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THIN SUPERCONDUCTING SOLENOID

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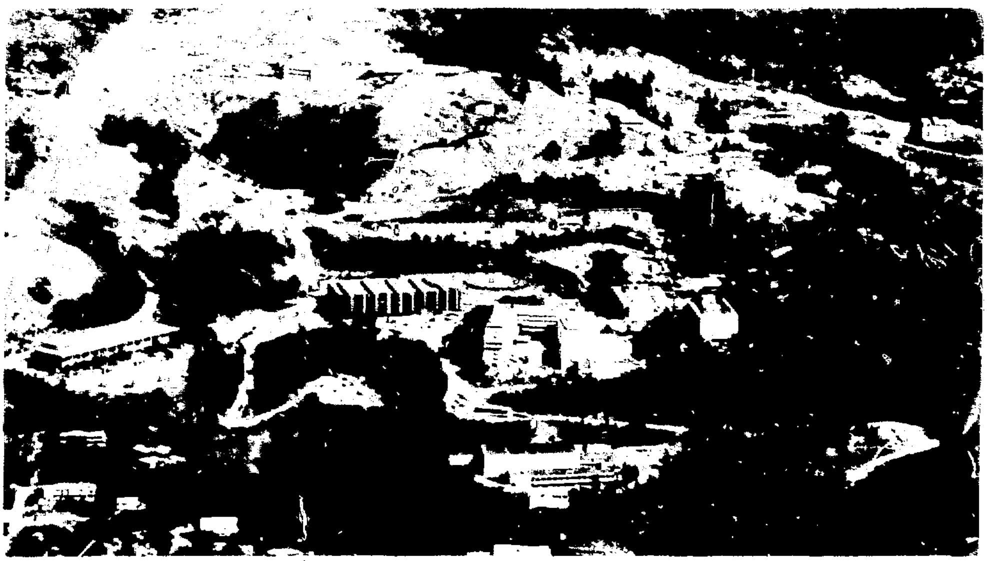

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ABSTRACT

High energy colliding beam physics often requires large detectors which contain large volumes of magnetic field. The TPC (Time Projection Chamber) experiment at PEP will use a 1.5T magnetic field within a cylindrical volume which is 2.04m in diameter bounded by iron poles which are separated by a gap of 3.25m. The TPC magnet, built in 1979 by the Lawrence Berkeley Laboratory (LBL), is the largest high current density superconducting magnet built to date. It is designed to operate at a current density of $7 \times 10^8 Am^{-2}$ and a stored energy of 11MJ, and it is protected by shorted secondary windings during a quench. This paper describes the basic parameters of the TPC magnet and the results of the first subassembly tests at LBL.

INTRODUCTION

The TPC experiment at PEP is one of several colliding beam experiments, which use thin superconducting solenoid magnets. The CELLO experiment at PETRA in Hamburg, Germany and a detector for the ISR at CERN in Geneva, Switzerland use superconductor with an aluminum matrix [1,2,3]. The TPC magnet and a magnet to be used at Cornell University use the concept of a shorted secondary circuit to protect a high current density copper based superconductor [4].

The Lawrence Berkeley Laboratory (LBL) has developed and tested the concept of protecting a large high current density solenoid magnet with shorted secondary windings [5]. This development work is reported in references [6]. The construction and testing of three test coils, with a diameter of 1-meter and 2-meters has led to the construction of the TPC detector magnet.

The TPC magnet is described in references [7] and [8] as well as in this report. This report presents the basic parameters of the TPC magnet, describes the steps of construction, (and presents the results of the first tests of some of the magnet system subassemblies.

BASIC PRINCIPLES BEHIND THE TPC MAGNET

The TPC magnet is different from almost all other large superconducting magnets which have been built to date. The data gathered on photons by the TPC detector will be enhanced by a magnet which is as transparent as possible to photons. As a result, the LBL thin solenoid design concept evolved. The features which make the TPC magnet unique among large superconducting magnets are:

1) The superconductor operates at matrix current densities which are much larger than conventional large superconducting magnets.

2) The TPC magnet is designed so that its quench is protected by a system of shorted secondary windings. These windings control the quench process and prevent hot spot formation.

