Double Pancake Exciting Coil with Back Yoke for Magnetic Field Generator to Medical Treatment

Regular Paper

Double Pancake Exciting Coils with Back Yoke for Magnetics Field Generator to Medical Treatment

Sotoshi YAMADA*1, Yoshio IKEHATA*1 and Ryouhei HAYASHI*1

Induction heating type hyperthermia treatment, as one of cancer therapies, needs both high magnetic fields (> 2 mT) and a few hundred kHz inside of a body. We proposed the double-pancake type coil system sandwiching human body. The proposed exciting coils can generate magnetic fields with both magnitude and frequency required to a medical treatment, and also can adjust the distance between two flat coils according to the bodily proportions of a patient. In order to make magnetic fields inside a body further increase, a back yoke as magnetic materials is added to both coils. The paper discussed magnetic- and electrical-circuit characteristics of the exciting coil with a back yoke.

Keywords: hyperthermia treatment, induction heating, magnetic field generator, back yoke, ferrite, flat coil
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1. Introduction

Induction heating type hyperthermia therapy is a low-inversive target treatment as one of cancer treatment[1]. The tumor with injected magnetic materials can be heated by hysteresis and eddy-current losses under external high frequency magnetic fields with more than 200 kHz×mT [2]. We considered two types of applicators (exciting coils), solenoidal coil and flat coil to generate magnetic fields for hyperthermia. The former system generates relatively uniform magnetic fields at deep position of body, but an apparent power capacity and input voltage of the applicator for human becomes huge. On the other hand, a simple flat coil can be excited within a realistic electric capacity. However a distribution of magnetic fields is uniform and decreased far form a coil. When installing the equipment in a therapy room, the flat coil type applicator is considered to be predominance by the physical size and electric power capacity of equipment[1].

With the basis of such considerations, we proposed the double pancake type exciting system with two flat coils sandwiching human body. The arrangement of the coils enables us to improve the decrease and gradient of magnetic fields in deep position as the drawback of flat coil system. Two pancake coils installed separately should be series-connected, and then we guess that an input voltage of series-connected coils increases more twice than a single coil. We applied a wireless transmission system to the excitation of double pancake coils, that is, one is the exciting coil connected with source and the other is an induced coil. The connection of coils recovers the increase of an input voltage. Moreover, it is easy to set a patient on the operating bed.

In order to make magnetic fields inside a body further increased, a back yoke is added to both coils. The flat magnetic materials cover the outside of exciting coils. The simple change of the coil configuration can yield the enhancement of magnetic strength far from coils and the shielding of leakage magnetic field outside coils. The paper discusses magnetic- and electrical-circuit characteristics of the exciting coil with a back yoke.

2. Double pancake type applicator and back yoke

2.1 Structure of double pancake coils and its benefit

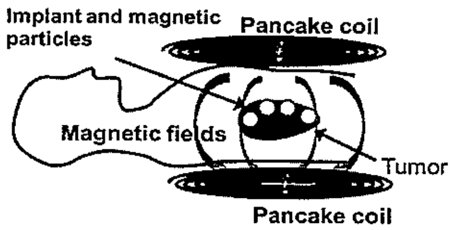
An applicator is installed outside of a body to heat magnetic implant and magnetic particles as a thermal source. Fig. 1 shows the double pancake exciting system with two flat spiral coils. Two coils sandwich a human body from both sides. The distribution of magnetic fields becomes flat and smooth near the centre of two coils (at a deep position of human body). The distance of pancake coils is variable and made into 280 mm usually in Fig. 1(b). The space fills the thickness of Japanese's breast up to 95 % [3].

2.2 Excitation by wireless transmission

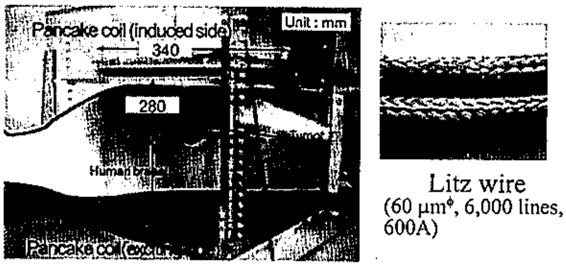
We apply a wireless transmission system to the excitation of double pancake coils [4]. One of pancake coils operates as exciting coil and current is induced on the other coil. Fig. 2 shows the outline of an applicator with double pancake coils by a wireless transmission system. The lower coil with series capacitor is connected to a high frequency power source directly and the upper pancake coil is connected to a resonance capacitor. Both coils are connected by magnetic coupling. The system gives the flexibility of coil gap and position to install a patient at an operation bed. Moreover, it is easy to adjust the distance of pancake coils according to bodily size and to align a position.

