The application of Superconductors in Medicine

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1 Introduction

The purpose of this article is to provide an overview of the areas of application of superconductors in medicine. After a brief outline of the various application each of the applications will be discussed in some detail along with the major benefits and problems with the technology. Most of the biomedical application of superconduction is in the area of biomagnetics.

2 Applications

2.1 Biomagnetic Measurements

One of the major claims of superconduction is the SQUID magnetometer. SQUID stands for **S**uperconducting **QU**antum **I**nterference **D**evice, the theory of operation of the SQUID device will be discussed in the next section2.1.1. This measurement device is capable of measuring magnetic fields in the order of femto tesla and makes it one of the most sensitive magnetic measurement devices known. Figure 1 shows the relative sizes of various magnetic fields.

The human body generates extremely small magnetic fields but the measurement of these fields is of great diagnostic value. The main device for measuring these fields is the SQUID magnetometer. After a discussion of the theory of operation of the SQUID device the various biomagnetic applications will be presented. These applications can be divided into magnetoencephalanography, magnetocardiography and other biomagnetic applications. There are two main types of SQUID devices that is used both these devices will be introduced in the following section2.1.1.

2.1.1 The SQUID magnetometer [7]

If two superconductor is separated by a weak link it forms a Josephson junction. Such a weak link can be formed by various methods. A SQUID magnetometer consists of one or two of these junctions in a superconducting loop. The DC-SQUID having two Josephson junctions is the one used in almost all cases for the pickup of biomagnetic signals.

To keep the inductance low the size of SQUID loop should be a small as possible, in order to have a small sensor loop but a very sensitive sensor a pickup loop is needed. This loop usually couples inductively with the SQUID loop although some high temperature superconductors use a directly coupled pickup loop. Together with the sensor some readout electronics is also needed. There are various readout schemes but the most commonly used one is either a fluxed locked loop or a current locked loop.

