Performance Evaluation of Square Coupled Coils at Different Misalignments for Electric Vehicle Battery Charging

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Keywords: Wireless Power Transfer, Mutual Inductance, Electric Vehicle, Misalignment.

Abstract: Wireless Power Transfer (WPT) for electric vehicle battery charging is an advancing battery charging technology. The crucial part in the WPT system is the coupling coil structure and it plays a major role in effective power transfer. This paper describes the mutual inductance and flux distribution characteristics of the square coupled coils with different misalignments also to make more realistic for Electric Vehicle (EV) battery charging applications the coupled coils are designed with and without core and chassis. The evaluation contains the mutual inductance gets affected by distance between the coils, lateral and angular misalignment effects. The results of the analysis are used in the implementation of the wireless EV battery charging system.

1 INTRODUCTION

The popularity of Electric propulsion vehicle in automobile industry sector has always been increasing due to many positive aspects of energy efficiency, environment friendliness, performance, and reduced energy dependence on fossil fuels. However, the use of EV faces some challenges like driving range, recharge time, battery cost, more bulk, and weight (Khaligh, 2012), (S. Li, 2014). Thus, with the growing EV market, we need to overcome the problems by stimulating new ideas and developments in this area. On that concern EV battery charging is an emerging research area. In conventional conductive battery charging introduces the inconvenience and risk hazards and this type of problems can be overcome by a simple concept wireless battery charging (Roman, 2016), (Seho Kim, 2017). The principle of the wireless power transfer (WPT) is like conventional transformer i.e., mutual induction. When a current carrying conductor or coil is excited with alternating source it will produce magnetic field around the conductor or coil. When another coil is brought in the vicinity of the magnetic field of the first coil an EMF will be induced due to alternating nature of the magnetic field (F. Y. Lin, 2015), (Fariborz, 2014). In the WPT system coil connected to the source is referred as transmitter coil (Tx), and the coil connected to the load called as receiver coil (Rx).

However, the potency of the power transfer over this inductive link predominantly depends on flux linkages between the coupled coils and structure of the coils. Based on the specific application, the coil structures like circular, rectangular, DD & DQ and square shapes (C. Y. Huang, 2015), (Ezhil, 2015) can be used. The shape of the coil and misalignment greatly affects the mutual inductance and flux linkage between the coupled coils. The amount of power transfer and efficiency mainly depends on MI (Dharavath, 2016). So, it is necessary to obtain the MI for designing of the any wireless power transfer system in particularly EV battery charging application. The design and optimization of circular magnetic structure is described (M. Budhia, 2011) for wireless EV battery charging applications. Based on the 3D field the mutual inductance between the circular coupled coils is obtained for IPT system (Yang Han, 2015) and presented the misalignment conditions for circular coupled coils. (Merugu, 2016) explained the effect of spiral square coil dimensions of the square coupled coils on power transfer capability, efficiency.

In this paper coupling characteristics of square inductive coupled coils are described with different misalignments. The basic schematic diagram representation of wireless electric vehicle battery

Nayak, P., Dharavath, K., Dey, R., Sundareswaran, K. and Simon, S.
Performance Evaluation of Square Coupled Coils at Different Misalignments for Electric Vehicle Battery Charging.
DOI: 10.5220/0006672402900297
In *Proceedings of the 4th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2018)*, pages 290-297
ISBN: 978-989-758-293-6

charging system is shown in Figure.1. The figure gives the power flow in the WPT system.

The WPT system representation of schematic diagram consists of High-frequency inverter, transmitter, and receiver compensation circuits, inductive coils and battery charging unit. The high-frequency inverter converts the DC input supply to high-frequency AC supply. The output of the inverter is fed to power compensation circuits which are used for performance improvement of the wireless power transfer system. The transmitter and receiver coil are connected to respective compensation circuits. The power transfer takes place between inductive coils maintained at the proper air gap. Battery Charging unit includes suitable power converters and the battery pack to be charged and it is connected to the receiver side of the system.

