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THE INFLUENCE OF AIR GAPS AT 0.4 DUTY CYCLE ON MAGNETIC CORE TYPE 'E' TO INCREASE THE EFFICIENCY OF CUK CONVERTER

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ABSTRACT

Cuk converters are used in various electro-technical applications because it is useful for automatic controller. Recently the controller relies with the conventional Pulse Width Modulation (PWM) which uses Insulate Gate Bipolar Transistor (IGBT). IGBT has several advantages such as good voltage regulation; however it needs higher cost and the Cuk converter efficiency is not optimum. In this paper, we proposed a Cuk converter with a magnetic core as a replacement of PWM with IGBT. Three magnetic cores type "E" are utilized by inserting air gaps in the feet. The first magnetic core type has an air gap at all feet. The second has an air gap at the left and right feet, where the third type has an air gap at the middle and right feet. In order to optimize the inductance and capacitance quantity of the magnetic core, the air gaps as parasitic effect are used. The air gaps used are varied from 0.075 mm to 2.54 mm. The magnetic core is made from Alnico with duty cycle of 0.4. The result of this research is, the third magnetic core type shows the optimum result, giving flux to 0.0098 Wb and efficiency of 94%. This type is designed with air gap of 0.19 mm at the middle feet and 0.254 mm at the left foot.

Keywords: geometry, magnetic materials, air gap, magnetomotance, flux magnet.

I. INTRODUCTION

Cuk converters are used in various electro-technical applications because it is useful for automatic controller. Recently the controller relies with the conventional Pulse Width Modulation (PWM) which uses Insulate Gate Bipolar Transistor (IGBT) [1] – [4].

IGBT has several advantages such as good voltage regulation; however it needs higher cost [1] and the Cuk converter efficiency is not optimum due to output ripple current [5].

In [6, 7], the output ripple current is reduced using magnetic core, but only for resistance load. However, in the real application, the load can consist of R, L and C, therefore the output ripple current still exist. Other methods to suppress the output ripple current are conducted by Lotfi [8], Chetty [9] and Lagari [10]. Lotfi uses a couple coil winding method, Chetty uses a current injected equivalent circuit, whereas, Lagari uses energy-storage pulsed. However all of these methods only consider the resistance load. Therefore if L and C is also considered, the efficiency of the Cuk converter will decrease. This is due to the change of the total reactance of the load which does not match with the magnetic core impedance.

Therefore, in this paper, three models magnetic core type “E” using air gap and considering the R, L and C load is proposed. We proposed a Cuk converter with magnetic core as a replacement of PWM with IGBT. Three magnetic cores type “E” are utilized by inserting air gaps in the feet. The first magnetic core type has an air gap at all feet, the second has an air gap at the left and right feet, and the third has an air gap at the middle and right feet this magnetic core made from Alnico are made with duty cycle of 0.4.

II. BASIC THEORY

The proposed magnetic core in this paper is based on the magnetic core mentioned in [6] and shown in Figure 1, which shows a magnetic core with two E-shape shell type separated by air gaps. However this magnetic core consider only the resistance load.

