Theoretical Lecture: Superconducting Magnet

1. Superconducting Magnet

Superconducting magnet (Figure1) is made by a direct current solenoid (niobium-titanium alloy in copper matrix).

- It is basically an air core cylinder of 1 m diameter and 2–3 m depth.
- It is cooled by a cryogen, liquid helium at 4 K (–269°C).
- It has negligible resistance, and large current can be used without overheating.
- It provides horizontal fields up to 3.0 T with high field uniformity.
- To shut down, the stored electromagnetic energy in the coil has to be removed carefully, to avoid quench. The liquid helium is kept in a cryostat, replenished periodically.

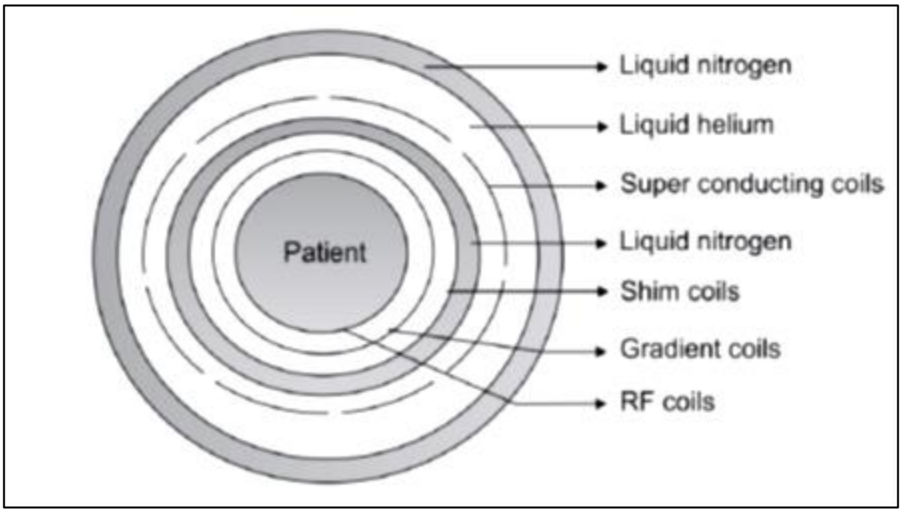


Figure 1: Cross-sectional view of MR gantry design using superconductive magnet.

The advantages of superconducting magnet includes:

- High field strength.
- High field homogeneity.
- Low power consumption.
- Fast scanning.

The disadvantages of superconducting magnet includes:

- High initial capital and sitting cost, and cryogen cost.
- Difficulty in turning off the field.
- Extensive fringe field.
- Uncontrolled quenching due to boiling of helium.
- It is large in size, Weighs about 6 ton.
- Claustrophobia to patients.
- It takes hours to cool and current build up. Current flows, even with no power, but consume cryogen liquid.

Magnet Design:

There are a number of different types of magnet design, with different geometries that relate directly to the intrinsic orientation of the magnetic field. Some current designs are shown in figure2.

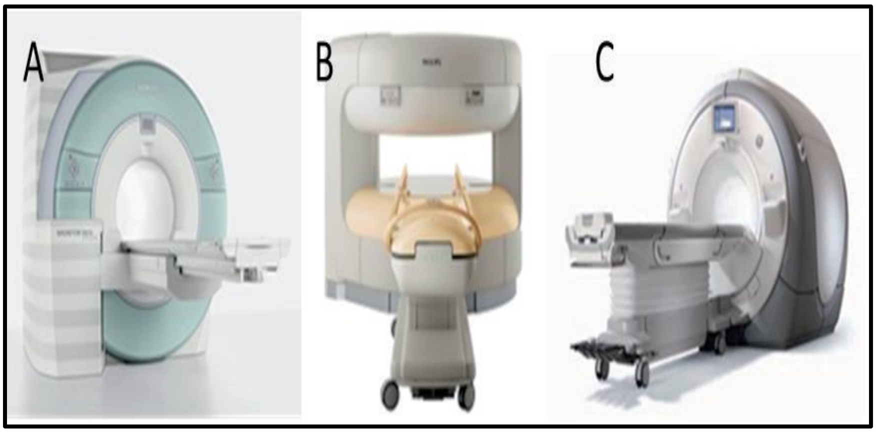
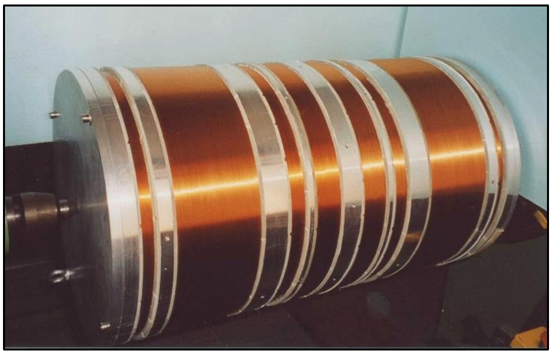


Figure 2: Different superconducting magnets: (a) Siemens 3 T Vario system; (b) Philips 1 T Panorama system; (c) General Electric 1.5 T Discovery MR450 system.

