

Liquid helium cryopump and reliable opening device for a balloon-borne mass spectrometer

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The design, technical characteristics, and test and flight results of a liquid helium cryopump and an opening device operating on board a balloon-borne mass spectrometer combining a cryopump and a quadrupole mass filter are reported. The gas inlet of this mass spectrometer is opened through a simple and reliable remote-controlled system, which is also described.

INTRODUCTION

The cryopump system and opening device presented here have been developed for a balloon-borne quadrupole mass spectrometer, which is used for measuring the stratospheric ion composition above 30 km altitude.¹ Because of the relatively high gas density in this region (approximately 3 Torr at 37 km), an appropriate ion sampling system and high-speed vacuum pump are necessary to enable operation of the quadrupole mass filter and the accessory electron multiplier.

In our experiment ions are sampled through a hole with a diameter of 100 or 200 μm in a stainless steel flange which has a thickness at the edges of the hole of 0.1 mm. Thus a leak with a conductance of approximately 5×10^{-3} l/s is obtained. Assuming an external pressure of 3 Torr, a pumping speed of at least 300 l/s is necessary to maintain a vacuum of the order of 10^{-5} Torr in the mass spectrometer section of the apparatus.

Originally, investigators² measuring the mesospheric ion composition by means of rocket-borne payloads were using liquid nitrogen cryopumps. Subsequently, liquid helium cryopumps have been introduced for such experiments.^{3,4} However, installing liquid helium cryopumps in balloon-borne experiments is greatly complicated due to the requirement of long sampling part of flight, high pumping speed, and a reliable relief valve. The use of liquid nitrogen cryopumping systems⁵ as well as titanium sublimators⁶ in balloon-borne mass spectrometers has been reported in the literature.

I. LIQUID HELIUM CRYOPUMP

The liquid helium cooled cryopump we are using was developed and manufactured by Leybold-Heraeus GmbH and CO-KG (Cologne, West Germany). A general view is shown in Fig. 1. Some parts are simplified or not drawn in this sketch (such as the electron multiplier). The pump body is stainless steel and all flanges are sealed either with copper or polyimide O-rings. This superinsulated cryopump is insulated by vacuum and two copper radiation shields, which are cooled by the evaporating helium gas passing through a copper spiral attached to these radiation shields. To improve the efficiency of the thermal insulation, several layers of metallized glass fiber foil are wound on the radiation shields.

An inner blackened chevron baffle separates the ion lens and quadrupole unit from the liquid helium reservoir. The volume of the liquid helium reservoir is approximately 2.3 l.

The design and dimensions of the top and bottom flanges of the cryopump allow easy mounting of the gas

