JPE 4-1-2

Performance Evaluations of a Novel Prototype of High Frequency Non-Contact Power Transformer

Laknath Gamage†, Manabu Ishitobi and Mutsuo Nakaoka

ABSTRACT

In this paper, a practical implementation to reduce leakage flux of a high-frequency inverter based non-contact type power transformer composed of EE-shape ferrite cores is presented for key technology of the next generation medical use X-ray CT scanner system Design consideration for the unique structure of the non-contact power transformer with 900mm in diameter is also introduced The complete non-contact transformer is actually arranged by several blocks of the magnetic circuit assembled by using 10 small EE shape cores with 120mm in length It is experimentally and analytically discussed from a reduced leakage flux viewpoint related to its inductively coupling coefficient A practical method to lower the leakage flux is described based on effective Copper-Sheet-Treatment placed on EE shape ferrite cores of magnetic circuit.

Keywords · Non-contact power transformer, EE shaped ferrite core assembly, Inductively Coupling coefficient, Copper-Sheet-treatment of magnetic circuit, Hight Frequency Inverter

1. Introduction

In general, conductive connecting terminals are widely required for transferring electric power to the secondary battery banks, supper capacitor assembly, electric mach ines, lighting equipments and electronic appliance How ever, because of inferior connection, water or dust, corro sion and electric shocks might occur where connectors or terminals are essential. Not only to overcome these probl ems but also to make use of some other advantages, several feasible developments on non-contact transformer type or inductively mutual coupling type power supply circuit and systems have been carried out from an application point of view Those related studies and developments are more required and acceptable for a variety of power conditioning and processing converters applicatations such as battery chargers for artificial hearts multi-links [3], [4], conveyance vehicles [5], [1] and the other

Table 1 A variety of Non-Contact Power Supply Systems

Input	Output	Output Power	Application
15V 2 5A DC	12V 2A DC	24W	Artificial Heart[7]
125V 0 4A DC	12V 3A DC	36W	EV-Battery Charger[17]
33 2V 3 6A DC	48V 2A DC	96W	EV-Battery Charger[15]
60V 2A DC	5V 20A DC	100W	Artificial Heart[18]
190V 3 2A DC	300V 1 9A DC	558W	Electric-conveyer Charger[19]
14 3V 333 6A	120 4V 24 1A	2 5kW	Under water power delivery[20]
230V 16A	200V 16A DC	3 2kW	EV-Battery Charger[14]
200V 30A	230V 14A DC	3 3kW	EV-Battery Charger[4]
300V 67A DC	400V 45A DC	20kW	EV-Battery Charger[16]
800V 150A DC	800V 141A DC	113kW	EV Battery* Charger[2]

*With matching transformer

organs, electric vehicles[2], robotics with aircraft- passen ger entertainment power distribution equipments [6] medical power electronics appliances [7], consumer prod ucts [8] and so forth Table 1 indicates some concrete pow er applica tion areas of non-contact inductively coupled power transmission systems [9] [10] As great possibilities of these related power transmission-processing fields, there

Manuscript received October, 8 2003
Revised November 30, 2003.
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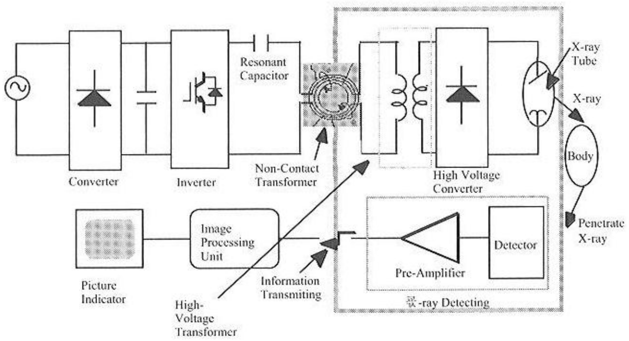

Fig. 1. CT Scanner System with Non-Contact Power.Conversion Transformer.

are now hundreds of patents on non-contact power transmission systems, starting from Nicola Tesla's patent on electric railway system in 1892[11]. On the contrary, only a few published papers are actually available in spite of a large number of patents [12]. Of these, as far as the authors know, there are not any published research works on a non-contact power transmission and delivering system applied to a CT scanner system. The main reason for this is that the required feasible conditions cannot be achieved due to the large magnetizing current flow. In other words, due to the small magnetizing indu ctance, it gives a loose magnetic coupling coefficient to the non-contact power transformer of such a system mentioned above. This paper deals with a unique practical technique to magnify the coupling coefficient based on "Copper-treatment" of its magnetic circuit.

