Neurology and Clinical Neurophysiology 2004:70 (November 30, 2004)

A Sensor Configuration for a 304 SQUID Vector Magnetometer

Schnabel, A, Burghoff, M, Hartwig, S, Petsche, F, Steinhoff, U, Drung, D, Koch, H
Physikalisch-Technische Bundesanstalt (PTB), Abbestr. 2-12, 10587 Berlin, Germany

Corresponding Author: Allard Schnabel, Abbestr. 2-12, 10587 Berlin, Germany
Phone +49-34-81238; Email: Allard.Schnabel@PTB.de

ABSTRACT

A novel SQUID vector magnetometer system is introduced which has been specially designed for the use inside the strongly magnetically shielded room BMSR-2 of PTB. The system is housed in a dewar with a flat bottom and an inner diameter of Ø 250 mm. The SQUIDs are arranged so that in addition to the usually measured Z-component of the field the horizontal magnetic fields are measured too. A total of 304 DC-SQUID magnetometers are divided up into 19 identical modules. The 16 low-T_c SQUIDs of each module are located in such a way that an estimation of the magnetic field in all three dimensions is possible at three points inside the module. The 57 SQUIDs of the lowest Z plane of all modules form a hexagonal grid with a base length of 29 mm. The design criteria and the physical principle behind the complex SQUID arrangement are explained. .

KEY WORDS

Vector magnetometer, Sensor configuration, DC-SQUIDs, Magnetically shielded room, Biomagnetic measurements.

INTRODUCTION

The new magnetically shielded room BMSR-2 [Bork, 2000] of PTB, which was manufactured by Siemens AG and VAC GmbH & Co KG, has a very high passive shielding factor. It exceeds 100,000,000 above 6 Hz. With additional active shielding the chamber has a shielding factor of more than 7,000,000 down to 0.01 Hz. This means that there will be virtually no power line interference if the grounding is done properly. It also allows one to use magnetometers rather than gradiometers which yield the maximum signal-to-noise ratio. Using SQUIDs with a low 1/f noise, direct observation of dc-like magnetic phenomena, such as injury currents, spreading depression or magnetic marker signals is possible.

Another requirement to the chamber was a low noise level produced by the chamber walls. Inside the measuring volume it is less than 2 fT/√Hz so that SQUIDs with a white noise level below 2 fT/√Hz together with a dewar that also has a white noise level less than 2 fT/√Hz are required for an optimal use of the chamber.

Apart from these general features of the measuring system arising from the parameters of the used chamber, there were other restrictions to the design. For practical reasons the amount of SQUIDs had to be limited to about 300 SQUIDs. The system should also be usable for a more general purpose. Therefore a dewar with a flat bottom surface built by Eagle Technology (ET) was chosen. Due to the forces produced by the insulating vacuum the sensor area of the dewar is limited to a circular area with ∅250 mm. The decision for a vector magnetometer is based on the good experience with a small version tested before [Burghoff, 1999]. This means that the SQUIDs must be arranged so that all three components of the magnetic field can be estimated at as many points as possible. It is desirable that these points, which we call vector points (VP), are located in at least three different z layers. Since the magnetic field strength of every local magnetic field source is rapidly decreasing with distance it is favorable to have a high sensor density at the bottom of the dewar. This provides high localization accuracy. To allow an easy extension of the measuring area for periodic or triggered signals a homogeneous SQUID distribution in the X-Y-plane is preferable which makes it easy to extend the measurement area by shifting the dewar in the X-Y-plane.

PRINCIPLE OF CONSTRUCTION

In the cube concept [Burghoff, 1999] six SQUIDs are placed on the centers of the sides of a cube. The three average values of the signals of opposing SQUIDs are a good estimate of all three components of the magnetic field at the center of the cube. However, the concept does not meet all conditions listed in the introduction. Two considerations lead to the modification of the SQUID arrangement

First: To adapt a pile of cube geometries to the decreasing field strength in Z-direction it is possible to deform the cubes to cuboids with growing heights. Second: It is not necessary to place the SQUIDs at the center of the cube sides. They can be anywhere on the plane defined by the surface of the cube as long as the corresponding partner SQUID is moved in the opposite direction so that the connecting line between the two parallel SQUIDs is still passing through the center of the cube. As long as the pick up coils of the SQUIDs are not turned they are still measuring the magnetic field perpendicular to the cube's surface.

