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# A Comparative Analysis for Optimization of Switching Frequency in Induction Heated System Employed For Hyperthermia Treatment.

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**ABSTRACT**

Hyperthermia treatment is a process adopted in cancer healing in which the affected tissues are exposed to a very high temperature. Details of hyperthermia treatment and its applications in cancer treatment are given. It has been found that regional hyperthermia treatment is the most suitable method extensively employed for cancer treatment. The different heat delivery methods along with their frequency range are also mentioned required for hyperthermia treatment. The existing heating technique used in the hyperthermia treatment with BSD-2000 equipment is resistance heating which is replaced by an induction heating concept in the present work. The drawbacks of conventional BSD-2000 instrument are mentioned & also method to overcome them with induction heating concept is explained. The different frequencies required for various hyperthermia treatments vary in wide range which makes the existing BSD-2000 system very difficult to operate under different health conditions of patients. The switching frequency used in the proposed system is optimized analytically using 'Stepest Descent' method which is found to be satisfactory for hyperthermia treatment. Thus hyperthermia treatment can be used uniformly for every circumstance. The result is then validated through 'Rosenbrock' method which confirms the switching frequency of the induction heated system.

**Keywords:** high frequency resonant inverter, hyperthermia, Induction Heating, Rosenbrock, Steepest Descent method

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## INTRODUCTION

Induction heating is the process of heating an electrically conducting object (usually metal) by electromagnetic induction, where eddy currents are generated within the metal and resistance leads to joule heating of the metal. It is a non contact heating process. It uses high frequency electricity to heat materials that are electrically conductive. Since it is a non contact, the heating process does not contaminate the material being heated. The process of hyperthermia treatment is shown in Figure 1.

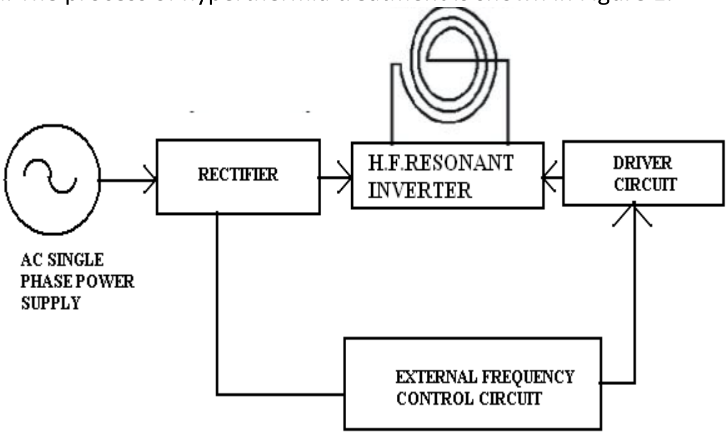


**Figure 1.Induction heated system with spiral heating coil**

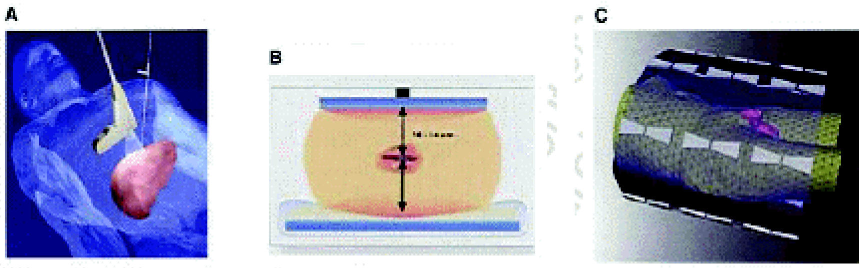


**Fig. 2(A) External Hyperthermia (B) Interstitial Hyperthermia (C) Endocavitary Hyperthermia**

**Fig. 3. BSD 2000 for hyperthermia treatment**

**Fig. 4. BSD 2000 device for hyperthermia treatment**

Fig. 5. Patient undergoing hyperthermia treatment in BSD 2000

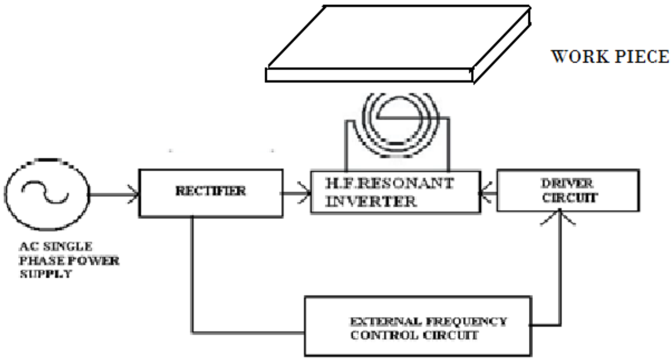


Fig. 6. Induction heated system applied for hyperthermia treatment showing the work piece

IGBT switches are used which can be turned on or off at a definite frequency.

