# Measurements of the Magnetic Shielding for the TTF Bath Cryostat

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**Abstract:**

The Liquid Helium bath cryostat used at the TESLA Test Facility (TTF) for testing the superconducting cavity structures houses two magnetic shielding cylinders. The outer cylinder is at room temperature, the inner one is cooled down to cryogenic temperatures.

Magnetic flux tubes change the Q-value of the cavity considerably and lead to high cryogenic losses. That limits the tolerable magnetic field in the cavity to approximately 1 % of the earth magnetic field.

Therefore, it was requested to check the shielding by measuring the remaining field inside. Since the measurement of small magnetic fields with Hall probes is difficult, a new detector based on magneto-resistive sensors was developed. This device is capable to measure the three components of the field down to 0.1 µT. Detailed studies of its performance are given.

The measurements of the magnetic field inside the shielding cylinders were done at room temperature. They demonstrated that after some constructional modifications a good shielding could be achieved. The remaining magnetic field is below 0.5 µT axial and below 0.1 µT radial .

## Introduction

The super conducting cavities presently designed for the use at the TESLA linear collider should have high Q-values. In the presence of an external magnetic field flux tubes show up in the superconductor and lead to an increase of the RF resistance. By that the Q-value of the cavity is reduced, which leads to a considerable increase of the cryogenic losses.

At the TTF vertical bath cryostat for testing the cavities an effective shielding of the earth magnetic field is requested. Two cylinders made of μ-metal with a closed bottom are used to shield the field. The "outer" one (∅ 1.3 m x 4 m) houses the cryostat equipment. Inside the cryostat an "inner" cylinder (∅ 0.6 m x 2 m) made of Cryoperm[1] is placed, which is cooled down to about 2 K during operation.

First measurements inside both shieldings were done by using a Hall probe. More accurate measurements followed, applying an improved equipment basing on a recent sensor development, which is especially appropriate for measuring small fields.

## Measurements in Both Shielding Cylinders with a Hall Probe

First measurements have been done using a Hall probe[2] connected to an Bell magnetometer[3] with the smallest range of 10 μT full scale. The measurement accuracy was limited by a short time stability of only about 0.7 μT and a temperature coefficient of 3 μT/K. In order to keep the temperature dependency small, the sensor was temperature stabilized. The measurement of small fields with this magnetometer is complicated by the modulation method used in the magnetometer. The Hall probe is driven by a rectangular current of 4.7 kHz. This causes a high sensitivity of the Hall signal with respect to capacity changes of the cable, which for instance occurs when the cable is bent.

The calibration of the set-up was done in a permanent magnet (0.4 T) by comparing the hall signal with that of a nuclear magnetic resonance probe. The magnetometer was connected to an DMM[4] and read out via a PC.

The measurements discussed here were done with a horizontal aligned Hall probe. Due to the field inclination angle at our geographical position the vertical component is about 90 % of the earth field. Inside the shielding cylinder the horizontal component is usually stronger reduced as the vertical (axial) component. Therefore, a comparison of the vertical component inside the cylinder to the unshielded field can only be done qualitatively.

Fig. 1 shows the axial field component as a function of the axial position in the outer cylinder. The data are compared to the vertical field without shield, which is about 37 μT. A shielding factor of only about 3 can be deduced from the curves. At the top (open end) of the shielding cylinder the field strongly rises up to a value of twice the earth field because of a focusing effect. An increase of the shielding factor to about 6

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[1] Shielding material for cryogenic temperatures made by Vakuumschmelze Hanau

[2] SBV613 from Siemens

[3] Bell Model 640

[4] HP 3458 with GPIB interface

could be achieved by mounting five layers of a 0.1 mm thick μ-metal foil to all horizontal gaps. Measurements in the inner cylinder show similar results.