3) The TPC magnet is cooled by forced two phase helium cooling instead of helium bath cooling.

4) The TPC magnet has an integrated coil and inner cryostat which is cast ir epoxy resin (see Figure 1).

The TPC magnet has a warm inside diameter of 2.04m. The outside diameter is 2.36m in the center and 2.44m at the ends. The length of the cryostat, which encloses the coil, coil cryogenic system and electrical leads, is 3.84m. Access to the coil, the electrical services, liquid helium, signal wires, and vacuum is restricted to a small portion of the outside corner of one end of the cryostat vacuum vessel. The TPC magnet refrigeration system (refrigerator cold box and control dewar) is connected to the magnet by about 18m of transfer line running under a wall of radiation shielding. The magnet is monitored by a small computer.

Table I shows the basic parameters of the TPC magnet as it runs at design current in its iron return yoke. When the TPC magnet is operated in its iron yoke, it behaves like an infinite solenoid which has a peak induction in the coil which is scarcely different from the uniform induction within the magnet bore. The TPC magnet is designed to produce a field near the center, uniform to better than 1 part in 1000. High field uniformity is required in order that the Time Projection Chamber detector functions properly. The design current density J in the superconductor is very high for a magnet which operates at a stored energy E of 11MJ. As a result, EJ^2 product is over 50 times that of conventional large superconducting magnets[9].

Table I: The Basic Parameters of the TPC Magnet in its Iron Return Yoke

Coil Diameter (m)	2.172
Coil Length (m)	3.295
Number of Turns	1772
Design Central Induction (T)	1.5
Design Current (A)	2225
Magnet Coil Inductance (H)	4.41
Current Density J in Superconductor Matrix at Design Current (Am^{-2})	6.87×10^8
Magnetic Energy Stored at Design Current (J)	10.91×10^6
EJ^2 product at Design Current ($J\ A^2m^{-4}$)	5.15×10^{24}
Maximum Charge Voltage (V)	5
Minimum Charge Time To Design Current (s)	2000

CONSTRUCTION OF THE TPC MAGNET

Construction of the TPC magnet began during the summer of 1978 with the fabrication of a 9.55mm thick 1100-0 aluminum bore tube, which is one of the shorted secondary circuits used for quench protection (see Figure 1) On the bore tube was wound a layer of 600 turns of ultra pure aluminum which was insulated turn to turn with dacron cord. The ultra pure aluminum, which is in the form of a 3mm diameter wire, has a residual resistance ratio at 4.2K of at least 1500. A great deal of care had to be used while winding the ultra pure aluminum, because this material deforms at almost no stress, resulting in increased resistivity of the aluminum at low temperature. Once the ultra pure aluminum layer was wound, it was vacuum impregnated in epoxy resin.

The cast ultra pure aluminum layer provided a firm platform on which to wind the 1.0 x 3.7mm Formvar insulated superconductor. The superconductor, which has a copper to superconductor ratio of 1.8, has over 2000, 25 μm diameter Nb-Ti filaments, which are twisted one twist every 50mm. This conductor will carry at least 3200 A at 4.2K and 2.0 Tesla. Figure 2 shows the superconductor being wound onto the cast ultra pure aluminum layer.

The 1772 turns of superconductor was wound in two layers under tension of 690N (155 lbs). This prestrains the superconductor to allow it to match the thermal contraction of the surrounding aluminum. The superconducting coil has an electrical center tap between the two layers. (see Figure 1 for the location of the superconductor.) A layer of flattened 19.1mm outside diameter, 3002 aluminum tube with 2mm thick walls is wound over superconducting coil. The aluminum tube serves a dual function. One third of the turns carry two phase liquid helium to cool the magnet,and the layer of aluminum tube serves as an elastic support for the coil system, thus limiting the total strain of the coil package when magnetic forces are applied. The superconductor and flattened cooling tube were vacuum cast with epoxy resin to form a rigid integrated structure. Figure 3 shows the finished coil package.

