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Pumping Effectiveness of a Magnesium Vapor Jet in the Presence of a High Power Neutral Beam Source

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Abstract

An experimental study of a supersonic magnesium vapor jet neutralizer has established the effectiveness of the jet in reducing cold streaming gas from a high current neutral beam source. The removal of molecular hydrogen gas by a magnesium jet neutralizer provides a means of simplifying beamline design by improved pumping characteristics of the jet compared with conventional technology while simultaneously improving performance.

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In a conventional neutralizer system, hydrogen gas issuing from the ion source is used as the charge-exchange target. This gas must be prevented from flowing to the target plasma in order to prevent hot plasma ions from undergoing charge-exchange reactions in the gas and escaping from the machine. Excess gas is limited by baffling and large pumping speeds of the beamlines. Present methods allow plasmas to build up in mirror machines, but the plasma lifetime is still limited by charge-exchange.

The present experiment tests an improved version of the magnesium jet with a full-scale ion beam source capable of 55 amperes extracted at 16.9 kV. The data shows that the magnesium jet is capable of maintaining a cold gas pressure differential in excess of three orders of magnitude over the full range of beam source operating conditions. Measurements of the neutral particle fraction obtainable with the magnesium jet and a study of possible magnesium plasma formation in the beam-jet interaction region are underway.

The magnesium vapor jet consists of four main components: oven, valve, vapor conduit and supersonic nozzle. Magnesium metal in the oven is heated to an operating temperature of 800° C, well above the melting point of 654° C. When the valve is opened, magnesium vapor flows out of the oven through the conduit to the supersonic nozzle. The vapor stream exits the nozzle at supersonic velocities and intercepts the ion beam/gas stream. The 20 kV beam particles are neutralized by the magnesium vapor as in a gas charge-exchange cell. From the point of view of the energetic beam atoms, the magnesium molecules are almost stationary. For the cold hydrogen molecules traveling with the beam, however, the magnesium stream presents a formidable barrier. Since the magnesium molecules are moving quite fast compared to the hydrogen gas molecules, the magnesium jet acts like a diffusion pump to sweep away the gas. In an ideal system, an arbitrarily large amount of gas can be pumped with this system simply by raising the oven temperature and increasing the mass flow rate of the evaporated material. In a real-world system, pumping is limited by temperature effects on reliability of components and gas leakage around the pumping region. In previous experiments, it was found that reliability of the heating units deteriorated for operating temperatures above 900° C.

Figure 1 shows the magnesium oven, valve and heating units. The oven, conduit and heating units are made from commercially available components. The electromagnetically operated valve, which consists of a molybdenum shaft and tungsten plug, was designed for a previous prototype and used with no modification with the current oven design. The magnesium jet neutralizer system is designed to operate with an oven temperature of 800° C. The oven and conduit are surrounded by layers of ceramic fiber insulation and a single steel heat shield. During operation, the valve is opened for 0.5 to 2 seconds per shot, with approximately 0.1 grams of magnesium evaporated per second. Figure 2 shows the experimental setup used in the gas pumping experiments. The magnesium oven (residing in its own vacuum chamber) is mated to a long conduit and nozzle inside the test stand vacuum chamber. A full-scale ion beam source is also mounted on the test stand, with the ion beam directed transversely through the magnesium jet. The baffles which delineate the chambers P1, P2 and P3 have been designed so as to simulate the actual relative volumes and conductances in the Tara Tandem Mirror experiment beamline. In this experiment, chamber P1 corresponds to the Tara source tank, chamber P2 corresponds to the plug region (which is to be screened by the jet) and chamber P3 represents a jet blow-down region. The magnesium vapor is collected on a liquid nitrogen-cooled surface used as part of the vacuum system. The ion beam source is fired for 50 milliseconds, and the pressures in the chambers are recorded by a CAMAC module. After the system has returned to its base pressure, the magnesium jet is turned on and the source fired again for 50 milliseconds. The results are shown in Figures 3, 4 and 5 which compare the pressure in the simulated plug region for low and high beam power and low and high magnesium oven temperature. Figure 3 shows a low temperature case (oven at 750° C) in which some gas leakage through the jet can be seen. As shown in Figure 4, when the oven temperature is brought up to its operating value of 800° C, the pressure pulse is virtually eliminated from the simulated plug region. In Figure 5, the ion beam source is at full operating power of 55 amperes extracted at 16.9 kV, and the oven is at 800° C.

