A MAGNETIC ANALYZER FOR COLLIDING BEAM EXPERIMENTS IN A STORAGE RING

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Abstract

A general survey of the project criteria of a magnet to get a uniform magnetic field to detect the products of the e^+e^- reactions is presented. The particular project chosen, to be used in connection with the "Adone" storage ring at the Frascati Laboratory, is described; some details are given regarding how to compensate the field produced by the magnet on the machine orbit in the straight section.

Many previous studies and discussions, since 1966, had confirmed the necessity to have a detection apparatus to completely analyze the particles produced in e^+e^- collisions in Adone at energies between 0.75 and 3.0 GeV. The magnetic detector main parts would have been a large cylindrical coil to produce a 4.5 kG magnetic field in its interior and a spark chamber system placed inside and outside the coil.

The internal spark chambers with thin electrodes would have measured the initial direction and the momentum of the charged particles. In the external thick plate chambers the γ-rays convert and the charged particles would have been further analyzed. Essentially there were two solutions proposed by a Study Committee, i.e., a solenoid which could be mounted with its axis parallel to the Adone straight section (see Fig. 1) (longitudinal arrangement) or perpendicular to it (transverse arrangement) (see Figs. 2 and 2a).

Let us spend a few words to say why the transverse arrangement has been chosen:

1) Both solutions needed a field integral compensation along the beam axis (really for the longitudinal arrangement, compensation is necessary only to reduce second order effects, i.e., coupling of vertical and radial betatron oscillations and can be done much more simply in this case).

2) The transverse arrangement allows an easy access to the Adone vacuum chamber and to the internal detection apparatus because the solenoid can be separated along a plane perpendicular to the magnet axis at the center with the two halves then being drawn apart. The magnet, the compensators, the detection apparatus and the support system are made all consistent with this requirement in simple way (see Figs. 3 and 4).

3) The longitudinal arrangement makes the magnet to be mechanically interlinked with Adone vacuum chamber and it is impossible to remove it without opening the vacuum chamber. This would be necessary every time that the detection apparatus, placed inside the coil, needs some repairs or controls. Opening the vacuum chamber is a complicated operation which makes Adone not functioning for at least three days during the vacuum chamber heating, needed to reach the suitable vacuum for the experiments (10^{-10} torr). This last was the most important reason to choose the transverse arrangement.

Project criteria. The magnet must have:

- a solid angle as large as possible for momentum measurement of the particles;
- a momentum resolution ΔP/P of few percent at

