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A CLOSED CIRCUIT AIR COOLING SYSTEM FOR THE NEW DESIGN OF PASSIVE TARGETS FOR ACOL

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1. INTRODUCTION

A new design of high density passive target for ACOL has recently been conceived, incorporating the concept of internal gas cooling, to keep the temperature of the inner titanium alloy case within the range 100-200°C, for PS beams up to intensities of 2×10^{13} p.p.p. Calculations have shown that this should just be possible with the closed circuit nitrogen system already available to the ACOL target zone but could be also accomplished using helium gas.

2. DESIGN FEATURES OF TARGET

A cross-sectional view of the new design is shown in Fig. 1 and incorporates the following features.

1) A titanium alloy (UTA6V) inner body surrounded by an outer case of aluminium alloy (6061), which is in contact with the inner case for much of its length, adding structural support. Both bodies are relatively thick (inner 7 mm wall and outer 12 mm wall thickness) and should stand the shock wave effects of the beam.

2) Four cooling ducts in the outer vessel inner wall which bring the cold gas to the snout of the titanium case. The return path is along four other cooling ducts, connected to the main aluminium case inlet parts by ducts at the interface.

3) The use of pyrolytic carbon to ensure an efficient flow of heat, in the radial direction only.

4) A separation of the iridium target slugs into three sections: thermally isolated from one another and from the front face of the inner titanium body.

3. *CALCULATIONS*

3.1 Target Inner Wall Temperature

Exact calculations are difficult because of the complex nature of the internal geometry of the target. The four inlet and four outlet channels are each of semicircular cross-section with R = 5 mm, each in contact with 10 mm of hot inner vessel wall and with 18 mm of somewhat colder outer aluminium wall. The temperature difference between these two parts of the channel wall will be a complex function of the thermal contact between them and the gas flow rate. Certain simplifying assumptions will have to be made. If it is assumed that all of these walls are at temperature Tw and for steady state heat transfer, then it can be shown[1] that the beam absorbed energy Q is given by the equation:

$$Q = \pi\, R_{eq}^2\, v_m\, \varrho\, c_p(Tw - T_0)\ 1 - 0.82e^{-m_0x} - 0.097e^{-m_1x} - 0.0135e^{-m_2x}$$

where R_{eq} is the radius of the equivalent size channel to the eight actually existing; x = length of the channels.

v_m is the gas flow velocity, ϱ the gas density, c_p the specific heat, T_0 the input gas temperature, and the coefficients m_0, m_1 and m_2 are given by the equation:

$$m_n = \frac{\beta_N^2}{2}\ \frac{\pi\lambda}{\varrho c_p \pi (R_{eq}^2) v_m}$$

where λ is the gas thermal conductivity, and where $\beta_0 = 2.705$, $\beta_1 = 6.66$ and $\beta_2 = 10.3$.

In order to use these equations, the parameters of the gas system must be evaluated. The nitrogen closed circuit system designed by G. Himbury is capable of delivering 17 m^3h^{-1} of nitrogen at up to 10 bar pressure and these figures will be used to evaluate the effect of nitrogen cooling.

Therefore

$$\dot{V}_m = 17\ m^3h^{-1} \qquad \text{giving} \qquad \pi R_{eq}^2 v_m = \dot{V}_m$$

or $\qquad v_m = 97.5 \times 10^3\ mh^{-1} \quad$ or $\quad 27.1\ ms^{-1}$

where $R_{eq} = (4/1.8)^{1/2}$ R = 7.45 mm since R = 5 mm, and there are four inlet channels, as shown.

For nitrogen, at 10 bar the density ϱ = 11.4 kg m^{-3}, the specific heat (c_p) = 1055 J kg^{-1}°C^{-1} and the thermal conductivity (λ) = 88 J $m^{-1}h^{-1}$°C^{-1}.

Therefore

$$m_0 = \frac{2.705^2 \times 3.142 \times 88}{2 \times 11.4 \times 1055 \times \dot{V}_m} = \frac{0.084}{\dot{V}_m} = 0.00494$$

and $\quad m_1 = 0.030 \quad$ and $\quad m_2 = 0.0716$

If the cooling channels are now assumed to have a length x of 0.10 m then the factor between square brackets in the equation is equal to f = 0.0709.

