OPERATION AND ACCURACY OF THE 12-FOOT BUBBLE CHAMBER MAGNET*

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Abstract

Between December 1968 and March 1972, the superconducting 12-foot bubble chamber magnet has been cooled down seven (7) times. Within this time, the magnet was kept full of liquid helium for ~ 15 months of which more than six months had the coils energized for fields between 10 and 18 kG. Throughout the actual runs of the bubble chamber, the magnet has proven itself as being extremely reliable without causing any major upsets in the overall system. The magnetic field has been mapped at 10, 15 and 18 kG using flip coils and NMR probes. Consequent fitting of the measured field variables yielded polynomials which reproduce the mapped fields to within 0.1%. Reproducibility and uniformity of the fields have been checked several times. The values agreed to within the measured accuracy. Fits to the K^o meson yielded a mass of 497.6 ± 0.3 MeV which is in excellent agreement with world averaged data and thereby confirms the accuracy of the used magnetic field maps.

I. Introduction

The magnet surrounding the 12-foot bubble chamber is needed to provide a vertical magnetic field which through the Lorentz force bends moving charged particles into curved orbits. A cross-sectional view of the entire chamber assembly is shown in Fig. 1. The shaded area signifies liquid volume space, for which a uniform magnetic field is required.

The momentum of charged particles is determined by

$$P = c H \rho \times 10^{-11}$$

where P = momentum in MeV/c,
c = speed of light = 2.99×10^{10} cm/sec,
H = magnetic field in kG, and
ρ = radius of curvature in cm.

From this formula alone, it becomes clear that a well-known magnetic field throughout the volume enhances the goal of reducing momentum uncertainties of the charged particles.

Description of Magnet

Some of the bubble chamber magnet parameters are displayed below[1]:

Type of Magnet	Superconducting
Field Strength	Up to 18 kG
Charge Rate	~ 10 kG/hr
Conductor Material	Niobium, Titanium, Copper Stabilizer (Coextruded)
Number of NbTi Strands per Conductor	6
Number of Turns per Pancake	84
Number of Pancakes	30
Total Conductor Length	40,000 m
Return Frame	Carbon Steel
Weight of Return Frame	1,600 tons
Total Weight of Magnet	1,750 tons
Discharge	Slow Rate (Days) or Fast Rate through 0.1 Ω Resistor (Minutes)

Several advantages are attributed to the return iron frame. These include:

1. With the iron, the required current in the windings for a particular field strength is less than that without the iron. Hence, the stresses on the windings are considerably reduced.

2. Nearly perfect field uniformity can be achieved over the entire chamber volume by use of the iron. (The absence of any appreciable radial field component allows the use of a metallic chamber piston.)

3. Large stray fields are eliminated. This results in reasonable working environments at the film drives, at the expander,

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etc. even under full field strength. (The stray field at the film drives was measured as ~ 500 G for the magnet at 18 kG.)

II. Operation and Performance of the Magnet

The 12-foot superconducting magnet was designed and constructed at Argonne National Laboratory. The first test was performed in December 1968. Since that time, the magnet has gone through several thermal cycles. No major difficulties were encountered with any of the magnet systems. A summary of the magnet usage from December 1968 to March 1972 is given below.

History of Magnet from December 1968 through March 1972

Number of Cooldowns	7
Cryostat at Liquid N_2 Temperature	280 Days
Time Spent at Room Temperature	285 Days
Magnet Filled with Liquid He	520 Days
Magnet Energized above 10 kG	200 Days

During the days with magnetic field, the magnet was energized and de-energized several times. High energy physics experiments were run with the field at 10, 15 or 18 kG depending on the experiment.

It should be emphasized once again that no major difficulties were encountered with any system belonging to the superconducting magnet.

III. Mapping and Accuracy of the Magnet

In August 1971, the magnetic field within the chamber volume was mapped using flip coils and NMR probes. Up to that time, geometric reconstruction of particle tracks was accomplished by use of a theoretical (predicted) field map. It turned out in the end that the predicted map was within 2% of the measured field map. Even though this was adequate for the initial test pictures of the bubble chamber, it was nevertheless required to obtain a field map good to 0.1%.[2]

The measuring equipment consisted of a manipulator (completely built of non-magnetic materials), Mark III Data Acquisition System,[3] interface electronics and an SEL810A computer. The manipulator had to be brought inside the chamber through one of the four camera ports. It was then attached horizontally to the main stem which was located at the center of the chamber (Fig. 2).