Correspondence: S. YAMADA, Institute of Nature and Environmental Engineering, Kanazawa University, Kakuma-Machi, Kanazawa, Ishikawa 920-1192, Japan
email: syamada@staff.kanazawa-u.ac.jp

*1 Kanazawa University



(a) Outline of hyperthermia



(b) Model with practical use size

Fig. 1. Induction heating type hyperthermia treatment.

We derive the equivalent circuit in order to analyze the performance of the pancake coils with wireless transmission in Fig. 3(a). When an exciting frequency is about some hundred kHz, we neglect the displacement currents and consider only the magnetic coupling between coils. Fig. 3(b) shows the equivalent circuit connected with resonance capacitors. The primary side is the exciting part and the secondary side is the induced part. The applicator system has no load but there are losses in coils and wires expressed by resistances, r_1 and r_2.

According to the analysis with typical parameters, the frequency characteristics on the exciting and induced circuit are shown in Fig 4. We observed two resonance frequencies (f_1 and f_2). The resonance frequency f_0 of the L-C circuit is between these frequencies. The resonance frequencies, f_1 and f_2, are expressed by,

$$f_1 = \frac{1}{2\pi\sqrt{C_1(L_1+M)}},\quad f_2 = \frac{1}{2\pi\sqrt{C_2(L_2-M)}}. \qquad (1)$$

It is remarkable that the exciting and induced currents have the same amplitude near two resonance

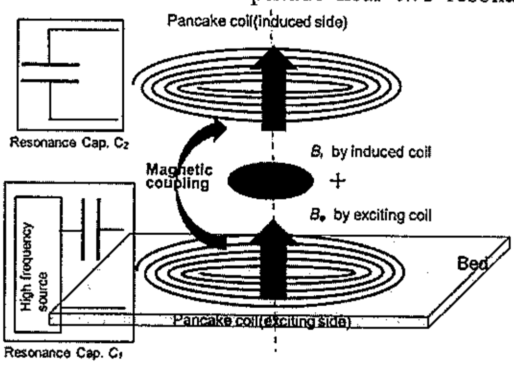


Fig. 2. Applicator system with wireless transmission.

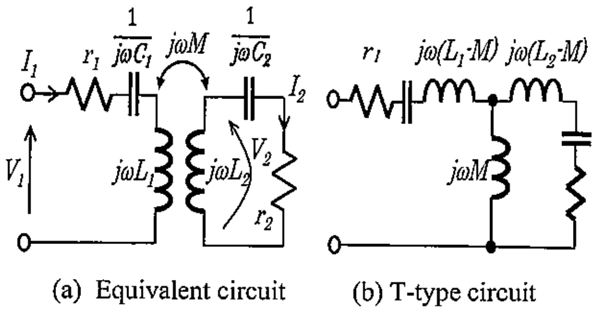


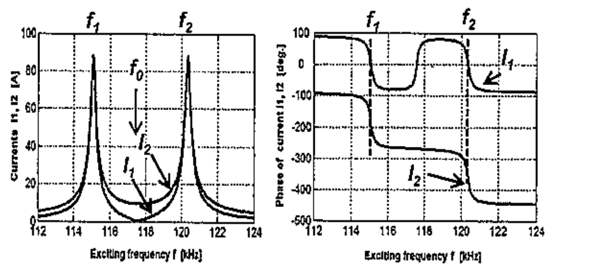
Fig. 3. Equivalent circuits of applicator with wireless transmission system.

frequencies. The phase difference between the exciti and induced currents is approximately π at f_1, and 2π f_2. In order to add the magnetic fields by two coils, t exciting frequency has to be tuned to the frequency strictly [4].

The resonance frequency depends on se inductance and mutual inductance. The parameters a changed according to the magnetic circuit and t distance between two coils. The recognition of t fluctuation of the resonance frequency is important foı high frequency electric source with variable frequency

2.3 *Enhancement of magnetic fields by back yoke*

The magnetic field distribution by a flat cc gradually decreases along z axis. We proposed tl addition of back yoke on the outside of coils as shov in Fig. 5. The comparisons of magnetic fie distributions by numerical calculation are shown in Fi 6. Fig. 6(a) on the applicator without back yoke denot that the magnetic field distribution decreases betwe two coils and leakage magnetic field arises outside coils. On the other hand, the back yoke worl effectively to increase magnetic fields at the centre coils and to decrease leakage fields as shown in Fi 6(b). The back yoke can clearly improve the magnet flux density to the required distribution. We need estimate the equivalent circuit parameters correspondir to wireless transmission and evaluate the changes losses and Q factor.



(a) Amplitude (b) Phase

Fig. 4. Frequency characteristics of currents.

