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Study on Design Development of Magnetic Resonance Imaging (MRI) System

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ABSTRACT

The Purpose of this Article to introduce Magnetic Resonance Imaging (MRI) System and study the function of major hardware of MRI like Gradient coil to varying Gradient coil field strength (Gradient strength) linearly across the imaging volume for spatially encode the positions of protons. Methods of Gradient Coil design are classified into Coils with Discrete Windings and Coils with Distributed Windings. Magnetic Resonance Imaging (MRI) System requires the use of gradient coils that generate magnetic fields, which vary linearly with position over the imaging volume. Gradient coils for MRI must therefore have high current efficiency, fast switching with low inductance, linearity of gradient over a large volume, power saving, and EMI/EMC harden.

Keywords : Gradient Coil, Magnetic Resonance Imaging (MRI) System, Gradient coil field strength, Gradient strength, Gradient Discrete Windings, Gradient Distributed Windings

I. INTRODUCTION

Magnetic Resonance Imaging (MRI) system was invented in 1973, by Paul C. Lauterbur and Peter independently described the use of nuclear magnetic resonance to form an image. For this research work, Paul C. Lauterbur and Perter shared the Nobel Prize for Medicine in 2003. Magnetic Resonance Imaging (MRI) system is internal body diagnosis instrument which is used for internal anatomical images, sophisticated bio-information, detailed images of organs and soft tissues examination. Basically, a MRI system consists of following major hardware systems, which are:

1. Main Magnet
2. Radio Frequency Coil
3. Gradient coils
4. RF pulse transmitter
5. RF receiver
6. Data acquisition system
7. Power supplies, and cooling systems

II. Main Magnet

Magnet Type	Material	Field strength	Working Principle
Permanent Type	iron, nickel, cobalt and some rare earth alloys	0.064T ~ 0.3T	A permanent magnet consists of self magnetized material which would not loose its magnetic field.
Resistive Magnets Type	Loops of wire and air-core and iron-core.	up to 0.3 Tesla	Resistive magnets are electro a magnet which is consists with wire loops. The magnetic field is induced by a current, which runs through loops of wire. Resistive magnets have two types: air-core and iron-core. Resistive magnets generate a lot of heat so water cooling is required for this type of magnet type.
supercond ucting magnets	Loops of wire and coolant, like liquid helium for low loss	up to 12 Tesla	Mostly superconducting magnets are used in modern and high precision Magnetic Resonance Imaging (MRI). The magnetic field is induced by a current, which runs through loops of wire. The loop of wire is surrounded with a coolant, like liquid helium, for reduction of the electric resistance of the wire.

It is very important part of MRI System which is use for aligns the nuclear spins of hydrogen atoms in the human body. It is very high magnetizing superconducting coils, which can be induced stable high magnetic field for Magnetic Resonance Imaging procedure. High magnetize superconducting coils produces a homogeneous static magnetic field along the z Axis. The super conducting magnet is perfect for Magnetic Resonance Imaging (MRI) system with respect to other type magnets which is describe in table –I

III. Radio Frequency Coil

RF coil play a very important role in acquisition of high quality diagnostic MR images in MRI system .RF Coils consists of multi turn wire loops that can play both roles either generated magnetic field or Received change magnetic field due to induced electrical current in wire loops. According to functioning RF coils categorized in three types 1. Transceiver coil 2. Transmitting coil 3.Recieving coil .Quality factor (Q-factor) and Signal to noise ratio (SNR) are very important parameter for RF coils selection. As Per structure RF coils categorized in to three type's 1.Surface coils 2.Volume Coils 3.Array Coils. Generally for achieving High Signal to noise Ratio (SNR) we use some specific material coils as per table No.2

Coils type	Composite Materials	Cause
Silver RF coils	Silver	Silver have lower resistivity than copper.
Cryogenic RF coils	Liquid nitrogen	For enhancing the SNR reduce the temperature of Cryogenic RF coils
High temperature superconducting (HTS) RF coils	**yttrium barium copper oxide (YBCO)**	High temperature superconducting(HTS) material is applied to the RF coils to provide much lower coil resistance(almost zero) while the HTS RF coil achieves the superconducting status in the Critical low temperature.

