Beam Tests with the CERN Plasma Lens

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Abstract

The results of the first beam test with the CERN plasma lens are reported and discussed. Two types of measurements were made. The antiproton yields were measured in collector mode after the antiproton production target. With an inversely injected proton beam the optical properties of the plasma lens were investigated. From both measurements the magnetic field gradient of the lens can be estimated to be about 185 T/m. The long term effects on the lens were studied by further pulsing and inspection of the lens in the laboratory after the first beam test. The results proove that the plasma lens technology is reliable for accelerator applications.

1. INTRODUCTION

The CERN plasma lens is based on a dynamical z-pinch discharge. Due to the cylindrically symmetric current distribution it focuses a particle beam by means of the azimuthal magnetic field. Comparable focusing strength can also be obtained with a magnetic horn or a lithium lens. The CERN plasma lens is especially designed for collecting 3.6 GeV/c antiprotons produced in a target [1,2].

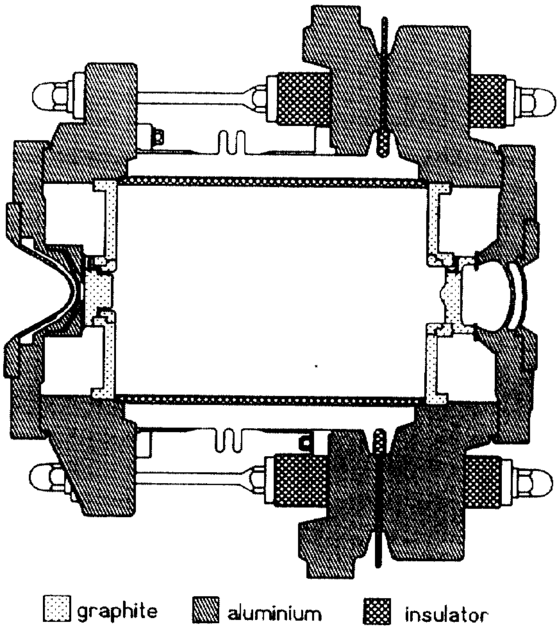
2. PULSE GENERATOR AND PLASMA LENS

The plasma lens consists of two graphite electrodes, separated by a 290 mm long alumina insulator (200 mm Ø). The vacuum chamber is sealed with graphite rings and contains helium in a pressure regime between 500 and 1500 Pa. The lens is operated with a steady gas flow through the cathode and anode flange. Both aluminium windows are protected against plasma erosion with graphite screens (Fig.1). Electrodes and windows are water cooled, whereas the insulator is cooled by compressed air.

For pulsing the lens a capacitor bank of 720 µF capacitance was discharged with a repetition rate of one pulse per 14 s. Table 1 shows the data of the pulse generator. Before starting the beam test the performance of the plasma lens was investigated in the laboratory by means of magnetic field measurements, short time photography and long term tests [3].

Table 1.
Data of the pulse generator

capacitance	720	µF
charging voltage	13	kV
inductance	85	nH
stored energy	61	kJ



3. BEAM TEST

The first plasma lens beam test took place in March 1991. The results with a short data evaluation, and the experimental set up are described in [3], whereas a detailed account of the beamtest is given in [4] and [5].

3.1 Optical Imaging Properties

With a proton beam passing in the inverse direction through the plasma lens the focussing properties of the lens have been investigated. The focus of the beam was monitored by a SIT-camera and a luminescent alumina-screen which was mounted 300 mm behind the nominal focal point. Since the magnetic field in the lens increases with time from zero the focal point starts at infinity and moves from down stream towards the screen. The smallest beam diameter is reached when the focal point is on the screen. When the focal point moves through the screen and finally comes to its designed position the beam diameter at the screen expands. This evolution of the focus diameter in time is shown in Fig.2 for two different gas pressures. The time is counted from the start of the discharge current through the plasma lens. For lower pressure, higher magnetic field gradients are achieved as the focus diameter at pinch time is larger.

