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High Frequency Converter for Magneto Fluid Hyperthermia

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Abstract: *Hyperthermia is a promising cancer treatment which is used as an additive therapy along with standard treatments like radiotherapy and chemotherapy. Many efforts have been made to improve hyperthermia techniques since last 20 years. It utilizes induction heating principle to destroy the tumor cell without damaging normal cells. This paper reviews on one of the most effective converter topology for developing high frequency high power density output required for hyperthermia. The simulation is done with both open loop and closed loop models by using MATLAB/SimPowerSystems tool and the simulation results are presented here.*

Keywords*: Current mode controller (CMC), High frequency (HF), Induction heating (IH),Super paramagnetic (SP), Voltage mode controller (VMC)*

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I. Introduction

Power electronics and biomedical are the areas which are connected to each other. Many power electronics systems are used in biomedical like X ray based diagnostic system, artificial heart pump, prosthesis etc. One such application is cancer treatment. The principle of a cancer treatment is to destroy only the cancel cell not the normal cells. As the blood flow through tumor cells are insufficient, tumor cells will be more acidic due to lack of oxygen. When Temperature sensitivity of cell increases, cells become more acidic. Hence tumor can be eliminated by simply rising the temperature in the presence of superparamagnetic (SP) nanoparticles under the influence of magnetic field. For this a high frequency high power density current must be provided to the coil which develops magnetic field. High frequency high power density current can be developed using a suitable converter topology. Also, coil used for developing the magnetic field and superparamagnetic nanoparticles also have an important role in deciding the overall effectiveness of hyperthermia. This paper reviews on suitable choice of nanoparticle materials, coil optimization technique and high frequency converter to destroy cancer cells.

II. Background

The first industrial applications of the induction heating phenomenon were identified in 1887 by Sebastian Z. de Ferranti. He proposed induction heating for melting metals, filling the first patent on industrial applications of IH. Experimental investigations of magnetic materials for hyperthermia was started in 1957 with the heating of tissue samples in a magnetic field [1]. In 1993 possibility of using magneto fluid in hyperthermia treatment was analyzed and efficiency of a superparamagnetic crystal suspension to absorb the energy of an alternating magnetic field and convert it into heat was discussed [2]-[3]. The first clinical patient trials were started by the research group of Jordan [4]-[9]. They built a hyperthermia-generating prototype instrument which is able to generate variable magnetic fields in the range of 0–15 kA/m at a frequency of 100 kHz. This prototype is capable of treating tumors placed in any region of the body. In 2011 Paolo Di Fabrizo Dughiero, Elisabetta Sieni ans alessandro Candeo proposed a coil design in which magnetic field is generated by means of coreless coils. This helps to supply current according to patient size and the treatment prone region [10].

III. Magnetofluid Herthermia

The word "Hyperthermia" means condition of having a body temperature greatly above normal. Term "Magneto fluid" is the colloidal suspension of superparamagnetic nanoparticles. National cancer institute from united states of America defied magneto fluid hyperthermia as the tumor treatment in which body tissue is exposed to high temperature to destroy tumor or to make them sensitive to radiation. Here a high frequency current is developed using suitable converter and is allowed to pass through a coil for producing magnetic field. The nanoparticles are injected into the tumor cells and the entire human body is placed under alternating magnetic field of sufficient strength and frequency. Due to magnetic loss and Neel relaxation, tumor temperature rises and get destroyed.

1.1 Techniques For Injecting Nanoparticles

There are four techniques for injecting nanoparticle into tumor cells like artificial injection, direct injection, in situ implant formation, active targeting. In artificial injection, fluid carrying magnetic particles is injected in the arterial supply of the tumor and used as a pathway to deliver them. In direct injection, the fluid is injected directly into the tumor. The particles will be located in the tumor tissue and the most of them in the interstitial space and a minor part in blood vessels or intracellularly [11]. In situ implant formation mentions that injectable in situ gelling formulations are used to form gels entrapping magnetic particles into a tumor [12]. A more complicated way to deliver these particles to the tumor tissue is the antibody targeting. This is done in active targeting [13].

1.2 Types Of Hyperthermia

The National Cancer Institute (www.nci.nih.gov) mentions three different types of hyperthermia treatments:

1.2.1 Local hyperthermia: the heat is applied only on tumor, using various techniques that deliver energy to heat the tumor. Different types of energy may be used to apply heat; including microwave, radiofrequency, and ultrasound

1.2.2 Regional hyperthermia: large areas of tissue are heated using different approaches such as external applicators or regional perfusion.