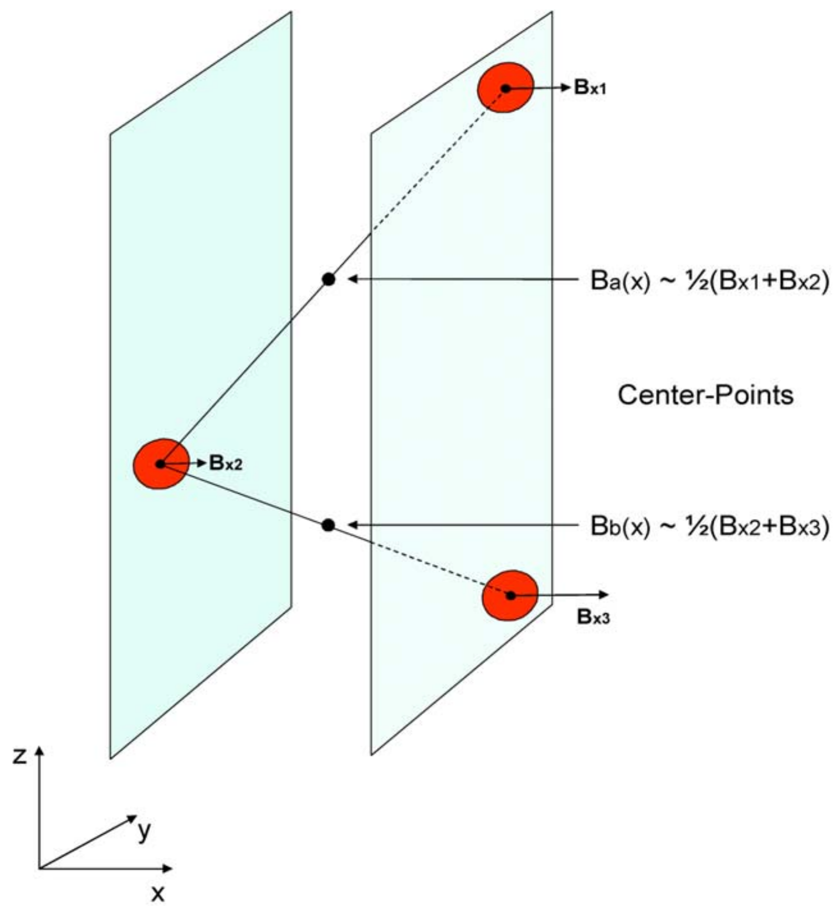

Figure 1. The average value of two sensor signals is measuring the same field component is a good estimate for the field at the center between the sensors. Note that in the shown arrangement the left detector is used for the estimation of the field at two center points.

The average value of the two SQUIDs is, as before, an estimate of the field at the center of the cube. If two cubes are placed on top of each other the upper SQUID of one side can be moved down and the lower SQUID of the same side moved up until they are at the same place. In this case only one SQUID is needed at this position. This is illustrated for the x-component in Fig. 1. Doing this consequently starting with three cubes stockpiled 12 SQUIDs will be needed for the three VP instead of 16.

The SQUID positions of one module are shown in Fig. 2. It is constructed out of three cubes put on top of each other as described above. The cubes are stretched to cuboids and then SQUIDs of opposed sides are moved. The module therefore still has 3 VPs at the Z-axis. Since we preferred a 16 channel electronics for each module 4 additional SQUIDs can be used to further increase the SQUID density at the bottom of the module. Two of them are added to the SQUID at the lowest Z-plane. The other two are added to the two lowest X-Y-planes. This leads to a triangular configuration in the lowest planes. As a result, the Y-component of the magnetic field has to be estimated by combining the output signals of two adjacent SQUIDs using a trigonometric function. Due to the triangular configuration, the distance between the SQUIDs is maximized and thus the crosstalk is minimized. The final cylindrical outer shape is chosen for practical reasons.

