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Rehyd Development and Installation Report

Robert L. Schuch, Haskell N. Woodall

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REHYD DEVELOPMENT AND INSTALLATION REPORT

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ABSTRACT

Rehyd, a low-impedance, HYDRA-type, water transmission line for bremsstrahlung exposures, has been installed on the north side of the REBA facility. Rehyd produces 300-kA beams of 1.2-MeV electrons with a pulse width of 170 ns. Nominal X-ray exposure dose capabilities of 7 cal/g and 20-25 kJ have been realized thus far. This report describes specific design parameters and facility layouts including the unique features of the REBA Marx generator/Rehyd line energy-transfer system. Diode configurations, magnetic-field applications, and output measurements are also presented.

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REHYD DEVELOPMENT AND INSTALLATION REPORT

Introduction

As part of the continuing development of simulation capabilities at Sandia Laboratories,¹ the HYDRA accelerator² was designed to satisfy the requirements for an X-ray radiation source. Because of the demands placed on a source of this type, it was decided to replace one of the REBA high-impedance oil Blumleins by a transmission line similar to one of the HYDRA, water-insulated, low-impedance (4Ω to 2Ω), pulse-forming transmission lines. Such a replacement was possible due to the similarity of characteristics between the REBA Marx generator and the HYDRA Marx generator. The HYDRA Marx has a capacity of 29.8 nF and an inductance of 10.5 μ H. For the REBA Marx, the capacity of 13.1 nF almost matches the single HYDRA line capacitance of 11.2 nF, while the inductance is larger (24 μ H). The HYDRA Marx is also capable of storing 200 kJ of energy (100 kJ per line), whereas the energy store of the REBA Marx (95 kJ) is nearly identical to the energy store per line for HYDRA. Furthermore, because of the similar characteristics, development work done on either source is applicable to the other. The north side of the REBA facility and the experimental cell were extensively modified to accommodate a newly fabricated HYDRA line. For reference purposes and operations identification, the modified line is known as Rehyd. A cutaway drawing of the Rehyd line and the north experimental cell is shown in Figure 1.

Figure 1. Cutaway Drawing of Rehyd

Figure 2 shows the location in Building 6596 of the Rehyd facility and the north experimental cell with respect to the REBA facility. The rest of the building is occupied by the HERMES II facility.

Figure 2. Layout of Rehyd and North Radiation Cell

Description of Rehyd

Marx Generator

The Rehyd line utilizes the REBA Marx generator, which stores 95 kJ at full voltage (100 kV) and has an output capacity of 13.1 nF. Detailed descriptions of the Marx are reported in References 3 and 4 and will not be repeated here, although the mechanical and electrical energy-switching transfer technique will be further defined in this report. No major modifications to the REBA Marx were required. An oil-heating system was installed in the oil line in order to maintain the Marx oil temperature at about 26°C.

Transmission Line

The Rehyd water-insulated transmission line is similar in size and design to a single HYDRA line except that it runs parallel to the REBA Marx tank and is electrically connected to the Marx by an oil-insulated, 90° transition (which is described below). Figure 3 shows a side view of the water-transmission-line assembly, including the outer conductor, inner conductor, SF₆ trigatron switch, lucite barriers, and diode area. Water is supplied to the transmission line through a deionizing system and can be recycled through a holding and debubler tank.

Figure 3. Rehyd Transmission Line (Side View)

90° Transition Conductor

In order to accommodate Rehyd in the REBA facility, it was necessary to design an oil-barrier conductor section that would be adaptable to the REBA Marx tank (Figure 4). A cylindrical, oil-filled tank is attached to the end of the Rehyd water-transmission line and bolted to the REBA tank. Due to the fact that an electrical shock is transmitted when the Rehyd is fired, the 90° transition section was designed in two sections. As shown in Figure 4, an in-line section is fixed to the oil/water barrier, while the Marx conductor is held in contact at a 90° angle by a spring-loaded cap. This configuration minimizes mechanical distortion of the conductor sections and relieves the strain on the lucite barriers when the machine is fired. Lucite barriers separate the transition oil section from the water line and also from the Marx tank. These barriers allow draining of each section separately without interference to the others. A computer code, FFEARS,⁵ was used to analyze the voltage gradients in the transition conductor in order to select an acceptable configuration; i.e., one having electric-field strengths on the high-voltage conductor of less than 0.91 MV/cm, which is the breakdown level for the oil used as an insulator. Values of electric-field strength calculated for various locations along the conductor are shown in Figure 5.

SF₆ Switch

The SF₆ switch used on Rehyd is similar to the enlarged trigatron used on HYDRA.² The switch electrodes were fabricated from tungsten-copper (Mallory 10w3) and mounted in a thick-walled lexan housing. As a precautionary measure to prevent the formation of air bubbles, all external parts of the switch assembly are wiped down with a wetting agent (Detergent, Cutscum, Fisher Scientific Co.) prior to filling the transmission-line tank with water. The switch is filled with SF₆ gas and is regulated between 40 and 100 psi through an external manifold and supply tanks.