Hyperthermia treatment can be applied in the treatment cancer using various processes. However, for the whole body hyperthermia treatment the device that is used most often is the BSD 2000. Here simple resistive heating is used for generating the required amount of heat for the cancerous cells at a desired frequency level.

Instead, induction heating is used which generate heat in a controlled manner.

**HYPERTHERMIA TREATMENT IN CANCER**

Cancer, known medically as a malignant neoplasm, is a broad group of diseases involving unregulated cell growth. In cancer, cells divide and grow uncontrollably, forming malignant tumors, and invading nearby parts of the body. The cancer may also spread to more distant parts of the body through the lymphatic system or bloodstream. Cancer can be detected in a number of ways, including the presence of certain signs and symptoms, screening tests, or medical imaging. Once a possible cancer is detected it is diagnosed by microscopic examination of a tissue sample. Cancer is usually treated with chemotherapy, radiation therapy .Hyperthermia also forms a part of the cancer treatment.

Hyperthermia (also called thermal therapy or thermotherapy) is a type of cancer treatment in which body tissue is exposed to high temperatures (up to 113°F). Research has shown that high temperatures can damage and kill cancer cells, usually with minimal injury to normal tissues (1). By killing cancer cells and damaging proteins and structures within cells (2), hyperthermia may shrink tumors. Hyperthermia is almost always used with other forms of cancer therapy, such as radiation therapy and chemotherapy. Hyperthermia may make some cancer cells more sensitive to radiation or harm other cancer cells that radiation cannot damage. When hyperthermia and radiation therapy are combined, they are often given within an hour of each other. Hyperthermia can also enhance the effects of certain anticancer drugs. Figure 2(A),2(B) and 2(C) depicts the various processes of hyperthermia treatment.

**ROLE OF INDUCTION HEATING IN HYPERTHERMIA TREATMENT:**

Hyperthermia treatment, done by conventional BSD 2000, uses resistive heating to raise the temperature of the infected body part. To generate sufficient amount of heat, frequency is increased and ranges up to 125 MHz but the other methods of hyperthermia treatment (like interstitial, loco regional) uses a frequency range of 33MHz to 118MHz. This wide variation in frequencies makes the treatment complex. In the present work we have replaced the existing heating technique in BSD 2000 by induction heating which can withstand the high frequency range and smoothen the process of hyperthermia treatment. Induction heating is the process of heating an electrically conducting object (usually a metal) by electromagnetic induction, where eddy currents are generated within the metal. It is a non contact heating process. It uses high frequency electricity to heat materials that are electrically conductive. Since it is non contact, the heating process does not contaminate the material being heated [6].

Components of induction heating: [7]

- A source of high frequency electrical power.
- A work coil to generate the alternating magnetic field.
- An electrically conductive work piece to be heated.

Power Supply: The power supply in an induction heated system is a rectified single phase ac supply [6]. The main disadvantage of uncontrolled rectifier used in the induction heated system is that an intermediate unregulated dc voltage is obtained which has to be processed further to obtain a regulated dc supply. [7]

Power Switches: The existing induction heated system uses IGBT (Insulated Gate Bipolar Transistor) switch [6]. It combines the simple gate drive characteristics of the MOSFETs with the high current and low saturation voltage capability of bipolar transistors by combining an isolated gate FET for the control input and a bipolar power transistor as a switch. But it can work satisfactorily in the medium frequency range from 25 kHz to 40 kHz [7]. As the frequency increases beyond 40 kHz switching loss increases drastically.

The shape of the work coil to be used in induction heated system can be of different shapes. We have considered the shape to be spiral [8].

Induction heated system can generate high temperature but in a controlled manner [9]. The heating system, conventionally used for hyperthermia treatment using BSD 2000 is being replaced by induction heating so that the heating will be fast and also in a controlled manner the affected spot can be heated up.[10].

