STUDY AND CONSTRUCTION OF TWO HIGH PERFORMING MAGNETS FOR 1.7 GeV/c SPECTROMETER

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Abstract

Two high performing spectrometer magnets, window-frame type with azimuthal fringing field magnetic radius have been studied, built and measured.

The two-dimensional computer program "MARE-C" gives an accurate knowledge of the magnetic field, specially of the effects of the coils real structure, and its errors of construction and location.

The magnetic study of the azimuthal fringing field with the same two-dimensional program "MARE-C" in connexion with measurements on a similar aperture magnet gives us a method to compute the fringing field with infinite and finite magnetic radius with and without clamp field and with and without shims. The fringing field magnetic radius can be determined better than 1 %.

I. Introduction

The 1 GeV high resolution nuclear spectrometry unit has been built in order to operate near the Saturne Synchrotron. It is described in reference 1.

The study and realization of the spectrometer and analysis magnets are the most interesting part from the magnetic point of view. The A12 analysis magnet and A23 spectrometer magnet are geometrically and magnetically similar. In the present paper, we shall study only the second one.

The magnetic measurements of the two magnets have been studied : influence of magnetic defects on the optic qualities, behaviour of the Hall probes used, and geometrical properties of the apparatus.[2]

The curvature radius of the central trajectory is 3.3 m with an angular aperture of 97°45'. The magnetic induction along this trajectory is 1.72 T for the nominal energy. The aperture of the magnet is 200 mm x 660 mm. The magnet is built to run at 0.86 T and 1.94 T when the 1.4 GeV proton beam can be extracted from the Synchrotron.

Between 0.86 T and 1.72 T the accuracy of the magnetic field integral must be ± 5000 G.mm. This condition obliged us to use iron of very good quality and to have very high mechanical tolerance for the polar profile and for the coils.

The magnet ends are non-saturated to 1.72 T and have magnetic curvature with a 1.5 m magnetic radius. The exit face has a 25° angle (Fig. 1). We used the 9 MW static power supply existing (10^{-4} stabilization) for the A12 and A23 magnets. This high power allows us to have a window-frame magnet which minimizes the yoke dimensions and gives a very homogeneous field (Fig. 1). The corrections of higher terms for a 1.72 T field were obtained with mechanical shims. For a 1.94 T field the corrections were obtained with electrical shims.

The window-frame structure allowed us to build the superior and inferior yokes with a single plane and homogeneous frame.

Both coils have to be symmetrical in relation to the median plane. They are stuck together with all necessary precautions in order to provide the conductor alignment required in that type of magnet (window-frame).

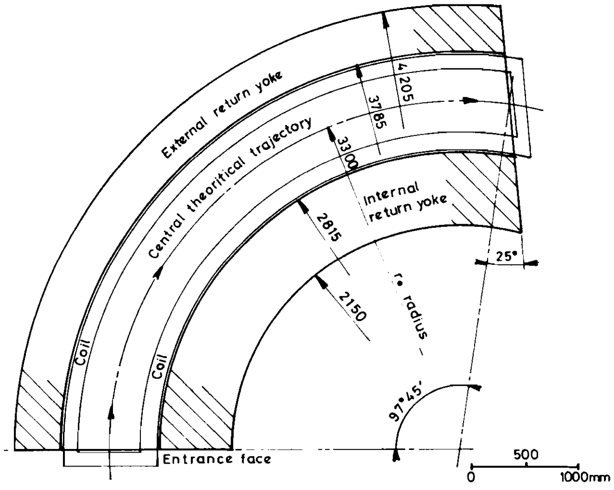

FIG : 1 A 23 Spectrometer magnet

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II. Magnetic study of the normal section

II.1 Saturation defects :

The magnetic field saturation defects were calculated with the "MARE" computer program[3] for three values of B(ro) (Fig. 2). With an infinite permeability in the iron, and a perfect location of conductors of the coils, the magnetic field is exactly constant between the coils. Owing to the real permeability in the iron, the field in the useful space can be approximated with a $\pm 5.10^{-5}$ accuracy by a sextupolar term. Therefore we can write

$$B(r) = B(ro) \quad 1 + k(r - ro)^2$$

The coefficients k are (with r - ro, in cm) :

$k = 1.35\ 10^{-6}$ for $B(ro) = 1.7215$ T

$k = 2.60\ 10^{-6}$ for $B(ro) = 1.8973$ T

$k = 5.10\ 10^{-6}$ for $B(ro) = 2.0820$ T

We can notice that for the three values of field considered, corresponding to increases of 10 % of A.T., the k coefficients are proportional to 1, 2, 4. This is used for the determination of the correction coils.