CONSTRUCTION OF THE CRYOSTAT

The TPC magnet aluminum cryostat vacuum vessel has an inside diameter of 2.04m and an outside diameter at the ends of 2.44m. The central section of the outer cylinder is recessed for some drift chambers which are about 3m long. The overall length of the cryostat is 3.84m. The TPC cryostat vacuum vessel not only provides vacuum for the superinsulation but it's inner wall is also an 11atm pressure vessel which holds the argon-methane mixture needed for the Time Projection Chamber. A cross-section showing the coil package within the cryostat is shown in Figure 4, this figure also shows one the compression support rods. Figure 5 is a photo of the completed TPC magnet cryostat.

The TPC magnet coil package is insulated with multilayer insulation and it has a liquid nitrogen shield. The insulation and the shield are not shown in Figure 4. The superconducting coil package is supported to the outer cryostat vessel with a bicycle type support system of 25mm diameter fiberglass epoxy rods. The support system will carry a load of 2×10^5N (20 tons) in any direction. The cold mass of the coil package is about 1500kg. The total refrigeration needed to cool the TPC magnet coil package is estimated to be between 10 and 15W at 4.4K (not including the gas used to cool the 2500A electrical leads).

CONSTRUCTION AND TESTING OF THE TPC CRYOGENIC SYSTEM

The TPC magnet is cooled with two phase helium carried in the tubes around the coil (see Figure 1). The principle behind the cryogenic system is described in reference[10]. The TPC magnet cryogenic system consists of a 200 liter control dewar, a conditioner dewar and 85m of liquid nitrogen shielded transfer lines which carry both liquid nitrogen and two phase helium to the TPC magnet and two 1.8m long compensating solenoids. The control dewar contains the LBL helium pump described in reference [10] and a copper tube heat exchanger. The control dewar reduces the inlet quality of the two phase helium entering the cryogenic distribution system and the control dewar is a controlled buffer volume of liquid helium between the refrigerator and the load. The TPC magnet control dewar with its helium pump is shown in Figure 6.

The control dewar, helium pump and the primary transfer lines were tested before final connection to the magnet. The measured control dewar heat leak varied from 2 to about 6 Watts depending on the liquid level in the control dewar. Initial tests of the transfer line performance showed a heat leak of about 0.3-0.4Wm^{-1}. This heat leak is high and we expect to reduce it through the elimination of oscillations and improved insulation. The helium pump was operated at mass flow rates from 8 to 40gs^{-1} circulating through the control dewar and transfer line system. Helium pump adiabatic efficiences of about 50 percent were measured.

THE MAGNET POWER SUPPLY, QUENCH PROTECTION SYSTEM & ELECTRONIC DATA LOGGERS

The TPC magnet power supply can provide the TPC magnet with up to 3000A at 10V. The power supply can charge the TPC magnet to full design field in about 40 minutes. The TPC power supply is a six phase supply which is regulated on the primary side of the transformer. The power supply has been successfully tested at full current.

The quench protection system consists of four distinct elements: 1) the 9.5mm thick 1100 aluminum bore tube, 2) the layer of ultra pure aluminum, 3) an SCR "circuit breaker" with a varistor across the leads, and 4) a capacitor bank which discharges into the center tap between the two layers of the coil. The first two quench protection systems are passive, the latter two elements are dynamic quench protection systems which require the quench to be detected quickly. Both of the dynamic quench protection methods have been tested on a 2MJ thin solenoid[11].

A microprocessor data logger is used to monitor 12 channels of data simultaneously every millisecond. The data logger is programmed to take data in a set sequence for 10 seconds after a quench has been detected. The magnet coil package has the following instrumentation built into it: 1) ten small coils, which can be used to initiate a quench and measure the velocity of normal region propagation, 2) five silicon diode temperature sensors, 3) five coils closely coupled to the superconducting coil which measure the change of magnetic flux during a quench, and 4) three voltage taps at the coil ends and at the center tap. The data from the instrumentation built into the coil package is transmitted to the data logger. The data stored in the data logger is then processed by the TPC experiment computer.

CONCLUSIONS

At the time of this 1979 conference, tests on the completed TPC magnet were in preparation and the extent of passive quench protection afforded by the design was not known. Tests of the TPC magnet without iron are scheduled at LBL during the fall of 1979. Tests of the TPC magnet with iron at SLAC are scheduled to occur in the spring of 1980.

