SYSTEMS TESTING OF A FREE HG JET SYSTEM FOR USE IN A HIGH-POWER TARGET EXPERIMENT*

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Abstract

The design and operational testing of a mercury jet delivery system is presented. The equipment is part of the Mercury Intense Target (MERIT) Experiment, which is a proof-of-principle experiment to be conducted at CERN in the summer of 2007 to determine the feasibility of using an unconstrained jet of mercury as a target in a Neutrino Factory or Muon Collider. The Hg system is capable of producing a 1 cm diameter, 20 m/s jet of Hg inside a high-field solenoid magnet. A high-speed optical diagnostic system allows observation of the interaction of the jet with a 24 GeV proton beam. Performance of the Hg system will be presented, along with results of integrated systems testing without a beam.

INTRODUCTION

The Mercury Intense Target (MERIT) Experiment is a proof-of-principle experiment to investigate the interaction of a proton beam with an unconstrained jet of liquid Hg within a high-strength magnetic field [1]. MERIT is scheduled to be conducted at CERN during the summer of 2007; the experiment has been approved at CERN with the designation of nTOF11. MERIT follows earlier efforts which observed how a Hg jet is constrained by a magnetic field [2] and dispersed by a proton beam in a zero-field condition [3]. It is envisioned that the MERIT experiment will prove that this type of high-power target concept can be used for a Neutrino Factory or Muon Collider. Design requirements for this experiment were that the Hg jet should have a velocity of 20 m/s and a diameter of 1 cm; the maximum magnetic field strength should be 15 T. It is expected that approximately 100 proton pulses will be conducted during the duration of the experiment. Beam momentum shall be either 14 GeV/c or 24 GeV/c, with up to 30×10^{12} protons per pulse, and the total number of protons on target shall be limited to 3×10^{15}.

EQUIPMENT DESCRIPTION

Figure 1 shows a cross-section view of the experimental equipment. The Hg system provides double containment of the hazardous liquid metal, and the Hg system can be inserted or removed from the solenoid bore without disassembly of either system.

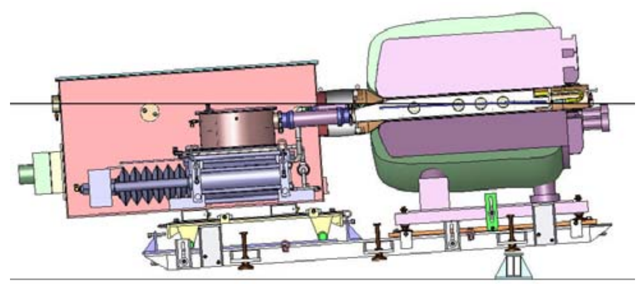

Figure 1: MERIT experiment equipment cross section.

In Figure 1, the proton beam is shown as a horizontal line; direction of the beam and the Hg jet is from right-to-left. The magnetic axis is positioned at a slight angle (66 mrad) to the beam, with the tilt provided by a common baseplate supporting all the equipment. Four viewports shown within the solenoid bore represent viewing locations for observation of the Hg jet within its primary containment. Numbered 1-4 from right to left, viewport #2 is positioned at the center of the high field within the solenoid and is the location where the center of the proton beam interacts with the center of the Hg jet. Descriptions of the major experiment components are given below; additional information can be found in [4].

Solenoid

Shown in Figure 2, the MERIT magnet is a DC-pulsed solenoid capable of producing a 15 T field at 7200A; with a maximum operating voltage of 700 V, its peak power is 5.5 MW. Its fabrication consists of three nested copper coils with a warm bore length of 1 m and diameter of 15 cm. It is a normally-conducting solenoid with an operating temperature of 77 K provided by liquid N_2 (LN2) cooling. Mechanical design was provided by the Plasma Science and Fusion Center at MIT [5].

To minimize the activation of LN2 during the experiment, prior to each beam pulse the solenoid is flushed of LN2 with 5-bar N2 gas. The magnet incorporates a field ramp-up of 9 s and is capable of sustaining its peak field for a duration of approximately 1 s. During this time the electrical energy input raises the magnet's temperature by approximately 30 K. The time required to cool the magnet down to operating temperature after each pulse is approximately 30 minutes.