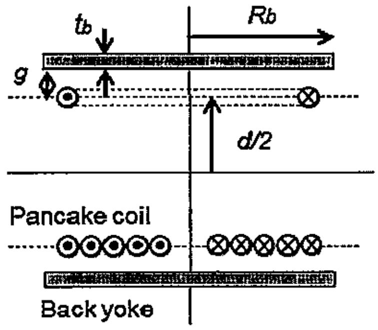
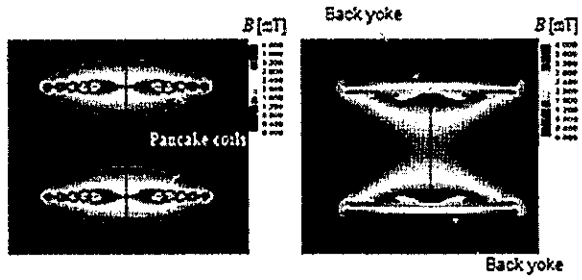


Fig. 5. Pancake coils with back yoke.



(a) Without back yoke. (b) With back yoke.

Fig. 6. Magnetic field distribution.

3. Magnetic and Electric Characteristics

3.1 Configuration of back yoke

We fabricated the magnetic cores as back yoke covering a flat coil with 5 turns in consideration of the structure of applicator, operation high frequency, and magnetic circuit. The core element is made of MnZn ferrite core with relative permeability, μ^{*}= 2400 and has a fan type shape with 45 degree in Fig. 7. The thickness of a core is 10 mm by a structural factor. The core elements do not cover the top of flat coil perfectly to reduce the weight and core losses. Fig. 8 shows the back yoke constituted from six elements (m = 6) and the circumference of the coil is covered by 270 degrees. We examined both the magnetic field distribution and the losses depending on the number of core element.

3.2 Distribution of magnetic fields

Figs. 9 and 10 show the z-component of magnetic field distributions between flat coils and outside back yoke. The condition of the measurement is that the frequency is about 100 kHz and the exciting current is 25 A as the rating current is 400 A. The distribution of magnetic field along z-direction decreases at the center of coils as shown in Fig. 9. By comparing with the applicator without back core, the amplitude of magnetic field increases from 50 to 75 % remarkably. Even if the number of core element, m changes from 3 to 6, the distribution has a slight decrease. The addition of a back core enhances the magnetic fields inside the operating area. These results confirm that the core does not need to covers with coil completely.

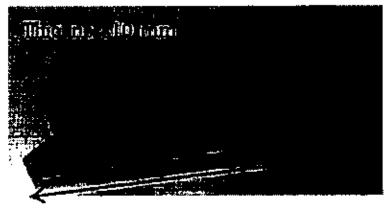


Fig. 7. Fan shape core element for back yoke.

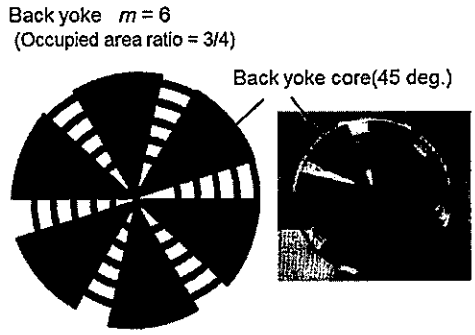


Fig. 8. Configuration of spiral flat coil with back yoke.

Fig. 10 shows the distribution of leakage flux density on the upper of back yoke. When the core is not uniform, the distributions were measured on both the core and the crevice of core. The amplitudes of leakage flux densities in both cases are almost the same and reduced up to 75 % compared with the core-less applicator.

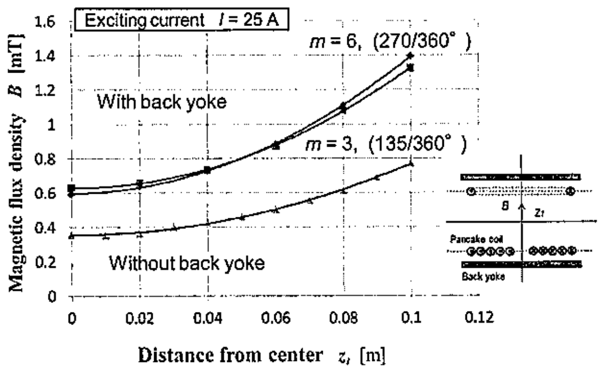


Fig. 9. Magnetic field distribution along z-axis when the number of core element, m increases.

