NOTICE

THE BROOKHAVEN SUPERCONDUCTING CABLE TEST FACILITY†

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ABSTRACT

Construction has started on an outdoor testing station for flexible ac superconducting power transmission cables. It is intended to serve as an intermediate step between laboratory-scale experiments and qualification testing of prototype-scale cables. The permanent equipment includes a 500 W supercritical helium refrigerator using a screw compressor and multi-stage turbine expanders. Helium storage for 250,000 cu ft of helium at 250 psi is provided. Initially, the cables will be tested in a horizontal cryostat some 250 ft long. High-voltage 60 Hz tests will be performed with the cable in a series resonant mode with a maximum line to ground capability of 240 kV, this is adequate for a 138 kV system design. Impulse testing up to about 650 kV is planned. The cable conductor will be energized by current transformers, initially at about 4 kA and later up to fault levels of 40 kA.

The refrigerator is now at the site and testing on a dummy load will commence in the Fall of 1976. The cryostat will be installed in 1977 followed about a year later by the first cable tests.

I. INTRODUCTION

The Test Facility forms an important intermediate step between laboratory-scale experiments and a full-scale demonstration transmission system. At the present time the high-voltage and high-current capabilities are evaluated on separate samples in the laboratory. Simultaneous excitation will be possible at the new facility. In addition, the cryogenic equipment has been designed to be similar to that envisaged for a full-scale system. This has the objective of providing highly reliable service and simple maintenance.

II. ELECTRICAL TESTS

Initially the facility is designed to test flexible cable designed for a maximum system voltage of 138 kV. The maximum values of available voltage and current sources are shown in Table I. At present, only the high-voltage 60 Hz transformer is on order, other equipment will be added progressively. The general layout of the site is shown in Fig. 1. Much of the electrical test equipment will be located in a weather-proof metal building. The cryostat is large enough to hold three 138 kV cables, thus permitting simultaneously (single phase) excitation by voltage and current. A three phase current source will also be provided so that unbalanced currents and the effect of axial magnetic fields can be studied.¹ The cryogenic envelope on order will permit about 300 ft of cable to be tested initially.

Care has been taken in the design of the electrical test equipment to avoid spurious ground transients which may complicate the measurement of losses and, on

Manuscript received August 17, 1976.

† Work supported by the Energy Research and Development Administration, the Electric Power Research Institute and the National Science Foundation.

* Operated by Associated Universities, Inc., under Contract to the U.S. Energy Research and Development Administration.

occasions, introduce an electrical shock hazard. A computer-based instrumentation system is being designed to assist in data gathering and reduction. The computer will also be capable of monitoring some aspects of the refrigerator operations.

III. REFRIGERATOR

The refrigerator is designed as a first step towards a system optimized for utility company service. The principle components include a 500 watt supercritical refrigerator with gas bearing turbine expanders, a 350 horsepower hermetically sealed, oil-injected screw compressor and four helium storage tanks with a capacity of 250,000 cu ft. The simplified flow schematic is shown in Fig. 2.

To provide long periods of uninterrupted service it is essential to ensure each component provides the highest possible reliability. It is well known that horizontal piston type compressor, both lubricated and nonlubricated, require maintenance at scheduled intervals. Moreover, dynamic o-ring seals are required which provide a path for air to enter the helium stream. The screw compressor was selected to avoid these problems. Records show that oil injected screw compressors have operated, without shutdown, in excess of 50,000 hours on freon and ammonia refrigeration systems. The screw compressor manufacturer indicates that the running time was limited in most cases by the instrumentation package. Therefore, it is likely that the screw compressor running time can be extended considerably by selecting high quality instrumentation. The oil which is injected into the suction side of the compressor must be removed from the helium before entering the cold box. Oil removal is accomplished in several stages; first, the oil and helium discharge into a sump where gravitational separation occurs, next the helium passes through a first stage demister and then through

TABLE I
Characteristics of Electrical Test Equipment

Description	Rating	No. of Phases	Purpose of Test
High-Voltage Transformer (Series Resonant)	240 kV,	1	i) Partial Discharge Measurements
	60 Hz		ii) Voltage Excitation
	14 A		iii) Dielectric Lifetime to Failure
Impulse Generator	600 kV	-	i) Switching Surge Tests
	100 kJ		ii) Lightning Surge Tests
Current Transformer	4 kA	3	i) Current Excitation
	(Continuous)		ii) Loss Measurement Under Rated Load
Current Transformer	40 kA	1	i) Fault Tests
	(short duty factor)		ii) Heat Impulse Under Fault
			iii) Quench Current

MASTER

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Fig. 1. General Layout of the Test Facility Site

an aftercooler and cyclone separator. The helium stream is finally purified by charcoal and molecular sieve adsorption beds. It is our belief that both the oil and water vapor will be < 0.1 ppm at the exit of the adsorber beds.

