ACTIVE SHIELDING IN MEASUREMENTS OF DC NEAR BIOMAGNETIC FIELDS

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Abstract-**Measurements of DC near biomagnetic fields are disturbed by low frequency noise, that are not reduced sufficiently by most of the magnetically shielded rooms or gradiometers. An effective SQUID based active shielding system has been developed and installed at the magnetically shielded rooms in the Biomagnetic Center of the University Jena to reduce external low frequency disturbances. A reduction of the magnetic noise of about 23 dB could be achieved at 50 mHz.**
Keywords **– SQUID, biomagnetism, active shielding**

I. INTRODUCTION

The advantage of the biomagnetic method is the touchless and noninvasive measurement. Magnetic source imaging (MSI) utilizes the possibility of source localization based on biomagnetic recordings [1]. MSI is a completely noninvasive diagnostic tool for source localization (e.g. presurgical mapping, localization of epileptic seizures). Biomagnetic fields fall within the range between Picotesla (1 pT = 10^{-12} T) and a few Femtotesla (1 fT = 10^{-15} T) as shown in Fig. 1 [2].

On one hand external disturbances which exceed the biomagnetic signals by more than 6 orders of magnitude have to be suppressed and on the other hand, the sensor has to be sensitive enough to detect the signal to be measured. The most sensitive magnetic sensor is the Superconducting QUantum Interference Device (SQUID).

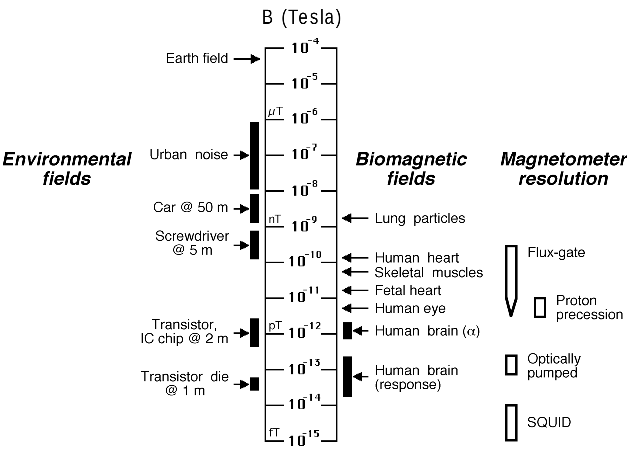

Fig. 1. Magnetic induction of biomagnetic fields and of environmental magnetic noise sources as well as the magnetometer resolution; by courtesy of J. Vrba.

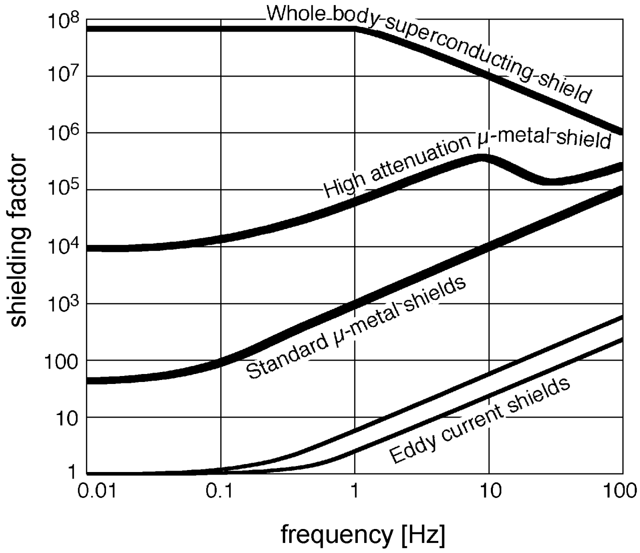

Fig. 2. Shielding factor of magnetically shielded rooms versus frequency.

The suppression of disturbing fields can be achieved by a magnetically shielded room (MSR). The shielding factor of such rooms is frequency dependent (Fig. 2). The solid line shows the best characteristic shielding curve of the standard magnetically shielded room AK 3b(Vacuumschmelze Hanau) made of two layers MUMETALL™ (2 mm thick) magnetic shielding and one layer aluminum electric shielding. Because of the decreasing shielding effect of these shielded rooms with decreasing frequency the recording of DC near biomagnetic fields (below 1 Hz) are very difficult or impossible.

