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Optimum Design of Continuously Workable Transcranial Magnetic Stimulator

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I. Introduction

- ***Background***: As a new non-invasive biotechnology, transcranial magnetic stimulation is widely used in the treatment of various psychiatric diseases. The stimulation coil of traditional transcranial magnetic stimulator produces a lot of Joule heat during treatment procedures, which leads to low stimulation efficiency.

- ***Methods***: Finite element analysis and coil heating analysis are adopted to obtain the optimal geometric structure of the low power consumption stimulation coil. Then, the heat dissipation design for low power consumption stimulation coil is carried out based on the coupled magnetic-thermal multi-physical field analysis. To prove that the new transcranial magnetic stimulator can work continuously on the premise of ensuring the medical effect, a homogeneous isotropic real head model is employed to verify the method.

- ***Results***: In this paper, a new transcranial magnetic stimulator which can work continuously is proposed. Its stimulation coil is winded by hollow copper wire and the central hollow part is used to circulate low-temperature deionized water. The Joule heat generated during medical treatment is taken away by the cooling deionized water, so that the temperature of the stimulation coil can be maintained within a safe threshold.

II. Magnetic Stimulator System Description

- ***System Description***: When the magnetic stimulator works, the switch valve opens, the deionized cooling water runs into the hollow part of the copper wire at the water inlet end of the stimulation coil through a rubber hose, and the discharge circuit is connected to stimulation coil through the copper clips.

- ***Control***: The computer control module controls the switch state in discharge circuit and charging circuit so that to adjust the stimulation parameters (stimulation current amplitude, pulse width, etc.). The control model can also adjust the pressure difference between the inlet and outlet and the cooling water velocity by controlling the working state of the booster pump.

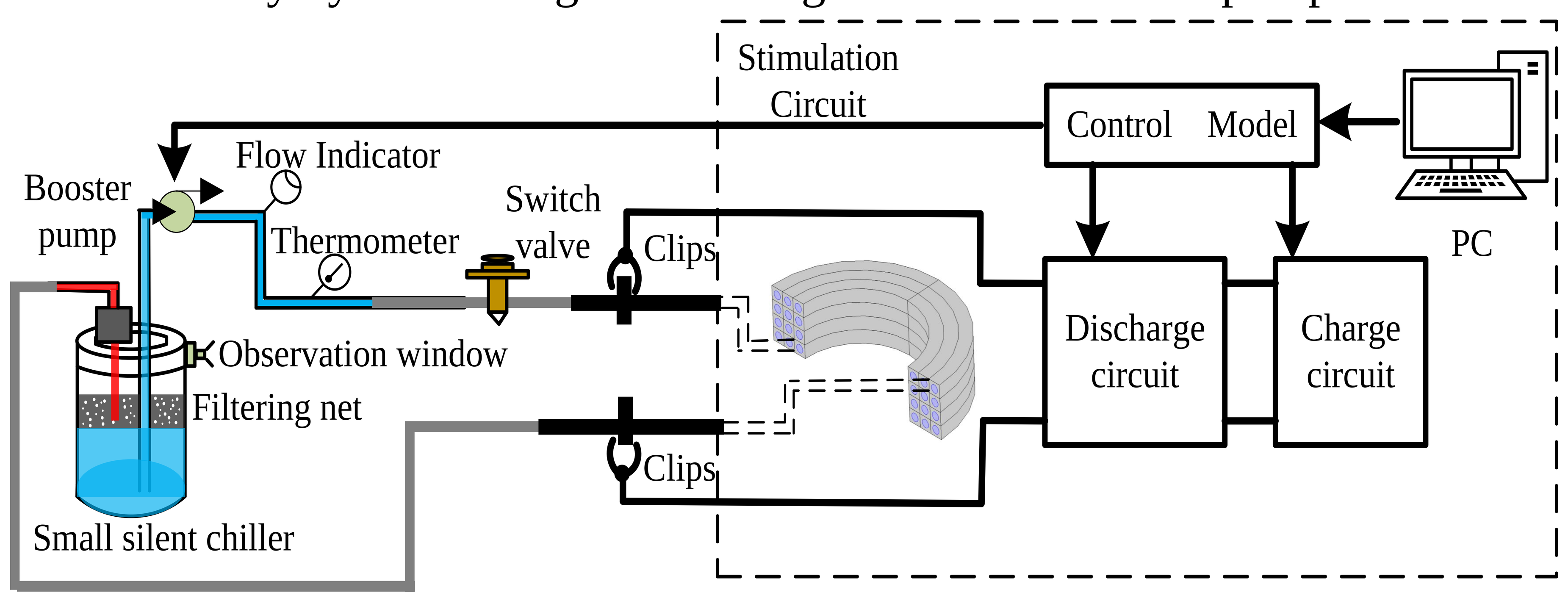

Fig. 4 System schematic diagram of the continuously workable transcranial magnetic stimulator

III. Geometric Structure of the Stimulus Coil Pair

- ***Placement***: The geometric structure of the stimulation coil not only in-fluences the power of Joule heat, but also is directly related to the spatial distributions of intracranial induced field. The stimulation coil is winded by copper wire with hollow center. The hollow part is used to circulate deionized cooling water, which forms a cooling water cycle and takes away the Joule heat generated by the stimulation coil. As shown in Fig1 and Fig.2 The blue transparent part in the figures represents cooling water.