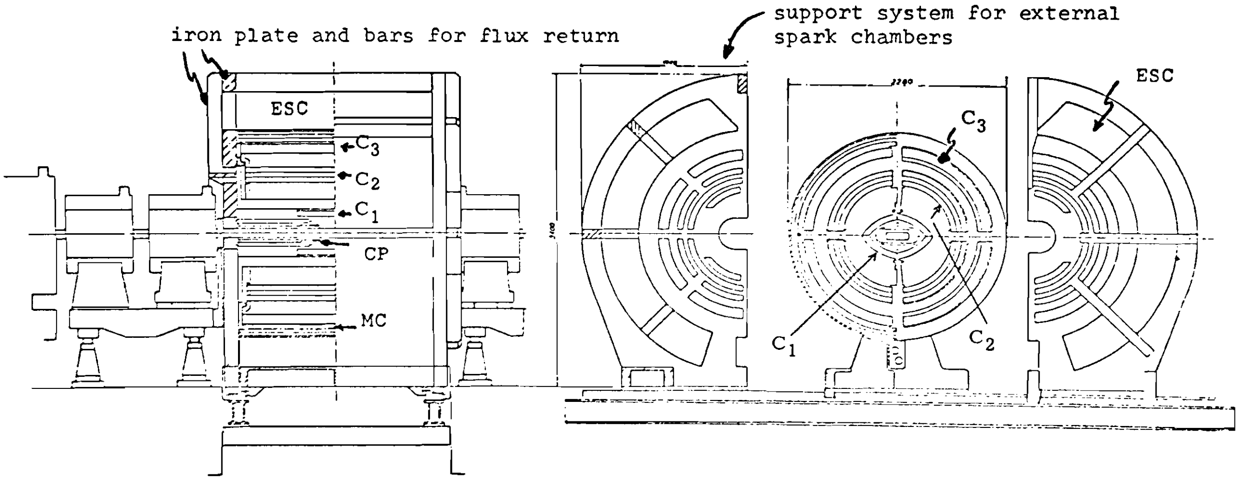

Fig. 1. Sectioned views of the longitudinal arrangement: MC = main coil; CP = compensators; C_1, C_2, C_3 = internal spark chambers; ESC = external spark chambers.

1 = quadrupole
2 = vacuum pipe straight section
3 = magnet main coil
4 = flux return iron
5 = compensator
6 = frontal iron plate
7 = main coil container
8 = rails for magnet disassembly
9 = support for compensators

