CONSTRUCTION OF A SUPERCONDUCTING TEST COIL
COOLED BY HELIUM FORCED CIRCULATION[*]

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I. GENERAL

Superconducting coils are normally operated immersed in a liquid-helium bath. Alternatively, it seems possible to wind the coils with a hollow conductor and to cool them with a forced circulation of helium.

We think that this method of cooling will show the following advantages:

1) Each point of the conductor will be correctly cooled, and thus a good coil stability will be guaranteed.

2) The absence of flow channels and of empty spaces between conductors will allow an improved mechanical design and construction of the coil. For the same reason, a better electrical coil insulation will be possible.

3) The cryostat construction will be simplified. In fact, the cryostat will reduce to a vacuum tank and, if necessary, a cold shield.

4) The amount of helium contained in the hollow conductor will, in general, be smaller than the corresponding amount of helium required to fill the cryostat of a conventional superconducting coil.

We think that these advantages will be particularly evident for coils of large dimensions. In the case of small coils, they might be counterbalanced by the difficulty of having (with forced cooling) at the same time a relatively small feeding current and a high over-all current density in the coil cross section. Large values of feeding current will cause power losses in the input leads which would normally be unacceptable for small coils.

For the purpose of studying experimentally the technical problems related to forced cooling of superconducting coils, we have constructed an apparatus to circulate the helium, and a test coil.

Details of this work are reported in the following sections.

II. FORCED CIRCULATION SYSTEM

Liquid helium at normal pressure is a poor cooling medium in the case of forced circulation. The small helium latent heat of evaporation permits easy formation of vapor and liquid mixture.

It has been demonstrated[1] that, on the contrary, supercritical helium at 4.2°K and at a pressure above the critical pressure of 2.26 atm is an excellent cooling medium. As a matter of fact, in these conditions, only one phase can exist, and hence the inconveniences originating from the mixture of liquid and vapor are eliminated.

We have constructed a system to circulate supercritical helium, very similar to the one described in Ref. 1. It should be noted that, while this system is excellent for testing purposes, it is somewhat doubtful whether it would also be convenient for cooling an operational coil. In this case, unless the coil is very small, it will probably be preferable to build the circulating system as an integral part of the helium liquefier.

The forced cooling system and the principle of operation are illustrated in Fig. 1. The vessel (6) is filled with liquid helium. Helium gas is introduced through the line (7) and the valve (8) to the closed loop (1), (2), (3), and (4). The helium is circulated in the closed loop by the pump (3). The helium is brought to a temperature of 4.2°K in the first heat exchanger (1), and subsequently cools down the coil (4). The second heat exchanger (2) of the circuit is used to recuperate, partly, the enthalpy of the helium vapors which are exhausted through (5). The helium in the closed loop is maintained at high pressure, while the pump (3) has only to produce the small pressure drop required for circulation. At the beginning of the operation, before equilibrium conditions are reached, helium must be introduced continuously into the closed loop through (7) and (8). When equilibrium is reached, the valve (8) can be closed.

Figures 2 and 3 give construction details and a general view of the forced cooling system.

The pump (3), which is illustrated in Fig. 4, is a double action piston pump. The piston has a plastic gasket. The valves have no gaskets, but good tightness is ensured by the fine machining of the surfaces. The pump is motor-driven through a long thin rod and crank mechanism, and can be operated at a speed varying between 5 and 200 turns per minute. The maximum speed corresponds to a nominal helium flow of approximately 420 liters/hour.

III. HOLLOW CONDUCTOR AND TEST COIL

The compound conductor used to wind the test coil is an aluminum pipe in the wall of which six, 0.25 mm, superconducting wires are embedded. The conductor cross section is shown in Fig. 5. The reason for this geometry of the conductor cross section is that, with all the superconducting wires being on one neutral axis, the conductor can be easily bent to a small radius in one plane. In fact, a bending radius of less than 1 cm is possible without damaging the wires, which are of Supercon heat-treated copper-plated NbZr alloy. The aluminum pipe is of high purity (better than 0.9999) metal.