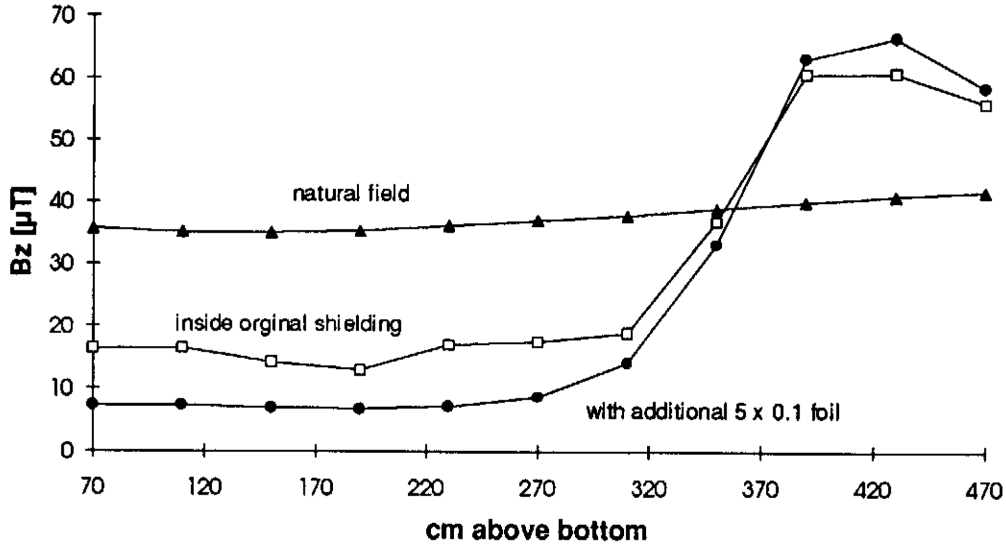


**Figure 1:** *Measurement of the axial magnetic field inside the outer shielding (on axis) compared with the vertical component of the earth field in the hall*

The measurements proved that the main source for the penetration of magnetic field was due to the horizontal gaps of the cylinder structure. So it was recommendable to change the production technology in such a way, that all gaps between the cylinder segments should be closed as far as possible by welding using the cylinder material as welding rod.

The expected higher shielding factors imply an improved measuring equipment capable to measure fields down to 0.1 μT and the possibility to measure all components of the field instantaneously.

## Magneto-Resistive 3D-Magnetic Field Sensor

### Measurement Principle

Beside the measurements mentioned we investigated a better method for measuring small magnetic fields. A new sensor with good properties and low costs was chosen. Since no commercial field measuring device based on this sensor was available, we were forced to develop an own system.

The sensor[5] uses the magneto-resistive effect in the ferromagnetic alloy Permalloy. Under the influence of an outer magnetic field the electrical resistance of the sensor changes by about 2 - 3%. Four such resistors are arranged to a Wheastone-Bridge on a chip with a sensitive area of about 1 mm². Normally, the magneto-resistance varies quadratically with the magnetic field in the sensor plane perpendicular to the current direction Hy (see Fig. 2). Due to the Barberpole-Structure[6] and the bridge arrangement,

[5] KMZ10A made by Philips

[6] Embedded Permalloy strips in a good conductor with a certain angle to the current direction

the resistance dependency on Hy changes completely. This leads to the sensor characteristics shown in Fig. 3, with a linear behavior in a wide range of ±Hy.