During actual measurements, air-driven flip coils attached to the manipulator signaled absolute reference $|B|$ values when flipped through 180°. By rotating the manipulator through 360°, ΔB values with respect to the reference points were measured by the coils. The coils were arranged in such a way that the vertical (B_z) and radial (B_r) field components were measured. The entire chamber volume was mapped in increments of 6" in the z and r directions at 1000, 1538 and 1800 amperes corresponding to ~ 10, 15.38, 18 kG, respectively. Throughout the measurements, NMR readouts were used as calibration and check points.

Figure 3(a) shows some B_z values at 18 kG for the 0° - 180° line were 0° points at "Beam" in Fig. 1. One should note the marked dropoff in the field close to the beam window. The curves for the top and bottom planes are 24 inches above and below the beam plane, respectively. The effects of the magnet iron are indicated by the field increase close to the chamber wall. Not indicated here are distortions due to the camera ports. These effects are clearly seen for the 45° - 225° and the 135° - 315° lines. At 18 kG, these distortions can still be measured in the beam plane which is ~ 50" below the lower edge of the camera ports.

Fitting the acquired data was done by using polynomials satisfying Maxwell's equations. The overall fits can be generalized by[4]

$$B_z = \sum_{m=0}^{9} a_m f_m (r, z) + \sum_{n=1}^{\ell} b_n F_n (r, z, \theta)$$

$$B_r = \sum_{m=0}^{9} a_m g_m (r, z) + \sum_{n=1}^{\ell} b_n G_n (r, z, \theta)$$

$$B_\theta = \sum_{n=1}^{\ell} b_n E_n (r, z, \theta)$$

It was found convenient to fit the data in two steps each of which by the least squares method. The first step involved 10 angle independent terms (for all three currents) as indicated above for B_z and B_r. Deviations of these fits were then subjected to angle dependent terms as indicated by the second summations of B_z and B_r. These latter terms were current dependent and required rather tedious selection in order to obtain a good fit with the least amount of terms. The index ℓ varied up to 11, 12, 16 for currents at 1000, 1538 and 1800 amperes, respectively. A sample of the difference between the final fit and the measured values for a current at 1800 amperes are plotted in Fig. 3(b). From this graph, it is clear that a 0.1% goodness of fit is achieved up to ~ 1.5 feet from the chamber wall. A more careful selection of the chamber volume has been done in Ref. 4 so that for physics purposes, a 0.1% field accuracy can be quoted.

IV. Conclusion

To check the accuracy of the magnetic field in a bubble chamber, physicists usually look at a large sample of K^o meson fits. By plotting the mass of this particle, one can get a feeling for the goodness of the field parameters.[5] In fact, most bubble chamber fields are not well known and the field parameters are determined by shifting the K^o mass until it peaks at the correct value for all parts of the chamber. In case of the 12-foot bubble chamber, the reverse approach was taken and the K^o mass found from the existing map. At present, the value stands at $M(K^o) = 497.6 \pm 0.3$ MeV compared with the world average of 497.8 ± 0.2 MeV. This number was obtained for a current of 1538 amperes. The obtained value is accurate enough and thereby confirms the goodness of the field map.

References

1. J. Purcell, "The Superconducting Magnet System for the 12-Foot Bubble Chamber," ANL/HEP 6813, June 1968.

2. The momentum error is calculated as

$$\left(\frac{\Delta P}{P}\right)^2 = \left(\frac{\Delta P}{P}\right)^2_{\text{Coul.}} + \left(\frac{\Delta P}{P}\right)^2_{\text{Meas.}} + \left(\frac{\Delta P}{P}\right)^2_{\text{Angle}} + \left(\frac{\Delta H}{H}\right)^2$$

where Coul. - stands for error due to Coulomb scattering,
Meas. - stands for error due to measuring,
Angle - stands for error due to dipping track.

The magnitudes of these errors are such that with $(\Delta H/H) \leq 0.1\%$, the magnetic field term can be ignored.

3. A complete description of the measuring apparatus and technique can be found in "Measurement of the 12-Foot Bubble Chamber Magnetic Field," AD/HEF/HEP Divisions, ANL/BBC 152.

