NST-44

TO: XXX/Scientific & Technical Information Division
   Attn: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. 3,310,765

Government or Corporate Employee: Rockwell Int., Corp.
   Carnegie Park, CA

Supplementary Corporate Source (if applicable): 

NASA Patent Case No. W-428-XM F-5373

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES □ NO □

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of ...

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(NASA-Case-XMF-05373-1) STABLE SUPERCONDUCTING MAGNET Patent (NASA) 5 p

CSCL 09A

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Another object is to provide a method wherein the superconducting magnet is not forced through a series of superconducting-normal transitions, nor is a large amount of liquid refrigerant lost by heat generation in order to reach operating conditions. Still another object is to provide a large, stable, superconducting magnet having means for carrying greater supercurrents than a similar magnet could carry without training.

Still other objects and advantages of the present invention will become apparent from the following detailed description and appended claims.

In the drawings, FIG. 1 is a perspective view of a superconducting solenoid embodying the present invention; FIG. 2 is an overall view, partly in section, of a superconducting magnet apparatus; and FIG. 3 is a graph representing critical current as a function of the solenoid temperature.

In accordance with the present invention, higher practical current levels are reached in large magnets than can otherwise be reached without training by adjusting the temperature of at least a portion of the magnet windings to above the temperature of the gas refrigerant in liquid form but below the critical temperature (T_0) of the superconducting material. In this manner, a higher practical current level is obtainable without a series of superconducting-normal transitions and, for a large magnet, the limiting current magnet and field obtained is thus higher.

The fundamental basis for the present improved performance is not entirely certain. It appears, however, that a "window" is provided for the escape of magnetic flux which is ordinarily trapped by flux pinning sites in a superconducting wire. Such magnetic flux tends to oppose electron travel by Lorenz forces, and hence diminishes transport current conduction. The heating of a portion of the superconducting solenoid above 4.2°K. (liquid helium temperature), but below T_0 provides an escape path for the expanding flux as a magnet is energized. It therefore appears that a material which is more porous to flux motion and possesses weaker pinning sites, both of which variables are a function of temperature, provides a more stable magnet. At elevated temperatures flux motion which is initiated by increasing solenoid current can thus be accommodated without large energy release to drive the material normal. A theoretical basis for the temperature effect of flux pinning which is utilized in the present invention is given by P.W. Anderson, "Physical Review Letters," 9, 309 (1962). While the theoretical I_c thus realizable at the higher temperature through practice of the present invention is below the theoretical I_c at the lower temperature (I_c increases with increasing temperature below T_0), the current level practically obtainable without training is actually higher.

Further explanation of the present invention may be had by reference to the graph in FIG. 3 in which the maximum temperature for an epoxy potted solenoid is plotted against the transport current observed at a first superconducting-normal quench. The magnet was composed of Nb-25% Zr wire, copper plated. It should be
understood that for other solenoid configurations and sizes or other superconducting materials, the proper temperature of operation would be different and may be readily determined by routine measurements. The cross-hatched region of the graph designates the training region where it is unpredictable where a first superconducting-normal transition will occur. Thus, it would be difficult in this region to design a magnet for a stable current level of more than about 20 amp level, although it is seen that within the higher current, up to about the 40 amp level, might theoretically be realized. However, at some higher temperature, for example, approximately 5.25° K., at least 30 amps may be assured without training. It is therefore evident from the graph, that while current declines with the increasing temperature, a higher stable current level can be achieved. In the given example, a magnet temperature of about 5—7° K. is preferred, for above about 7° K., current level drop is not compensated by any increased stability. Interestingly, after such stable current level is obtained, the magnet temperature may then be reduced to that of the bath without going normal or losing its current. This is consistent with the above-mentioned indication that flux motion leaves superconductors-normal; in this case temperature reduction causes no flux motion and therefore leaves the magnet current stable at the previous level. While reducing the temperature to the liquid helium after a stable current level is reached is convenient and safer because one is then further below the critical value, economic advantages in terms of refrigerant cost may be had by operating the system (magnet and bath) at the higher temperature. Thus, in this embodiment of the invention helium could be in the gaseous phase above 4.2° K.