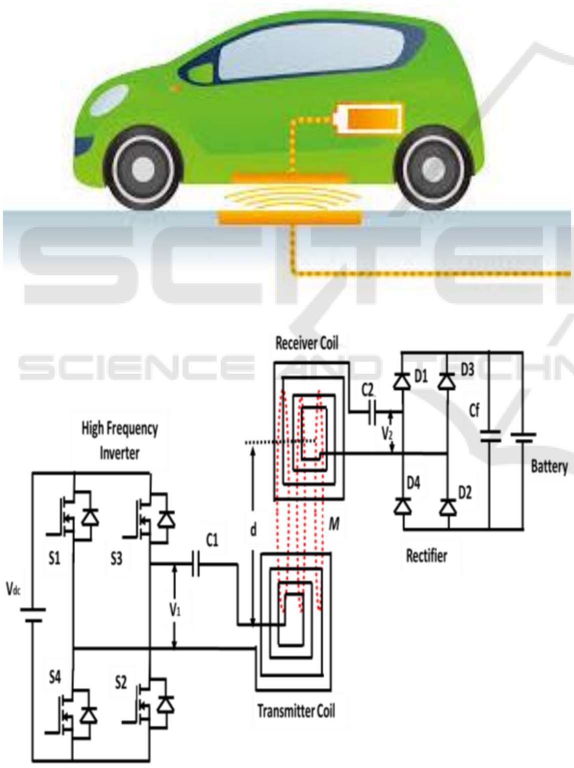


Figure 1: Basic schematic diagram of the WPT system.

This paper is organized into five sections. Section 2 describes possible misalignment variation of the square coils. Correspondingly finite element modeling (Ansys Maxwell simulation) is presented in section 3. Results and discussions are described in section 4 and the conclusion is given in section 5.

2 POSSIBLE MISALIGNMENTS IN SQUARE COUPLED COILS

This section presents the possible variations of misalignments of the transmitter and receiver coils such as perfect alignment, lateral or planar misalignment and angular Misalignments. The misalignments of the coupled coils are shown in Figure. 2. Figure. 2(a) depicts the perfect alignment of the transmitter and receiver coils i.e. the coinciding axes of the flat planar surface. For instance, when receiver coil is moved some more distance away in vertical from transmitter coil the flux linkages will decrease which as a result in a decrement of mutual inductance. In the above case, the coupling between them is weak. If transmitter and receiver coils are perfectly aligned, and vertical distance between them is very less, the flux linking with the receiver coil is more, and the coupling between them is strong. Also, the mutual inductance is very high. Figure. 2(b) shows lateral misalignment between the transmitter and receiver coil. In this case transmitter and receiver, coils are placed in a parallel plane and varied in horizontally. In contradiction to the above two alignments, in angular misalignment and Lateral and Angular Misalignment (as shown in Figure.2 (c) to 2 (d)) the mutual inductance between the coils depends on horizontal, vertical distance and tilted angle since they are placed at certain angle (0^o to 30^o) up or down. In all the above misalignments the inductive coupling characteristics are investigated.

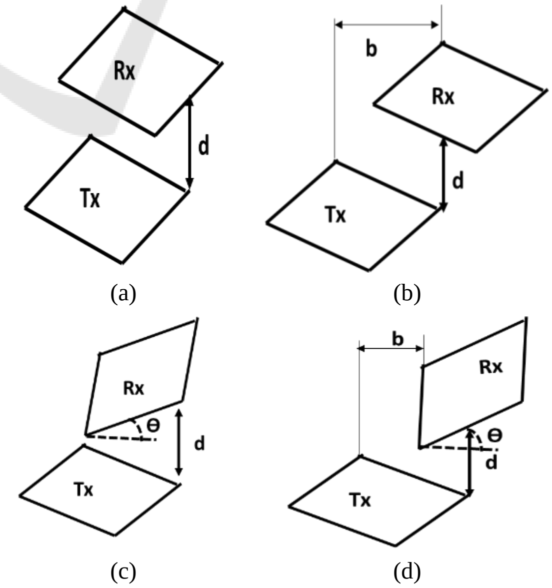
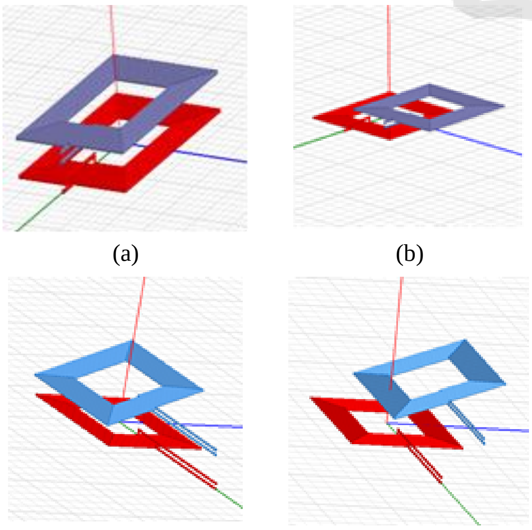