The most common design:

- Using superconducting cable.
- A single continuous solenoidal winding will only produce a completely homogenous central field if infinite in length.
- For coils truncated to the 2-3 meter range, a single solenoid would not provide a sufficiently uniform field for MR imaging.
- The homogeneity problem is solved by breaking up the main coil into 6-10 separate windings with gaps in between as shown below.

- This configuration maintains symmetry of the field along the *z*-axis (**B_o** direction) see figure 3.
- minimizes fringe fields
- Typically, in modern magnets, the liquid helium is surrounded by a helium vapour barrier, as well as a vacuum.



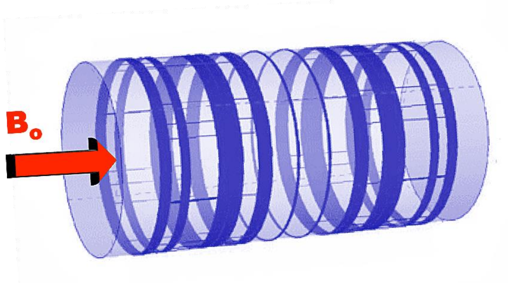


Figure 3: Solenoidal superconducting magnet under construction before being placed in cryostat.

Shimming (shim coils):

Once the magnet is sited in the imaging suite, its field will be further distorted by the presence of metal in pipes, wires, ducts, and structural beams in the immediate environment. Fringe fields of nearby scanners may also affect the field of the newly installed magnet .

Shimming is the process by which the main magnetic field (Bo) is made more homogenous. Shimming may be passive, active, or both.

In passive shimming small pieces of sheet metal or ferromagnetic pellets are affixed at various locations within the scanner bore.

Passive shimming (figure4) is a method of field correction involving the use of ferromagnetic materials, typically iron or steel, placed in a regular pattern at specific locations along the inner bore of the magnet.

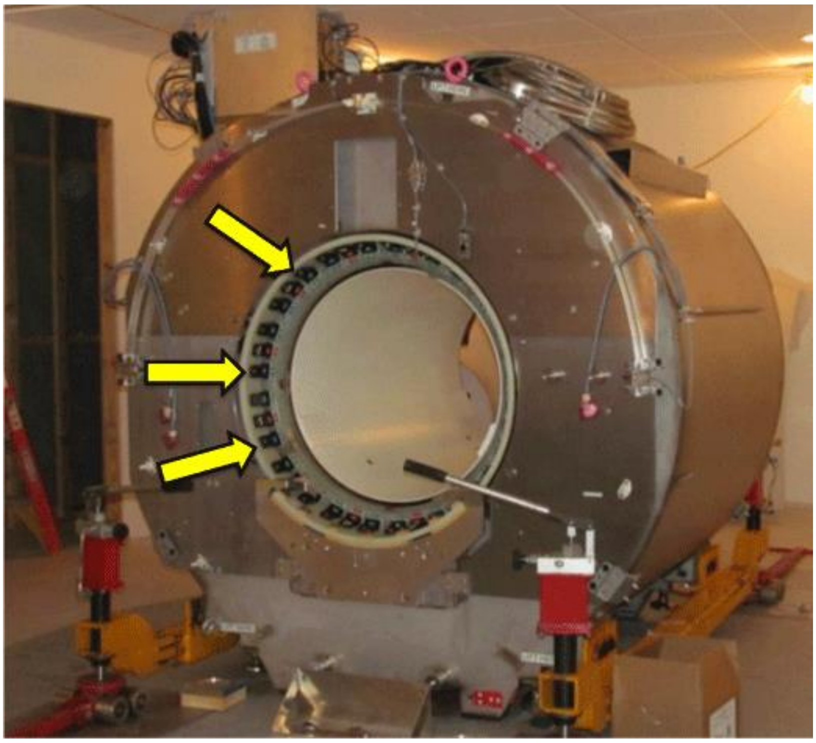


Figure 4: Passive shim trays (arrows) in a MR magnet during installation.

The most common design for cylindrical superconducting scanners involves the use of 12-24 trays arranged symmetrically around the circumference of the magnet. Each tray slides along the z-axis of the scanner and contains pockets into which a desired number of ferromagnetic shim elements can be placed.

In active shimming (figure5), currents are directed through specialized coils to generate a "corrective" magnetic field and improve homogeneity.

Active shim coils can be: 1) superconducting, located within the liquid helium-containing cryostat; or 2) resistive, mounted on the same support structure as the gradient coils within the room-temperature inner walls of the scanner. Both types of active shims require their own power supplies and are controlled by special circuitry. Some scanners use both types.

