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Improving the performance of the cryogenic heat pipe-target system for the COSY-TOF experiment

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ABSTRACT

Very lightweight, thin liquid hydrogen/deuterium heat pipe-target systems are used in the Time Of Flight (TOF) spectrometer at the COSY accelerator facility. The proton beam impinges upon LH_2/LD_2 targets thereby heating the target. The stability of the liquid targets depends on the thermal capacity of the whole system, the energy losses from the proton beam and heat losses from the surrounding of the heat pipe-target system. The radiation heat load has been reduced by a factor of 4.5 by reducing the length of the gas tube from 180 cm (long tube) to 40 cm (short tube). Furthermore, the 40 cm long gas tube was coated with a thin polished gold layer, thereby reducing the heat load by an additional factor 22. The thermal capacity is improved by reducing the mass of the gas tube from 23 g to 5 g. The cool down time of the 7 mm diameter gold coated heat pipe with the gold coated 40 cm gas tube is reduced by 12 min.

1. Introduction

Proton and deuteron beams from the COSY accelerator with momenta from 1 to 3.6 GeV/c are directed onto liquid H_2 and D_2 targets in order to study nuclear reactions. A long and narrow heat link between the target and the cooling machine is needed for two reasons. Firstly, the cooler has to be as far as possible from the reaction point to avoid secondary interactions. Secondly, shadowing of the detectors needs to be avoided. It is very important to minimize the background reactions and to have a stable liquid target. The heat pipe for the target and the mechanical system for liquefaction were designed to reduce the heat capacity and thus the cool down time. Fig. 1 shows a schematic diagram of the heat pipe with the target appendix, the internal tube and the aluminum condenser. A 7 mm diameter, 32 cm long heat pipe with a 0.1 mm thick stainless steel wall was developed. Many modifications have already been done to improve the performance of the heat pipe [1,2]. The amount of material, the surface area and the heat capacity have been reduced compared to the previously used 16 mm diameter heat pipe [1]. A copper heat conductor, condenser, stainless steel heat pipe of 16 mm diameter and an Al condenser were developed [3,4]. The Al condenser and the 7 mm diameter heat pipe significantly improve the performance of the system [5]. In the present work the gas tube length has been reduced from 180 cm to 40 cm and coated by a thin polished gold layer in order to reduce the heat load due to the thermal radiation and the thermal capacity in order to reduce the cool down time.

The stainless steel gas tube is polished before coated by many steps of polishing to get like mirror surface. The surface polishing is started with diamond paper grade number 400, 600, 800, 1200, 4000, 8000 and finally with 12,000. The polishing steps are followed by ultrasonic cleaner after every step. The gold coating is done in a professional company by evaporation method. The thickness of the gold coat is 0.1 mm. After coating the gas tube is highly polished by fine clothes until the surface was like mirror. Insulation against heat radiation to the cold parts of the target system was done so far by a stack of very light aluminized Mylar foils (super insulation). The heat pipe and the target are kept in high vacuum 0.5×10^{-6} mbar. As a further improvement, we show that sufficiently small heat load to the cold parts can also be achieved by coating the heat pipe and the target finger with a thin polished gold layer as shown in Fig. 2. The emissivity of a polished gold surface is 0.018 while it is 0.39 for polished stainless steel type 310 [6]. Coating the gas tube surface with 0.1 mm gold layer reduces the radiation heat power and improves stability and the characteristics of the target.

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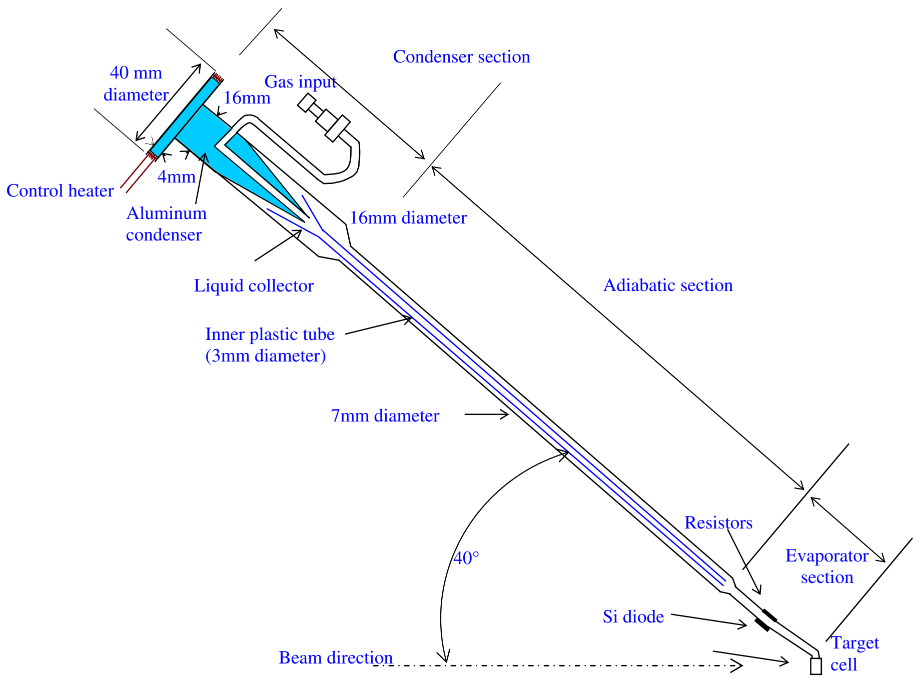

