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LIQUID HELIUM DUMP CONCEPT FOR A LARGE SCALE SUPERCONDUCTING MAGNETIC ENERGY STORAGE PLANT

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ABSTRACT

Superconducting Magnetic Energy Storage (SMES) is a potentially cost effective technology for electric utility load leveling. Design concepts and cost estimates of SMES plants capable of delivering 5000 MWh daily have been previously identified. An important feature of a large commercial plant is a system that will reliably shut down the magnet by thermally dissipating the stored energy in the event of an imminent or actual loss of superconductivity. To prevent damage to the coil during such a protective energy dump, the entire coil must be driven "normal", i.e., resistive rather than superconducting, in a short period of time. This requires rapid removal of the liquid helium coolant surrounding the coil.

This paper describes a simple system that has been developed to rapidly remove the liquid helium from the helium vessel. The system requires only a small number of active components, no external helium storage, and is practical to reset and maintain.

INTRODUCTION

The design of large superconducting magnets for electrical energy storage has progressed to a stage where SMES appears commercially feasible for utility use.[1,2] Energy is stored in a magnetic field supported by current in the superconducting coil. The principle of operation of a SMES plant is shown schematically in Fig. 1. Engineering efforts to date have produced a cost effective, constructible concept by focusing on design of the coil, conductor, support components, and the helium and vacuum vessels. The arrangement of these components, constructed in an open trench, is shown in Fig. 2.

One additional aspect of plant design requiring careful attention is the provision for a safe shut-down of the plant in the unlikely event of an imminent or actual loss of superconductivity. The only currently identified events which could lead to a loss of

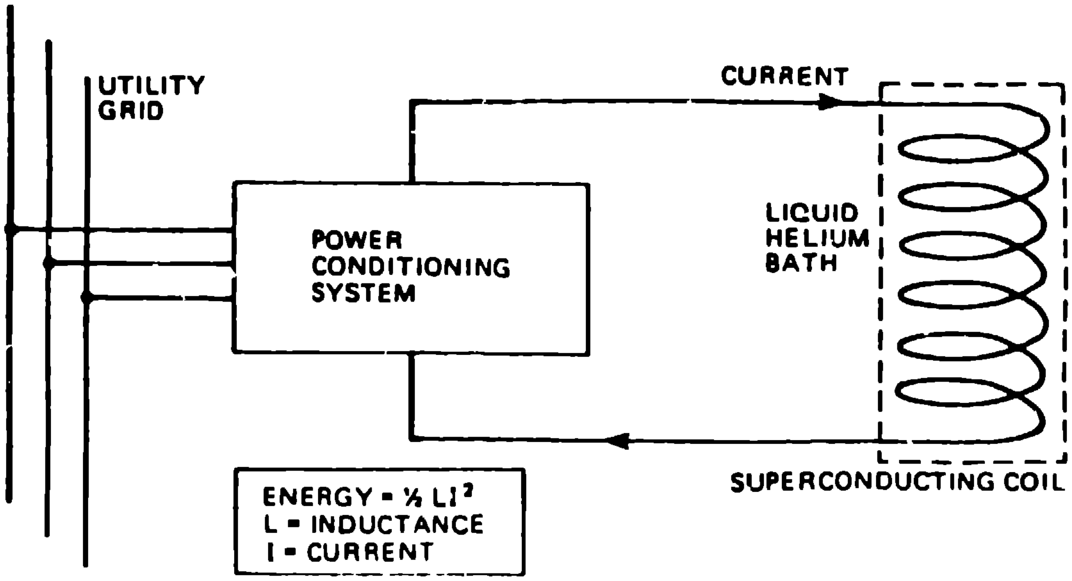

Figure 1 SMES – PRINCIPLE OF OPERATION

vessel breach or increased thermal load caused by a loss of vacuum. If one of these events occurred while the coil was charged, there would be no opportunity for normal coil discharge, which could take hours. Therefore, the stored energy would be dissipated as heat in the coil. To avoid excess voltage and to prevent thermal damage to the coil, a controlled procedure is followed, so that the entire coil becomes normal and the energy is dissipated uniformly rather than locally. This procedure, called a coil protective energy dump, requires that the helium bath which usually surrounds the coil be removed in a matter of seconds. The subsequent energy dissipation takes approximately 5 minutes for a fully charged coil, which warms to ambient temperature.