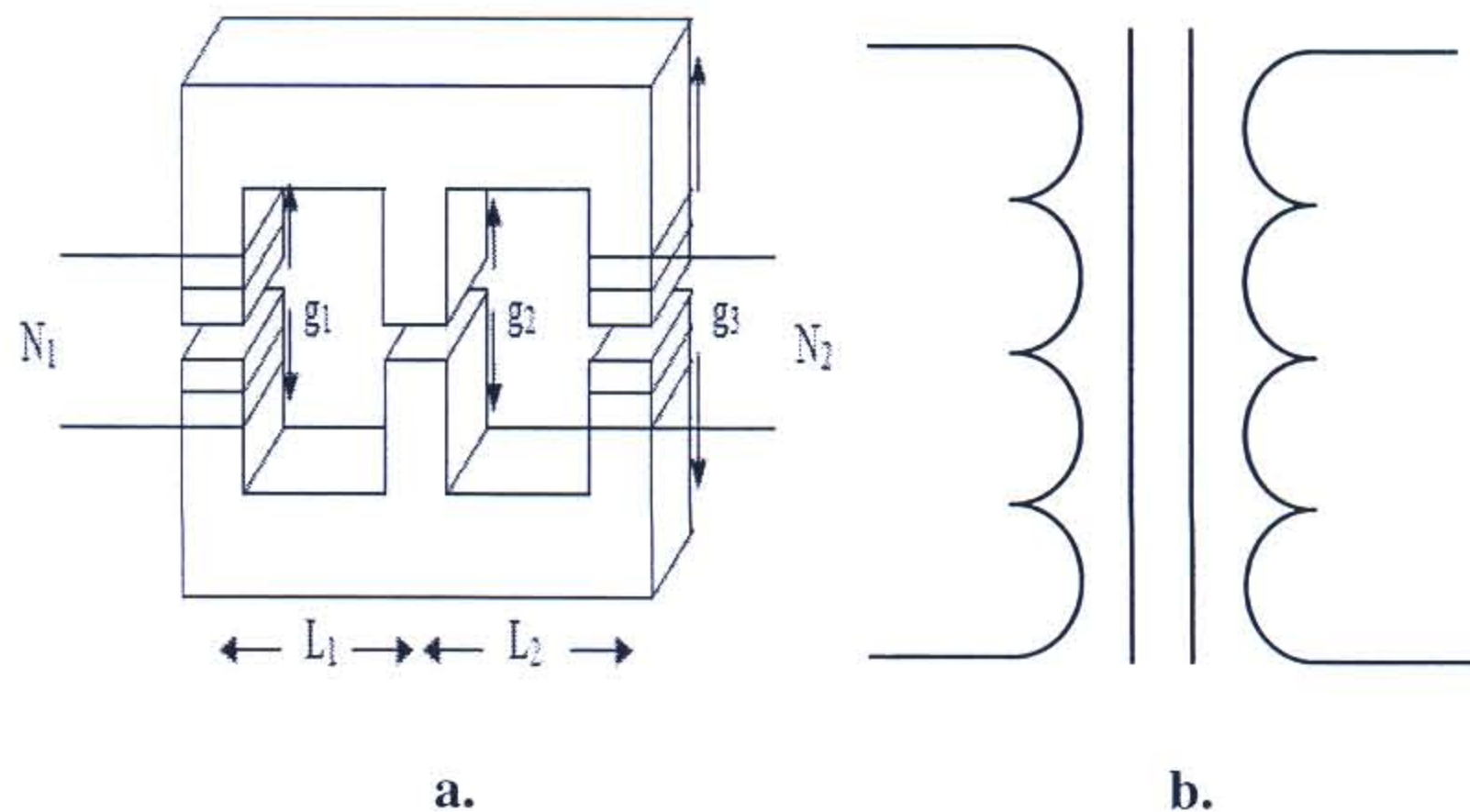


Figure 1. a. Magnetic core type E [6]. b. Transformer in Electric circuit.

Therefore in this paper, L and C is also considered and shown in the modified Cuk converter circuit diagram depicted in Figure 2:

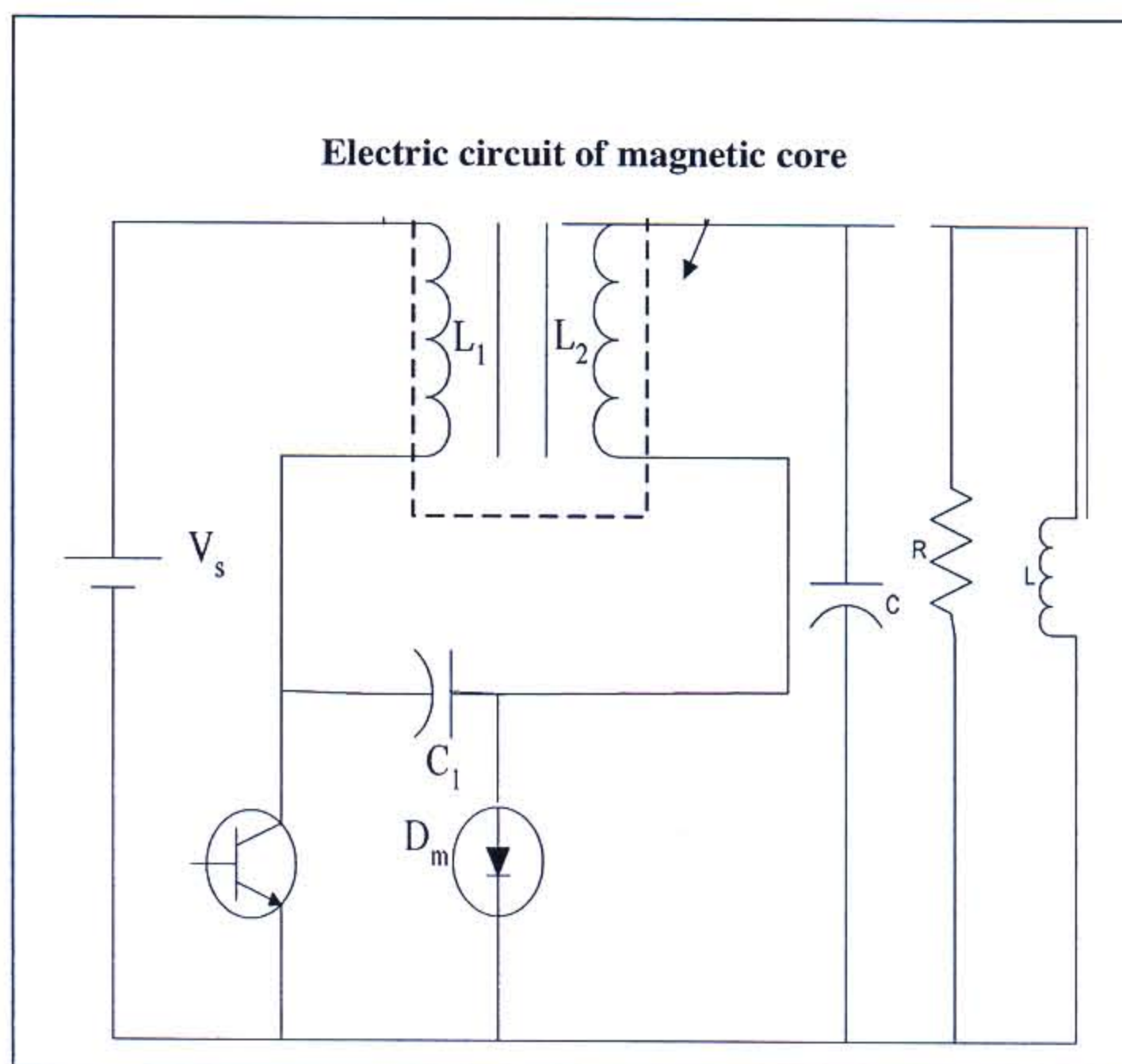


Figure 2. Modified Cuk converter circuit diagram of magnetic RLC parallel load.