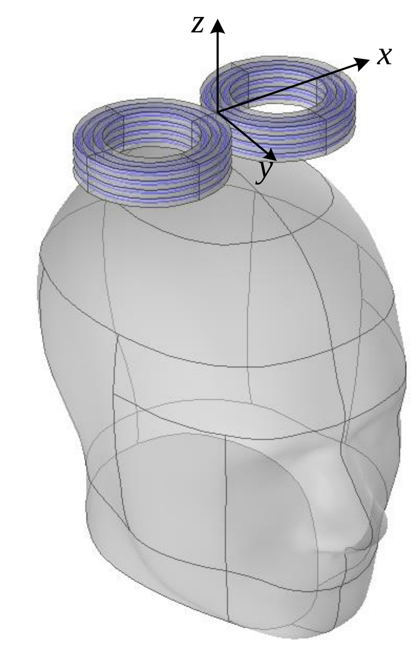

Fig 1 . Sectional view of single circular coil on the XZ plane

- ***Geometric Structure***: The stimulation coil used in this paper is traditional coil pair consisting of two identical circular coils which are placed above human head. The inner diameter is R_1 =25 mm and the wire arrangement of stimulation coils is described as $a \times b$, where a represents the number of turns parallel to X axis and b represents the number of layers parallel to Z axis. The width of copper wire is d=5mm and the radius of the hollow part is r =2mm.

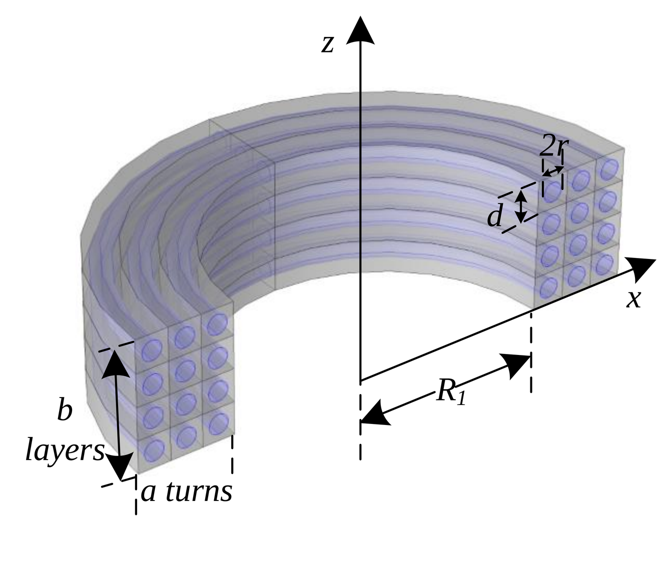

Fig 2. Placement of the stimulation FOE coil

IV. Design of Low Power Loss Coil

- ***Stimulation Intensity***
  Intracranial induced electrical field plays a neuroregulatory role by changing the membrane potential of neurons.
- ***Localization***
  To achieve accurate stimulation and avoid side effects caused by unnecessary stimulation of non-targeted tissue in the clinical application of TMS, intracranial focusing field should be limited to a smaller area.
- ***Intracranial Longitudinal Attenuation Ratio***
  For deep stimulation, the larger the ratio δ, the better the attenuated performance of the stimulation coil.