The specific objective of the work described in this paper was to establish a reliable system for rapid removal of liquid helium in the event of a coil protective energy dump. The only previously reported concept for helium removal was based on the use of large quantities of externally stored 300 K helium gas to drive the liquid from the helium vessel through large valves of extremely complex design.[3] The following guidelines were used for this work:

1. For reliability, minimize the number and complexity of active components, specify passive components wherever possible, and locate active components in an accessible location.

2. The temperature of the injection or driver gas which displaces the liquid must be consistent with thermal-electrodynamic requirements to avoid excess coil voltage and overheating of the conductor. Calculations have shown that 40 K is an approximate upper limit on the injection gas temperature[4].

3. The liquid dump time must also satisfy thermal-electrodynamic requirements. A dump time of approximately 10 seconds is adequate and a coil shorting switch is not required[4].

4. Reset should be simple and remote so that it is not necessary to

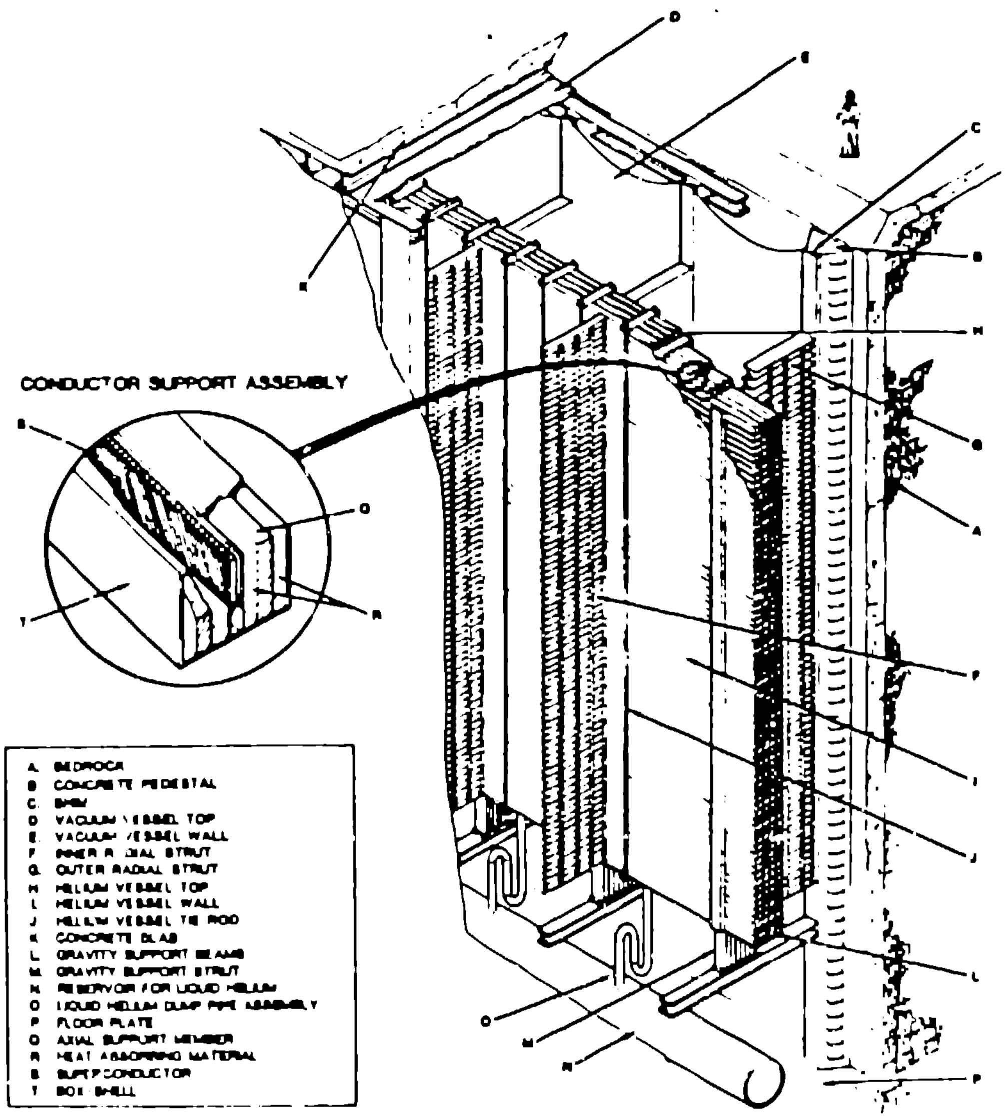

Figure 2 SUPERCONDUCTING MAGNETIC ENERGY STORAGE PLANT

LIQUID HELIUM DUMP SYSTEM AND OPERATION

The selected concept for the helium dump system is shown schematically in Fig. 3. It makes use of the liquid helium storage reservoir located beneath the coil. Gas lines connecting the storage reservoir with the top of the helium vessel, gas and liquid check valves, and active gas valves at the top of the gas lines are the only additional components. During normal operation the storage block valves at the dump reservoir are open and the gas valves at the top are closed. This arrangement separates the helium vessel, which is filled with superfluid helium at about atmospheric pressure and 1.8 K, from the reservoir, which is pressurized with cold helium gas. The pressure in the reservoir seats the liquid check valves.