This data demonstrates that the magnesium jet is capable of reducing cold hydrogen gas flow by three to four orders of magnitude in the presence of a full scale ion beam developed for use with the Tara Tandem Mirror experiment. Such a gas reduction would allow a substantial increase in plasma lifetime. In addition, a magnesium jet system would also work to reduce cold gas flow from a beam dump into the plasma region.

The oven heaters and valve operated very reliably with an oven temperature of 800° C. When the vacuum chamber was opened, all magnesium deposits were found to reside on the liquid nitrogen panel used as a magnesium scavenger. Although no evidence of magnesium migration down the beamline was seen, a more sensitive experiment to detect stray magnesium flow is underway.

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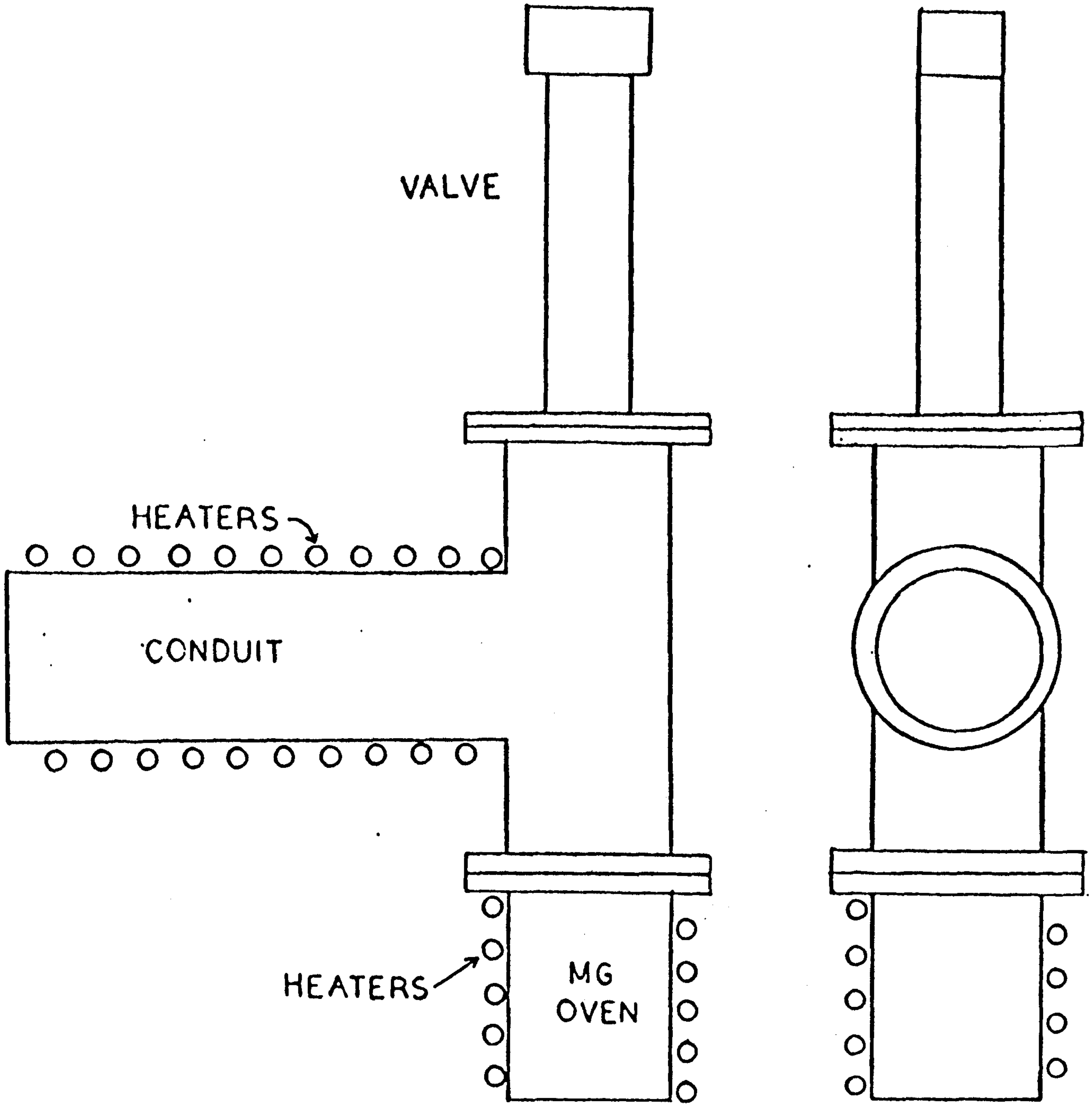