The aluminum resistivity, measured on a heavily cold worked sample at 4.2°K in a transverse magnetic field of 40 kG, is approximately 1.4×10^{-8} $\Omega \cdot$cm.

The conductor has been produced, by an extrusion process, by the firm "Atelier électromécanique de Gascogne — R. Creuzet," Marmande, France. The test coil wound with this conductor is shown in Figs. 6 and 7. It consists of 16 double pancakes (each having 36 turns) electrically connected in series. Approximately 300 m of conductor were used to wind the coil. For cooling, the 16 pancakes are fed in parallel

1. H.H. Kolm, in Proc. Intern. Symposium Magnet Technology, Stanford 1965, p. 611.

by a common manifold to which they are connected through special insulating joints. The coil has been operated at a pressure between 3 and 4 atm and at a pumping speed of ≃ 80 turns/min. The pressure drop in the coil was approximately 0.1-0.15 atm. The coil temperature was measured by means of carbon resistors immersed in the helium flow at the coil input and output. The temperature was ≃ 4.7°K. In these conditions the current in the coil could be raised up to ≃ 900 A corresponding to a field in the center of ≃ 28 kG without detecting any dc voltage at the coil terminals. During the current rise time (≃ 2 min from 0 to 900 A) the usual flux jumps could be observed. The maximum value of current was in very good agreement with the value which could be predicted by knowing the short sample characteristic curve of the superconducting wire.

When the current was raised slightly above 900 A, a dc voltage could be detected at the coil terminals. If the current was kept constant, this voltage and the average coil temperature slowly and steadily increased with time. The coil temperature rise was shown by a pressure variation in the circulating helium.

To re-establish the equilibrium conditions it was sufficient to reduce the current to ≃ 600 A. The coil current could also be cut rapidly without any inconvenience. In this case the largest fraction of the magnetic energy stored in the coil (approximately 10 000 J at 28 kG) was discharged into an external resistor of 0.2 Ω connected in parallel with the coil. After a fast current cut-off the helium pressure in the coil increased by 1 to 2 atm.

The coil was fed by an external power supply through current leads which were cooled by helium vapor. Figure 8 shows the cross section of a lead.

1	First Heat Exchanger
2	Second Heat Exchanger
3	Liquid Helium Pump
4	Coil
5	Helium Vapour Exhaust
6	Liquid Helium Vessel
7	Helium Gas Input Line
8	Valve
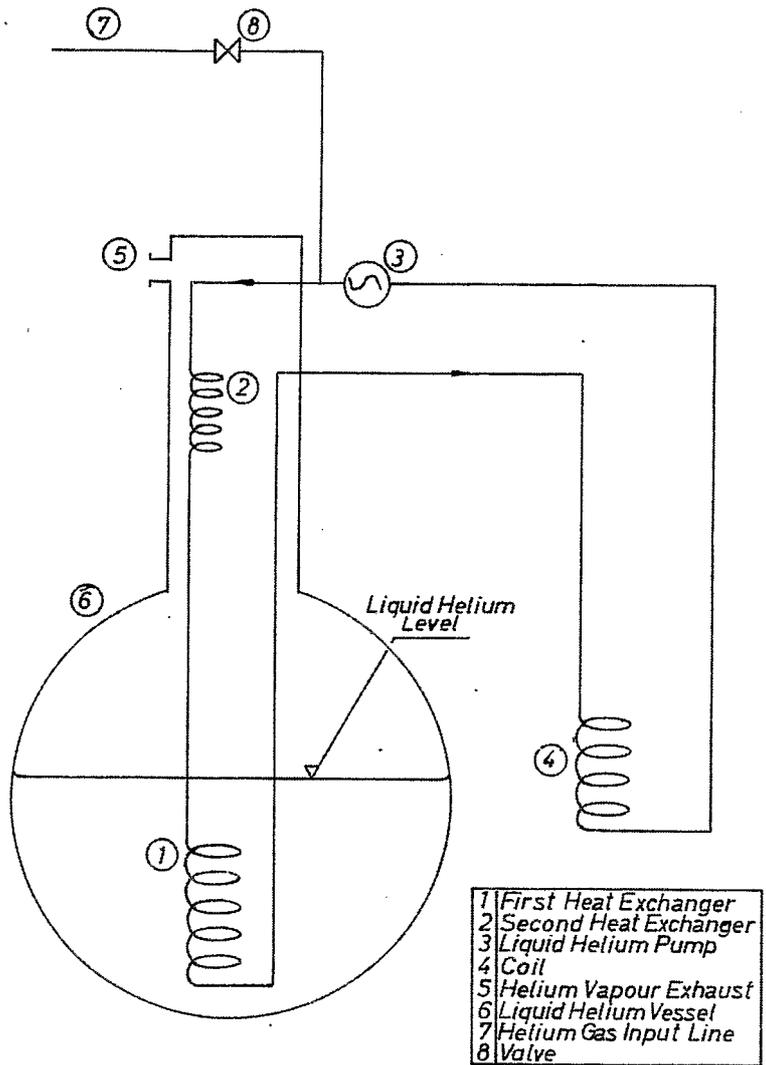
Fig. 1.   Schematic diagram of the forced cooling system.