As the first step of a coil protective energy dump, the "active" gas valves are opened to connect the pressurized reservoir with the top of the helium vessel. These valves are small and can be actuated and fully open in a fraction of a second. The following sequence of events then occurs during a helium dump:

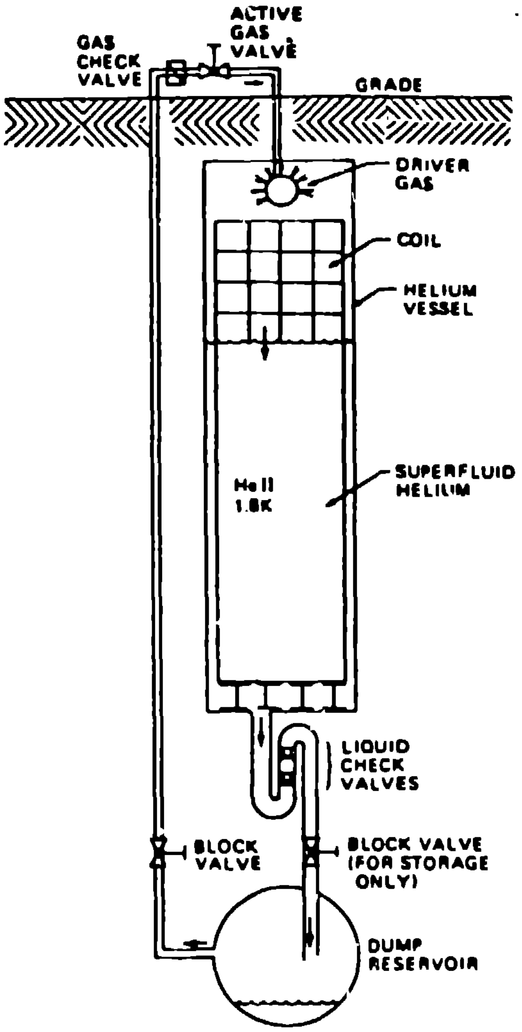

Figure 3 HELIUM DUMP SYSTEM WITH SELF-CONTAINED DRIVER GAS

- Helium gas from the reservoir flows into and pressurizes the top of the helium vessel.

- The pressures in the reservoir and the top of the helium vessel equalize, allowing the lower check valves to open and begin the flow of liquid helium from the helium vessel and into the reservoir.

- The uncovered coil turns at the top of the vessel are warmed by the incoming gas, causing loss of superconductivity and subsequent resistive heating in the conductor.

- The reservoir pressure drops rapidly due to cooling by liquid helium.

- The upper check valves close when the helium vessel pressure exceeds the reservoir pressure.

- Joule heating from the normal conductor turns expands the gas in the helium vessel, which, in turn, forces the remaining liquid into the reservoir and drives the remaining coil turns normal. Excess pressure in the helium vessel during warm-up is relieved to the vacuum vessel.

- After the dump is complete the block valves are closed to isolate the liquid helium for storage in the dump reservoir.

This liquid helium dump system concept has a number of positive characteristics: No external helium storage is required. The dump time is fairly insensitive to the initial thermal capacity of the reservoir, so that the material selection and mass are not critical. Only a small number of components require actuation for a dump; the design of these active components can be fairly conventional because they are small, accessible and warm. The liquid check valves are passive, so they can be numerous and small; because they can be small, no extensive development is required. The conditions of the energy dump are "tunable" through the selection and maintenance of gas temperature and pressure in the dump reservoir during normal operation.

