Commissioning Status of the Continuous Wave Deuterium Demonstrator*

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Abstract

Grumman Aerospace Corporation, Argonne National Laboratory, and Culham Laboratory are commissioning the Continuous Wave Deuterium Demonstrator (CWDD) in a facility at Argonne National Laboratory. CWDD is a high-brightness, high-current, 7.5-MeV negative deuterium accelerator. The 352-MHz rf accelerating cavities are cryogenically cooled with supercritical neon to reduce the rf power requirements. Installation of the accelerator into the Argonne facility began in May 1991, and first beam from the injector was extracted in February 1992. The accelerator and facility are described, and current status and future plans are discussed.

I. INTRODUCTION

Cryogenically cooled, high-brightness, negative deuterium accelerators have been proposed as part of a future defense system, either space-based or launched-on-demand, which could discriminate or destroy incoming ballistic targets. The Continuous Wave Deuterium Demonstrator (CWDD) has been developed to investigate some of the beam physics and accelerator engineering technologies required of such a system. The accelerator consists principally of a volume negative deuterium source designed to inject 92 mA at 200 keV into a 4-meter radiofrequency quadrupole (RFQ), a single-cavity intermediate matching section (MS), and a 2.6-meter ramped-gradient drift-tube linac (RGDTL). The injector and rf cavities are designed to operate cw or pulsed with an output current of up to 80 mA at 7.5 MeV (figure 1).

II. ACCELERATOR SUBSYSTEMS

The CWDD injector was designed and fabricated at Culham laboratory. A permanent-magnet suppressor and electrostatic collector at the source aperture limits the electron current. Additional reduction is obtained through the use of a pair of dipole magnets with rotating fields, incorporated into the triode accelerator, which sweep the electrons out of the beam before they reach the full 200 keV. Downstream, another pair of dipoles in the LEBT correct the steering introduced by the electron removal. The beam is focused to the RFQ match point by a solenoid lens. Beam centroid position and angle are monitored by a beam emission diagnostic (BED) that views hydrogen Balmer alpha radiation produced by the beam interaction with residual deuterium gas. Injector emittances are measured with an Allison scanner mounted in a removable diagnostic tank located between the injector and the RFQ.

The injector was assembled and operated prior to shipping and re-assembly at the Argonne site. After a suite of tests was conducted to verify the installation, an engineering upgrade was initiated to eliminate power supply problems caused by breakdown induced transients at 200 kV[1]. The upgrade was completed in October 1992 and reliable, stable performance at 200 kV has now been demonstrated. To date, the maximum ion current from the source has been 20 mA. It has been shown that the introduction of cesium into the plasma discharge of a source can increase the current by a factor of two or more[2]. It is planned to modify the CWDD source to enable cesium experiments in late 1993.

The RFQ accelerates the D^- beam from 200 keV to 2.0 MeV. The mechanical design and fabrication approach is an extension of the techniques used for the Beam Experiment Aboard a Rocket (BEAR) RFQ built by Grumman for Los Alamos National Laboratory in 1988[3]. The CWDD RFQ is made from four one meter long segments; each machined from solid tellurium copper and electroformed into a four-vane assembly. The segments are bolted together to form the 3.96 meter (4.63λ at 352.2 MHz) structure. Unlike BEAR, which is un-cooled, the CWDD RFQ has extensive internal cooling passages to allow for removal of 161 kW (at QEF=4) of dissipated power during CW operation. The cavity structure has 48 parallel cooling passages to minimize thermal detuning effects. In addition, all ancillary components are actively cooled; including tuners, RF power couplers and end walls.

