POWER TRANSMISSION CHARACTERISTICS OF FEASIBLE N0N-CONTACT PICK-UP COIL COUPLED TO HIGH-FREQUENCY POWER SUPPLY SYSTEM

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ABSTRACT- This paper conducts a study on a non-contact power delivering system using high-frequency inverter with the purpose of discussing the non-contact electric power transmission characteristics through circuit analysis, magnetic analysis and feasible experiments. In this power delivering scheme. various properties pertaining to the non-contact transformer of the power system such as the design, the core depth, core material, primary side frequency etc. are considered with a view of improving the non-contact power dilivery to the secondary.

1. INTRODUCTION

A non-contact power delivery system utilizes the concept of magnetic inductive coupling to transfer power from one point to another with absolutely no direct electric contact. Non-contact power supply systems have a variety of practical advantages such as safety and reliability with regard to explosion and electric shock, less maintenance, no wear and tear etc. as compared to a conventional power delivery system which has to have a connector or adapter which would give rise to all the aforesaid negative aspects. Furthermore, the system itself is extremely clean since it does not carry any dust, has no particles arising from wear etc. Hence, there is great potential for non-contact power supply techniques in carriers which use high-frequency rails for propulsion.

Even though the basic principle of the non-contact power supply system have a long history as presented in Nicola Tesla's patent for electrostatic coupling and Maurice Hutin's patent for electromagnetic coupling which were published over 100 years ago, it holds greater potential now as never before with the recent developments in power electronics and non-contact power supply techniques. With this technical background, some interesting papers have been presented recently on non-contact power transmission supply circuit and system techniques . Even though various non-contact power transmission systems have been evaluated in [1], [2] and [3], the transformer characteristics and its influence from the core part has not been evaluated in detail so far. On the other hand, the circuit aspect of the magnetic coupling core with windings has been discussed in [4].

In this paper, our purpose is to give clear evaluations of the power transmission characteristics on a type of non-contact coupling transformer by circuit analysis, magnetic analysis and experimental results.

2. TOPOLOGY OF THE PICK-UP COIL

The high frequency inverter-fed non contact power transmission supply system consists of a specially designed non-contact pick-up coil with an externally parallel resonant capacitor, AC-DC converter and the motor drive load. The most important component in the non-contact power transmission system is the specially-designed non-contact magnetic inductive coupling which is shown in Fig. 1. As can be seen in this figure, the high frequency current flowing through the single turn primary winding which is connected to the high-frequency power transmission busline generates high-frequency flux across the secondary winding and receives the power without any moving or static contact .

Due to the large gap between its primary and secondary windings of the magnetic inductive coupling device of the pick-up coil with a non-contact transformer configuration develops a weak magnetic coupling coefficient.

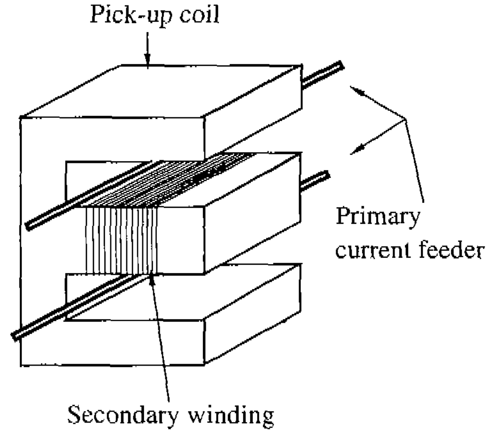

Fig. 1 Configuration of inductive coupled pick-up coil

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As a result, much of the primary current becomes an exciting current of this magnetic coupling system and in order to overcome this while increasing the effective power, it is necessary to parallely connect a resonant capacitor to the secondary winding of the pick-up coil. Furthermore, it is necessary to select the primary current frequency to be equal to the resonant frequency.

In order to get a better understanding of the pick-up coil and its power transmission characteristics, the magnetic field of the pick-up coil was analyzed by a computer software developed by Shinko Electric Co. Ltd.. The analytical results of the magnetic field when the high-frequency power supply primary winding lies in the innermost part of the magnetic core flux path is given in Fig. 2.

From these results it can be seen that the large air gap between the primary and the secondary core gives rise to a large flux leakage. Hence, it is necessary to place the secondary winding in the inner most part of the magnetic core window in order to increase the efficiency of power transmission in the contactless coupling system.

