

Theoretical Lecture: Superconducting Magnet

1. Superconducting Magnet

A superconducting magnet (Figure1) is made by a direct current solenoid (niobium-titanium alloy in the 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 ($-269\text{ }^{\circ}\text{C}$). It has negligible resistance, and a 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 and reload periodically.

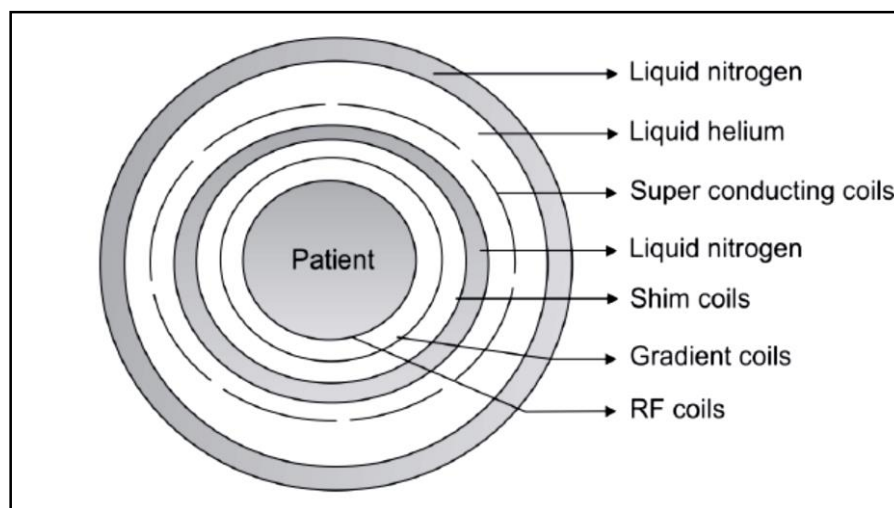


Figure 1: Cross-sectional view of MRI gantry design using a superconductive magnet.

The advantages of a superconducting magnet include:

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

The disadvantages of superconducting magnet include:

- ✚ 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 tons.
- ✚ Claustrophobia to patients.
- ✚ It takes hours to cool and current build-up. Current flows, even with no power, consume cryogen liquid.

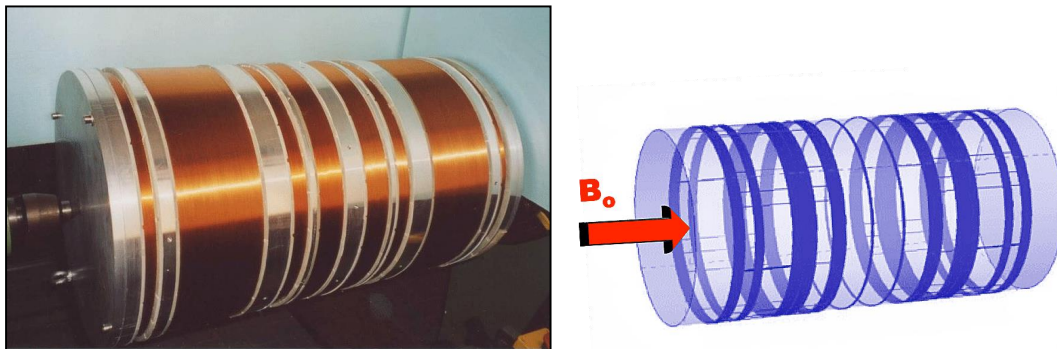


Figure 2: Solenoidal superconducting magnet under construction before being placed in cryostat.

Shimming (shim coils):

Shimming is the process by which the main magnetic field (B_0) is made more homogenous. Shimming may be passive, active, or both.

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

Passive shimming (figure 3) is a method of field correction involving the use of ferromagnetic materials, typically iron, placed in a regular pattern at specific locations along the inner bore of the magnet.



In *active shimming* (figure4), 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.

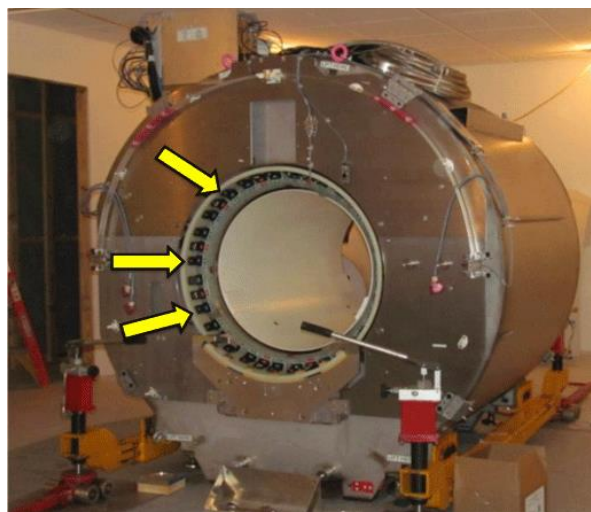


Figure 3: Passive shim trays (arrows) in a MRI magnet during installation.