Similar design considerations are reflected in the design of the expansion engines, which consist of three gas-bearing high speed turbines. Work is performed on room-temperature helium, thus avoiding the possibility of introducing contaminants into the helium stream.

IV. SYSTEM DESIGN

The refrigerator is essentially a Claude cycle at the high temperature end and a Brayton cycle at the low temperature end. Pre-purified helium gas is supplied from a 4,000 Cu ft buffer volume at 6 atmospheres pressure, enters the oil injected screw compressor at 3 atmospheres and is raised to 15 atmospheres at the outlet. Helium gas and oil exit the drive motor and enter the compressor sump for initial helium-oil separation. The helium stream is then purified and cooled by passing through a bulk oil separator, aftercooler, cyclone separator, coalescer, coalescer and molecular sieve beds. The helium is cooled by aluminum plate fin heat exchangers located in the cold box. Three high-speed gas-bearing turbines placed in a separate pod serve as expansion engines. The 15 atmosphere 6°K supercritical helium is available to cool the cable and terminations. The final expansion turbine may be located in the cold box assembly or at the far-end of the cryogenic envelope.

The system will include on-line continuous gas analysis. Presently, the helium gas analysis program is being conducted on a 150 HP oil lubricated screw compressor loaned to Brookhaven National Laboratory by Cryogenic Technology Inc. Work is continuing on our system which includes gas chromatographs utilizing helium ionization, thermal conductivity and flame ionization detectors. Moisture is measured with a hygrometer. These instruments when perfected give us the

capability to measure down to the parts per billion level. However, the methods for sampling and interpretation of the results are being continuously modified, and therefore the documentation of concrete results will be presented at a future date. The performance specifications of many of the refrigerator components are shown in Table II.

The important characteristics of the cryogenic envelope are shown in Table III. It is planned to install 4 or 5 sections initially.

V. SITE LAYOUT

A general layout is shown in Fig. 1. The location of the cryogenic components is shown in more detail in Fig. 3. The helium refrigerator plant layout is arranged such that a minimum distance is provided between connected components while allowing adequate distances for operation and maintenance. Of course, it is also desirable from a cost standpoint to move the equipment together in order to minimize the interconnecting piping and wiring.

The equipment located inside the building is concerned with the compression, control, purification and overall management of the main process stream when operating the refrigerator at design temperature under steady-state conditions. Components included low pressure filter, compressor, aftercooler, cyclone separator, coalescer, absorber beds, refrigerator turbine assembly, process vacuum system and all necessary automatic controls. Much of this equipment can be seen in a photograph of the interior of the refrigeration equipment building shown in Fig. 4.

Located outside the main building are helium storage tanks, vaporizers; used in the event of refrigerator failure, and water chiller. The helium buffer volume and helium storage tank are 14' dia x 50' long and have been prepared for outside service. Auxiliary equipment includes instrument air, plant air, air driers, and cooling water pumps. This equipment is protected from the weather by small enclosures.

Fig. 2. Simplified Flow Diagram of the Supercritical Helium Refrigerator

VI. PRINCIPAL CONTRACTORS AND VENDORS FOR CRYOGENIC EQUIPMENT

The scale of the installation is such that virtually all of the components were purchased from commercial firms. In some cases, the components have specific requirements and were designed and fabricated to performance specification from Brookhaven National Laboratory. However, many of the components were selected on the basis of previous applications and performance and are commercially available.

Vendor	Component
Cryogenic Technology Inc.	Refrigerator
Sulzer - CTI	Turbine
Dunham-Bush - CTI	Screw Compressor
McCormack Engineering	Oil Cooler
McCormack Engineering	Water Chiller
AMF - Beaird	Helium Gas Storage Tanks
Kahn Co.	Adsorber Purifier
Pall Trincor Corp.	Coalescer and Filters
Dollinger	Filter
Dover Corp.	Control Valve
R. P. Adams Co.	Aftercooler
R. P. Adams Co.	Cyclone Separator
Delaval	Oil Pump
Leybold - Heraeus Inc.	Vacuum Pump
Niboc, Jamesburg	Ball Valve
Scientific Instrument & Equipment Division	Diffusion Pump

Vendor

Anderson - Greenwood
Circle Seal
Combination Pump Valve Co.
Grove
Victor
Hex Industries Inc.
Cryogenic Technology Inc.