4. For detailed description of the formulae and the fitting technique, the reader is referred to "Fits to the Three Magnetic Field Measurements of the 12-Foot Bubble Chamber," K. Jaeger, ANL/BBC 153, February, 1972.

5. Note that the K^o mass is usually chosen because of the associated large Q value $[(Q = M(K^o) - M(\pi^+) - M(\pi^-)]$. Using some kinematic arguments, one can show that a large Q value implies great sensitivity in determining the mass from the momentum measurements of the decay products (in this case π^+ and π^-).

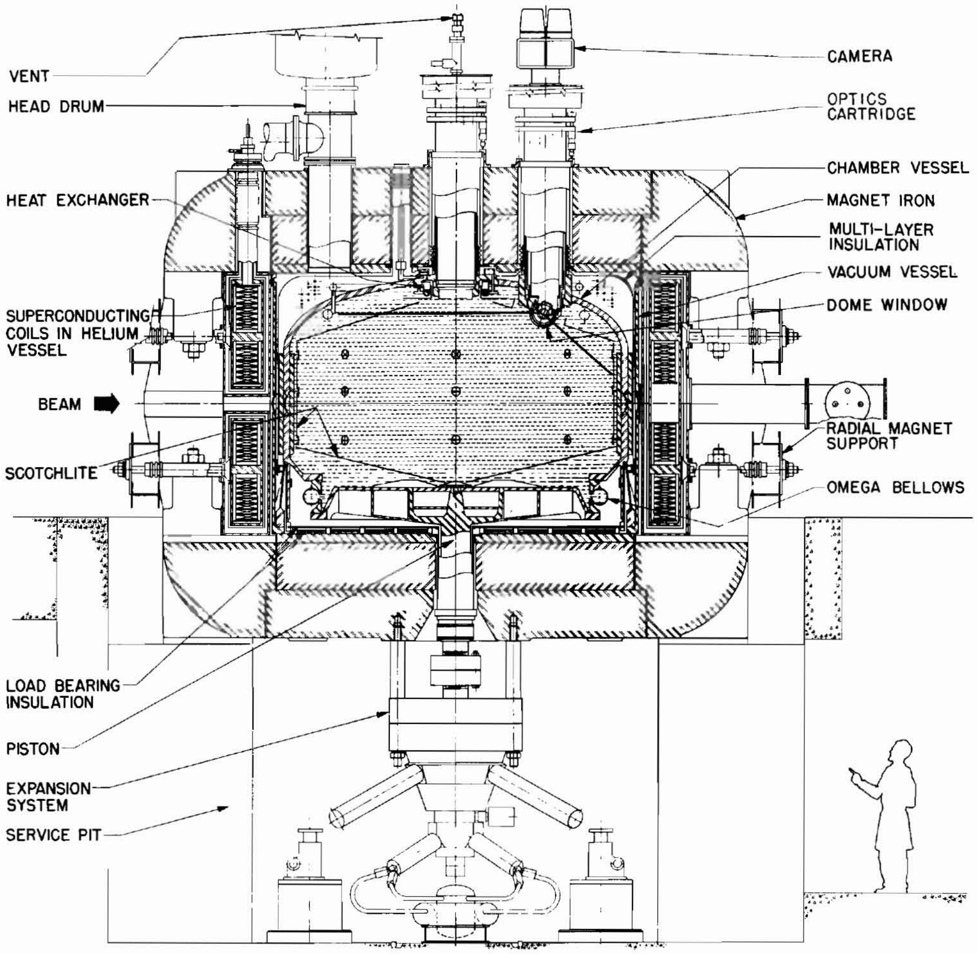
VENT
HEAD DRUM
HEAT EXCHANGER
SUPERCONDUCTING COILS IN HELIUM VESSEL
BEAM
SCOTCHLITE
LOAD BEARING INSULATION
PISTON
EXPANSION SYSTEM
SERVICE PIT
CAMERA
OPTICS CARTRIDGE
CHAMBER VESSEL
MAGNET IRON
MULTI-LAYER INSULATION
VACUUM VESSEL
DOME WINDOW
RADIAL MAGNET SUPPORT
OMEGA BELLOWS