Figure 2: Various misalignment of square inductive coils (a) Perfect Alignment (b) Planar Misalignment, (c) Angular misalignment, (d) Planner and angular misalignment.

3 MODELING AND DEVELOPMENT OF SQUARE COUPLED COIL STRUCTURE IN FEM (ANSYS MAXWELL)

Finite Element Modelling tool-ANSYS MAXWELL is one of the world's leading engineering simulation tool for real-time simulations with design and analysis of electromagnetic and electromechanical devices, including motors, actuators, transformers, sensors and coils. In this section, ANSYS MAXWELL is employed to estimate the mutual inductance and flux distribution of the square coupled coil with different misalignments which were discussed in section 2. In this software, all simulations are carried out using 2-D FEM modelling. Maxwell's field distribution calculator calculates the magnetic flux linked with the receiver coil. The transmitter and receiver coils are developed by the simulation tool with different misalignment is as shown in Figure. 3. The FEM coil setup with ferrite core for suitable applications for EV battery charging are shown in Figure. 4.

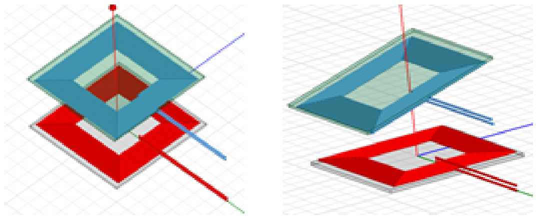
In this modelling 0.25cm diameter solid copper wires are used. Coil winding has started at a distance of 4cm from their origin. Both the coils are made up of equal number of turns as 12 and the gap between each turn is 0.018cm, 16 x 16 x 0.1cm dimensioned ferrite core and 24 x 24 x 0.2 dimensioned steel chassis are used for transmitter and receiver coils. The gap between core and coil is set to 0. 07cm.The transmitter coil is energized by 5A AC current.



(a) (b)

(c) (d)

Figure 3: Square Coil arrangement in FEM Simulation (a) Perfect Alignment (b) Planner Misalignment, (c) Angular misalignment, (d) Planner and angular misalignment.



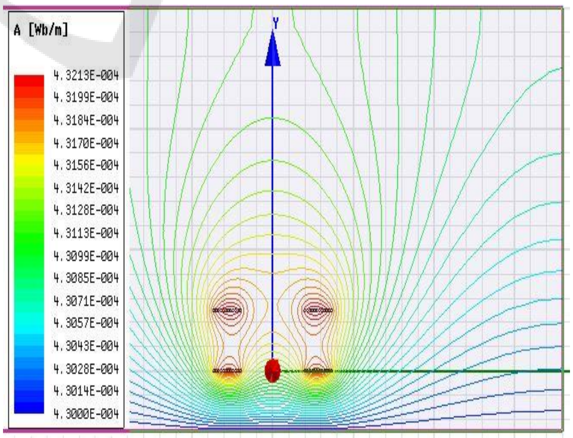
(a) (b)

Figure 4: Square Coil arrangement in FEM Simulation (a) Coil setup with Ferrite Core (perfect alignment), (b) Coil setup with Ferrite Core (misalignment).