Figure 4. 90° Transition Conductor (Oil Section)

Figure 5. FFEARS Plot, 90° Transition Conductor

Water Deionizer System

In order to maintain the integrity of the low-impedance line, the water contained in the transmission line is deionized and kept at a resistance level greater than $1 \text{ M}\Omega/\text{cm}$. Water circulates continually through the deionizer tanks, then through the storage/debubbler tank, and finally reenters at the center of the transmission line. The storage/debubbler tank must be located well above the transmission line in order to allow the circulating water to enter the line by gravity flow, thereby minimizing the number of bubbles entering the diode area.

Diode Configuration

The basic diode assembly on Rehyd is similar to that used on HYDRA² and consists of a flat plexiglas insulator, a cylindrical cathode, an anode chamber, and a perforated torus through which the diode area can be evacuated. The electron beam is formed in the anode-cathode gap and is extracted through a thin mylar window. The beam can then be drifted externally and generally is focused into a specific target, utilizing a solenoid for magnetic-beam compression. Figure 6 shows the diode, the cathode, and the solenoid.

Figure 6. Diode and Magnetic Compression Solenoid

Vacuum Station

The Rehyd diode area is evacuated through the perforated torus. Although the diode area to be evacuated is relatively small (0.075 m^3), vaporized residues that accumulate within the torus are difficult to remove and, in turn, hinder vacuum pumping. A dual, 15-cm^3 , diffusion-pump system (Figure 7) is mounted as close as possible to the torus, which aids in pumping down the diode and the anode drift chamber. Under ideal conditions, the system will pump down to 1×10^{-5} torr in 20 minutes but, after a few shots, pumping time is increased to 30 to 45 minutes. An open (rather than a perforated) torus is being fabricated in an attempt to improve the diode vacuum levels and pumping times.

Figure 7. Rehyd Vacuum System (Front View)

Capacitor Banks

Two self-contained capacitor banks are located on top of the concrete radiation-shield wall that separates the north and south experimental cells of the REBA facility (Figure 8). These storage banks are used to energize magnetic-field coils (solenoids) which are used in conjunction with the electron-beam output of REBA and Rehyd.

Figure 8. Capacitor Banks and Selector Relays

Each capacitor bank consists of 20 Aerovox, PC100-32, 20-kV, 2.8-kJ capacitors. The maximum storage energy with both banks connected in parallel is 112 kJ. A selector relay is used to supply stored energy from the capacitor banks to magnetic-field coils in either the REBA or Rehyd experimental cells. Each unit is covered with a safety-debris shield (not shown in the figure).

The capacitor banks are operated from a console located adjacent to the REBA/Rehyd control console. To insure proper voltage and current to the magnetic-field coil at the time of electron-beam injection, the capacitor bank can be made to fire the Marx generator with a selected, variable delay.

Oil Heaters

To alleviate the effects of cold oil which, at times, crystallizes or adheres to the diode rings and lucite barrier plate, an oil heater system was permanently installed on the north side of the Marx tank. The system consists of two 8240-Btu electric boilers connected in series, a circulating pump, a temperature controller, and a thermometer, along with the necessary plumbing to circulate oil through the Marx tank and filters. After initial heating, the oil temperature is automatically maintained at 26 to 30°C.

Operating Characteristics and Parameters

Performance Characteristics

The primary goal of the Rehyd development program was to obtain a reliable, 5-cal/g, bremsstrahlung exposure capability with a beam energy of about 25 kJ applied over an area of 7 cm^2 . Actual performance characteristics were established at various stages in the development. Changes included improvements in the diode design and convertor assemblies and optimization of the external magnetic field. Applied analytical techniques along with test results on various system components are described in detail in a previous report¹ and will not be repeated here. The Rehyd performance characteristics obtained with a Mod II diode configuration and advanced convertor assembly (see Figure 9) are given in Table 1. The magnetic compression ratio was 2:1.

Figure 9. Diode Mod II and Converter Assembly with Standoff and Gap for Rehyd

TABLE I
Rehyd Performance Characteristics With Mod II
Diode Configuration and Advanced
Converter Assembly

Diode Design	V _{max} (MV)	I (MA)	Δt_p (ns)	E _B (kJ)	Dose _{max} (cal/g)	Δt_{brem} (ns)	Exposure Area
Mod II	1.2	0.30	170	20-25	7	90	9 cm ²

Photon Energy Spectrum

Monte Carlo calculation techniques were used to generate the bremsstrahlung energy spectrum (Figure 10) as determined from traces of diode current and voltage. For these calculations, the peak anode-cathode gap voltage was assumed to be 1.0 MV and peak current was assumed to be 325 kA. As a low-resolution check on the spectral data, the ratio of dose (1-mil Au) to dose (LiF TLD-100) was calculated to be 15, which is in reasonably good agreement with the measured value of 13. Additional spectral data were obtained with filter-fluorescence measurements,⁶ and comparisons of these measured spectra with theoretical results are shown in Figures 11 and 12.

