BNL 18548

**REVIEW OF BROOKHAVEN NATIONAL LABORATORY
SUPERCONDUCTING POWER TRANSMISSION PROGRAM**

October 11, 1973

Krzhizhanovsky Power Institute

Moscow, USSR

by

J. E. Jensen

The program has two primary objectives:

- (1) The development of a superconducting ac cable system leading to
- (2) the construction of a 1/2 mile (804 m) model cable of 200 MVA capacity at Brookhaven and a cable of larger (>2000 MVA) capacity for test at a utility testing site. The cable itself as we envisage it is shown in Figure 1. It is a coaxial cable of flexible design using Nb_3Sn superconductor and a tape wound dielectric, helium impregnated, of a material to be determined. To reach these objectives the program is broken down into four areas of research and development that are carried out in parallel. These are:

- (1) Dielectric materials
- (2) Cryogenic enclosure
- (3) Refrigeration
- (4) Superconducting materials

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Each of these is discussed in greater detail in the following sections. It must be remembered that Brookhaven is not a producer of materials or a manufacturer of equipment. In this particular project we believe it is necessary to test available materials and equipment working closely with industry so that as our results become available we can feed our requirements back, and thus stimulate production of items more suitable to the application.

MASTER

DISTRIBUTION STATEMENT 1

14

Dielectric Materials

In this area the effort is directed at finding a suitable material for use in the cable, and although dielectric losses are important, they are considered secondary to breakdown stress at this time. We have a dielectric test cryostat, shown in Fig. 2. The test chamber can be operated at temperatures from 4.5 K to 20 K and pressures to $16 \times 10^5 \text{ N/m}^2$ at voltage levels to 150 kV ac, and dc. Figure 3 shows the winding machine and a test mandrel being wound with tape. Figure 4 shows the test chamber removed from the cryostat which is in a hole below the floor. The tapes to be tested are purchased from the manufacturer and tested for breakdown stress at various temperatures and pressures in a helium atmosphere. These, it must be stressed, are engineering measurements and additional dielectrics work will be done at Oak Ridge National Laboratory. There is also an arbor for measuring the breakdown in supercritical helium. Figure 5 shows some preliminary breakdown values for some materials being tested. In addition to the electrical properties, the mechanical properties are being measured as a function of temperature.

Cryogenic Enclosure

The Brookhaven cable concept is based on flexibility and therefore, the enclosure is considered to be a pipe into which the cable is pulled after the enclosure is installed. With this in mind it is our desire to have a design that is as simple as possible taking into consideration the heat leak, field installation and cost. We have a program within Brookhaven looking at various designs, also we have a contract with Cryogenic Engineering Company of Denver, Colorado to study this problem and make recommendations on such things as shields, end

connections, etc.. This study is to result in a report of their findings including costs and heat loads for 804 m of enclosure. In addition to these studies we have purchased two pieces of flexible enclosure from Kabelmetal in West Germany for test and evaluation. A cross section of this later enclosure is shown in Figure 6. In this case all of the enclosure walls are corrugated and the N_2 shield is actually formed by an annulus between two corrugated tubes. Insulation is provided in the form of multilayer material in a vacuum between both ambient and N_2 temperature and N_2 temperature to helium temperature. The results of the studies and tests of actual sections should be complete in 4 to 6 months and a choice will then be made for the 804 m model cable.

Refrigeration

The area of refrigeration covers not only the refrigerator proper but also the hydrodynamics and heat transfer in the cable system. This work is being performed at both Brookhaven and the Cryogenic Engineering Laboratory of the National Bureau of Standards in Boulder, Colorado. At Brookhaven we are presently preparing specifications for a refrigerator of 500 to 1000 W capacity to be used as a test machine to show long term reliability. Later it would be used on a model cable. The NBS group has been reviewing oscillation phenomena and are at present writing a system stability analysis for a refrigerator and cable system operating under steady state conditions. We hope to continue this work and extend the model to non-steady state for transient and fault conditions. At a later time thermoacoustical phenomena may also be considered in some detail.

The refrigerator work will culminate in a set of specifications within a few months. The modeling program will of course, continue until data from

flow systems and actual cable systems have either verified the models or empirical relations have been developed to replace them.

Superconducting Materials

This is again a program incorporating both Brookhaven personnel and industrial producers of superconducting materials. At Brookhaven there is a continuing program directed at measuring ac losses and critical currents of Nb_3Sn superconductors supplied by both industrial producers and from within Brookhaven. The results of these measurements are studied to understand the source and nature of the losses and is then returned to the producers with suggestions for improving the materials for cable use. Figure 7 is the loss data taken on a commercial sample. Figure 8 shows loss data of the best samples in the last 3 years. As you can see the losses have decreased each year and this year a material produced by Dr. M. Suenaga of Brookhaven has been tested with the measured losses approaching those for pure Nb.

Electrical Utility Cooperation

In order to have a viable research and development program, Brookhaven believes that frequent interactions with the ultimate users are very important. To this end, we have a working cooperative arrangement with local utility companies on overall system studies. These studies have two purposes, (1) they keep the utilities informed on the progress of a new technology and (2) they insure that our designs are technically and economically attractive.

Figure 1. Flexible Superconducting Coaxial Cable.

Figure 2. DIELECTRIC TEST CRYOSTAT

Figure 4. Test Chamber and Arbor Removed
From the Gyrostat

SUMMARY OF BREAKDOWN RESULTS

DIELECTRIC	NUMBER OF LAYERS	RADIAL THICKNESS mm	H TEMP K	HE PRESSURE ATM	BREAKDOWN LEVEL KV	AVERAGE STRESS AT BREAKDOWN MV/m
TYVEK	10	2.03	7.0	7.9	15.6 ac	8
TYVEK	10	2.03	6.6	7.9	24. dc	12
TEFLON	10	0.76	6.7	14.1	27.5 ac	36
TEFLON	10	0.76	8.2	14.1	95. dc	124
NOMEX	15	0.76	12.9	14.1	23 ac	30
NOMEX	15	0.76	7.0	14.1	51 dc	67
MYLAR	8	2.03		14.1	37 ac	18

Figure 5. Preliminary Breakdown Results

All dimensions shown are diameters (in mm)

Figure 6. Cryogenic Flexible Dewar

Figure 7. Loss Data of a Commercial Sample

Figure 8. Hysteretic Loss Characteristic of Nb_3Sn Tape, 60 Hz