In figure 2, we can see the measured and calculated points at 1.72 T. Their correspondence is better than 10^{-4}.

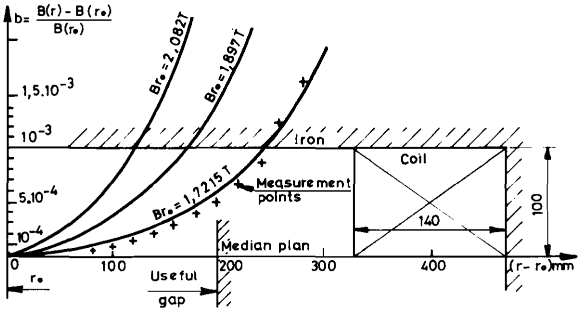


FIG : 2 Saturation magnetic field defect b

II.2 Conductors location defects :

For the window-frame magnets, the location of the coils is very important. The following defects have been studied.

Location defect of the first conductors :

We considered the influence of 1 mm radial position defect for the three first conductors of the half-coil (2 pancakes) next to the median plane (Fig. 3-1). One mm defect is equivalent to ± 0.5 mm of building tolerance. We considered also the influence of ± 1 mm radial position defect for the first conductors of the half-coil (2 pancakes) next to the iron (Fig. 3-1').

(The two half-coils are symmetrical in relation to the P plane).

Let us notice that the curves of magnetic field defects relative to 1 and 1' are symmetrical and the defects relative to 1, 2 and 3 are decreasing (Fig. 3).

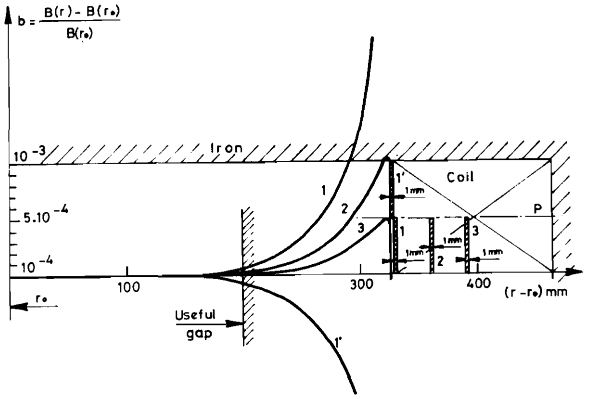


FIG:3 Influence of bad location of the conductors

Field defect due to the water holes :

The study has been made for the first holes (Fig. 4). The defects of the holes 1, 2, 3 and 4 are represented by the curves 1, 2, 3 and 4. These defects are not symmetrical, but the result defect of the 4 holes is practically zero. This is due to the symmetry of the holes in relation to the P plane (Fig. 4).

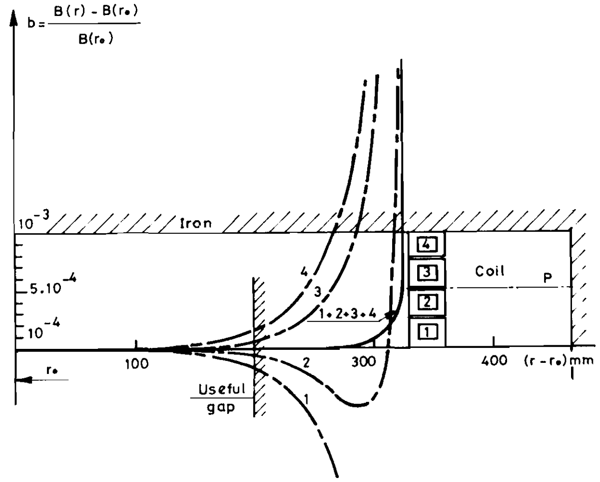


FIG:4 Influence of conductors holes

Field defect due to miscellaneous effects (Fig. 5)

We studied the following cases represented in figure 5 : a displacement of the 2 half-coils (cases a and a') the effect of insulation (case b) and a bad vertical location of the coil (case b'). We represented in the same figure the saturation defect at 1.72 T.