Fig. 2.   Construction details of the apparatus.
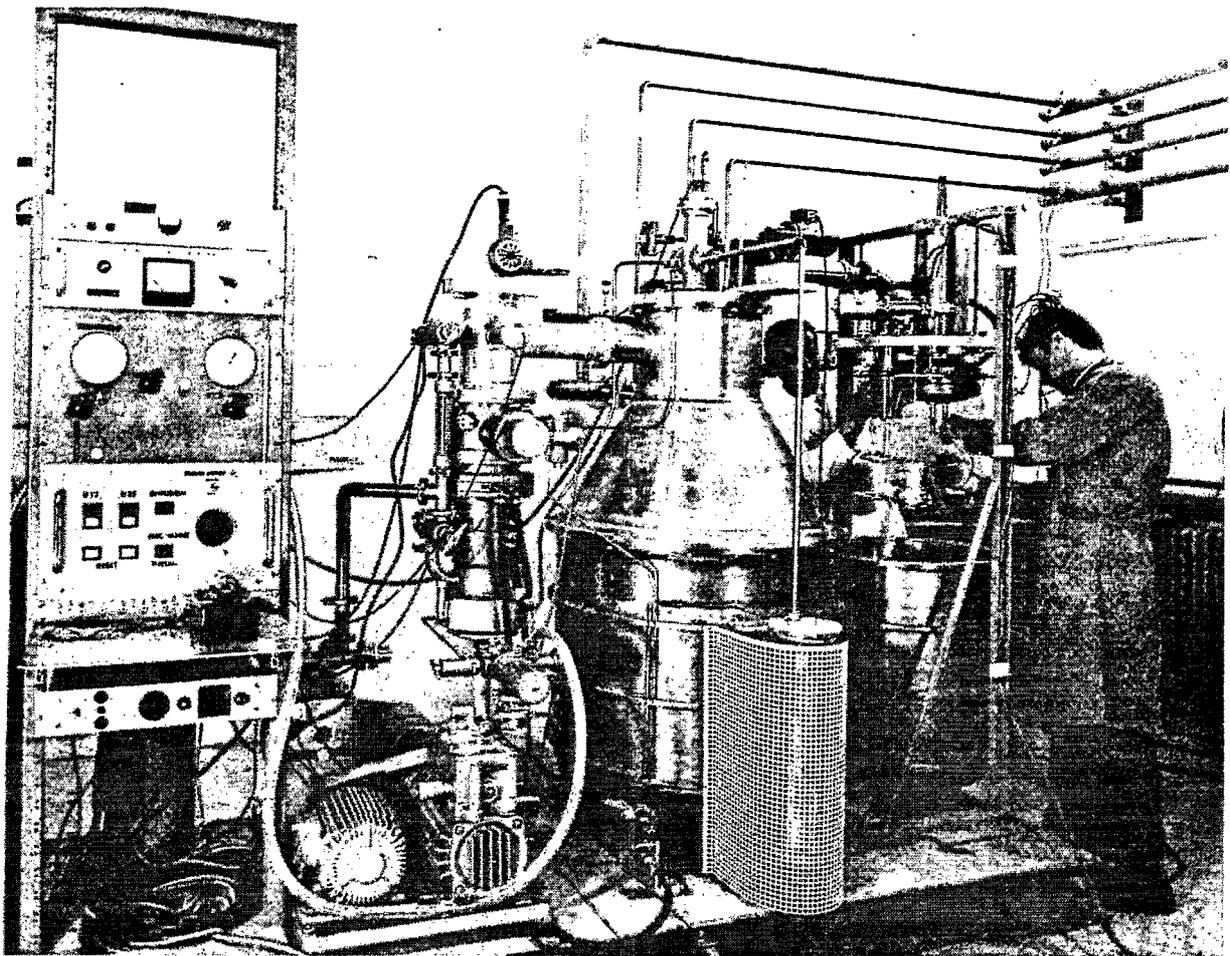
Fig. 3.　　　General view of the system.