4 RESULTS AND DISCUSSIONS

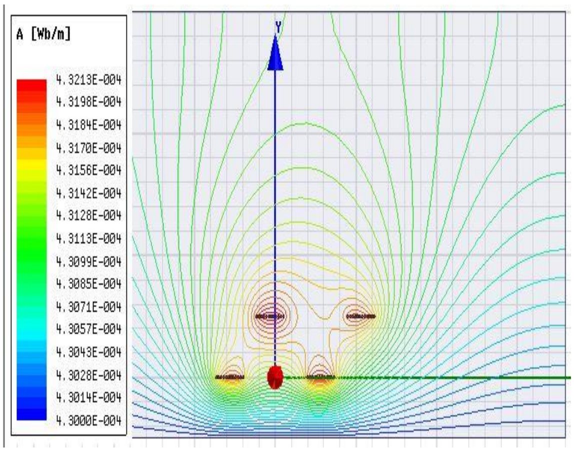
The flux lines between the square inductive coupled coils at 5cm vertical distance with different misalignments for both air cored, ferrite cored and ferrite core with chassis structure are shown in Figure. (5), Figure. (6) and Figure. (7) respectively. As if the receiver coil moves away from the transmitter coil the flux linkage will reduce as a result in reduction of mutual inductance.

The mutual inductances are computed between the coupled coils with all misalignment conditions which are the vertical distances 8cm, 12cm, 16cm, 20cm and 24cm for each horizontal distance such as 0cm, 5cm and 10cm and also for each angular variation such as 0°, 15° and 30° for both at air cored, ferrite cored and ferrite core with chassis structure and it is shown in Figure.7. section must be in one column.



(a)

Figure 5: 2-D Magnetic flux distribution between coupled coils Without core (a) Perfect Alignment, (b) Planar Misalignment, (c) Angular misalignment, (d) Planar and angular misalignment.



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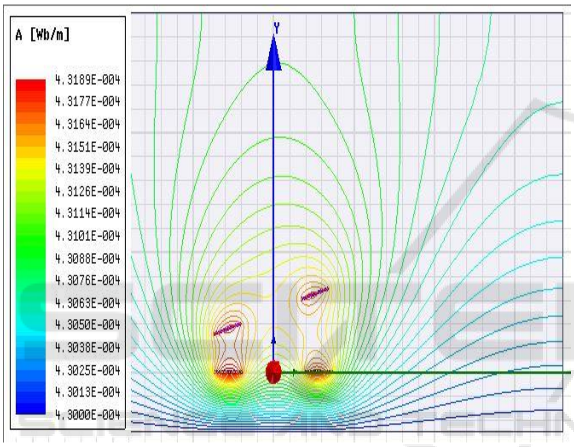

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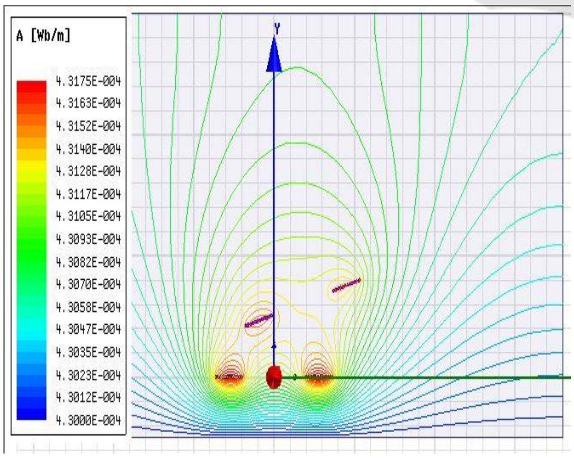
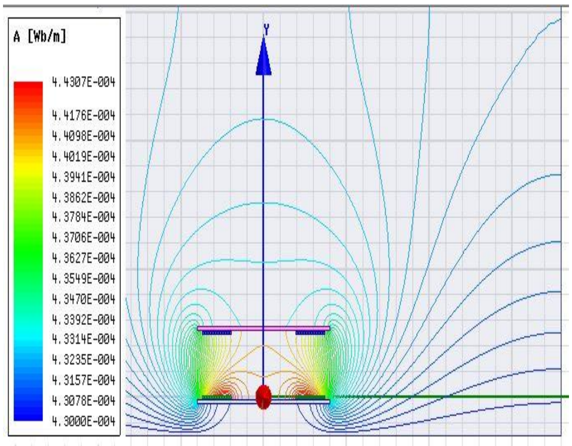
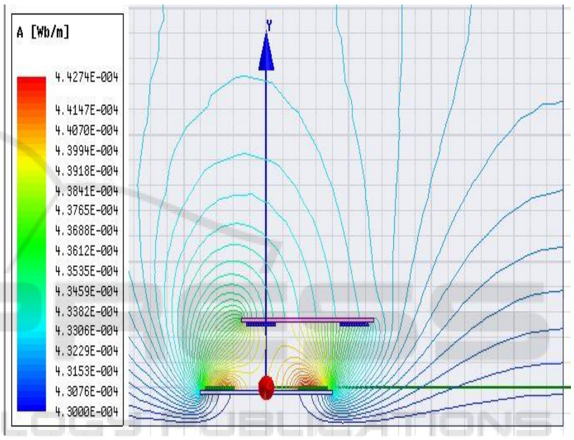