1.2.3 Whole body hyperthermia: is used to treat metastatic cancer that has spread throughout the body [14]-[17].

1.3 Setup for magneto fluid hyperthermia

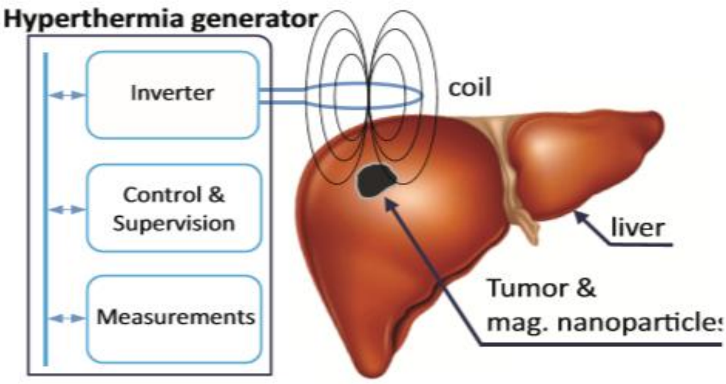

Fig 1 Magnetic hyperthermia for cancer treatment [18]

A high frequency current is given to coil by the inverter to produce the required magnetic field where tumor cells are placed. Inverter should be capable of developing high intensity magnetic field. The main components required are superparamagnetic nanoparticles, coil and hyperthermia generator. In this paper a high frequency three level inverter is proposed due its simplicity and ability to control output voltage and current.

IV. Superparamagnetic Nano Particles

There are several magnetic nanomaterials available for using in hyperthermia applications. This include SPIONs (Fe_3O_4 and γ-Fe_2O_3), iron–palladium and cobalt, ferrimagnetic spinels ferrite particles, copper–nickel, cobalt ferrite, ferromagnetic perovskites $La_{1-x}Sr_xMnO_3$, $Ni_{(1-x)}Cr_x$, gadolinium-, Mn–Zn and Mn–Zn–Gd, calcium lanthanum complexes, and ferrimagnetic $SrFe_{12}O_{19}$/γ-Fe_2O_3 composites

SPIONs exhibit a medium heating during hyperthermia in comparison with other magnetic materials [19]. But magnetic nanoparticles must have many characteristics to qualify for biomedical applications such as biocompatibility, nontoxicity, ability to escape from the reticuloendothelial system (RES), and low protein adsorption [20][21]. So experimentally and commercially available magnetic nanoparticle for hyperthermia applications is considered to be of SPION cores The cytotoxicity of SPIONs has been tested via various methods such as the cell-life cycle assay, MTT assay, comet assay, TUNEL assay (i.e., for apoptosis detection). No considerable toxicity was found [14] [22]-[35].

V. Coil Optimisation

A current carrying coils should be selected in such a way that a uniform distribution of the magnetic field in the target tissue is obtained. F or that we can assume liver as a sphere and the tumor as another sphere located inside liver with the radius of 40mm. The approximation variables are functions of z and dz (Fig 1(a)). It is also assumed that nanoparticles in the tumor have uniformly distributed diameter of 28mm and concentration of 0.3%. There are two optimization procedures named magnetic-field oriented optimization and thermal-field oriented optimization. They identify different configurations of inductor coils.