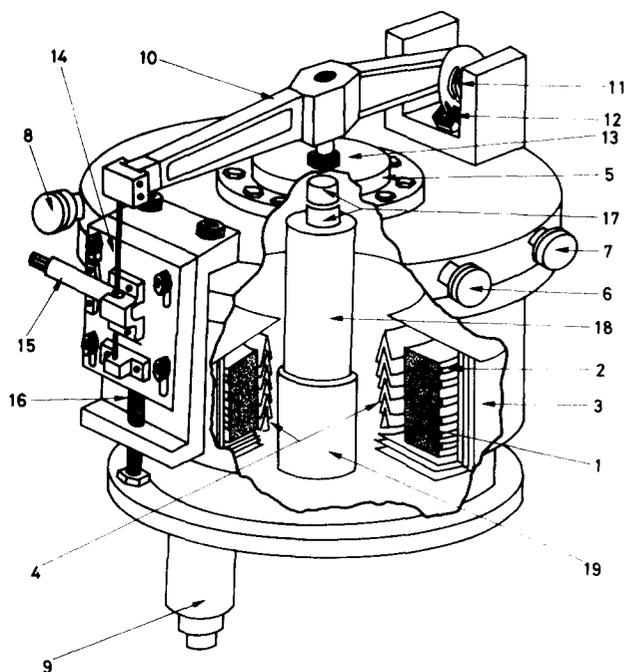


FIG. 1. Sketch of pumping system and opening device. 1—Liquid helium reservoir; 2—radiation shields cooled by cold gas; 3—metallized glass fiber thermal insulation; 4—chevron baffle; 5—perforated stainless steel flange (electrically insulated from pump body); 6—liquid helium filling inlet (Mini-Conflat); 7—gaseous helium outlet, to relief valve (Mini-Conflat); 8—entrance for liquid helium level sensors (Mini-Conflat); 9—Penning vacuum meter (Edwards); 10—spring loaded aluminum arm; 11—steel springs; 12—optical switch; 13—polyimide seal; 14—steel cable; 15—cable cutter; 16—adjusting bolt and nut; 17—ion lens; 18—quadrupole; 19—electron multiplier.

inlet leak, the opening device, and the quadrupole unit, as well as easy installation of the cryopump on the balloon gondola. The overall weight of the cryopump unit, leak, and opening device is 61 kg.

The cryopump is evacuated by a rotary and turbopump unit (PT 200/20 and Turbovac 200 CF, Leybold-Heraeus) from atmospheric pressure down to 10^{-6} Torr in about 48 h. Normal evacuation is followed by a bake-out at 150°C for 48 h, resulting in pressures of approximately 5×10^{-7} Torr. The pressure falls into the lower part of the 10^{-8} and 10^{-9} Torr ranges, respectively, after cooling with liquid nitrogen and filling the liquid helium.

Cooling from room temperature to 77 K takes 2–2.5 h and uses approximately 8 l of liquid nitrogen. The liquid nitrogen transfer system is connected to the normal helium gas exhaust, which results in precooling of exhaust spiral and radiation shields. Evaporating nitrogen vents through the normal liquid helium filling inlet.

Cooling to 4.2 K and filling with liquid helium takes $\frac{3}{4}$ h; 2.5 l of liquid helium is used for cooling. The liquid helium transfer system is then connected to the normal liquid helium filling inlet. The liquid helium filling procedure is facilitated by evacuating the exhaust spiral with a helium-tight rotary pump. During cool-down and transfer, temperatures and liquid levels are controlled by two carbon resistor temperature and level sensors, which are introduced into the liquid helium reservoir through a separate connection.

After transferring, a pressure relief valve (Air Liquide—soupape absolute, 6.35 mm) set at 1160 millibars on the liquid helium reservoir, maintains the liquid helium under a slight overpressure. During pumping with a rotary pump at the outlet side of the relief valve, liquid helium evaporation rates of 125–140 l/h of gaseous helium were measured. The total retention time for liquid helium was experimentally determined to vary between 10 and 14 h, depending upon the number of bakeouts and manipulation prior to the actual filling and tests. The pumping speed has been investigated by measuring simultaneously the pressure decay in a vessel with known volume mounted above the inlet leak and the pressure in the cryopump. It was found that the flow through the inlet hole is of the intermediate flow type. The conductance of the hole can be represented within experimental error by the integrated value.⁷

A pumping speed of 1150 l/s was found at 2×10^{-6} Torr; this value was relatively independent of the pressure at pressures from 4×10^{-5} to 10^{-6} Torr.

II. OPENING DEVICE

One of the common problems for either rocket- or balloon-borne mass spectrometers is the remote opening of the instrument to allow either neutral or charged particle flow into the apparatus. Several devices have been developed in the past for this purpose, ranging from squib operated hammers⁸ and cutting devices⁹ to

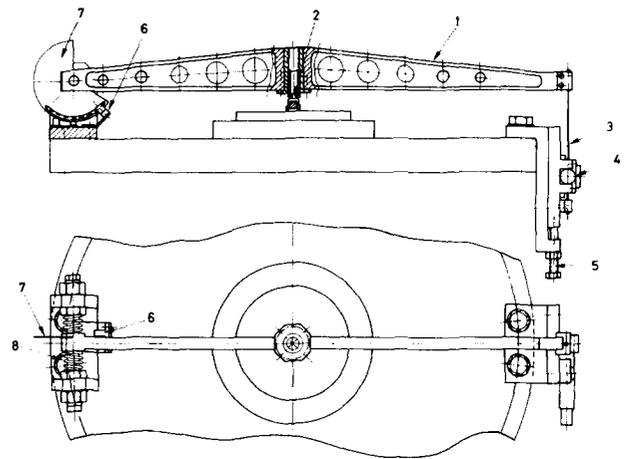


FIG. 2. Opening device. 1—Aluminum arm; 2—polyimide plunger; 3—steel cable; 4—cable cutter; 5—adjusting bolt and nut; 6—optical switch; 7—chopper to indicate position of arm; 8—steel springs.

