Use of Kapton film as a cryogenic construction material

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Research and technical notes

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The construction and use of tubing fabricated from glued Kapton film is discussed, including various methods of attachment to metallic cryostat parts. A method for construction of He diffusion free gamma-ray windows of Kapton film is also mentioned.

Keywords: cryogenics, tubing, construction material

Among the various new construction materials for low temperature use, Kapton* film is one that has received relatively little attention. Since this is a material with a number of attractive characteristics, such as very low thermal and electrical conductivity, high tensile strength, and elasticity down to very low temperatures, coupled with relative ease of handling for normally equipped workshops, we wish to present some of our findings on this material.

Kapton as a film—obtainable in a wide range of thicknesses—has the additional characteristic that it is easy to glue. If the surface is roughened by fine emery paper or scotchbrite and thoroughly degreased, it can be attached with any of the commercial two-component cements (Stycast 1266, Deltabond 151, etc) to most metals and plastics. This property has been utilized for the construction of strong custom-made tubing of extremely low thermal conductivity for the modification of a cryostat originally equipped with thin-walled stainless tubing.

The high flexibility and tensile strength of Kapton at low temperatures lead us to the choice of Kapton film of maximum available thickness (125 μm) and the consequent minimum amount of cement for the winding of tubing. Up to now, we have constructed tubing varying between 10 and 65 mm internal diameter, with wall thicknesses between 0.5 and 1.5 mm. A Kapton tube of 64 mm internal diameter and 1.5 mm wall thickness is very strong, much more so than a thin-walled stainless tube of minimum practicable wall thickness ($\approx$ 0.3 mm), and yet has an effective thermal conductivity a factor of about 20 times smaller than the stainless tube.

Construction of tubes

A delrin form turned to the exact inner diameter desired was used for slowly (1 cms^{-1}) winding the Kapton film in a lathe (see Fig. 1) while pouring the two-component cement into the space between the layers, the whole being held in place with small pieces of tape. Curing at 80°C, as is usually done, will lead to tubing of too-large an internal diameter, due to thermal expansion of the delrin. Therefore curing at room temperature in the slowly turning lathe is necessary. Afterwards, the delrin form can be removed by cooling the whole to liquid nitrogen temperature (at least 10 - 15 min should be allowed for thorough cooling of the delrin). After removal, final hardening of the Kapton tubing can easily be performed in an oven.

If one wishes to turn down the outside of the Kapton tubing, the original form can be reinserted with no difficulty. In turning Kapton tubing, two precautions are advisable: turn only with the direction of the layers to avoid peeling, and use a sharp cutting tool. The low thermal conductivity of Kapton will lead to more rapid dulling of the cutting edge than is usual for plastics. Although Teflon can also be used as a winding form, the shape and size instability have been a nuisance in practice.

It has also proven simple to construct Kapton-metal composite tubing with alternate layers of Kapton and copper or Kapton and aluminium, as a very quick and strong alternative to 'coil foil'. Despite the relatively large differences in thermal contraction, such composites withstand repeated cooling without deterioration.

The only precaution necessary for the preparation of the two-component cement is that it be placed under vacuum (10^{-2} to 10^{-3} Torr) for about 15 min before use in order to remove all air bubbles entrained during mixing.

Applications

A number of methods have been tested for attaching Kapton tubing to the metal parts of a cryostat.

A Kapton tube, either as-wound or turned and polished to about 3 to 5 ‰ internal diameter smaller than the outside diameter of a polished stainless tube-stub, could be forced over the stainless tube for a distance of one or two centimetres, if both tubes were well lubricated with Dow Corning silicone high vacuum grease (other vacuum greases proved unreliable); the Kapton tube should be rotated around the

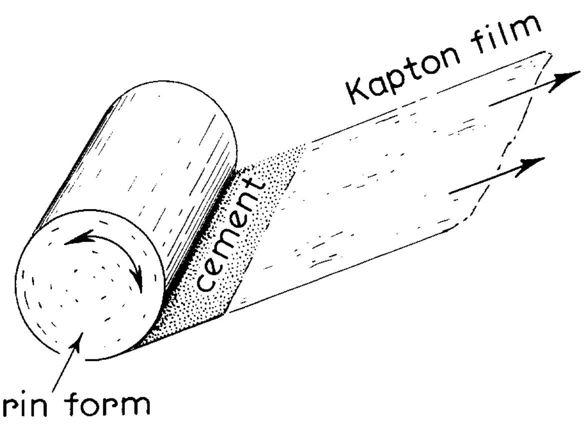

Fig. 1 Method of winding Kapton film on a delrin form turning in a lathe

*Kapton is a trademark of du Pont

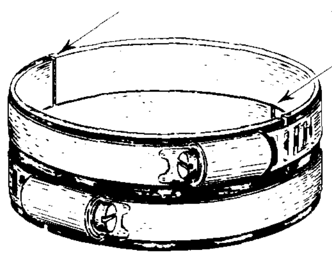

Fig. 2 Double split-cylinders with hose-clamps for clamping larger diameter Kapton tubing onto stainless steel tube-stubs

stainless tube several times to remove out any entrained air bubbles. *As long as the pressure is larger outside than inside,* this type of seal has proven lambda-tight on repeated cycling from room temperature. If the pressure gradient is inverted, or if mechanical strength is needed, a 'strangulation' type hose clamp or a double split cylinder (Fig. 2) must be used. This is because of the great elasticity of Kapton film, even at temperatures down to 1 K.