From this magnetic field analysis it can be further construed that the mutual induction between the secondary and primary winding differs around 3 percent on account of the placement of the single turn primary winding and hence, the magnetic inductive coupling of the power transmission system will not be stable. It is also noted that the non-contact power supply core does not saturate within the applied limits of flux .

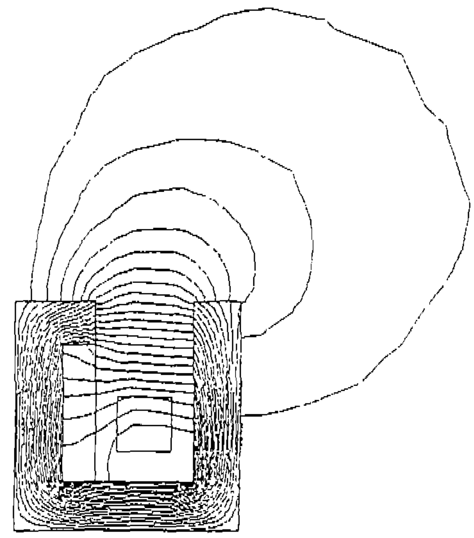
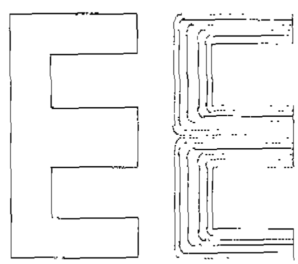


Fig.2 Analytical results of magnetic fields



Ferrite Steel laminated core

Fig. 3 Laminated layer direction of the Silicon Steel Laminated core

3. EFFECT OF CORE DESIGN ON POWER TRANSMISSION PERFORMANCE

Core material

The influence on the power transmission characteristics with materials for magnetic inductive coupling pick-up coil. Ferrite core (2500B) and Silicon steel laminated core (0.1mm), is discussed here. The thin Silicon steel core is designed as shown in the Fig. 3 where the laminated layer direction consists of two U-cores whereas the Ferrite is of one E-shaped core. The experimental results conducted with this core for the two different materials on the delivered power for various equivalent load resistances are shown in Fig. 4.

The results show that delivered power transmission capability is high for the Ferrite core as compared with the Silicon steel laminated core under the same primary current and resonant capacitor in parallel with load. Under further analysis, the cause of this low power transmission of the Silicon Steel laminated core can be attributed to the piling layer direction, where the flux direction is perpendicular to it and also due to the current losses generated by the high frequency. By considering the piling layer direction in more detail, it is possible to de

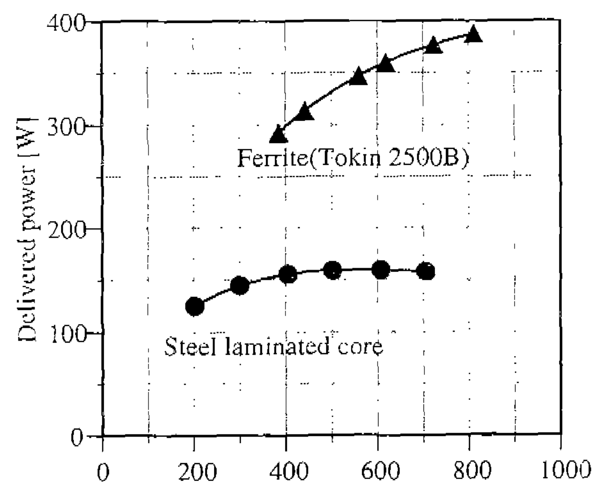


Fig. 4 Power transmission characteristics for magnetic core materials

crease the current losses due to high frequency and obtain a Silicon steel laminated core characteristics close to that of the Ferrite core characteristics. However, considering the unsteady flux direction due to the large flux leakage of the pick-up coil the characteristics of the Ferrite core is much better than that of the Silicon steel laminated core.

Core depth

The variation of the power transmission characteristics with the core depth for two different loads are depicted in Fig. 5. Observing these results, it can be concluded that the power transmission characteristics are proportional to the depth of the core, the lager the depth of the core the better the transmission characteristics.