The helium reservoir consists of modular units of aluminum or stainless steel dewars, approximately 10 meters long and 1.2 meters in diameter, as shown in Fig. 4. These are sized so that simultaneous failure of liquid check valves and/or inadvertent opening of gas valves to several modules would not dump enough liquid from the helium vessel to uncover the top coil turns, and thus would not cause an inadvertent coil energy dump. Each unit would be connected to the helium vessel by several pipes containing the check valves. A design concept for a check valve spool is also shown in Fig. 4. The two check valves in each spool provide redundancy. The heat leak through such a valve has been calculated to be very small and the mass leak would be minimized by careful design of the valve seats.

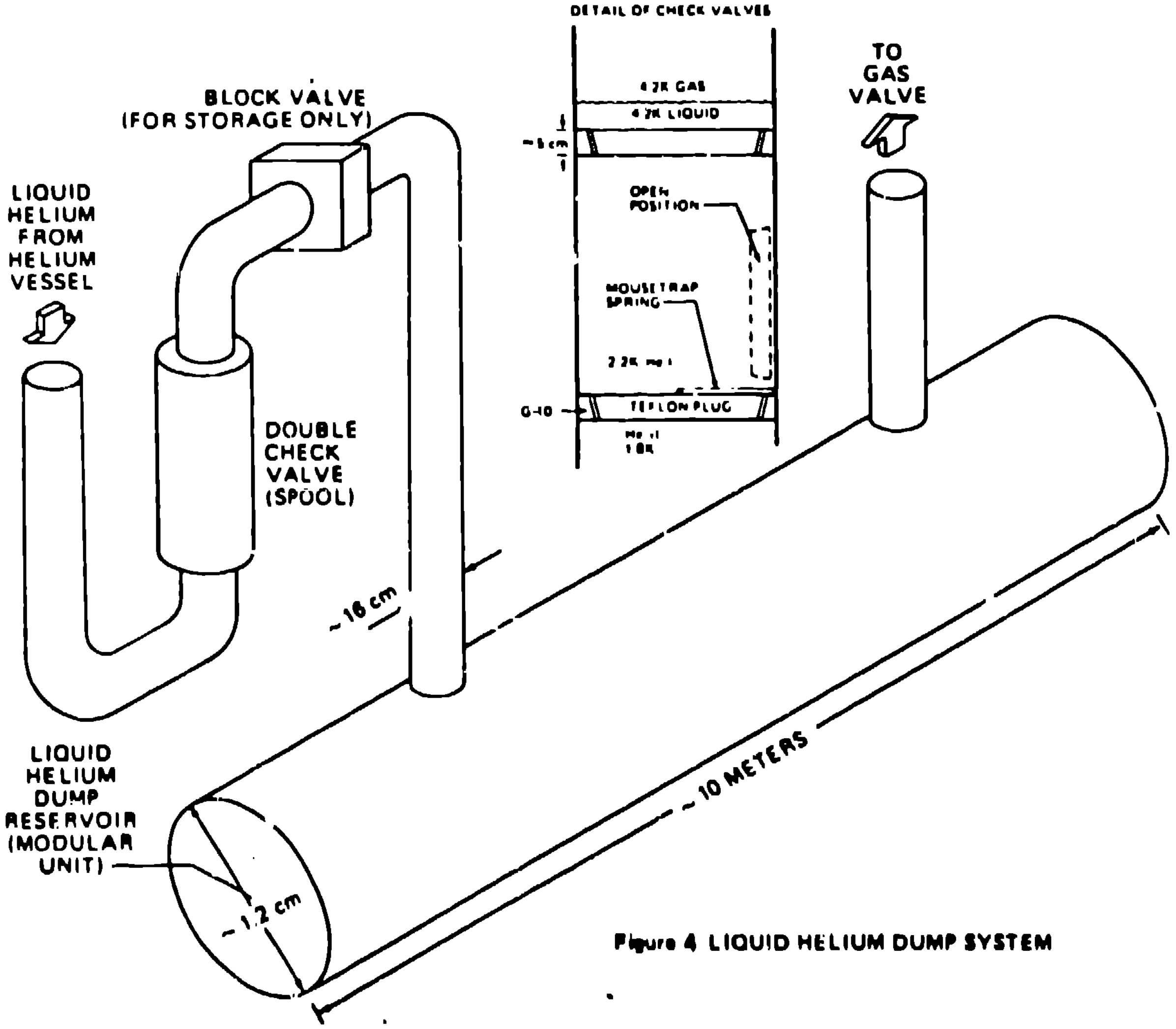

Figure 4 LIQUID HELIUM DUMP SYSTEM

SYSTEM PERFORMANCE

The heat and mass transfer processes which occur during a helium dump have been modeled in sufficient detail to calculate helium flows and states throughout the event. Real helium properties are used. Assumptions which are used to simplify the calculation include:

1. The dump reservoir and its contents are in thermal equilibrium at all times.

2. The gas flow from the reservoir to the top of the vessel is adiabatic.

3. The helium vessel gas pressure above the liquid level equals the reservoir pressure (minus a small pressure drop) at early time.

4. The helium vessel gas pressure is held constant at a selected value after the upper gas check valves close.

5. The pressure drop in the liquid as it flows downward through the coil is approximately 1 atm, based on calculations using actual coil geometry.