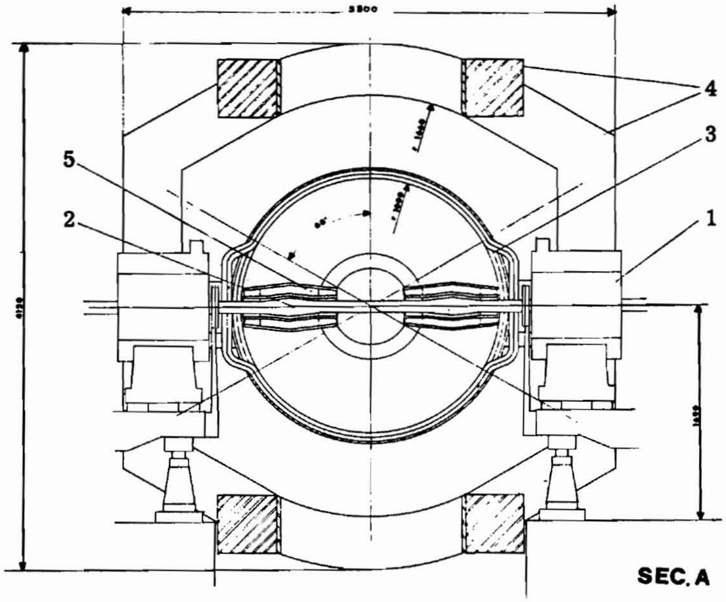

Fig. 2

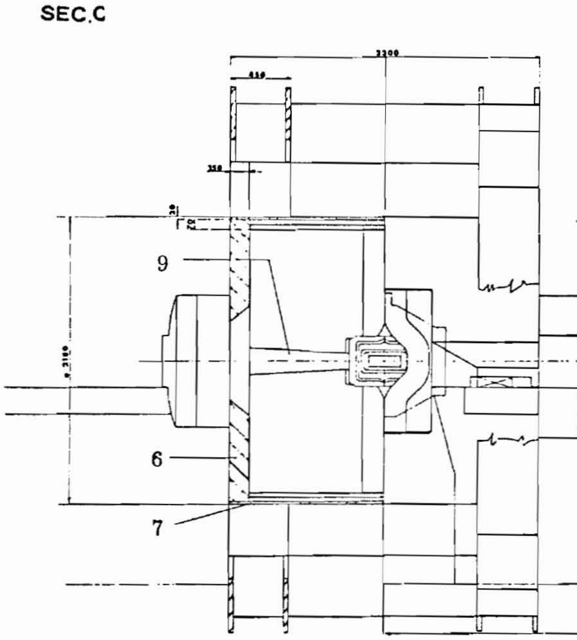

Fig. 2a

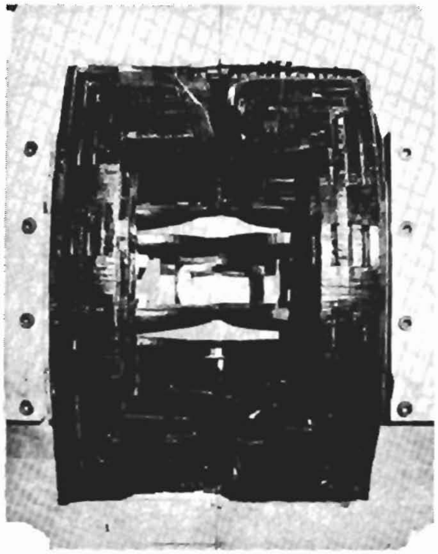

Fig. 3

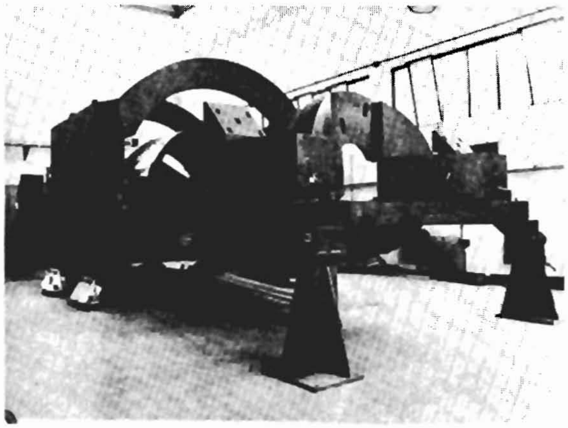

Fig. 4

1 GeV/c. Because the momentum resolution of the particles is proportional to $BL^{1.5}$, BL^{2}, $BL^{2.5}$ depending on the kinds of spark-chambers we use, it is important to get B = magnetic field and L = particle track perpendicular to the magnetic field as large as possible.

Limitations:

- the power supply must not exceed 2 MW for economic reasons;
- the main coil diameter must not exceed the free length of Adone straight section; really for mechanical reasons the coil external diameter must be not more than 2.2 m;
- the main coil thickness must be little in order to avoid an excessive particles absorption before they reach the external spark chambers (less than 1 R.L.);
- compensator magnet encumbrance reduces the useful solid angle for particle detection. On the other hand in order to reduce the nonlinearity of the field characteristic we must keep the flux return iron of the main coil and of the compensator magnets far enough from saturation. This limits the total flux generated by the magnet. A good compromise seemed the following Table I;
- compensators: as we said before, in order to avoid magnetic interference with Adone, the described magnetic system must satisfy the conditions:

$$\int B_n dz = 0 \ , \qquad B_n(-z) = B_n(+z) \ .$$

TABLE I

MAGNET	
Magnet yoke	
Iron type	Martin XC 10
Iron cross section (flux return)	1.008 m^2
Max magnetic field in iron	1.5 Wb/m^2
Total weight	80,300 kg
Main coil	
Dimensions:	
Length	2 m
Internal diameter	2 m
External diameter	2.14 m
Max magnetic field	0.45 Wb/m^2
Number of turns	164 in two overlapping layers
Conductor cross section	22 x 34 mm^2 with a 9 mm diam central hole
Max current	5000 A
Voltage drop (T average 50°C)	260 V
Current density	7.5 A/mm^2
Cooling water flow rate	16 liters/sec
Temperature controls	Thermo couples and thermo switches
Power dissipated	1300 kW
Total weight	2000 kg

The variation of B along z is qualitatively shown in Fig. 5; in the segments A_1, A_2, A_3, A_4 the field B is that of the main coil, whereas B_1, B_2 corresponds to the compensators. Each compensator consists of two coaxial coils N_1, N_2 (see Fig. 6) generating, in the absence of edge effects, an opposite magnetic field on 50% of the beam path, keeping uniform the external field. The field uniformity inside and outside the compensators is obtained by interposing some iron between N_1 and N_2 which acts as a shield preventing the flux generated by the main coil from linking itself with the beam. Hence the coil N_1 is placed in a zero field cavity and its field is perfectly uniform. As the lateral flux generated by N_1 is nearly zero, also the field outside N_1 and N_2 will be uniform.

