KERNFORSCHUNGSZENTRUM

KARLSRUHE

Mai 1970

KFK 1218

A 12 cm Bore Superconducting DC Quadrupole Lens

N. Fessler
Institut für Experimentelle Kernphysik

G. Bogner, H. Kuckuck, D. Kullmann
Siemens AG, Forschungslaboratorium Erlangen

GESELLSCHAFT FÜR KERNFORSCHUNG M. B. H.

KARLSRUHE

KERNFORSCHUNGSZENTRUM KARLSRUHE

May 1970 KFK 1218

A 12 cm Bore Superconducting DC Quadrupole Lens+

N. Fessler
Institut für Experimentelle Kernphysik

G. Bogner, H. Kuckuck, D. Kullmann
Siemens AG, Forschungslaboratorien Erlangen

Gesellschaft für Kernforschung m.b.H., Karlsruhe

+Paper presented at the Third International Conference on Magnet Technology, 19-22 May 1970, Hamburg

Abstract

An optimization with respect to a high solid angle acceptance in a FP-target-doublet leads to the following parameters of the first quadrupole: straight length = 1m, warm bore = 12 cm, field at the circumference of the aperture = 30 kG. The winding conception is that of Beth, Sampson, Krueger and Snyder (BNL). The poles are wound with suitable, selected Nb_3Sn tape. Improved winding techniques have been developed to get a mechanical solid structure. First experiments with one test pole and first measurements on the complete quadrupole will be described.

Zusammenfassung

Optimierungsrechnungen bezüglich großer Raumwinkelakzeptanzen in einem Fokus-Parallel-Target-Doublet führten zu folgenden Parametern des ersten Quadrupols: Länge der geraden Windungsstücke = 1m, warme Apertur 12 cm, Feld am Rand der warmen Apertur = 30 kG. Zur Wicklung des Magneten wurde das Konzept von Beth, Sampson, Krueger und Snyder (BNL) verwendet. Die einzelnen Pole wurden mit geeignetem, ausgesuchtem Nb_3Sn-Band gewickelt. Um eine feste mechanische Struktur zu erhalten, wurde die Wicklungstechnik verfeinert. Erste Experimente mit einem Probepol und erste Messungen am vollständigen Quadrupolmagneten werden beschrieben.

1. Introduction

A first step in studying superconducting components for high energy accelerators in Karlsruhe has been done in designing a quadrupole doublet with high solid-angle acceptance for use as a focus-parallel target-doublet.

A calculation of acceptances for 10 GeV/c secondary particles has shown that it is necessary to produce a magnetic field as high as possible at the circumference of the aperture of the first. Taking an optimistic value of 40 kG of this field the following parameters were obtained:

Table I

Effective length	100 cm
Diameter of the warm bore	12 cm
Diameter of the cold bore	15,5 cm
Field at the circumference of the warm bore	40 kG
Gradient	6,6 kG/cm
Gradient error	1 %

2. Winding Conception

We have considered two possible conceptions to realize a quadrupole magnet of such parameters, the trapezoidal type (Septier)[1] and the circular type (Beth, Sampson, Krueger and Snyder)[2,3].

The circular concept is the more attractive one because of the following points:

a) Compact construction with one layer of conductor,
b) all conductors are positioned near the cold aperture,
c) a better field accuracy within the useful aperture.

In the case of the trapezoidal-conception the quadrupole field is approxiamted with given accuracy only in a certain region. To get a higher accuracy more outer windings are necessary which hardly contribute to the field in the aperture. The amount of superconducting material necessary made this type unattractive for us. There are also some disadvantages with the circular type magnet. The one-layer conception - the only economical one - requires a high current density and is therefore rather risky.

After some laboratory studies it was finally decided to build a circular type magnet with a reduced field i.e. 30 kG at the warm aperture. To reach this field value with the given geometrical dimensions, a maximum overall current density of 55 $kamps/cm^2$ was required at field strengths of about 40 kG in the straight winding parts and more than 40 kG at the coil heads. Nobody had obtained such values with a magnet of this size at that time (June 1968).

