CONDUCTING TARGETS FOR $\bar{p}$ PRODUCTION OF ACOL. PAST EXPERIENCE AND PROSPECTS

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Abstract

The Antiproton Collector (ACOL) project at CERN calls for a production target providing at least twice as many antiprotons into a given acceptance as the present passive target. The pulsed target under study must be able to withstand large current pulses of a hundred kiloamperes or more for 10 to 20 μs whilst at the same time it is hit by the proton beam of up to $2 \cdot 10^{13}$ ppp. Because of the very high radioactivity of the target region this new device should show a sufficient reliability before it is put into operation. Previous experimental work with an active target, both in the laboratory and in the AA proton beam line, has shown that such a target gives a measured gain of 50% in the $\bar{p}$ production yield, although the problem of making an assembly to withstand many weeks of pulsing has not been solved. A comparison of the main features of the four tests made in the AA is given. The mechanical and thermal behavior of a conducting metallic, solid or liquid target is studied, with particular emphasis on the shock wave, the thermal expansion and the magnetic unstable pinch effects, by means of computer calculations. A preliminary design of a metal conducting target is reported.

Introduction

The ACOL project, presently under way at CERN, aims to improve the antiproton production rate by a factor of ten, attaining eventually $6 \cdot 10^{10}$ $\bar{p}$'s per hour. In order to achieve this the antiproton production efficiency has to be improved by at least 50% although a final factor of 2 is sought.

Antiprotons are normally produced by the interaction of high energy protons (26 GeV/c in the case of the AA, the CERN antiproton source) with the nucleons along the length of a passive metal target. The points of production of the $\bar{p}$'s thus extend over a length typically of the order of one nuclear absorption length. In most suitable target materials this amounts to about 10 cm. The angular distribution of the $\bar{p}$'s is such that most of them are produced near to the maximum acceptable angle of the downstream focusing devices and clearly, the larger this acceptance angle, the greater the number of $\bar{p}$'s transported to the accumulator. Furthermore, the first focusing device, after the target, should have a short focal length, in order that its acceptance aperture is kept within realistic limits. Short focal lengths imply short depths of focus, which is incompatible with the extended line sources resulting from the use of passive metal targets.

This problem can be overcome by applying a large pulsed current (up to 200 kA) through the target itself, coincident with the passage of the interacting protons. In this way, the extended line source is transformed into a disc, aligned with the end face of the target, onto which the first downstream focusing lens can then be focused.

Such conducting targets are under development for the ACOL project and this paper reports on this work and the series of experiments carried out at CERN, both in the laboratory under high current loading only, and in the 26 GeV/c proton beam from the proton synchrotron.

Experience Gained with the Laboratory Tests

It is well known that the proton beam, hitting the AA passive target, produced temperatures close to that of the melting point of copper. The additional effects expected from applying a high current pulse were such that it was considered necessary to separate out the two effects and carry out laboratory tests on prototype high current targets in the laboratory, without beam.

Early in 1982 pulsed currents of up to 200 kA maximum and of 30 μs duration was delivered to more than 20 prototype targets of various materials and geometries (Fig. 1). The purpose of such tests was to point out any weak points in design and to seek solutions to a) the metal becoming plastic due to the high current heating and b) the problems of target assembly and welding, and c) the fact that the metals tested (hard copper, tungsten, Cu-Be 2%, Al, Cu-W alloys) have shown softening and pinch effect fracture as well as brittle fracture in the hard materials. Furthermore it was observed that the insulators, of graphite, Macor or Alumina also showed brittle fracture due to a combination of insufficient cooling and sparking after target breakdown.

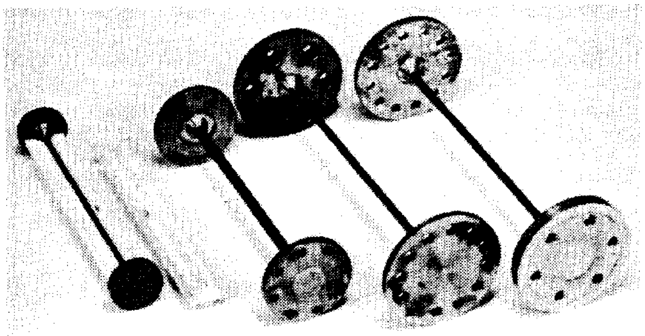

Fig. 1 - Prototype targets: the left hand side one with its insulator in two halves.

