OPTICAL DIAGNOSTIC RESULTS FROM THE MERIT HIGH-POWER TARGET EXPERIMENT

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Abstract

We report on the analysis of data collected from the optical diagnostics of the MERIT experiment. The breakup of the free-mercury jet resulting from the impact of intense proton beams from the CERN PS within a magnetic field environment is described.

INTRODUCTION

The MERIT high-power target experiment was run in the Fall of 2007. The purpose of the experiment was to validate target concepts [1, 2] proposed for generating intense muon beams suitable for injection into storage rings which are the bases of future facilities such as a Muon Collider and/or a Neutrino Factory. In order to provide the desired luminosity for a Muon Collider or the neutrino beam intensity for a Neutrino Factory, the target will be required to accept proton beams with multi-megawatt beam power.

The core of this proposed target system consists of a high-Z liquid-metal mercury jet which intercepts the proton beam within the confines of a high-field (15-20 T) solenoid. The operation of a mercury jet inside a strong magnetic field as a target for an intense proton beam raises several issues as to the disruption of the liquid target by the proton beam, and the possible effect of that disruption on the mercury containment system. The MERIT experiment was designed to address these issues. The concept for this experiment has been previously reported [3].

We describe in this paper the results of the optical diagnostics used to examine the characteristics of the proton beam/mercury jet interaction.

THE MERIT EXPERIMENT

A cut-away side view of the MERIT apparatus is shown in Fig. 1. The proton-mercury jet interaction occurred inside the 15-cm-diameter bore of a 1-m-long solenoid magnet precooled with LN_2. The solenoid could be pulsed to fields up to 15 T with a 30-min cycle [4]. The mercury injection system [5] provided a free Hg jet with a nominal diameter of 1 cm, velocities up to 20 m/s, and durations up to 7 seconds. The mercury jet and proton beam were both tilted with respect to the magnet axis to maximize the collection of soft pions [6] that later decay into muons.

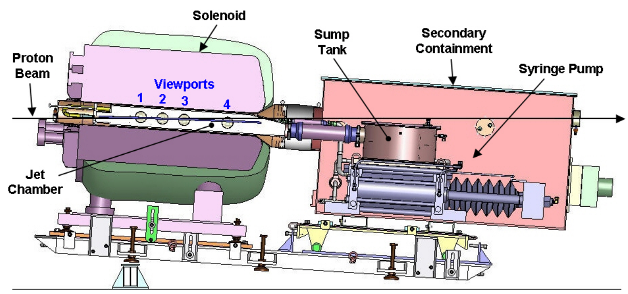

Figure 1: Cut-away view of the MERIT experiment. The solenoid/Hg jet system was tilted by 67 mrad with respect to the horizontal proton beam that moved left to right in the figure. The copper magnet was cooled by LN_2 and could be pulsed to 15 T once every 30 min. The hydraulic injection system was capable of delivering an Hg jet of 1-cm in diameter with velocities up to 20 m/s.

The experimental apparatus was installed in the TT2A area of the CERN PS complex. Proton beams of energies up to 24 GeV could be transported into this area, but multiple extractions of individual bunches during several turns of the PS was possible only at energies up to 14 GeV. As such, the MERIT experiment operated at the two proton-beam energies of 14 and 24 GeV.

Diagnostics for the experiment were obtained mainly from two systems: 1) an optical system with high-speed cameras that observed the region of the Hg jet/proton beam interactions through four view ports installed on the primary containment vessel (Fig. 2) [7]; and 2) a series of charged-particle detectors placed downstream of the interaction region [8]. The four optical view ports were aligned such that the upstream three ports were 15 cm apart with the second view port located at the magnet center; the fourth view port was displaced 45 cm downstream from the magnet center.

For the MERIT experiment, the CERN PS was typically run in a harmonic-16 mode (although several shots were

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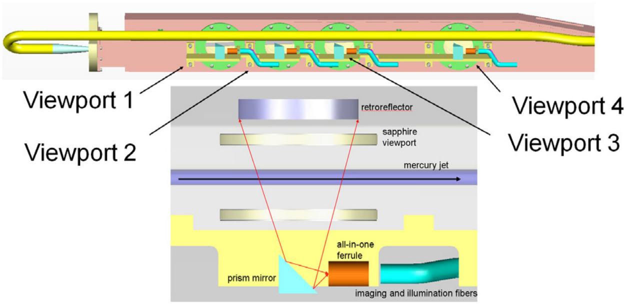

Figure 2: Details of the optical diagnostic system. The Hg jet was photographed by high-speed cameras at view-ports 1, 2, 3, and 4 as it streamed from left to right. The center of the overlap of the Hg jet and the proton beam was at view port 2, and the aftermath of the interaction was viewed at view ports 3 and 4.

also done with the proton beam in a harmonic-8 mode and a few with a harmonic-4 structure). The proton beam intensity was varied from 0.25 to 30 $\times 10^{12}$ (Tp) protons per pulse (the latter at 24 GeV being a record intensity for a single CERN PS pulse). The field of the solenoid magnet was varied from 0 to 15 T. The mercury jet was injected with velocities of 15 or 20 m/s.