Hyperthermia treatment, applied with the help of BSD 2000, as shown in figure 3. 4 and 5, works at a frequency of 120 MHz whereas the other hyperthermia treatment uses a lower range of frequency range which is nearly equal to 38 MHz The switching frequency is optimized so that any method of hyperthermia treatment can be applied without making any harm to the patient and also the power switches of the high frequency inverter can operate in such frequency range. In the next section the specified range of switching frequency is optimized which is essential for effective performance of induction heated hyperthermia treatment. There are various disadvantages of BSD 2000

- Patients who have implanted, worn or carried medical devices, including cardiac pacemakers, implanted defibrillators, infusion pumps, insulin pumps, cardiac monitoring electrodes and devices, deep brain stimulators, cochlear implants, radiofrequency identification devices attached to devices, or any other implanted active electronic device or monitoring system[21]
- A body diameter >49 cm from left to right.
- Severe dysfunction of the heart or lungs
- Severe pulmonary disease with a forced expiratory volume (FEV) <50%
- Patients who cannot adequately respond to pain (those with significant neuropathies)
- Patients who have electrically conductive, metal, or foreign objects in or on or attached to their body
- Heart rate >90bpm
- Inability to place either an intratumoral or an intraluminal temperature sensor for monitoring of tumor indicative temperatures.

**OPTIMIZATION OF THE SWITCHING FREQUENCY:**

We are minimizing the switching frequency as it has a relationship with the work coil parameters (coil inductance and ac resistance).The resistance depends on frequency because the effective cross sectional area changes with frequency. For ac, the skin effect causes the resistance to increase with increasing frequency. Moreover, the proximity effect can significantly increase the ac resistance which also increases the frequency. [15] The switching frequency, which is generally 125 MHz, required for Hyperthermia treatment using BSD 2000, is minimized to 38 MHz using steepest descent method. The steepest descent algorithm is a gradient based algorithm which uses the negative of the gradient vector at each point as the search direction for each iteration. The gradient vector at a point $g(x_k)$, is also the direction of maximum rate of change(maximum increase) of the function at that point. This rate of change is given by the norm $\| g(x_k) \|$.

Algorithm for Steepest Descent Method:

i. Select starting point $x_0$ and convergence parameters $\varepsilon_g$, $\varepsilon_a$, $\varepsilon_r$.
ii. Compute $g(x_k) \equiv$ delta $f(x_k)$. If $\| g(x_k) \| \leq \varepsilon_g$ then stop. Otherwise compute he normalized search direction to $P_k = -g(x_k) / \| g(x_k) \|$.
iii. Find the positive step length $\alpha_k$ such that $f(x_k + \alpha P_k)$ is minimized.
iv. Update the current point $x_{k+1} = x_k + \alpha P_k$
v. Evaluate $f(x_{k+1})$. If the condition $| f(x_{k+1}) - f(x_k) | \leq \varepsilon_a + \varepsilon_r \; |f(x_k)|$ is satisfied for two successive iterations then stop. Otherwise, set k=k+1, $x_{k+1} = x_k + 1$ and return to step 2.

In the present problem, initially the positive step length is considered 1. As the objective function gets minimized by taking the first step length, we have not increased it.

## RESULTS

The ac resistance of the work coil has a relation with the skin effect factor $y_s$. If a conductor is composed of one or more concentric circular elements, then the centre portion of the conductor will be enveloped by a greater magnetic flux than those on the outside. Consequently, the self induced back emf will be greater towards the centre of the conductor, thus, causing the current density to be less at the centre than the conductor surface. This extra concentration at the surface is known as skin effect, which results in an increase in the effective resistance of the conductor. The skin effect factor ( $y_s$ ) is expressed as:

$$y_s = x^4 / (192 + x^4) \qquad (1)$$

$$\text{Where } x^2 = (8\pi f k_s \times 10^{-7}) / R_{dc} \qquad (2)$$

f- Frequency (Hz)
$k_s$- Factor determined by conductor construction
$R_{dc}$- Dc resistance at normal operating temperature
Substituting the value of ‘x’ from equation (2) in equation (1), we get

$$(8\pi f k_s \times 10^{-7})^2 / 192 + (8\pi f k_s \times 10^{-7})^2$$

Let us define a function $\phi (k_s, Y_s) = \sum_{K=1}^{N} P \, \phi_k (K_s, Y_s)$ $\quad |P| \leq 1$

$$\emptyset(k_s, y_s) = \sum_{k=1}^{N} P \emptyset_k (k_s, y_s)$$

To get the optimum point $\partial\varphi / \partial k_s = 0$

After performing the partial differentiation we get,

$16\pi f \times 10^{-7}=191$
$f=191/(16\pi f \times 10^{-7})$
$f=37998242.7$ Hz **f= 37.99 MHz**

The optimisation of the fequency is done by two different optimisation method-Rosenbrock method(deterministic method) and Steepest Descent method(improvement directions method).

