MR Instrumentation

Magnets

Class I
MRI Instrumentation

• In this class we are going to introduce the basic components of a MRI Scanner.
• We will also discuss its operating principles and maintenance.
Each MR system has the following basic components:

- Magnet
- Patient table
- Shim coils
- Three sets of gradient coils
- Body RF coil
- Surface coils
- Host computer
- Pulse sequence controller
- Image processor
- Main console
- Image storage
- Various power units
Magnetism

Magnetic field lines will be present in all types of magnet:

a) Permanent magnet
b) Cylindrical coil
c) Iron-core electromagnet
d) Straight current-carrying wire
e) Circular current-carrying loop.
In MRI number of magnetic fields are used to generate an image:

• The main magnetic field or static magnetic field. This is known as the primary field $B_0$
• The radio frequency field or RF field this is known as secondary magnetic field or $B_1$
• The time varying magnetic field (TVMF) produce by the gradients coils
Primary Magnet

• The primary magnet, or external magnetic field, or main magnetic field, or static magnetic, or Bo, is the magnetic field used to magnetize the patient tissues.
Primary or Static Magnetic Field

- Ultra high field (4.0 to 8.0 T)
- High field (1.5 to 3.0 T)
- Mid field (0.5 to 1.4 T)
- Low field (0.2 to 0.4 T)
- Ultra low (<0.2 T)
There are three different types of primary magnets.

- Permanent magnets
- Electromagnets
  - Resistive
  - Superconductive
Permanent magnets

- Since ferromagnetic substances retain their magnetism after being exposed to a magnetic field, these substances are used in production of permanent magnets.
Permanent magnets

- Permanent magnets are made of materials such as magnetized ceramics or ferromagnetic plates, iron, cobalt, and nickel.
- They are capable of producing magnetic field up to about 0.3 T.
- They are usually horizontal magnets.
Permanent Magnets

The principal characteristics of the permanent magnet are:

• Ferrous material
• Always on
• No power requires
• Low field
• Usually vertical
• Small fringe field
Permanent Magnets

**Advantages**
- Are much less expensive than other magnets
- Cost virtually nothing to operate.
- Table moves in two directions
- Small fringe Field
- Less SAR to the patient
Permanent Magnets

- Disadvantages
  - Low magnetic field strengths
  - Relatively no uniform fields (inhomogeneous)
  - Low SNR
  - Very heavy (around 20 tons)
<table>
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<th>Scanner Model</th>
<th>Magnet Strength (Tesla)</th>
<th>Approx. Weight (lbs.)</th>
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Resistive magnets operate using the physical properties linking electricity and magnetism.

Remember that a moving electric charge generates a magnetic force.

This is also true for an electric current running through a wire loop (a magnetic field can be detected around the wire).
Electro Magnets

• If current is passed through two parallel straight wires in the same direction, contribution to the resultant magnetic field is additive.
**Electromagnets**

There are several factors that can alter the strength of an electromagnet:

- Number of loops in the coil
- Current passing through the loop
- Diameter of the loop
- Spacing of the loop
Number of loops in the coil

1T

.5T

550 Volts

550 Volts
Current passing through the loop

1T
550 Volts

.5T
225 Volts
Diameter of the loop

1T

2T

550 Volts

550 Volts
Spacing of the loop

1T

550 Volts

.5T

550 Volts
Electro Magnets

- Resistive magnets used in MRI consist of several large coils arranged in a configuration that provides the most uniform field possible.
- Once the coils design is set up the magnetic field strength depends on the current that passes through its coil of wire.
Electro Magnets (Resistive)

• The disadvantage of this type of magnet is that a great deal of power (too much for practical purposes) is required to achieve high magnetic field strengths.

• These type of magnets need to be cooled with water (water chiller).

