PS/ ACOL Note - 15
JCS/afm

12 January 1984

PROPOSAL FOR A RELIABLE SOLUTION OF THE IMPROVED PRODUCTION OF ANTIPROTONS FOR ACOL

J.C. Schnuriger

Summary

It is proposed to design, make and install in the AA target region a new high current horn to be used with a separated conducting target.

The horn and the conducting target being then fed by two independent pulsers, shall give a good reliability and the separate optimization of the horn and target currents should result in a substantial gain in antiproton production for AA and for ACOL.

Introduction

The accumulation rate of antiprotons in AA is lower than the designed rate by about a factor five. It was decided early in 1982 to study one of the possible ways to increase the antiproton production: the conducting target. Laboratory tests were made by connecting in series a horn and the experimental target (these tests were reported in the AA Long Term Note n° 4). These tests, all destructive, revealed the major weak points of a metallic rod of a diameter of 3 mm, submitted to a current pulse up to 200 kA and lasting 30 μs. In parallel with these laboratory tests, three experiments were made in AA with a conducting target and a horn electrically in series. Very encouraging results were obtained in which the best yields of antiproton production were 50% above the common yields (cf. ME Notes e.g. PS/AA/ME Note 58). In the last test the huge amount of energy released by the proton beam inside the target in half a microsecond during the current pulse of 140 kA caused the fracture of the target after one hour of antiproton accumulation.

Because of the very high radioactivity of the target region, it is necessary to get a sufficient reliability before this new technique may be considered for long operations. In the following a solution is proposed in which:

1. the horn and the target are independently fed by two pulsers allowing an independent replacement of either one.
2. a new horn is proposed for larger current, able to focuse antiprotons produced over larger angles than the present horn can.
3. only existing electrical equipment is used (except small items in the electronics) allowing the installation in the target region during next summer.

The Conducting Target: the Present State of this New Technique

A pulsed current is sent into the conducting target to focuse the antiprotons as soon as they are created. The current necessary to this focusing is in the range of 100 kA and the current pulse duration for a 3 mm diameter copper target is of the order of 30 µs in order to get a sufficient field penetration. These figures already represent a drastic problem of technology but what is more, the proton beam suddenly appearing inside the target releases an enormous amount of energy when the current is at its maximum. For example, in the last test made in AA (September 1983) we have the following figures:

Cu target diameter	3	mm
Cu target length	88	mm
Max. pulse current	140	kA
Max. magnetic field	18.66	T
Magnetic field gradient	12.44	T/mm
Max. current density	19.80	kA/mm^2
Max. magnetic pressure	1850	bars
Max. magnetic stress	37	daN/mm^2

Assuming an interpulse mean temperature of 100°C, the mean temperature rises to 123°C at the top of the current, then it jumps to 732°C because of the beam and continues to rise to 806°C at the end of the pulse (for a beam of 10^{13} protons whose energy deposited in the target is estimated to be 1300 J).

The maximum energy density is 2.4 kJ/cm^3, the total energy in the target is 1506 J and this energy gives an energy flux of 181 J/cm^2 to be extracted in 2.4 s. The stress is above the yield strength and even above the tensile strength of annealed copper at ambient temperature ! The estimated temperatures are well above the temperature where the metal becomes plastic.

The magnetic stress varies as the current squared and the inverse radius squared: to reduce the stress it is necessary to reduce the current or to increase the target radius. For a given proton beam the amount of energy density adiabatically introduced by the current is proportional to the current squared, the pulse length and inversely proportional to the radius to the power 4. If a ratio of radius upon skin depth is assumed to be constant (for the same field penetration), the energy density varies as the current squared and the inverse radius squared, and there is no other way to lower the energy density than a current reduction and/or a radius increase. For the matter of cooling a similar conclusion can be drawn: the energy flux varies as the current squared and the inverse radius. It is preferred to reduce the current instead of increasing the target radius mainly because the present proton spot size matches with the chosen target radius.

Technology of a Conducting Target

The engineering of a reliable conducting target depends primarily of the lifetime one can expect for. If it is assumed to last one day (or less) a system to remotely replace it must be considered. If it is assumed to withstand one month or more a manual replacement can be considered, similarly to the common replacement of the AA horn, in case of breakdown. One has then to accept a limitation in the improved antiproton production, as discussed in the last paragraph.