The CWDD RFQ has 76 fixed slug tuners distributed axially along the quadrants. The tuning process uses techniques and code developed at LANL. Automated beadpulls are run on the RFQ to determine the field profiles in the four quadrants. Data produced by the QUADPULL/QUADPLOT[4] software is then input to RFQTUNE[5], which uses perturbation theory to determine tuner movements necessary to correct the measured field profiles. Using this technique, the 76 tuner settings were determined in 5 iterations with a field quality of better than ±0.5% for the quadrupole and dipole components. Some retuning was required due to repairs made on the RF end walls. This tuning was done with the RFQ in the vacuum vessel with restricted access, therefore, only a limited number of tuners (10) were adjusted. The final field quality is ±1% quadrupole, 0 to -1% dipole 1 (1-3), and 0 to -1.5% dipole 2 (2-4). This is well within the specification value for field quality of ±5%.

In December 1992, the completed RFQ was installed into its cryostat. All instrumentation has been installed, cooling lines have been proof pressure tested, and drive loops and field pickups have been coupled. In July 1993, the rf drive lines will be installed and final alignment will be performed.

The room-temperature quality (Q) of the completed cavity, 7795, was better than the design goal of 6582 (70% of the SUPERFISH predicted value of 9403). This results in a drop

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in the total dissipation power in the RFQ from 161 kW to 136 kW during operation at cryogenic temperature.

The MS cavity has a 5-mm aperture, is 16 mm long, and is attached to the high-energy faceplate of the RFQ. Four samarium cobalt permanent magnet quadrupoles (PMQ) provide beam focusing. The axis of two of the PMQ's can be offset by stepping motors to provide beam steering. A 4-button capacitive pickup provides beam position, intensity, and phase spread information. Tuning of the cavity will be performed remotely at cryogenic temperature using a sliding-short tuner (SST).

The MS cavity has been fabricated, tested with low-level rf power, and will soon be installed on the RFQ. The SST has been designed but fabrication has not yet begun.

The 2.64 m long by 0.512 m diameter RGDTL is fabricated from a single extrusion of annealed OFHC copper. It is attached to the high energy faceplate of the MS and accelerates the 2.0 MeV D^- beam to 7.54 MeV. The accelerating field gradient is linearly ramped from 2.0 MV/m at the low energy end to 4.0 MV/m at the high energy end by detuning the end cells. Each of the 46 drift tubes contains a PMQ in a FOFODODO lattice.

The RGDTL cavity has been fabricated, cooling channels have been machined, and all of the drift tubes have been assembled. Procurement of the remaining components, including the post couplers, pickup loops, tuners, and cryostat is planned to begin in October 1993. Delivery to the Argonne site is scheduled for October 1994 and installation will be completed by December .

The 352.2 MHz RF System (cw or pulsed) was designed and manufactured by the GE Marconi Communications Systems Ltd.(GE-MCSL). It consists of two 1-megawatt amplifier subsystems with Valvo YK-1350 klystron output tubes, and one 25-kilowatt amplifier which uses a Thompson TH-571B tetrode. The 1-MW systems power the RFQ and RGDTL, and the 25-kw amplifier drives the MS. All stations have identical 100-kHz bandwidth analog phase and amplitude (APC/ALC) control loops with an accuracy of $\pm 1°$ in phase and $\pm 1\%$ in amplitude. The tubes are driven by a master oscillator and solid state driver amplifiers. A mod-anode control system insures that the klystron collector dissipation never exceeds the YK-1350 maximum allowable limit of 900 kW.

Universal Voltronics Corporation (UVC) was subcontracted by GE-MCSL to design and manufacture the high voltage power supply equipment for the 1-MW systems. The power supplies can deliver up to 100 kV DC at 20 amperes. A crowbar, consisting of four ignitrons, reduces the power supply voltage to near zero in ≤ 10 μs to protect the klystrons in the event of a fault. Energy into a load fault is limited to approximately 40 joules.

Rf power is distributed to the RFQ and RGDTL through WR-2300 waveguide and to the MS by 6-1/8 inch coaxial line; A.N.T. Bosch Telecom Co. circulators are used to prevent reflected power from damaging the output tubes. An absorptive harmonic filter is placed between each klystron and circulator. The transmission lines for each of the 1-MW stations are terminated with "magic tee" power dividers for connection to the drive loops of the RFQ and RGDTL cavities.

