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A 15 TESLA CRYOGEN FREE MAGNET SYSTEM

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Abstract

We have constructed a number of superconducting magnets which are directly cooled by cryocoolers and can achieve fields up to 15 Tesla at temperatures of about 4K. No liquid helium is required. The magnets have bores in the range of 50 to 800mm. The current to the magnet is in the range of 100 to 240 Amps. It is carried by HTS conductors from 50K to 4K with resistive leads above this temperature. The bore can be at room temperature or a variable temperature sample space can be provided.

Due to the exceptionally compact design there is very good access to the high field region. The magnetic field can be orientated in any direction and the cryomagnet can even be rotated while in operation. A patented thermal buffer can be used to allow fast ramp rates to field.

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1.0 Introduction

Cryogenic is a world leader in magnet technology. It is now routine to establish and operate a cryomagnetic research station without worrying about the availability of liquid cryogens. Cryogen-free systems with magnetic fields up to 15 Tesla for general research purposes as well as for specialist applications have been supplied to many countries where liquid helium is not readily available.

Helium cooled magnets with fields up to 20 Tesla and complex geometry magnets have been built. As a result of a government award Cryogenic was able to develop magnets that operate in vacuum and are cooled by a mechanical refrigerator.

2.0 Principal Benefits Of Cryogen Free Systems

Low operating costs. No expensive liquid Helium or Nitrogen is required keeping the running costs to the minimum.

Cryogenic is now offering systems that allow cooling of both the sample and the magnet using a *single cryocooler*. Previously it was not possible to do this as the magnet requires bulk of the cryocooler refrigeration power, especially when the magnetic field is being changed as this imposes a high heat load on the magnet. The design has been submitted for patent.

Fast Ramping Capability. When the magnetic field is charged both on sweeping the field up and down, considerable heat is generated by flux flow in the superconductor. This heat must be removed. For fast ramps the heat load can exceed the cooling power of the cryogenerator. The patented *thermal reservoir* is used to extract this heat from the magnet. It consists of a reservoir of high density helium gas or liquid in good thermal contact with the magnet, which is a specific heat sufficient to absorb the heat energy generated on the magnet during a fast ramp

Ease of use. No specialist cryogenic knowledge is required to operate the system. Simply switch on the cryogenerator, wait for it to reach operating temperature and the system is ready to use. It may be kept cold on standby so that measurements can be made at short notice or for extended periods.

Independent and convenient. Only mains electric power is required to operate the system so that measurements can be made at any time at the convenience of the user.

Automated Operation. The system is automated using a LabVIEW software which includes all the necessary operational fail-safe features. This allows measurements to be performed in a repeatable and reliable fashion.

3.0 Cryomagnetic Assembly

The cryomagnetic system contains the high field superconducting magnet, cryostat with thermal reservoir, cryocooler and compressor and HTS current leads. The cooling for the magnet and cryostat housing is provided by a standard cryocooler with a base temperature of 3K (or 6K) depending upon the system performance requirements.

The standard 15 Tesla system delivers a high magnetic field in a 30mm or 50mm room temperature bore and comprises the following items:

3.1 Superconducting magnet

The liquid helium free magnet is wound from copper stabilised filamentary conductors which are vacuum impregnated with epoxy resin to form a composite structure of excellent mechanical strength and electrical insulation. For a coil giving 14 Tesla 2 windings are used, one containing NbTi wire and the inner using NbSn. This coil is made by the wind and react process.

Example CFM specifications:

Central field (guarantee)	14.0 Tesla
Imax for Bmax	~140A
Homogeneity in 10mm dsv	0.1%
Clear cold central bore	80mm
Clear room temperature bore	50mm

3.2 Cryostat and cryocooler assembly

The main cryostat is constructed using aluminium and stainless steel. It has an outer vacuum vessel on which is mounted the cryocooler which cools the 50K radiation shield and with a second stage the magnet to 4K or less.

A thermal reservoir to absorb energy during ramping of the field is attached to the magnet. It contains helium gas under pressure connected by a fine tube to a closed reservoir at room temperature.

There is an electronic instrumentation port for magnet current leads and temperature sensors. The central bore of the magnet may be at room temperature or the cryostat can be fitted with a variable temperature sample space.

The cryocooler provides up to 1W cooling at 4K and more than 50W on the 60K stage, more than sufficient to cope with the heatloads experienced in general operation. Initial cooldown from start-up at ambient temperature to operating temperature takes from 24 to 36 hours, depending on the size of the magnet. No liquid helium or nitrogen are required.

Example cryostat specifications:

RT Bore length:	50mm
RT Bore diameter:	270mm
Outer vacuum can diameter:	550mm
Total length (inc. cryocooler)	1000mm
Typical cooldown:	24 hrs
Maintenance interval	10,000 hrs

4.0 Automated Operation.

The system is automated using the National Instruments LabVIEW software environment and a standard Cryogenic applications package, which allows the complete system to be run under computer control. The automated features include control of the magnetic field, temperature monitoring in the cryostat and fail-safe shutdown.

5.0 Summary

With the advent of reliable cryocoolers that can operate to 3K, superconducting magnets can provide very powerful magnetic fields without any of the difficulties associated with the use or costs of liquid cryogens. In time it should be possible to produce higher fields to 18 Tesla using the same technology.