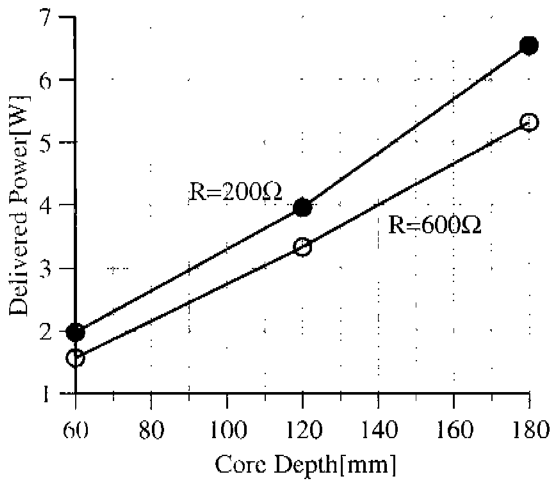


Fig. 5 Power transmission characteristics of magnetic core depth

4. EFFECT OF PRIMARY AND SECONDARY WINDINGS

Equivalent Circuit

The transformer equivalent circuit of the magnetic coupled pick-up coil is depicted in Fig. 6. In this equivalent circuit, the load is considered as a resistive load R and the circuit analysis has been conducted with P-SPICE (Micro. Sim Corp.). The variation of the analyzed power transmission with the equivalent resistance R is depicted in Fig. 7 where curve A refers to the ideal conditions of both iron loss r_0 and copper loss r_2 are zero. On the other hand, curve B gives the results when both r_0 and r_2 have been taken into account. From this Figure, it can be seen that the delivered power proportionately increases with the equivalent load resistance under ideal conditions but whereas the delivered power has a peak value when both losses are at play.

In order to confirm the simulation results, an experiment was conducted using the test circuit illustrated in Fig. 8 and the corresponding results are given in Fig. 9. The parallely connected capacitor in the test circuit was selected so that the resonance frequency is identical to the frequency of the primary winding. Upon comparison of Fig. 9 with Fig. 7, it is seen that the test results agree well with that of the simulation, with a peak delivered power at a given value of the equivalent resistance.

As a result, it is to be noted that the power transmission characteristics of the inductive coupling pick-up coil treated here is easy to be influenced by the iron loss and copper loss. Furthermore, it is also noted that the magnetic inductive coupling coefficient of the pick-up coil is quite weak which gives rise to a power loss.

