DEVELOPMENT OF A 20-MEV DIELECTRIC-LOADED ACCELERATOR TEST FACILITY*

S. H. Gold, Plasma Physics Division, NRL, Washington, DC 20375, U.S.A.
A. K. Kinkead, LET Corporation, Washington, DC 20007, U.S.A.
W. Gai, C. Jing, R. Konecny, J. G. Power, ANL, Argonne, IL 60439, U.S.A.
C. D. Nantista, S. G. Tantawi, SLAC, Menlo Park, CA 94025, U.S.A.
H. Chen, Y. Hu, Y. Lin, C. Tang, Tsinghua University, Beijing 100084, P.R.C.

Abstract

This paper presents a progress report on a joint project by the Naval Research Laboratory (NRL) and Argonne National Laboratory (ANL), in collaboration with the Stanford Linear Accelerator Center (SLAC), to develop a dielectric-loaded accelerator (DLA) test facility powered by a high-power 11.424-GHz magnicon amplifier. The magnicon can presently produce 25 MW of output power in a 200-ns pulse at 10 Hz, and efforts are in progress to increase this to 50 MW. The facility will include a 5-MeV electron injector that was developed by the Accelerator Laboratory of Tsinghua University, Beijing, China. The DLA test structures are being developed by ANL, and some have undergone testing at NRL at gradients up to ~8 MV/m. SLAC is developing a means to combine the two magnicon output arms, and to drive an injector and accelerator with separate control of the power ratio and relative phase. The installation and testing of the first dielectric-loaded test accelerator, including injector, DLA structure, and spectrometer, should take place within the next year. The initial goal is to produce a compact 20-MeV dielectric-loaded test accelerator.

INTRODUCTION

In recent years, there has been a new effort to find high-gradient alternatives to the metal disk-loaded structures that are used in conventional rf linear accelerators to create synchronism between the particle velocity and the phase velocity of the wave [1]. One promising concept is the dielectric-loaded accelerating (DLA) structure, in which a smooth dielectric-lined metal tube replaces the periodic metal structure [2]. A DLA structure can be used as a slow-wave electron accelerator by choosing an appropriate liner material, such as a low-loss ceramic with high dielectric constant, and an appropriate geometry, with the inner and outer radii of the dielectric chosen to match the phase velocity of the TM_{01} accelerating mode to c. Compared to conventional iris-loaded copper slow-wave structures, the DLA geometry is simpler, potentially easier to fabricate, can have comparable shunt impedance, and permits simple suppression of higher-order modes [3]. In addition, DLA structures have no field enhancements at the dielectric surface, unlike conventional disk-loaded structures, which have a typical factor-of-two field enhancement on the metal irises. Argonne National Laboratory (ANL) and the Naval Research Laboratory (NRL) are carrying out a joint program, in collaboration with the Stanford Linear Accelerator Center (SLAC), to develop and test DLA structures for possible use in future high-gradient linear accelerators. ANL develops test DLA structures and carries out low-power cold tests. The structures are then tested at the NRL Magnicon Facility to determine their performance at high accelerating gradients. The focus of this paper is on the overall program, whose goal is to develop a compact high-gradient 20-MeV dielectric-loaded accelerator test facility. A separate paper in these Proceedings presents results from high-power tests of alumina and magnesium calcium titanate DLA structures [4].

DESCRIPTION OF THE NRL MAGNICON FACILITY

The heart of the NRL Magnicon Facility (see Fig. 1) is a high-power microwave amplifier tube that was jointly developed by NRL and Omega-P, Inc. as an alternative to klystrons to power X-band accelerator structures [5]. The magnicon operates over the approximate frequency range of 11.420–11.440 GHz, and can presently produce 25 MW of output power in 200-ns FWHM pulses at a repetition rate of 10 Hz, and 10 MW in 1.1-μs flat-top pulses. Efforts are in progress to increase the output power to at least 50 MW by replacing the electron beam collector, which appears to be the source of an oscillation that causes multipactor and pulse shortening in the magnicon output cavity [5]. The magnicon is a frequency-doubling amplifier that operates with a frequency-stable drive sig-

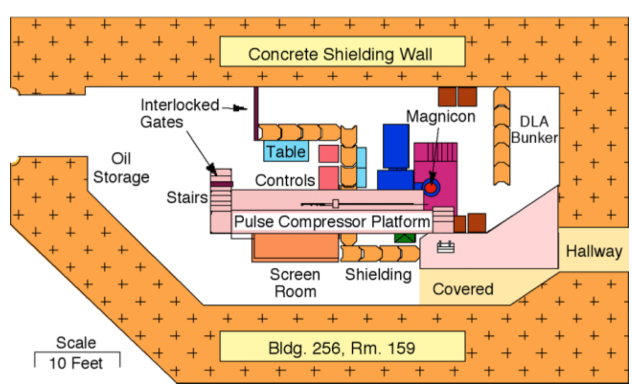

Figure 1. Floor plan of NRL magnicon facility.