(d)

Figure 5: 2-D Magnetic flux distribution between coupled coils Without core (a) Perfect Alignment, (b) Planar Misalignment, (c) Angular misalignment, (d) Planar and angular misalignment (cont.).



(a)



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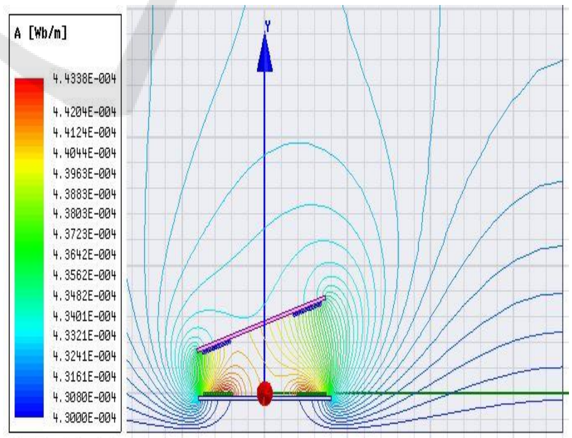
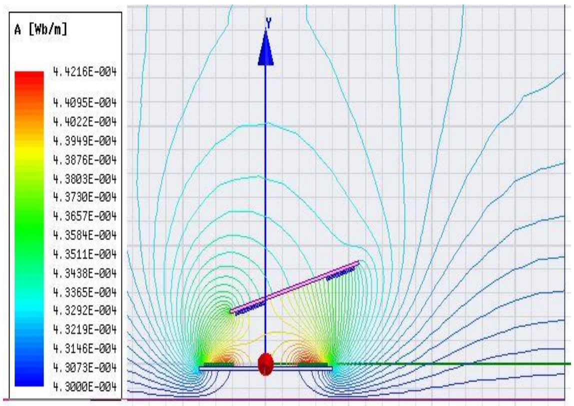


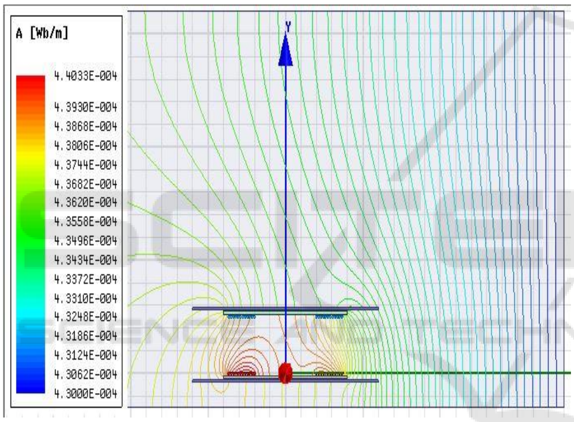
(c)

Figure 6: 2-D Magnetic flux distribution between the coupled coils with core. (a) Perfect Alignment, (b) Planar Misalignment, (c) Angular misalignment (d) Planar and angular misalignment.