MAGNESIUM OVEN

Figure 1.

EXPERIMENTAL SET-UP

P1 - Ion Gauge for Chamber 1
P2 - Ion Gauge for Chamber 2
L1 - Langmuir Probe in Beam-Jet Region

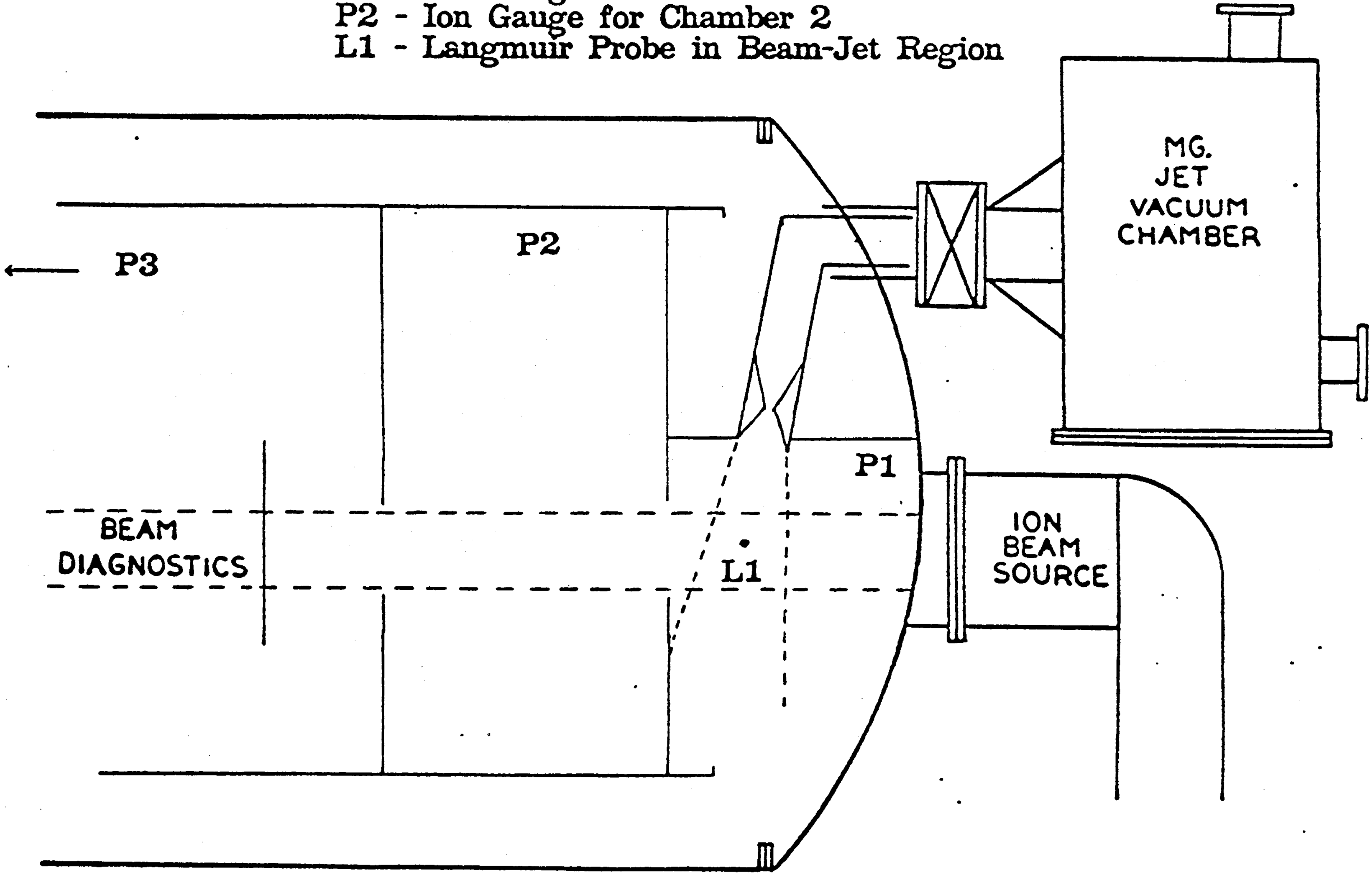

Figure 2.