All rf conditioning of the CWDD cavities will be performed at 26K. The CWDD cavities experience an upward shift in resonant frequency of 1.1 MHz when cooled from room temperature to 26K, but the YK-1350 klystron has a 1-dB bandwidth of 1 MHz; implying that if the cavities were operated at 352.2 MHz at cryo temperature, then the klystron output would be about 3 dB down (from the peak output) at 351.1 MHz. Since the cavities must be conditioned to a power level of 1.4 times their anticipated dissipation, the cavities can only be conditioned at cryo temperature—unless the cavities are retuned. Experience at Grumman has shown that copper cavities can be conditioned for cw at cryogenic temperatures alone.

The rf systems have been installed in the facility and commissioning is underway. The 25-kW amplifier has been tested to 28 kW into an absorptive load and low power (100 W) phase and amplitude loop tests are scheduled for April, 1993. The HV systems for the 1-MW amplifiers were successfully tested into a resistive load at 446 kW and 91 kV. Testing of the 1-MW systems into absoptive loads will begin in May, 1993, but final testing of the rf systems into the cavities must await the completion of the cryogenic system, now scheduled for early 1994.

The HEBT is designed to allow configuration for operation with the RFQ and MS alone or with the RFQ, MS, and RGDTL. This permits testing of the RFQ and MS, as well as commissioning of the diagnostics, to proceed in parallel with the final assembly of the RGDTL. The HEBT contains a quadrupole (to expand the beam and thus reduce the power density at the beam stop), conical beamlines, instrumented graphite beam scrapers, a transverse emittance measurement system, and a set of three 4-button capacitive pickups that can measure the beam energy by a time-of-flight method.

The power density of the beam at the RGDTL output can be as high as 250,000 W/cm^2. This is reduced by a factor of 1000 by the beam expanding quadrupole and by the use of a V-shaped graphite beam stop. The beam stop is designed to dissipate 750 kW of heat for a 20 s pulse every 90 minutes.

The HEBT and beam stop have been installed into the CWDD vault. Final assembly of the instrumentation and diagnostics will be completed by July 1993.

Although the preferred cryogen would be liquid hydrogen, supercritical neon was chosen as a safer surrogate with scalable thermal properties. At full rf power, 78 kg/sec of 26K neon at 30 atmospheres absolute will be required to cool all three cavities. The major components of this system are a 4.7 kW helium refrigeration system, a supercritical pressure neon circulation loop, and a secondary gaseous/liquid neon loop. Although the entire accelerator system was designed to operate cw, a cryogenic system with sufficient capacity for continuous operation would have been too costly. Consequently, the accelerator test plan was structured to allow all of the required cw tests to be conducted in a series of 40 second or less "shots". The cryogenic system provides peak output during these shots followed by a variable length recovery period, depending on the thermal load. Those tests that do not require cw operation can be performed using a pulsed beam, lowering the refrigeration requirement. The recovery period is a maximum of 90 minutes for a shot of 40 seconds at full power loading. Pulsed operations can be conducted indefinitely, as long as the rf duty cycle does not exceed 0.75%.

The cryogenic system was designed by Cryogenic Consultants, Inc. and manufactured by Meyer Cryo Tech. All of the components have been fabricated and the system is currently being installed. Procurement of the 150,000 standard cubic feet of neon required for operation will begin early in October 1993 and commissioning of the system will start in early 1994.

III. SUMMARY

The CWDD is a unique machine that will test the technology of cw, high brightness, cryogenically-cooled, D^- acceleration. All of the major components have been designed and fabricated; most have been assembled into the facility and beam has been available from the injector for more than a year. Operations of the RFQ will begin in early 1994 when the cryogenic system is completed. Installation of the RGDTL will begin in late 1994 and operation of the full-energy accelerator will commence in early 1995.