The total sum of 57 Z-SQUIDs in the lowest plane of all 19 modules is arranged on a hexagonal grid (see Fig. 3) with a base length of 29 mm (the resulting hexagonal grid baseline of the modules is 50 mm). The structure of the modules allows the calculation of further VPs between the modules if data of neighboring modules is used. This increases the number of possible VPs. In each plane 61VPs can be estimated at 15 mm, 50 mm, 105 mm above the bottom Z-plane. These are enough VPs to allow a 3-dimensional image of the measured magnetic field.

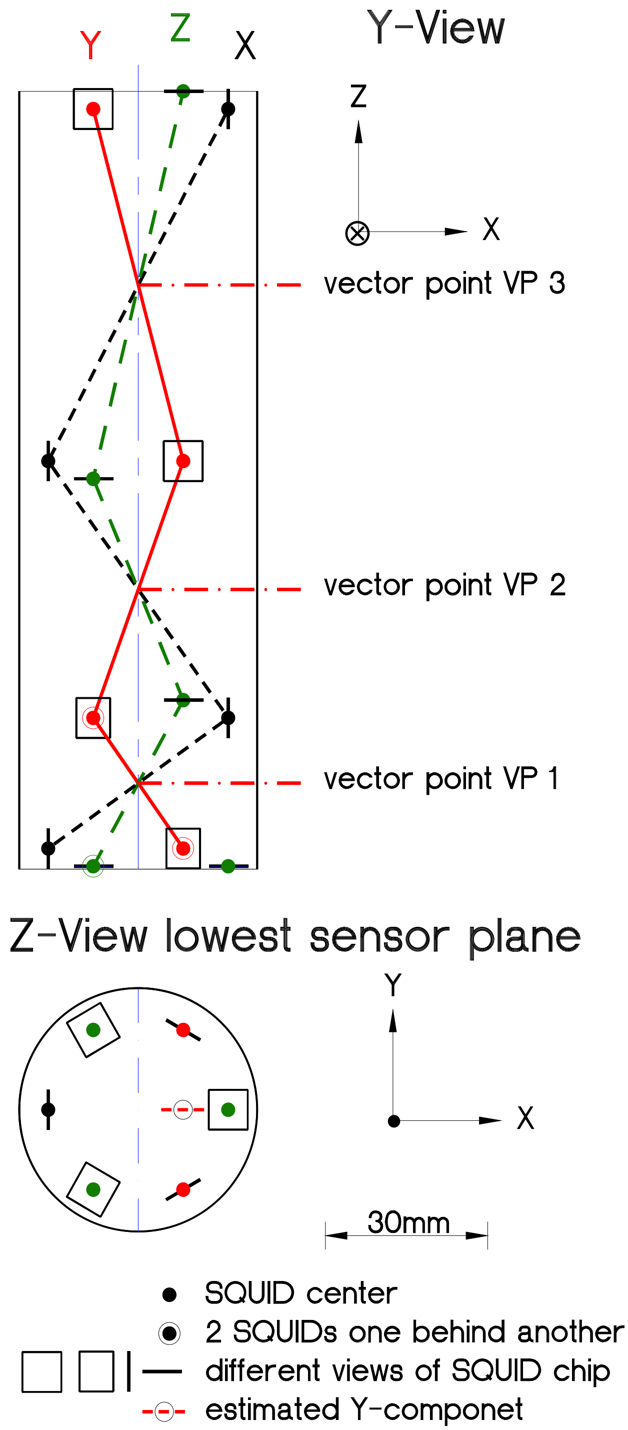

Figure 2. Sensor arrangement of the 16 channel SQUID vector magnetometer module manufactured by PTB. The SQUID sensors are located so that all vector components of the magnetic field can be estimated at three vector points (VPs). The lines connecting the SQUIDs illustrate the construction of the VPs.