3. Selection of Superconductor

Since a very high current density was required a suitable Nb_3Sn ribbon had to be found. After some experiments with pancake windings a GE-ribbon (GE 22 CY 232) with a short sample current rating of more than 1300 amps at 42 kG was selected. This tape is 15 mm wide and has a thickness of 0.15 mm. Both sides of the ribbon are cladded with copper of a thickness of 0.05 mm. The lowest short sample value was I_c = 1320 amps at 42 kG, meaning that the magnet must work near the short sample value.

4. Winding Details

A quadrupole field can be exactly produced by current sheets of small constant radial thickness on a cylindrical surface with a current distribution of $I(\theta) = I_0 \cos 2\theta$. In practice it is not necessary to vary the current density continuously. A number of steps which follow the cos 2 θ-curve will produce a field of sufficient accuracy[4]. A calculation shows that the field error at the circumference of the aperture is less than 0.1 % if a pole is wound in 9 equiangular steps of 10^o with a winding density ratio of 0 : 5 : 10 : 13 : 15. The variation of the turn density is achieved by interlayers of Mylar foil of appropriate thickness. In order to reduce degradation effects caused by movable turns improved winding techniques have been developed to get a solid mechanical structure. The mechanical support and the ring girders were constructed in such a way that the ribbon could be wound and fixed without detrimental stresses. The coil heads were constructed with special care. To improve magnetic stability of the windings, double-edge cooling was applied. A test pole of original size was built and tested to study the mechanical conception and winding technique. After that the original poles were wound with a more elaborate winding technique.

The winding parameters of the test coil and the original poles are as follows:

Table II

calculated winding density ratio	5	10	13	15
number of turns	24	48	62	72
thickness of Mylar-shims in mm	0,35	0.1	0.045	0.01

Fig.1 shows the head winding of an original pole, where the accurate windings are to see. In Fig.2 the completely mounted quadrupole is shown with a lot of ring girders and screws to fix the windings in order to have a solid mechanical structure. The cryostat with the warm bore in which the quadrupole is mounted with all the equipments is shown in Fig.3.

5. Experimental Results

a) Test Pole[5]

During experiments the coil was vertically mounted in the cryostat. Field measurements have been done at 4.2 K with Hall-probes for low temperatures. The results are shown in Table III and Fig.4. The limits of the hatched area in Fig.4 are given by the highest and lowest short sample values of the ribbons used. This I_c-H_c-

curves are approximated by straight lines given by two short sample values of GE at 42 kG and 80 kG. The solid curve a) shows the load line of the coil, the points indicate the "quench"-values. The first series of tests shows training effects up to a maximum current of 1120 amps. The dotted line b) represents the estimated H_{max}-line of the coil. The highest current density corresponding to I = 1120 amps is j_{max} = 44,8 kamps/cm^2 in the section of highest turn density.

b) Complete Quadrupole[6]

Test measurements in Erlangen were also performed in the vertical cryostat before mounting the quadrupole horizontally in the original cryostat with warm bore. These results are shown in Table III and Fig.4, curve c) and e).

After the final assembly of the cryostat, the quadrupole has been tested in the Kernforschungszentrum Karlsruhe. Table III and curve d) of Fig.4 shows these test results. The quenching region lies between 980 and 990 amps. Because of the iron shielding a higher magnetic field at the warm aperture was measured. Curve e) shows the estimated H_{max}-line at the windings.

The first rough field measurement in the warm bore along the radius has been done with an automatic field measuring machine. The result is shown in Fig.5. Field strength values were measured at a current of 900 amps in steps of R = 0,5 cm from the magnetic axis to R = 4,5 cm. These points lie on a straight line i.e. the gradient of B is constant. The accuracy of this measurement is 1 %.

More detailed field measurements, especially end field measurements, will be done in the near future with better accuracy.

6. Conclusions

In spite of the careful selection of suitable Nb_3Sn tape and the effort of constructing a well fixed winding with improved cooling, the specified field gradient could not be achieved. On the other side the maximum overall current density of nearly 40 kamps/cm^2 at about 30 kG surpasses the values reached in tape winding of similar geometrical configuration and dimension known up to now. It is our opinion that the performance of the Nb_3Sn ribbon available today and the tightly packed windings set a limit of stable overall current density which is well approximated by the prototype-magnet presented. This opinion is supported by an estimation of M.N. Wilson et al.[7] which yields a limiting field of only some tens of kG (e.g. 30 kG) for the stability of such tape packing.