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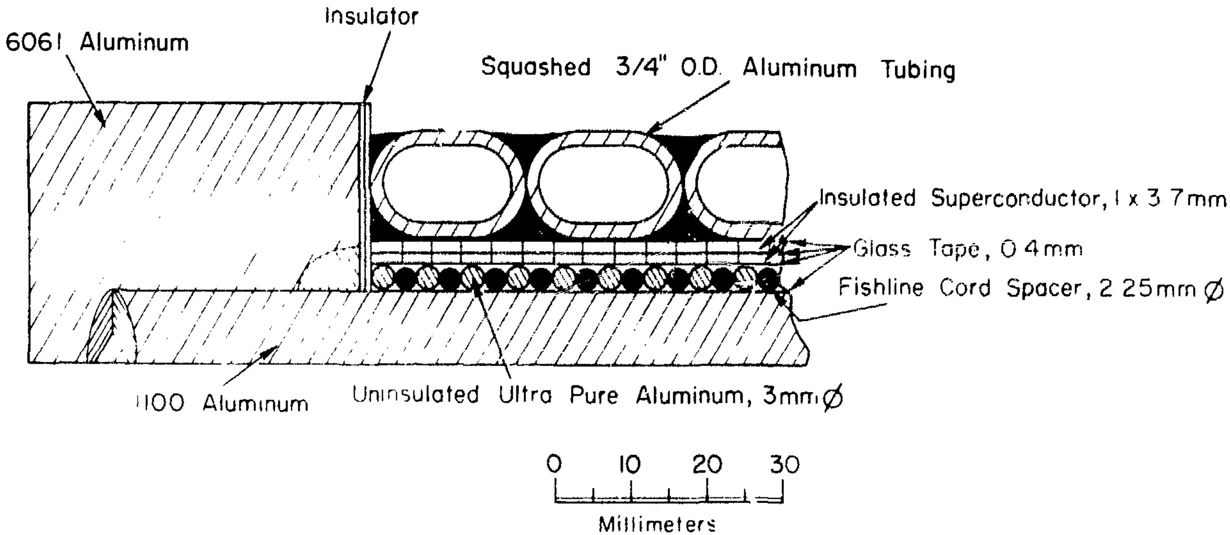
LIST OF FIGURES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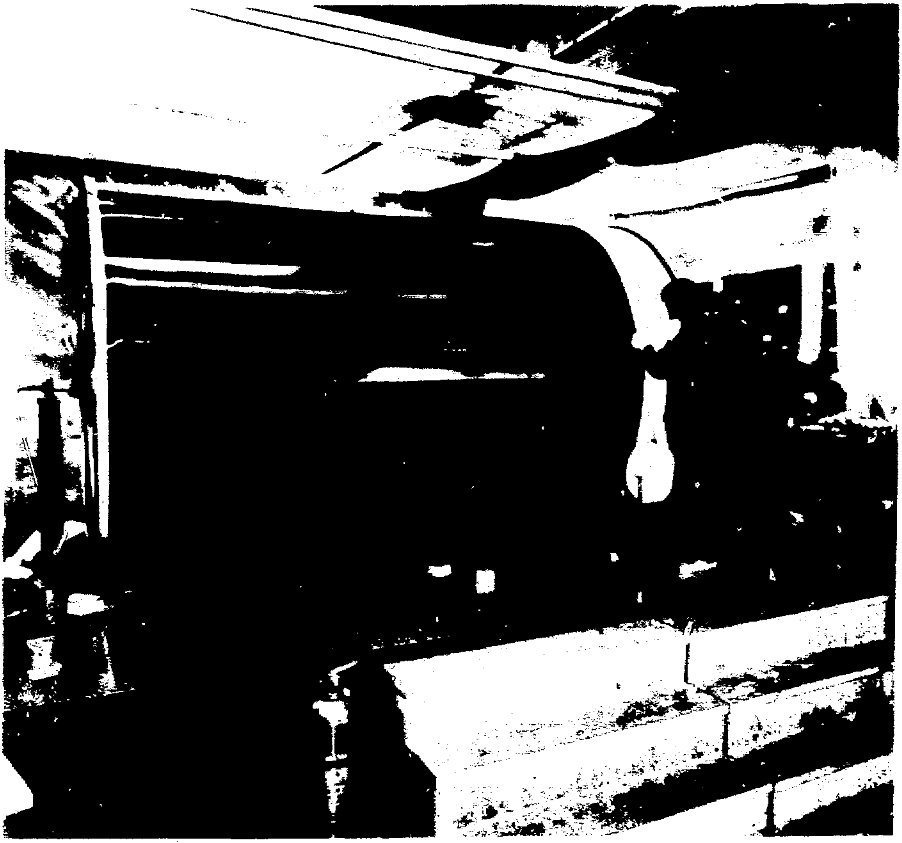