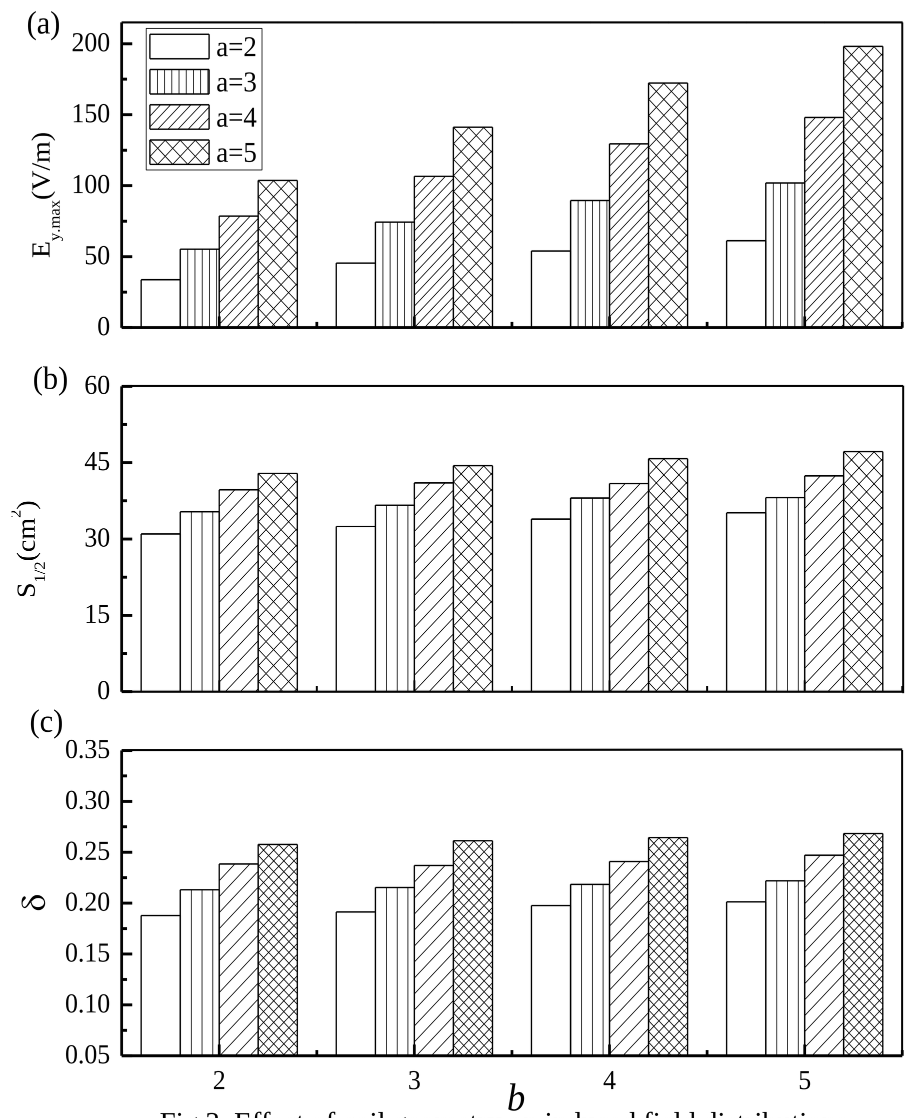

Fig 3. Effect of coil geometry on induced field distributions.

V. Heat dissipation design

- ***Cooling Water Inlet and Outlet***: Finite element method based on electromagnetic-thermal coupling analysis of multiple physical fields is adopted to design heat dissipation parameters for OP coil.
  In order to avoid scalp burns caused by coil overheating, the cold-end in-let is designed at the lower end of the coil center and the outlet is set at the upper and outer edges of the coil.