The tests made so far in the laboratory or in AA have permitted to draw a set of design principles for a conducting target (Fig. 1):

1. The target has to be radially and longitudinally constrained.
2. A strong cooling must be put as close as possible to the heat source.
3. The choice of materials of the target and its container must be made having in mind the thermal shock due to the high temperatures.

These principles are satisfied as well as possible in the present fabrication technique: the target is cast in a graphite mould of the wanted shape (a rod with two conical end flanges). This technique eliminates the small voids in the plane of contact, but shrinkage of the cast target in its mould is present. The graphite is then machined to its final shape including small grooves for the passage of nitrogen to give the necessary close cooling.

Gas cooling is preferred for reasons of practicability and reliability. Its limitation is in the maximum gas speed one can achieve below the sound velocity. Nitrogen has been chosen as air can give a surface combustion of graphite at temperatures higher than 450°C.

The casting technique sets a limited choice of target materials. The oven used for that being limited to 1400°C, copper or copper alloys only have been used till now. The best choice of target material seems to be copper + 2% beryllium as it gives a very hard material, but other alloys as copper-cadmium, molybdenium, steel and tungsten alloys should also be considered if a higher temperature oven can be used.

Alumina is used as insulator around the graphite: a thermal schock resistant quality is chosen. Alumina could also be used as mould instead of the graphite mould but it is difficult to machine it to complicated shapes. This solution is being pursued at present. Other solutions one can imagine to satisfy the constraint principle: shrink-fitting of the target in a hard metallic tube, extrusion of the target in a hard metallic tube or alumina insulator, etc., and those are also being pursued but with a lower priority

Horn to Capture Large Angles

The horn which has shown a quasi-perfect reliability in AA is a coaxial air-core magnet made of a thin sheet of conductor shaped to focuse the particles. It is used in AA to focuse the diverging antiproton trajectories coming out of the target into a quasi-parallel beam. For a given current going through the horn, its shape can be made such as to focuse the trajectories issuing from a point source but the resulting shape is reentrant for large angles (the inner conductor of the horn has a maximum radius in between its two ends). This raises technical difficulties of fabrication and a large antiproton reabsorption for large angles. If one considers only horns with non-reentrant shapes, one can show that the maximum angle α the horn can focuse is only dependent on the current. A study of horn shapes for different currents can be summarized in the following way:

1. for shapes similar to the AA horn shape the maximum angle $\hat{\alpha}$ is approximately:

$$\hat{\alpha} \simeq 0.78\theta$$

with θ = strength of the horn (in rad).

$$\theta^2 = \frac{\mu_0 I}{2\pi(B\rho)} = 2 \cdot 10^{-7} \frac{I}{(B\rho)}$$

$B\rho$ = particle rigidity (Tm).

2. For horn shapes having a long end cone the angle $\hat{\alpha}$ is between $0.78\,\theta$ and θ.

3. For horn shapes giving a constant focal length one has $\hat{\alpha} = \theta$.

It is proposed to make a new horn of non-reentrant shape, able to withstand currents up to 250 kA, shaped to focuse angles up to 65 mrad.

The equations of the horn shape giving a focal length f are (see figure in the appendix):

$$\left\{ \begin{array}{l} R_H = f \ \alpha \ \exp(-\alpha^2/2\theta^2) \\ Z_H = f \ \exp(-\alpha^2/2\theta^2) \end{array} \right.$$

$$\left\{ \begin{array}{l} R = f \ \alpha \\ Z = Z_H + R \ \sqrt{(\pi/2)} \ \mathrm{erf}(\alpha/\sqrt{2} \ \theta)/\theta \end{array} \right.$$

Parameter List of the Horn

I	250	kA
θ	64.75	mrad
f	0.3	m
$R_{H\ max}$	11.8	mm
$Z_{H\ max}$	181.2	mm
R_{max}	19.5	mm
Z_{max}	439.6	mm
Thickness	> 1	mm
Neck radius	4	mm
Neck hole	2	mm
Material	Anticorodal	
Cooling	Compressed air (through hole and outside)	
Resistance	0.15	mΩ
Inductance	70	nH