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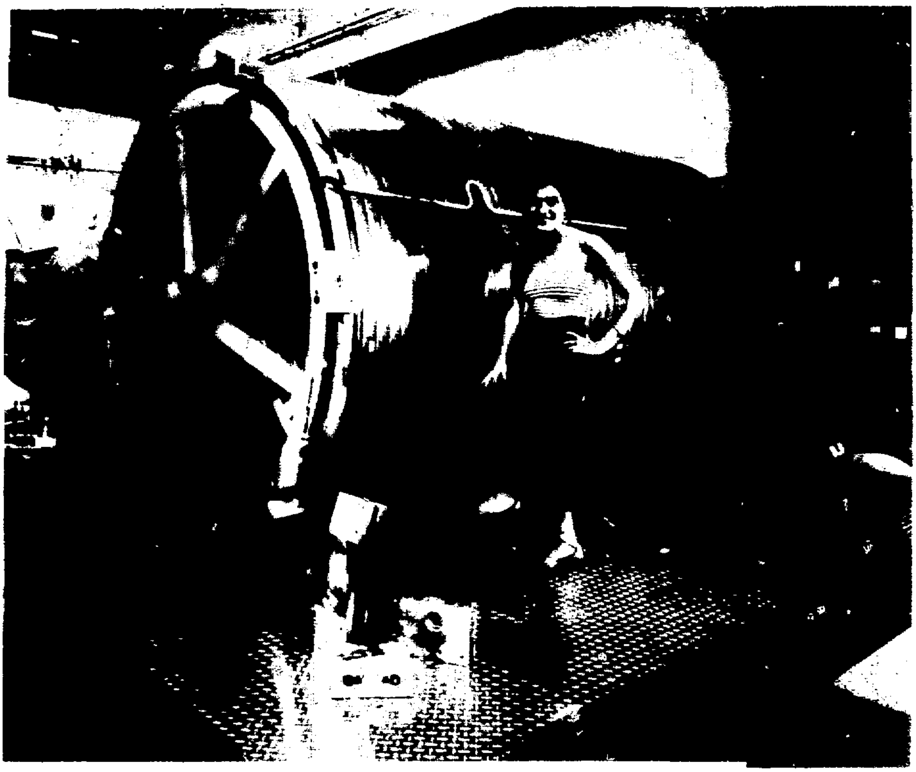