CONNECTION FOR COMPENSATING VACUUM

ITEM 19 IS CLAMPED TO ITEM 21 BY MEANS OF STUDS 6x

RETAINING SCREWS FOR ITEM 3
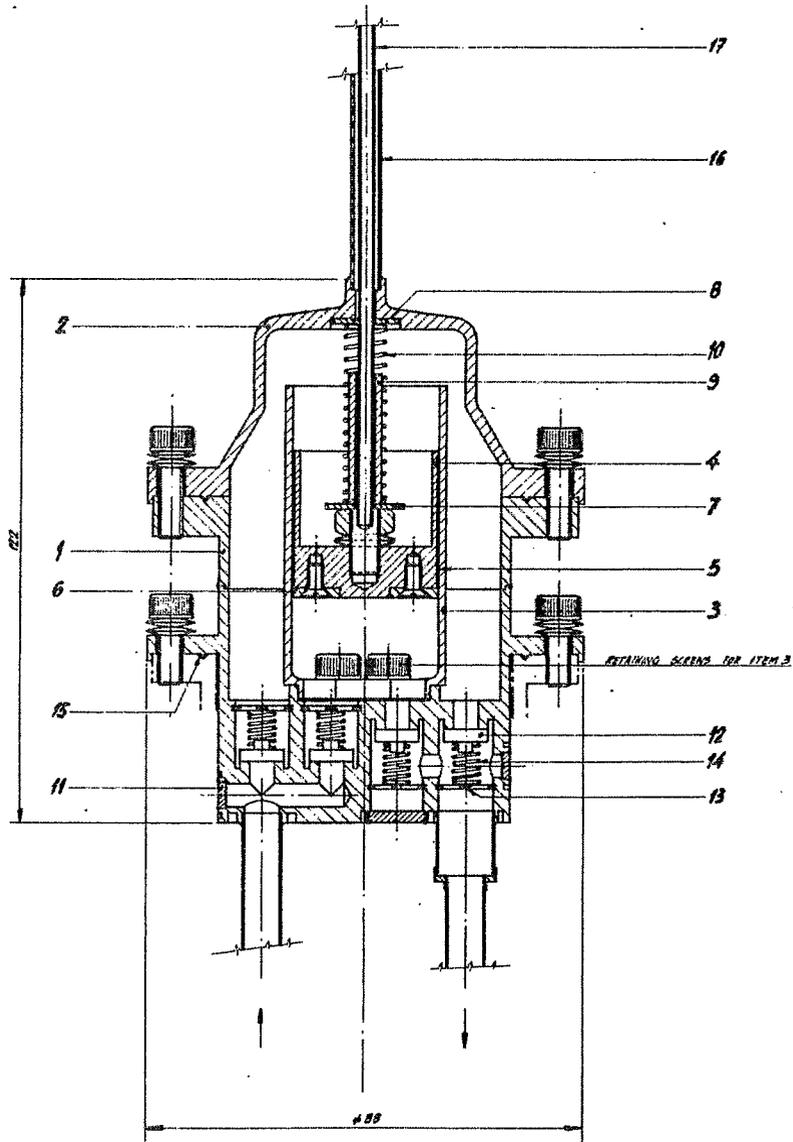