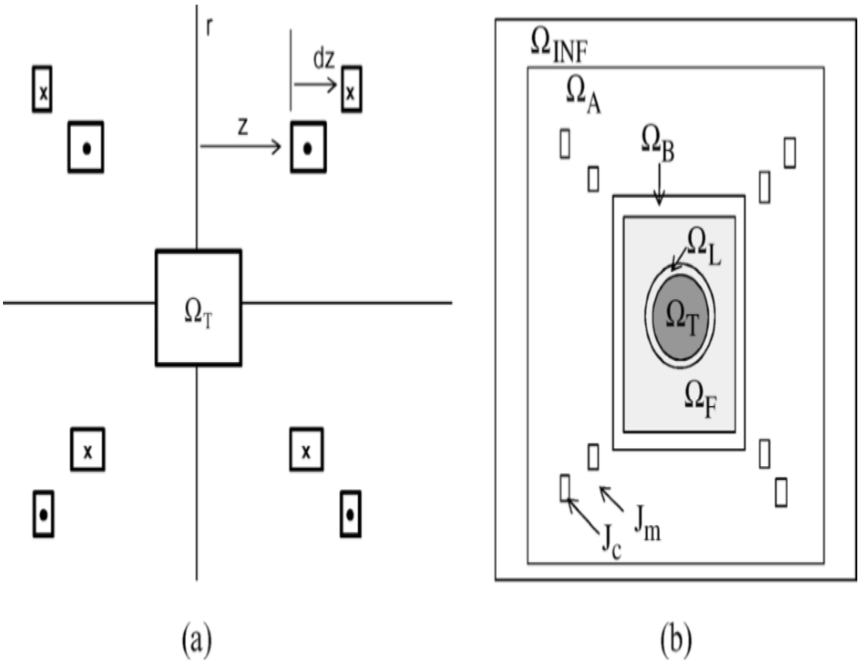

Fig 2 (a) Coils in controlled region. (b) Various regions of magnetic and the thermal problems with Ω_T tumor, Ω_L liver, Ω_F fat, and Ω_A and Ω_B air, and Ω_{INF} truncated external region [10]

Here various regions considered are with Ω_T tumor, Ω_L liver, Ω_F fat, and Ω_A and Ω_B air, and Ω_{INF} truncated external region. By means of a time-varying magnetic field heat is generated and results in the rotation of nanoparticles and their magnetic moments in the biological fluid. Thermal transient problem coupled with a time-harmonics magnetic problem is to be solved for computing the temperature in the treated region as a function of time and space. Maxwell equation is solved for magnetic problem where as in thermal problem we consider Fourier equation. In the conductive regions Ω_T, Ω_L, Ω_F, the phasor $\dot{H}$ of the magnetic field is computed after solving the electromagnetic problem in terms of the phasors of electric vector potential, $\dot{T}$, and total magnetic scalar potential Φ:

$$\dot{H} = \dot{T} - \Delta\Phi \quad (1)$$

In conductive regions Ω_T, Ω_L, Ω_F the temperature due to the heat generated by nanoparticles is computed solving the Fourier equation:

$$c_p \gamma\, \partial T/\partial t = \lambda\, \Delta^2\, T - c_b w_b\, (T\text{-}Ta) = P(x, y, z, P,H) \quad (2)$$

Both optimization procedures determine an improvement of thermal or magnetic inhomogeneity in the controlled tumor region. The starting point is taken same for both the methods. If the magnetic or thermal field is optimized then the final temperature after 300 s of treatment will be different. Thus we can say that the thermal field optimization gives a better level of uniformity of the temperature in the controlled region, corresponding to a value of temperature suitable for a therapeutic treatment of mild hyperthermia [10].

VI. High Frequency Converter For Hyperthermia Generator

Different types of high frequency inverters are available nowadays due the development of power electronics. Here we use a simple three level inverter with voltage and current control to limit the output voltage and current within safe limits. The proposed high frequency inverter is as in Fig [2].