• They are horizontal magnets
MR Chiller Systems

• To help to maintain the MR system cool, a chiller is connected to the system.
• The chiller system has a close circuit where a liquid (Glycol) circulates through it.
• The glycol pick up heat when it passes through the MRI unit and is cool down when it passes through the chiller.
Electro Magnets (Resistive)

Advantages
• Can be shut off
• Small fringe field

Disadvantages
Active current
High power consumption
Superconductive Magnets

- Superconducting magnets solve the problem of resistance by using superconducting material to carry electricity current.
In superconductive magnets the wire used to produce the primary magnetic field are made up superconductive materials (an alloy of niobium and titanium).
Superconductivity

• After been cooled to extremely low temperatures:

  ➢ 4⁰ Kelvin
  ➢ -452⁰ Fahrenheit
  ➢ -270⁰ Celcius

• Superconductive materials have virtually no resistance to an electric current.
Superconductive magnets

- Superconducting magnets are cooled by cryogen, liquid helium.
- The magnet itself is housed in a large, insulated container called *Dewar*, which functions like a thermos bottle.
- The typical volume of liquid Helium in an MRI magnet is 1700 liters.
Superconductive Magnets

• Initially, current is passed through the loop of wire to create the magnetic field or bring the field up to strength (ramping up). The wires are supercooled with substances called cryogens (usually liquid helium) to eliminate resistance.
Superconductive Magnets

- Liquid helium and nitrogen are subject to evaporation and must be replaced periodically.

- This represents a significant cost, since cryogens are very expensive and their handling requires special training.

- Also, superconducting magnets do not need continuous supply of electric current to function.
Cold-Head

• Ambient heat causes the helium to slowly boil off. Such magnets, therefore, require regular refill with liquid helium.

• Generally a cryocooler, also known as a cold-head, is used to recondense some helium vapor back into the liquid helium bath.

• The constant knocking sound hear in a MRI suite even when there is not scanning going on, is the result of the cold-head working.
Superconductive Magnets

• Advantages:
  • High field strength
  • High field homogeneity
  • Low power consumption
  • High SNR
  • Faster scanning
  • They are horizontal

8T Magnet
Superconductive Magnets

Disadvantages:

- High capital cost
- High SAR Levels
- More Chemical shift artifacts
- More Motion artifacts
- Loud acoustic noise
- Lack of research
Stored Energy: 338 MJ
Inductance: 308 H
Current: 1483 A
Overall Length: 5.2 m
Overall diameter: 5 m
Weight: 132 t

Magnet main parameters:
- B0 / Aperture: 11.75 T / 900 mm
- Field stability: 0.05 ppm/h
- Homogeneity: < 0.5 ppm on 22 cm DSV
- 170 wetted double pancakes for the main coil
- 2 shielding coils to reduce the fringe field
- NbTi conductor @ 1.8 K

Local membrane: 405 MPa
General membrane: 180 MPa
Membrane + Bonding: 412 MPa
MRI Unit Main Parts

- Gantry
- Gantry Board
- Patient Table
Magnet Gantry
Gantry Board
Detachable Table
Dedicated Breast Unit Table
OPEN MRI vs CLOSED MRI

Wide Bore MRI
Closed Bore MRI
Open MRI
Hybrid Magnets

• In an attempt to get the best of both worlds, some manufactures have combined superconducting with permanent systems to create high field open magnets.
Niche Magnets

• They are ultra low imaging systems orthopedic applications.
• Some of this operate at field as low as 0.01 T.
Stand up Magnets

• Another type of Magnets are the standing up which will provide additional information to the physicians because studies are performing weigh bearing.

• This magnets are less claustrophobic for the patients.

• These type of magnets are usually permanents.
Interventional MR
Interventional Room with MRI
Interventional Room with MRI
PET-MR
PET-MR

• Positron Emission Tomography is a Hybrid technique that combines MRI and Nuclear Medicine.
• A radioactive material fluorodeoxyglucose (FDG) is injected in the patient and detected by the nuclear camera, then MR images are obtained and superimposed with the nuclear ones.
PET-MR
Fringe Field

• The static magnetic field has no respect for the confines of conventional wall, floors or ceilings.
• The stray magnetic field outside the bore of the magnet is known as the fringe field.
• All magnets have a fringe field to some extent.
Main Magnetic Field