From the Cuk converter model, some parameters are obtained. These parameter would become total capacitance in the air gaps, reluctance, resistance and mutual inductance. All of these parameters influence the efficiency of the Cuk converter as in Equation (1) [6].

$$\eta = \frac{\left| (R_{a2} / R_e)^2 + R_{a2}^2 (\omega C_p - M / B)^2 \right|}{R_2 \sqrt{(R_{e2})^2 + (Im)^2} \sqrt{(R_{e2})^2 + (Im)^2 (1 + R_{e2} / R_2) \cos^2(\theta)}} \quad (1)$$

Where, R is equivalent resistance, Im is total reactance and le is the effective length of magnetic core from DC resistance. B is the flux density between self inductance and mutual inductance. M is the mutual inductance of the load from several magnetic feet and C_p is the total capacitance equivalent from the magnetic core geometric

III. MAGNETIC CORE DESIGN

The three models of the magnetic core uses the material Alnico. The model is varied by the position of the air gap in its feet and the width of the air gap. The width of the air gap is varied from 0.016 mm until 2 mm with step size 0.01. the dashed line shows the circuit diagram of the magnetic core and this modified Cuk converter also shows the RL and C load consideration as shown in the circuit diagram as R L and C load. position of the air gaps in the magnetic cores feet will be varied into three models. The first model has air gap at all feet. The second has air gap at the left and right feet, whereas the third type has air gap at the middle and right feet. These variation will change the load current of the magnetic current of the magnetic core.

a. Model 1.

The proposed first design is depicted in Figure 3. The Figure shows air gaps at all foot ($\delta_1, \delta_2, \delta_3$).

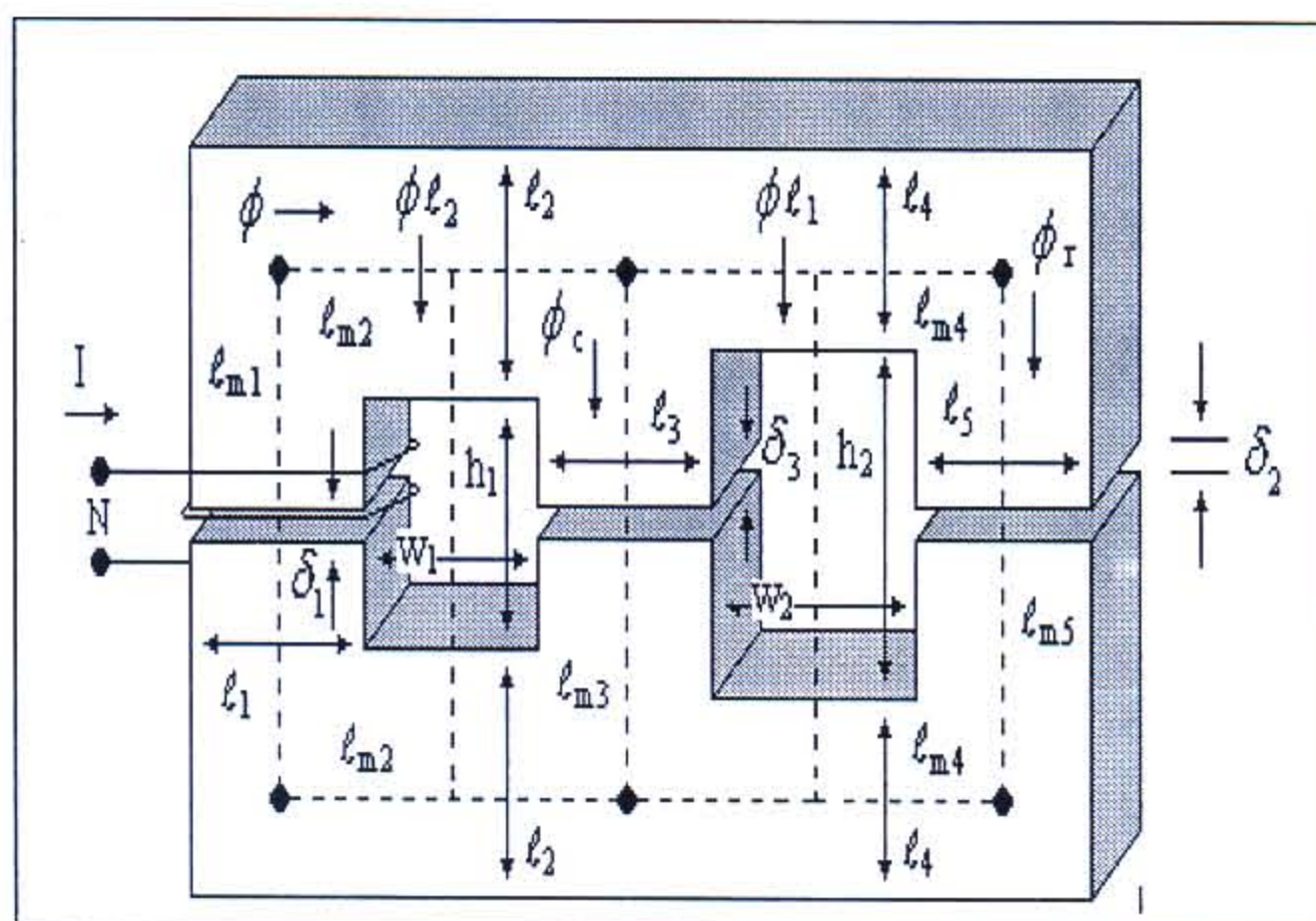


Figure 3. Magnetic core design for three feet air gap.

From the geometry of the model, it could achieve new parameters as shown in the equivalent circuit in Figure 4.

