Department of Medical Physics & Biomedical Engineering

MPHY0001: Introduction to Medical Imaging
Magnetic Resonance Imaging

3. MRI instrumentation

MRI scanner has four main components:

- magnet
- three gradient coils
- RF coil
- electronic computer system.

3.1 MRI magnet

Almost all clinical magnets are superconducting, operating with fields of 1.5T or higher (3T is typical).

From section 1.3:

$$\frac{n(spin\,up)}{n(spin\,down)} = \exp\left(\frac{\gamma hB}{2\pi kT}\right) \approx 1 + \frac{\gamma hB}{2\pi kT}$$

Thus available signal is proportional to B, so higher B means better SNR, higher spatial resolution, and faster scans.

Magnets must:

a) produce highly homogeneous fields so T2* is long enough to be measurable;

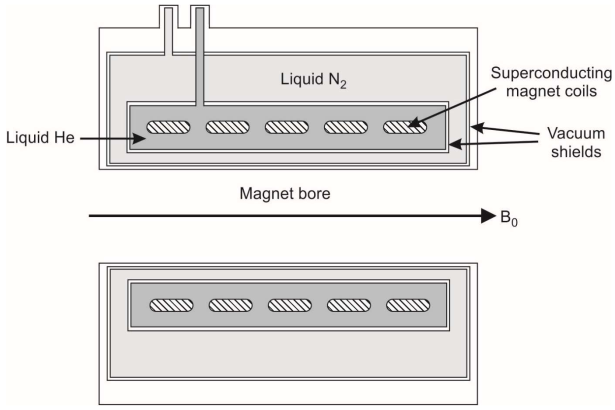
b) stable enough so that B_0 does not vary significantly during scan.

Field strength B in centre of simple solenoid consisting of N turns of wire carrying a current I is given by:

$$B = \frac{\mu_0 NI}{\sqrt{L^2 + 4R^2}}$$

where: μ_0 = permeability of free space (1.257×10^{-6} T/mA),
L = length of the solenoid
R = radius.

A strong B requires a large N and high I. Resistance of such coil would produce significant heating which will cause thermal expansion and temporal instability.



Magnets contain superconducting coils (e.g. a niobium-titanium alloy) with zero resistance at liquid He temp (4.2K). Several (up to ten) solenoids are used to improve homogeneity. Each contained within liquid He, and surrounded by vacuum shields, which are cooled by liquid N.

(Cheap) liquid N is topped up weekly, while (expensive) liquid He is replenished annually. Current of a few 100A is injected into coils, which then flows indefinitely.

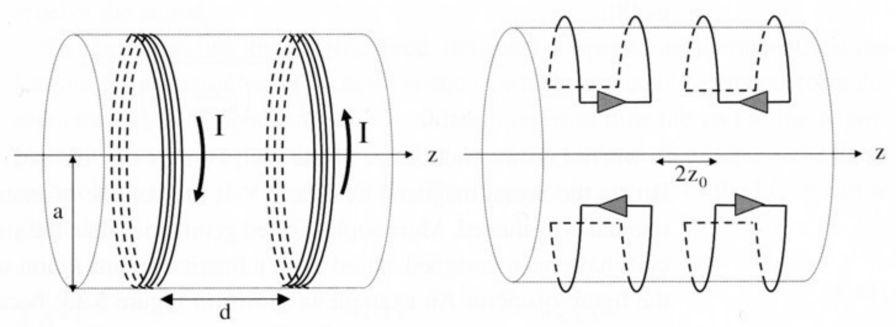
Inside magnet bore is set of resistive coils through which current is passed to adjust, or "shim" the magnetic field B_0 to ensure homogeneity.

► Coils produce fields varying with x, y, z, x^2, y^2, z^2, and higher orders.

► Need to correct for effects of placing object (containing diamagnetic and paramagnetic materials) into magnet.


SIEMENS
MAGNETOM

3.2 Gradient coils

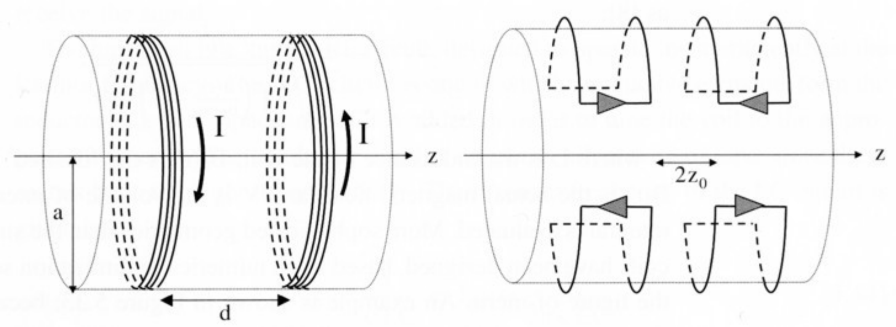


Gradient fields in *x*, *y*, and *z* directions are provided by resistive copper coils inside magnet.

By convention:

z-axis = main field direction
y-axis = anterior/posterior direction
x-axis = left/right direction of a patient lying in the magnet.

3.2 Gradient coils



The *z*-gradient is generated by pair of cylindrical coils, whereas *x*- and *y*-gradients are generated by "saddle" coils wrapped around inner cylindrical surface of magnet.

Each coil carries current of up to several 100A, and can be switched on/off in < 1 ms. The current in coils flows in opposite directions so net effect at midpoint is neutral. Interaction between fields produces force on gradient coil, causing vibration (producing loud sound).

3.3 Radiofrequency (RF) coil

These coils serve two purposes:

a) Generate RF pulses (**B1** fields) which cause net magnetisation **M** to move;
b) Detect the precessing **M**, which induces current to flow in the coil.

The frequencies of pulse and resulting signal are the same, so a single coil “tuned” to this (Larmor) frequency is used. The coil is part of tuned RF circuit containing inductance (L) and capacitance (C) so that it produces/detects signals at a frequency given by:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

In practice, coils consist of one or two turns of copper or silver wire or tape. To maximise signal, they are placed <u>close</u> to part of the body being scanned. For head imaging, coil often consists of solenoid into which head is inserted.