In this paper, a practical implementation to reduce leakage flux of a high-frequency resonant inverter based non-cont act type power transformer composed of EE-shape ferrite cores is presented for key technology of the next gener ation medical use X-ray CT scanner system. Design considerations for the unique structure of the non-contact power transformer (900mm in diameter) for the power delivery system, are also introduced. In this paper, part of the whole non-contact transformer, designed for 120mm in length is designed and arranged by 10 small EE shape cores which is analytically and experimentally discussed and evaluated from the reducing leakage flux viewpoint related to the inductively coupling coefficient. The practicle method to lowered the leakage flux is described and discussed on the basis of effective Copper-Sheet -Treatment placed on the EE shape ferrite cores as the magnetic circuit.

2. Non-contact high frequency power transformer and X ray CT scanner system

The developments of advanced medical power electronics technology required for high speed operation of X-ray CT scanner, have attracted special interest for introducing non-contact power transmission transformers instead of slip-rings used commonly in conventional[13] X-ray CT scanners to deliver the electric power from the stationary part to the rotary part.

In general, magnetic inductive coupling in non contact transformer is the most important design factor in realization of a non-contact power transmission and delivering system. Therefore, the authors have focused upon the main research and development topics on the coupling coefficient of a non-contact power transformer incorporated into an X-ray CT scanner for medical use. An X-ray CT scanner system configuration with the non-contact power transmission transformer is schema tically demonstrated in Fig. 1; and a detailed system configuration of the non-contact power transfor mer to be connected to a high-frequency inverter is illustrated in Fig. 2. This structure of the most essential non-contact power transformer is quite different from the other non-contact power supplying systems which have been discussed so far. That is because, the secondary side of the non-contact transformer in an X-ray CT scanner equip ment can rotate and the high-frequency non contact transformer size is relatively large since a human body has to enter in to this rotating non contact high-frequency transformer for medical X-ray imaging diagnosis. As the secondary side of non contact transformer is usually rotating, the high-frequency non contact power trans former is designed so as to be symmetrical. Therefore, using a non -contact transformer of O-O type(That is ring type) magnetic coupling cores make best fitting for this kind of power processing system. Since the diameter of a core is practically 900mm as shown in Fig. 2, it is difficult to craft such a big core out of one lump of ferrite. Even though it is possible, the cost could be very high for practical implementation. Therefore, the authors propose small EE type ferrite cores assembly as illustrated on Fig. 2, that can cheaply be purchased on the market to fabricate the magnetic circuit of the unique high-frequency non -contact power transformer.

In experiment, the authors have build 3kW power level

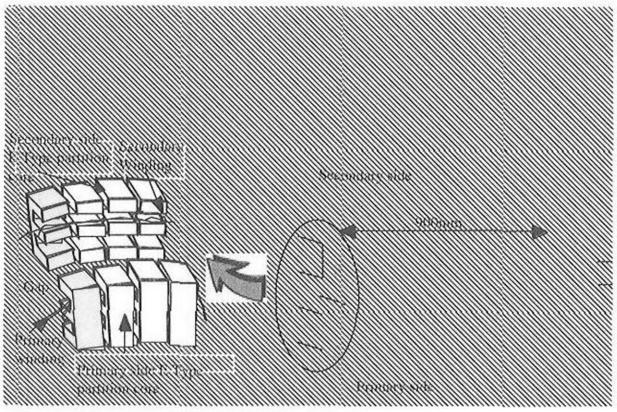

Fig. 2. Detailed Non-Contact Power Conversion Transformer.

setup with high efficiency. It is difficult to meet more than 3kW as output power rating, due to the drastic increase of excitation current in non-contact transformer with a small magnetizing inductance. The large leakage flux at the air gap of non-contact power transformer is the reason for this.