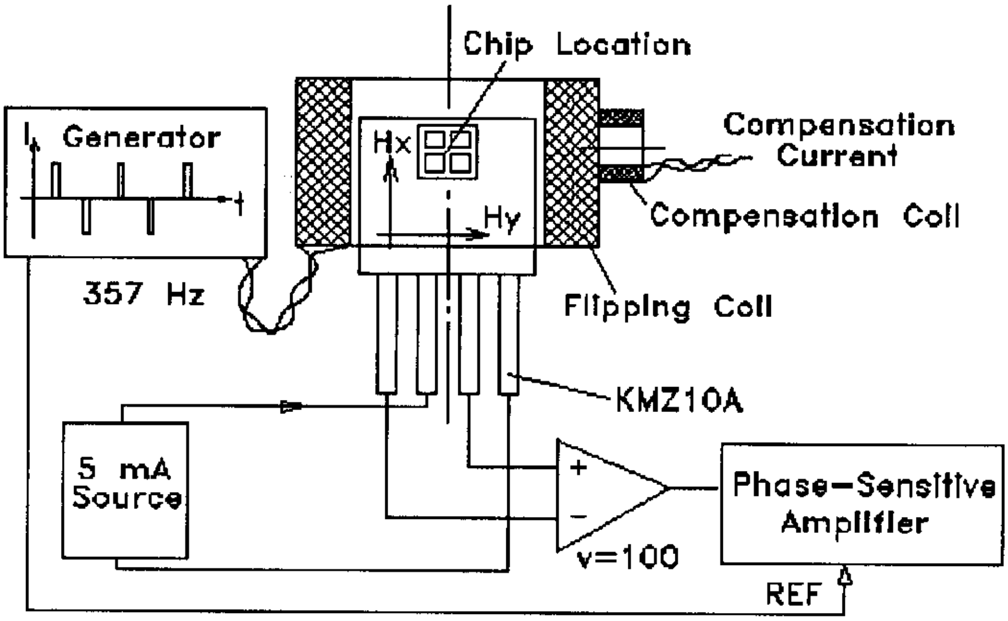


**Figure 2:** *Principle diagram of the magneto-resistive sensor*

During the thin film manufacturing process the sensors are exposed to a strong magnetic field leading to a preferential direction of magnetization in the Permalloy parallel or anti-parallel to the strips (±Hx). An auxiliary field in x-direction of an appropriate strength initiates flipping between the two states leading to a mirrored sensor characteristics as shown in Fig. 3.

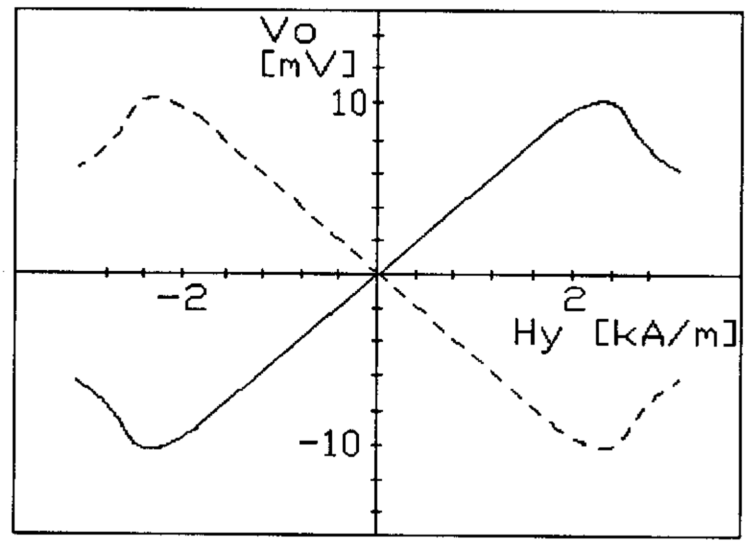


**Figure 3:** *Sensor characteristics for both states, the parallel or anti-parallel magnetized Permalloy (KMZ10B)*

If the switching between both states is periodically enforced by a flipping coil with short positive and negative current pulses, the output signal becomes an AC voltage (Fig. 2). The advantage of using AC signals is the suppression of slow varying drifts in the sensor or amplifier and also the possibility of applying phase sensitive rectifying techniques by lock-in detectors. Details about technical parameters, special features, boundary conditions and useful applications are given elsewhere [1, 2, 3]. It is suggested to use a constant current source for driving the sensor. This reduces the temperature dependence of the output signal considerably.

The principle sensor setup used is illustrated in Fig. 2. The coil surrounding the sensor generates the flipping field Hx. The field pulses must be strong enough (>3 kA/m) to flip all magnetization districts. The time constant of the modulation coil mainly determines the pulse duration of 13 µs. During this time the signal is undefined. In order to get a good time ratio between stable measuring (generator current zero) and the flipping time, a low repetition rate of 357 Hz was chosen. A commercial lock-in amplifier[7] measures the amplified voltage with a time constant of 1 s.

A sensor specific offset of up to 1% of the earth field can be explained by the asymmetry in both signal dependencies of Hy (Fig. 3) which leads to a non zero signal at Hy = 0. Therefore, a compensating coil for each sensor has been added. The current has been adjusted individually, so that the additional field considerably reduces the offset and pushes the low field limit for measurements below 0.1 µT. The suspicion of existing ferromagnetics in the neighborhood of the sensors was not confirmed.