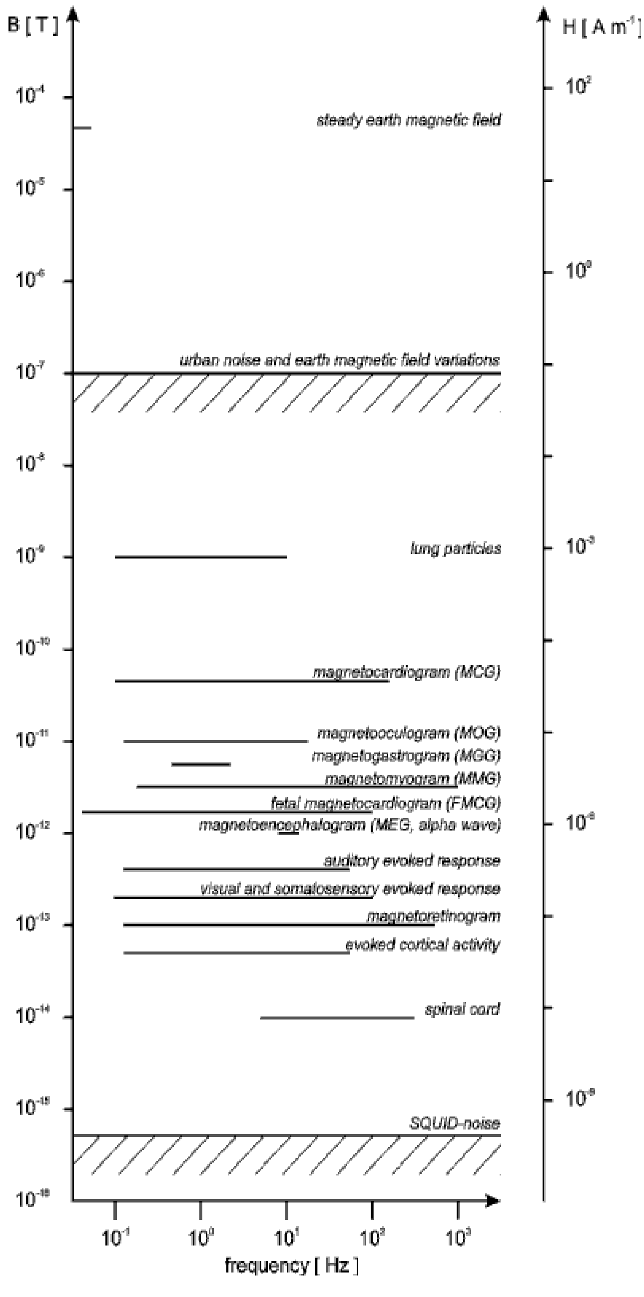

Figure 1: Magnetic field sizes

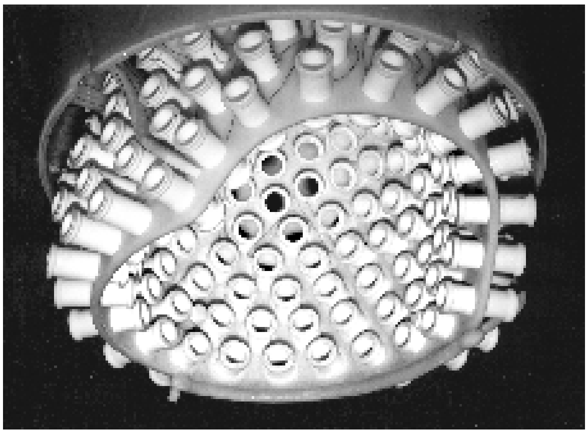

Figure 2: Whole head MEG system.

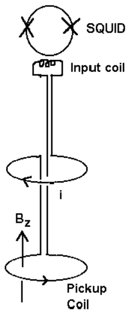

Figure 3: Gradiometer configuration

2.1.2 Magnetoencephalanography [1]

The sources of biomagnetic signals is mostly intra-cellular current flow resulting from muscular or neural excitation. These cells represent the current source, the circuit is completed by an extracellular current flow through the volume conductor. This current flow causes measurable electric fields that can be measured by EEG techniques. It also causes a magnetic field that is measurable although very weak. The advantage of measuring the magnetic field is that the currents vertical to the body surface is measured. These currents mainly result from the intra-cellular current flow, intra-cellular current flow is less distorted than volume current and this allows MEG to obtain much higher resolutions than can be obtained with EEG. It can also be used in conjunction with EEG methods because the two measurements are complementary.

MEG systems usually consist of an array of low temperature SQUID sensors in a dewar that surrounds the whole head see fig 2 . The array is usually consists of 37 to 255 SQUID sensors either in a gradiometer configuration or in a magnetometer configuration with a few sensors dedicated to noise cancellation. A gradiometer configuration consist of two pickup coils mounted on a baseline in such a way that magnetic field flowing through both coils cancel and only the difference gets amplified (fig3) . The magnetometer is just a single pickup coil with a SQUID sensor. Because of the small signal sizes MEG measurement are always made in a magnetically shielded room.

Applications MEG is used in various clinical and research applications. In some area MEG is eminently suited to the task like functional mapping of cortical areas, there is also areas in which MEG is the unique tool like investigating temporal aspects of signal processing in the brain and other even more complex brain functions. Used in conjunction with PET, MRI, fMRI and EEG MEG provides many other unique research application. The following is a list of a few recent applications of MEG, all the application come from the recent conference on Biomagnetism held at the Helsinki University of Technology in Espoo, Finland, August 2000. The applications is referenced to the proceedings of the conference[2], page numbers will be given.

In the field of Neuroscience MEG has found applications in various research areas, research into audition (p47-71), vision(p72-84), somatosensation, pain and other senses(p85-102), motor functions(p103-107) and cognition and language(p108-123). Some of the primary recent advances has been in the study of object representation where certain brain signals has been isolated to be specifically related to object representation irrespective of whether the object is from visual information or from memory. In the auditory field the plasticity of the auditory cortex has been measured and functional reorganization observed after intense "ear" training and reversible "functional deafferentation"(p8).

The main clinical application of MEG is the localization of lesions and the center of epileptic discharges. In conjunction with MRI or fMRI this enables accurate preoperative planning. Other application include the planning of rehabilitation for stroke patients by determining the extend of brain damage, the planning of stereotactic radiation therapy by precisely localizing the primary sensory cortex by functional mapping -this way radiation of this region is kept a low a possible(p21-24 and p124-138).