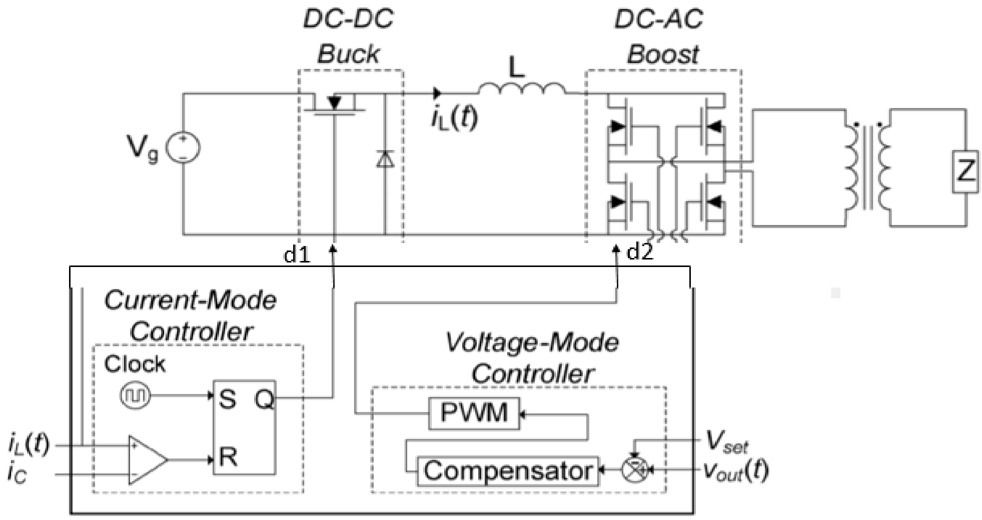

Fig 3 Proposed high frequency inverter

It consists of a basic buck converter, a high frequency boost inverter, isolation transformer and a controller [36]. The input dc voltage is step downed using buck converter for obtaining fixed conversion ratio and provided to boost inverter. Now the input dc is converted to ac of high frequency by keeping the switching frequency of 400 kHz. The duty of controller is to provide duty cycle to buck converter and HF inverter. Controller block consists of current mode controller (CMC) and voltage mode controller (VMC). In this control method, we are sensing three parameters; output ac voltage, input ac current, and output ac current. In current mode controller, input dc current or inductor current is sensed and compared with a current reference, i_c. The error is fed into the reset pin of SR flip flop. Output of SR flip flop is obtained when set pin goes high. Based on output Q, required duty cycle is selected and provided to the buck converter. In voltage mode controller, we are regulating voltage and current of the inverter output stage. Output voltage of the inverter is compared with reference voltage, V_{set} and error is fed to PI controller. The gain of PI controller is tuned to obtain the current reference. This is further compared with ac output current to obtain the duty cycle for regulating inverter. The error of actual current and reference current is given to another PI controller to obtain duty cycle. After obtaining duty cycle, compare this with a carrier wave to obtain PWM pulses and the duty cycle is given to the HF inverter. The output obtained is a three level output with high frequency. The proposed system will have a high power density as shown in Fig 3

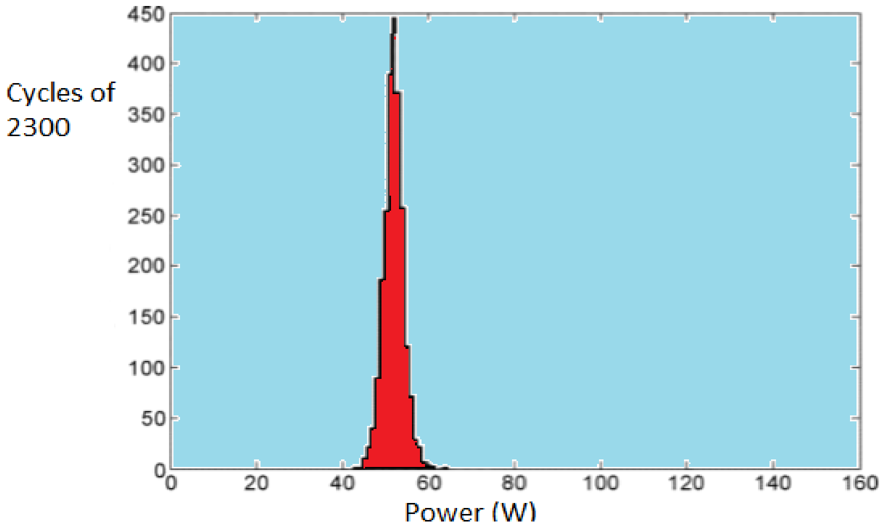

Fig 4 Power density of proposed converter

VII. Simulation Results

Simulink model of the proposed system in open loop is given in Fig 4 and output voltage and current waveform is shown in figure 5. The input voltage is given to buck converter and high frequency boost inverter convert dc to ac. Here duty ratio is 0.5 and is provided to each of the converter through a pulse generator. Output voltage obtained is 100V.