EXPERIMENTAL RESULTS

Length of Disruption of the Jet by the Beam

Figure 3 shows images at view port 3 of an interaction of a 15-m/s jet and a 24-GeV, 10×10^{12} proton pulse in a 10-T solenoid field. A sequence of 200 images was collected for each proton pulse with a 2-ms frame interval .

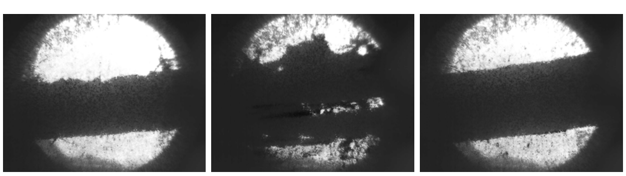

Figure 3: A proton beam/jet interaction as viewed in view port 3: Left: image of the jet before interaction; Middle: image of the interaction aftermath; Right: image of the reformed jet stream.

The dispersal of the Hg jet resulting from the impact of the proton beam was observed at the third view port, located 15 cm downstream of the center of the solenoid. The region of disruption of the mercury jet was typically less than the 28-cm (2-interaction-length) overlap of the proton beam with the jet.

Figure 4 shows the observed disruption lengths of the Hg jet along its axis for both 14 and 24 GeV proton beams, and for various magnetic fields. Stronger magnetic fields reduced the extent of dispersal of the Hg jet at high beam intensities, and increased the threshold for disruption at lower intensities.

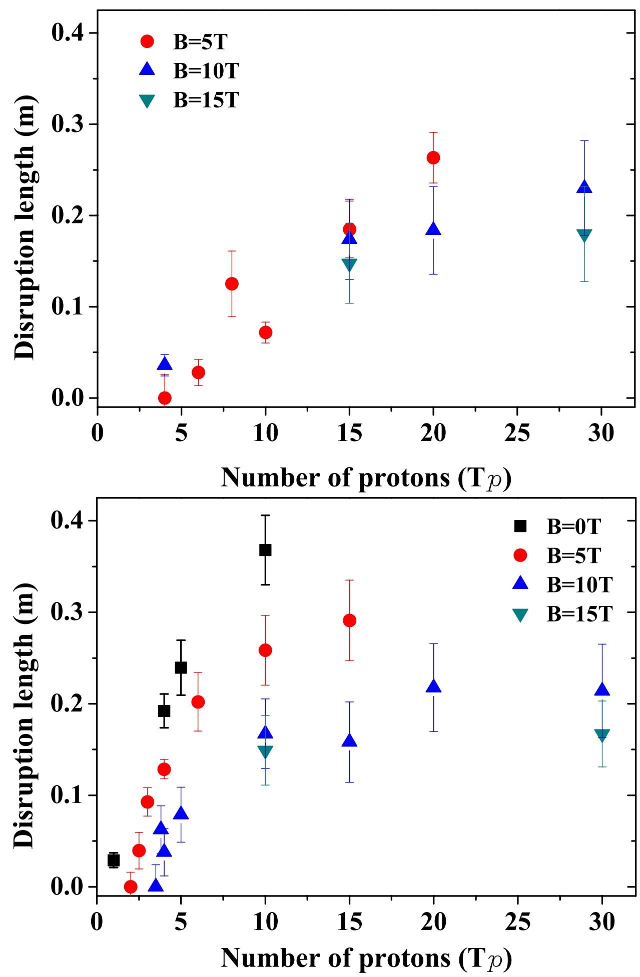

Figure 4: Extent of the proton-beam-induced disruptions: Top: the jet disruptions resulting from a 14-GeV proton beam; Bottom: jet disruptions with a 24-GeV proton beam. In both cases, the proton beam intensity and solenoid magnetic field were varied.

For pulses of 30×10^{12} protons and a solenoid field of 15 T, the extent of the Hg jet disruption was less than 28 cm, thus permitting a 70-Hz beam rep-rate option with a 20m/s jet. For such a 24-GeV, 30×10^{12} proton pulse, the total energy content of the pulse is 115 kJ, corresponding to a total beam power of 8 MW at 70 Hz.