Nevertheless, such fields occur in human stroke patients (periinfarct depolarization) and in migraineurs (spreading depression) as well as in patients (malignant tachyarrhythmias) after myocardial infarction. The noninvasive measurements of such fields give a powerful diagnostic tool in this clinical area.

II. METHODOLOGY

Measurements of DC near biomagnetic fields are disturbed by low frequency noise, that are not reduced sufficiently by most of the magnetically shielded rooms, gradiometers or the combination of both.

There are several proposals to overcome the problem of insufficient reduction of disturbances for measurements of DC near biomagnetic fields. An electronic noise suppression was demonstrated by Matlashov et al. for unshielded biomagnetic measurements in urban area [3]. The biomagnetic signals were recorded by a second-order gradiometer and a vector-magnetometer was used to record

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Abstract

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the ambient noise. They achieved a noise suppression of about 20 dB at 2 Hz.

Ter Brake et al. reported the shielding improvement via active compensation [4]. They achieved a reduction of 40 dB for magnetometers at low frequencies (around 0.1 Hz) for an applied vertical field as an artificial source of disturbances, but only in the vertical direction.

An active shielding system was described by Pasquarelli et al. which consists of two parts: (1) a static compensation with a set of three pairs of coils generating a DC-magnetic field to reduce the bias effect of the earth field and (2) a dynamic compensation of low frequency AC-compensation stray fields [5]. They achieved a reduction of the 1/f noise inside their magnetically shielded room by one order of magnitude below 1 Hz.

A similar cancellation technique of external noise inside a magnetically shielded room used for magnetocardiographic measurements was published by Kandori et al. [6]. They used a multichannel SQUID consisting of four gradiometers recording the source signal and two gradiometers as a reference. To compensate for the different magnitudes of the gradiometer wave forms they calculated a fitting parameter. This cancellation method provided an additional attenuation of over 20-30 dB [6].

Our aim was to achieve an active shielding system for all three spatial axes. For this reason an effective SQUID based active shielding system (Fig. 3) has been developed and installed at the magnetically shielded rooms in the Bio-

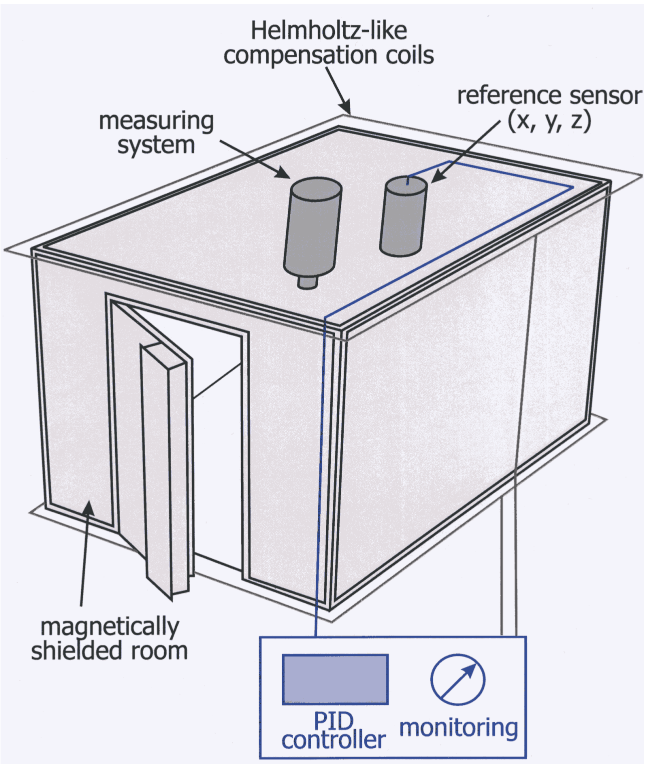

Fig. 3. Scheme of the active shielding system with reference sensor, measurement device, compensation coils and PID-controller.

magnetic Center of the University Jena to reduce external low frequency disturbances [7]. A Helmholtz-like orthogonal coil system (compensation coils) is installed outside the MSR. Both the biomagnetic measurement device (biomagnetometer: first order gradiometer) and the reference sensors are located inside the MSR. The reference sensor system consisting of three orthogonal SQUID-magnetometers is connected with a PID (Proportional-Integral-Differential)-controller. The signal of the reference system is proportional to the disturbing magnetic field and is the base for the PID to generate a current supplying the compensation coils.