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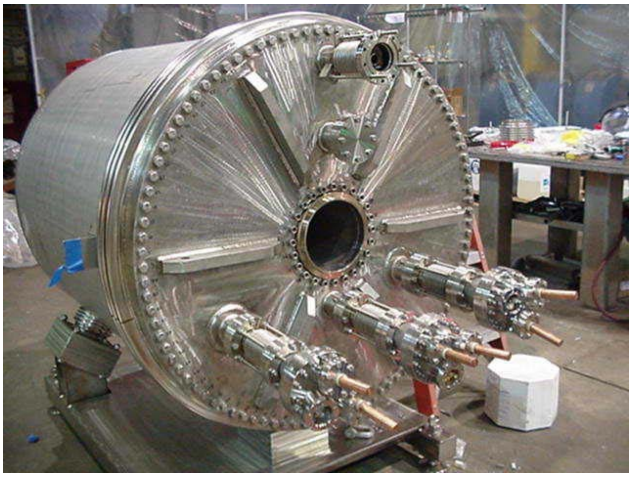

Figure 2: 15 T solenoid.

Hg System

The Hg delivery system is a hydraulically-actuated syringe pump that produces the desired unconstrained liquid metal target jet. Due to discharge pressure and fluid heating concerns, as well as the intermittent nature of the experiment, a syringe pump was chosen over a centrifugal pump. The pump is shown in Figure 3 and consists of three hydraulic cylinders – a centered 25 cm diameter Hg cylinder actuated by a pair of side-mounted 15 cm diameter drive cylinders through a mechanical tie beam. The syringe can provide a maximum steady-state jet duration of 12 s. The Hg flow rate during a 20 m/s jet is 1.6 liter/s, with a corresponding syringe piston velocity of 3.0 cm/s.

Figure 3: Hg delivery system.

The rated pressure for the Hg cylinder is 100 bar, while the drive cylinders' rated pressure is 200 bar. Due to safety requirements at the various testing facilities, the hydraulic fluid used to move the drive cylinders is a low-flammability, vegetable-oil based fluid. A 30 kW, 200 bar hydraulic power unit provides the driving pressure needed to move the syringe cylinders. All Hg-wetted metallic components of the primary containment are fabricated from either stainless steel or titanium to avoid attracting forces from the solenoid.

Hg system design and fabrication oversight were provided by Oak Ridge National Laboratory (ORNL).

Optical Diagnostic System

A back-illuminated, laser shadow photography technique is employed to capture the dynamics of the interaction of the proton beam with the Hg. Design and integration of the optical diagnostic system was provided by Brookhaven National Laboratory (BNL).

Due to the limited space inside the magnet bore, object illumination and image capture are transmitted through radiation-hard multimode optical fibers and coherent imaging fibers, respectively, all positioned externally on one side of the Hg jet chamber. Synchronized short laser light pulses are used to illuminate the target and freeze the motion of the jet after impact by the proton beam. Optical light pulses are sent through 20 m lengths of multimode illumination fibers. A sapphire ball lens position at the tip of the fiber expands the numerical aperture to fully illuminate the target. After passing through 2 AR-coated sapphire viewports, the light pulses are retro reflected by a spherical mirror positioned on the opposite side of the jet chamber. This retro reflected light shadow is collected by a tiny Grin objective lens butt-coupled directly onto a 0.9 mm diameter flexible coherent imaging fiber that is 10 m long and has 30,000 picture elements. The light sources used in this experiment are all Class 4 lasers capable of emitting peak optical power of 20 Watts in 150 ns duration at the wavelength of 850 nm where ionization radiation has minimum effects on the fiber transmission. High-speed cameras with capture rates of up to 1 μs/frame are used to simultaneously record images on all 4 viewports, shown in Figure 4. The locations of the viewports are designed to capture the dynamics of the proton interaction at different parts of the Hg jet after proton impact.

Figure 4: Fiber bundles and optic components.

The high-speed cameras and associated laser equipment are shown in Figure 5. All active components and electronics were located in an adjacent tunnel, safe from any radiation area.

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Figure 5: High-speed cameras and laser equipment.

