MECHANICAL SUPPORT FOR A TWO PILL ADIABATIC DEMAGNETIZATION REFRIGERATOR

FIELD OF THE INVENTION

This invention relates to low-temperature technology and provides an improved mechanical support for a two-pill Adiabatic Demagnetization Refrigerator (ADR).

BACKGROUND OF THE INVENTION

The three commonly employed cooling techniques in low-temperature physics and in technologies based on the properties of materials at low temperature are evaporative cooling, for example a pumped helium bath, refrigeration by dilution, in a Dilution Refrigerator, or adiabatic demagnetization, in an Adiabatic Demagnetization Refrigerator (ADR).

In any refrigeration technique there is a need to thermally isolate certain parts of the assembly from the environment, so that those parts may be cooled to, or held at a desired temperature.

While the first two techniques, in principle, allow continuous extraction of heat from a body, adiabatic demagnetization refrigeration is a 'single shot' technique. That is to say, the total heat which can be extracted in a cooling cycle is finite. Therefore great attention needs to be paid to proper thermal isolation, so that low temperatures can be reached and the refrigerator can be held cold over a period of time (hold time) if desired.

ADRs are an important technology for reaching temperatures below 1 Kelvin (K). These refrigerators contain a paramagnetic material, hereafter referred to as a pill, that is placed in a high magnetic field region, typically the bore of a magnet. Cooling is achieved by first thermally clamping the pill to a thermal ground at the starting temperature and by isothermally imposing a large magnetic field on the pill. After the field has been ramped up, the pill is disconnected from the thermal ground. When the field is then reduced, the pill cools. The temperature reached by the pill depends on its magnetic susceptibility and total heat capacity. The total energy available for cooling by the pill is proportional to the susceptibility, the total heat capacity, and the mass of the pill.

Most ADRs start their cooling from a thermal ground of 2 Kelvin which is obtained by pumping on a helium bath. With a pill made from ferric ammonium sulfate, a starting temperature of 2K and a magnetic field of 2 Tesla, a base temperature of 50 mK can be readily achieved. The pill is supported by low thermal conductivity material to isolate it thermally. Typically this is done with Kevlar strings, which are very thin and of low thermal conductivity, thus minimizing the heat leak. At the same time the Kevlar strings are strong enough to support the pill. The use of fine Kevlar threads allows hold times of up to 24 hours which is sufficient for most applications.

One would wish to eliminate the need for a pumped helium bath at 2K and be able to simply use an atmospheric pressure helium bath at a temperature of 4K. However, in order to cool from 4K, a larger initial magnetic field, typically 4 Tesla, is needed. Reliable high-field magnets are commercially available and a 4 Tesla magnet is only slightly more costly than a 2 Tesla magnet. The main disadvantage in this design is the larger heat leak from the starting temperature of 4K to the pill at 50 mK, because this heat leak scales as T^x, where T is the temperature of the thermal ground, the exponent x lies between 2 and 3, and the base temperature is assumed to be of order 50–100 mK.

In a recent paper (Cryogenics, v.35, no.3, 224 (1994), which is incorporated by reference herein in its entirety) Hagmann and Richards proposed an apparatus to reach ultra-low temperatures starting from a temperature of 4K. This design has great advantages because pumping on liquid helium is not required which simplifies the apparatus and thus makes it more reliable.

Richards and Hagmann suggested that a refrigerator be constructed of two pills where both pills reside in the bore of a magnet, in contrast to alternative designs where two magnets are used, thus eliminating the need to purchase a second magnet. One pill (base pill) would be of the type typically used in single-pill ADRs, e.g., chromium caesium alum (CCA), and would reach a base temperature of 50 mK. The other pill (guard pill) would be made of gadolinium gallium garnet (GGG), which has a magnetic ordering such that at zero field a temperature of 1K can be reached. The GGG acts as a cold platform to intercept the heat leak from the 4K thermal ground to the 50 mK base pill, thus greatly reducing the heat leak of the pill at base temperature. Because GGG has a high heat capacity, a relatively small amount of material is needed, leaving more room in the magnet bore for the base pill.

FIG. **1** shows the two-pill ADR proposed by Richards and Hagmann. The base pill **20** and guard pill **30** sit inside the bore of a superconducting magnet **10**. A magnetic shield **40**, hereafter referred to as shield, at 4K surrounds the magnet which itself is also at 4K. The guard pill occupies the lower half of the bore. A thermally conductive hollow cylinder **31** of the diameter of the guard pill is attached to the guard pill and reaches all the way to the top aperture of the bore. This guard pill assembly is suspended at the top and the bottom by Kevlar strings **50** which are attached to a support structures **41** and **42** on the shield at 4K. The base pill is connected to two thermally conductive rods **21**, **22** running axially out of the top aperture and the bottom aperture of the magnet and its shield respectively. Rod **21** leads to cold platform **23**. The base pill **20** is located inside the volume of the cylinder of the guard pill assembly and the lower rod **22** of the base pill traverses through a clearance in the guard pill. There is no mechanical contact between the two assemblies. The base pill assembly is attached to support structures **41** and **42** by low thermal conductivity Kevlar strings **51**. These strings attach indirectly to the shield's thermal ground at 4K. They are thermally intercepted about midway by additional Kevlar strings **52** coming from the guard pill assembly, thus reducing the heat leak from the base pill to the 4K thermal ground. The design of Hagmann and Richards has some inherent disadvantages which are discussed next.

For good thermal conductivity at low temperatures the cylinder connected to the guard pill and surrounding the base pill **31** is preferably a metallic (or at least electrically conductive) tube. A high thermal conductivity is desired to assure that the thermal intercepts **52** on the top of the magnet are at the guard pill temperature. However, an electrically conductive cylinder of large cross section in a magnetic field can develop eddy current problems.

Furthermore the proximity of the thermally very conductive cylinder material at 1K to the base pill at 50 mK and the magnet at 4K increases the chance of mechanical thermal contact with either side or both sides, which would result in immediate failure of the refrigerator due to a massive heat leak.

The volume available to the base pill is also reduced to make room for the cylinder and to allow enough play for the