The position of the compensators, chosen to minimize their angular dimensions and the perturbation on the orbit in the segments B_1 and B_2, is such that:

$$l(A_1) = l(A_4) = 15 \text{ cm}; \quad l(A_2 + A_3) = 70 \text{ cm};$$

$$l(B_1) = l(B_2) = 50 \text{ cm}.$$

The orbit in the vertical plane is shown in Fig. 5 (the vertical scale is magnified by a factor of two) for E_{beam} = 300 MeV in the extreme case that at this energy the field B can be set at the maximum value of 4.5 kG. In these conditions the vertical perturbation of the orbit at the exit of the compensators has a maximum displacement of 1.75 cm. The perturbation has a maximum at the center of the straight section; the displacement of the interaction point is about 1 cm at 1.5 GeV and 5 cm at the injection energy (375 MeV), where it is not necessary to work with maximum intensity of the magnetic field anyway.

The size of the compensator yoke depends on the saturation value of the iron employed (13 - 18 kG). The total power absorbed by the compensator coils is 315 kW (one compensator magnet).

We provide a variable shunt for fine current adjustment to accurately satisfy the condition of zero field integral.

The field integral compensation will ultimately be made to some nonzero value. Choosing a 0.1% deviation in the correct field value in one of the compensators, theoretical calculations give: an acceptable vertical beam displacement (also assuming full field in the solenoid at injection energy); an acceptable radial lens effect due to a non-normal entry of the particles into the fringe fields of the compensators if the magnetic field is reduced in proportion to the beam momentum below 1 GeV/beam. So, the required compensation accuracy is $\sim$ 0.1% or $\sim$ 2 gauss x meter.

In each compensator magnet there is a third coil fed by a power supply driven by a magnetic field pickup on the vacuum chamber. This coil is needed to guarantee an automatic fine compensation

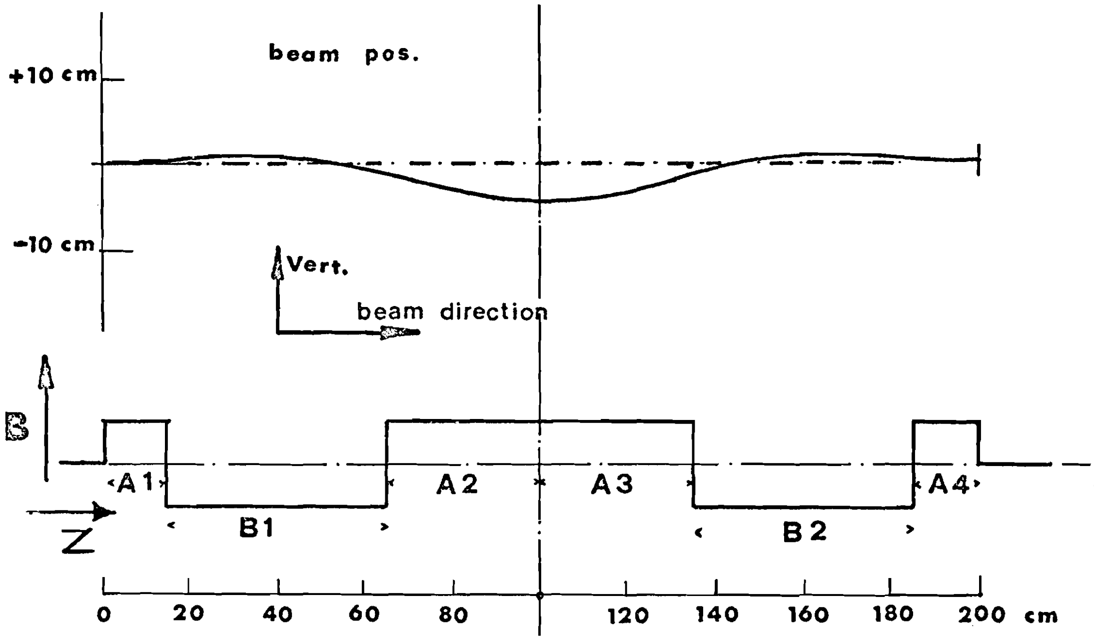

Fig. 5. Qualitative behaviour of B as a function of z and the electron orbit in the vertical plane (the vertical scale is magnified by a factor 2).

