A MEGA WATT ELECTRON POSITRON CONVERSION TARGET A CONCEPTUAL DESIGN

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Summary

Intense sources of positrons are required to achieve in high energy electron-positron colliders the desired elevated luminosities. Positrons are produced by diverting part of the high energy electrons onto a target, from which low energy positrons are collected and re-injected into the e^--e^+ collider. Within the frame of a design study for a high luminosity beauty factory, ARES [1] presently under consideration at FRASCATI, a conceptual design has been worked out for the targeting of a 2 GeV-electron beam with an average current of 770 µA and an average power of 1.5 MW. In order to handle these extreme power densities, a rotating wheel is considered intercepting the beam at its periphery such that the beam power is spread around its circumference. The target concept has already been described earlier in Ref.[2]. In this article we summarize the principle features, consider certain critical technical aspects and discuss in some detail the prevailing radiation problems.

Layout of the Target Station

The principal parameters of the e^+ -source for ARES [1] are given below:

Energy of incident electrons	2 GeV
No of e^-/bunch	4×10^{11}
No of bunches/s	12×10^{3}
Beam diameter (FWHM)	1.2 mm
Average e^--beam current	770 µA
Average e^--beam power	1.5 MW
Tungsten target rods	$\diameter$=2 mm, l=20 mm
Average power absorbed in targets plus target support	ca. 0.8 MW

It is proposed to use a "multi-target" system where 628 targets, spaced by 5 mm from each other are arranged around the rim of a rotating, water-cooled wheel which has a diameter of 1 m. To synchronise the rotation of the wheel with the train of bunches incident at 12 kHz, a circumferential velocity of 60 m/s i.e. a rotational frequency of 1150 r.p.m. is required. The layout of the target station is shown in Fig.1 together with its principal components. For further details, the reader is referred to Ref. [2].

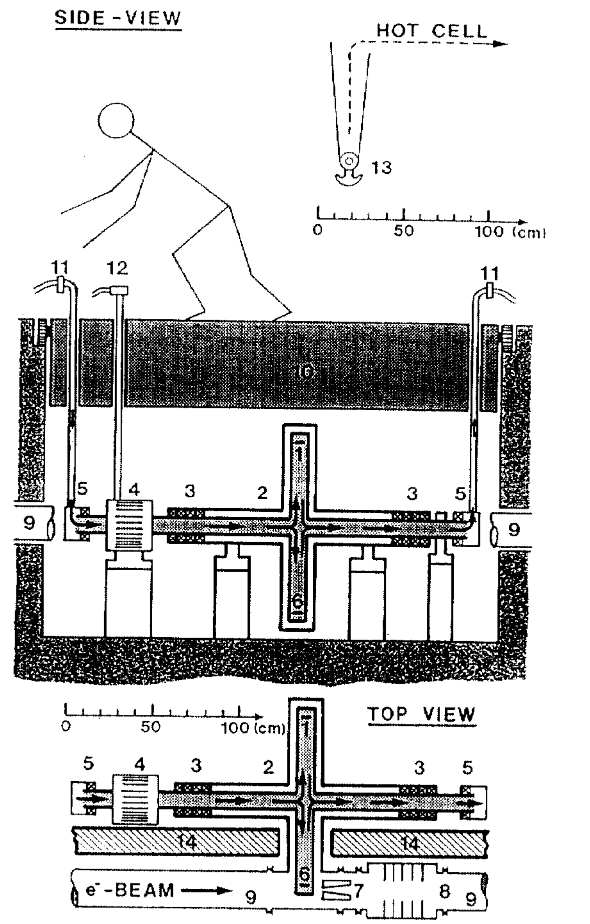

Fig.1: Side and top view of the e^+-target station. 1:Target Wheel; 2:Vacuum Tank; 3:Rotating Vacuum Feed-Through; 4:Motor; 5:Rotating Water Feed-through; 6:Tungsten Target; 7:Solenoid; 8:Acceleration Stage; 9:Beam Pipe; 10:Mobile Top Shield (Thickness 80 cm); 11:Cooling Water In/Outlets; 12:Electrical Supply; 13:Overhead Crane; 14:Local Shield.

Fig.2 shows various possibilities to contain the tungsten target proper within the water cooled copper of the wheel. Solution "1" might be technically the most convenient, since the rotation of the wheel does not have to be locked to the bunch frequency. On the other hand, the copper adjacent to the target is likely to be destroyed due to thermal shocks and fatigue. Solution "2" is presently adopted at the e^+ source of the SLC [3] for a, however, stationary, single target where no long term experience is yet available.

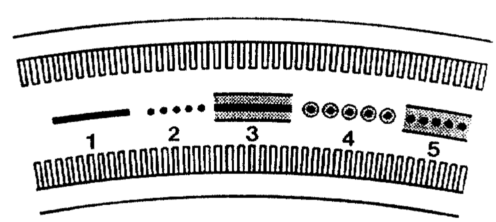

Fig.2: Various possibilities to mount the target material (solid parts) around the periphery of the water cooled target wheel. The target ribbon resp. rods are inserted either directly into the copper (1,2) or into intermediate graphite jackets (3,4,5).