solenoid operated valves.^{5,10} Most devices are quite complicated from a technical point of view; the solenoid operated devices have the advantage of allowing remote closing. However, in view of the long holding time of our cryopump and the high pumping speed, our opening device need not be closed again. Therefore a simple device could be designed, offering the advantage of a higher reliability.

The opening device which we have constructed is shown in Fig. 1, and in more detail in Fig. 2. The system consists of a spring-loaded aluminum arm held in place by a steel cable of 1 mm diameter. The position of the arm is sensed by an optical switch (Monsanto MCT 8) for which the signal is sent by telemetry.

In the middle of the arm a polyimide plunger with a diamondlike knife edge is mounted with a bolt. The force of the plunger on the stainless steel flange can be controlled either by turning the mounting bolt or by tightening the steel cable with bolt 16 (see Fig. 1). A $10\text{-}\mu\text{m}$ diamond lap of the stainless steel surface was quite sufficient to obtain a helium-tight seal. No special hardening treatment of the metal surface was necessary.

A squib-operated cable cutter (Pyrotechnique type 359D), hermetically sealed, can be operated through telecommand to cut the steel cable. The springs then swing the arm around and the mass spectrometer is opened. The device has been thoroughly tested at room temperature and at -60°C without failure, even when covered with an ice layer formed by condensing water vapor from the air.

This system has the advantage of allowing an unobstructed flow of gas and ions into the mass spectrometer, which leaves free a large area of the upper flange surface of the cryopump. This avoids charging up of insulating materials mounted on the upper flange that would hamper ion sampling. It is evident that the cable cutter can be duplicated if one wants to avoid a flight failure due to a single faulty cutter. So far no problems have been encountered with failure of the cable cutter.

The device can be baked out to 150°C when the

cable cutter is dismantled. Prior to a flight, the pump body is baked out at 150 °C with heat tape, after the cable cutter has been removed.

III. PERFORMANCE OF THE SYSTEM

The experiment was flown on June 12, 1977 from the C.N.E.S. launching site at Tallard (near Gap, France). Few useful scientific data could be obtained due to a balloon failure. The gondola reached an altitude of only 12 km. Nevertheless the opening device was activated and opened without any problems. The pressure in the cryopump increased to 2×10^{-4} Torr, the outside pressure being approximately 150 Torr. No sparking in the electromultiplier was observed and on some occasions part of a mass spectrum could be measured. The flight lasted only 20 min and termination of the experiment was necessary in view of the danger of losing the payload in the Alps. The liquid helium sensors, to which signals were sent by telemetry, were still immersed in liquid helium. Although the temperature at 12 km is of the order of -50°C , the pressure in the cryopump was 2×10^{-7} Torr before activating the cable cutter, proving the leak tightness of the polyimide plunger.

A second flight was performed on September 10, 1977 from the C.N.E.S. launching site at Aire-sur-l'Adour (France). The balloon reached an altitude of 38 km after 2 h (outside pressure being approximately 2.5 Torr) and stayed at this altitude for about 2.25 h. A pressure of 2×10^{-6} Torr was measured in the cryopump and during

the whole flight both liquid helium level sensors were immersed in liquid helium.

On September 30, 1977 a third flight was realized from the same launching site. Again the opening system, as well as the pumping system, performed without problems during the entire flight. The results of the last two flights are being analyzed now.

In view of the severe testing in laboratory and during actual flights, the performance of pumping and opening systems may be called satisfactory in every respect.

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