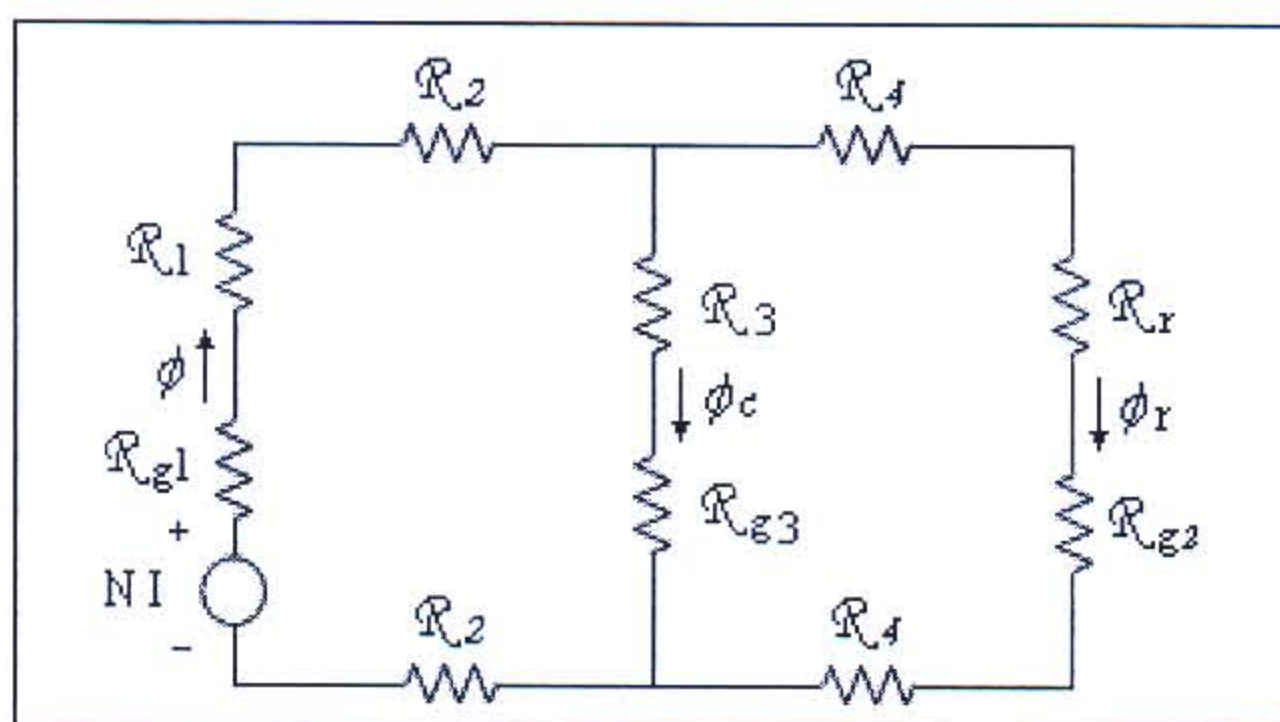


Figure 4. Equivalent circuit of air gaps on three feet

From Figure 4, the total reluctance and capacitance of the magnetic core can be calculated to find the efficiency of the magnetic core.

The total reluctance of the magnetic core depends on the width of the air gap. The width of the air gap is varied from 0.016 mm to 2 mm to find the optimized air gap width in order to optimize the load current. Figure 5 shows the simulation result of the air gap optimization.

From this model, the best results shown in Figure 5 shows that the air gap width in foot 1, foot 2, and foot 3, are 0.254, 0.5, 0.8 cm, respectively. The maximum load current achieved for this model is 9.055 A.

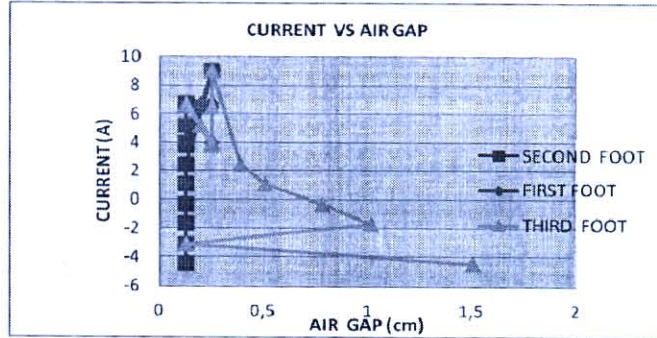


Figure 5. The relation of air gap and the current of model 1.

b. Model 2.

The second design is depicted in Figure.6. The figure shows air gaps at the left (δ_1) and right (δ_2) feet, where the middle foot has no air gap.

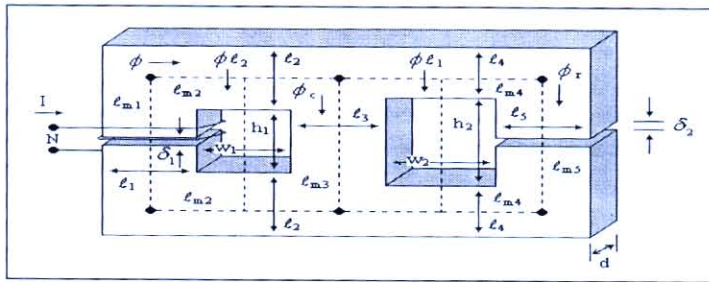


Figure 6. Magnetic core with air gaps on the Model 2.

From the geometry of the model, the new parameters are shown in the equivalent circuit in Figure.7.

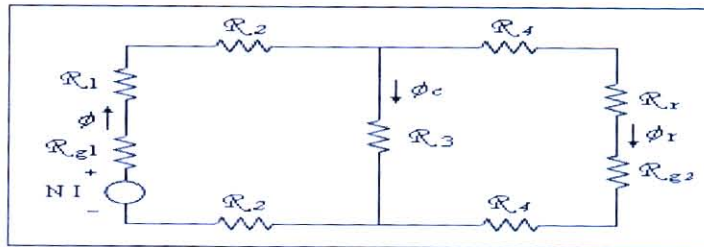


Figure 7. Reluctance equivalent circuit with air gap on the Model 2

For this model the best result occurs when the width of the air gap at the left and right feet is 0.254 mm, and 0.45 cm, respectively. The maximum load current for the Model 2 is 21.23 Amper as shown in Figure 8.