POS 1-17 ASS⁷ OF HELIUM PUMP
SCALE 2:1
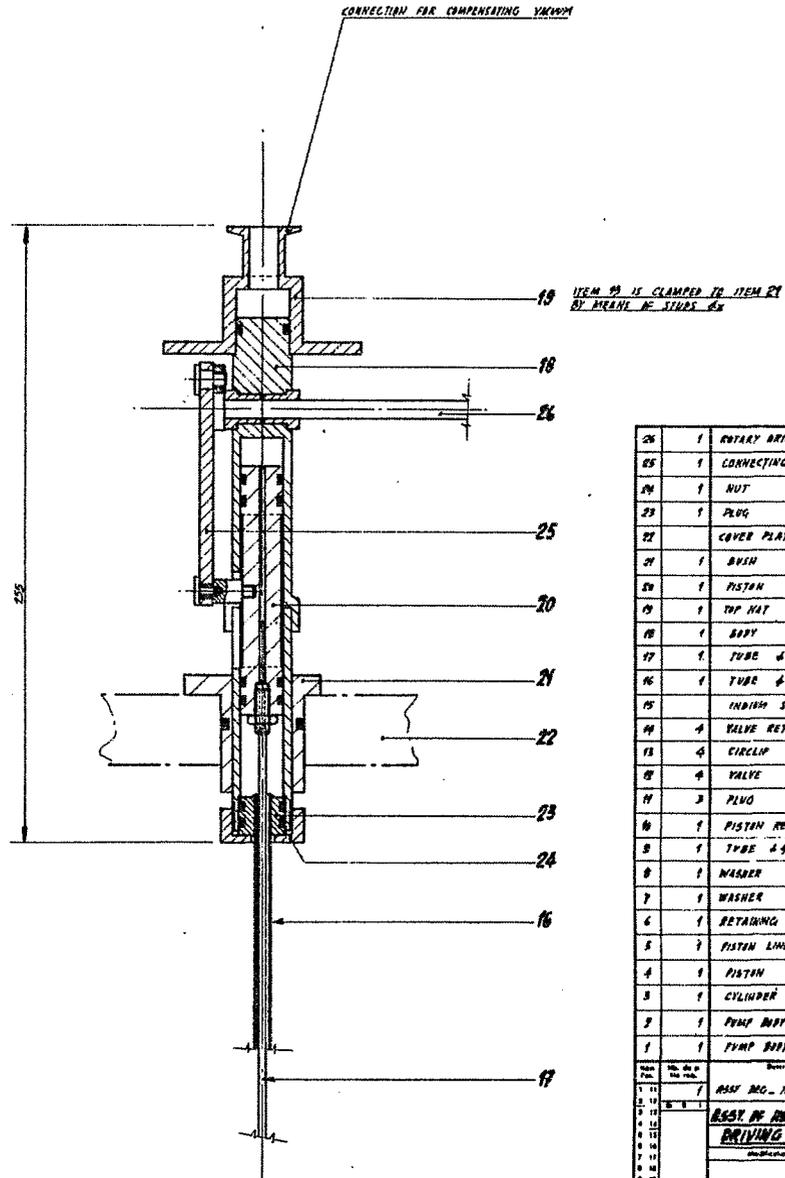
POS 16-26
ASS⁷ OF PUMP OPERATING MECHANISM
SCALE 1:1