Fig. 4 shows the combination of three sensors perpendicular to each other to a three dimensional sensor (3D), which allows to measure all field components simultaneously.

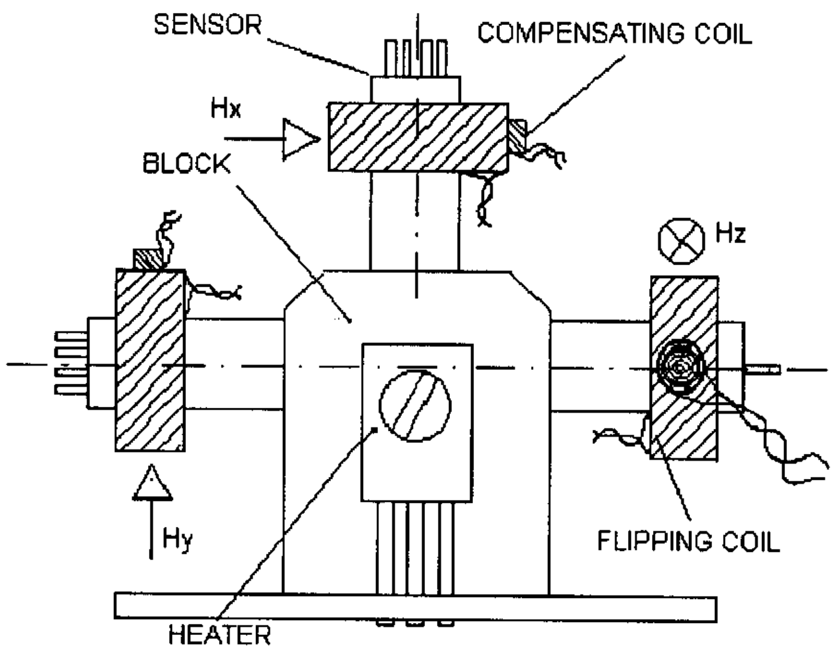


**Figure 4:** *Schematic design of the 3D magnetic field sensor*

### Features of the new device

The performance of the 3D-sensor was studied systematically. A small µ-metal cylinder, closed at one end, with a shielding factor of >100 was used as a test environment. The measurement of the time stability inside this shielding shows an excellent result of ±0.03 µT for short (Fig. 5a) and even for longer times (Fig. 5b).

[7] NF Electronic Instruments 5610

With the help of an excitation coil surrounding the sensor inside a good shielding we determined the linearity of a sensor element. The sensors work reliable from 0.1 to 600 µT. In the region between 0.5 and 75 µT the deviation from linearity is better than 2%. Below 0.5 µT it increases to 5% due to the increasing signal-to-noise ratio. Above 75 µT a non-linear behavior shows up due to saturation effects of the ferro-magnetics extending to a deviation from linearity of 18% in the region up to 600 µT.

