ORNV-P-1438

JUL 20 1965

CONF-650512-4

P

Operating and Repair Experiences on DCX-2 Coils*

MASTER

S. M. DeCamp

Oak Ridge National Laboratory
Oak Ridge, Tennessee

The DCX-2 coils were designed and manufactured in 1960-61 and have been in operation since July 1961.

With a few exceptions, coil operation has been satisfactory. The repair of a mirror is now underway and essentially completed. During operation of DCX-2 from July 1961 until December 1964 when the east mirror coil was taken out of service to be replaced by a spare, a number of shorts and grounds were detected; however, in all but three cases it has been possible to repair the trouble with the coils in place on the machine.

Figure 1 shows a general view of the machine with one mirror coil on the left and the inboard coils down the center section of the machine, with diagnostic ports located between coils. Figure 2 perhaps gives a better idea of coil locations.

Under operating conditions for hydrogen injection, the coils require 11 Mw of dc power. Three Mw are required for each mirror coil, and 2.5 Mw are required for the inboard coils as well as the outboard coils. With hydrogen injection the field in the inboard and outboard coils is 12 kilogauss and the field in the mirror coils is 37 kilogauss. During operation, the field in the central 80 in. of the machine is maintained flat to within 2 to 3 gauss out of 12,000.

* Research sponsored by the U. S. Atomic Energy Commission under contract with the Union Carbide Corporation.

PATENT CLEARANCE OBTAINED. RELEASE TO THE PUBLIC IS APPROVED. PROCEDURES ARE ON FILE IN THE RECEIVING SECTION.

LEGAL NOTICE
This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission, makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report will not infringe privately owned rights; or that the use of any information, apparatus, method, or process disclosed in this report will not cause damage to property or health. The Commission reserves the right to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report will not infringe privately owned rights; or that the use of any information, apparatus, method, or process disclosed in this report will not cause damage to property or health. B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report. C. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. D. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. E. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. F. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. G. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. H. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. I. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. J. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. K. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. L. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. M. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. N. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. O. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. P. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. Q. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. R. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. S. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. T. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. U. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. V. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. W. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. X. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. Y. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon. Z. Notwithstanding any copyright notation that may appear hereon, the Commission hereby grants to the general public permission to reproduce and distribute reprints for Government purposes not withstanding any copyright notation that may appear hereon.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of 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. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

This flat field is achieved by the use of water-cooled shunts across each section of the inboard coils plus a small, variable buck or boost power supply connected across $1/3$ of each inboard coil.

The magnetic forces between mirror coils are supported by the main tank of which the mirror coil spool is essentially a part. The forces of the inboard and outboard coils are carried by stanchions placed between coils and between coils and the mirror coil spool faces. No inboard or outboard coil forces are transmitted to the main tank.

All coils on the machines are of the dc type, wound multiple in hand, of hollow, water-cooled copper conductors.

Design criteria for the coils called for operation with both hydrogen and deuterium injection plus the possibility of fields of 24 kilogauss in the inboards and 81 kilogauss in the mirrors for short intervals not to exceed two hours, which is the overload limit of the generators.

For the condition of deuterium injection, magnetic forces between mirror coils was calculated to be 116 tons.

Due to the field requirements and needed space for access ports into the plasma region of the machine, it was necessary to build coils with a large space factor. This, plus trouble with previously built coils, lead us to build a coil system that is flexible rather than rigid, and one that we hoped would be easily repairable.

The outboard coils, which were manufactured by the Y-12 Plant in Oak Ridge, are wound six in hand of 0.565 x 0.565 in. hollow conductors. They have an ID of 42 in. and an OD of 66 in. They are made up of three sections, each section consisting of five pancakes. Conductor insulation

consists of two layers of mylar tape applied lengthwise on the conductor rather than with conventional spiral fashion. To date we have experienced no trouble with these coils.

