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FIRST TEST RESULTS FROM THE NEW CERN PLASMA LENS

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ABSTRACT

Earlier investigations of the magnetic field dynamics of z-pinches and of the long-term plasma-wall interactions have led to the construction of a new plasma-lens device for the CERN antiproton source. After testing, the plasma lens will be installed in the target area of the CERN Antiproton Accumulator Complex. The mechanical design of the lens and the layout of the 85 kJ pulse generator are described. First results of measurements on pinch dynamics are reported.

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Abstract

Earlier investigations of the magnetic field dynamics of z-pinches and of the long-term plasma–wall interactions have led to the construction of a new plasma-lens device for the CERN antiproton source. After testing, the plasma lens will be installed in the target area of the CERN Antiproton Accumulator Complex. The mechanical design of the lens and the layout of the 85 kJ pulse generator are described. First results of measurements on pinch dynamics are reported.

History and Status

The first powerful plasma lens for charged-particle focusing was built and installed in the AGS at BNL in 1965 [1]. This plasma lens successfully focused muons for a neutrino experiment, but then failed completely after a few hours of operation. Since then, no further applications of this kind have been pursued, partly because of this dramatic failure, but also because of the general cessation of z-pinch research for fusion purposes.

In 1984, an experimental study of z-pinch plasma lenses was started at CERN, with the aim of providing a strong collector lens for the CERN antiproton source [2, 3]. Using several prototype lenses and pulse generators, the plasma dynamics in such lenses was investigated over a large range of geometrical, electrical, and plasma parameters. The experimentally determined scaling laws of pinch radius, pinch time, and maximum current in the pinched column as functions of the gas filling and of the geometrical and electrical parameters, were introduced into a one-dimensional magnetohydrodynamic z-pinch model [4]. The optimization of focusing power requires good temporal matching of the pulse generator and the plasma dynamics. Plasma instabilities have been generally observed only after the moment of maximum plasma-column contraction. In long-term tests, the potential failure mechanisms of the plasma lens—such as insulator wall evaporation, electrode erosion, and dust formation rates—were quantitatively investigated.

After these basic studies a collaboration between CERN and the Phys. Inst. of the Univ. of Erlangen was started in January 1989 with the aim to build a plasma lens for testing in the CERN AAC target area. The design parameters for this lens are a stable plasma column of a radial dimension of 20 mm and a length of 29 cm, carrying an axial current of 400 kA for a time of at least 0.5 μs. On the radius of 20 mm a poloidal magnetic field amplitude of 4 T shall be reached. The plasma geometry is optimized to an iridium target, 55 mm long, positioned 70 mm upstream of the plasma column.

Design of the New Plasma Lens

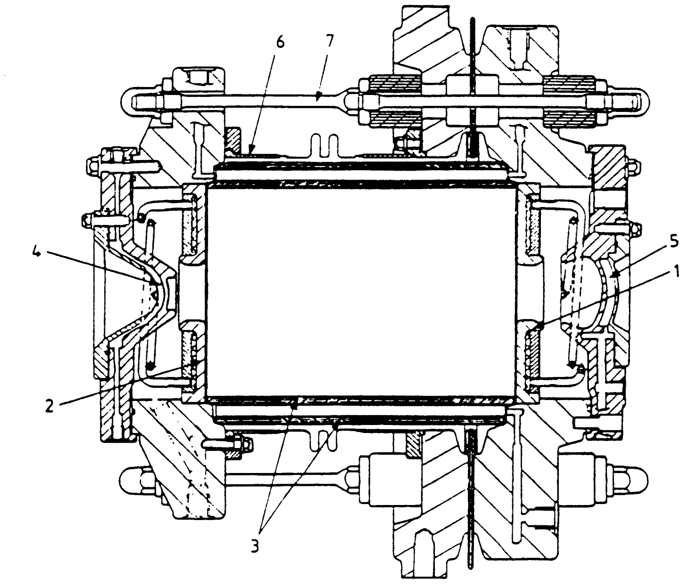

Fig. 1 Cross-section of plasma lens: 1: Hollow anode. 2: Hollow cathode. 3: Insulator tubes. 4: Beam entrance window. 5: Beam exit window. 6: Return conductor. 7: Clamping bolts.