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nal at 5.712 GHz from a solid-state sweep oscillator that is monitored with a frequency counter and pulse amplified by a TWT for injection into the magnicon drive cavity. Its output is stable, even in the presence of resonant loads. The magnicon output is extracted through two SLAC-style WR-90 waveguide lines, each with a high power TE_{01} output window, and SLAC-style directional couplers and loads are employed. Experiments making use of the magnicon output are connected to one of the two output waveguides, with the second terminated in a vacuum load. A power combiner is under development at SLAC that will permit the power from the two arms to be combined to drive a single load, or split in any desired ratio, with separate phase control, to drive separate loads, such as an electron injector and an accelerating structure. Two test stands are located adjacent to the magnicon output. The first, a 5'x25' raised platform for pulse compressor experiments, is 8' high, and passes over the concrete shielding wall. The second, a 10'-high concrete deck area, is currently used for testing DLA structures. A concrete bunker behind the shielding wall will provide additional radiation shielding for future accelerator experiments with an injected beam.

THE DIELECTRIC-LOADED TEST ACCELERATOR

Figure 2 shows a schematic diagram of the planned dielectric-loaded test accelerator. A 5-MeV injector will inject ~1 pC electron bunches into a long dielectric structure (e.g., 50 cm). The injector and structure will be fed by separate output waveguides from a power combiner/ phase shifter assembly fed by the two output arms of the magnicon, which will allow the injector to operate at constant power while the power and relative phase of the accelerator section is varied. The energy gain of the electron bunches will be diagnosed by a magnetic spectrometer of conventional design. The test accelerator will be located in a concrete bunker behind the shielding wall in the magnicon facility. In the remainder of the paper, we describe the various separate efforts that are under way in support of this overall goal.

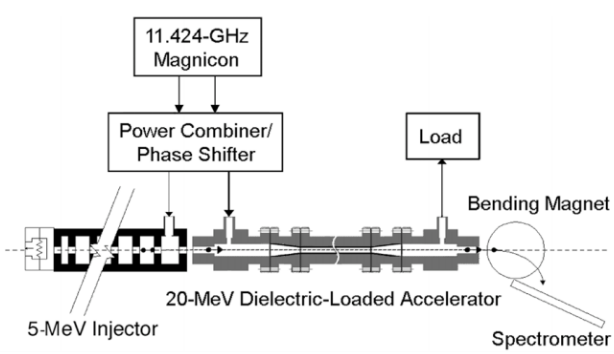

Figure 2. Schematic diagram of a dielectric-loaded test accelerator.

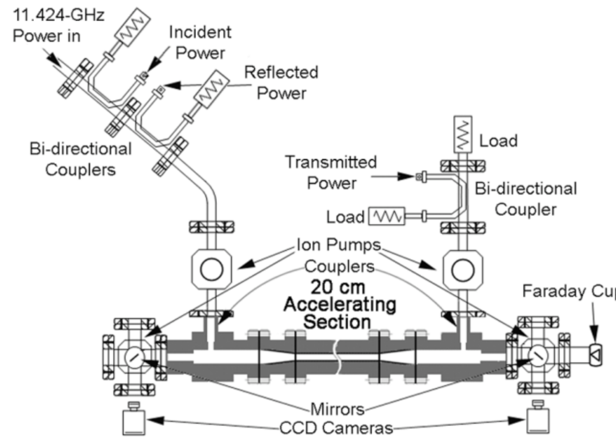

Figure 3. Experimental setup for DLA structure tests.

EXPERIMENTS ON DLA STRUCTURES

The first goal is to develop high-gradient DLA structures suitable for a test accelerator. Fig. 3 shows the experimental setup for DLA structure tests. The coupler design is described in Ref. [6]. A set of tests have been carried out on a number of traveling-wave DLA structures employing either low-loss alumina (Al_2O_3), often with a low-secondary-electron-emission TiN coating on the interior, or magnesium calcium titanate ($Mg_xCa_{1-x}TiO_3$) ceramics. Measurements have been made at incident powers ranging from 10 kW to ~10 MW, and at accelerating gradients up to ~8 MV/m. Two key problems have been identified in these experiments: 1) Strong multipactor loading of the dielectric structures [7], and 2) rf breakdown at the joints between uniform and tapered ceramic sections. Both of these problems are under investigation. Thus far, there has been no sign of rf breakdown in the uniform sections of the accelerating structures. This work is described in more detail in an accompanying paper [4].