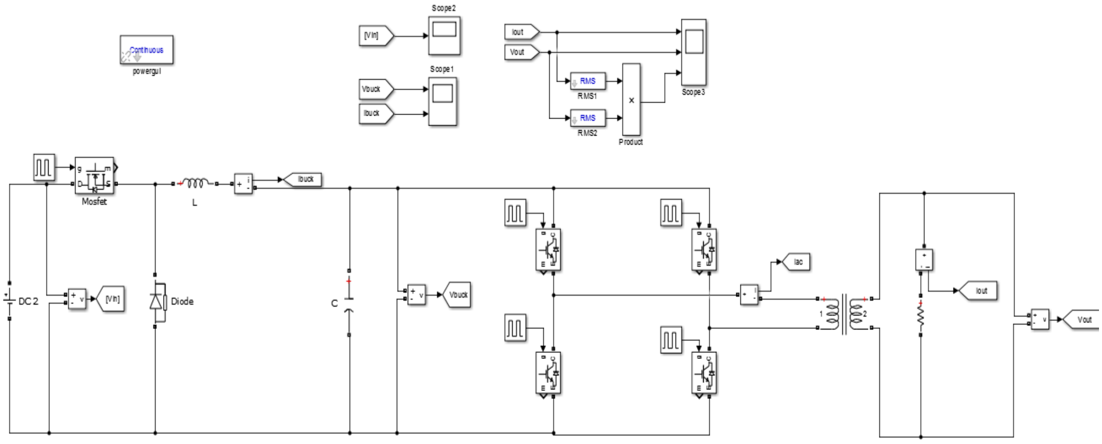

Fig 5 Open loop simulation of proposed converter

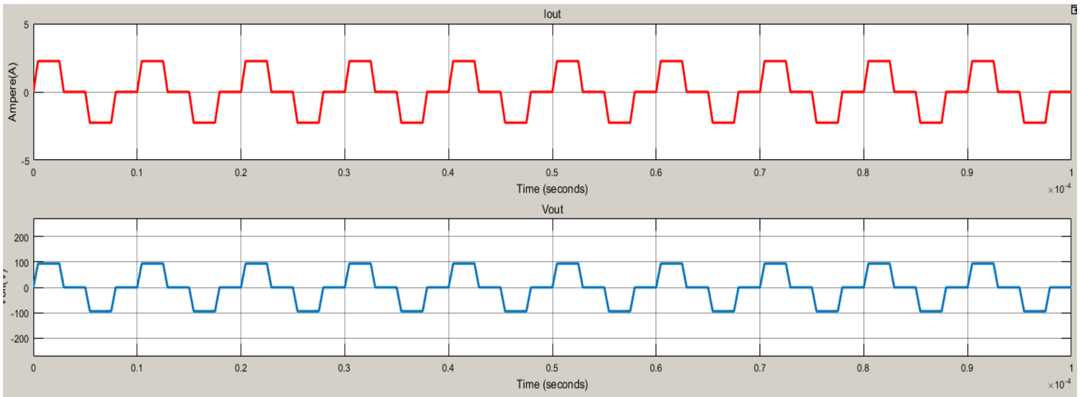

Fig 6 Output voltage and current waveform

Closed loop system and the sub blocks are shown in Fig 6 and Fig 7. The output voltage and current waveforms in closed loop are given in Fig 8. Here the duty ratio of each of the converter is given by current mode controller and voltage mode controller on controller block. Duty ratio will be selected according to the requirements by comparing with reference value. The three level output obtained will have high power density as shown in Fig 8.