In FIG. 1 is illustrated a superconducting solenoid comprising a plurality of layers of a fine superconducting wire 4, such as 1900 ft. of 0.010-in. diameter Nb-25% Zr copper plated wire, wound on a 0.9-in. I.D. spool and rated at 0.343 kg./amp. A copper wire was wound back and forth between successive layers of the superconducting wire and parallel to the solenoid axis. The heated volume was a 10 percent pie section (cylindrical coordinates) of the solenoid. The critical current was plotted against varying solenoid temperatures and the measurements shown in FIG. 3 taken. From FIG. 3 it is seen that the solenoid temperature limits the attained current. When I max. was adjusted with temperature to less than about 35 amps, at temperatures above about 5° K., no training was observed. For lower solenoid temperatures (below about 5° K.) at current levels above about 20 amps considerable training (i.e., superconducting-normal transitions) was observed.

The foregoing example is illustrative rather than restrictive of the present invention. It is understood that different configurations of the present invention may be devised by those skilled in the art within the scope of the present invention, including the specific temperatures employed, the composition of the superconducting material, and the magnet power level. Accordingly, the present invention should be understood to be limited only as is indicated in the appended claims.

What is claimed is:

1. A method of obtaining a relatively high current in a magnet of a superconducting material, positioned in a bath of a gas refrigerant, which comprises

(a) adjusting the temperature of at least a portion of the superconducting material to a temperature above the critical temperature for said superconducting material, and

(b) passing a supercurrent through said magnet.

2. The method of claim 1 wherein the refrigerant is in the vapor phase and the magnet is at the same temperature below said critical temperature.

3. The method of claim 1 wherein the refrigerant is in the vapor phase and the magnet is at a temperature above 4.2° K. but below said critical temperature and wherein the superconducting material is at the same temperature.

4. A method of operating a superconducting magnet at a relatively high current level without training, which comprises

(a) placing said magnet in a bath of a liquid gas refrigerant,

(b) increasing the temperature of a portion of the superconducting material above the temperature of said liquid refrigerant at the same temperature,

(c) then initiating the passage of supercurrent through said magnet.

5. The method of claim 4 wherein the liquid gas is helium in the vapor phase and is at a temperature above 4.2° K. but below said critical temperature and wherein the superconducting material is at the same temperature.

6. The method of operating a superconducting magnet at a relatively high current level without training, which comprises

(a) placing said magnet in a bath of liquid helium,

(b) heating said magnet to a temperature of about 5—7° K., and

(c) while said bath is at a temperature of about 4.2° K. and said magnet at a temperature of about 5—7° K.,

...
5 establishing the passage of a superconducting current in said magnet.

8. The method of claim 7 wherein said niobium-zirconium consists of Nb-25 weight percent zirconium alloy.

9. The method of claim 7 wherein the magnet temperature is reduced to about 4.2° K. after establishment of a superconducting current therein.

10. A method of operating a superconducting magnet containing a plurality of turns of a niobium-zirconium wire at a relatively high current level without training, which comprises
   (a) placing said magnet in a bath of gaseous helium which is at a temperature of about 5-7° K., and
   (b) initiating the passage of a superconducting current in said magnet.

11. A superconducting magnet assembly comprising
   (a) a plurality of turns of a superconducting wire wound on a magnet core,
   (b) said magnet positioned in a container in a bath of a liquid gas refrigerant at a temperature below the critical temperature of said superconducting material,
   (c) electrical means connecting to said magnet for initiating the passage of superconducting current therethrough, and
   (d) electrical means connecting to said magnet for heating a portion thereof to a temperature above the temperature of the liquid gas refrigerant and below said critical temperature.

12. The superconductive magnet of claim 11 wherein said liquid gas in helium and said superconducting wire consists of niobium-zirconium alloy.

13. The superconducting magnet of claim 11 wherein said superconducting wire is further wound in a plurality of layers on said core and wherein said electrical heating wire is interleaved between said layers.

References Cited by the Examiner

UNITED STATES PATENTS

3,156,850 11/1964 Walters __________ 335—216 X
3,253,193 5/1966 Lubell et al. __________ 335—216

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