Results of an example calculation of the helium dump process are plotted in Fig. 5. The input parameters for the calculation were as follows:

Liquid helium volume = 3 million liters
Initial reservoir temperature = 10 K
Initial reservoir pressure = 1.3 atm
Liquid flow area (through pipes to reservoir) = 20 square meters
Gas flow area (from reservoir to top of vessel) = 0.16 square meters
Helium vessel pressure after gas check valve closure = 2 atm

The results show that the liquid helium level drops at an accelerating rate throughout the dump. The temperature of the reservoir and its gas falls quickly to saturation conditions and then more slowly as the gas condenses. The equilibrium vapor pressure falls along with the temperature. For the example case, the gas check valves were open for less than a second and the dump was complete in approximately 7 seconds.

There are many parameters involved in the modeling of the helium dump, but only a small number of these have a significant effect on the helium dump time. These include liquid flow area, initial helium vessel inventory and helium vessel pressure throughout the dump. Results of a sensitivity analysis of the dump time are shown in Fig. 6. As expected, the greater the helium vessel pressure, the smaller the helium inventory, and the greater the liquid pipe flow area, the faster the dump. The liquid flow area can be achieved by using a large number of small pipes and valves or a smaller number of larger components. Figure 6 also shows that dump time is very insensitive to gas flow, which serves only to start the dump, so that the number of active gas valves can be minimized.