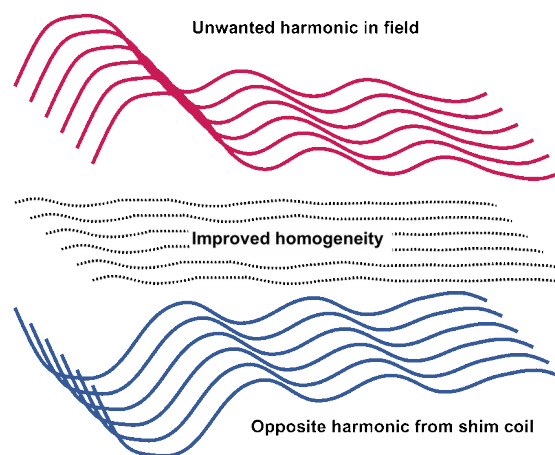


Figure 4: Theory underlying active shimming. Unwanted harmonics in the inhomogeneous field are canceled/neutralized by a shim component of equal and opposite polarity.

Types of MRI scanners

MRI scanners are classified into:

Open scanner with the field oriented perpendicular to head-feet direction of the patient

Closed scanner (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 a current through a solenoid kept at superconducting temperatures. The coils are immersed in liquid helium allowing a stable, homogeneous field to be created, typically 1 T and higher (figure 5).

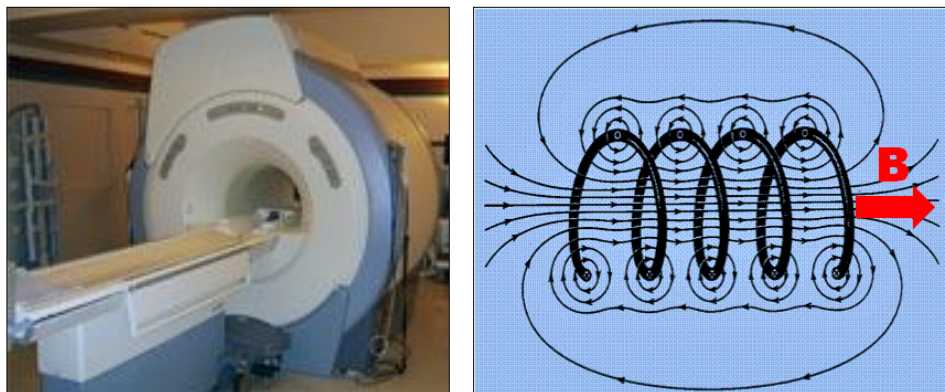


Figure 5. **Left:** superconducting scanner, **right:** Magnetic field created by solenoid

- 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 0.064 T to 1.0 T (figure 6).

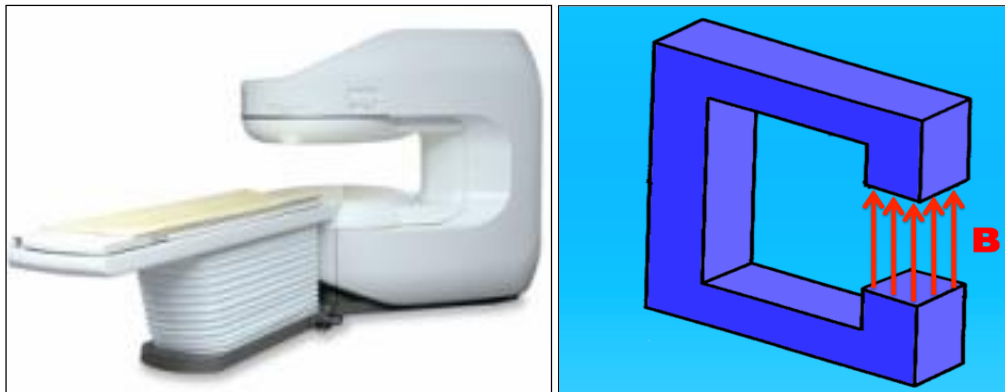


Figure 6. **Left:** permanent magnet scanner, **right:** c-shaped permanent magnet

Questions

- 1- Define the superconducting magnet and explain its structure.
- 2- What are the advantages and disadvantages of superconducting magnets?
- 3- State the properties of a superconducting magnet.
- 4- Define the shimming and explain its various types.
- 5- What are the types of MRI scanners?