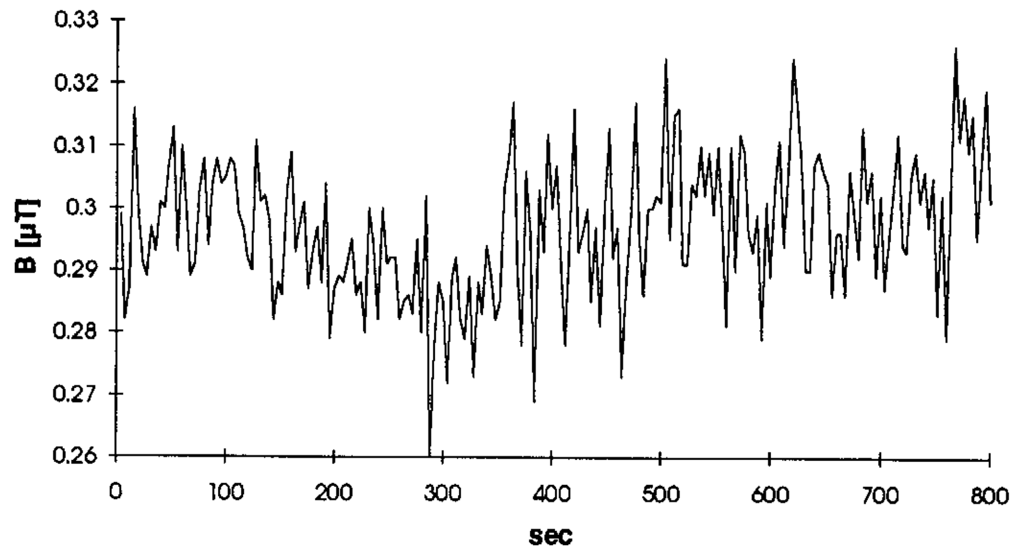


**Figure 5a:** *Shorttime stability of 3D-Sensor*

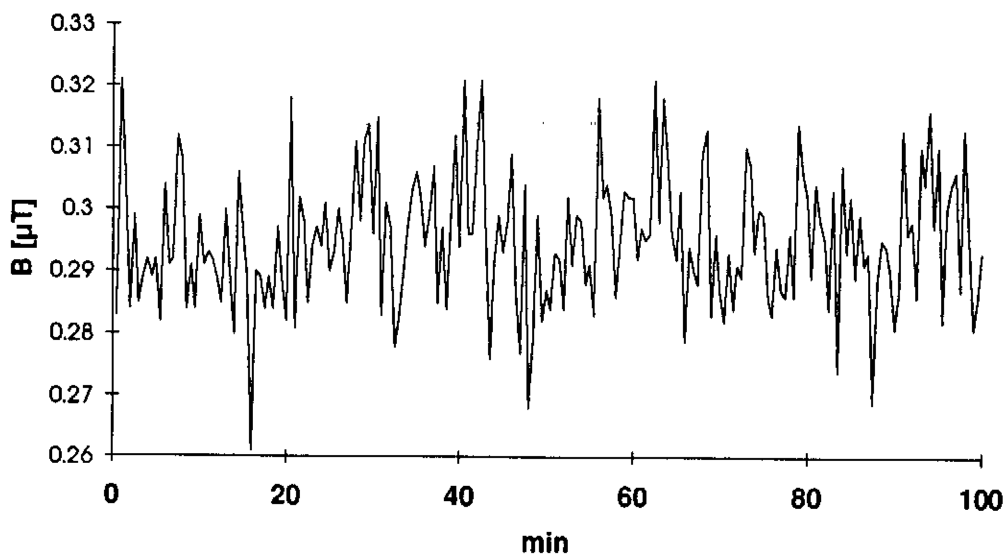


**Figure 5b:** *Longtime stability of 3D-Sensor*

The quality of a 3D-sensor is mainly determined by its signal dependence during rotation in a known field. An ideal sensor has no angular dependence, i. e. when the field strength is calculated from three field components. We calibrated the response of the sensors in a single layer solenoid specially built for this purpose. It was designed such that the field in-homogenity inside a distinct volume in the center is less than 1% [4]. The calibration factors obtained were in a good agreement with values from measuring the maximum signal of each sensor in the earth field. By applying the individual calibration factors of the sensors in the calculation of the field magnitude we could reduce the orientation dependence of the 3D sensor to 2.5%. The remaining effect is due to geometrical misalignment of the three sensors and an additional signal dependence of the field component in the current direction "Hx" (Fig. 2). A signal decrease of 5% is observed in the presence of Hx with the strength of the earth field [2]. In practice, this influence can often be neglected since one field component is usually dominant.

### Measuring Assembly

A motor driven transport system moves the 3D sensor on a aluminium support along the z-axis. For automatization of the measuring process a program based on LabWindow[8] is used. It takes 15 minutes for 200 equidistant z-points. The program controls the relay multiplexer and the lock-in amplifier, calculates the field, presents the data graphically and stores the results on disk.

## Measurements in the Improved Cylinder with a New 3D-Sensor

Fig. 6 shows the measurement of the axial field in the improved version of the inner cylinder obtained with the new sensor. The three curves correspond to movements along the cylinder axis (a), 37 cm out of axis (b) and 4 cm close to the cylinder surface (c). In the bottom region the field drops below to 0.5 µT. That corresponds to a shielding factor of about 100. When leaving the central axis two peaks build up. They are getting more distinct in the direct vicinity of the gaps between the cylinder segments, which are not entirely welded.