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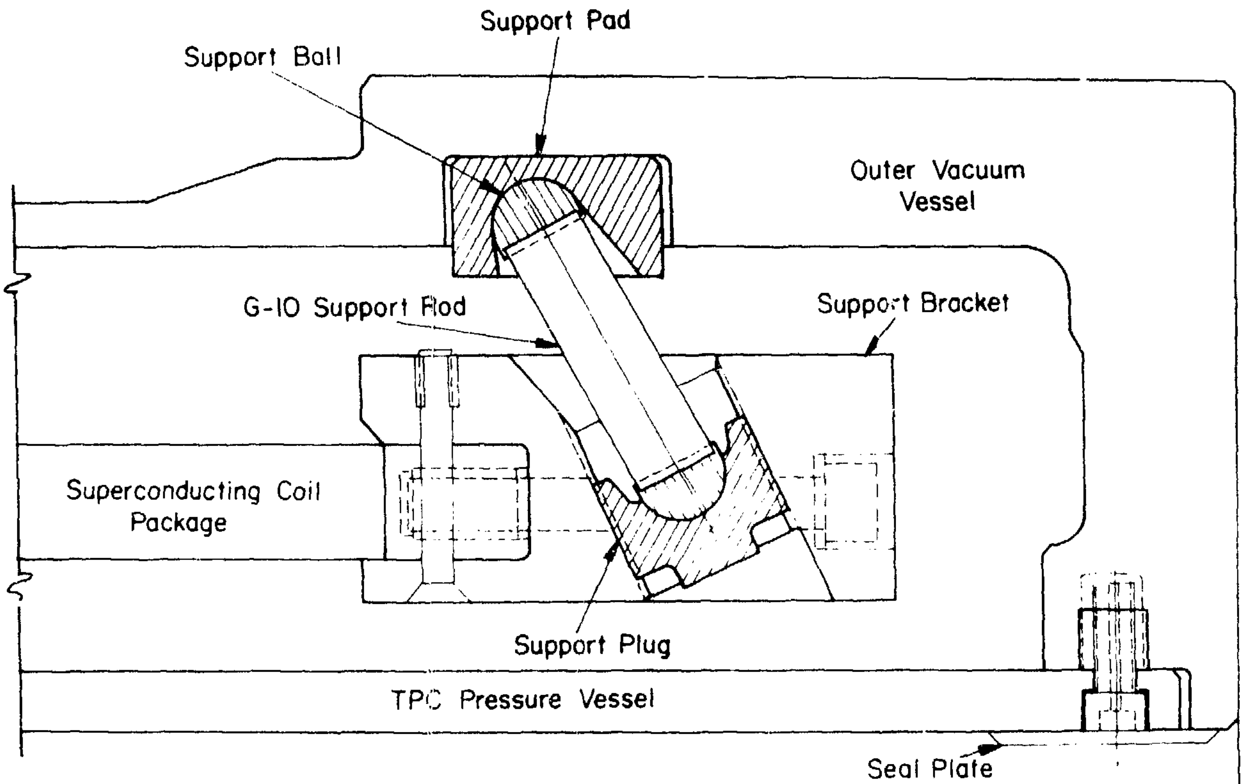

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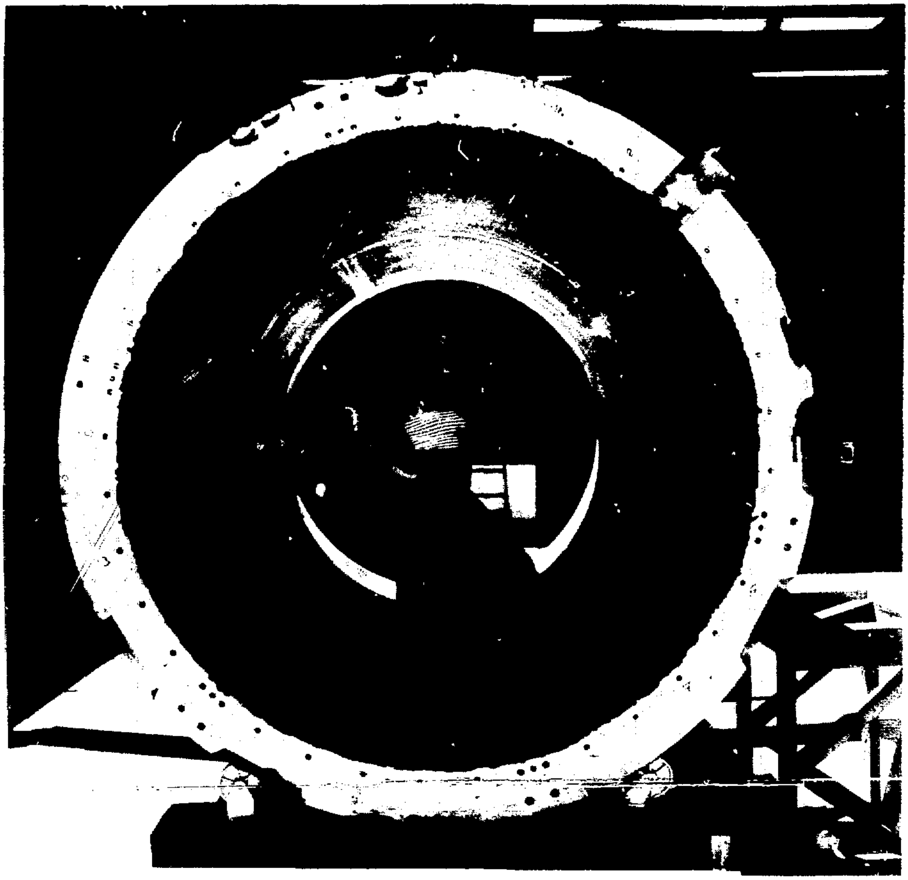