III. Results

To demonstrate the efficiency of the active shielding system dc recordings are shown in Fig. 4 and Fig. 5. The Butterfly plot of the magnetic field disturbances by 31 magnetic SQUID-sensors connected with symmetrically first-order gradiometers inside the shielded room during 15 minutes (ordinary working hours, daytime) is shown in

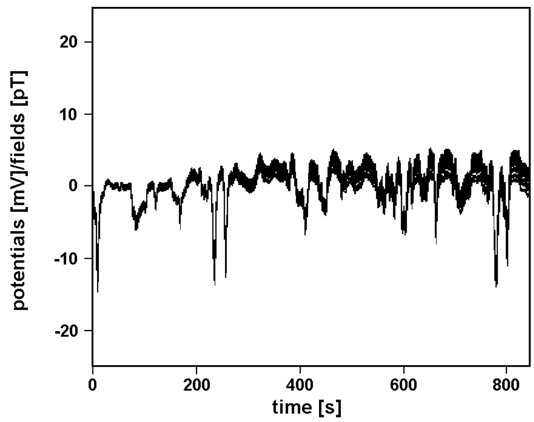

Fig. 4. Butterfly plot of the magnetic field disturbances by 31 magnetic SQUID-sensors (first-order gradiometers) inside the shielded room during 15 minutes (ordinary working hours, daytime). The 10pT signal changes are due to external disturbances.

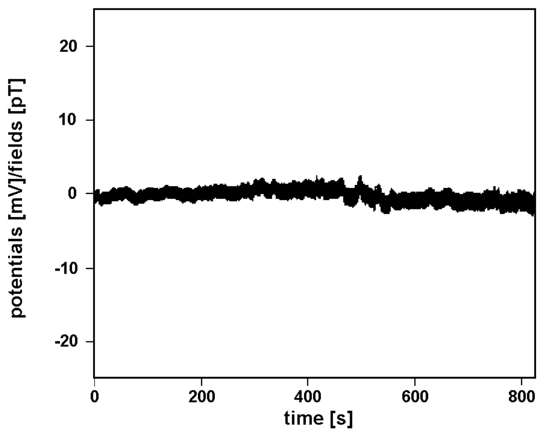

Fig. 5. Butterfly plot of the magnetic field disturbances by 31 magnetic SQUID-sensors (first-order gradiometers) inside the shielded room during 15 minutes (ordinary working hours, daytime) with active shielding system on. The external disturbances are significantly reduced.

Fig. 4. The 10pT signal changes are due to external disturbances. In Fig. 5 the Butterfly plot of the residual magnetic field with active shielding system on is recorded. The external disturbances are significantly reduced.

Applying an additional solenoidal coil located about 10 m away from the MSR controlled magnetic interference was produced and the transfer of this interference to the reference sensor and to the measuring system was recorded.

Fig. 6 shows the transfer function between magnetic noise and the reference sensor in an MSR without an active shielding (A), with active shielding using a Proportional (P) controller (B) and using a combined Proportional-Integral (PI) controller (C) in an MSR. Curve A in Fig. 6 shows an increased transfer of noise to the reference system at low frequencies which is due to the decreasing shielding factor of the MSR towards low frequencies. By using the active shielding with a P-controller the transfer of noise to the system stays constant at frequencies below one Hertz. This is because the shielding factor with active shielding is much greater then the shielding factor of the MSR. With the use of a combined PI-controller the amplification of the feedback circuit increases towards lower frequencies which in turn increases the shielding factor of the active shielding. This can be seen in curve C as the decreased noise transfer towards low frequencies. Curve C also shows a slight overshoot where the amplification of the integral component becomes unity. This can be explained with the phase shift of the compensation field introduced by the integrating part of the controller.