Finally, for a beam of 1.4×10^{13} p.p.p., the absorbed energy can be shown to be $\dot{E} = 2.205 \times 10^6$ J h^{-1}, therefore:

$$T_W - T_0 = \frac{2.205 \times 10^6}{\pi(0.00745)^2 \times 97.5 \times 10^3 \times 11.4 \times 1055 \times 0.0709} = 152°C$$

This value is not unreasonable for the mechanical properties of titanium at elevated temperatures and one is therefore encouraged to continue the calculations, specifically with respect to the gas flow. For this several quantities must be defined for nitrogen.

a) the gas velocity v = 27.1 m s^{-1},

b) the nitrogen gas density at 10 bar = 11.4 kg m^{-3},

c) the kinematic viscosity $\nu_0 = 0.146 \times 10^{-4}$ m^2 s^{-1},

d) the equivalent diameter for gas flow (D) of each channel = 8.18 mm,

e) the thermal conductivity of nitrogen (λ) = 0.0247 W m^{-1} °K^{-1},

f) the gas flow $m_0 = \varrho v(4\pi D^2/8) = 0.0325$ kg s^{-1},

The Prandtl Number $Pr = c_p\varrho\nu_0/\lambda = 7.11$.

The Reynold Number $Re = v\cdot D/\nu_0 = 15.183$.

The Nusselt Number $Nu = 0.023\ Re^{0,8}Pr^{0,3} = \alpha D/\lambda$ gives α = 276 $Jm^{-2}s^{-1}$°C^{-1}, from the equation of convection heat transfer for a gas in a channel of diameter D, and the temperature rise in the gas $\Delta T = T_1 - T_0$ is given by the equation:

$$\Delta T = \frac{\alpha \cdot S(T_W - T_0)}{m_0 c_p}$$

where S is the area of the heat transfer surface = $(\pi D/2) \cdot L \cdot 8 = 0.0103\ m^2$.

Finally $\underline{\Delta T = 13.8°C}$

a value which can be dealt with quite adequately by the existing system.

The pressure drop across the target (Δp) is given by the equation:

$$\Delta p = \varrho \left(\frac{\dot{E}}{\dot{m}} - c_p \cdot \Delta T\right)$$

$$= 11.4 \left(\frac{612.5}{0.0325} - 1055 \cdot 13.8\right)$$

$$= 11.4(18846 - 14559) = 48871.8\ Nm^{-2}$$

$$= 0.48 \times \text{atmosphere pressure}$$

i.e. very little of the × 10 atmosphere pressure delivered from the nitrogen supply system.

An additional feature which could be envisaged being added to the cooling system are 1 mm orifices placed in the gas input lines at position X of Fig. 1. These orifices are beyond the main body channels and would serve to cool the gas down before the snout region, assuming the process to be isentropic. If the pressure and temperature of the gas before the orifice are respectively P_1 and T_1 then the corresponding value of T_2 after the orifice is given by the expression:

$$T_2 = T_1(p_2/p_1)^{\gamma-1/\gamma}$$

where $\gamma = 1.4$ for a diatomic gas. If T_2 is taken as 300°K and $p_2/p_1 = (2/\gamma+1)^{\gamma/\gamma-1} = 0.53$ critical pressure ratio, then T_2 = 250°K, a drop of 50°K in temperature.

The conductance $\dot{V}_m$ of the orifice is given by the equation:

$$\dot{V}_m = 353 A\ r^{\gamma-1/2\gamma} \cdot r^{2\gamma-1/\gamma-1}\quad m^3 s^{-1}$$

for air at 20°C, where A is the orifice area, $r = p_2/p_1 = 0.5$.

For an orifice radius of 0.5×10^{-3} m, $A = 0.79 \times 10^{-6}$ m^2, yielding a $\dot{V}$ of 1.177×10^{-3} m^{3}s^{-1} or 0.64 m^{3}h^{-1}. Now this is approximately 1/25 of the output of the air system and since there are four orifices the whole throughput generated is approximately 20% of that of the system and this therefore suggests than an aperture somewhat greater than 1 mm in diameter is required.

The net gain will be that not only will the gas be cooled by 50°C before reaching the critical snout region but there will also be a barrier to reverse gas flow. Furthermore, more heat will be passed to the slower gas before the orifices on entry through the four inlet parts.

4. CONCLUSION

A nitrogen closed circuit system appears adequate for the target cooling provided the maximum throughput of 17 m^{3}h$^-$1 is possible at a pressure of 10 bar. The temperature rise of the target inner vessel wall has been shown to be 152°C above ambient, the gas temperature rise 14°C and the pressure drop across the target $\times$ 0.5 atmosphere pressure. Although one would gain from using helium, because of the high specific heat (5225 J kg^{-1}°C for air) the loss in density requires a pressure of at least 4 bar, for the system to be comparable. This is not practical with conventional Roots pumps, even if the system is proven leak tight which is difficult in itself.

