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°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 replenished periodically.

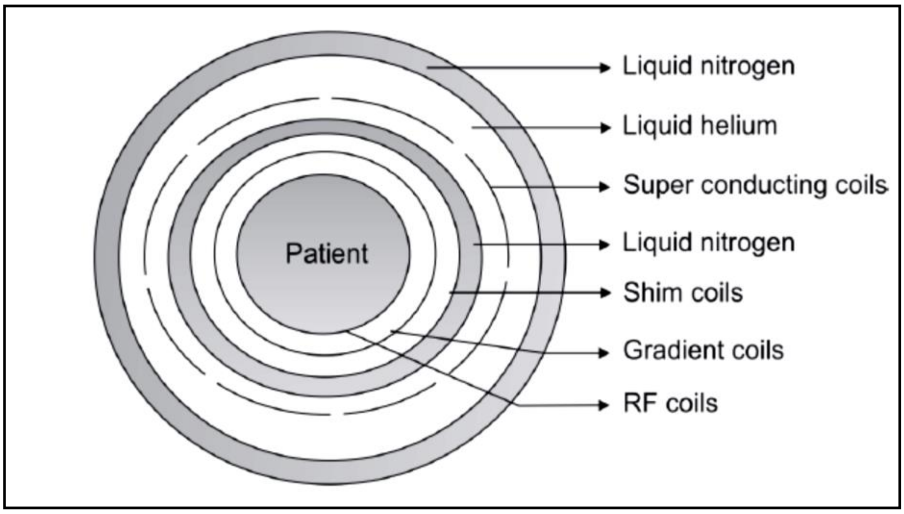


Figure 1: Cross-sectional view of MRI gantry design using a superconductive magnet.

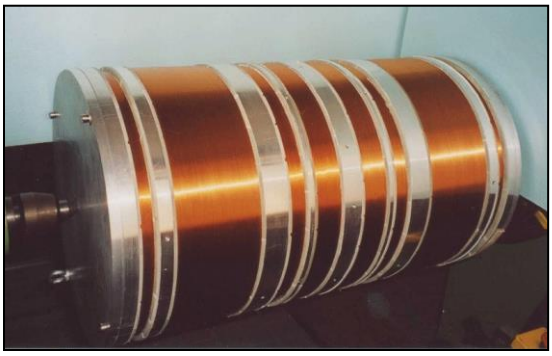
The advantages of a superconducting magnet include:

- 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.



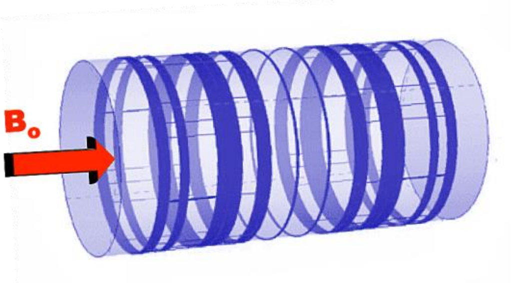


Figure 3: Solenoidal superconducting magnet under construction before being placed in cryostat.

Shimming (shim coils):

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 (figure 4) 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.

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.

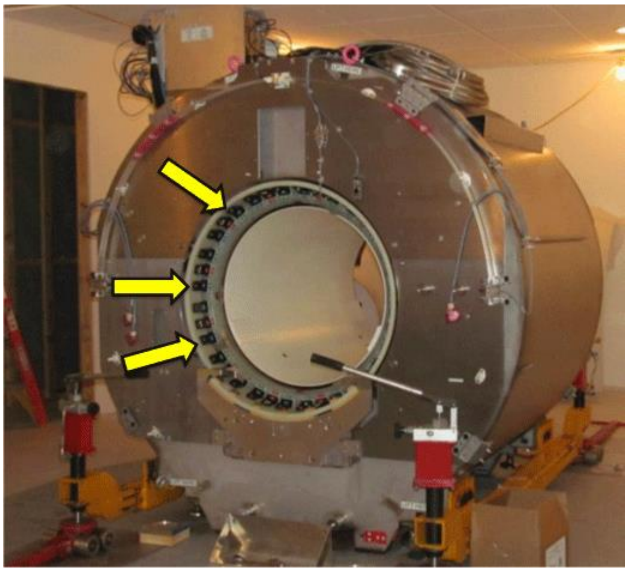


Figure 4: Passive shim trays (arrows) in a MR magnet during installation.

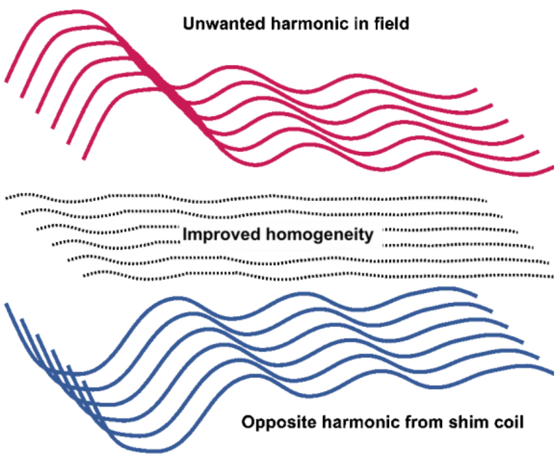


Figure 5: Theory underlying active shimming. Unwanted harmonics in the inhomogeneous field are canceled/neutralized by a shim component of equal and opposite polarity.

Types of MRI scanners

MRI scanners are classified into (Open, 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 a 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).

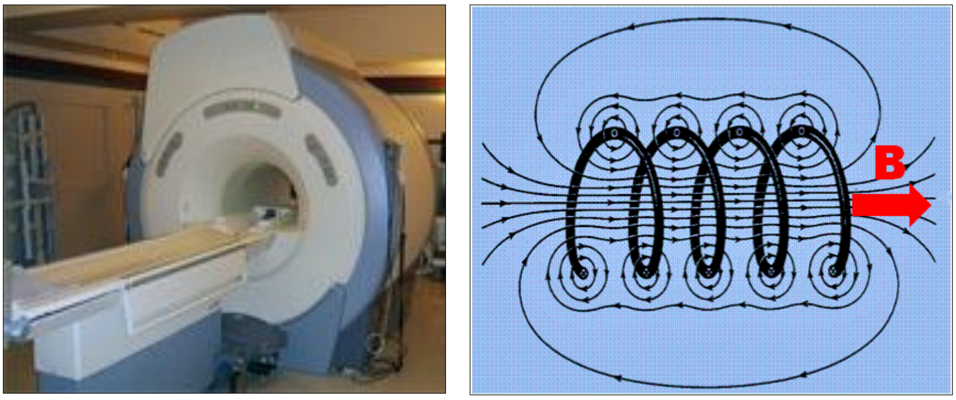


Figure 6. **Left:** superconducting scanner, **right:** Magnetic field created by solenoid

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).

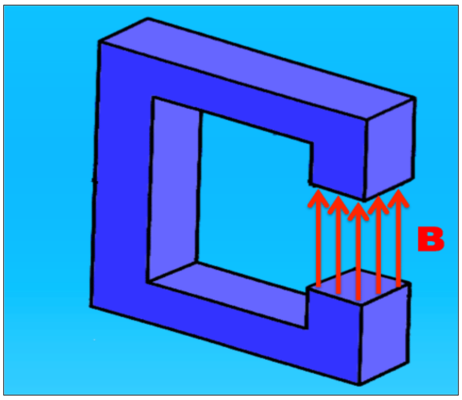


Figure 7. **Left:** permanent magnet scanner, **right:** c-shaped permanent magnet