Fig. 7 shows the transfer functions between magnetic interference on the measuring system without active shielding (A), with active shielding using a P-controller (B) and using a PI-controller (C). Curve A in Fig. 6 and Fig. 7 look very similar as the noise has almost the same effect on both sensors. By using the active shielding with a P-con-

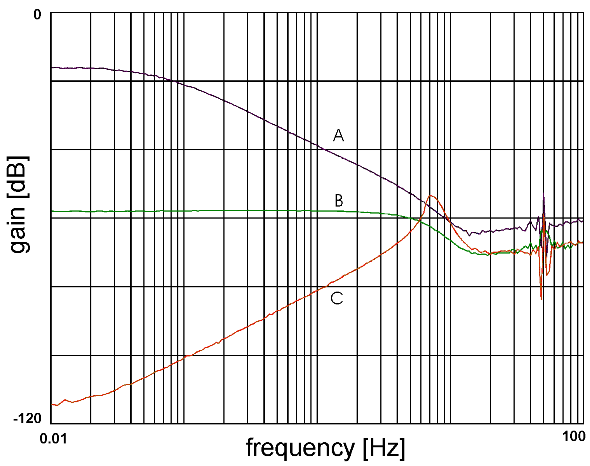

Fig. 6. Transfer functions of magnetic interference on the reference system (SQUID magnetometer) without any active shielding (A), with active shielding using a P-controller (B) and a PI-controller (C)

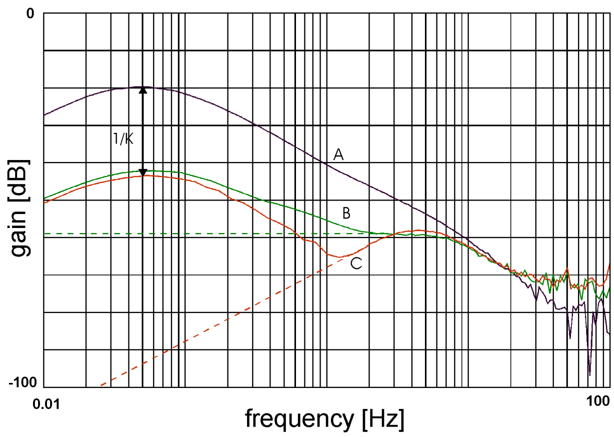

Fig. 7. Transfer functions of magnetic interference on the measuring system without any active shielding (A), with active shielding using a P-controller (B) and a PI-controller (C). Dotted line: transfer function of magnetic interference on the reference sensor applying P-controller (B) and PI-controller (C).

troller the noise transfer function to the measuring system (Fig. 6, curve B) is shifted ca. 20 dB below curve A. The dotted line in Fig. 7 represents the transfer function of magnetic interference on the reference sensor applying a P-controller (B) and a PI-controller (C).

The according transfer functions in Fig. 6 and Fig. 7 differ due to the different positions of the reference sensor and the measuring sensor in the MSR. The difference between curve B in Fig. 6 and Fig. 7 is caused by the different transfer of both the noise and the compensation field to the two sensors. This difference limits the shielding factor of the active shielding on the measuring system. This can be seen in Fig. 6 curve C as there is no significant increase in shielding factor by using an additional integral controller component.

With the use of a PI-controller we achieved a reduction of external low frequency magnetic fields by about 23 dB (Fig.6) at 50 mHz.

IV. Conclusion

DC near biomagnetic fields caused by spreading depression could be detected with an active shielding system in animal experiments [8]. Furthermore, the active shielding system enables measurements of dc near biomagnetic fields in human stroke patients in search for periinfarct depolarizations and spreading depression in migraineurs.

The system can be installed at every usual magnetically shielded room. Reference sensors inside a measuring system can be used as feedback signal for the PID controller, so that no additional magnetic sensor is required.

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