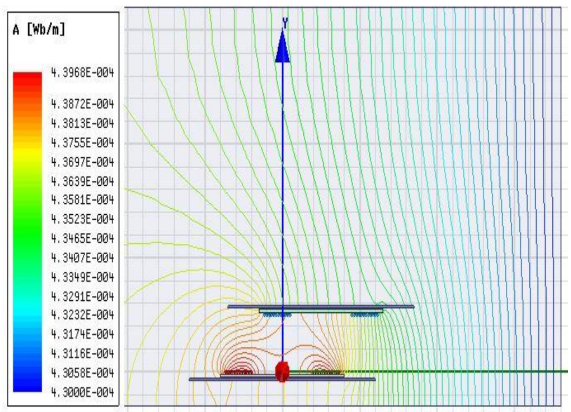


(d)

Figure 6: 2-D Magnetic flux distribution between the coupled coils with core. (a) Perfect Alignment, (b) Planar Misalignment, (c) Angular misalignment (d) Planar and angular misalignment (cont.).

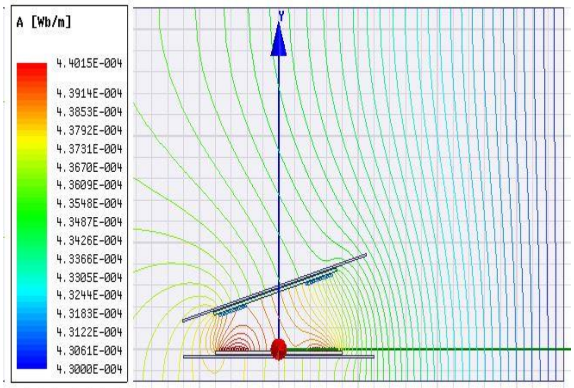


(a)



(b)

Figure 7: 2-D Magnetic flux distribution between the coupled coils with core and chassis. (a) Perfect Alignment, (b) Planar Misalignment, (c) Angular misalignment (d) Planar and angular misalignment.



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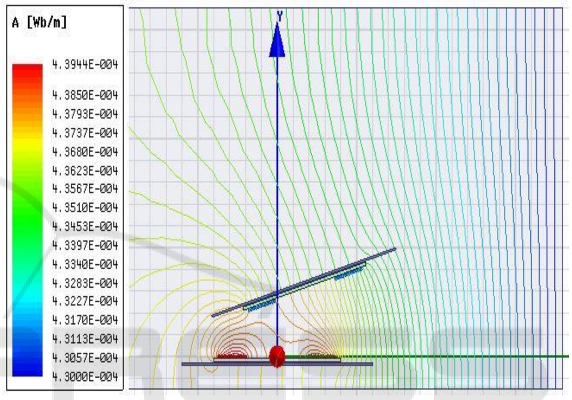
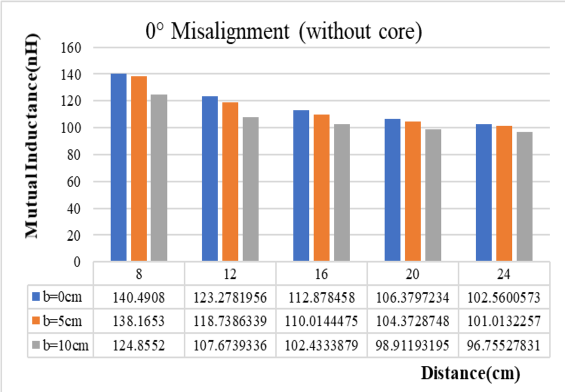


(d)

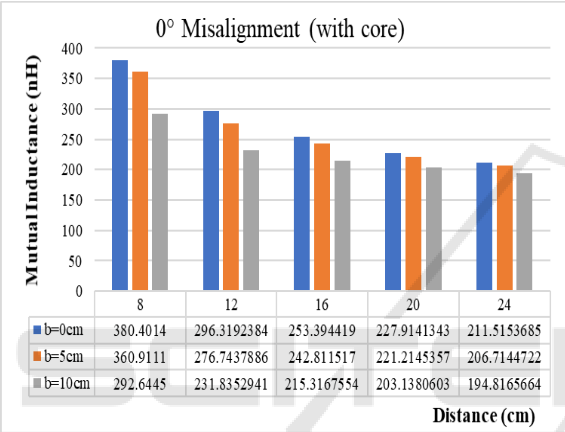
Figure 7: 2-D Magnetic flux distribution between the coupled coils with core and chassis. (a) Perfect Alignment, (b) Planar Misalignment, (c) Angular misalignment (d) Planar and angular misalignment (cont.).