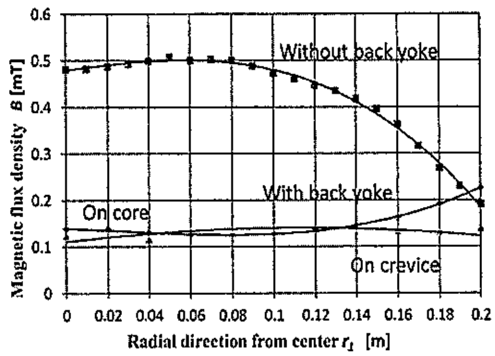


Fig. 10. Leakage magnetic fields distribution outside back yoke (m = 8).

3.3 Change of electric parameters in equivalent circuit

The back yoke becomes the change of magnetic circuit parameters and both self-inductance and mutual inductance rise up with increasing the magnetic flux as shown in Fig. 9. Fig. 11 shows the fluctuation of self-inductance on both exciting coil and induced coils when the number of core element, m changes up to 6. Both coils have a slight difference because of the coil termination. The increase in a self-inductance is less than 38 % at most. The magnetic circuit is like open circuit even if the back yoke is added. Although magnetization voltage increases with the increase in inductance, the magnetic flux density between coils increases further.

An iron loss at back yoke is added to the ohmic loss by coil resistance by addition of a magnetic core. We estimated the total losses as equivalent series-resistance, R_s by measuring Q value in the resonance circuit as shown in Fig. 12(a). The series-resistance R_s is the equivalent resistance containing a coil loss, iron loss, and capacitor loss. The fabricated resonance has a high Q-value more than 400 as shown in Fig. 13. The equivalent series-resistance calculated from Q value has a very little increase. The result proves that the core loss is negligible comparing with ohmic loss of coils. Because the amplitude of magnetic flux density is much less than saturation of ferrite core.

4. Conclusion

The completion of a magnetic field generator with more than 200 kHz×mT is indispensable to utilization of induction heating type hyperthermia therapy. We proposed the double-pancake type coil system with back yoke to increase magnetic fields. The obtained conclusions are summarized as follows,

(1) The structure of a back yoke on a flat coil is fabricated by the combination of fan shape cores.
(2) We obtained the increase of magnetic fields and the suppression of leakage fields by addition of back yoke.
(3) The increase of core loss was not observed almost and the Q factor was increased especially.

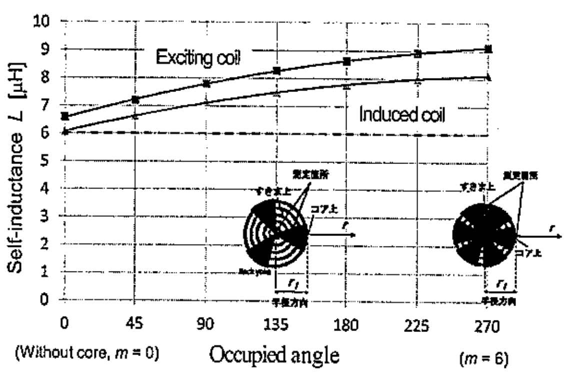
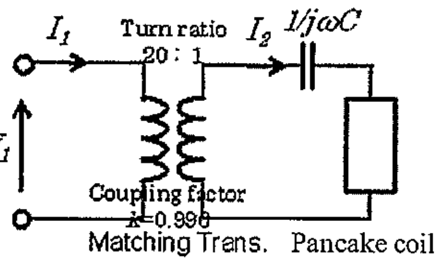
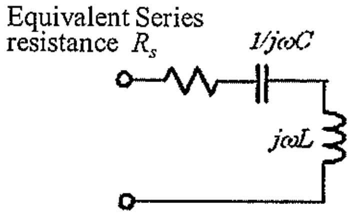


Fig. 11. Self-inductance when the number of core element increases.



(a) Measuring circuit.



(b) Equivalent circuit.

Fig. 12. Measuring circuit for Q-factor.

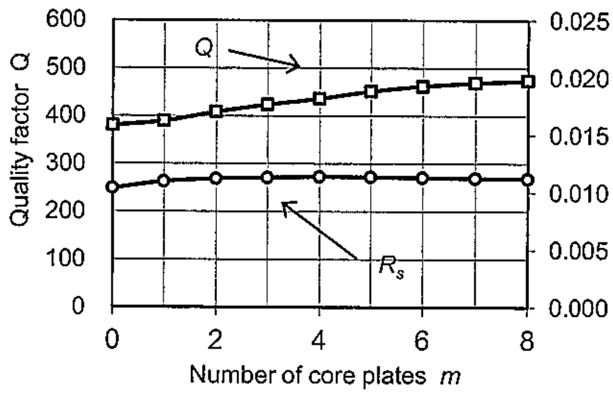


Fig. 13. Equivalent series-resistance and quality factor.

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