TEST RESULTS

Operational tests of the Hg delivery system were conducted at ORNL, first with water and later with Hg. During this time the optical diagnostic system was mounted onto the Hg containment system. Once this configuration was successfully tested, the entire apparatus was shipped to MIT, where an integrated systems test was performed with the solenoid. After the successful completion of this testing, all equipment was shipped to CERN for installation into the experimental area.

Integrated testing consisted of 14 completed runs, with various field strengths (5 T, 10 T, and 15 T) and jet velocities (10 m/s, 15 m/s, and 20 m/s). Figure 6 shows some of the optical diagnostic results from the testing. The images came from viewport #2, which is the location of the highest field intensity. The upper images show the jet at various velocities in a no-field condition, while the lower images show the jet in a 15 T field.

Due to the limited number of runs completed, definitive conclusions could not be reached in all cases. However, several observations were noted:

- the magnetic field certainly constrained the jet by smoothing out jagged edges of the flow
- as the field level increased, the size of the jet also tended to increase, which may be evidence of a quadrupole effect that would cause the jet's circular cross-section to become elliptical
- jet size was relatively unchanged in 0 T and 5 T fields, but increased in 10 T and 15 T fields
- jet size increased as its velocity increased
- for a 20 m/s jet, its size in a 10 T field was smaller than in a 15 T field, again showing possible evidence of a quadrupole effect

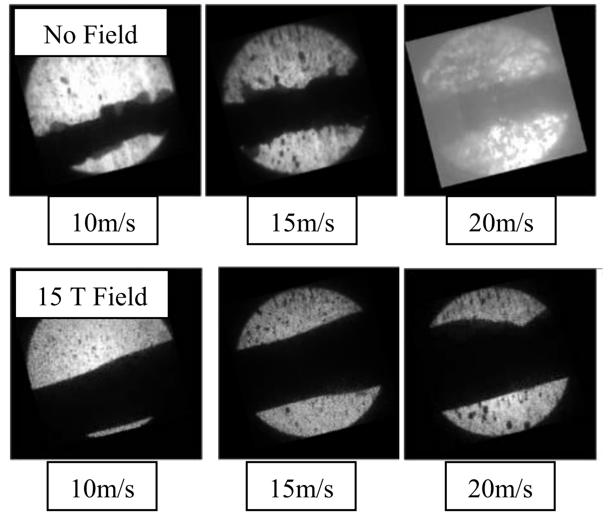

Figure 6: Diagnostic images at viewport #2.

Further testing will be conducted at CERN during the equipment commissioning phase in an attempt to better quantify these observations.

Currently, the equipment is in the process of being installed in the experimental tunnels at CERN in preparation for the planned in-beam tests.

REFERENCES

[1] J.R.J. Bennett et al, “Studies of a Target System for a 4-MW, 24-GeV Proton Beam,” A Proposal to the ISOLDE and Neutron Time-of-Flight Experiments Committee, CERN-INTC-2004-016, INTC-P-186, April 26, 2004.

[2] J. Lettry, A. Fabich, Simone S. Gilardoni, M. Benedikt, M. Farhat, E. Robert, "Thermal shocks and magnetohydrodynamics in high power mercury jet target,". *NuFact02: 4th International Workshop on Neutrino Factories*, London, England, 1-6 Jul 2002. Published in J.Phys.G29:1621-1627, 2003.

[3] H.G. Kirk et al, "Target Studies with BNL E951 at the AGS," PAC-2001-TPAH137, Aug 2001. Presented at IEEE Particle Accelerator Conference (PAC2001), Chicago, Illinois, 18-22 Jun 2001. Published in *Chicago 2001, Particle accelerator* 1535-1537;
A.Fabich, M.Benedikt, J.Lettry, "Experimental Observation of Proton-Induced Shocks in Free Surface Liquid Metal Targets," proceedings IWSMT5, J.of Nuclear Materials, 2002.

[4] V. Graves, et al, “A Free Jet Hg Target Operating In a High Magnetic Field Intersecting a High Power Proton Beam,” *Nuclear Instruments & Methods in Physics Research, Proceedings of the 7th International Conference on Accelerator Applications*, June 2006, p. 928.

[5] http://psfcwww2.psfc.mit.edu/people/titus/#BNL %20Memos