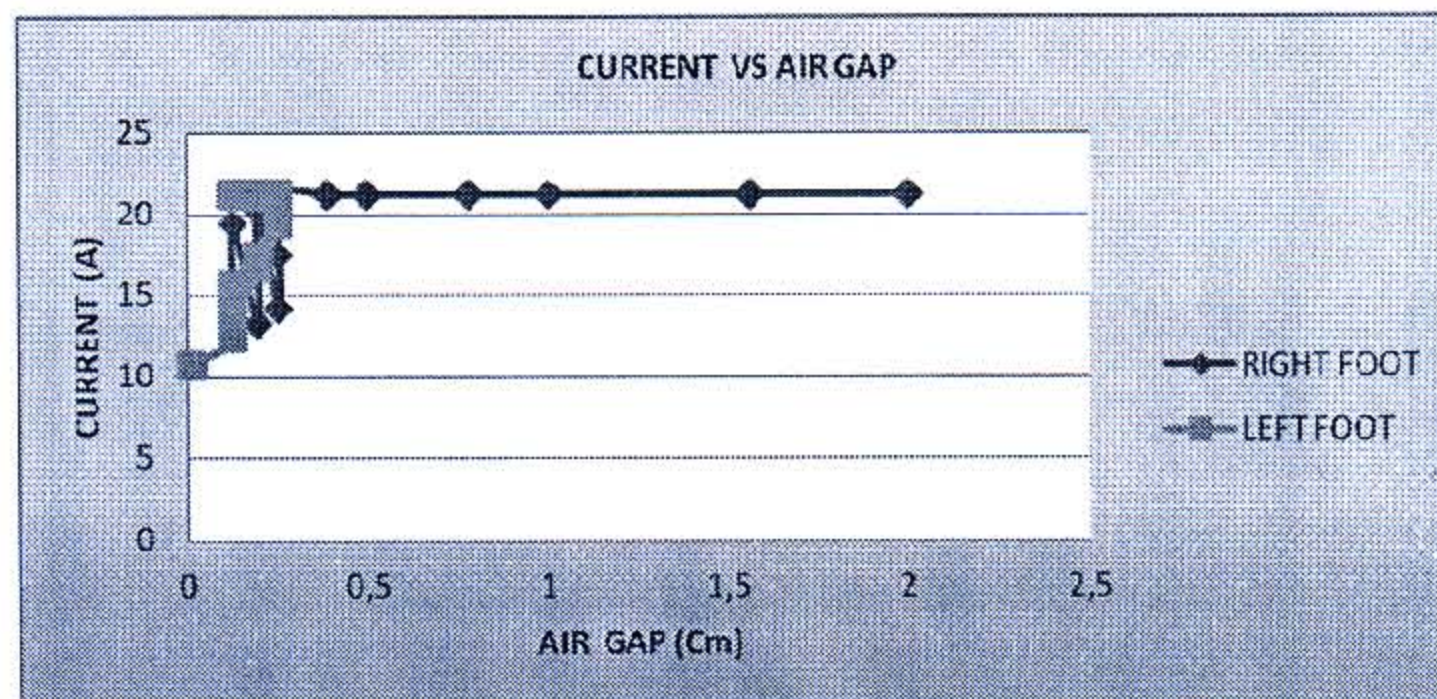


Figure 8. The relation of the current and air gap of model 2

c. Model 3.

The third design of the modified magnetic core is shown in Figure.9. The figure shows air gaps at the middle (δ_1) and right (δ_2) feet, while the left foot has no air gap but only has coil winding.

