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Cryogenic Systems for HTS Power Cables

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***Abstract*-- Cryogenic systems are requirement for the operation of HTS power cables. In general, HTS power cables require temperature below 77K, a temperature that can be achieved from the liquid nitrogen at 1atm or sub-cooled LN2 above 1atm. HTS power cable needs sufficient refrigeration to overcome its low temperature heat loading. This loading typically comes in two forms : (1) heat leaks from the surroundings and (2) internal heat generation.**

This paper explains the cooling test system of 10m HTS power cable. This system is composed of storage dewar, auto fill system, core cryostat and cold-box. Storage dewar is a LN2 storage tank and auto fill system is a LN2 supply device to the sub-cooler. Core cryostat is a LN2 flow line. Cold box is a control unit of temperature and flow rate. It is composed of control valve, flow meter, sub-cooler and circulation pump, etc..

1. Introduction

To deploy an HTS power cable, it must be maintained at operating temperature typically below 77K. This is accomplished by thermally isolating the cable from the surroundings. So, HTS power cables are cooled with a forced flow of sub-cooled liquid nitrogen. The heat leaking into the cable or dissipated in the cable itself is absorbed by the nitrogen, which thus warms up and has to be cooled back. The amount of heat which can be absorbed by a given mass flow of liquid nitrogen is limited by the freezing temperature of nitrogen at the cold end and critical temperature of the conductor at the warm end.

The HTS cable thermal loads are determined on a unit length basis so the total refrigeration load depends on the length of the cable. The load from the environmental heating and electrical loading depends on the thermal performance of the cryostat used in the system.

At least two configuration options are available. In one configuration, the three phases are contained in three separate cryostats, and in the second configuration all three phases are in a single large cryostat.

The HTS cable cryostat typically has a flexible double walls with vacuum multi-layer insulation(MLI). The ambient temperature could range from 245K to 320K depending on the HTS cable location and time of the year.

The performance of several thermal insulation systems for both rigid and flexible piping, or cryostat, used in HTS is described in two papers[1,2].

Our cable cryogenic system design is based upon single large flexible cryostat.

2. Design Specification

2.1. Thermal Loads and Operating Conditions of Cryogenic System

TABLE I
THERMAL LOAD OF THE COOLING SYSTEM COMPONENTS

Component	Type	Load(W)
Storage Dewar	Radiation	32.00
	Conduction	1.62
	Sub-sum.	33.62
Transfer Line	Radiation	6.10
	Conduction	1.40
	Sub-sum.	7.50
Core Cryostat	Radiation	16.50
	Conduction	0.95
	Sub-sum.	17.45
Cold box	Radiation	10.00
	Conduction	1.76
	Sub-sum.	11.76
HTS Dummy Cable	Radiation	37.00
	Conduction	0.93
	Sub-sum.	137.93
Total Load		108.26

Conductive and radiative thermal load of the cryogenic system is shown in Table I. Total thermal load is about 108.3W. It contains the heat leak of storage dewar, core cryostat, cold box, transfer line, and dummy cable.

TABLE II
OPERATING CONDITION OF THE CRYOGENIC SYSTEM

	30m System	250m System
Pressure condition & Pressure drop		
- Cable del P	0.03 bar below	2.0 bar below
- Cable outlet P	3.00 bar over	3.0 bar over
- Other del P	0.005 bar below	3.0 bar below
Temperature Condition		
- Cable inlet	70K	70K
- Cable outlet	72K	72K
- Max. del T	7K	7K
Mass flow rate Condition		
- Former	0.0144 kg/s	0.12 kg/s
- Return	0.0432 kg/s	0.36 kg/s

Table II shows the operating condition of the cryogenic system along the cable length. In order to prevent the evaporation of LN2 the cable outlet pressure must be greater than 3.0 bar. Temperature drop across the cable cryostat is 2K in the normal operating condition. Mass flow rate of the former in single phase is about 1/3 times to the whole(3-phase) circulation flow rate of return line.

3. CRYOGENIC SYSTEM DESCRIPTION

This cryogenic system configuration is similar to other systems shown in [3]. The flow diagram of liquid nitrogen is shown in Fig. 1. The main components of cryogenic system are shown in Fig. 2 through Fig. 4. The LN2 supply tank serves to maintain the circulating loop pressure through the distribution lines. The liquid nitrogen supply and return lines for the three-phase HTS cable are connected using bayonets. The internal circulation loop consists of the circulation pump, followed by the subcooler. The subcooler heat exchanger uses saturated liquid nitrogen boiling on the shell side to subcool the circulating high pressure liquid nitrogen stream that cools the HTS cables. The gas boiled off in the subcooler can be directly vented to atmosphere or can be discharged through a vacuum pump system. The vacuum pump system is used to produce sub-atmospheric pressures on the shell side of the subcooler heat exchanger to obtain temperatures below 77K. Auto fill system is used to replenish the liquid nitrogen boiled off in the subcooler .