Comparison The main advantage of MEG is that it give much greater temporal resolution compared to other imaging methods (see fig 4) . Its main disadvantage is that it gives no anatomical information. For this reason it is often used in conjunction with a method like MRI.

2.1.3 Magnetocardiography [1]

The current flow through the heart generates a magnetic field of the order of 50pT. This is well within the detection range of both low and high temperature SQUIDS. It is the first medical field where the use of high temperature SQUIDs has become a viable alternative. Again the magnetometer measures the intra cellular current flow that is much less distorted by the body than the volume current flow measured by EEG machines. MCG is also a true non-invasive method requiring no electrodes. The main obstacle to MCG is the need for shielding, the few unshielded sensors has still to be improved somewhat before clinical application will be a reality.

The basic MCG device also consists of an array of SQUID sensors often covering the whole chest area, sometimes both the front and back area is covered. The number of sensor varies from 7 to 64. With the exception of a few experimental models all operate in a magnetic shielded room.

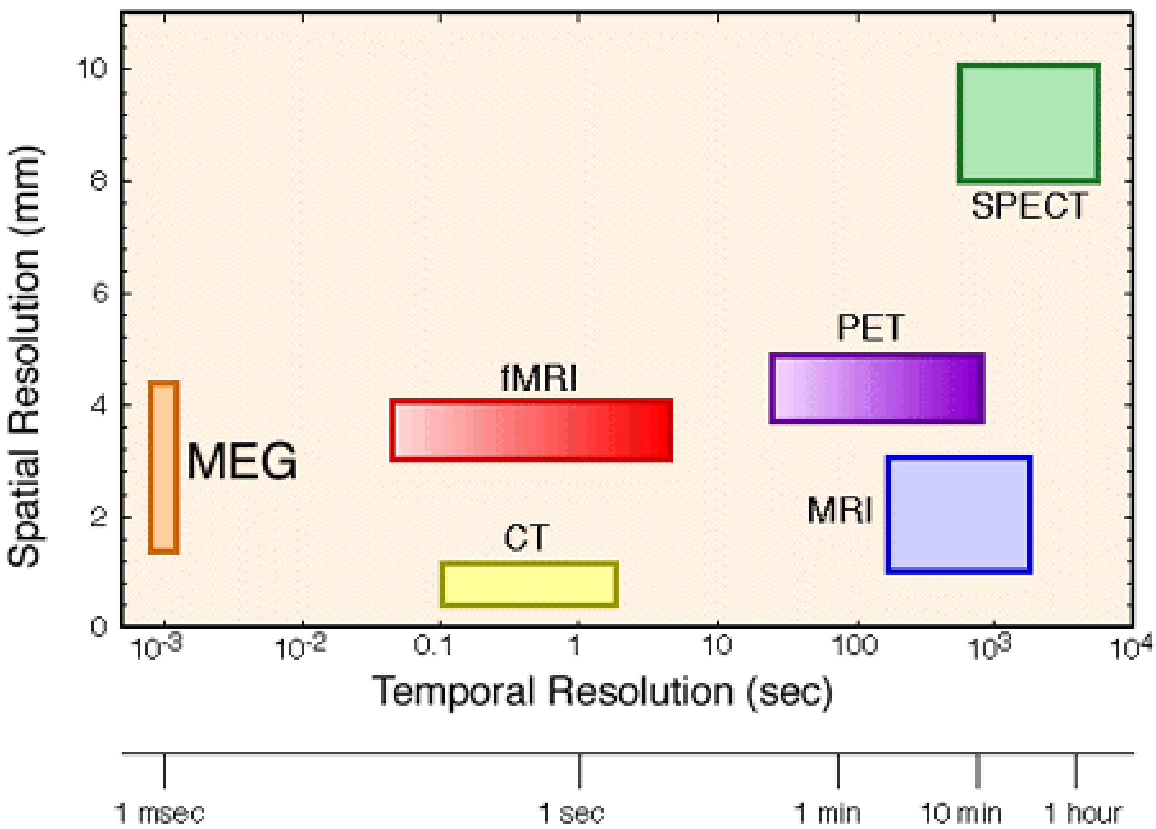

Figure 4: MEG vs other imaging technologies

Applications MCG find application in the screening of patients since the setup time is much lower than for ECG measurements. It has also been used to map cardiac arrhythmias together with the catheter method. The MCG is used for the general localization of the arrhytmia and then to map the catheter position as a more precise measurement of the area to be ablated. MCG has been shown to predict malignant cardiac arrhythmias with much greater accuracy then ECG, it is also used for predicting myocardial ischemia[2](p25-28 and p139-147). A main application that is developing in the field of MCG is that if fetal magneto cardiography. Fetal ECG is prone to extensive distortion due to an isolation layer called the vernix caseosa, MCG is not prone to this distortion and as such have great clinical significance for the analysis of fetal heartbeat in high risk pregnancies[1](p176-178),[2](p38-39 and p148-153).

2.1.4 Magnetoneurography

The measurement of peripheral nervous signals by means of magnetic fields is called magnetoneurography. The size of the peripheral nervous signals is extremely small, in the order of 15fT, and thus can only be measured in heavily shielded rooms by very sensitive low temperature SQUIDs, even then special noise cancellation is needed since the magnetic disturbance due to the heart is almost 1000 times bigger[5]. This technique find application in the localization of conduction blocks or slowing in peripheral nerve and could serve as a diagnostic tool in this respect. It can also be used to locate the focal nerve in cases of acute nerve root lesion accompanied by severe back pain and muscle spasm[6].

2.1.5 Gastroenterology