PRESSURE RISE DURING SHOT - LOW BEAM POWER

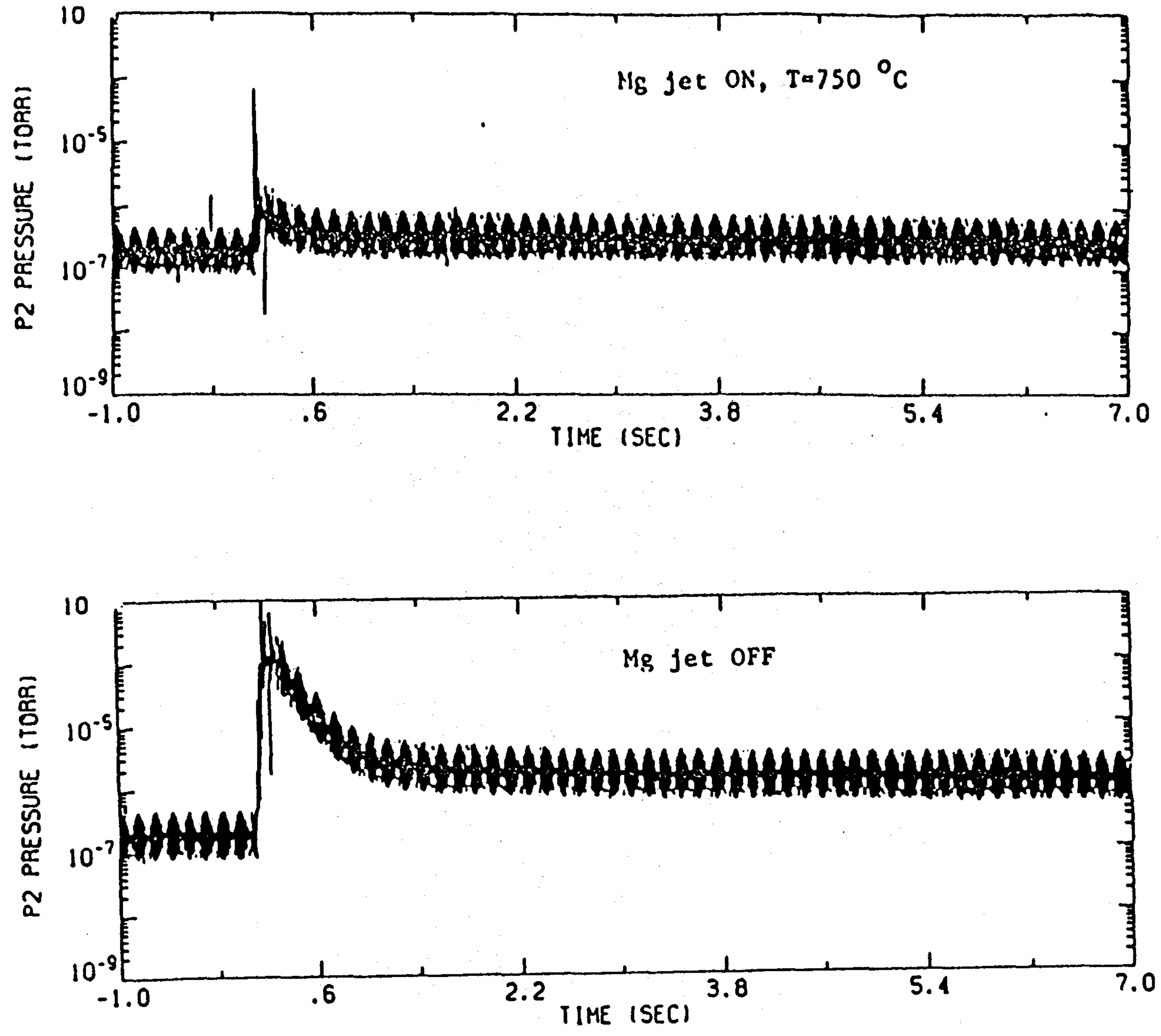

Figure 3.