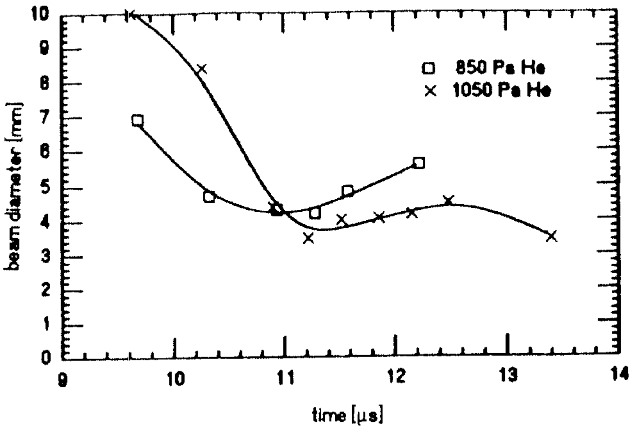


Figure 2. Evolution of the focus diameter with time

Figure 3 shows the observed beam diameter and the diameter computed with linear optics. The magnetic field gradients used for computation were measured by magnetic probes in the laboratory. In the early stage of the discharge the current in the plasma column is flowing in a hollow cylinder due to the skin effect . At this time no magnetic field exists at the axis of the lens and the inner part of the proton beam is not focused onto the screen. So the observed beam diameter is larger than the calculated one. Here the magnetic field was extrapolated for the inner radii, as it was not possible to perform probe measurements at the axis.

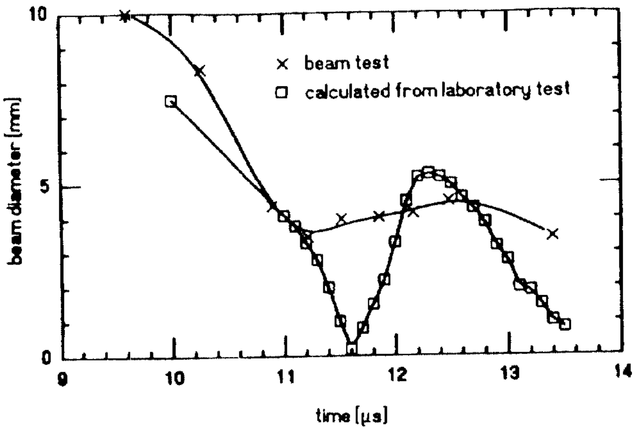


Figure 3. Comparison of calculated and experimental beam diameters

The lens has its maximal focusing force when the beam diameter reaches the maximum after the first minimum. The magnetic field gradients calculated from measured beam diameters are shown in Fig. 4 as a function of gas pressure and charging voltage. In the dashed region no stable and symmetric focusing was obtainable. A maximum magnetic field gradient of about 170 T/m was achieved.

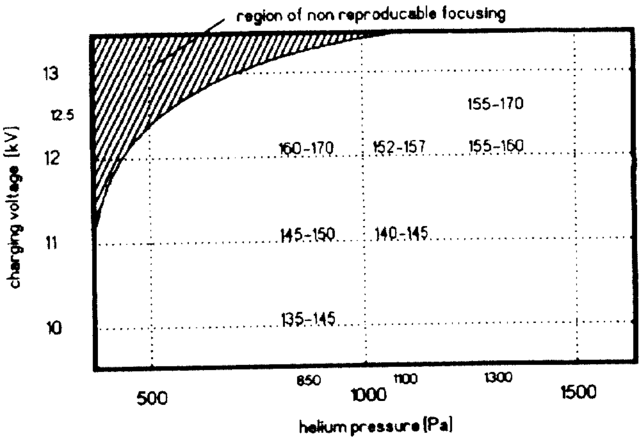


Figure 4. Magnetic field gradients [T/m] at pinch time as calculated from focus diameters

3.2 Antiproton production

For antiproton production a proton beam was focused onto an iridium target. The diverging antiprotons were collected by the plasma lens. The antiproton yield, i.e. the number of antiprotons with respect to the incident protons, was measured over a wide range of lens and machine parameters [4,5]. The results are summarized in table 2.