26	1	ROTARY DRIVE FROM MOTOR	ST.STEEL		
25	1	CONNECTING ROD	ST.STEEL		
24	1	NUT	ST.STEEL		
23	1	PLUG	ST.STEEL		
22		COVER PLATE	ALU ALLOY		
21	1	BUSH	ST.STEEL		
20	1	PISTON	BRASS		
19	1	TOP HAT	ST.STEEL		
18	1	BODY	ST.STEEL		
17	1	TUBE Ø5x6	ST.STEEL		
16	1	TUBE Ø25x3	ST.STEEL		
15		INDIUM SEAL			
14	4	VALVE RETURN SPRING	PHO.BRONZE		
13	4	CIRCLIP	STEEL		
12	4	VALVE	ST.STEEL		
11	3	PLUG	ST.STEEL		
10	1	PISTON RETURN SPRING	STEEL		
9	1	TUBE Ø4x7	BCH 9040		
8	1	WASHER	BCH 9040		
7	1	WASHER	BCH 9040		
6	1	RETAINING PLATE	ST.STEEL		
5	1	PISTON LINER OF TUBE	BCH 9040		
4	1	PISTON	ST.STEEL		
3	1	CYLINDER	ST.STEEL		
2	1	PUMP BODY - UPPER	ST.STEEL		
1	1	PUMP BODY - LOWER	ST.STEEL		
	1	ASSY DRG - TA 5282_AB			

ASSY OF HELIUM PUMP & DRIVING MECHANISM

C.E.R.N. GENEVE

TA 5282_A1

Fig. 4.   Cross section of the helium pump.

.5mm

5mm

/ø0.25mm Nb-Zr Wires
in 99,99% pure Al Matrix
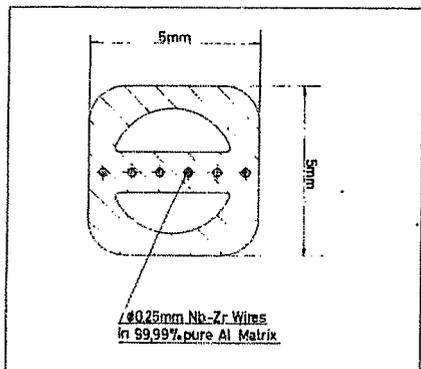
Fig. 5.   Cross section of the hollow conductor.

16 Pancakes(double) 170mm

ø250

ø60

Section x-x

View y-y

He

He

He(Liquid)