PRESSURE RISE DURING SHOT - LOW BEAM POWER

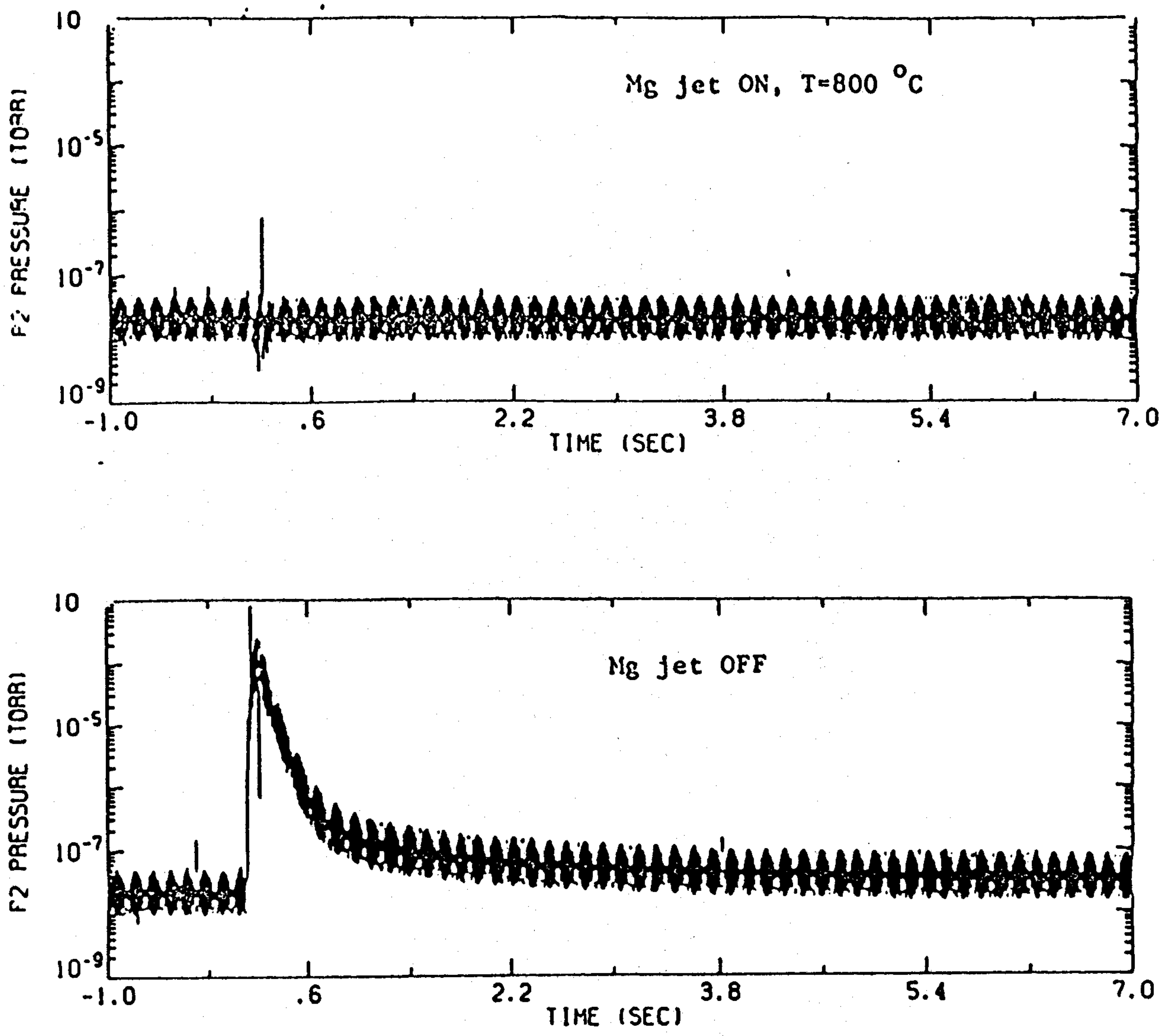

Figure 4.