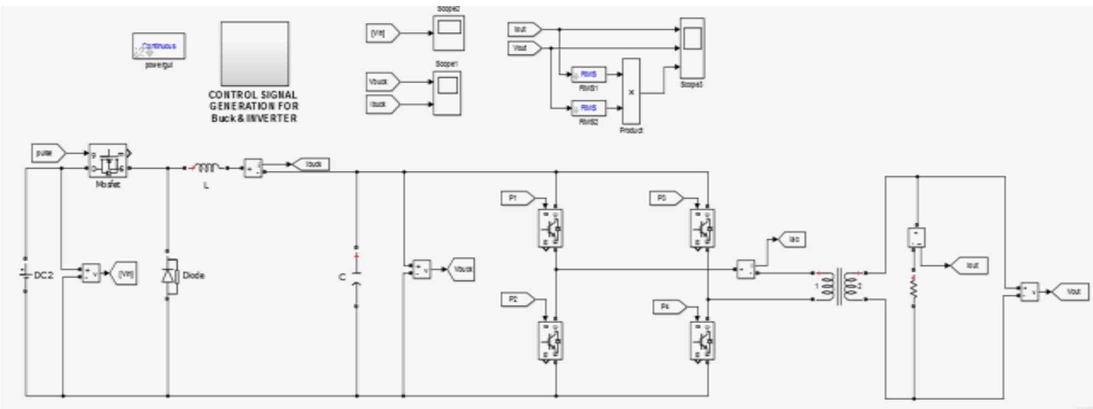

Fig 7 Closed loop control of proposed converter

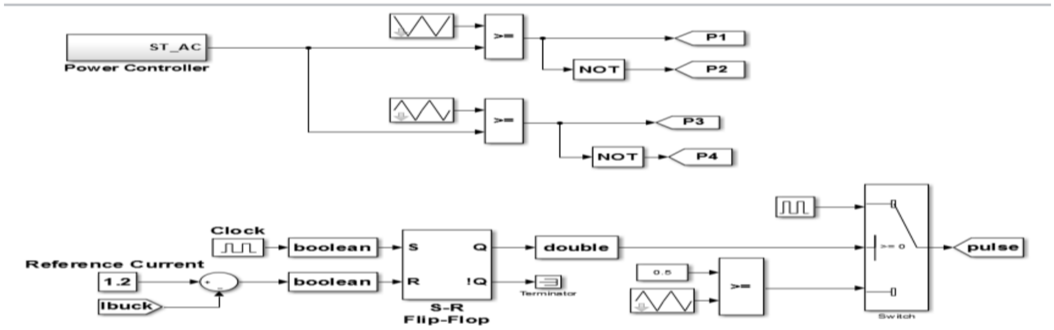

Fig 8 Sub blocks of controller

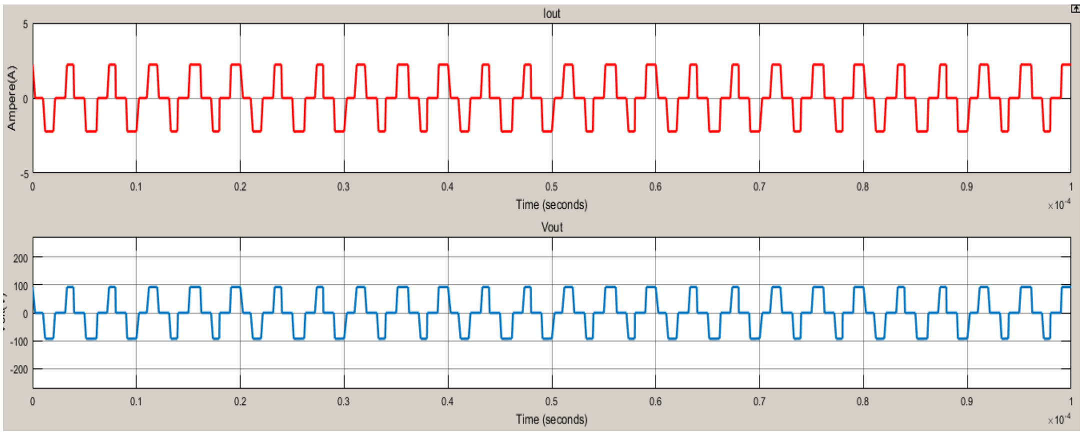

Fig 9 Output voltage and current waveforms in closed loop control.

VIII. Conclusion

A high-frequency and high-power density inverter has been presented in this paper. The proposed design enables voltage and current control improving magnetic hyperthermia therapies and opening new future possibilities in cancer treatment. Such type of converter can also be used in electrosurgical generators. The proposed design has been simulates using MATLAB, proving its correct operation and suitability for nanoparticle heating.

References

[1]. Gilchrist RK, Shorey WD, Hanselman RC, Parrott JC, Taylor CB. Selective inductive heating of lymph. Ann Surg 1957;146:596–606.

[2]. Chan DCF, Kirpotin DB, Bunn PA. Synthesis and evaluation of colloidal magnetic iron-oxides for the site-specific radiofrequency-induced hyperthermia of cancer. J Magn Magn Mater 1993;122:374–8.

[3]. Jordan A, Wust P, Fahling H, John W, Hinz A, Felix R. Inductive heating of ferrimagnetic particles and magnetic fluids: Physical evaluation of their potential for hyperthermia. Int J Hyperthermia 1993;9(1):51–68.

[4]. Maier-Hauff K, Ulrich F, Nestler D, Niehoff H, Wust P, Thiesen B, et al. Efficacy and safety of intratumoral thermotherapy using magnetic iron-oxide nanoparticles combined with external beam radiotherapy on patients with recurrent glioblastoma multiforme. J Neuro Oncol 2010:1–8.