Figure 1 shows the mechanical design of the plasma lens. Two hollow electrodes enclose two concentric aluminium-oxide insulator tubes, 290 mm in length. The inner diameter of the inner cylinder is 200 mm. The interior is tightly closed by graphite seals between the electrodes and both ceramic tubes. The electrode disks, with centre holes of 52 mm diameter facing the discharge volume, are made of pure tungsten. The upstream entrance window extends into the hollow cathode so as to cope with the correct positioning of the target. Its diameter is smaller than that of the exit window because the lens will accept only a finite angle (100 mrad) of the entering antiprotons, whereas the exit window is passed by a quasiparallel beam of 40 to 50 mm diameter.

All parts of the hollow electrodes, the beam windows, and the double insulator tubes are water-cooled. There are only two gases that lead to an acceptable evaporation rate of the aluminium-oxide tube: hydrogen and deuterium. The gas is injected from the anode side and pumped out through the hollow cathode. Dust, which is formed inside the plasma-lens volume, is blown out when necessary by a special evacuation circuit. The plasma-lens current flows back through a fully symmetric return conductor, which is connected by a flange to the cold conductor of a short strip-line (Figs. 1 and 2a). The hot conductor of this strip-line is connected directly to the plasma-lens anode flange.

The plasma lens and its short strip-line are mounted on a movable trolley. A clamp provides the connection between this short strip-line and a long one, which is the link to the main pulse generator.

Pulse Generator

The main plasma lens pulse generator was assembled from existing components, such as capacitor banks equipped with ignitron main and crowbar switches, trigger units, pulse cables,

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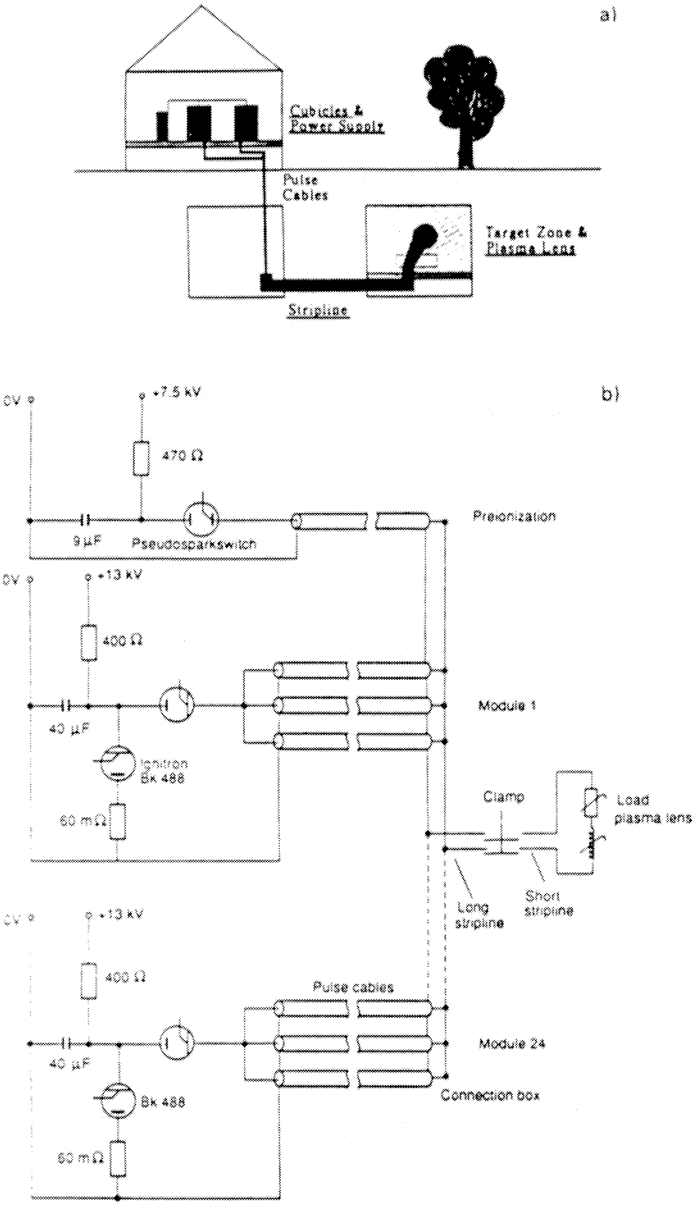

Fig. 2 Plasma-lens pulse generator: a) Topological layout for installation at AAC; b) Schema of electrical circuit.

and a 6 m long strip-line. Eight capacitor banks, each with a capacity of 120 μF and comprising three main and three crowbar ignitrons, can be connected in a modular way (Fig. 2b). The maximum charging voltage is 13 kV, corresponding to a total stored energy of 81 kJ. A 13 kV/6.5 A HV power supply charges the capacitor banks. In a laboratory area, the capacitor banks were connected to the plasma lens by 72 low-inductance HV pulse cables, each 25 m long. This layout is identical, electrically, to the final system (Fig. 2a), which will be installed in the AAC target area.