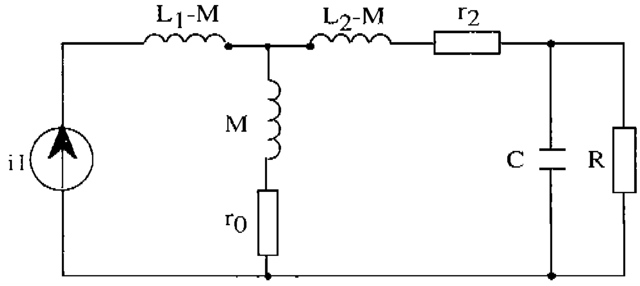


Fig. 6 Equivalent circuit of pick up-coil

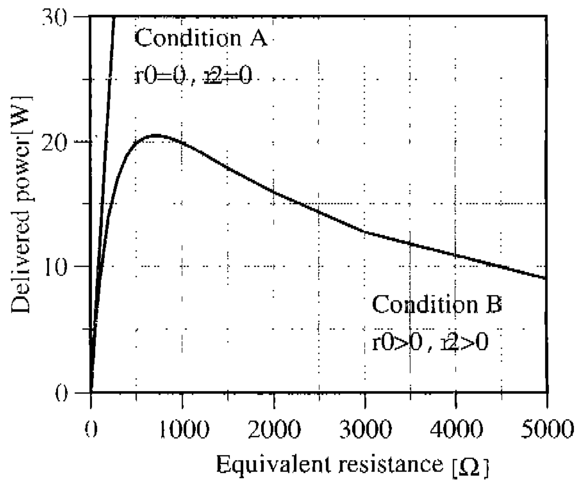


Fig. 7 Analytical ooutput performances obtained from equivalent circuit

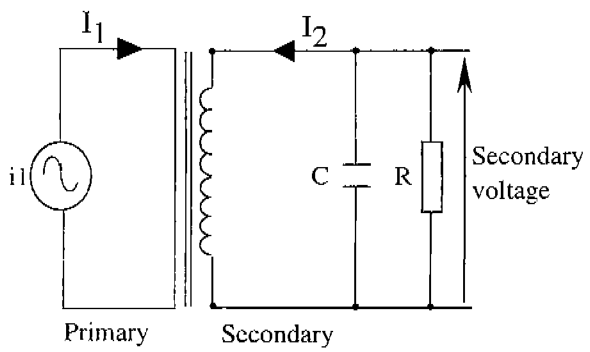


Fig. 8 Test circuit of pick up-coil

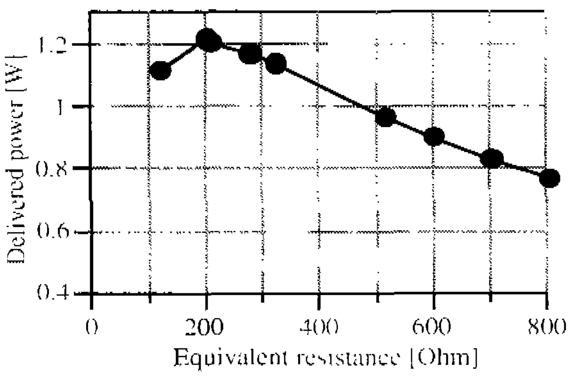


Fig. 9 Power transmission characteristics between delivered power and equivalent resistance

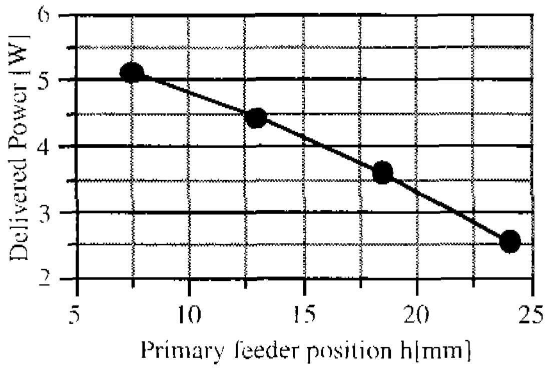


Fig. 10 Power transmission characteristics for position of primary feeder

Effect of Primary Winding Position

All the experiments have been conducted by placing the primary winding at a fixed position of 7.5mm from the innermost part of the core. However, in this experiment the power transmission characteristics are measured by changing the position of the primary winding and the corresponding results are displayed in Fig. 10. Observing these results, it is noted that the maximum power transmission is obtained when the primary winding is placed at the innermost part of the magnetic core.

Analyzing the magnetic field of the core it is seen that the power transmission depends on the position of the primary feeder and should be placed such that there is maximum flux crossing the secondary winding perpendicularly. When the position of the primary feeder moves away from the magnetic core, the flux that cross perpendicularly reduces and as a result the power transmission decreases. This result has an influence on the mutual induction which occurs due to the change of the primary feeder position.

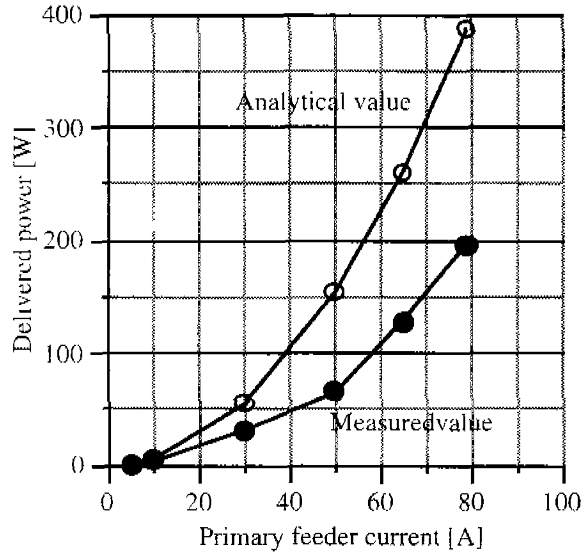


Fig. 11 Power transmission characteristics for primary feeder current

Effect of Primary current

The influence of the current I_1 in the feeder side on the power transmission characteristics of the non contact power supply is discussed within the limits of core saturation. Experimentally measured and analytical results taken for the case when current of the equivalent circuit is identical to the primary feeder current of the test circuit ($i_1=I_1$), are given in the Fig. 11.