Table 2.
Yield for different lens and machine parameters

yield $10^{-7}\bar{p}/p$		helium pressure [Pa]				
		850	900	950	1000	1450
voltage [kV]	11		$46^{\square}$			
	12		$54^{\square}$			
	12.5	$45^{\diamond}$		$62^{\times}$	$55^{\square}$	$56^{\square}$
	13		$51^{\diamond}$			

optimized
- × timing, target distance, transport channel optics
- □ timing, target distance
- ◇ timing

The optimum yield, which is comparable to that obtained from other collecting devices like the magnetic horn or the 20-mm-lithium-lens, was achieved when all machine parameters were optimized simultanously for one plasma lens setting. In particular the timing between beam and lens, the distance between target and lens, and the optics of the transport channel to the storage ring had to be adjusted. During optimization the distance between target and lens was also changed. From the target position with the maximum yield the focal strength of the lens can be estimated. It corresponds to magnetic field gradients of about 185 T/m, a value which is in good agreement with the data of the inverse proton beam test and with the magnetic field measurements in the laboratory.

3.3 Long-term behaviour

During the beam test the plasma lens was pulsed 20000 times with a repetition rate of 1 shot per 14.4 s at a stored energy level of 56 kJ. After a warm up of about 50 pulses the lens runs stably and very reliably over hours. After a run of one hour at the highest possible energy level of 61 kJ (13 kV charging voltage) a deviation in the voltage signal was visible. Nevertheless the lens was still running very reliably at a lower charging voltage.

In the last night of the test a spark appeared between two earth points of the quadruple stripline feeding the lens and the test was stopped. At this time also the voltage waveform of the lens had changed. After five months cooling-down, the lens was opened in the laboratory. A small graphite ring of the anode (Fig.1) was found loose in the bottom of the insulator tube. It may have caused a wall current which explains the distorted voltage signal. After removal of the graphite ring the lens showed the same performance as in the final life test which was performed in the laboratory just before the beam test.

Both graphite screens and both electrodes showed erosion and were covered with deposits but no damage was detected. The evaporation of the insulator tube was much less than expected.

Due to the fact that the complete plasma lens is made of low Z-material, the induced radioactivity is much less than for a lithium lens with transformer. Also the decay of radioactivity is more rapid. Therefore it was possible to run the lens in the laboratory after five months cooling-down. After exchange of the stainless steel screws, the radiation in direct contact was about 2 mrem/h at this time (Fig. 5).

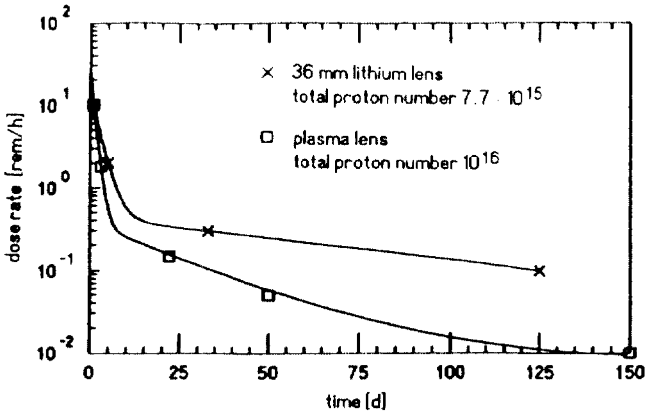


Figure 5. Induced radioactivity

The powder inside the lens was investigated, both by chemical analysis and by radiation measurements. A survey of the radioactive isotopes within the lens powder is given in table 3. The powder itself consist mainly of aluminium and alumina from the insulator tube. No carbon was detected. Most of the evaporated material was extracted by the pumps.

Table 3.
Isotopes of lens powder

Isotope	T(1/2)	activity Bq/g
7 Be	53 d	236
22 Na	2.6 y	64
54 Mn	312 d	0.27
57 Co	271 d	0.28

4. OUTLOOK

For the second beam test which will take place in May 1992 an improved diagnostics for the inverse proton beam is foreseen. Then it should be possible to determine the focusing properties of the lens during pinch time properly.

Meanwhile further laboratory tests show an improved stability of the z-pinch discharge if a few per cent of nitrogen is added to the discharge gas (helium). Also a reduced pinch diameter was observed. This results in a higher focusing strength of the lens as higher magnetic field gradients are achieved. Therefore an improved lens performance can be expected.

5. CONCLUSION

The first beam test of the plasma lens and the check of the lens performance in laboratory after the test, show that the plasma lens may be a reliable component of future accelerators. The limits of the focusing strength of a plasma lens are not yet investigated. The plasma lens may cover a wide range of applications. But one has to keep in mind that each plasma lens with new parameters needs development in the laboratory.

6. REFERENCES

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