In the further layouts "3-5" graphite is used as the immediate target container which has excellent thermal shock and radiation resistance. Solution "5" although leading to relatively high average temperatures is presently considered as the safest one since it has been successfully used for the CERN ACOL target [4] operating in a similar regime as each of the e^{+}-targets. No severe problems are expected in the copper structure adjacent to the graphite [2].

Computations with EGS4 were made to study the energy deposition downstream of the target where 60% of the incident energy escapes. Fig.3 shows a cut in radial direction through the wheel, where the copper has been extended in downstream direction for maximum energy containment in order to protect as much as possible the e^{+}-collecting elements. The power densities in the dashed area are valid for "stationary" copper, placed in the shadow of the rotating part of the wheel (not dashed). The closest possible position from the beam axis where thin walled and water cooled stationary copper structures, such as magnetic coils, might be placed, is at a radial distance of 2 cm where the power density is below 1 kW/cm³.

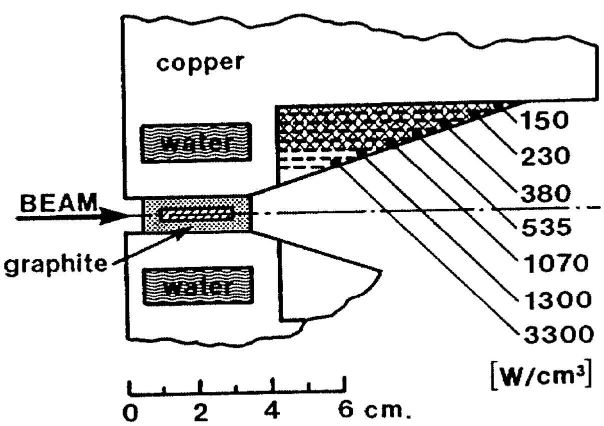

Fig.3: Radial cut through the periphery of the target wheel. The power densities in the dashed downstream zone are those for stationary copper, not rotating with the wheel.

Components placed along the circumferential direction of the wheel in the shadow of the graphite ribbon, cannot be protected by additional copper shielding and are thus submitted to the full radiation emerging from the target. Fig.4 shows the power density at that location, in stationary copper and aluminium. There the distance R to be respected for the safe operation of "unshielded", stationary components, is about 2 cm and 3.5 cm for thin-walled aluminium and copper structures respectively. To reduce further this distance which may be necessary for high field solenoids, as applied at the SLC[3], more efficient systems for the removal of heat such as liquid metals used as cooling fluid may be required.

As a last resort, one could envisage dedicating to each target on the wheel its proper focussing solenoid, as indicated in Fig. 5. The coils are individually energised when passing through the gap of a stationary

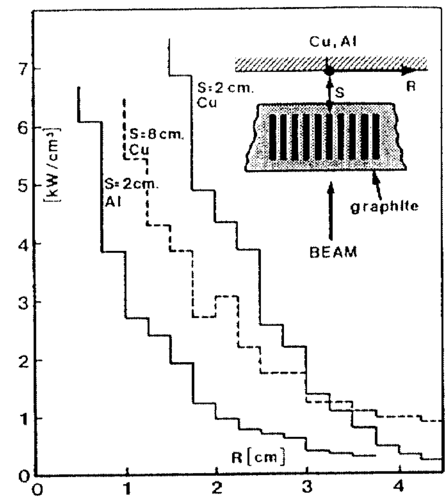

Fig.4: Power densities for stationary copper resp. aluminium placed downstream of the target wheel in the shadow of the graphite ribbon, containing the target rods.

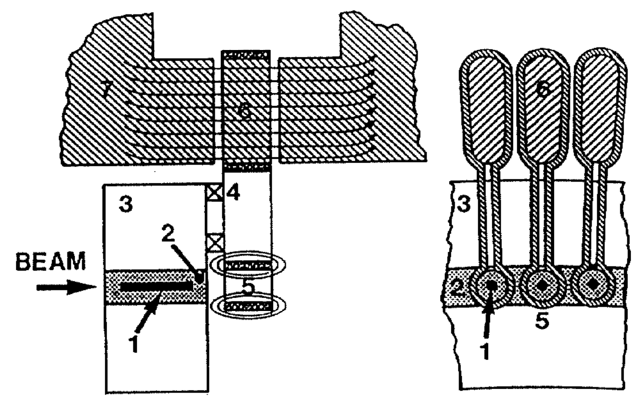

Fig.5: Radial cut and front view of the target wheel fitted with an array of focussing, single turn induction coils.
1:Target rod; 2:Graphite container; 3:Copper wheel; 4:Electrically insulating fixture; 5:Single coil solenoid; 6:Induction loop for solenoid; 7:Stationary, pulsed C-magnet.

induction coil placed well outside the radiation field. To create the space required for each coil the distance between the targets has however to be increased from 5 mm to at least 8 mm which could be achieved by modifying somewhat the parameters of the wheel, as its diameter, rotation frequency and number of targets.