The inboard coils were designed by ORNL and manufactured by the General Electric Company in Schenectady, New York. They are wound seven in hand of $1/2 \times 1$ in. hollow copper conductor. The four center coils on the machine consist of three pancakes each. Coil ID is 42 in. and OD is 66 in. The two outer coils are made up of nine pancakes divided into three sections of three pancakes each.

Coil ID is 42 in. and OD is 75 in. No shorts have been experienced with these coils, but due to the open type construction some difficulty has been experienced with grounds.

The mirror coils also were designed by ORNL and manufactured by the General Electric Company. The spool piece and assembly were done by the Y-12 Plant in Oak Ridge. Since the mirror coils have been our main source of trouble, a more detailed description of the coil is in order. Figure 3 shows a close-up of one of the coils on the machine. The coil is 37 in. long with an OD of 48 in. The ID is from 22 in. at the outside to 16 in. in the throat. The coil consists of 36 pancakes divided into six sections of six pancakes each. There are a total of 252 water paths per coil. Your attention is called to the weld on the conductor which is a source of some of our troubles. The pancakes are wound seven in hand with six water path junctions welded together to form one electrical path. Coil insulation is shown in Fig. 4. The 0.010-thick mylar sheet between pancakes is a late addition and was not included in the first two coils. During the $3-1/2$ years the coils have been operated, we have detected about 30 shorts in

the coils. Most of these shorts were in the vicinity of the weld joints previously mentioned. In every case the short was caused by high pressure between pancakes due to improper control of pancake thickness at the weld or weld metal extending beyond the side of the conductors. Obviously, a more rigid inspection is called for at this point. On the mirror coil now under repair we are hydraulically upsetting the copper at these critical points. Other shorts have occurred in the coils due to small particles of metal getting between pancakes. Most of these appeared to be copper and were probably introduced into the coil during manufacture. Rigid inspection is again a necessity. However, since the coil is not potted or sealed, there always remains the danger of getting foreign particles in the coils. During repair of the east mirror coil a close pancake by pancake examination revealed that at least 26 separate shorts had occurred and cleared by themselves undetected. All evidence points to small foreign particles as the source of trouble.

The three shorts that we could not fix in place occurred in the crossover. This is where a conductor crosses from one side of the pancake to the other at the inside diameter of the coil. Here, magnetic forces have moved the conductors with respect to one another enough to develop a scissors action and cut through the insulation between two adjacent water paths.

Our "fix" for this in new coils has been to slightly chamfer adjacent conductors to remove the possibility of this scissors action. In the case of repair, the interference was removed by cutting away some copper and filling the coil with fiberglass and epoxy.

Originally, coil shorts were detected by a comparison of shunt current readings in the three parallel paths through the coils or by making a

magnetic scan of the machine. This was rapidly replaced by building a stepping switch and recorder to continuously scan voltages across the various coil sections.

In general, coil operation has been satisfactory. Obviously, as magnetic forces increase, so does the probability of trouble. The possibility of potting individual pancakes appears to be worth investigation. Coil construction such as that described in this paper appears to offer much from the standpoint of repair of minor troubles while the coils are in place and assures the ability to repair a coil removed from service.

FIGURE CAPTIONS

<u>Fig. Number</u>	<u>Title</u>	<u>Identification</u>
Fig. 1	General View DCX-2 Machine Showing Coil Location	ORNL-Photo-38647
Fig. 2	DCX-2 Cutaway Pictorial Drawing	ORNL-LR-Dwg-66165
Fig. 3	DCX-2 Outboard and Mirror Coils on West End of Machine	ORNL-Photo-37769
Fig. 4	Mirror Coil Pancake Insulation	ORNL-Dwg-65-4714

Fig. 1. General View DCX-2 Machine Showing Coil Location

ORNL-LR-DWG. 66165

Fig. 2. DCX-2 Cutaway Pictorial Drawing

Fig. 3. DCX-2 Outboard and Mirror Coils on West End of Machine

.005 FISHPAPER
.001 MYLAR

.010 MYLAR

2 LAYERS .0035
MYLAR TAPE

CONDUCTOR

Fig. 4.

MIRROR COIL PANCAKE INSULATION