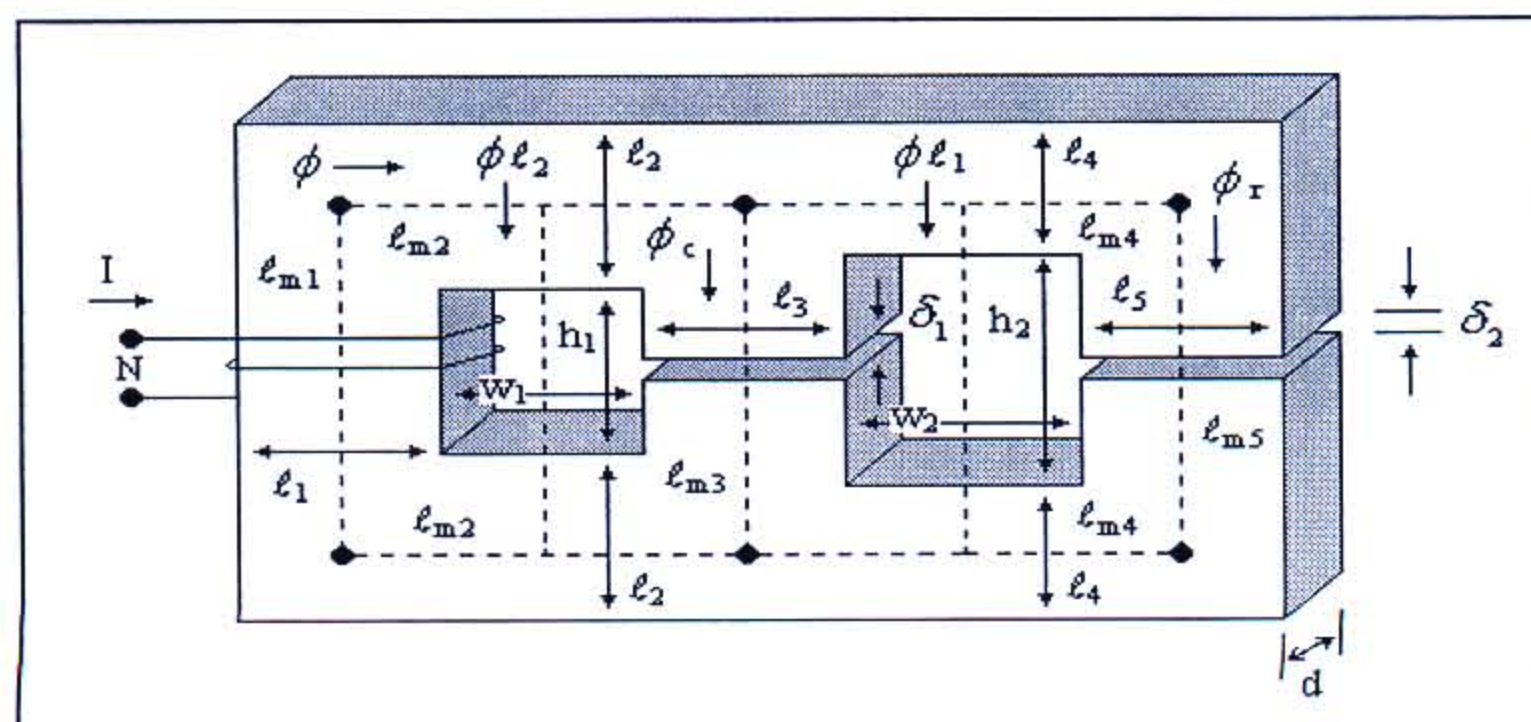


Figure. 9. Model 3- Magnetic core with the right and middle feet

The equivalent circuit of the model is shown in Figure 10.

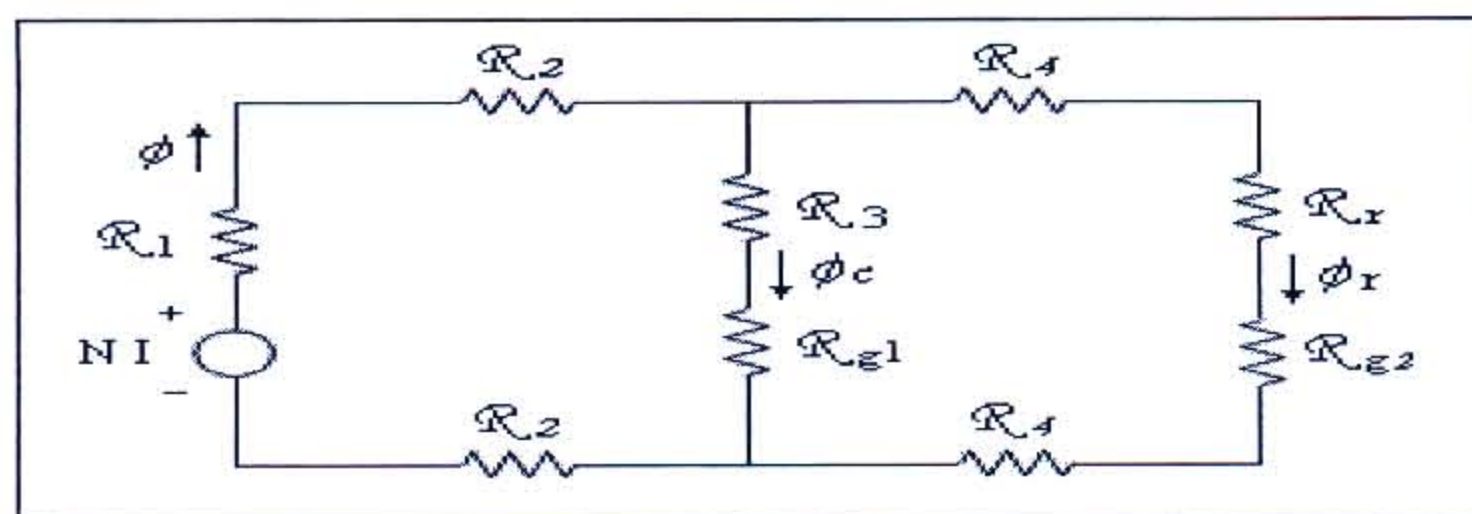


Figure 10. Reluctance equivalent circuit of Model 3 with air gap on the middle and right foot.

From Figure. 10, the total reluctance and capacitance of the magnetic core can also be calculated to find the efficiency of the magnetic core. Similar with model 1 and 2, the air gap

width in this model, is also varied from 0.016 mm to 2 mm, and different results occurred. From this model as depicted in Figure 11, the best results show that the air gap width in the middle and left foot is 0.27 and 0.357 Cm, respectively. The maximum load current for this model is 12.6 A. The dimensions of all the models is shown in Table 1.

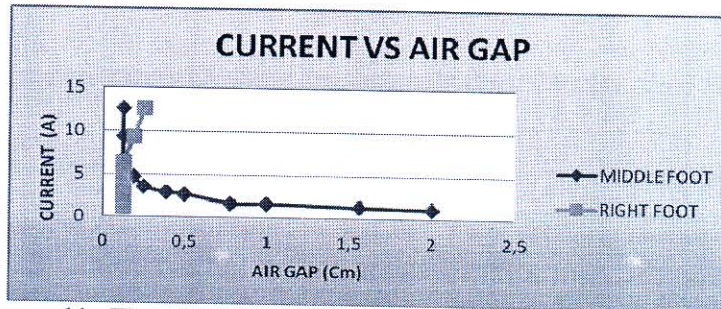


Figure 11. The relation of the air gap and the current of model 3.