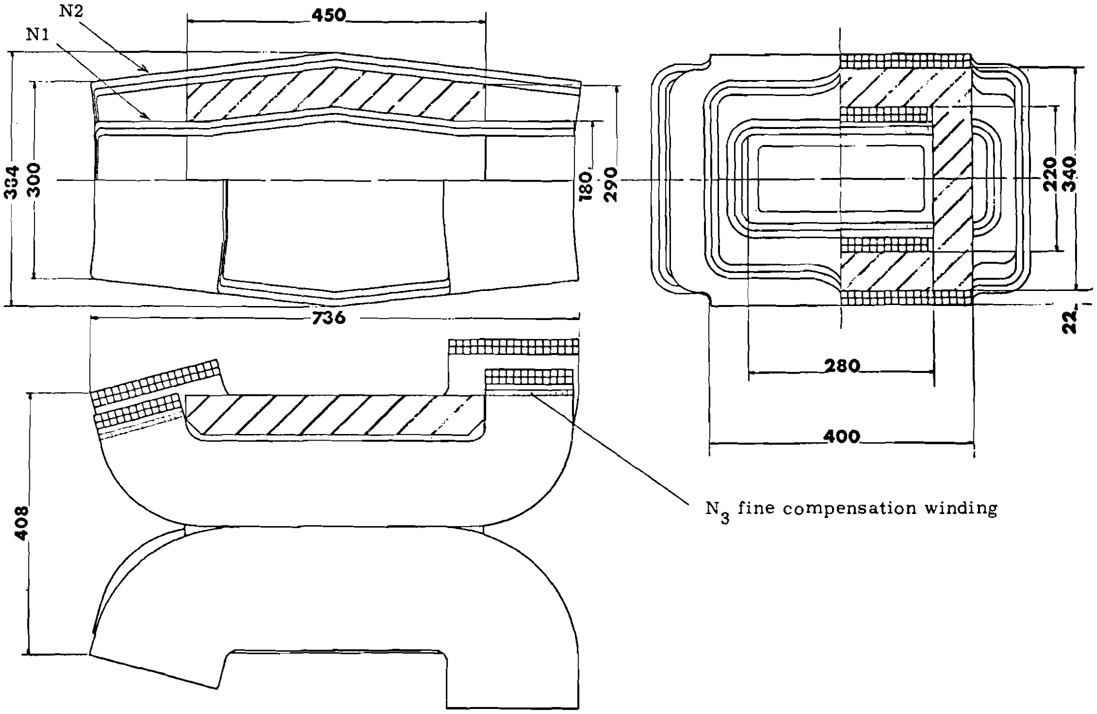

Fig. 6. Compensator: shape and main dimensions.

of the integral $\int B_n dz$ on the electron-positron orbit when varying the main magnet field. The causes of perturbation that this coil has to compensate are the variation of the iron magnetic permeability between low and high field, the variation of magnetic length of the compensator between low and high field.

The most important cause of perturbation is the first one: the maximum magnetic field produced by the main coil is 4% less than it should be if the iron permeability were infinite; in the compensator is 6% less. Keeping in mind this reason the third coil is made sufficient to get a value of ampere-turns 10% of the inner coil of the compensator.

In Table II are listed the compensator magnets data. In Table III are listed the supply characteristics.

Figures 7, 8, 9 and 10 give some constructive details of the magnet and of the detection apparatus.

References

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3. A. Catitti and G. Pasotti, Relazione sul progetto del magnete per esperienze con Adone di tipo solenoide trasversale e longitudinale, Frascati Report LNF-68/72 (1968).
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TABLE II. Compensator magnets.