Oxide Film Insulation

Detail of insulated junction on manifold

View z-z
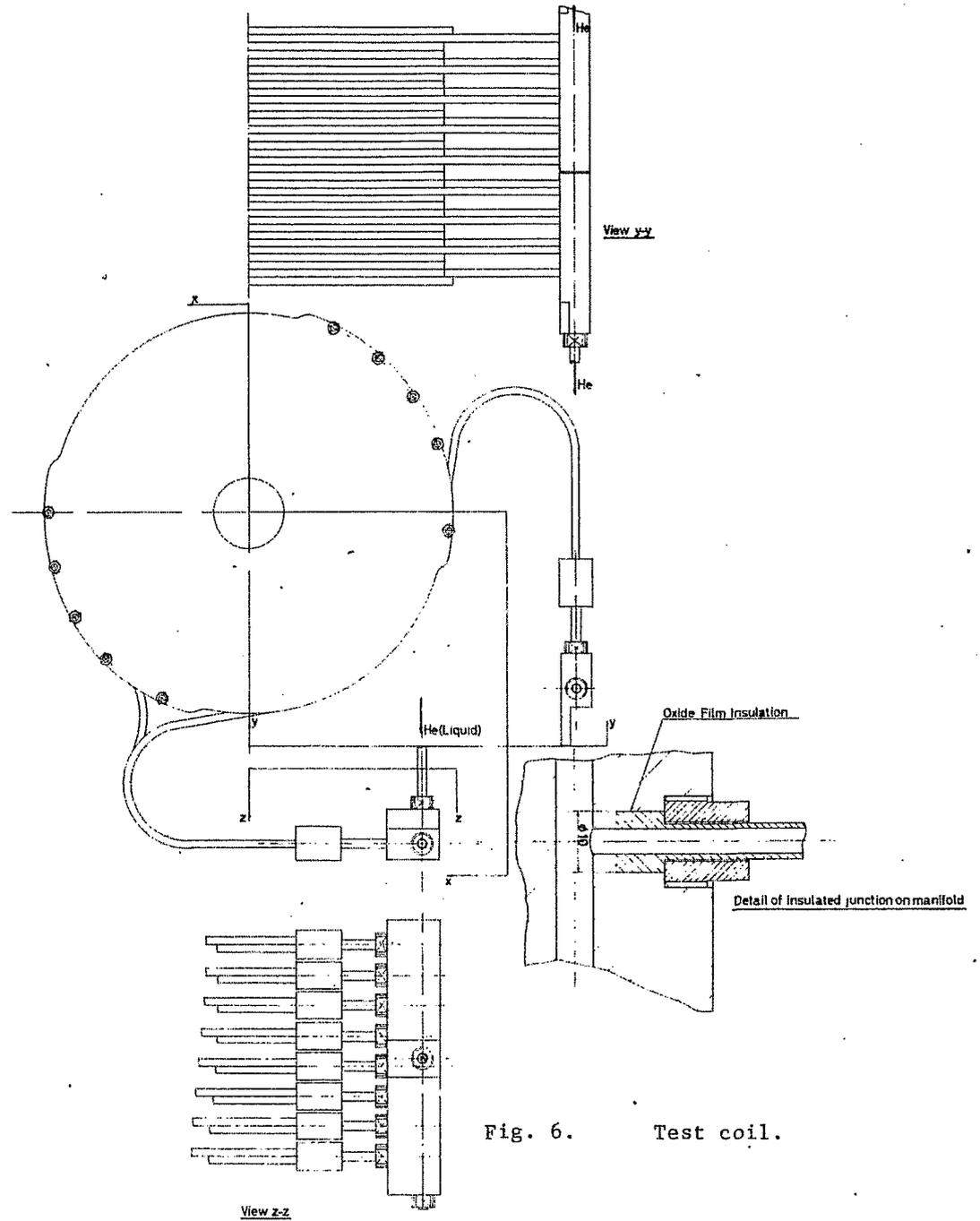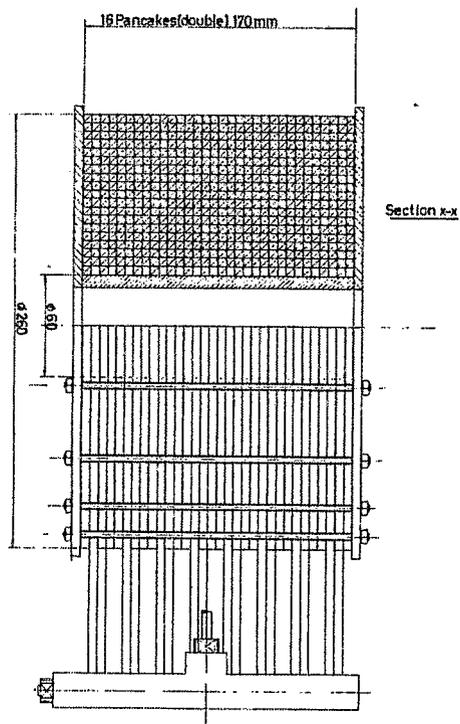
Fig. 6.   Test coil.