Our main research aim is to develop only the non-contact

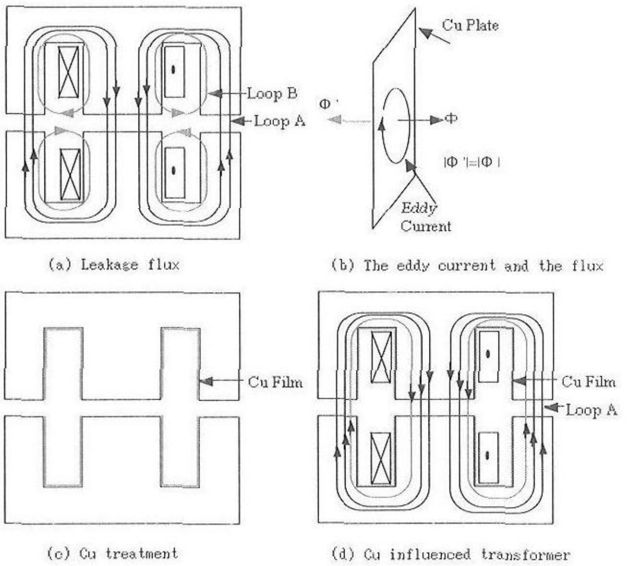

Fig. 3. The Copper-treatment at Ferite EE Core of Non-Contact Power Supply Transformer.

power transmission transformer of the proposed X-ray CT scanner system on the basis of magnifying the coupling coefficient by introducing the innovative Copper-treatment approach of EE shape cores based magnetic circuit. The technical problem is discussed for the following items.

(1) The influence of the air gap on the coupling coefficient of EE ferrite cores.

(2) The influence of the Copper-treatment on EE ferrite cores on coupling coefficient of the non-contact power transmission transformer.

3. Core assembly concept of Copper-treat ment on EE shape cores based magnetic circuit

Since the flux leakage at the air gap of the non-contact power conversion transformer is unavoidable, the authors desire to stop other flux leakage in the sense of having a better coupling coefficient by placing a Copper thin film at the window frame of the non-contact power transmission transformer as shown in Fig. 3. Figure 3(a) illustrates that the leakage flux in the core window and Fig. 3(d) depicts the reduced leakage flux because of the Copper-treatment. For EE ferrite core shape, as can be seen in the Fig. 3(c), a Copper thin film produces eddy current that makes another flux against the leakage flux and the leakage flux can in principle, be conveniently eliminated as shown in the 3(b).

4. Experimental and Simulation Results

As can be seen in Fig. 4, the experimental results show that the coupling coefficient k of the non-contact power transmission transformer goes down in accordance with the air gap. In the case of high power applications a low coupling coefficient is troublesome for the required air gap.

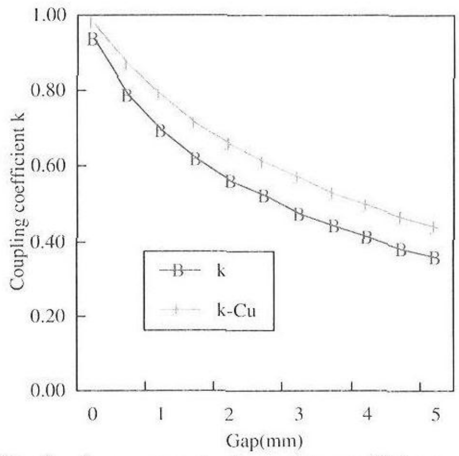

Fig. 4. Improvement of coupling coefficient in. non-contact transformer.

At the same time, Fig. 4 depicts the coupling coefficient (k-Cu in the figure) of the non-contact power transmission transformer that is treated by a thin copper film is much higher than that of the normal non-contact power transmission transformer. The results of magnetic analysis with MSC/Patran and ELF/Magic tools, that use the integral element method also prove of this. For the analysis in this case, primary and secondary side cores of the non-contact power transmission transformer were divided in to 698 small elements as shown in Fig. 5.

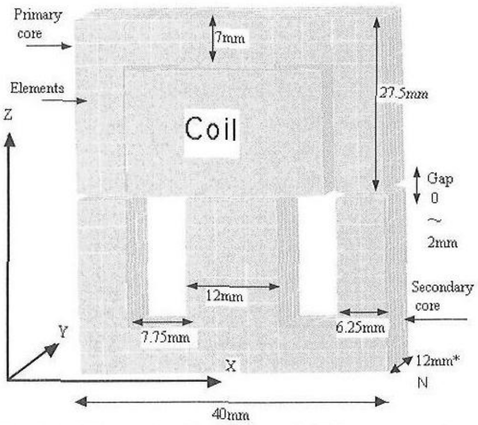

Fig. 5. EE type traformer model for maganetic field analysis.