The unstable pinch effect phenomenon is very dependent upon the size of the gap which exists between the target and its enclosure. For example, a 0.01 mm radial gap over the whole target length represents a volume equivalent to 1% of the target volume and as such is too large to inhibit such pinch effects. It was concluded that a much closer tolerance is necessary in the conducting target, at its steady state working temperature.

The high current tests were not reproducible enough to allow definite conclusions to be reached about the best target material. However, it was fairly well established that: 1) copper or its alloys were good provided there was a full homogeneity over the whole of the target, including its end flanges, 2) with such materials, close and effective cooling is vital in order to avoid local melting and subsequent metal flow into interfaces. The resulting prototype target design involved a copper rod, machined with end flanges from one piece, and tightly held in graphite or ceramic half-shells, into which were machined small longitudinal grooves for cooling. The coaxial housing was designed to allow a small thermal expansion and tungsten "coins" were added to each end to prevent axial flow of

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the copper. Nitrogen gas cooling vented to the atmosphere was included, with the provision to revert to a closed circuit system using nitrogen or compressed air.

Tests in the AA Proton Beam Line

Conducting target tests in the AA were carried out in order to a) observe the effects of the proton pulse, of 10^{13} particles, repeated every 2.4 s, b) to verify the expected enhancement of $\bar{p}$ yield.

In these tests $\bar{p}$ yield was never fully optimized, and so the results obtained represent lower limits to the performance of respective targets.

In the first test the target was a 4 mm diameter copper rod, 110 mm long, imbedded in graphite, cooled by nitrogen (240 ℓ/min), and electrically in series with a standard horn. No drift space between the target and horn resulted in a best measured yield of $6 \cdot 10^{-7}$ $\bar{p}/p$ which is about equal to the best passive target yield. After dismounting, the target was found to be broken at the upstream end, after suffering only 50 pulses at the AA repetition rate.

Subsequent tests in 1983 were basically identical except that a drift space, between target and horn, was incorporated, as shown in Fig. 2. In March, a yield of $8.1 \cdot 10^{-7}$ $\bar{p}/p$ was obtained with a current of 110 kA into a Cu target 100 mm long and 3 mm diameter. Theoretical predictions were somewhat higher than this, the discrepancy being due to a poor proton beam emittance and imperfect downstream optical matching. A shorter drift space was included in the next test for which a yield of $9.2 \cdot 10^{-7}$ $\bar{p}/p$ was recorded, with a current of 140 kA and a proton beam intensity of $9 \cdot 10^{12}$ p. This measurement was the first to show that a 50% gain in yield was really a possibility. A subsequent stacking test with the same target resulted in breakdown after 2 h total operation time with 10^{13} p every 4.8 s. After radioactivity cool-down, the target was dismantled and found broken at the upstream end as was also the surrounding graphite sleeve.