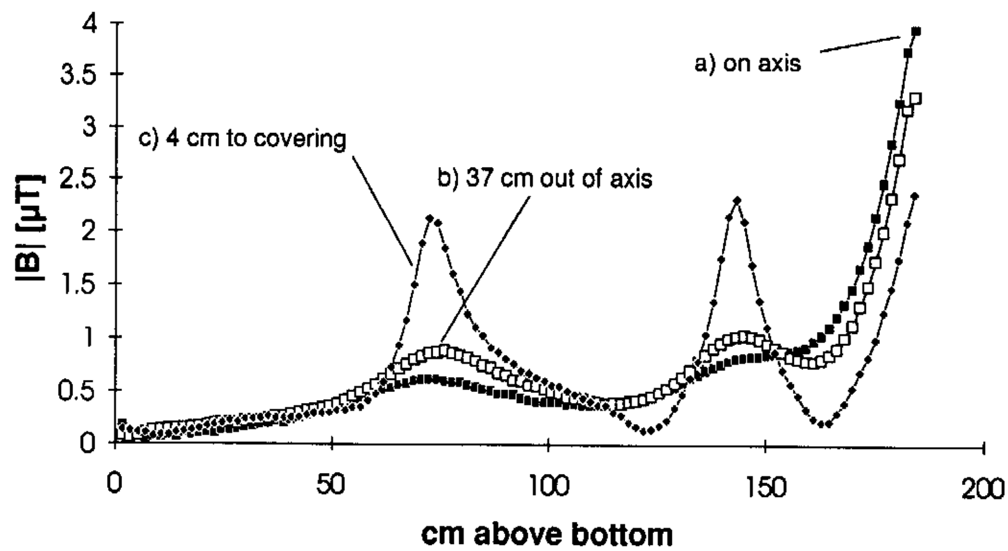


**Figure 6:** *Magnetic field inside the inner cylinder*

This influence to the field is depicted in Fig. 7. The position of this z-scan corresponds to Fig. 6c. The y-direction is essentially radial, the x-direction tangential. Near the gaps By has a sharp zero crossing as one would expect for the horizontal gap between two cylinder segments.

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[8] National Instruments Software

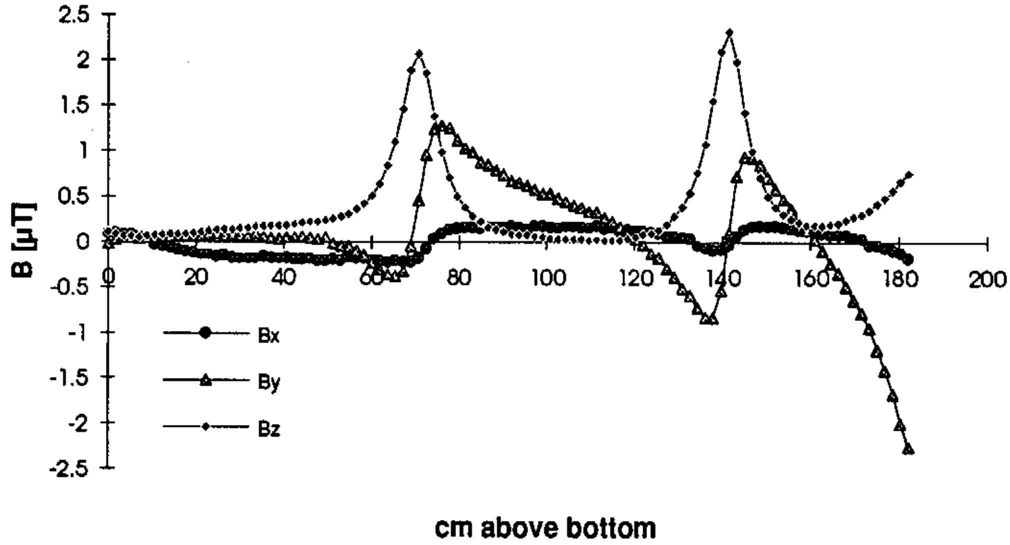


**Figure 7**: *The three magnetic field components near the cylinder surface*

Fig. 8 shows the remaining field in the inner cylinder when both shieldings were assembled in the bath cryostat. The measurements were done at room temperature. They nicely demonstrate the concurrence of both shieldings because both peaks disappear and a homogeneous field reduction builds up in the whole volume. Fig. 9 illustrates the difference between the axial and the radial field component on the cylinder axis. The radial field (~0.1 µT) is about a factor of three smaller than the axial field.