The right hand side of the line in the middle of Fig.6, shows the secondary side of the non-contact power transmission transformer and the contrary is primary side of the non-contact power transmission transformer. From this analysis, it is noted that the flux density belongs to those elements depicted in Fig. 5. It is clear that the difference of the flux density varies with the place of the EE cores, but on the whole, the flux density is higher when the thin copper film in the core window frame or legs is present. However, the flux leakage of the air gap of the non-contact power transmission transformer can not be blockaded by this copper treatment. As described above, the flux density of the EE shaped ferrite cores takes high values, after treating it on the basis of the thin copper film and therefore, the coupling coefficient of the non-contact power transmission transformer increases. It is proved that, according to experiment and simulation results, this thin copper film treatment is useful in improving the coupling coefficient of a non-contact transformer or an inductive coupler.

5. Ring Type Transformer with Small EE Shape Cores

The magnetic flux that leaking around the core is shown in Fig. 7(a), and the direction Z is the height direction of the EE shape ferrite cores. Large flux leakage can be seen in the region of the gap area, inside the core window. The arrow marks representing the vector of the leakage

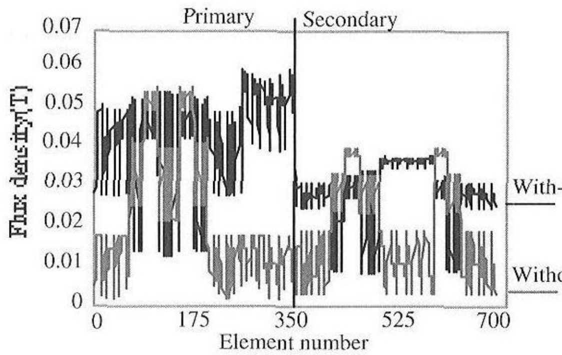

Fig. 6. Comparision of magnetic flux density when Copper-treatment applied to ferite EE Core of non-contact Power Supply transformer.

flux. Fig. 7(b) depicts the flux density inside the core and the leakage flux around the core towards the Y direction,

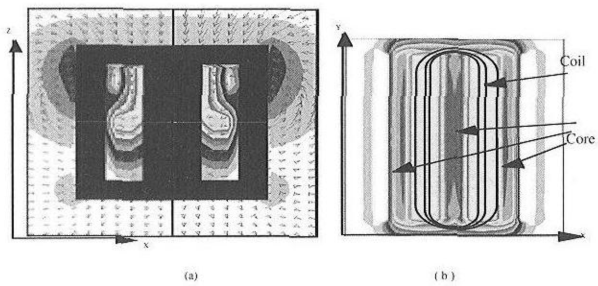

Fig. 7. Magnetic flux around the EE type traformer core.

where the next small type EE core to be fixed for manufacturing the large ring type non-contact power transmission transformer. As can be seen in the Fig. 7(b), fixed flux distribution has leaned towards the Y direction.

At the same time, to some extent, leakage flux can be seen at the end of the small non-contact power transmi ssion transformer block. This amount can be neglected since it is not big enough to effect the neighboring small type transformers in the ring type non-contact power transmission transformer structure .Therefore it is possi ble to manufacture a large ring type non-contact power transmission transformer with the use of small type EE shaped cores that is cheap in the market.

6. Conclusions

The paper described a novel method to increase the magnetic coupling coefficient of a non-contact power transmission transformer. The actual efficiency in a non-contact power transmission transformer deteriorates with the air gap distance between the primary and the secondary sides of this non-contact transformer. This condition does not change even after the Copper-treatment for EE shape ferrite core, explained in this paper. However, after this Copper-treatment, It is proved in experiment and simul ations that the leakage flux of the non-contact power transmission transformer can be substantially reduced by applying the Copper-treatment on EE shape cores. As a result, the magnetic coupling coefficient of non-contact power transmission transformer goes up, effectively. At the same time it is capable of manufacturing a large ring type non-contact transformer with the use of small EE type ferrite cores that is cheap in the market.

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