Figure 8(a), Figure 8(b) and Figure 8(c) give the bar diagram of the MI values between the coupled coil with perfect alignment without, with core and with both core and chassis at all three cases of horizontal distances and various vertical distance and at 0° angular misalignments. Similarly, Figure 8(d), Figure 8(e) and Figure 8(f) show the MI values at 15° and Figure 8(g), Figure 8(h) and Figure 8(i) at 30° angular misalignments.

From Figure 8 it is clear that the mutual inductance decreases as the distance between the coupled coils increases either in horizontally, vertically or in angularly for both the cases such as air core and ferrite core



(a)



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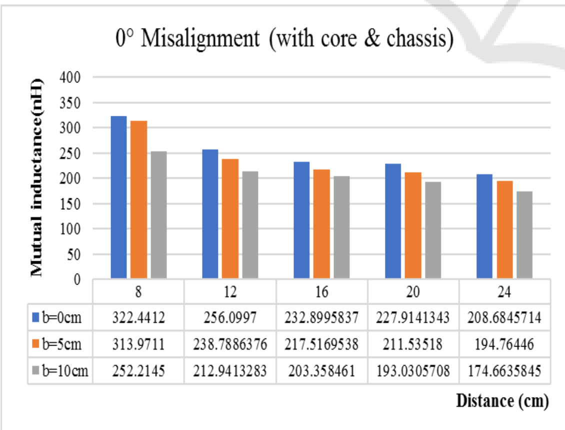

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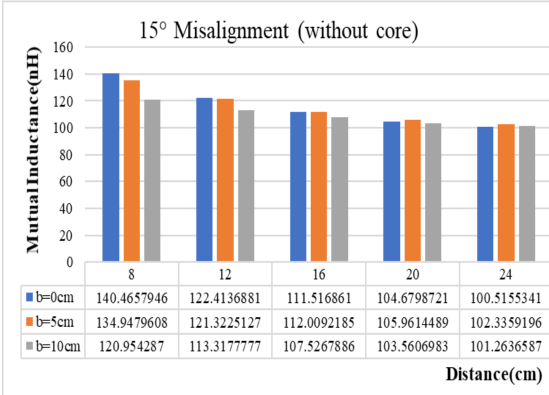

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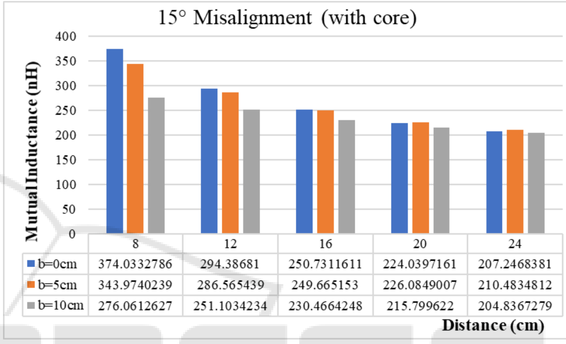