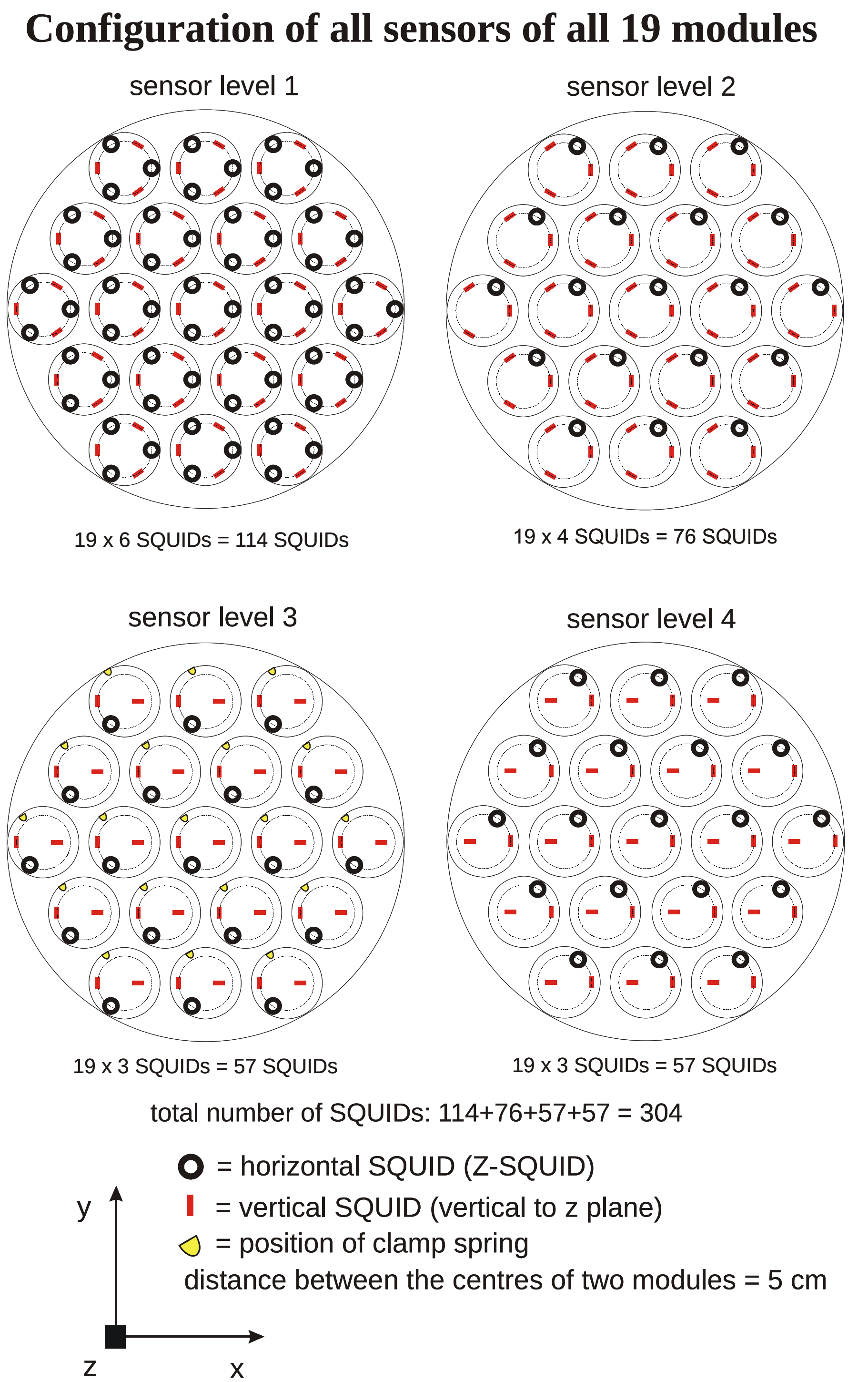

Figure 3. Arrangement of the 19 modules with a total sum of 304 SQUID sensors. The diameter of the area covered by the sensor configuration is 250 mm.

FURTHER DETAILS

The described concept requires a complex non-magnetic SQUID holder. We designed it by using a 3D CAD program and manufactured all parts of the holder by a five-axis CNC-machine. A photograph of one module is shown in Fig. 4. The FLL electronics for the PTB W9A SQUIDs [Drung, 2002] [Drung, 2003] is placed at the top of the Dewar. It is connected to a data acquisition system [Müller, 2003] situated in an RF shielded room which is directly connected to the RF shield of the BMSR 2. First tests to record the magnetic vector field were performed using sequential measurements with one module [Burghoff, 2004], [Burghoff, 2004], [Steinhoff, 2004].

Figure 4. Photograph of one of 19 identical modules of the 304 SQUID vector magnetometer system.

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