• As the magnetic field increases the fringe field also increases. The strongest magnetic field is at the entrance of the board.
These fringe fields must therefore be taken into account when silting a magnet, so that they do not extend into areas where potentially contraindicated patients, monitoring devices and other mechanical and magnetically activated devices are present.
Fringe Field

• This line specifies the perimeter around a MR scanner within which the static magnetic fields are higher than five gauss.
• Five gauss and below are considered 'safe' levels of static magnetic field exposure for the general public.
Fringe Field

• The magnetic field strength will increase as we get closer to the magnet.
• Initially most of the magnets had a very extensive fringe fields.
• As technology had advanced the fringe field has been confided closer to the magnet.
The main purposes of reducing the fringe field are:

- Ferromagnetic objects are less prone to being attracted to the magnet
- Ancillary electronic equipment, credit cards and computer disks can be brought closer to the magnet
- The MRI safety limit for pacemaker wearers (the 5 gauss line = 0.5 mT) is reduced from, typically, 10 m to 2 m from the magnet
Most of the electronic equipment should operate at the 10 G line to avoid the main magnetic field to interfere with the equipment functionality.
Magnetic Shielding

- Fringe field can be compensated by the use of magnetic field shielding.

- MR systems can be shielded by two processes which are:
  - Passive shielding
  - Active shielding
Fringe Field
Passive shielding can be accomplished by:

- Surrounding the magnet with steel plates
- Lining the wall of the MR scan room with Steel or Iron plates.
Passive Shielding

Surrounding the magnet

Lining the room
Passive Shielding

• Surrounding the magnet with steel plates is an undesirable method for two main reasons:

• Magnets become extremely heavy (up to 40 tonnes)

• Very expensive
Passive Shielding

• Lining the magnet room is the second method of passive shielding. This is less expensive, and will confide the fringe field inside the room.

• The major disadvantage of this method is that as soon as the magnet doors room opens the magnetic field will be there.
Active Shielding

• The principle of active shielding is to pass a current in a superconductive coil located at each end of the main magnet inside the cryostat, this current will go in the opposite direction of the one in the main magnetic field.

• This will create a magnetic field in the opposite direction of the main magnetic field.
Active Shielding

• Magnetic shielding through the use of secondary shielding coils designed to produce a magnetic field that cancels the field from primary coils in regions where it is not desired.

• These coils may be inside the magnet cryostat.
Active Shielding
Shimming

- In MRI ppm is used to measure the homogeneity of the magnetic field.
- More homogenous magnetic field better quality images.
Shimming

- MRI superconductive magnets have a field homogeneity of approximately 1000 parts per millions (ppm) when delivery from factory.
- Imaging requires homogeneity of approximately 4 ppm across the imaging volume
- Spectroscopy procedures require better than 1 ppm.
Shimming

• ppm is a way of expressing very dilute concentrations of substances.

• Just as per cent (%) means out of a hundred, so parts per million or ppm means out of a million. Usually describes the concentration of something in water or soil.

• One ppm is equivalent to 1 milligram of something per liter of water (mg/l) or 1 milligram of something per kilogram soil (mg/kg).
Magnets

- In any type of magnet the magnetic isocentre is the center part of the magnetic field.
Shimming

- The isocentre is the most homogeneous area of the magnet, about the size of a basketball.
Shimming

• To correct the magnetic field inhomogeneities either a piece of metal or other loops of current carrying wire are placed around the bore.
• This process is called *shimming*. 
Shimming

• There are two different methods of shimming a magnet:
  • Passive shimming
  • Active shimming

Both active and passive shimming produce magnetic field evenness or homogeneity.
Passive Shimming

• Passive shimming is performed by adding pieces of metal to the magnet to even the magnetic field; this process is done during the installation of the magnet.
Active shimming is performed with loops of current carrying wires (shim coils) and can be used to shim the system for each patient or even each sequence of the protocol.
Active Shimming
Control Room
Computer Room
Computer Room

• Gradient Amplifiers Cabinets
• RF Amplifiers Cabinets