By monitoring the magnetic signal generated by the stomach and intestines it is possible to discern the various stages of digestion and to monitor the contractions and movements. Among the parameters that can be measured is gastric emptying, orocaecal transit time, esophageal transit time, pharyngeal transit time and clearance,oroanal transit time and stomach mixing time[1](p430-442),[2](p33). Along with this magnetic markered materials can be traced through the intestine in the same way that radioactive material is traced, but the there is no radiation present. A spin off of this technique enables pharmacists to study the path and release of solid oral dosages by studying the disintegration of magnetic marker pills [2](p220).

2.1.6 Magnetopneumography

A weak remanent field can be measured from lungs that has been exposed to ferri/ferromagnetic particles. These include metal dusts in welding and foundry fumes, grinding dust, asbestos particles, coal mine dust etc. Some of the particles can stay in the lungs for longer than 40 years while others are absorbed after a few week. Using the remanent moment of know particles the amount of particles in the lung or for a known amount of particles some lung parameters can be determined.

This is done by magnetizing the particles in a magnetic field and measuring the remanent magnetic field as a function of time with a SQUID magnetometer. Since the field are rather large high temperature SQUIDs can be used.

2.1.7 Liver iron suspectometry [1]

SQUIDs are also being used for none invasively determining the amount of iron stored in the liver through a technique called suspectometry. A homogeneous magnetic field is applied to the liver area and the magnetic suspectability is determined by measuring the disturbance in magnetic field over the area. From this measurement the iron concentration in the liver can be determined. Due to the type of measurement only excess concentration in liver iron can be measured.

2.2 Superconducting Magnets [3]

Because of the high current carrying capability of superconductors they are frequently used to generate high magnetic fields. Specifically in the field of MRI superconducting magnets has long been used. The advent of cyro free magnets enables low temperature superconductors to be used without the need of liquid helium by using low temperature cyrocoolers.

Using these high intensity magnets a new imaging technology has been developed based on the Hall effect. An ultrasound beam is used to create vibrations in the tissue sample, this is done in a strong magnetic field which causes opposite charges in the tissue to diverge and lead to a Hall voltage, this voltage is picked up by electrodes. It can also be done the other way around, using a pulsed current through the electrodes in a strong magnetic field to generate a acoustic wave that is picked up by an ultrasound detector.

The other application of these supermagnets is in magnetic surgery where a small magnetic tip is attached to a catheter or guidewire and a steered through the body by rapid adjustments to strong magnetic fields (5T). This enables the the surgeon to steer around very sensitive structures to the part that needs to be operated instead of taking the straight line approach. It is possible to measure the position of the tip with an accuracy of 1mm and a real time X-ray image in two dimension is used for the control. It is also used to guide magnetized pellets in for instance the brain to deliver drugs and other therapies to directly into deep brain tissues.[4]

References

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