MAGNET YOKE	
Iron type	Martin XC 10
Flux return cross section	0.063 m^2
B_{max} in the iron	1.8 Wb/m^2
Iron weight (one compensator	320 kg
Magnetic field at the center gap	0.45 Wb/m^2
COILS	
External coil (N_2)	
Number of turns	30
Conductor cross section	12 x 12 mm^2 with a 7 mm diam central hole. Two conductors in parallel.
Material	Copper
Max current	5000 A
Current density	23.5 A/mm^2
Internal coil (N_1)	
Number of turns	24
Conductor cross section	11 x 11 mm^2 with a 6 mm diam central hole. Two conductors in parallel.
Material	Copper
Max current	5000 A
Current density	27 A/mm^2
N_1 and N_2 in series	
Voltage drop (T average 60°C)	63 V
Power dissipated (one compensator magnet)	315 kW
Cooling water flow rate	2.8 liters/sec
Fine compensation coil (N_3)	
Number of turns	32
Conductor cross section	8 x 8 mm^2 with a central hole 5 x 5 mm^2
Material	Copper
Max current	470 A
Voltage drop (T average 60°C)	15 V
Power dissipated	7 kW

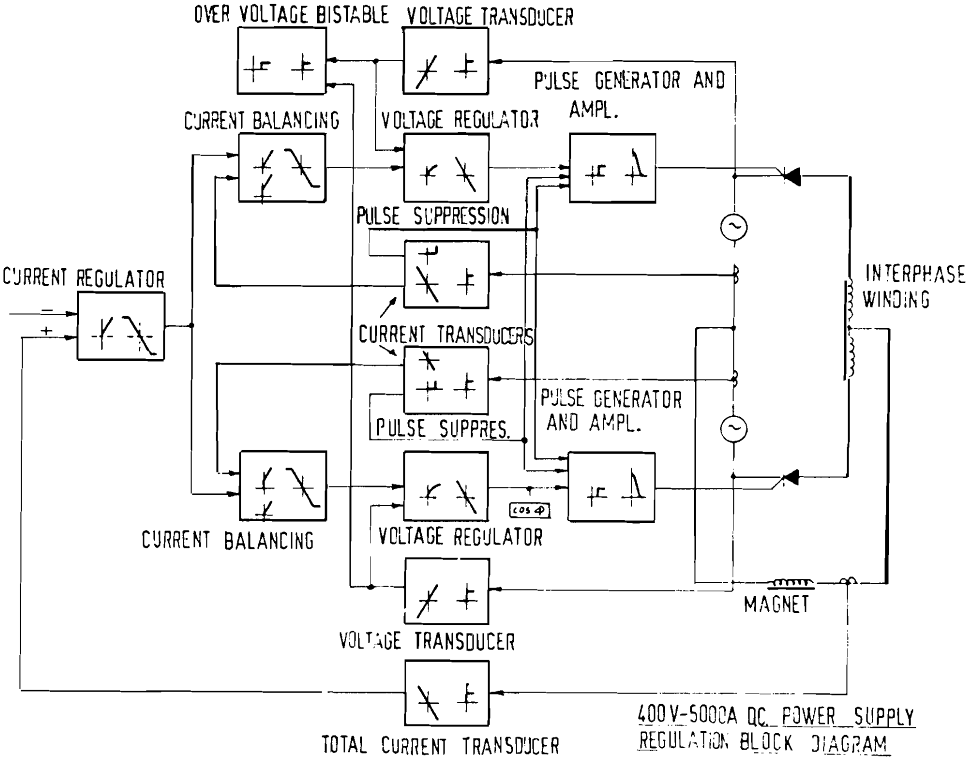
TABLE III

POWER SUPPLY FOR THE MAIN MAGNET AND FOR THE COMPENSATORS

Input transformer: Three phase mains (3 kV) is fed to two delta connected primary windings. Each output winding (one of star and the other of delta configuration), producing 365 V at 2100 A max, is fed to a three phase full wave rectifier bridge whose elements are all SCR (thyristors).
Rectification: The two 3-phase thyristor bridges are connected in parallel via a 300 Hz interphase winding. A 12-phase rectification is obtained due to the 30° phase shifted secondary windings of the transformer.
Regulation: By feed-back circuits with high closed loop gain, acting on the firing time of the SCR (see the block diagram).
Output power: 400 V at 5000 A max.
Output stability: Better than 0.1%.