In a situation in which the inner stainless tube-stub may cool from room temperature much faster than the Kapton tube (as, for example, a room temperature connection that carries cold exiting helium gas out of the cryostat), it has proven necessary to make up the hose clamp connection with the stainless tube-stub, Kapton tube, and hose clamp all at liquid nitrogen temperature.

An alternative is to glue the Kapton tube onto the stainless tube-stub. Where demountability is necessary, the Kapton tube can also be glued onto a brass or stainless flange, for indium O-ring connection, using Deltabond 151 as cement (see Fig. 3). In this way, a demountable parallel connection of six tubes† was achieved. For centering purposes, short stainless tube stubs were used here as well. Because of the flexibility and elasticity of Kapton, it has been quite easy to make up all six indium O-rings simultaneously, and this has already been repeated several times, without problems.

In addition to the advantages already mentioned, such as great mechanical strength and elasticity and low thermal conductivity, we wish to point out the high electrical resistance, which makes it possible to electrically separate inner and outer portions of metallic cryostats. The fact that a tube of practically any diameter and up to about 55 cm length (the maximum available width) can be made within about a day and a half in a shop containing only a lathe is also an advantage, especially for emergency repairs.

In addition to use as a normal construction material, a short section of Kapton tube can be used to quickly and reliably couple two metal tubes of the same diameter, for example in a helium bath, without having to resort to soldering or welding indium O-ring flanges.

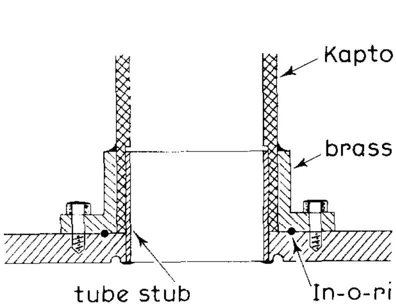

Fig. 3 Cross-section of glued Kapton tube-flange for In O-ring connection

One major disadvantage in using Kapton tubing is that, due to the high coefficient of thermal expansion relative to metals, and the resulting differential contraction, all tubing running directly between common anchorages at two widely different temperatures must be made of Kapton.

Diffusion of helium gas through Kapton at temperatures above that of liquid nitrogen causes a problem with Kapton tubing extending between room temperature and 77 K. Although the diffusion rate for a tube of a millimetre wall thickness is very low, for high vacuum applications it may be necessary to include one layer of household aluminium film within the Kapton tube (only necessary over the length from room temperature to about 77 K) to curb the diffusion. In the above mentioned parallel connection of six tubes of various diameters, the diffusion through the walls from the bath section to the insulation vacuum required the use of a small liquid-helium-cooled charcoal pump to maintain adequate vacuum over periods longer than several days. During tests, where all the tubes were directly in contact with the helium bath, no measurable increase of the evaporation rate due to the inclusion of the charcoal pump was detected.

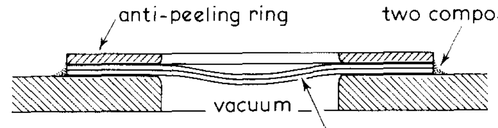

Fig. 4 Sketch of a layered gamma-ray window with anti-peeling ring

Gamma-ray windows

Kapton film is preferable to Mylar film for use as gamma-ray windows for low temperature applications because of its greater mechanical strength and elasticity, and better glueability. For both Mylar and Kapton, it is necessary to use an extra 'anti-peeling' ring (Fig. 4) to ensure a permanent seal in the eventuality of accidentally applying a pressure gradient in the wrong direction. Both types of film are porous to helium gas at room temperature, making leak detecting in the vicinity of such gamma-ray windows a serious problem. An adequate solution for this problem is provided by the use of a composite window of Kapton film and household (7 μm) aluminium foil.

Kapton film can be obtained from the manufacturer with a 12.5 μm layer of Teflon on one side (or both). A sandwich of Kapton–Teflon–aluminium–Teflon–Kapton, when heated to 300°C, forms an ideal starting material for a helium gas tight window, which can be cemented in place like a pure Kapton window. In this case, it is possible to use much thinner Kapton film.

†In the original cryostat there were the five thin walled commercial stainless steel tubes with a total perimeter of 83% of that of the six Kapton tubes mentioned above and 1.8 times as long. The evaporation rate (70 $cm^3\ h^{-1}$) of the Kapton version was 64% of that of the stainless steel version. Due to the short length (25 cm) and large diameters of the Kapton tubing, about half of this is due to gas conduction tubes.