[5]. Dudeck O, Bogusiewicz K, Pinkernelle J, Gaffke G, Pech M, Wieners G, et al. Local arterial infusion of superparamagnetic iron oxide particles in hepato-cellular carcinoma: a feasibility and 3.0 T MRI study. Invest Radiol 2006;41(6): 527–35.

[6]. Johannsen M, Gneveckow U, Eckelt L, Feussner A, Waldfner N, Scholz R, et al. Clinical hyperthermia of prostate cancer using magnetic nanoparticles: presen-tation of a new interstitial technique. Int J Hyperthermia 2005;21(7):637–47.

[7]. Johannsen M, Gneveckow U, Taymoorian K, Cho CH, Thiesen B, Scholz R, et al. Thermal therapy of prostate cancer using magnetic nanoparticles. Termoter-apia ccer de prstata mediate el uso de nanopartculas magnticas 2007;31(6): 660–7.

[8]. Johannsen M, Gneveckow U, Taymoorian K, Thiesen B, Waldofner N, Scholz R, et al. Morbidity and quality of life during thermotherapy using magnetic nanoparticles in locally recurrent prostate cancer: results of a prospective phase I trial. Int J Hyperthermia 2007;23(3):315–23.

[9]. Johannsen M, Gneveckow U, Thiesen B, Taymoorian K, Cho CH, Waldufner N, et al. Thermotherapy of prostate cancer using magnetic nanoparticles: feasibility, imaging, and three-dimensional temperature distribution. Eur Urol 2007;52(6): 1653–62.

[10]. Paolo Di Barba, Fabrizio Dughiero, Elisabetta Sieni, and Alessandro Candeo "Coupled Field Synthesis in Magnetic Fluid Hyperthermia", IEEE TRANSACTIONS ON MAGNETICS, VOL. 47, NO. 5, MAY 2011

[11]. Jordan A, Scholz R, Maier-Hauff K, Johannsen M, Wust P, Nadobny J, et al. Presentation of a new magnetic field therapy system for the treatment of human solid tumors with magnetic fluid hyperthermia. J Magn Magn Mater 2001;225 (1–2):118–26

[12]. Le Renard P-E, Jordan O, Faes A, Petri-Fink A, Hofmann H, Rüfenacht D, Bosman F, Buchegger F, Doelker E. The in vivo performance of magnetic particle-loaded injectable, in situ gelling, carriers for the delivery of local hyperthermia. Biomaterials 2010;31(4):691–705.