Fig. 1. Schematic diagram for the condenser–heat pipe-target combination.

2. Heat load to the heat pipe system

The condenser is fixed to the 2nd stage of the cooling machine by four stainless steel screws. The cooling machine (RGD 210 Leybold AG) uses a closed helium cycle with a compressor of which the input power cannot be regulated [7]. A target appendix with very thin copper walls (30 μm, made by galvanization) was used in the lower part as the evaporator. A silicon diode is attached to the target appendix to measure the liquid temperature in the target cell. A 3 mm diameter plastic tube with 0.1 mm wall thickness was used in the center of the heat pipe for liquid transportation between the condenser and the evaporator. The parameters of this target version are reported in [4]. The heat pipe, the target appendix and the gas tube have been coated with a thin polished gold layer to reduce the heat radiation from the surroundings (Fig. 2) instead of using super insulation made of a stack of 20 layers of aluminized Mylar foil.

The gas inside the heat pipe system has a pressure of 205 mbar at room temperature (i.e. the filling pressure required for sufficient liquid). This low pressure must be stabilized during the operation to stable values that are higher than the gas triple point (70 mbar, 13.9 K for hydrogen, and 171 mbar, 18.7 K for deuterium) to prevent the formation of solid hydrogen/deuterium that blocks the heat pipe operation. A pressure stabilization system is used for that purpose [4,5]. A very flexible cylindrical bellow (surface area 374 cm^2) with a weight of 77 kg on the top (lead blocks) is used as a reservoir. It is under the same vacuum as the target cell (enclosed by the same vacuum $\approx 10^{-6}$ mbar). The target and the reservoir are connected making a closed system that contains a constant amount of target material (H_2 or D_2, etc.) sufficient to fill the target cell with liquid. The absolute pressure in the gas reservoir and target cell is the sum of the pressure in the vacuum chamber and the additional pressure resulting from the weight.

In this work the performance of the cryogenic LH_2/D_2 targets for the COSY-TOF experiment has been improved by two modifications:

1- The gas inlet tube has been shortened from 180 cm to 40 cm.
2- The external surface of the gas tube has been coated by a highly polished thin gold layer.

The gas tube is used to connect between the outlet tube near the 1st stage ($T = 300$ K) and the inlet to the heat pipe ($T = 15$ K). Using a short gas tube reduces the surface area for radiation and also reduces the heat capacity because the mass of the gas tube is reduced from 23 g to 5 g. Fig. 2 shows the heat pipe-target system with the 180 cm and the 40 cm gas tubes.

The new system is extremely lightweight, extremely reliable and is now used as the standard system for the external COSY experiments. This allows for better access to the detectors in the reaction area. No bulky super insulation is needed anymore. Vacuum is improved around the target by avoiding the degassing between the many layers of super insulation.

The thermal heat load during liquefaction is very important because the stability of the liquid depends on the power of the cooling machine and the total heat losses. If the total heat losses are higher than the power of the cooling machine then the amount of liquid inside the target system will continuously gets smaller until it completely evaporates. However, if the total heat losses are lower than the cooling power of the cooling machine then a sufficient amount of liquid can be maintained in the system.

The heat losses are particularly important during the liquefaction phase, because they will determine the rate of liquefaction. The liquid will only arrive at the target cell if the liquefaction rate is above a minimum value. The heat losses to the target system result from three sources:

The first is the radiation heat from the surroundings, the second is the conduction heat from the contact with hot surfaces, and the third is convection. The convection heat losses are negligible due to the high vacuum isolation around the target system.

The radiation heat losses to the target system can be estimated by the following equation.