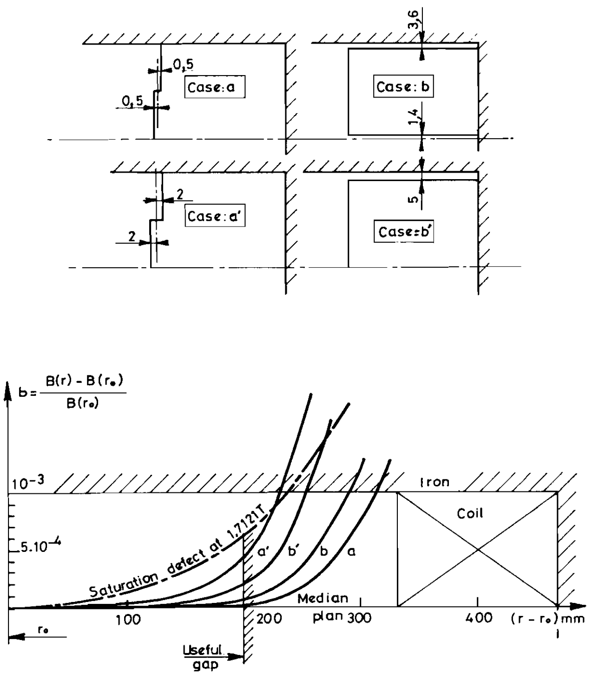


FIG:5 Influence of bad location of the conductors

The current location defects gives in the useful space a field which can be approximated by a 6 order term with a 10^{-5} accuracy.

The coefficients are :

case (a) : $k' = 0.28.10^{-11}$

case (a') : $k' = 2.8.10^{-11}$

case (b) : $k' = 0.52.10^{-11}$

case (b') : $k' = 1.3.10^{-11}$

For a possible correction, we cannot use the same coils as those used for the correction of the saturation effects. It is better to have a good accuracy for the building of the coils. To limit these effects we must have a mechanical tolerance of ± 0.5 mm for the location of the first conductors and ± 1 mm for the others. For the insulation we must have a symmetry in relation to the P plane and to the median plane.

These tolerances particularly difficult to obtain have been reached by the manufacturer.

II.3 Coils :

Due to the window-frame structure, the coils have curved ends. The complete study of electrodynamics and thermal stresses obliged us to use a mechanical system to minimize these stresses on the ends of the coils. The high current density obliged us to use many safety devices.

III. Study of the ends of the magnet

The main properties of the ends are : magnetic length quasi independent of field inductions, short fringing fields, straight ends, for A12, ends with magnetic curvature for A23. These properties are obtained by the use of non-saturated profiles and field clamps.

We shall consider successively the calculation of a straight end, the experimental study of different profiles, and a predetermination method of a geometrical radius corresponding to a magnetic radius.

III.1 Theoretical study of a straight end :

Our possibilities of calculation are not sufficient to do a three-dimensional study. The most simple approximation is to do a two-dimensional study applied to the profiles obtained by the intersection of the magnet end and of the perpendicular planes to the median plane. These different planes parallel to the central trajectory are named by their distance (r - ro) in relation to the ro central trajectory. By closing artificially the magnetic circuit, we are involved in the study of a C-type magnet (Fig. 6).

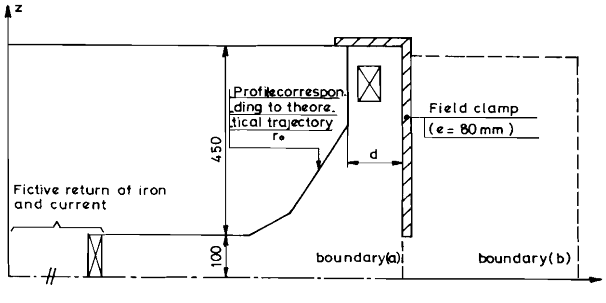


FIG :6 C type magnet equivalent of the end profile

The non-saturated profiles have been studied by several authors, we only note that they can be theoretically represented by exponential and hyperbolic function which can be approximated by profiles of Braams type or by chamfered edges. We used a two-chamfered edges profile easy to build (Fig. 7).

For the study of the equivalent C-type magnet represented in figure 6, we used the "MARE-C" computer program.[3] The thickness of the iron has been adjusted in order to obtain the same saturation state in the return path as that obtained in the normal section studied in chapter II.

The fictive return current must be as illustrated in figure 6. The magnet part of constant field must be longer or equal to 2.5 times the gap. The field clamp is materialized by the return equipotential (Fig. 6 (a)), the field clamp being first considered without hole.