Even though the measured and analytical values agree when the primary feeder current is small, the results indicate a growing difference between these values as the latter increases. The main reason for this difference is attributed to the additional increase of iron loss with the increase in the perpendicular flux that crosses this core as a result of the increase in the primary feeder current.

Under these consideration excellent power transmission characteristics could be obtained in accordance with increasing the primary feeder current, but beyond a certain limit, the increase of the power transmission will not be that significant..

Effect of Primary frequency

In order to study the effect of the inverter frequency of the primary feeder current on the power transmission characteristics, this frequency is varied while keeping the secondary side resonant frequency f_0 of the inductive coupling pick-up coil constant.

Two types of equivalent load resistances R in the test circuit shown in Fig. 6 are selected to measure the frequency and the power transmission characteristics and the results are represented in Fig. 12. These results illustrate a maximum Delivered Power when the inverter frequency of the primary is equal to the resonant frequency f_0 in secondary side for both load resistances.

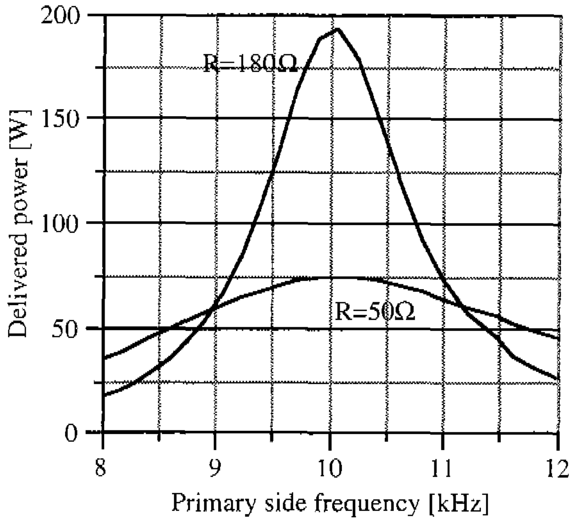


Fig. 12 Power transmission characteristics for primary current frequency

It also depicts a considerable enhancement of the power transmission for a large load resistance. However, the larger load resistance also gives a high Q-value which results in a greater sensitivity to frequency variations. From the view point of the frequency variation of the system and its effect on the performance it is better that the load resistance is small which would, though, give a smaller power transmission. Therefore, considering these facts, it is necessary to carefully design the system taking into consideration the frequency variations of the system and the required level of power transmission.

5. CONCLUSION

Steady-state power transmission performance of a non-contact inductive coupling pick-up coil which could be used for an inverter-fed carrier vehicle system has been presented here. Following conclusions could be derived from the magnetic field analysis of non-contact core, in addition to the system circuit analysis and experiments for power transmission of the pick-up coil which has been coupled inductively.

(a) In order to deliver effective power from a non-contact power transmission system, the secondary circuit of the inductively coupled pick-up coil should be a resonant circuit in parallel with the desirable load.

(b) Extremely low magnetic inductive coupling coefficient appears on the non-contact pick-up coil system which links to the primary feeder connected to the high frequency inverter.

(c) Power transmission characteristics of the non-contact power supply system treated with the specially designed core is greatly influenced by the Iron loss and the Copper loss factors of the magnetic inductive coupling pick-up coil.

(d) This non-contact power delivering system would deliver a maximum power transmission at a particular equivalent load resistance value.

(e) By using a Ferrite core instead of Silicon steel laminated core for the non-contact transformer, it is possible to have 2 to 3 times of power transmission efficiency.

(f) Transmission power is almost proportional to the core depth of the pick-up coil.

(g) To obtain a high power transmission efficiency, the primary feeder should be placed in the most inner part of the magnetic core.

(h) The power transmission capability would increase with the rise in the primary feeder current but would not be that significant beyond a certain limit of the primary current.

(i) A greater power transmission could be obtained for a large load resistance but will be very sensitive to frequency variations. Hence, the system should be carefully designed to reap the maximum power transmission whilst taking into consideration the frequency variations of the system.

Further more , in the future, the precise equivalent circuit and system modeling of contactless magnetic inductive coupling device driven by efficient high-frequency resonant inverter, which includes the iron and copper loss components, should be studied together with performance evaluation of the resonant type non-contact magnetic inductive coupling device. Also, the efficiency of non-contact power supply from the view point of the primary side should be evaluated as compared with the system when several pick-up trolleys are fitted to one primary supply coil.

6. REFERENCE

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