**Rosenbrock Method**

The Rosenbrock method is a development of Hook and Jeeves method. The Hook and Jeeves method includes the pattern search and the exploratosy search.
Pattern Search

- Create a set of search directions iteratively
- Should be linearly independent Exploratory
- Find the best point in the vicinity of the current point.

The algorithm for Hook and Jeeves method is given below-

**Exploratory Move:**

Current Solution is $x^c$; set i=1; $x=x^c$
Step 1: f=f(x), $f^+=f(x_i + \Delta i)$,
$f^-=f(x_i - \Delta i)$
Step 2: $f_{min}= \min(f, f^+, f^-)$;
set x corresponding to $f_{min}$
Step 3: If i=N, go to step 4;
else i=i+1, go to step 1
Step 4: If $x \neq x^c$, it is considered as
success, else its failure.
**Pattern Move :**

Step 1: Choose $x^{(0)}$, $\Delta_1$,for
i=1,2,…….,N,ε and set k=0
Step 2: Perform exploratory move
with $x^{(k)}$ as base point-if
success,$x^{k+1}=x$, go to 4
else go to 3.
Step 3: If $|\Delta|<\varepsilon$, terminate.
Else set $\Delta_i= \Delta_i/\alpha$………..,
go to ii.
Step 4: k=k+1; $x_p^{k+1}= x^k + (x^k - x^{k-1})$
Step 5: Perform another exploratory move with $x_p^{k+1}$ as the base point; results= $x^{k+1}$
Step 6: If $f(x^{k+1})< f(x^k)$, go to 4. Else go to 3.

## RESULTS

It has already been stated that the ac resistance of the work coil has a relation with the skin effect factor $y_s$. The skin effect factor ( $y_s$ ) is expressed as:

$$(8\pi f k_s \times 10^{-7})^2 / _{192} + (8\pi f k_s \times 10^{-7})^2 \text{....(iii)}$$

Where $x^2 = {(8\pi f k_s \times 10^{-7})}/{R_{dc}} \dots \dots (ii)$

f- Frequency (Hz)
$k_s$- Factor determined by conductor construction
$R_{dc}$- Dc resistance at normal operating temperature
Substituting the value of 'x' from equation (ii) in equation (i), we get

$$ {(8\pi f k_s \times 10^{-7})^2}/{192} + (8\pi f k_s \times 10^{-7})^2 \text{....(iii)} $$

For different values of $k_s$,differentiating the equation (iii), we get
F(x)=37.99Mhz, F(x+Δx)=40.2Mhz, F(x - Δx)= 42Mhz
$F_{min}$= min {F(x), F(x + Δx), F(x - Δx)}
Therefore, $F_{min}$= 37.99 MHz

So, after optimizing the switching frequency by steepest descent method and 'Rosenbrock' method, we find that the values are same.

## CONCLUSION

Cancer, a threatening disease, is always an area to be much discussed with and it also opens new path of research. Hyperthermia forms a part of cancer treatment which means heating the tumor to certain high temperature range so that the damaged cells get burnt out. Chemotherapy is also heat treatment which is used in the treatment of cancer but it heats up the region around the tumour which is not desirable. There are various benefits of hyperthermia over chemotherapy like it has low host toxicity, easily controllable (heating precisions in the range of ±0.1°C and specific definable localized areas) and also low resistance.

Conventional techniques that are available for hyperthermia treatment are very costly and sophisticated in application. The technicians and the doctors dealing with hyperthermia treatment should have sound knowledge about the system, its installation, its use and its precautions. Today the most common equipment that is being used for hyperthermia is BSD 2000.

This equipment is actually an assembly of several subsystems. It is intended to deliver focused therapeutic heating with temperature greater than 104°F (40°C) to cancerous tumours by applying radio frequency range of 75 to 120MHz. But this particular device has got certain restrictions. It cannot be used with patients having other physical ailments. Moreover it requires large space for its installation, much costly and also the operators should be very familiar with the operation of this equipment. In this particular paper, a scheme has been presented in which the conventional resistance heating used in BSD 2000 is being replaced with induction heating process as shown in figure 6.The malignant tumours will be heated with the help of electrodes which will be heated up by induction heating. This may overcome the shortcomings of BSD 2000 and pave a new horizon in the direction of combating cancer.

## REFERENCES


[1] Kang-Yul Bae, Young-Soo Yang, Chung-Min Hyun –"Analysis of triangle heating technique using high frequency induction heating in forming process of steel plate"- International Journal of Precision Engineering and Manufacturing, Volume 13, pp 539-545,2012.