We can see in figure 7 the curves of field tails obtained for different distances "d" between the field clamp and the end of the magnet. This calculation has been made for the profiles corresponding to the ro plane. The differences between the magnetic lengths lm and the geometrical lengths lg are function of the location of the field clamp. Their values are :

$^{d}/_{mm}$	160	250	400	∞
$\Delta lm = lm - lg/_{mm}$	- 34	- 15	+ 5,4	+ 20

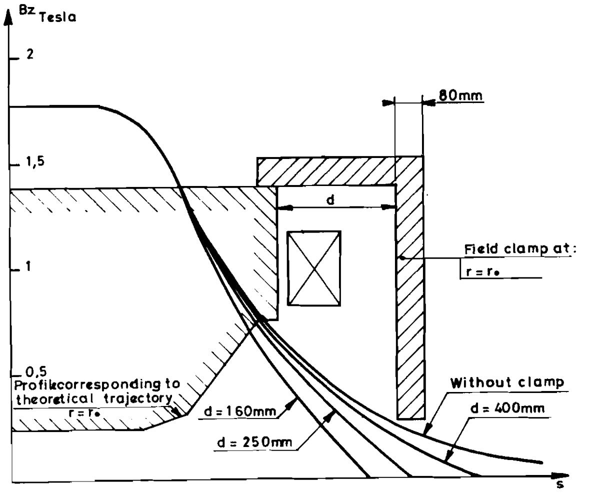


FIG : 7 Fringing field for different distances "d" between magnet and field clamp.

III.2 Experimental study of an end with magnetic radius :

Let us give a definition of a magnetic radius. We assume that the field map of an end of a magnet in the median plane is known by the calculation. For every trajectory located at a(r - ro) distance of the central trajectory ro we determine the magnetic length lm(r). In the median plane (r,s) we consider the lengths lm(r). The extremeties of these lengths are located on a curve which can be in the useful area approximated by a circle, the radius of which is called magnetic radius (Fig. 8).

A magnet with a 330 x 120 mm x mm useful aperture has been modified to be used as a model. Several profiles with different geometrical radii have been tested. Different curvatures of the field clamp have also been tested. The results[5] were used to develop the following method of a geometrical radius predetermination.

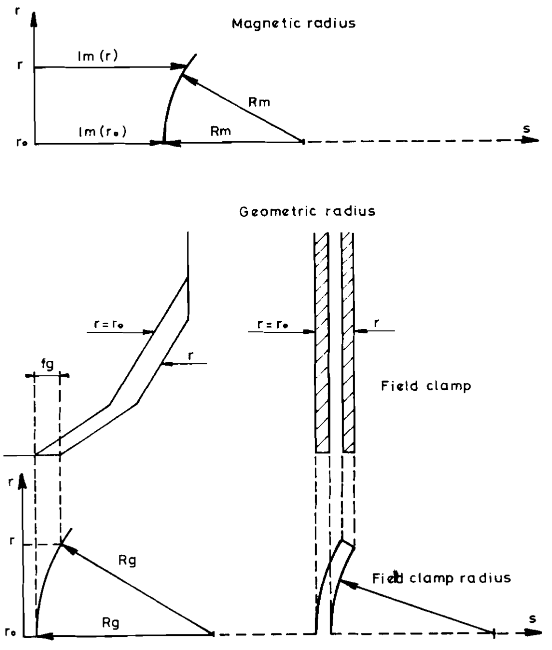


FIG : 8 Definition of magnetic and geometric radius

Method proposed

We consider the two-dimensional C-type magnets (§III.1 - Fig. 6) which are the intersections of the magnet end and of the perpendicular planes to the median plane (r,s) and named by their, distances (r - ro) to the central trajectory ro.

The proposed method is the following one :

1°) We determine the non-saturated profile, the calculation being made in the plane ro (plane perpendicular to the median plane, and containing ro). This calculation is performed with the same hypotheses as those of the straight end, the field clamp being considered without hole (Fig. 6 boundary (a)).

2°) Once the profile has been determined, we made the calculation only in the air, the iron surface being equipotential. So we can take into account the fringing field of the field clamp hole, considering the boundary (b) of figure 6.

This profile corresponding to the C-type of the ro plane gives us the magnetic length lm(ro).

