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Report on High-Field Performance of a Modified Proton-Beam Lithium Lens

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The first version of the lithium lens developed by the Institute of Nuclear Physics, Novosibirsk, to focus the proton beam onto the target of the Fermilab antiproton source was matched to the requirements of using the booster to decelerate the antiprotons. Therefore it was designed for rapid cycle operation. The rapid cycle requires fast heat transfer from the lithium conductor to the cooling water flowing in the hollow cylindrical shell of the titanium containing it. It proved possible with this lens to produce reliably a field of 100 kG at the surface of the .5 cm diameter conductor on a 13 Hz cycle. The details of this lens are described in TM-1000.[1] The targeting scheme evolving for the Tevatron Phase I project,[2] however, requires stronger proton beam focussing.[3] Fortunately, the longer cycle (∿ .1Hz) greatly simplifies the problem of raising the maximum field by allowing a thicker and thus stronger titanium envelope for the lithium conductor. This note reports the result of testing a lens very similar to the one described in TM-1000 except for a slightly heavier central piece.

A cross-section of the proton beam lens, is shown in the figure. The inner cylinder of lithium (2) is the optical element and carries the high current density. The water cooled titanium cylinder (1, 4) is the critical element in determining the maximum sustainable field. For the 13 Hz design the inner wall (1) is .7 mm thick. The field on the surface is 100 kG for 125 kA current. The average temperature of the lithium in 13 Hz operation is 170°C, only slightly below the melting temperature of 186°C. The lens has survived for > 10^7 pulses at 13 Hz.

At a length of 10 cm the 100 kG lens provides a maximum integral $\int Bd' d\ell$ of (10T/.0025 m) x .1 m = 400T, which is suitable for the original $\bar{p}$ proposal. Current ideas call for > 700.T.(3) The lens which had been used in the 10^7 pulse life test was tried at successively higher excitations to see how the existing design could be pushed. A 3-second cycle was used to avoid any problems from average power dissipation. As previously reported(1) the unmodified lens appeared to be able to survive 144 kG operation for at least a while (> 10^2 pulses) but failed at 164 kG. The failure occurred near the center of the inner titanium wall. One can lengthen the lens to increase the integral but only at the cost of increased beam loss to nuclear interactions. If one holds to the criterion of ∿ 10% absorbtion loss then the limit is about 10 cm of lithium. As a first step toward achieving the desired focussing, the lens shown in the figure was modified solely by increasing the thickness of the titanium (1) from the original .7 mm to 1 mm. This step reduces the water passage correspondingly but still permits several changes of water in a 2-second cycle. The joint between the inner and outer walls (2, 4) was expected to be more difficult to weld in the new version. When the first attempt at arc welding in argon failed, electron beam welding was tried with excellent results. However, analysis of the arc welding problem indicated that it resulted from failure to flush the cooling channel with argon rather than from special difficulty arising from the new design. A second attempt to use arc welding produced an apparently satisfactory joint. The lens which was tested was made with arc welds.

The new lens was determined to be free of serious construction errors by pulsing it at .5 Hz for about 4000 pulses at 150 kG (188 kA). The current was then increased in approximately 20 kA steps allowing ∿ 100 pulses at each step. The lens survived at 184 kG (230 kA) but failed after a few pulses at 200 kG (250 kA). The failure was again in the inner titanium wall; in this instance there was a clean transverse break near the center. Thus, the weld at the joining of the two titanium walls, which had been a problem during the development of the 13 Hz lens, has been improved sufficiently so that it can be relied upon at far higher fields than required originally.

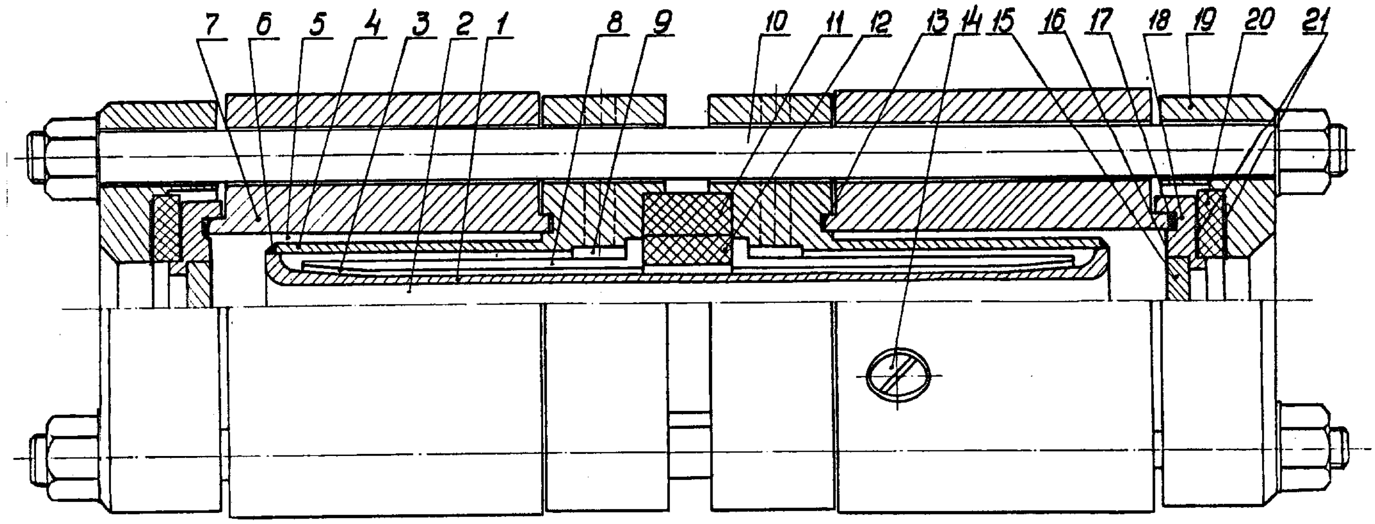
A conservative interpretation of these results is that one can rely on a lens with 1 mm inner wall to perform reliably at 150 kG. To obtain what is now thought to be the needed focussing strength, the external beams group at the Institute for Nuclear Physics is building a 12 cm version of the lens using nearly the same principles. Although the design will be the same, a number of new parts must be fabricated in the longer length and tests are not expected until late fall.

References

1. B. F. Bayanov et al., TM-1000 (August, 1980).

2. Design Report, Tevatron Phase I, Fermilab (February 1980).

3. B. F. Bayanov et al., XI Int'l. Conf. on High Energy Acc., CERN (to be published).



Cross section of the Proton-Beam Lithium Lens