The shielding of the field down to a level of below 0.5 µT fulfils the requirements for the bath cryostat. A further improvement is expected with the new outer shielding cylinder based on a welded construction like the inner cylinder.

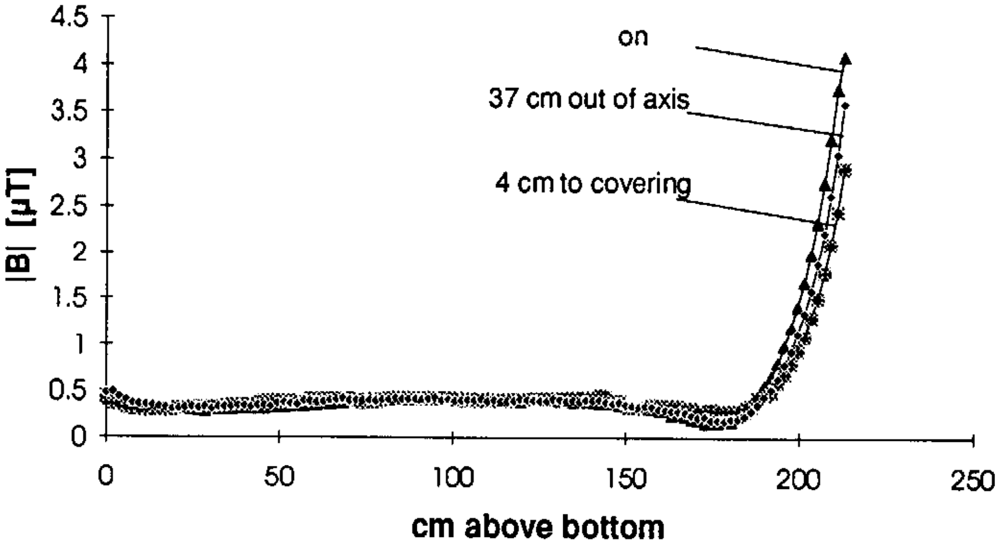


**Figure 8:** *Magnetic field in the assembled bath cryostat*

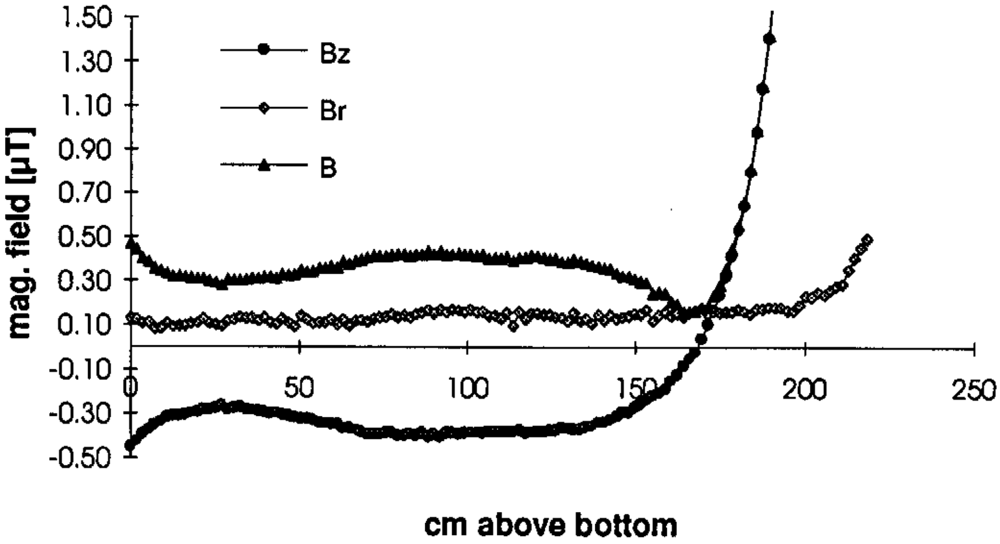


**Figure 9:** *Composition of the field into radial and axial components*

## Acknowledgment

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