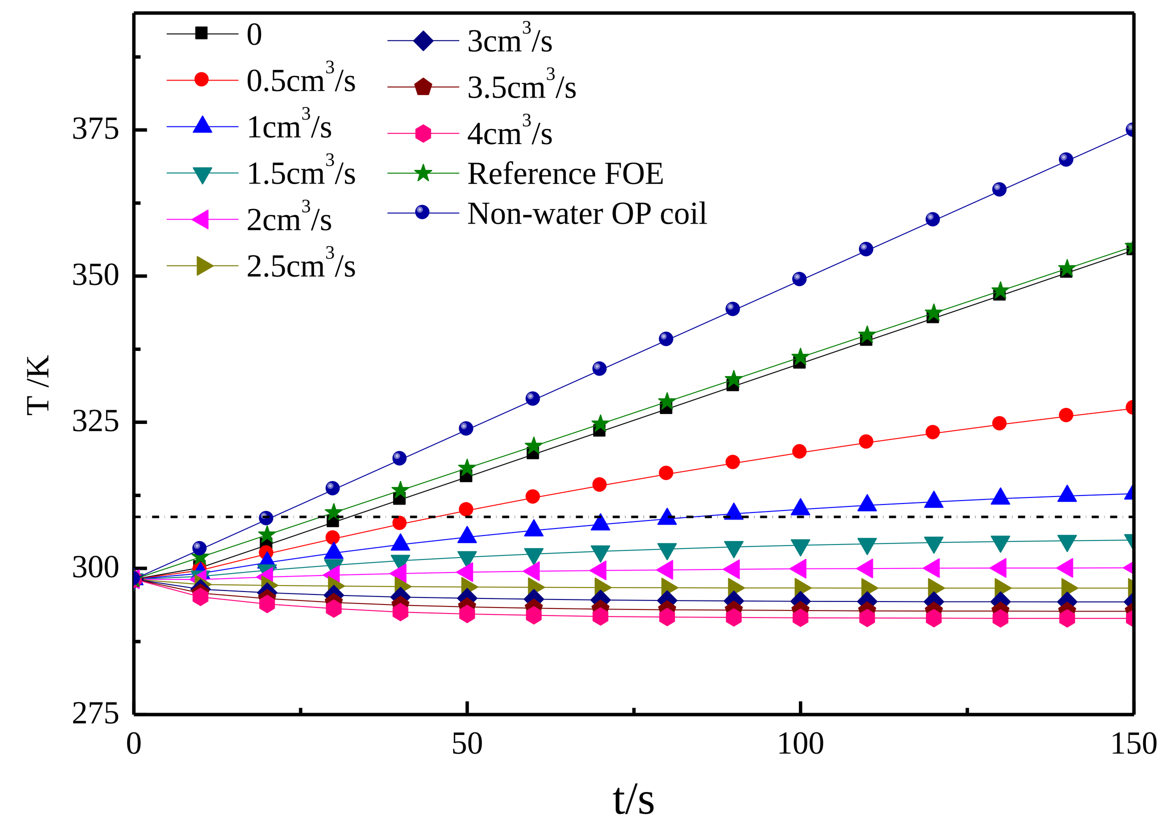

Fig.5. Temperature rise of the stimulation coil under different flow Q_W.

- ***Initial Water Temperature:*** Both the OP coil and the reference FOE coil are considered. The initial water temperature of the intake is set at 283.15K, and the initial temperature of the stimulation coil is 298.15K.

TABLE I
TEMPERATURE RISE AND PRESSURE CHANGE UNDER DIFFERENT FLOW RATES

Q_w cm^3/s	Coil T_{max} (K)	ΔP (Pa)	Deionized water T_{outlet} (K)
0	357.44	0	357.77
0.5	327.37	2570	326.98
1	312.80	6820	312.54
1.5	304.84	12100	304.27
2	300.10	17950	299.33
2.5	296.61	23760	296.15
3	294.24	29200	294.00
3.5	292.67	35180	292.44
4	291.45	45650	291.28

- ***Temperature Rise***
  Based on the repetitive frequency of the routine stimulation sequence for depression treatment, 3000 pulses were continuously applied. Temperature rise and pressure change under different flow QW is shown in Fig.5 and Table.1.

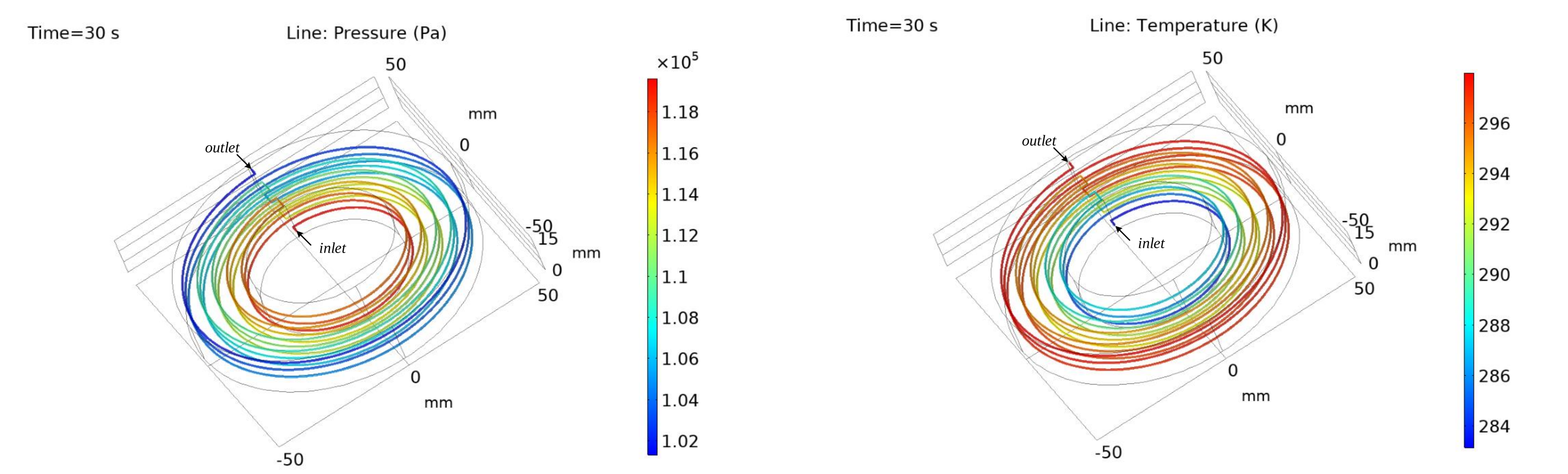

Fig. 6. Pressure and Temperature distribution on the cooling water channel at t=30s.

V. References

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