References

1. A. Spetier, J.C. Mouza, and L. Donadieu, "Realization of an Iron-Free Superconducting Quadrupole Lens", IEEE Transaction on Magnetics, Vol. MAG-2, No.3 (1966), pp 326-330
2. R.A. Beth, "Field Produced by Cylindrical Current Arrays", BNL Accelerator Dept. Internal Report AADD-102, March 25, 1966
3. W.B. Sampson, "Superconducting Magnets for Beam Handling and Accelerators", Proceedings of the Second Intern. Conf. on Magnet Technology, Oxford 1967, pp 574-578
4. R.A. Beth, "Step Function Approximations to cos n θ", BNL Accelerator Dept. Internal Report AADD-135, April 11, 1967
5. Siemens Internal Report, January 14, 1970
6. Siemens Internal Report, March 25, 1970
7. M.N. Wilson et al., "Experimental and Theoretical Studies of Filamentary Superconducting Composites", Paper I., "Basic Ideas and Theory", Rutherford Laboratory Preprint RPP/A 73, November 1969, pp 5-23

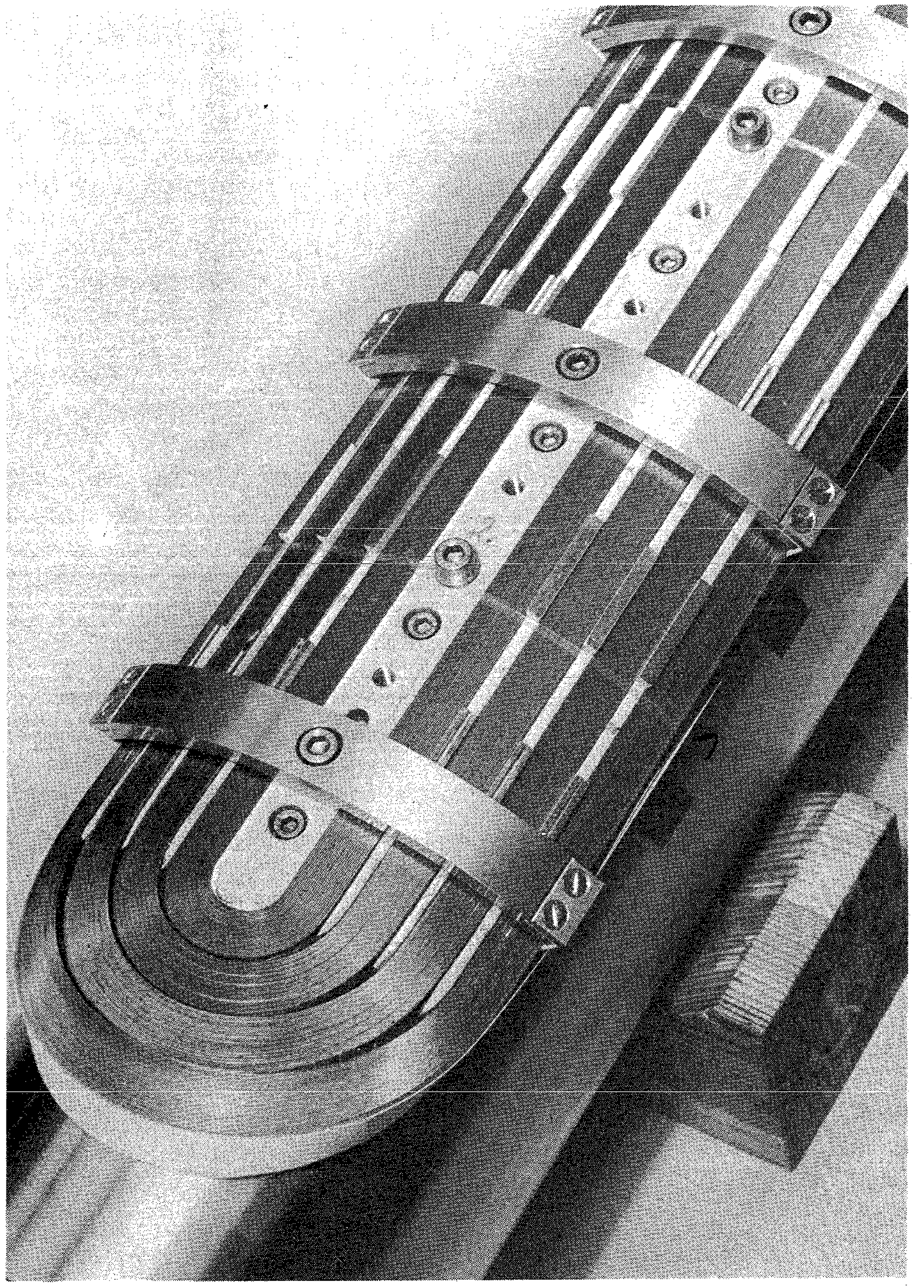


Fig.1 Head winding of an original pole

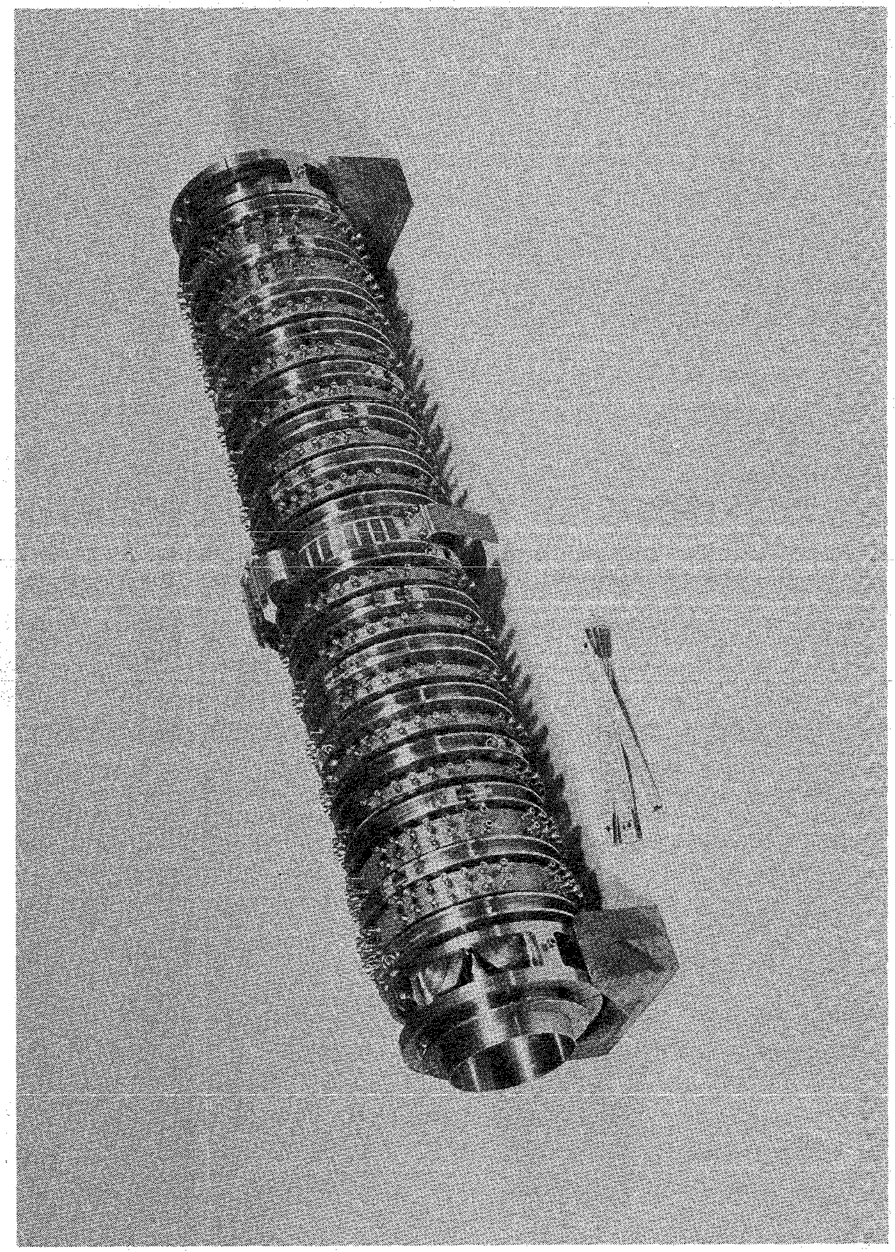


Fig.2 Completely mounted quadrupole

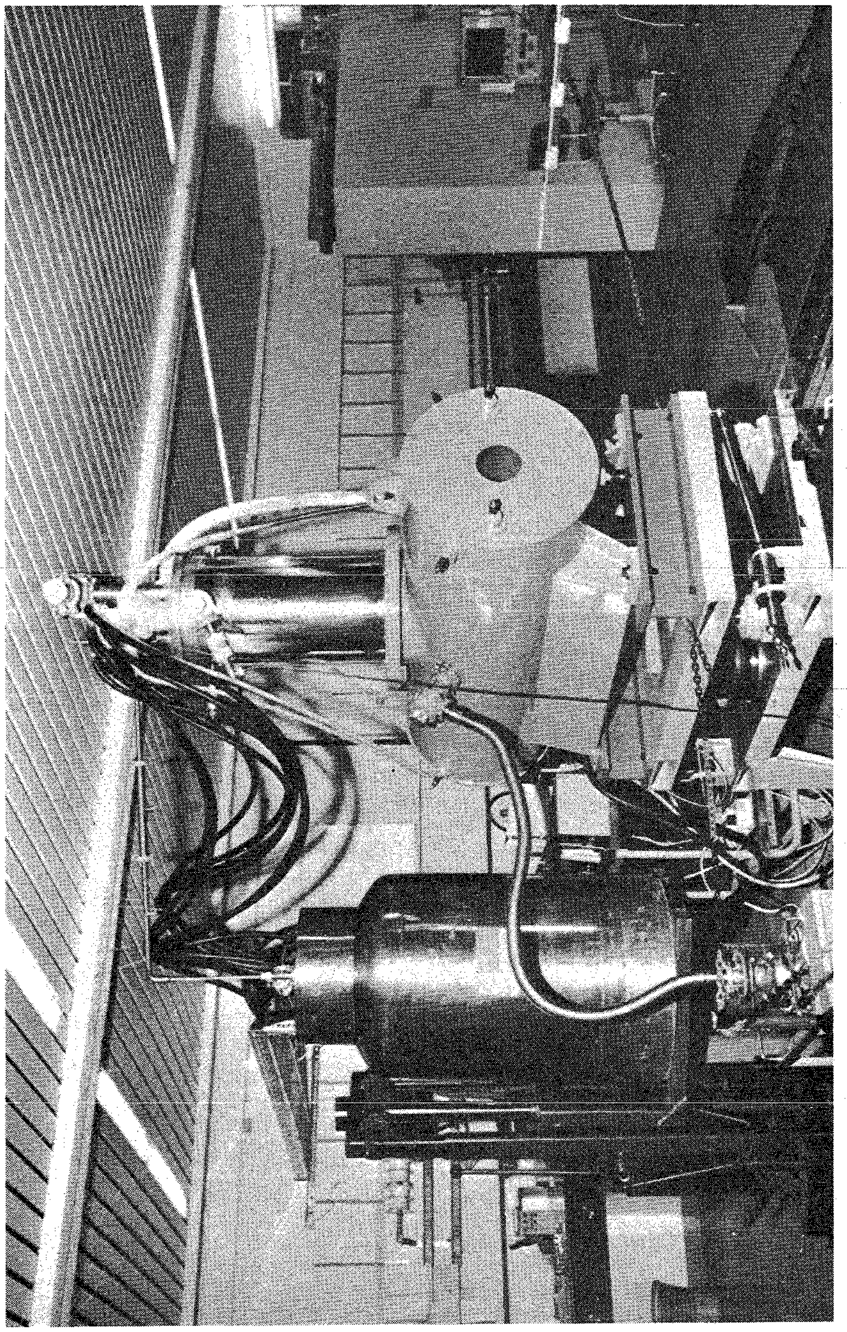
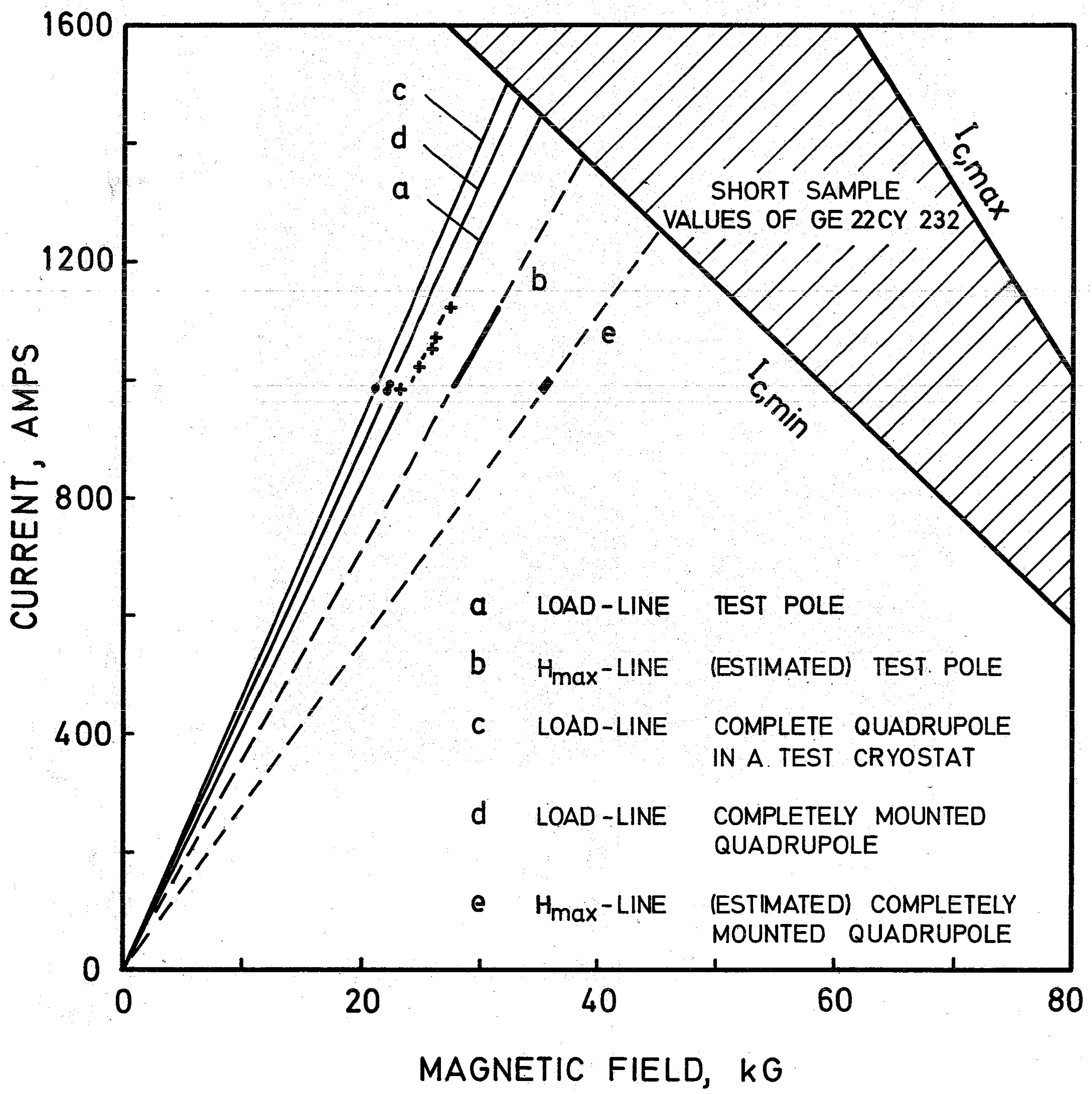