POWER SUPPLY FOR THE FINE COMPENSATION COILS

Input transformer: A main contactor and variable voltage transformer is fed to a second transformer with two primary delta connected windings. Each secondary winding (one of star and the other of delta configuration) producing approximately 35 V at 370 A is fed to a 3-phase full wave rectifier bridge.
Rectification: The two 3-phase diode bridges are connected in series in a buck-boost system to produce a 12-pulse rectified output. An L.C. filter network is incorporated, connected as a choke input filter.
Regulation: The reference signal is applied to the input of a summing amplifier together with the feed-back current. Any error in the equality of these opposite polarity signals is amplified and used to control the conduction of a transistor series element.
Output power: 75 V at 450 A.
Output stability: Better than 0.05%.



400V-5000A DC POWER SUPPLY REGULATION BLOCK DIAGRAM

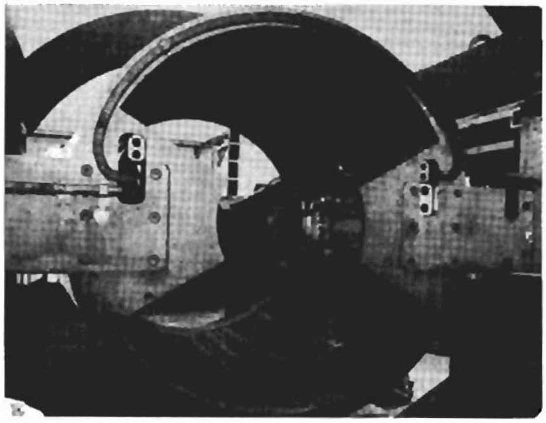


Fig. 7

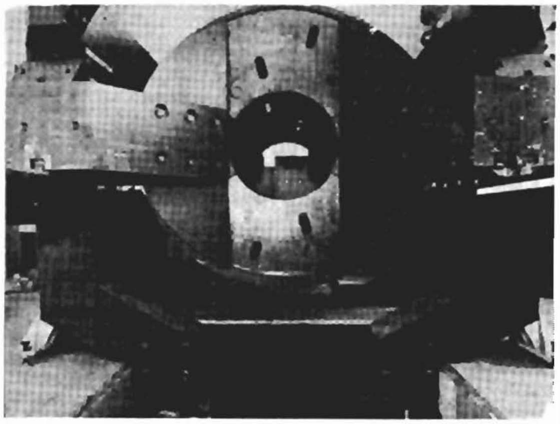


Fig. 8

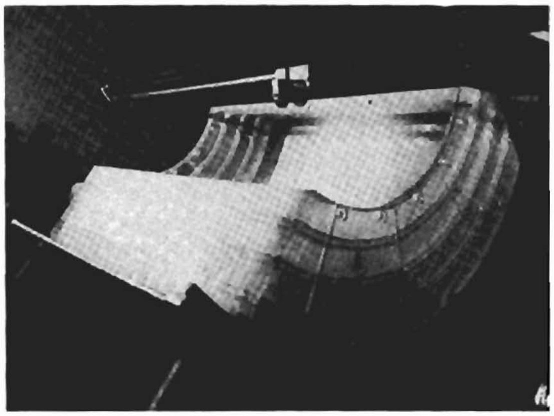


Fig. 9

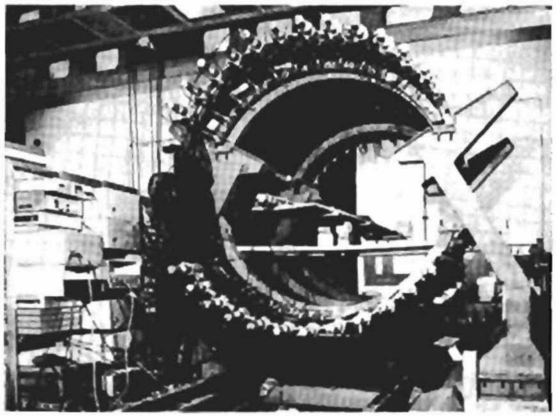


Fig. 10