Design Study on High Frequency Magnets for Magnetic Hyperthermia Applications
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Introduction

Research objective
Discussion of the engineering feasibility of High frequency magnet systems for the magnetic hyperthermia cancer therapy.

Technical challenges and Feasible solutions
Diabolic breakdown in magnetic windings (should be less than 10 kV)
Reduction of the ampere-turns based on a iron core coil design
Skin effects and magnetic losses due to the high frequency operation
Use of Litz wires and the feasibility of cooling water magnets
Required capacity of high frequency power converter system
Compensation of the magnetic reactance using series capacitors

Thermal Design Analysis

Joule heat loss distribution of high frequency magnets

Thermal Properties vs. Current Density

Power Supply System

Voltage source type high frequency inverter

Design and Control

Inverter Voltage and Switching Current Switching Waveforms Loading current

Voltage Balancer

Schematic waveforms Current

GCSC: gate controlled series capacitor

Future works

Developing laboratory prototype for particles and medical investigations
Experimental verifications of the proposed design principles of the system

Conclusions

Results of the Design Study
One turn voltage of the winding can be reduced to 8.47 kV even when the magnet is excited up to 0.06 T of the peak magnetic field with 200 kHz of the operating frequency

Iron Core Magnet Design

Overview of the Hyperthermia Magnet System

Magnetic path length should be designed while taking into account the wavelength of electromagnetic waves propagated through the iron core.

Key Parameters

Peak magnetic field 0.06 T
Frequency 200 kHz
Operating time 300 s
Air gap 0.30 m (Treatment space)
Magnet outer diameter 0.40 m
Magnet inner diameter 0.20 m
Peak magnet current 200 A
Total number of turns 290 turns
(Max: 1.45 turns x 4 layers)
(Magnet 2 x 10 turns x 4 layers)
Self inductance 8.75 MΩ
Peak voltage 2.20 MV
1-turn peak voltage 8.67 kW

Magnet path 3.95 m

Basic data for the magnetic hyperthermia cancer therapy.

- MOSFET can be operated with soft switching, 200 kHz operation is feasible.

- Dielectric breakdown in magnetic windings (should be less than 10 kV)

- Reduction of the ampere-turns based on a iron core coil design

- Skin effects and magnetic losses due to the high frequency operation

- Use of Litz wires and the feasibility of cooling water magnets

- Required capacity of high frequency power converter system

- Compensation of the magnetic reactance using series capacitors

- Peak heat loss distribution of high frequency magnets

- Thermal Properties vs. Current Density

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- The winding loss is 3.3 kW, which result suggests that the magnet can be operated without a water cooling system. Even if the magnet cooled by water, conventional chillers are available.

- Single voltage source high frequency inverter using commercially available SiC-MOSFET (≤ 1.2 kV) can drive the magnet with balanced circuits.

Graphs and charts

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