3°) We consider now the profiles obtained by the intersection of the magnet end surface, and the parallel planes to the ro plane, located at the distance r - ro from the ro central trajectory. The calculations made as above-mentioned with the C-type magnet give us magnetic lengths lm(r). The extremeties of these lengths are located on a curve whose curvature can be approximated inside the useful area by

$$Rm = \frac{(r - ro)^2}{2\left[lm(r) - lm(ro)\right]}$$

Results obtained

This method used for the definition of the ends of our magnet gives the following results :

	Δlm(ro)=lg-lm (mm)	Magnetic radius (mm)
1/ Measured value	44	1370
2/ Calculated values		
a) Field clamp without hole (fig. 6 - (a))	47	1350
b) Field clamp with hole (fig. 6 - (b))	44.5	1380

The experimental results (Fig. 9) are :

magnetic radius Rm = 1370 mm
geometrical radius Rg = 1250 mm
angle between geometrical and magnetic face : 0°55'

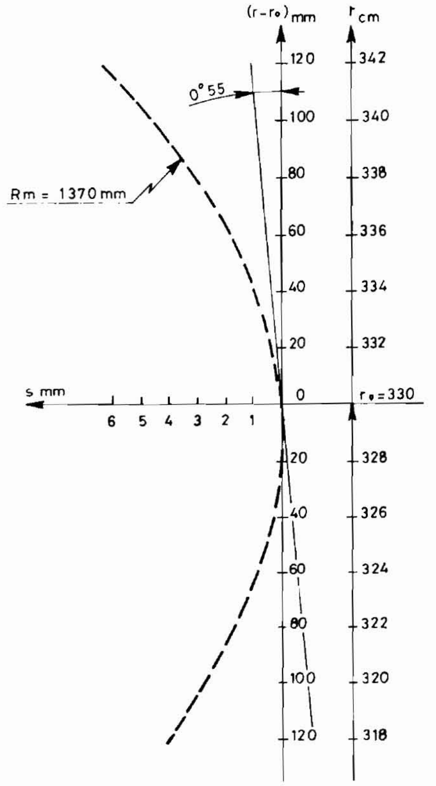
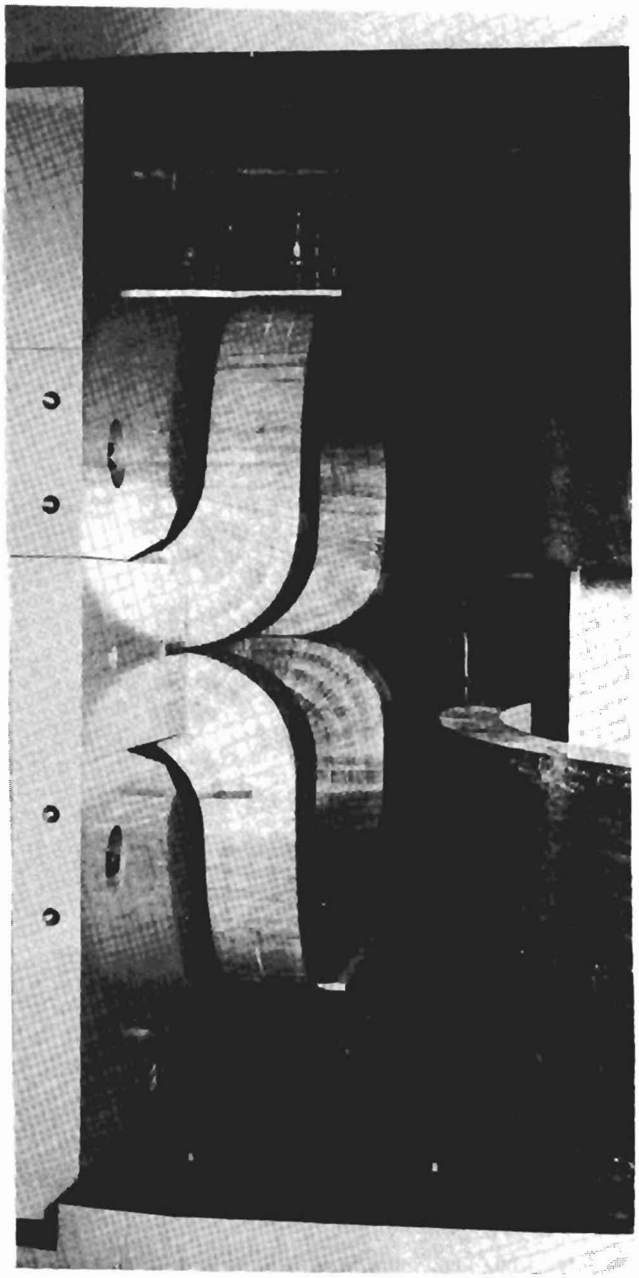
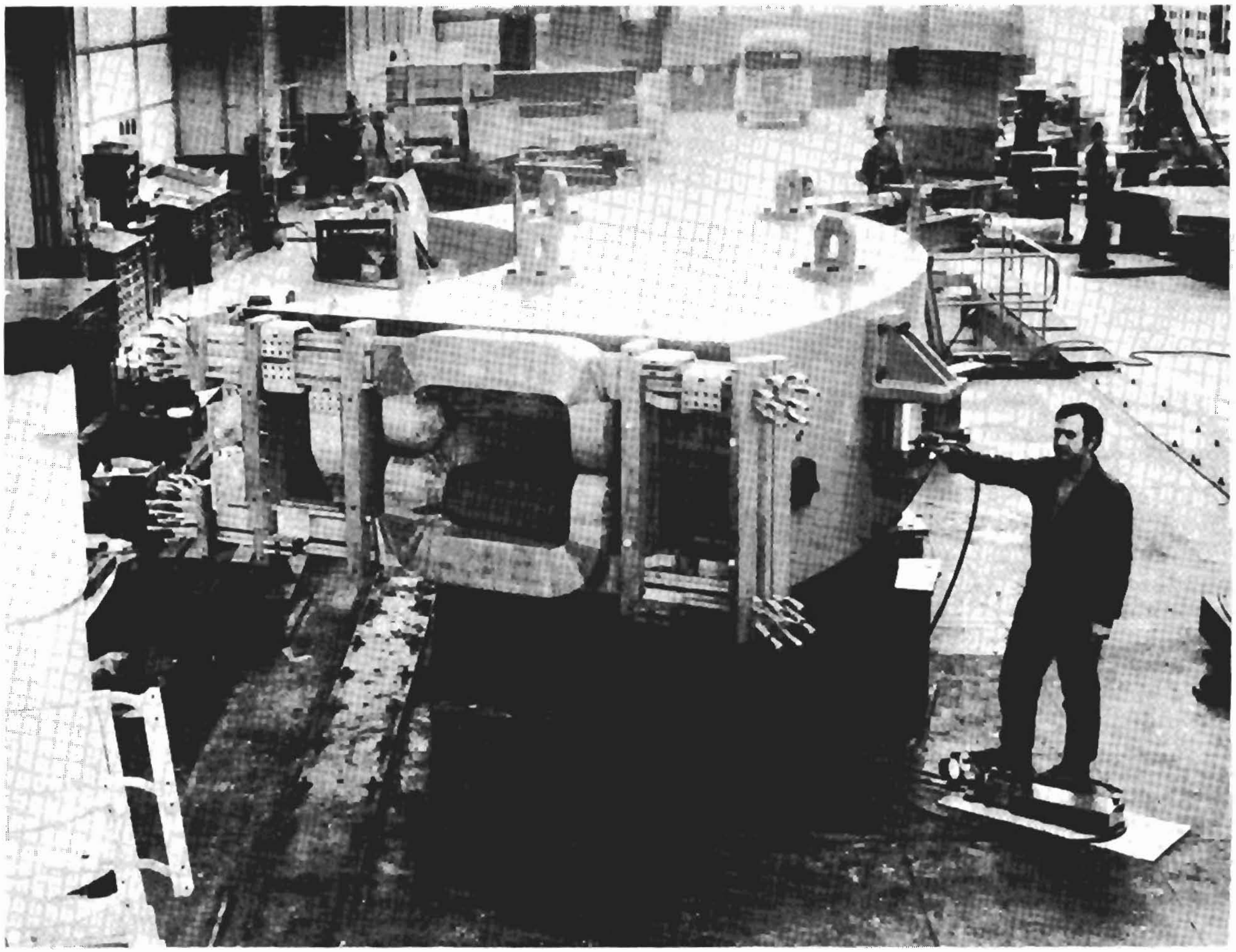


FIG.9 Magnetic radius of the entrance face



IV. Conclusion

These magnets have been built by the manufacturers "Creusot-Loire" in Le Creusot for the magnetic circuit and by "Oerlikon-France" in Ornans for the coils. Two years have been necessary for the realization and tests. We can see on the first picture the end of the A23 magnet with its curved field clamp and on the second picture the assembly of the A23 magnet in Le Creusot during the mechanical tests.



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