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Simple thermo-level meter for HeI and HeII by a dynamic method

H. Yoshiki

A simple liquid helium level monitoring device has been developed using pairs of carbon resistors mounted on a stainless steel 'dipstick'. The device described has a resolution of 50 mm and negligible power dissipation. The level of both superfluid and normal helium, and the liquid temperatures, can be determined. The device has no moving parts and after some years of use has proved to be sturdy and durable. A similar device is proposed with a resolution of 12 mm and a microcomputer data recording system.

Keywords: cryogenics, helium, level meter

A number of reports on cryogenic level meters has been published utilising resistors[1], capacitors[2], transmission lines[3] and other elements[4], some of which are elaborate in electronics, continuous in operation, and possess high resolution in level determination. In our laboratory, where cooling a certain cryogenic device was the objective, it sufficed to monitor the helium level within several centimetres, and a less sophisticated, negligibly power dissipating, quick direct reading device was preferred which also had no moving parts, was sturdy and cost relatively little.

McClintock[5] reported a 'dipstick' type level sensor to measure the HeII level within an accuracy of a millimetre by introducing a thin wire heater close to a thermal sensor (a carbon resistor) to burn off the superthermal film formed on its surface. Working with HeII several years ago[6], we followed this approach but replaced the heater by a carbon resistor identical to the thermal sensor as shown in Fig. 1. A pair of 51 Ω 0.125 W Allen Bradley carbon resistors on a 4 mm diameter stainless steel tube fixed by GE7031 varnish constituted the thermal device unit, whose longitudinal length was less than 12 mm. Of the paired resistors, the lower one functioned as a heater while the upper served as a thermal sensor by its variation in resistivity with temperatures. The motivation of developing this system was to eliminate the toil of lifting or lowering the sensor and the labour of wire winding[6] at the price of high resolution. Several of such pairs were prepared every several centimetres (x) along the 4 mm tube, where the number of pairs and x were deliberately chosen according to different experimental purposes. The assembly also cleared the 7 mm inside diameter tube. The whole assembly was then lowered through a port into a helium bath and fixed to the port by a flange connected to the tube. In monitoring the level, the heater resistor of each pair was switched on and off in turn from the lowest pair upward. When any first pair appeared above the superliquid level, the typical discontinuous change in the resistance of the output resistor occurred, indicating the burning of the superthermal film[6]. For example, for the heater voltage of 2.5 V (which corresponded to 1.6 mW at $t = 0$), the resistance of the output resistor jumped down in $t = 2 - 3$ s from 3.8 kΩ to 850 Ω. If the pair was in the liquid, any appreciable change in the resistance did not take place in this time, and the difference was so apparent that it was possible to discern the level lying in fact between such successive pairs.

In the course of experiments, it turned out that the device not only monitored the superfluid helium level but also was useful for monitoring the level of the normal helium. Let us discuss this point in more detail. A 3 mm outside diameter stainless steel tube, with a pair of resistors glued in the same fashion as shown in Fig. 1 at the end, was placed in a liquid helium container so that it could be manually moved in the vertical direction. A measurement was taken as an example using this set-up. In Fig. 2, we present the behaviour of the voltage across one of the paired

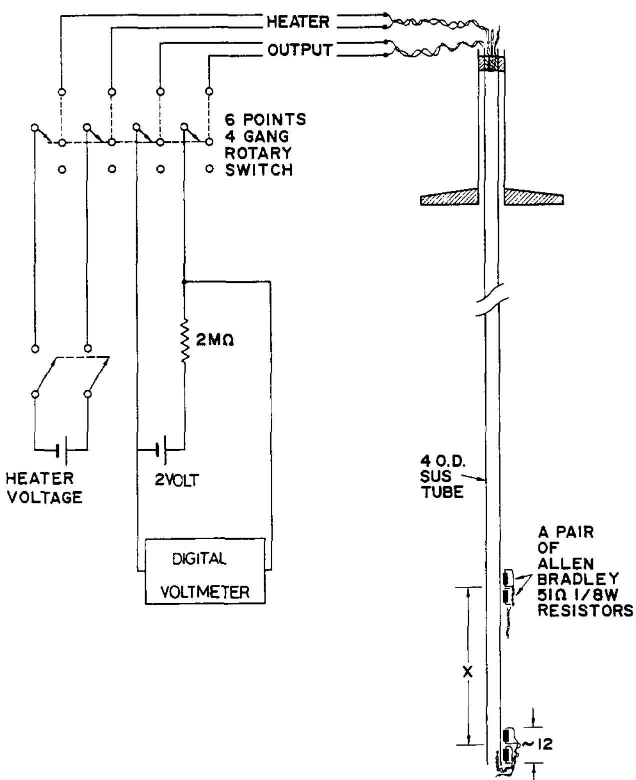

Fig. 1 Thermo-level meter and circuit