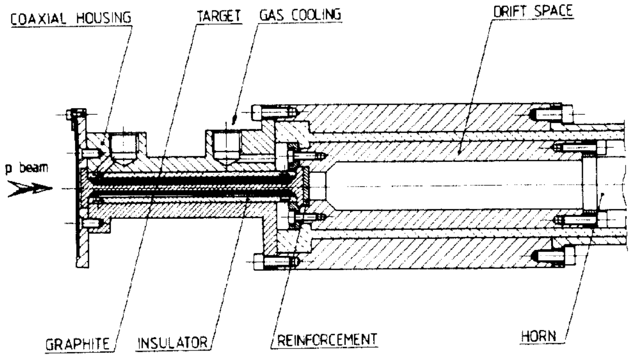

Fig. 2

At this moment in time it was decided to separate the horn and the conducting target in order to allow different currents in each. A movable support to the target was also fabricated, allowing for an optimization of the target-horn separation. With these additional facilities, the measured yield with a Cu-Be 2% target, of length 110 mm and diameter 3 mm, was found to be $8.3 \cdot 10^{-7}$ $\bar{p}/p$ with a horn current of 145 kA and a target current of 70 kA. A stacking test again resulted in target fracture after 2 h of total running time. Subsequent examination revealed that 20 mm of the target length had disappeared and the Al_2O_3 insulator was broken into many pieces. It is assumed that under the combined effects of the magnetic pinch and the target heating, an irreversible process of plastic flow occurs which leads to target breakage. Shock wave effects cannot be discounted and may in future designs be minimized by appropriate matching of shock wave impedances.

Beam Shock Wave Effects in Antiproton Targets

Hydrodynamic calculations of shock wave transients, resulting from sudden beam energy deposition, have been carried out, using the computer code REXCO[1]. Emphasis was placed in these calculations on targets of solid copper and liquid mercury in order to see whether or not, from the shock wave point of view, a liquid target produced less dramatic and detrimental effects, which, when used in conducting mode, might lead to a long target lifetime.

The conclusions reached were:

a) predictions of the program, in the case of a simple enclosed mercury column, were as expected and could provide hope that, with a ceramic of gradually increasing bore, self pumping of the mercury could be possible, although no precise calculations were made to verify this.

b) very large radial strains were shown to exist in the components of the conventional copper target, especially at the copper ceramic interface which agree with the damage observed in metallurgical examination of such targets. Pinch distortion effects have also been observed in the copper at long times after energy injection. These were not apparent with mercury.

c) the stresses and strains of the vessel in conventional Cu target and the pre-stressed Cu target are oscillatory in nature. High radial strains also exist at the copper-ceramic interface of the pre-stressed target, which could produce the same damage as observed in the conventional target. Hydrostatic loading does not appear to prevent dynamic separation of copper and ceramic. Non-axial uniformity of the container response, combined with the magnetic field induced pinch may lead to axial flow of the copper.

d) both solid targets display a non-return to normal central zone density over the time of computation and, if this effect is cumulative, one might conclude that the $\bar{p}/p$ efficiency would decrease with time, due to this effect, combined with metallurgical deterioration or change in structure of the target.

e) sufficient evidence exists to suggest that a liquid metal target may have more chance of long term survival than a solid one, especially if the enclosure problem is overcome by containing the liquid metal in a closed circuit or pre-pressurized tantalum or titanium cylinder.

The shock wave impedances of target and container materials, can be evaluated as a function of shock wave of pressure. It is interesting to note that the impedances of titanium, Al_2O_3 and mercury are very similar at the shock wave pressures encountered in the antiproton target, whilst those of copper and graphite are very different. It is suggested that this is the main reason for the large difference in the stresses observed in the two types of target, as described previously. Consequently, a liquid target may not be the answer unless there is a complete shock impedance matching throughout the target.

Pre-Stressed Target

A new design of conducting target, shown in Fig. 3, was tested in March 1985. A comparison between calculated expectations and measured $\bar{p}$ yield are sum-

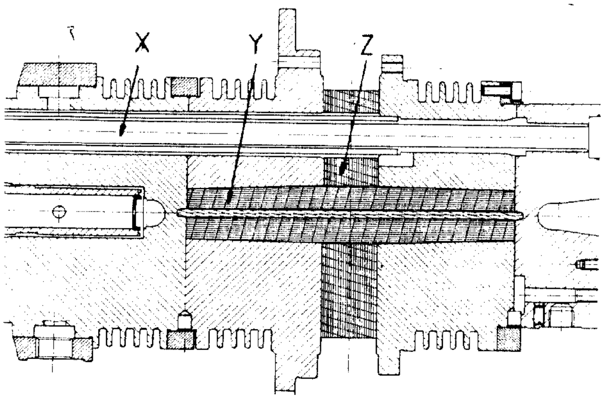

Fig. 3 - Pre-stressed geometry of conducting target

marized in Fig. 4. The target material was a silver rod, compressed into a conical Al_2O_3 insulator, and enclosed in a titanium alloy case. Although this target performed satisfactorily under high current testing, failure occurred after only a few hours in beam, the main symptom being an erratic pulsed current, varying from 130 kA to 80 kA. Subsequent examination of the target revealed a) the downstream current contact between the titanium and the silver was virtually destroyed, there being evidence of high current erosion of the titanium, coupled with pronounced silver liquid flow between the titanium-ceramic interface, even as far as the main tie bolts X; b) the main ceramic Y was split radially and flow of silver had occurred through the cracks; c) the spacer ceramic Z was split radially; d) the cooler upstream end of the target, although pitted, was far less damaged.