DEVELOPMENT OF A 5-MEV ELECTRON INJECTOR

While accelerating gradients can be inferred from the drive power injected into the DLA structures, the real test of these structures is to measure the energy gain of accelerated electrons using an electron spectrometer. This requires an rf-driven electron injector that will produce bunched relativistic electrons for acceleration by the DLA test structures. The Accelerator Laboratory of Tsinghua University, Beijing, China, has developed a 5-MeV elec-

Parameters	
Energy	5.2 MeV
Charge/Bunch	>5 pC
RF Frequency	11.437 GHz
RF Power in	~2 MW
Norm.Emittance	3.1 π mm mrad
Energy Spread	~6%

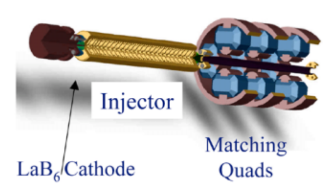

Figure 4. 5-MeV electron injector for DLA experiments.

tron injector that is designed to be driven by approximately 2 MW of rf power from the magnicon. The injector uses a LaB_6 cathode, and a 24-cell disk and washer accelerating structure. Fig. 4 shows a schematic diagram of the injector, and a table of its design parameters. The table of parameters is based on a cold test and bead pull of the completed injector, and PARMELA simulations based on the measured fields. The injector should be delivered to NRL early in 2005, where it will be installed in a bunker in the NRL Magnicon Facility.

DEVELOPMENT OF AN X-BAND POWER COMBINER

One essential element for this program is a means to use the combined power from the two magnicon output waveguides to drive an electron beam injector and an accelerating structure. The two output waveguides of the magnicon have approximately equal power and a fixed phase relationship. The injector will require a fixed input power of ~2 MW, while optimization of the accelerator operation will require varying the input power as well as the relative phase of the accelerator rf. As an important element of the collaboration, SLAC is developing a device that will combine the two magnicon outputs in a 3-dB hybrid coupler. An inline phase shifter will be used to vary the phase of one of the two inputs, in order to vary the power split in the two output arms of the hybrid, and a second inline phase shifter will be used to vary the relative phase of the two outputs.

Figure 5 shows a block diagram of this device and its components. A single SLAC magic-H type hybrid [8] will carry out the power combination and splitting. A new TE_{01}-mode mechanical phase shifter, flanked by new TE_{10}-TE_{01} rectangular-to-circular mode converters incorporating a taper similar to that of Ref. [9], will vary the phase of one of the two magnicon lines feeding the hybrid to vary the ratio of power in the two output arms of the hybrid.

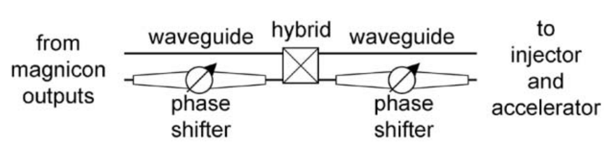

Figure 5. Design of the SLAC power combiner assembly.

The first phase shifter will provide 90° of phase adjustment, which will be sufficient to change between a state where one arm has essentially all of the power, and a state of equal power split. However, it will be necessary to begin at the correct relative phase, so that 90° of phase adjustment is sufficient. This may require a one-time adjustment of the relative phase of the two magnicon output arms, such as by adding a short waveguide section or a mechanically deformable waveguide. A second phase shifter with 90° of adjustment will be used for tuning the accelerator to optimize the relative phase of the injector and accelerating structure. This phase adjustment may be supplemented by varying the physical spacing between the injector and accelerating section.

SUMMARY

The goal of this project is develop a test bed to study structure-based advanced accelerator concepts in X-band, and in particular, to study dielectric-loaded accelerating structures, as illustrated in Fig. 3. The heart of the facility is an 11.424-GHz magnicon amplifier that can produce 25 MW of output power, split evenly over two waveguide feeds, in 200-ns FWHM pulses. To date, only a single output arm has been used in the structure tests. Efforts are in progress to increase the available power to at least 50 MW by eliminating a collector multipactor problem that is causing pulse-shortening of the magnicon output pulse. In order to move from high-gradient tests of accelerating structures to actual tests of electron acceleration, an electron injector is required. Such an injector was built by the Tsinghua University in Beijing, China, in an agreement with ANL, and should be delivered to NRL in 2005. It is designed to produce ~1 pC bunches of 5-MeV electrons for injection into the accelerating structure. The accelerator configuration will require separate power and phase controls for the injector and the accelerating structure. To permit this, a power combiner/phase shifter is being developed for the project by SLAC. All of these related efforts are intended to lead to a working dielectric-loaded test accelerator within approximately one year.

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