Table 1. Dimensions of all the proposed model

	MODEL		
	I	II	III
δ_1 (Cm)	0.24	0.24	0
δ_2 (Cm)	0.5	0	0.27
δ_3 (Cm)	0.8	0.45	0.357
l_1 (Cm)	76		
l_2 (Cm)			
l_3 (Cm)	50.8		
l_4 (Cm)			
l_5 (Cm)			
h_1 (Cm)	10.16		
h_2 (Cm)	7.62		
w_1 (Cm)	0.889		
w_2 (Cm)	63.5		

IV. ANALYSIS AND DISCUSSION

The aforementioned of three magnetic core designs, show maximum load current for model 1, 2, and 3 at 9.05 A, 21.23 A and 12.6 A, respectively. Based on the maximum load current result, model 2 shows the highest load current result. However this does not guarantee that the highest efficiency occurs for the model 2 To obtain the highest efficiency for the Cuk converter system, several parameters have to be determined based on the Equation 1 and from the equivalent circuit of each model shown in Figure 3, Figure 6 and Figure 9.

Table 2 show the results of each models. It is shown, that the highest efficiency is achieved by model 3 which has air gaps at the middle and left foot. Model 3 shows efficiency of 94 %.

Table 2. The result of the modified Cuk converter

	MODEL		
	I	II	III
δ_1 (mm)	0.254	0.254	0
δ_2 (mm)	0.254	0	0.127
δ_3 (mm)	0.254	0.254	0.254
I (A)	9.132	21.23	12.6
($\angle V_1$ & I_1)	37.31	38,01	6.91
$C_p 10^{-6}$ (F)	62.4	59.5	3.343
$R_{eal} 10^{-3}$ (Ω)	59,215	56,780	417
$I_{m1} 10^{-3}$ (A)	1159	11051	164
$R_{ea2} 10^{-2}$ (A)	77	76	767
$I_{m2} 10^{-3}$ (A)	0.3682	0.3511	0.0196
H A-t/m	31,772	2,640	218,789
Fc A-t	2139	3194.5	31.945
$\Phi B_{=Left}$ (Wb)	0.0093488	0.010698	0.00988
ΦB_{Center} (Wb)	0.00635	0.0077	0.00687
ΦB_{Right} (Wb)	0.003	0.003	0.003
η (%)	54	57	94

The graphics below shows that the 0.4 Duty Cycle is the most suitable ones for all models since it produce the lowest ripple current output for all those models. Therefore 0.4 Duty Cycle chosen for the Model 3.

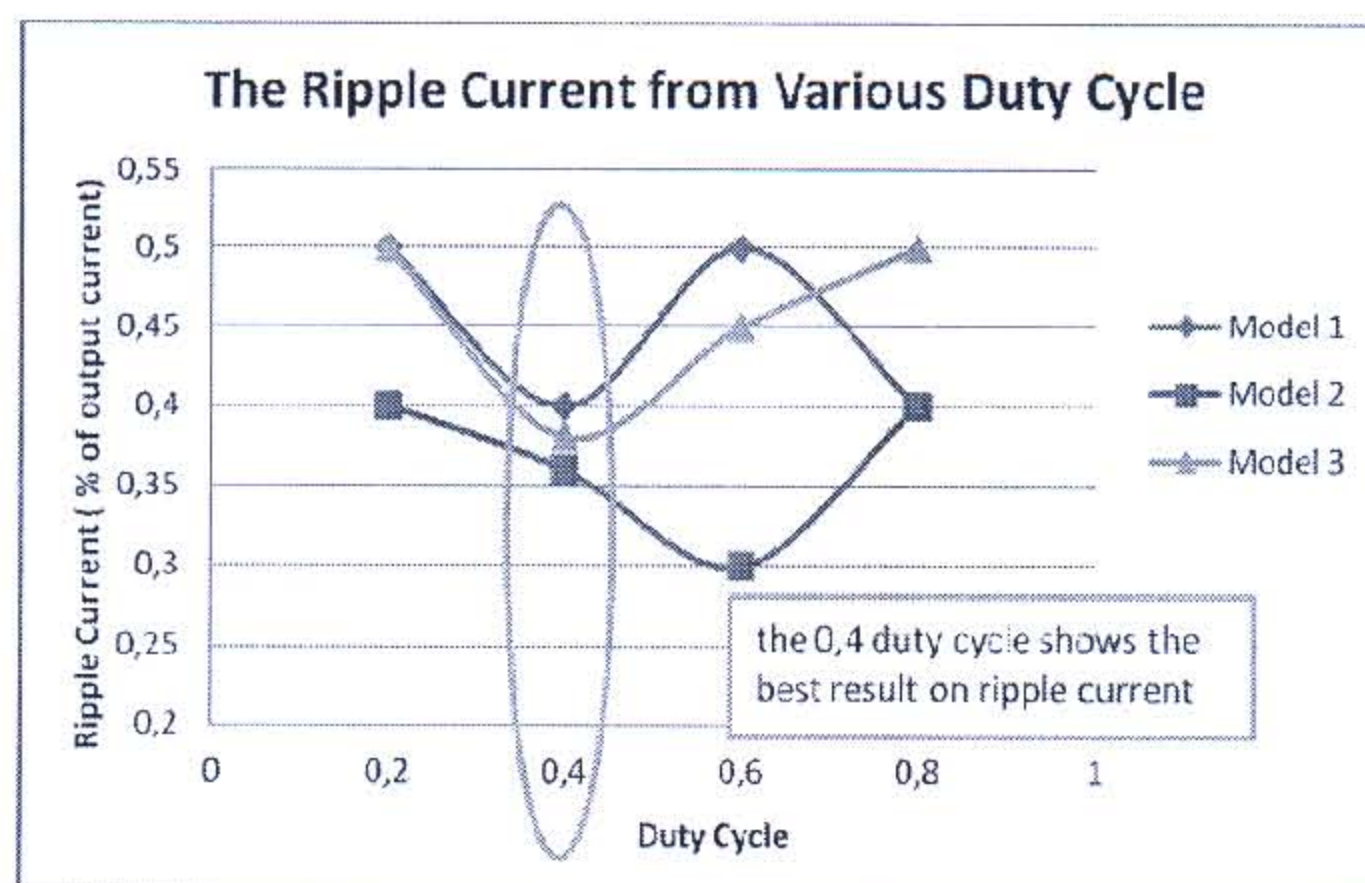
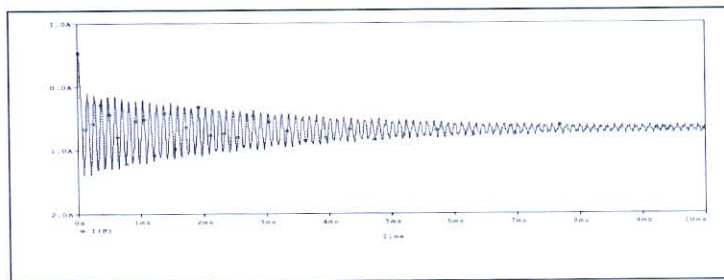
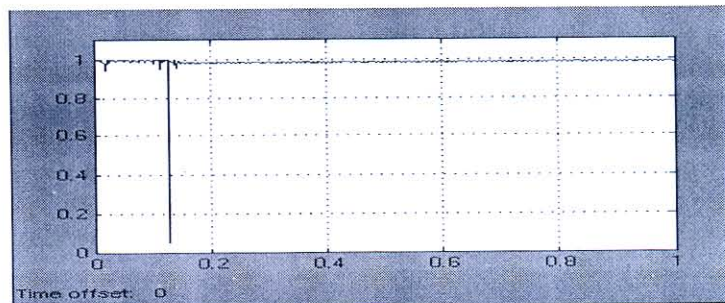