Gradient coils

The Gradient coil is play pivotal role in MRI scanning. Gradient coils are multi turn loops of wire or ultra thin copper conductive metal sheets on a cylindrical shell applying to inside the bore of an MRI scanner. When electric current is applied through gradient coils a secondary magnetic field is generated. Generated gradient field slightly alter the main magnetic field in as expected pattern, due to the resonance frequency of protons to vary in as a function of position. It spatially encodes the positions of hydrogen nuclei by varying magnetic field intensity across the imaging volume. Three set of gradient coils X-Gradient, Y-Gradient and Z-Gradient are used in MRI scanning. Each gradient coil system is driven by an independent power amplifier and generates a gradient field.

S.No.	Gradient coil Type	Design configuration of gradient	Operation
1	X-Gradient Coil	Saddle (Golay) coil	Golay coil consists of 4 inner and 4 outer arcs on the surface of a cylinder connected by 8 straight wires running parallel to the z-axis. The electron flow along the inner arcs are mainly responsible for forming the required gradient, while the straight wires parallel to the z-axis serve as return pathways for current and do not contribute to the gradient field.
2	Y-Gradient Coil	Saddle (Golay) coil	
3	Z-Gradient Coil	Circular (Maxwell) coils	Z-gradient field is generated using two coils carrying current in opposite directions.

IV. RF pulse transmitter

The RF Pulse transmitter generates the RF power signal, which is applied to the RF coils and then transmitted to the patient's body. The RF power is generated as a series of discrete RF pulses. The RF signal is used to excite the protons in the imaging volume. The RF pulse transmitter consists of several components, such as power amplifiers and RF Pulse modulators, but for our purposes here we will

consider it as a unit that produces pulses of RF energy. The RF Pulse transmitter must be capable of generating high power RF outputs on the order of several thousand watts. Magnetic field strength is used to calculate required RF power. Required RF power for MRI scanning is proportional to the square of the Magnetic field strength. Therefore, a 1.5 T system might require about nine times more RF power applied to the patient than a 0.5 T system. Power monitoring circuit is play pivotal role in MRI Transmitter system. Power monitoring circuit is a safety feature in MRI scanner which is controlled excessive power being applied to the patient's body and it's protect the patients from SAR effect. Most of the RF energy is absorbed by the tissue and is converted to heat that has the potential of increasing the temperature within the body this phenomena is called SAR.

V. RF receiver

After a sequence of short wave RF pulses is transmitted to the patient's body, the resonating Body tissue will respond by reflecting an RF signal. Reflected signals are picked up by the RF coils and processed by the receiver. The reflected RF signals are converted into a digital form and transferred to the data acquisition system

VI. Data Acquisition System

Data acquisition is a data collection process; first step in data acquisition is the acquisition of the reflected RF signals from the patient's body. Repetitions of an imaging cycle are very important factor in data acquisition process. During each cycle, RF Pulse Transmitter a sequence of RF pulses is transmitted to the patient's body, the gradients coils system is activated, and reflected RF signals are collected. Unfortunately, one imaging cycle does not generate enough signal data to create an image then whole process is repeated. The time required to acquire images is determined by the duration of the imaging cycle, Repetition time (TR) and the number of cycles. The number of cycles used is directly related to image quality with detail information. A lot of cycles are produced best quality and detailed information images. The acquisition process is controlled by SCADA protocols.

VII. Power supplies, and cooling systems

Constant linear power supply is one of the important parts of MRI System. Power supply should have very linear and constant behavior because small fluctuation is not acceptable during scanning period. Cooling system plays pivotal role in MRI system. Two cryogen chambers based cooling system was used in superconducting scanners during1980's, one cryogen chamber a containing liquid helium and another one containing liquid nitrogen. The nitrogen was consumed weekly and the helium consumed monthly. During the 1990's only helium based systems were developed and in the time of 2000's refrigeration systems had become so sophisticated and efficient that liquid helium needed to be added only every 3-4 years. Zero boil off (ZBO) refrigeration systems have become standard over the last decade, allowing essentially unlimited normal operation without need for helium refill.

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