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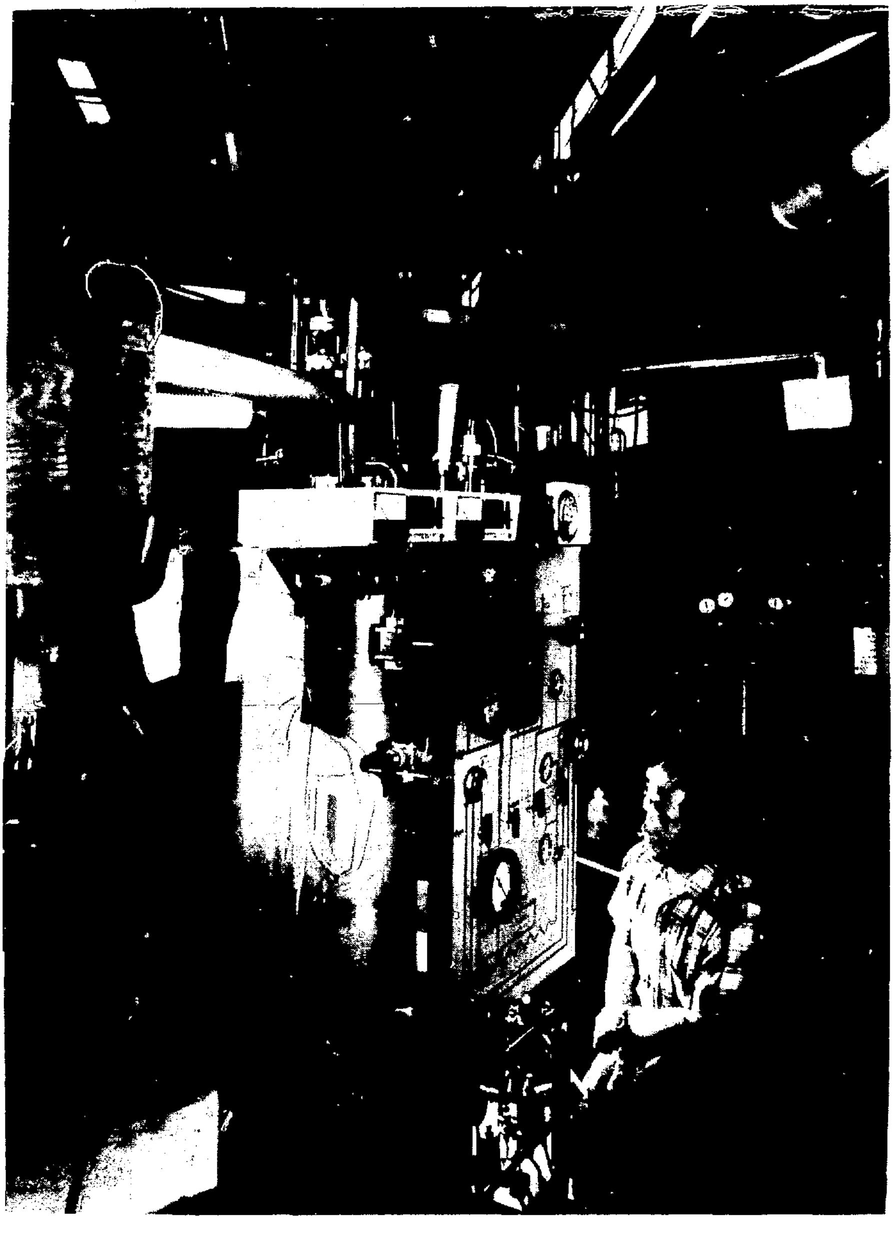

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