Fig.3 Completely mounted quadrupole within the cryostat

Fig. 4 : Current vs. magnetic field; test pole and complete quadrupole



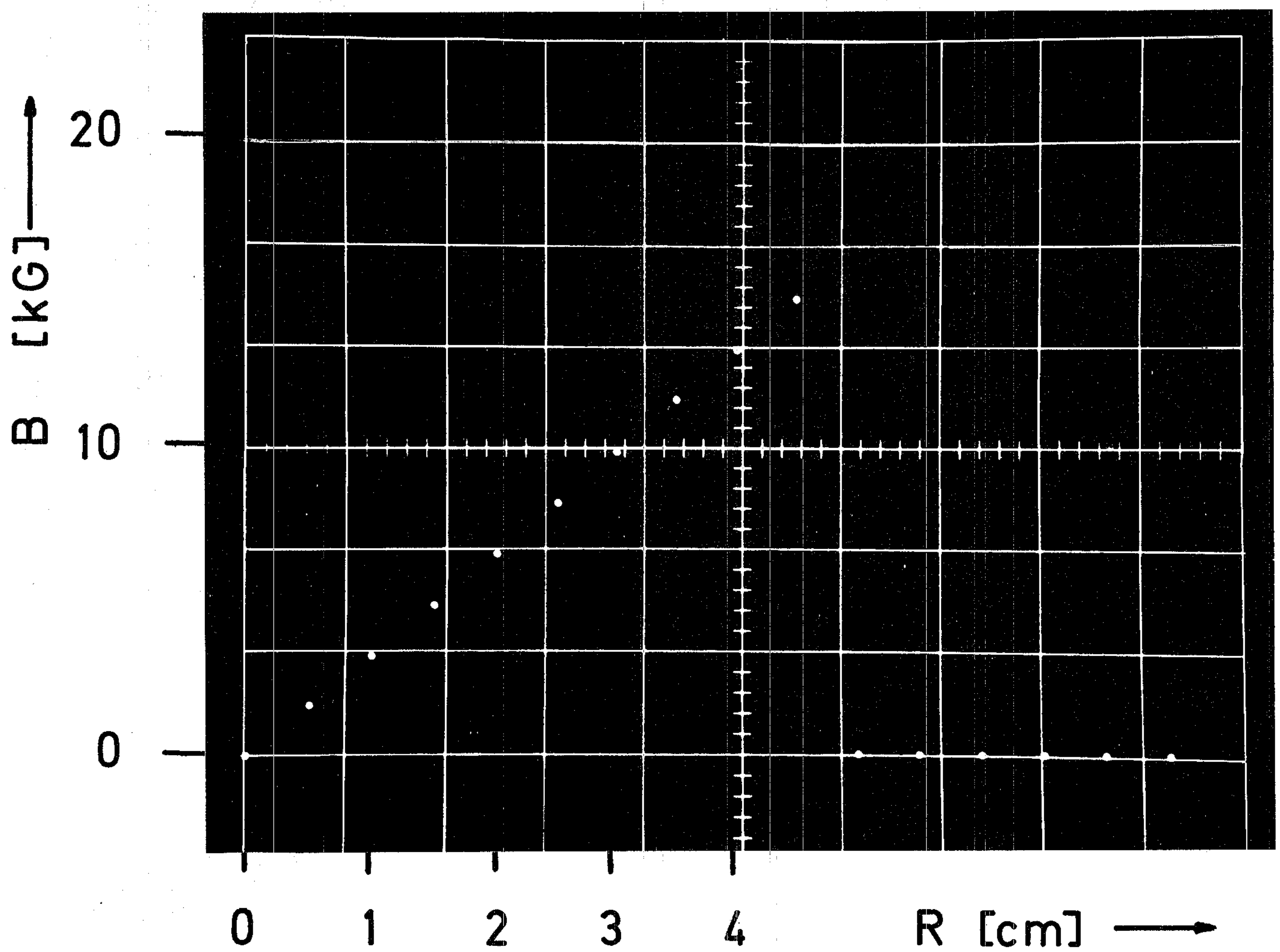


Fig.5 Magnetic field vs. radius in the warm bore

TABLE III

	RUN - NO.	J_{quench} /amps	j_{max} / $\frac{Kamps}{cm^2}$	H_0 /kG	H_{max} /kG at the windings (estimated)	
TEST POLE	1	987	39,5	23,4	26,7	
	2	1050	42,0	25,95	29,6	
	3	1120	44,8	27,5	31,4	

COMPLETE QUADRUPOLE		RUN - NO.	J_{quench} /amps	j_{max} / $\frac{Kamps}{cm^2}$	H(R=6cm)/kG	H_{max} /kG	E/kWsec
	ERLANGEN	1	980,1	39,2	21,2	35,4	74,6
		2	982,5	39,3	21,4	35,5	74,8
	KARLSRUHE	1	990	39,6	22,3	35,7	75,9
		2	985	39,4	22,2	35,6	75,2