PRESSURE RISE DURING SHOT - HIGH BEAM POWER

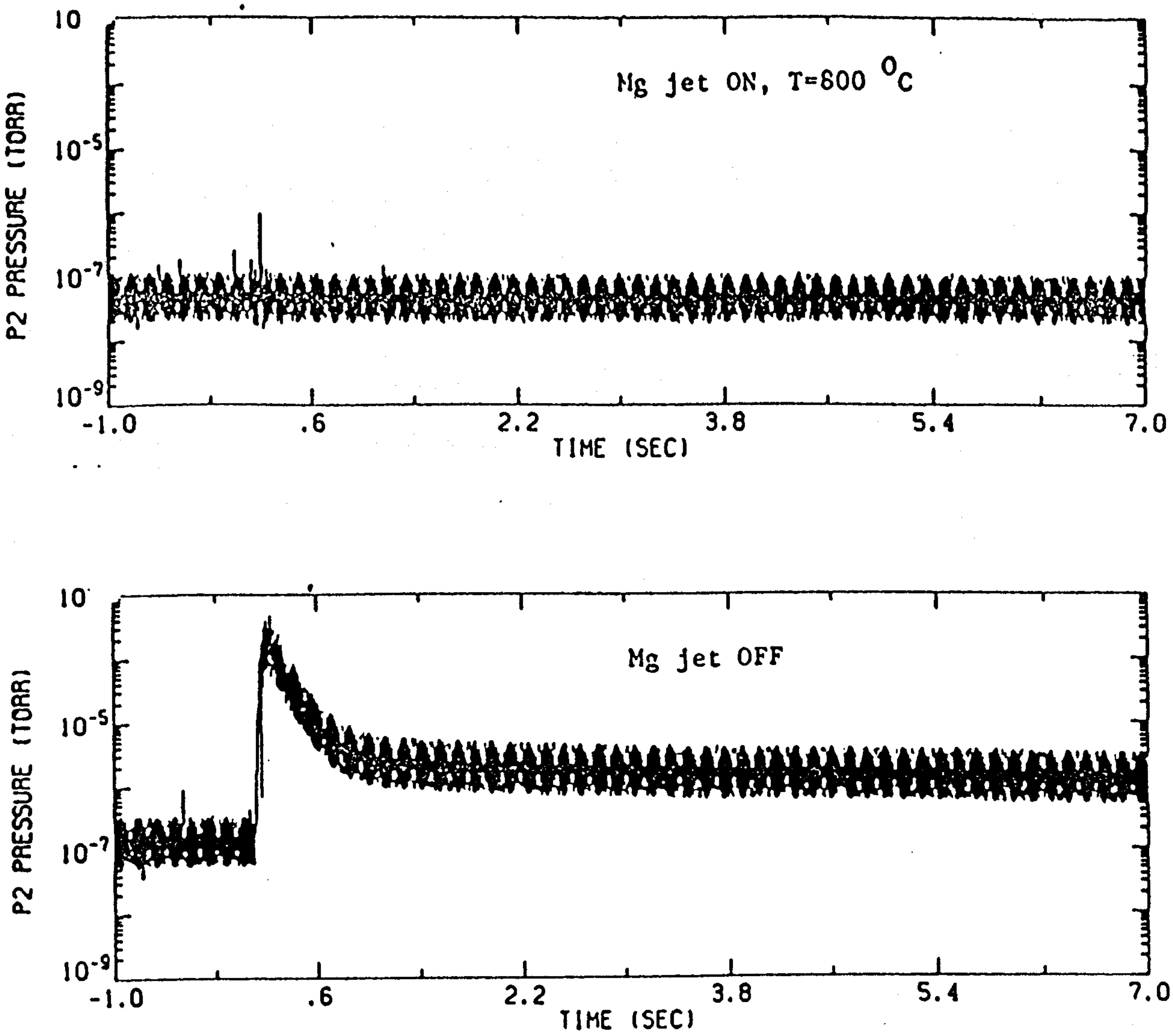

Figure 5.