The heat loads were determined from measurements of the temperature drop across the subcooler and measured flow rates of the liquid nitrogen. The pressure drop of the supply and return line is measured by difference pressure gauge using the evaporated nitrogen gas. The mass flow rate of circulation is measured at two points. One point is return line where whole mass flow rate flows. The other point is one former line.

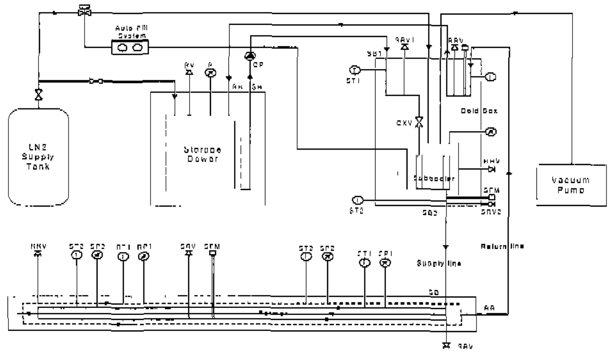

Fig. 1. LN2 flow diagram

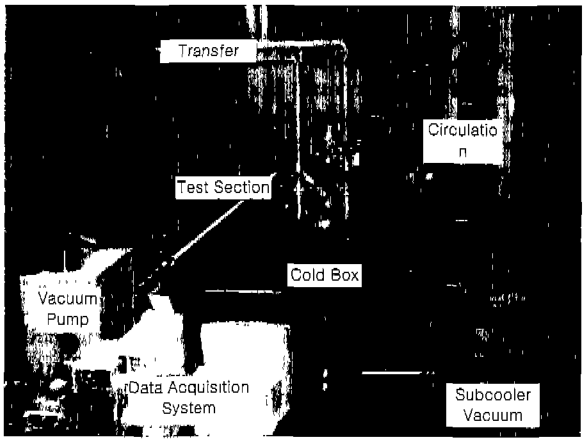

Fig.2. An apparatus of cryogenic system for HTS power cable

3.1. Component Specification

3.1.1. Storage Dewar

- Liquid nitrogen supply and storage
- Component : Auto fill system, Relief valve, Pressure sensor
- Pressure drop : 0.1 bar at 0.36kg/s
- Heat leak : 20W

3.1.2. Circulation pump

- Liquid nitrogen circulation equipment
- Maximum driven pressure : 15 bar
- Maximum pressure drop : 12.5 bar

3.1.3. Subcooling System

- Absorbing the heat leaking by the subcooled LN2
- Component : Heat exchanger, Vacuum pump, Control valve, Mass flow meter, Relief valve
- Pressure drop : 0.2 bar at 0.36kg/s
- Heat leak : 18W

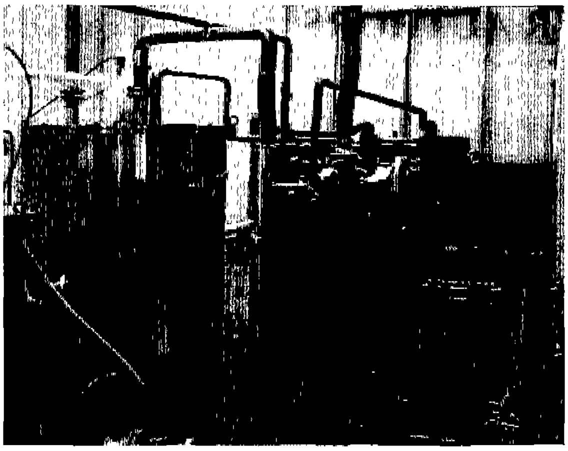

Fig. 3. Storage Dewar and Circulation Pump

Fig. 4. Subcooling System

4. TEST ITEMS

- ○ Heat Exchanging Performance of Subcooler.
- ○ Pressure Drop between Supply and Return Lines.
- ○ Heat Transfer Coefficient Inside Former.
- ○ Heat Leak of the Cable Cryostat.
- ○ Simulation of Electrical Load of HTS Cable System.

ACKNOWLEDGMENT

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