FIG. I

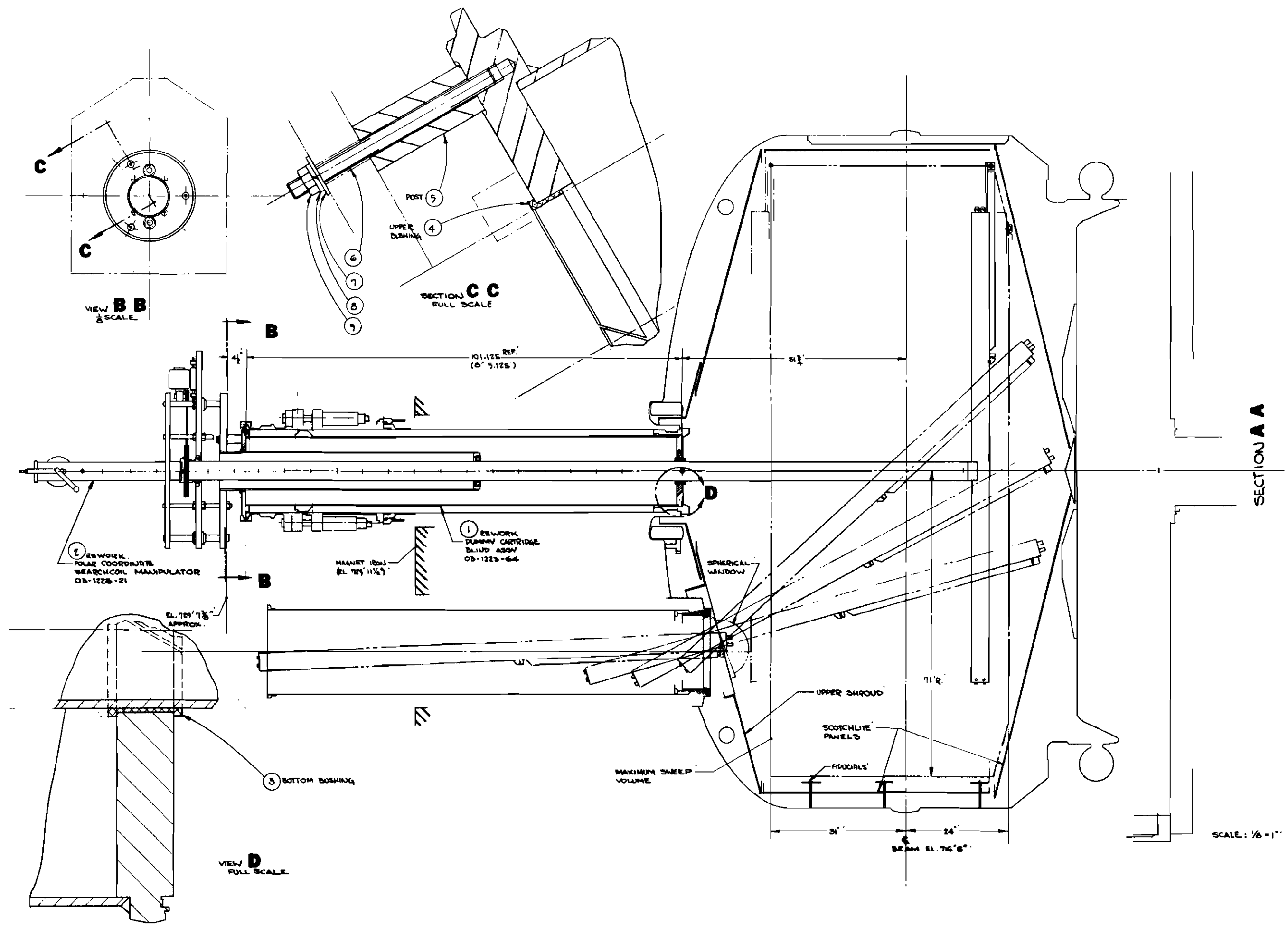
VIEW B B
1/8 SCALE
SECTION C C
FULL SCALE
POST 5
UPPER BUSHING 4
2 REWORK POLAR COORDINATE SEARCHCOIL MANIPULATOR OD-1223-21
1 REWORK DUMMY CARTRIDGE BLIND ASSY OD-1223-64
MAGNET IRON
SPHERICAL WINDOW
3 BOTTOM BUSHING
VIEW D
FULL SCALE
UPPER SHROUD
SCOTCHLITE PANELS
FIDUCIALS
MAXIMUM SWEEP VOLUME
SECTION A A
SCALE: 1/8 = 1"