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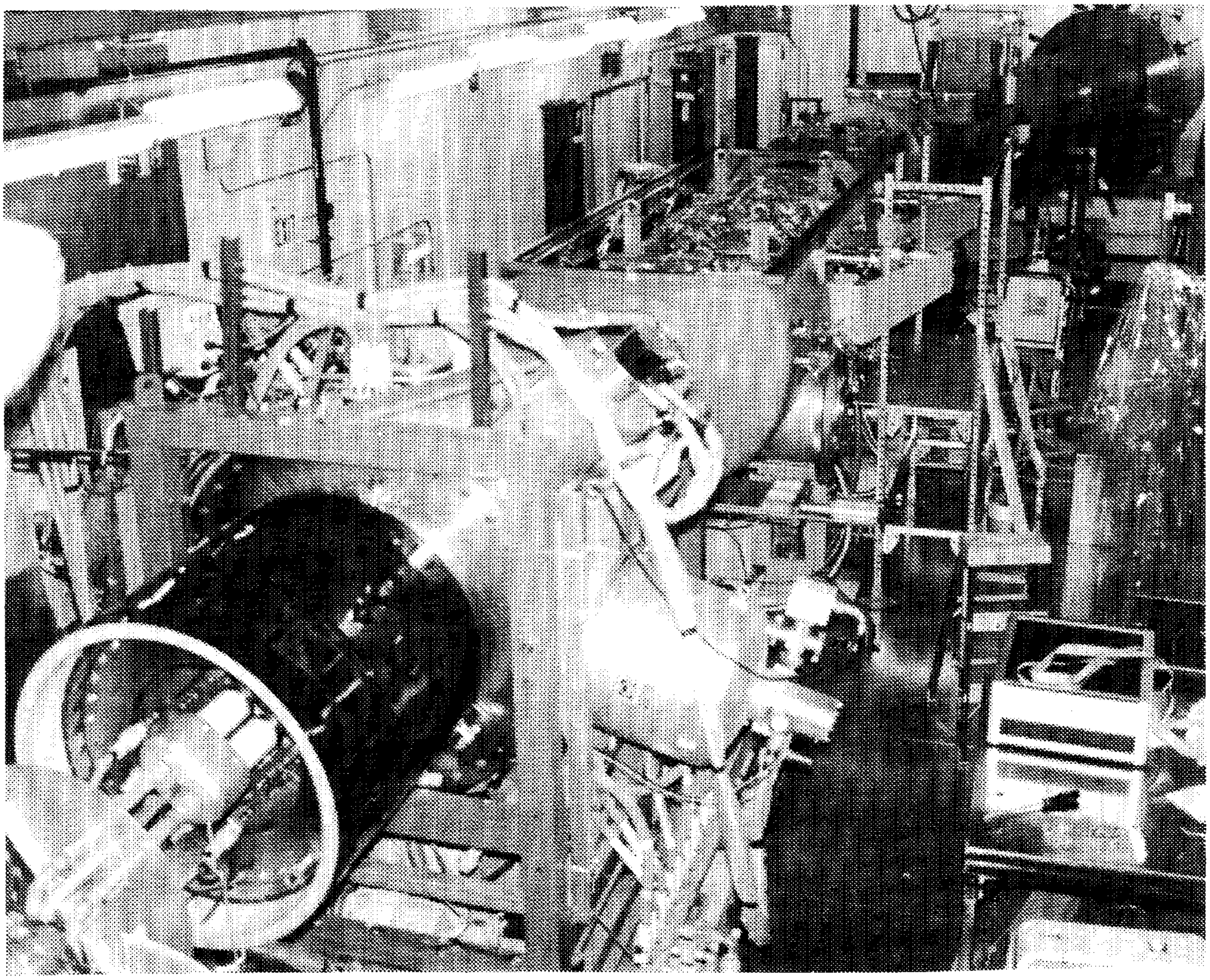

Figure 1. The CWDD accelerator showing the injector in the foreground, the RFQ in its cryostat with the lid removed, the HEBT, and the Beam Stop in the upper right corner. Vacuum insulated cryo lines will be connected to the large ports on the side of the RFQ.