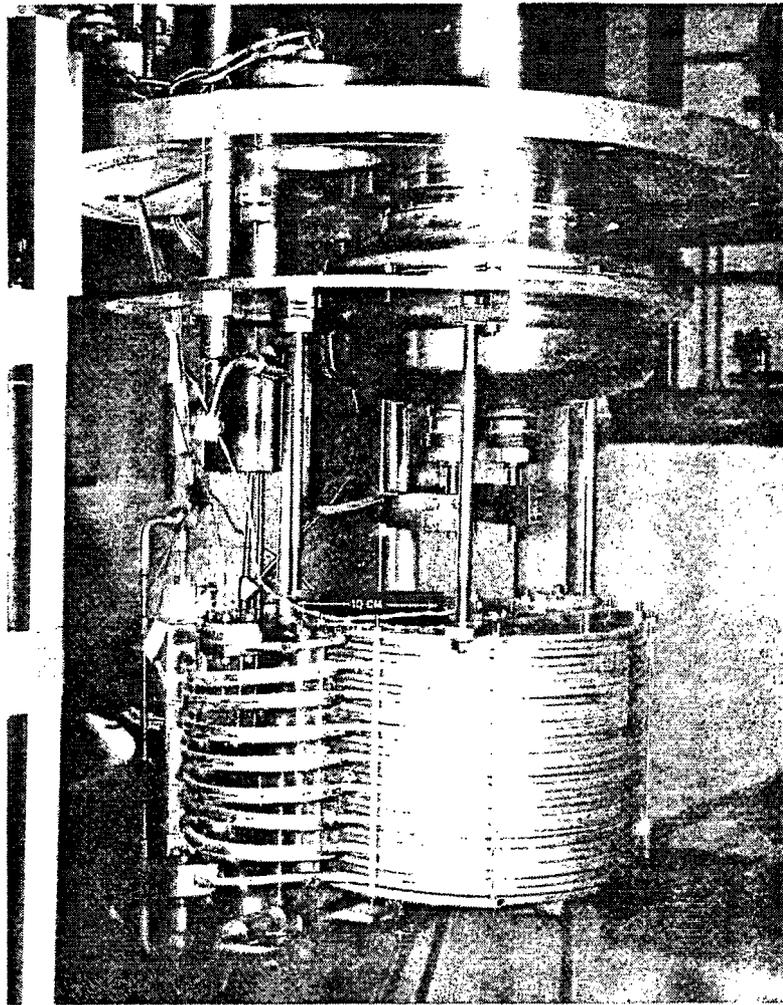
Fig. 7.   Test coil with helium manifold and current leads.
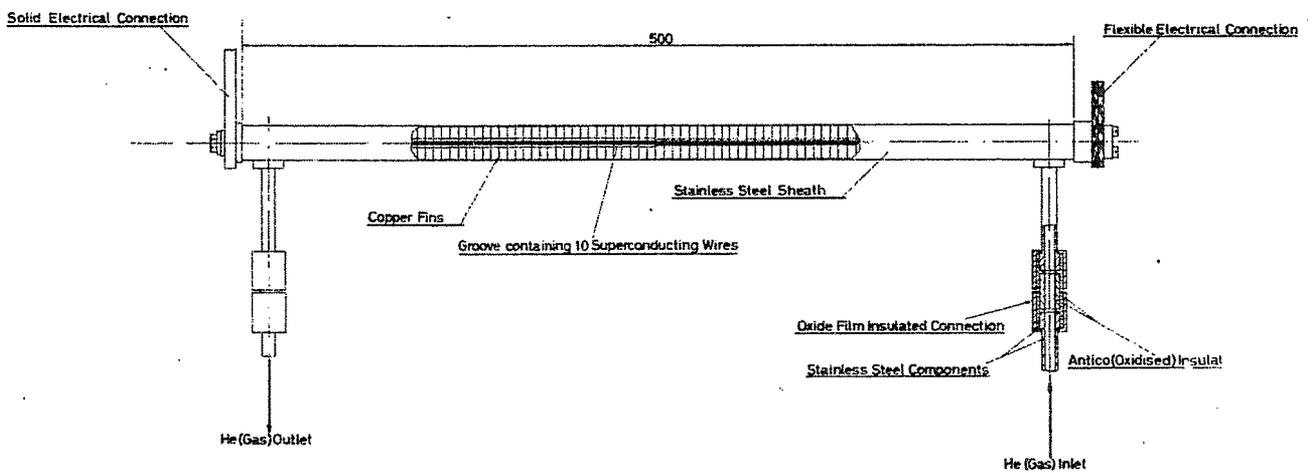
Fig. 8.   Detail of electrical connection cooled by helium boil-off gas.