Velocity of Filaments Ejected from the Jet

Figure 5 shows images at view port 2 of the same beam shot already depicted in Figure 3. These images were taken with a 25-μs frame interval and an exposure time of 150 ns.

Fits to the position of the tips of mercury filaments as a function of time determined the filament velocity, and the earliest time of appearance of the filament after the proton beam interaction. The highest velocity filaments were associated with the earliest times of appearances, with results for the maximum observed filament velocities shown in Figure 6.

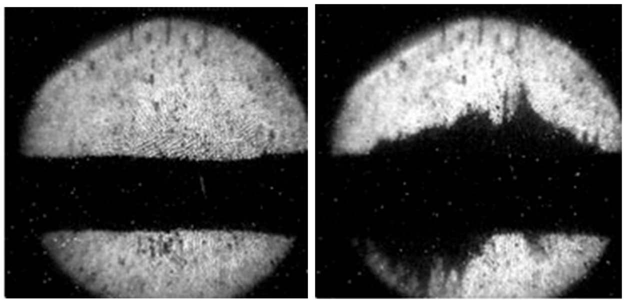

Figure 5: A proton beam/jet interaction as viewed in view port 2: Left image: before interaction; Right image: 350 μs after proton beam arrival.

With a magnetic field, all filament velocities were less than 100 m/s (typical for splashes induced by a stone thrown into a liquid), and the velocities were reduced in higher magnetic fields.

The onset of jet filamentation occurred 25-100 μs after the beam interaction, with longer times in higher magnetic fields. This unexpected phenomenon is under further investigation.

In another study [8] with "probe" proton bunches up to 700 μs after an initial set of "pump" pulses, the rate of secondary particle production was observed to be little affected by the disruption of the mercury jet on these time scales.

CONCLUSIONS

The MERIT high-power target experiment was run using the CERN PS proton beam, and established the proof-of-principle of a proposed system for generating an intense muon beam by interaction of a megawatt proton beam with a free mercury jet target. The disruption of the mercury jet by the proton beam was less than the region of overlap, and was reduced in high magnetic fields. The velocity of mercury ejected from the jet by the proton beam was low enough that damage to the containment vessel was negligible. Although short segments of the mercury jet were completely disrupted on the scale of several ms, secondary particle production was little affected for several hundred μs after arrival of the first bunches of a train.

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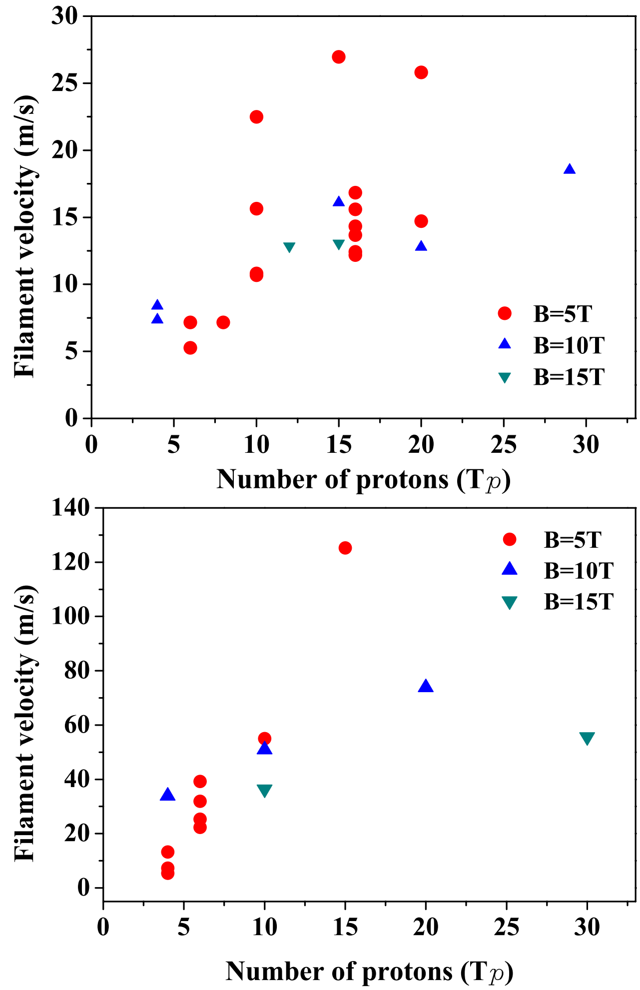

Figure 6: Measured filament velocities: Top: 14-GeV proton beam with various solenoid field strengths; Bottom: 24-GeV protons.

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