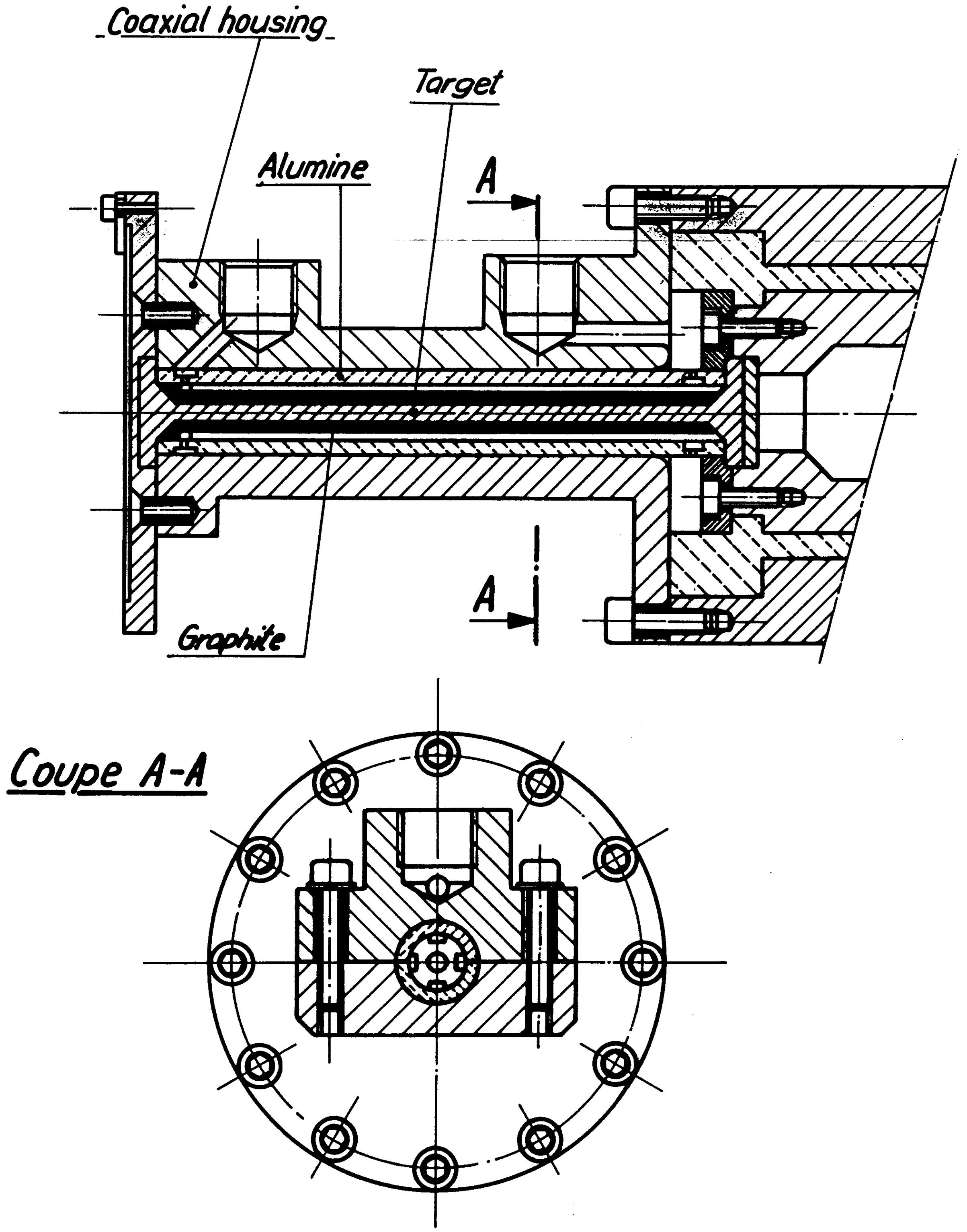
The detailed shape is given in the appendix.