Component

Relief Valve
Check Valve
Check Valve
Pressure Regulator
Pressure Regulator
Air/Helium Heat Exchanger
Liquid Nitrogen Purifier

VII. TIMETABLE

The status and projected goals for the various components of the facility are shown below:

Description	Status
Refrigerator	Now in final assembly. Test on internal load in late 1976.
Cryogenic envelope	On order. Installation planned for mid 1977.
H. V. Transformer	On order. Installation planned for early 1977.
Impulse generator	It is planned to order this in late 1976 and install it in late 1977.

1. Screw Compressor	25. Gen'l Supply Air Comp.
2. Turbine Refrig.	26. Vac Pump-Main Pump
3. After Cooler	27. Portable Hi-Vac Pump
4. Cyclone Separator	28. 6" Vac Diff. Pump-Cold Box
5. Coaleser Filter	29. 4" Vac. Diff. Pump-Turbine
6. Main Purifier System	30. Electrical Service Yard
7. Suction Filter	31. Electrical Services
8. Discharge Filter	32. Shielded Signal Room
9. LN ₂ Purifier	33. Buffer Tank
10. Watch Desk	34. Storage Tanks
11. 60 SCFM Comp.	35. Freon H ₂ O-Glycol Cooler
12. LN ₂ Purifier	36. Oil Cooler
13. Surge Tk.	37. Aux. Oil Cooler
14. LH ₂ Dewar	38. Gen'l Service Area
15. Warm Up Ht. Exch.	39. Control Room Above
16. Warm Up Ht. Exch.	
17. Dual Oil Pumps	
18. Filter-Oil	
19. Final Stage Oil Filters	
20. Dual H ₂ O Pumps	
21. H ₂ O, Glycol Volume Tk.	
22. Filter	
23. Air Drier "Freon"	
24. Instrument Air Comp.	

Fig. 4. Interior of the Refrigeration Equipment Building. The Cold Box is the Left Foreground. Helium Filters and Vacuum Piping are on the Right, the 350 HP Screw Compressor can be Seen in the Background

Fig. 3. Refrigerator Equipment Layout With Key to Majority of Components

TABLE II

Summary of Design Features of RefrigeratorHelium Refrigerator

Capacity @ 6°K - 8°K : 500 W
 System Inlet Pressure: 15 atms
 Mass Flow : 130 g/s

Nominal Turbine Operating Conditions

Turbine No.	Temperature, K		Pressure, Atm		Flow Rate g/sec	Efficiency %	Turbine Power W
	Inlet	Outlet	Inlet	Outlet			
1	8.0	5.7	14.0	3.0	59.3	50.0	322.8
2	23.0	17.1	9.0	3.0	54.6	70.2	1604.0
3	90.0	79.0	15.0	9.0	54.6	67.0	3224.3

Helium Gas Storage

Capacity 250,000 ft³
 Pressure 15 atms
 Temperature 300°K

Component Cooling System

Freon Chiller 40 ton
 Pump Capacity 120 gal/min
 Head 3.5 atms
 Fluid water-ethylene glycol

Screw Compressor

Capacity 1700 SCFM
 Inlet Pressure 3 atms
 Discharge Pressure 15 atms
 Volumetric Efficiency ~ 80%
 Isothermal Efficiency ~ 50%
 Volume Ratio 2.6
 Pressure Ratio 4.9

Oil Cooler

Capacity 230 kW
 Fluid oil to air
 Operating Pressure 265 psia

Kahn Adsorber Purifier

Number of Beds 2
 Activated Carbon/Bed 400 lbs.
 4A Molecular Sieve/Bed 400 lbs.
 Inlet Water Content 100 PPM
 Outlet Water Content 0.1 PPM
 Inlet Oil Content 500 PPM
 Outlet Oil Content 0.1 PPM

Hex Heat Exchanges

Flow 2000 SCFM
 Design Pressure 15 atms
 Operating Pressure 5 atms
 Intermittant Rating 195 kW or 665,535 Btu/hr.
 Pressure Drop 2 atms

DescriptionStatus

Pothead Termination Prototype will be constructed in 1977.
 Single Phase Cable First test planned in mid 1978.
 Three phase cable First test planned in late 1979.

For the far future it is planned to test splices and longer lengths of cable. If success warrants it the capability of the facility can be extended to test 230 kV cables.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the contribution made by all members of the Power Transmission Project to the design and construction of the Fifth Avenue Test Facility.

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TABLE III

Characteristics of the Cryogenic Envelope Section

Length:	60 ft
Outside Diameter:	16 in
Bore:	8.4 in
Average Heat Leak:	0.4 W/m
Vacuum:	Permanent, $< 1 \times 10^{-4}$ Torr
Intermediate Temp Shield:	None