FIG. 2

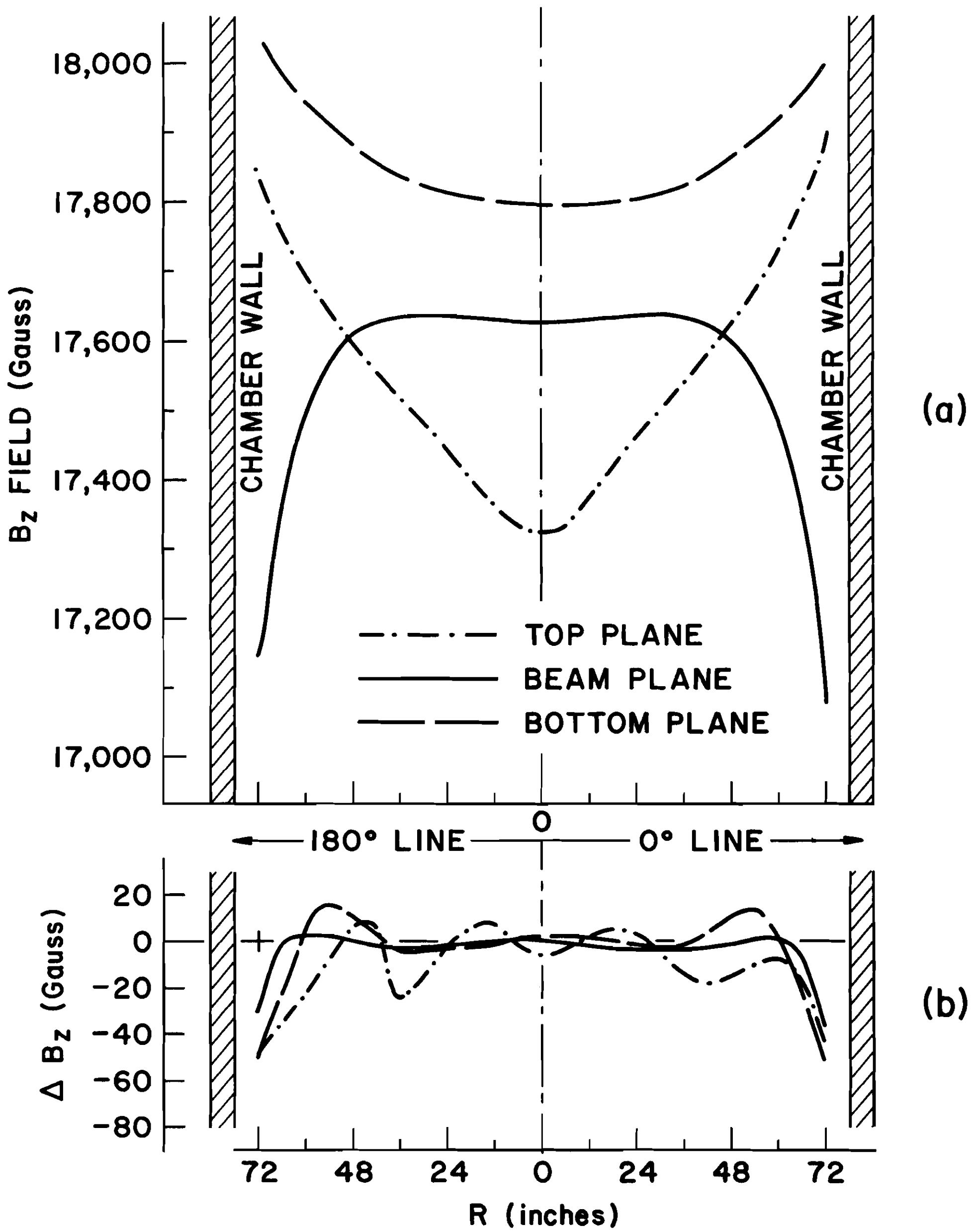
18,000
17,800
17,600
17,400
17,200
17,000
B_z FIELD (Gauss)
CHAMBER WALL
CHAMBER WALL
TOP PLANE
BEAM PLANE
BOTTOM PLANE
(a)
180° LINE
0
0° LINE
20
0
-20
-40
-60
-80
ΔB_z (Gauss)
(b)
72
48
24
0
24
48
72
R (inches)

FIG. 3