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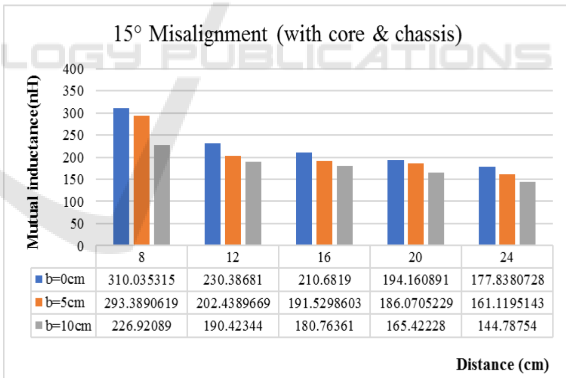
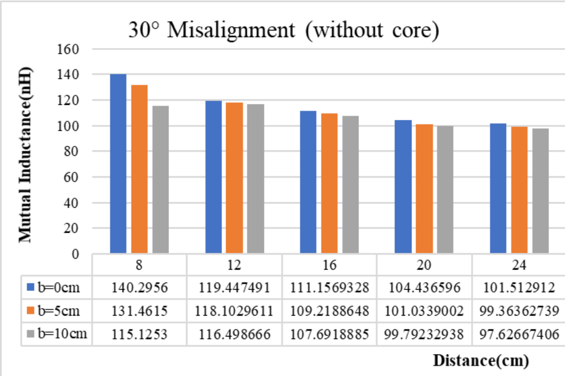
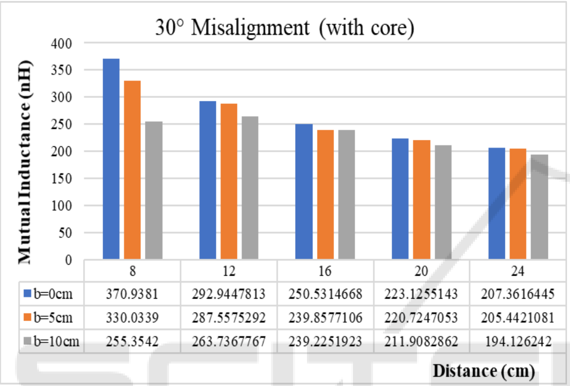


(f)

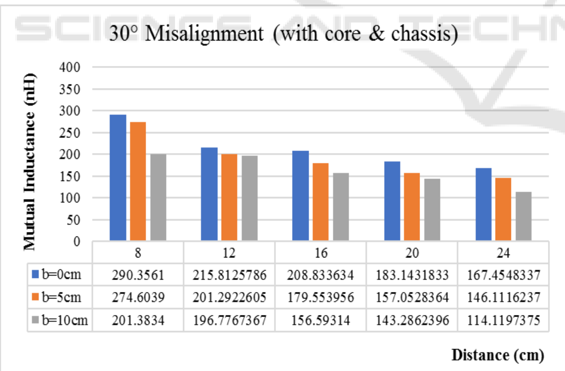
Figure 8: Graphical representation of MI vs Vertical distances (a) 0° Misalignment (without core), (b) 0° Misalignment (with core), (c) 0° Misalignment (with core and chassis), (d) 15° Misalignment (without core), (e) 15° Misalignment (with core), (f) 15° Misalignment (with core and chassis), (g) 30° Misalignment (without core), (h) 30° Misalignment (with core), (i) 30° Misalignment (with core and chassis).



(g)



(h)



(i)

Figure 8: Graphical representation of MI vs Vertical distances (a) 0° Misalignment (without core), (b) 0° Misalignment (with core), (c) 0° Misalignment (with core and chassis), (d) 15° Misalignment (without core), (e) 15° Misalignment (with core), (f) 15° Misalignment (with core and chassis), (g) 30° Misalignment (without core), (h) 30° Misalignment (with core), (i) 30° Misalignment (with core and chassis) (cont.).

5 CONCLUSIONS

This paper describes the inductive coupling characteristics of the square coupled coils with variations in distance between the coils vertically and horizontally with different misalignment conditions. Further it has been designed the inductive coupled coils ferrite core and chassis. The magnetic characteristics such as mutual inductance is studied for different misalignments. It has been concluded that by using ferrite core the magnetic characteristics can be improved.

Table 1: Specifications of the Coils.

Description	Specifications
Number of turns in transmitter (N1)	12
Number of turns in receiver (N2)	12
Radius of the conductor	0.25 cm
Width of the coil	3cm
Inner length of the coils	4 cm
Ferrite core material	N96
Core dimensions	16*16*0.1 cm
Steel Chassis material	Stainless steel
Chassis dimensions	24*24*0.2 cm

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