[2] Hung Seo Park and Xuan-Phuong Dang-"Optimization of the In-Line Heating Process for Hot Forging in terms of saving Operating Energy"-International Journal of Precision Engineering and Manufacturing,Vol.13, No.7, pp.1065-1097,July 2012

[3] Parallel Resonance Based Current Source Inverter for Induction Heating - European Journal of Scientific Research ISSN 1450-216X Vol.58 No.2 (2011), pp.148-155© EuroJournals Publishing, Inc. 2011.

[4] Single Phase High Frequency AC Converter for Induction Heating Application-M.A Inayathullaah et al. / International Journal of Engineering Science and Technology Vol. 2 (12), 2010, 7191-7197.

ISSN: 0975-8585


[5] Shimizu, K.; Ishii, T.; Blajan, M., "Emission Spectroscopy of Pulsed Power Microplasma for Atmospheric Pollution Control," *Industry Applications, IEEE Transactions on*, vol.46, no.3, pp.1125, 1131, May-june 2010

[6] Power Control of Series-Parallel Resonant Inverter For Induction Heating Using Buck Converter- Eng.& Tech. Journal, Vol. 28, No.10, 2010.

[7] Efficiency optimization of half-bridge series resonant inverter with asymmetrical duty cycle control for domestic induction heating," *Power Electronics and Applications, 2009. EPE '09. 13th European Conference on* , vol., no., pp.1,6, 8-10 Sept. 2009.

[8] Jung-Tang Huang; Po-An Lin; Po-Chin Lin; Kuo-Yu Lee; Hou-Jun Hsu, "The development of high frequency induction heating embedded coil," *Microsystems, Packaging, Assembly and Circuits Technology Conference, 2009. IMPACT 2009. 4th International*, vol., no., pp.701, 704, 21-23 Oct. 2009

[9] Achara, P., Viriya, P., Matsuse, K., 2007, Analysis of a half bridge inverter for a small size induction cooker using positive-negative phase shift control under ZVS and non-ZVS operation, *PEDS*, 157-163.9.

[10] Cook, J.A.; Kolmanovsky, I.V.; McNamara, D.; Nelson, E.C.; Prasad, K.V., "Control, Computing and Communications: Technologies for the Twenty-First Century Model T," *Proceedings of the IEEE*, vol.95, no.2, pp.334, 355, Feb. 2007.

[11] Acero, J., Burdio, J. M., Barragan, L.,A., Artigas, J. I., Alonso, R., 2006b, An electromagnetic-based model for calculating the efficiency in domestic induction heating appliances, *37th IEEE Power Electronics Specialists Conference, pp.*1-6.

[12] "Designing of suitable construction of high-frequency induction heating coil by using finite-element method," *Magnetics, IEEE Transactions* on , vol.41, no.10, pp.4048,4050, Oct. 2005

[13] Journal of Rural and Tropical Public Health 6: 16-23, 2007 “A survey on the effects of vehicle emissions on human health in Nigeria” Ojolo SJ *PhD*1, Oke SA *MSc* 1, Dinrifo RR *MSc*2, Eboda FY *BSc*1 cancerres. Aacr journals. org/content/39/6_Part_2/2285.full.pdf

[14] BSD MEDICAL CORPORATION,2188 West 2200 South,Salt Lake City, UT 84119-1326 USA-Journal issue focuses on benefits of Hyperthermia in Cancer treatment-Jan 21,2011

[15] BSD Medical Corp.BSD-2000 Hyperthermia System**,** Essential Prescribing Information-October 26, 2011

[16] Kettenbach J, Köstler W, Rücklinger E. et al. Percutaneous salin-enhanced radiofrequency ablation of unresectable hepatic tumors: Initial experience in 26 patients. AJR. 2003;180:1537.

[17] Hyperthermia Cancer Therapy Utilizing Super paramagnetic Nanoparticles- Nano/Micro Engineered and Molecular Systems, 2007. NEMS '07. 2nd IEEE International Conference, 16-19 Jan. 2007,pp. 163 – 166.

[18] Optimization of patient position in hyperthermia treatment for head and neck region- Antennas and Propagation Society International Symposium, 2009. APSURSI '09. IEEE, 1-5 June 2009, pp. 1-4

[19] Experiences with Superficial Hyperthermia in the Treatment of Patients with Head and Neck Cancers- Microwave Techniques, 2008. COMITE 2008. 14th Conference, 23-24 April 2008, pp. 1- 4.

[20] Treatment planning guided RF hyperthermia- Microwave Conference (EuMC), 2012 42nd European, Oct. 29 2012-Nov. 1 2012, pp.628-631.