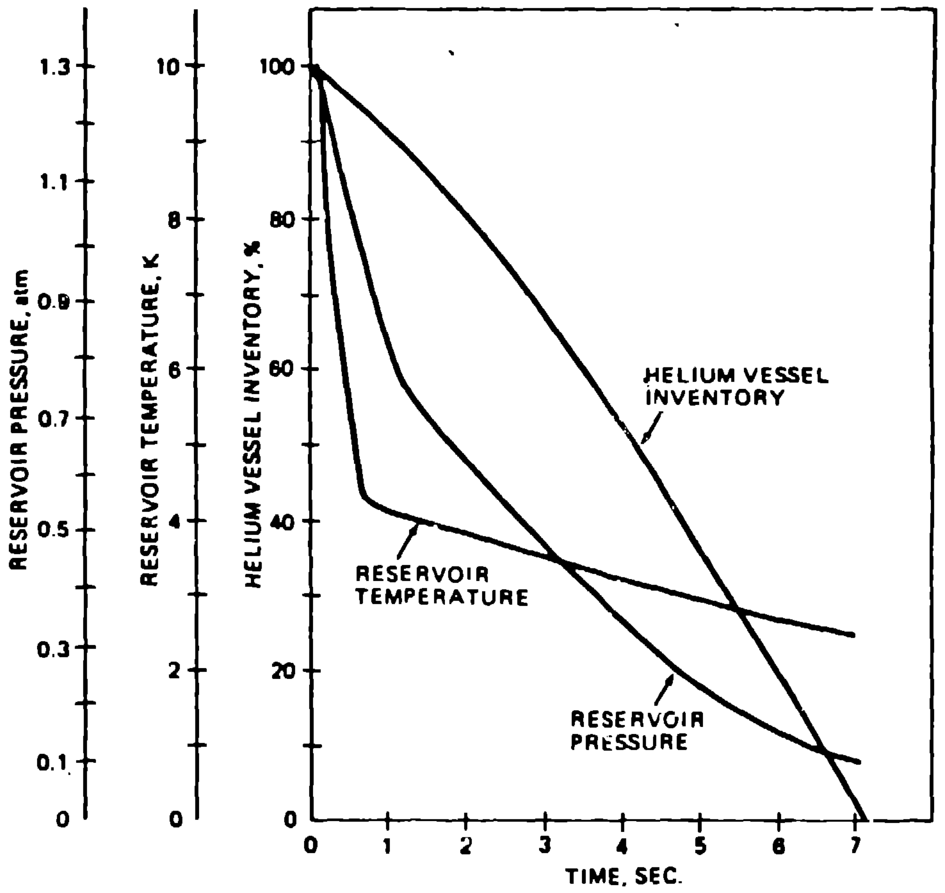

Figure 5 HELIUM DUMP CALCULATION RESULTS FOR EXAMPLE CASE

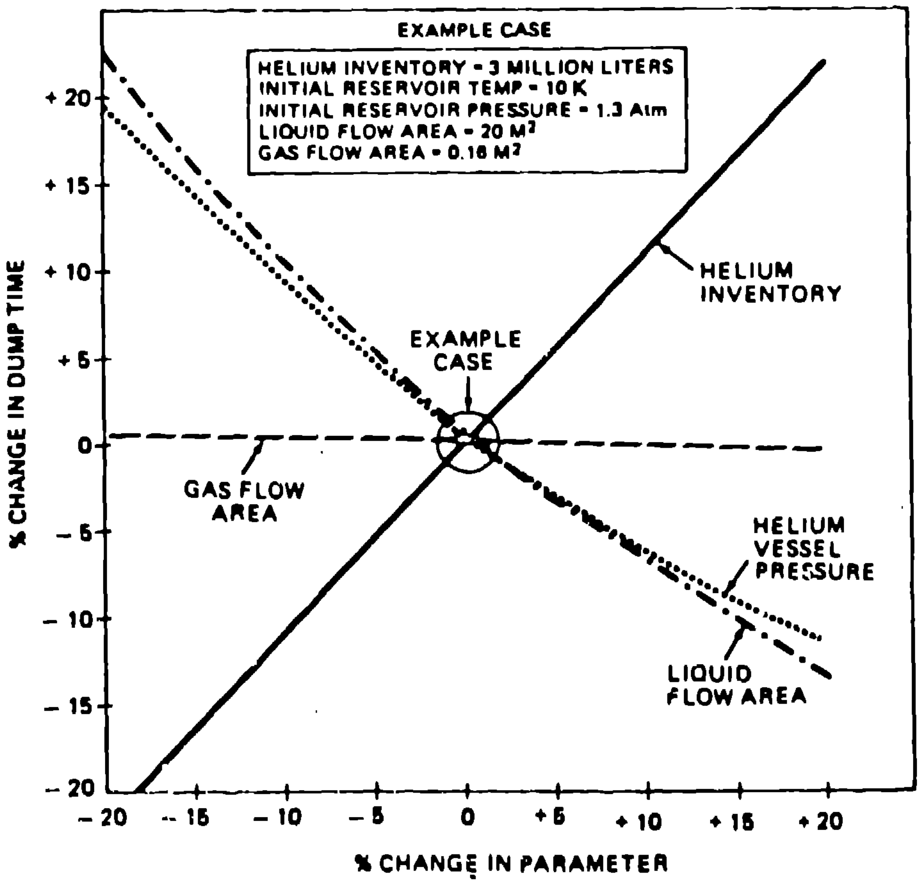

Figure 6 HELIUM DUMP TIME SENSITIVITY

SUMMARY AND CONCLUSIONS

An important requirement of a commercial SMES plant is provision for a non-destructive, rapid and reliable coil protective energy dump. This requires rapid removal of the liquid helium bath surrounding the coil. A design providing for this rapid removal of liquid helium has been developed. None of the system components require extensive development and all active components are accessible. The helium dump process has been modeled and and shown to perform well.

ACKNOWLEDGMENT

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