.

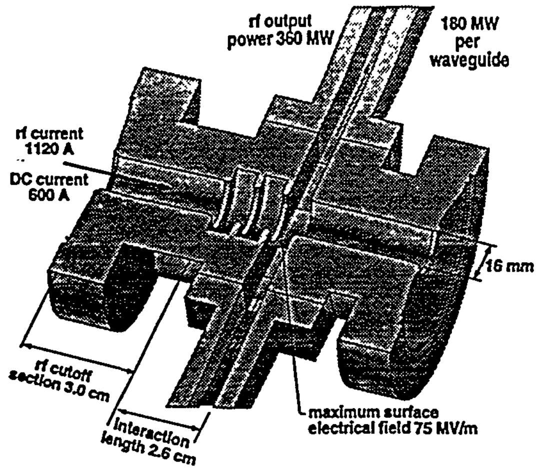

Figure 5. Drawing of traveling-wave output structure.

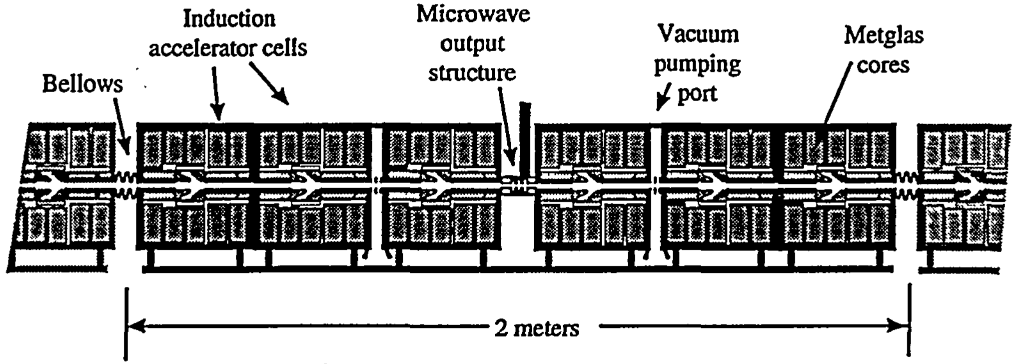

Figure 6. A 2–meter unit of the Extraction Section.

III. PROGRAM OBJECTIVES

The overall objective of the prototype is to validate the PDR findings related to cost, efficiency, and feasibility, and provide a technological base for a practical power source for large linear colliders. Specific objectives are:

1. Validate cost and efficiency projections. Our design is very modular in terms of the machine architecture and the associated pulsed power. The prototype uses several 2-m modules described in the PDR for a full-scale RK-TBA. Our experiments will allow us to verify the pulsed power system efficiency. As the prototype involves substantial R&D, we do not expect construction costs to be representative of a RK-TBA employing mass production techniques. But, we do expect to gain the engineering experience required for accurate cost projections of a full scale system.

2. Demonstrate technological feasibility. Technology of individual components is well known, and the PDR found no pathology, but an actual integrated system needs to be demonstrated. The prototype will constitute the first of these new, long, compact induction accelerators.

3. Progress towards demonstrating beam stability. Key beam dynamic processes will not be fully exhibited in the relatively short prototype. Nevertheless, impedances of the rf and induction cells, and beam response characteristics can be determined. The fundamental concepts of the "Betatron Node Scheme" [8] for suppressing transverse instabilities and inductively detuned traveling-wave structures for longitudinal stability can be measured. We expect to gain a sufficient experimental base for code validation.

4. Production of high quality rf power at 11.4 GHz. The rf extraction structures described in the PDR are required to generate a peak power of 360 MW with good phase and amplitude stability over 200 ns. The objective of our experiment is to produce this level of quality power from each of the four rf extraction structures in the prototype. The pulse length for the prototype will be set by the performance of the modified SNOWTRON injector, but is expected to be approximately 200 ns.

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