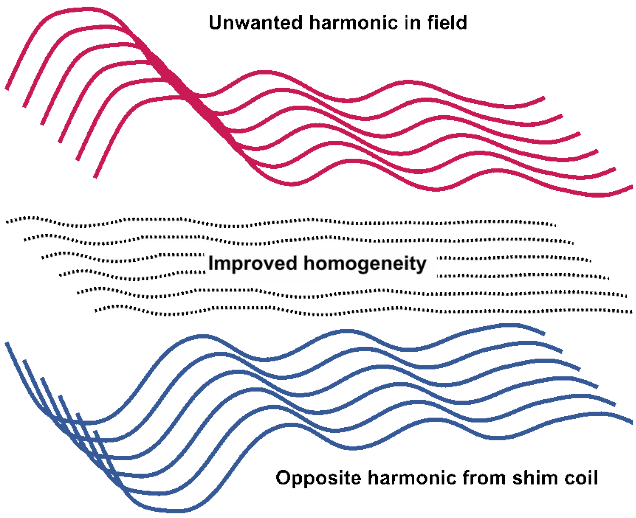


Figure 5: Theory underlying active shimming. Unwanted harmonics in the inhomogeneous field are cancelled/neutralized by a shim component of equal and opposite polarity.

Types of MRI scanners

MRI scanners are classified into (Open, with the field oriented perpendicular to head-feet direction of the patient or cylindrical/closed bore, with the field along the head-feet direction)

1- **Closed-bore scanner:** Over 90% of scanners worldwide are of the closed-bore cylindrical design and generate their fields by passing current through a solenoid kept at superconducting temperatures. configuration with superconducting solenoidal design. The coils are bathed in liquid helium allowing a stable, homogeneous field to be created, typically 1T and higher (figure 6).

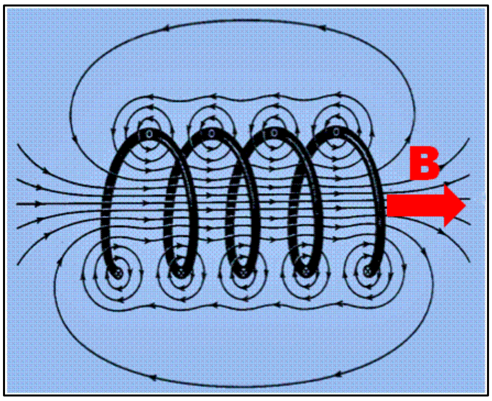


Figure 6. **Left:** superconducting scanner, **right:** Magnetic field created by solenoid

2. **Open bore scanners** contain an air gap between two magnetic poles. These may utilize permanent magnets or electromagnets. Permanent magnets in a C-shaped or horseshoe configuration. These operate at field strengths typically ranging from 0.064T to 1.0T (figure 7).

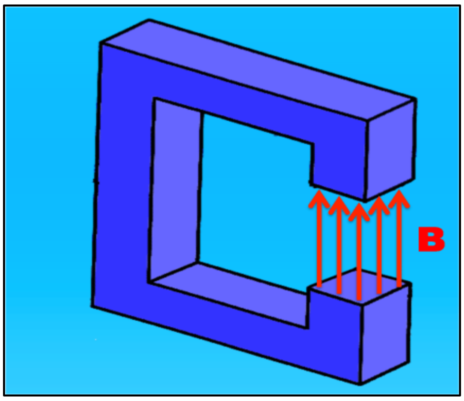


Figure 7. **Left:** permanent magnet scanner, **right:** c-shaped permanent magnet

3. **Dipolar electromagnet** configuration with coils on either side of the patient. These coils can be superconductive or resistive and range from 0.5T to 1.2T (figure 8).

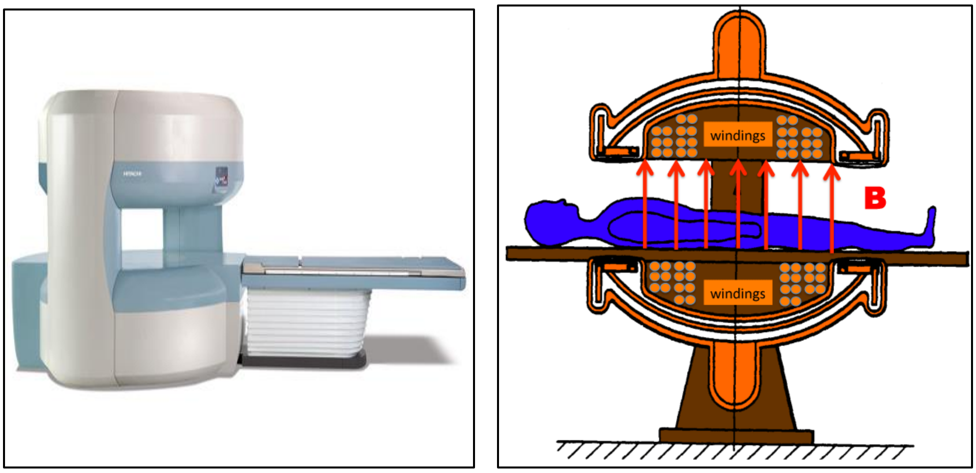


Figure 8. **Left:** superconducting scanner, **right:** dipolar electromagnet design.

Questions:

1. What is the simplest design of magnet?
2. Draw a cross section of MR gantry design using superconductive magnet using?
3. What are the limitations of superconductive magnet?
4. What is the work of shim coil?
5. list the types of shim coils?