An important factor for the symmetric and stable implosion of the plasma column is to have a sufficient and symmetric preionization of the plasma-lens volume. Direct-current preionization was not possible with currents below 0.5 A, because the large capacity between the ignitron switches and the plasma-lens load caused erratic discharges inside the lens. These high d.c. preionization currents destroy the symmetry and the homogeneity of the dynamic z-pinch due to their magnetic self-fields, which lead to a resultant inhomogeneous preionization. Therefore, a dedicated pulse generator with a storage capacity of 9 μF was built. The capacitors are discharged directly into the plasma lens by means of a high-current pseudospark switch [5] and a pulse cable, 40 m in length. With a charging voltage of 7.5 kV, a peak current of 20 kA is reached in the lens during the first half-wave. During this first half-wave, also the discharge of the capacitor banks of the main pulse generator has to be triggered.

First Test Results

Voltage and current measurements have been performed on the complete set-up, using commercial HV probes and Rogowski coils, respectively. Magnetic field distribution measurements were done with two probes, in the same way as described in Ref. [6]. Figure 3 shows a set of magnetic field waveforms measured at a radius of 40 mm at a charging voltage of 7.5 kV and with a deuterium fill of 1000 Pa. The good reproducibility up to the moment of the pinch shows the positive influence of the pulsed preionization (7.5 kV/20 kA), which leads to a symmetrical implosion of the plasma front starting from the inner insulator wall. Figure 4 shows the trigger pulse and the waveforms of the total lens current, including the preionization current and the lens voltage, measured at 7.5 kV, 1000 Pa hydrogen.

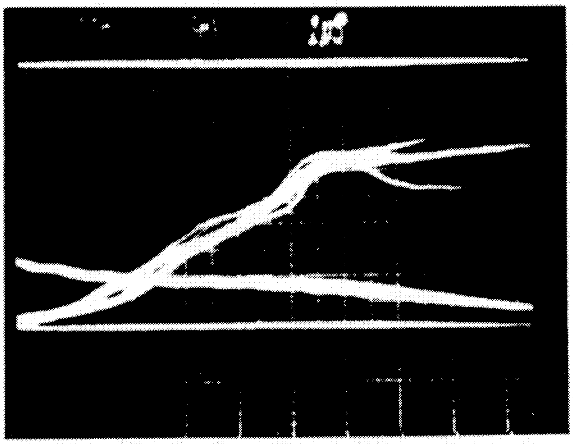

Fig. 3 Waveforms of magnetic field measured with a field probe at a radius of 40 mm, with a charging voltage of 7.5 kV and a deuterium fill of 1000 Pa.

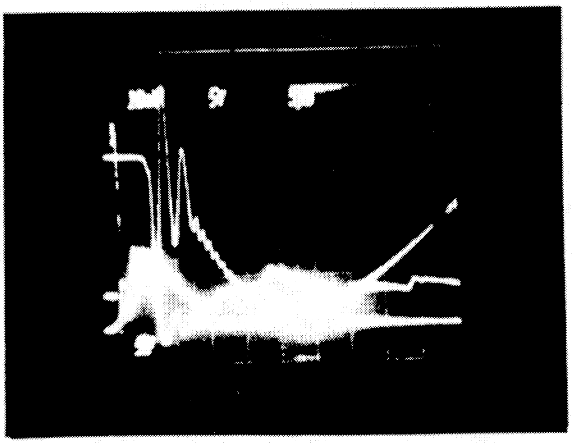

Fig. 4 Waveforms of plasma-lens preionization and main current and voltage across the lens for a charging voltage of 7.5 kV, 1000 Pa hydrogen, and a preionization current of 20 kA produced by 7.5 kV.

Outlook

The desired design figures of the AAC plasma lens are expected to be reached during the first tests of the full system. Now the specifications and parameters for a long-term test have to be determined. The life-test has to prove that a plasma lens can operate reliably over periods corresponding to accelerator runs (several months). The repetition rate of the system will be 0.21 Hz.

The installation of the plasma lens for tests in the AAC target area is planned for early 1991. Graphite electrodes will be developed, which may then replace the tungsten electrodes. Graphite leads to less induced radioactivity, absorbs considerably fewer antiprotons than does tungsten, and reduces the weight of the lens. The first aim of the target-area installation is to optimize the lens parameters. The antiproton yield is, theoretically [7], about 15% higher than that obtained with the focusing lenses used previously in this area.

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