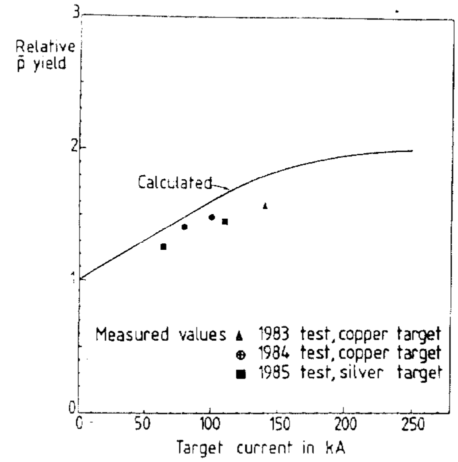

Fig. 4

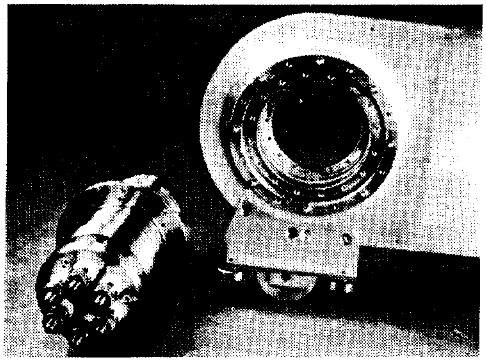

Fig. 5 - The pre-stressed target housing and sandwich line.

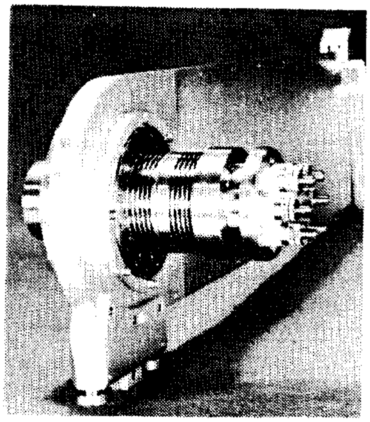

Fig. 6

The pre-stressed target mounted in the sandwich line.

Future Plans

Design and fabrication studies are under way with a view to testing three conducting targets, in beam, in July 1985. All of these designs are based upon the prestressed geometry of target, discussed in the previous section, and it is hoped that the targets ultimately chosen, will provide experience both with solid and liquid metal target materials. Likely candidates for these tests are:

a) a super strong, high melting point alloy, such as nickel base René 41 or Inconel 713C, but with a lower resistivity, operating in a solid condition.

b) a low melting point alloy, such as 70% indium-30% silver enclosed in a containing tube made from a refractory metal such as tantalum.

c) a soft low-resistivity metal, such as copper or silver, enclosed in tantalum.

d) a separated function target made up of alternating regions of high density material for high $\bar{p}$ production with low density, low resistivity material for $\bar{p}$ focusing.

All of these targets have been designed in order to minimize stresses, produced by beam and pulsed current, at an operating temperature of 800°C. Consideration has also been given to shock wave impedance matching throughout the whole target. Final choice will depend upon $\bar{p}/p$ yield calculations presently being made.

Conclusion

The tests made so far with this new technique have shown:

1) improvements in $\bar{p}$ yield of more than 50% have been observed.

2) the technical difficulties are now better understood though they are not yet solved.

The development of this new technique will be pursued in two directions: liquid metal targets which provide an automatic renewal of the target after each pulse and solid metal targets of high strength alloys for which reasonably long lifetimes have to be achieved

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