REFERENCE

1. E. Jones, Heat Dissipation and Temperatures in the AA Target Shielding Wall, PS/AA/EJ/79-2, 1979.

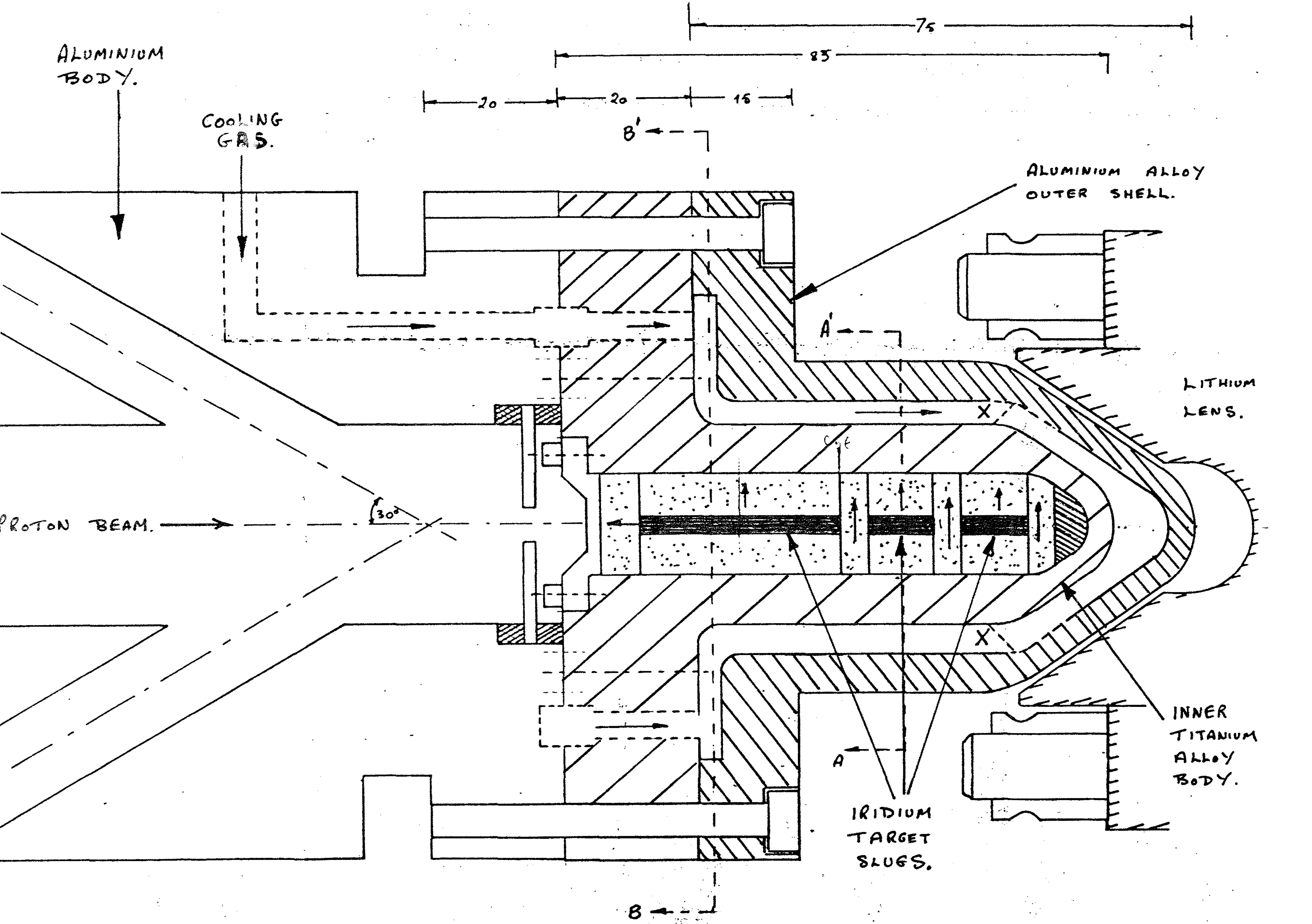

FIG 1 TENTATIVE DESI[illegible] OF HIGH DENSITY IRI[illegible]IUM TARGET.