Figure 10. Calculated Rehyd Photon Energy Spectrum for Shot No. 282

Figure 11. Rehyd X-Ray Spectra Along Forward-Directed Normal to Converter for Energies Less Than 0.2 MeV (Normalized to 1.0 keV/sr-electron)

Figure 12. Rehyd X-Ray Spectra Along Forward-Directed Normal to Converter for Energies Greater Than 0.1 MeV (Normalized to 1.0 keV/sr-electron)

Electrical Parameters

Rehyd electrical parameters are similar to those for one line of HYDRA, and many experiments may be performed on either accelerator. Electrical parameters and other Rehyd specifications are outlined in the appendix.

Data Acquisition and Monitors

Diode Monitors

Permanent detectors are installed in the diode area to monitor current and voltage. Such detectors usually consist of B_θ coils and capacitive voltage monitors. Data from an experiment are extracted through external diagnostic systems and collected in a shielded screen room or else transmitted to an instrumentation van.

Instrument Screen Rooms

At the time of the modification of the REBA facility, the existing screen room was relocated to the east end of the REBA Marx (see Figure 2). This has been recently expanded and affords screen-room access to both the Rehyd and REBA facilities. Another screen room (which contains a computer-access substation) is located in the low-bay office area of Building 6596 (not shown).

Instrumentation Van

The Rehyd facility is supported by an instrumentation van from Sandia Laboratories' Simulation Instrumentation Division. An instrumentation cable boom 2.1 m in length is attached to the south wall of the test cell at a height of 2.1 m above the floor on a hinge which allows it to be swiveled to various positions. Cables are routed in shielded, ground-level troughs to the instrument van.

The van provides a multitude of data acquisition capabilities, including oscilloscopes, signal generators, power supplies, recorders, and transient digitizer systems. Data from the digitizer system are received in the form of either hard-copy plots and/or digital data recorded on cassettes.

Safety

Both Rehyd and REBA experimental cells are equipped with "Machine Active" warnings and, in addition, both areas are monitored with closed-circuit television from the control console. The Rehyd Experimental Review Committee considers all tests that may be hazardous or that contain toxic materials. In such cases, modifications may be made to the Rehyd cell or special equipment may be utilized to insure personnel safety.

Summary

Rehyd was first made available to experimenters in January 1975 and has been utilized in a variety of experiments, including simulation tests, materials effects, and fusion experiments.⁷ Approximately 1545 shots have been recorded through May 1977. No major modifications have been required except for changes in power levels or ventilation schemes for particular experiments.

The performance of Rehyd has been better than originally expected and, in most cases, the design operating parameters have been exceeded. As mentioned earlier, many Rehyd experiments are also compatible with single-line HYDRA operations and, therefore, Rehyd has increased the capability to perform experiments utilizing a high-current, pulsed-beam source.

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APPENDIX

General Physical and Electrical Characteristics of Rehyd

Output

A-K	1.2 MV
Current	0.3 MA
Total Tube Impedance	3 Ω
Electrical Pulse Length	170 ns
Beam Energy	35 kJ max.
Number of Cathodes	1

Line Characteristics

Electrical Length	170 ns
Outer Diameter	1.37 m
Inner Diameter	0.76 m
Nominal Impedance	2 Ω
Maximum Charge Voltage	3.0 MV
Maximum Electrical Field in Coax	-150 to +85 kV/cm
Maximum Electrical Field on Interface	100 kV/cm
Capacity	11.2 nF
Equivalent Series Resistance (1 M Ω /cm, H ₂ O)	700 Ω
Prepulse Level	< 1.0 kV
Switch Inductance	240 nH
Tube Inductance	36 - 85 nH
Insulation	H ₂ O
Stored Energy	60 kJ

Marx Generator

Capacitance per Stage	0.5 μ F
Number of Stages	38
Number of Spark Gaps	19
Charging Voltage	100 kV max.
Total Energy Stored	95 kJ
Output Capacity	13,100 pF

Marx Generator (continued)

Inductance	26 μ H
Series Resistance	3 Ω
Parallel Resistance	1,000 Ω
Marx Lossless Output Voltage	3.8 MV

Mod II Diode Characteristics

Peak Diode Voltage	1.2 MV
Peak Anode-Cathode Voltage	1.1 MV
Peak Current	0.3 MA
Current Risetime	40 ns
Tube Impedance	3 Ω
Tube Inductance	65 nH
Cathode Diameter	7.62 cm
Total Cathode Area	45.6 cm ²

X-Ray Environment

Dose/Pulse	7 cal/g (1-mil Au)
Pulse Width	120 - 140 ns (base-to-base)

Electron-Beam Environment

Beam Energy	20 - 25 kJ
Peak Power	0.4 TW
Pulse Width	170 ns (base-to-base)
Dose/Pulse	1000 cal/g (20-cm ² graphite)

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