Figure 12. The Ripple Current from Various Duty Cycle.

Furthermore, this new magnetic core design can improve the output ripple current of the Cuk converter. This is shown in Figure 13. The output ripple current of Cuk converter the depicted in Figure 12.a is based on the magnetic core [6], while Figure 12.b shows the result after using the modified Cuk converter model 3. Both output ripple current from Cuk converter in [6] and model 3 are calculated with RL and C loads. Figure 12 a. Shows that the output ripple current is decreased to below 1 Amper with steady state at 8 ms. The output ripple current from [6] is enhanced by model 3 to 1 Amper and steady state at 20 ms. The modified Cuk converter model 3 shows that the ripple current is suppressed to 0.03 % .



(a)



(b)

Figure 13. The output ripple current of Cuk converter (a) before modification (b) after modification

V. CONCLUSION

In order to optimize the inductance and capacitance quantity of the magnetic core, the air gaps as parasitic effect are used. The result of this research shows that from the three different models, the third model which is designed with air gap at the middle and right foot shows the best result with efficiency of 94 % and 0.4 Duty Cycle.

The third magnetic core “E” type shows the optimum result with efficiency of 94% and output ripple current suppressed to 0.03%. This model is designed with air gap of 0.19 mm at the middle foot and 0.254 mm at the left foot. In addition, the output ripple current from this models can suppress the output ripple current to 0.03%.

REFERENCES

- [1] Uthen K and Viboon C, "Analysis and Design of a Modular Three-Phase AC-to-DC Converter Using CUK Rectifier Module With Nearly Unity Power Factor and Fast Dynamic Response", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 24, NO. 8, AUGUST 2009.
- [2] Javaid M, Mohammad R, Nasiri, and Ali A, "Application of Neural Network and State – Space Averaging to DC/DC Cuk Converters on Over Sliding – mode Operations," IEEE/ASME TRANSACTIONS ON MECHATRONIC, VOL 10, no 1, februari 2005,
- [3] Shiu C W, She G W. and Chin k S, "Sustained Slow- Scale Oscillation in High Order Current – Mode Controlled Converter," IEEE Circuit and System Express Brief. Vol. 55 No 5, Mei, 2008.
- [4] Boris A R, Yefim B and Adrian I, "Switch - Capacitor/Switch - Inductor , Structur for Getting Transformless Hybrid ", DC-DC PWM Converter. IEEE Circuit and System Regular Paper . Vol. 55 No 2, March, 2008.
- [5] Hisman A.B. W.. T. Johns , "Air gap reluctance and inductance calculations for magnetic circuit using Swarz – Chistoffel transformer.," Transa ction Power Electronic, Vol. 12 .No 4, July, 1997.
- [6] Herawati YS, "Rancangan konverter Cuk Slobodan akumulasi energi dengan metoda pendekatan rangkaian magnet Gyrator - kapasitor untuk meminimisasi arus riak". Thesis Master ITB 1996.
- [7] Herawati Ys, Eko T R, and Iwa G " Performance Electromagnetic Bandgap in Core E Type Make High Frequency and Low Ripple", International Symposium on Antenas and Propagation, November 1- 4, 2006.
- [8] Lotfi A.W, Pawel M, Gradzki and Fred C.L , "Proximity effect in coil for high frequency power application", IEEE Transaction on Magnetic, Vol 28, No.5, September 1992.
- [9] Chetty P.SR.9 , "Modelling and analisis of Cuk converter Using Current Injected Equivalent Circuit Approach", IEEE trnasaction on Industrial Electronics, Vol. IE-30, no.1, February 1983.