[13]. Ito A, Shinkai M, Honda H, Kobayashi T. Medical application of functionalized magnetic nanoparticles. J Biosci Bioeng 2005;100(1):1–11.
[14]. Sophie Laurent, Silvio Dutz, Urs O. Häfeli, Morteza Mahmoudi, "Magnetic fluid hyperthermia: Focus on superparamagnetic iron oxide nanoparticles", Advances in Colloid and Interface Science 166 (2011) 8–23
[15]. Mahmoudi M, Sant S, Wang B, Laurent S, Sen T. Superparamagnetic iron oxide nanoparticles (SPIONs): development, surface modification and applications in chemotherapy. Adv Drug Deliv Rev 2011;63(1–2):24–46.
[16]. www.magforce.de.
[17]. Gordon RT, Hines JR, Gordon D. Intracellular hyperthermia. A biophysical approach to cancer treatment via intracellular temperature and biophysical alterations. Med Hypothesis 1979;5:83–102.
[18]. H. Sarnago,, O. Lucia,, and J.M. Burdio, "High Frequency and Power Density Gallium Nitride Based Inverter for Magneto Fluid Hyperthermia", Industrial Electronics Society , IECON 2016 - 42nd Annual Conference of the IEEE, 23-26 Oct. 2016
[19]. Pollert E, Veverka P, Veverka M, Kaman O, Z v ›ta K, Vasseur S, et al. Search of new core materials for magnetic fluid hyperthermia: preliminary chemical and physical issues. Prog Solid State Chem 2009;37(1):1–14.
[20]. Mahmoudi M, Milani AS, Stroeve P. Surface architecture of superparamagnetic iron oxide nanoparticles for application in drug delivery and their biological response: a review. Int J Biomed Nanosci Nanotechnol 2010;1(2/3/4):164–201.
[21]. Mahmoudi M, Simchi A, Imani M. Recent advances in surface engineering of superparamagnetic iron oxide nanoparticles for biomedical applications. J Iran Chem Soc 2010;7:S1–S27.
[22]. Dutz S, Clement JH, Eberbeck D, Gelbrich T, Hergt R, Mueller R, et al. Ferrofluids of magnetic multicore nanoparticles for biomedical applications. J Magn Magn Mater 2009;321(10):1501–4.
[23]. Mahmoudi M, Milani AS, Stroeve P. Surface architecture of superparamagnetic iron oxide nanoparticles for application in drug delivery and their biological response: a review. Int J Biomed Nanosci Nanotechnol 2010;1(2/3/4):164–201.
[24]. Mahmoudi M, Simchi A, Imani M. Recent advances in surface engineering of superparamagnetic iron oxide nanoparticles for biomedical applications. J Iran Chem Soc 2010;7:S1–S27
[25]. Mahmoudi M, Hosseinkhani H, Hosseinkhani M, Boutry S, Simchi A, Journeay WS, et al. Magnetic resonance imaging tracking of stem cells in vivo using iron oxide nanoparticles as a tool for the advancement of clinical regenerative medicine. Chem Rev 2011;111(2):253–80.
[26]. Mahmoudi M, Shokrgozar MA, Simchi A, Imani M, Milani AS, Stroeve P, et al. Multiphysics flow modeling and in vitro toxicity of iron oxide nanoparticles coated with poly(vinyl alcohol). J Phys Chem C 2009;113(6):2322–31.
[27]. Mahmoudi M, Simchi A, Imani M. Cytotoxicity of uncoated and polyvinyl alcohol coated superparamagnetic iron oxide nanoparticles. J Phys Chem C 2009;113(22): 9573–80.
[28]. Mahmoudi M, Simchi A, Imani M, Häfeli UO. Superparamagnetic iron oxide nanoparticles with rigid cross-linked polyethylene glycol fumarate coating for application in imaging and drug delivery. J Phys Chem C 2009;113(19):8124–31.
[29]. Mahmoudi M, Simchi A, Imani M, Milani AS, Stroeve P. An in vitro study of bare and poly(ethylene glycol)-co-fumarate-coated superparamagnetic iron oxide nanopar-ticles: a new toxicity identification procedure. Nanotechnology 2009;20(22): 225104.
[30]. Mahmoudi M, Simchi A, Imani M, Shokrgozar MA, Milani AS, Hafeli UO, et al. A new approach for the in vitro identification of the cytotoxicity of super-paramagnetic iron oxide nanoparticles. Colloids Surf B Biointerfaces 2010;75(1): 300–9.
[31]. Mahmoudi M, Simchi A, Milani AS, Stroeve P. Cell toxicity of superparamagnetic iron oxide nanoparticles. J Colloid Interface Sci 2009;336(2):510–8.
[32]. Mahmoudi M, Simchi A, Vali H, Imani M, Shokrgozar MA, Azadmanesh K, et al. Cytotoxicity and cell cycle effects of bare and poly(vinyl alcohol)-coated iron oxide nanoparticles in mouse fibroblasts. Adv Eng Mater 2009;11(12): B243–50.
[33]. Mahmoudi M, Sardari S, Shokrgozar MA, Laurent S, Stroeve P., Interaction of superparamagnetic iron oxide nanoparticles with human transferrin: Irrevers-ible changes in human transferrin conformation. Nanoscale 2010 Revised.
[34]. Mahmoudi M, Simchi A, Imani M, Stroeve P, Sohrabi A. Templated growth of superparamagnetic iron oxide nanoparticles by temperature programming in the presence of poly(vinyl alcohol). Thin Solid Films 2010;518(15):4281–9.
[35]. Karlsson HL, Cronholm P, Gustafsson J, Muller L. Copper oxide nanoparticles are highly toxic: a comparison between metal oxide nanoparticles and carbon nanotubes. Chem Res Toxicol 2008;21(9):1726–32.
[36]. D. A. Friedrichs, R. W. Erickson, and J. Gilbert, "A New Dual Current Mode Controller Improves Power Regulation in Electrosurgical Generators," IEEE Transactions on Biomedical Circuits and Systems, vol. 6, pp. 39-44, 2012.

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