The vacuum feed-through for the rotating axis of the target wheel is one of the basic components of the proposed concept for which adequate reliability and lifetime is essential. Thus, a system without gaskets is suggested (See Fig.6). It consists of a series of stationary chambers arranged around the axis. The diaphragms between the chambers are centered around the axis with a radial play of about 0.1 mm which limits the conductance between the chambers. By evacuating them separately with the appropriate type of pump and capacity, sufficiently low pressure should be attained [5].

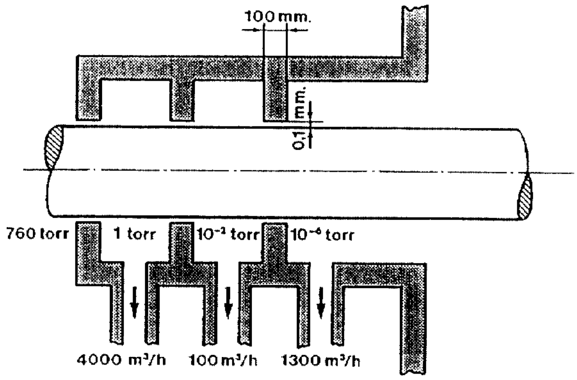

Fig.6: Feed-through for the rotating axis of the target wheel into the vacuum, achieved by differential pumping of a series of stationary chambers around the axis.

Radiation Problems around the Target Station

The layout of the target station as shown in Fig. 1 was set up in program EGS4, both in cylindrical and combinatorial geometry in order to calculate the energy deposition in the components, the shielding, the cooling water and the air of the cave. In addition, the energy depositions can also be related to induced radioactivity, to a definition of sufficient shielding around the target station and to a consideration of the production of noxious gases and corrosive chemicals. All these questions are extensively discussed in Ref.[6] hence only the most important results will be mentioned here.

In order to reduce dose rates on top of the shielding outside the target station during operation to levels of a non radiation area, a total bulk shielding of 4.5 m of concrete or equivalent has to be provided. Moreover, muons which often determine the shielding requirements in forward direction are absorbed in about three meters of earth or concrete due to their rather soft energy spectrum. A concrete shield above the target vault proper, 80 cm thick, is sufficient to protect components and to permit safe access into that area, once the beam is switched off.

The critical components with respect to radiation damage are the vacuum feedthroughs around the rotating shaft and the motor driving the target wheel for which the absorbed doses are given in Table 1. A value of 10^7 Gy is considered to be the limit for electrical components like motors. These can readily be achieved if a shielding wall of 25 cm thickness is placed between the beam line and the axis of the wheel (See item 14 in Fig.1).

Induced radioactivity is mostly due to (γ,n) reactions forming radionuclides in the various materials of the target cave. The target wheel presents the dominating radiation source. Following Ref.[7], with 800 kW of beam power lost in the wheel, dose rates of about 5-8 Sv/h are estimated at one meter distance from the target after 24 hours of radioactive cooling.

Table 1: Absorbed doses in Gy for a beam with 4.8 10^{15} e^-/s operating continuously over 100 days. For positions see Fig.1.

Positions	No Shield	25 cm Concrete Shield	25 cm Iron Shield
"4"	1.9 10^7	2.6 10^5	<10^5
"3" Upstream	4.5 10^7	1.1 10^5	<10^5
"3" Downstream	1.4 10^9	1.4 10^8	2.4 10^5
"5" Downstream	1.0 10^9	4.0 10^7	<10^5
Doses along the wall:			
Opposite "4"	2.6 10^6	4.7 10^5	<10^5
Opposite "6"	3.7 10^7	1.7 10^7	1.7 10^7
Opposite "3", downstream	1.2 10^8	9.9 10^6	<10^5

2.8 kW of beam power is directly absorbed in the cooling water which leads to a few mSv/h along the piping and in the heat exchangers outside the target cave. Moreover, radiolysis of the cooling water close to the targets is expected due to the high instantaneous dose rates of the order of 2 10^6 Gy/s during the pulse length of 10^{-12} s. Thus the formation of hydrogen and hydrogen peroxide and their catalytic recombination has to be considered.

Finally, a concentration of 6 10^3 Bq/cm³ of ^{13}N is formed in the air of the target cave. The area has to be ventilated in a closed system and a maximum reduction of a factor of six can be expected for a turnover of air of the order of twenty times per hour. Hence the air activity shortly after the beam has been switched off is about 1000 times the concentration limit. Another well-known problem around electron accelerators is the formation of ozone. For a specific energy of 2 10^{14} eV/cm³ deposited in the air of the target cave as calculated with EGS4 a concentration of 16 ppm is estimated, a value that can only be decreased by a massive increase in the ventilation rate. However, after switching off the beam and some cool-down time, the remanent activity as well as the ozone level will have decayed to tolerable levels.

References

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