The modified pulser used for the Li lens test of September 1983 can be used to feed the conducting target and the separated horn by adequately dividing the 12 existing modules between them. The charging power supply developed for this test can also be used to charge the horn modules, the present horn charging supply being used to charge the modules feeding the target. Providing the necessary electronics can be implemented in due time, the present proposal makes use of existing electrical equipment only. The delivery time would therefore only rely upon the target closed circuit cooling system and the horn: it is not impossible that this equipment can be ready for Summer 1984 if the manpower can be found for them.

Conclusion

It is proposed to improve the antiproton production for AA and ACOL by use of a separated conducting target and a new high current horn. By choosing a reasonable current for the target, it will be possible to get a sufficient reliability and therefore interventions of the staff in the radioactive target region will be minimized. To the contrary by feeding the new horn by current larger than the present horn current, it will be possible to capture efficiently angles up to 65 mrad. This proposal makes use of existing electrical equipment and can then be implemented in a short delivery time leaving open the progressive completion of the improved production of antiprotons for ACOL by a more efficient conducting target, by the lithium lens and/or the plasma lens now under study. The antiproton production yield will then progressively increase according to the progress of the various elements.

INDICE	DATE	NOM	MODIFICATION



QUANT.	DESCRIPTION	POS.	MATIERE	OBSERVATIONS

ENSEMBLE / ASSEMBLY

S. ENS./ S. ASSY.

Figure 1

Conducting target

ECHELLE SCALE		NOM	DATE
1:1	DESSINE		15.12.83
	CONTROLE		
	VU		
	REMPLACE		

INDICE

ORGANISATION EUROPEENNE POUR
LA RECHERCHE NUCLEAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

DIMENSION	≤ 6	> 6	>30	> 120	>315	>1000	> 2000
USINAGE GROSSIER / ROUGH MACHINING	±0,2	±0,5	±0,8	±1,2	±2	±3	±4
MECANO. SOUDURE / WELDED STRUCTURE	±0,5	±1	±2	±3	±5	±7	±10

TOLERANCES GENERALES

DESSIN, RUGOSITE, TOLERANCES SELON NORMES ISO
DRAWINGS, RUGOSITY, TOLERANCES ACCORDING TO ISO STANDARDS

Projection européenne
First angle projection

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APPENDIX
HORN SHAPE

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B*RO= 11.926 T*m
I= 250000 A
θ= 6.47496760096E-2 RAD
F= .3 m
RMAX= .02 m
α= .005 RAD
RH= 1.49553441039E-3 m
ZH= .299106882078 m
R= .0015 m
Z= .300894001567 m
α= .01 RAD
RH= 2.96443449862E-3 m
ZH= .296443449862 m
R= .003 m
Z= .303570436357 m
α= .015 RAD
RH= 4.38085493848E-3 m
ZH= .292056995899 m
R= .0045 m
Z= .308014217241 m
α= .02 RAD
RH= 5.72049573862E-3 m
ZH= .286024786931 m
R= .006 m
Z= .314198264701 m
α= .025 RAD
RH= 6.96129500198E-3 m
ZH= .278451800079 m
R= .0075 m
Z= .322086213034 m
α= .03 RAD
RH= 8.08403053974E-3 m
ZH= .269467684658 m
R= .009 m
Z= .331636170453 m
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α= .035 RAD
RH= 9.07280753627E-3 m
ZH= .259223072465 m
R= .0105 m
Z= .342790670267 m
α= .04 RAD
RH= 9.91541532638E-3 m
ZH= .24788538316 m
R= .012 m
Z= .355489241978 m
α= .045 RAD
RH= 1.06035429458E-2 m
ZH= .235634287684 m
R= .0135 m
Z= .369668999928 m
α= .05 RAD
RH= 1.11328500434E-2 m
ZH= .222657000868 m
R= .015 m
Z= .385250873658 m
α= .055 RAD
RH= 1.15028965884E-2 m
ZH= .209143574335 m
R= .0165 m
Z= .402161738249 m
α= .06 RAD
RH= 1.17169411715E-2 m
ZH= .195282352856 m
R= .018 m
Z= .420318347938 m
α= .065 RAD
RH= 1.17816232467E-2 m
ZH= .181255742257 m
R= .0195 m
Z= .439638716795 m
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