Study of Halbach Array Winding

Abstract- This work presents a study of a new type of winding arrangement forming a Halbach array. The study consists of introducing the halbach array flux formation in permeant magnets and adapting this formation in a coil formation. The halbach coil is then compared with two different conventional coils, i.e. horizontally and vertically wound coils. From the comparison study, it has been concluded that halbach coil can achieve a high level of flux with lower inductance and consequently power factor in comparison with its counterpart conventional coils. Finally, a halbach array coil has been constructed and tested to verify the halbach array flux generation of the coil.

I. INTRODUCTION

Halbach array formation of magnets have been used in several applications since such magnets can significantly reduce or eliminate the flux in one side (weak side) and strengthening the other side (strong side). Despite the name Halbach, this type of magnet formation was firstly proposed by J. C. Mallison in 1973 as a magnetic curiosity [1]. The term Halbach comes from Klaus Halbach, the physicist who made this magnetic array formation to focus particle accelerator beams [2]. Since then Halbach magnets found many applications including electrical machines, magnetic drug targeting and wiggler magnets in which the Halbach magnets are used to strengthening the flux and recues the overall magnetic circuit .

This paper presents a study of Halbach array winding. Initially, using FEA, Halbach array coil is designed and compared with two conventional coils, i.e. horizontally and vertically wound, operating under the same current density. The comparison includes the magnetic field production and the coil inductance and power. From this comparison it is found that Halbach array winding can produce higher magnetic field and have lower inductance and therefore higher power factor.

II. HALBACH ARRAY WINDING

It is know that DC coil can be a permeant magnet (PM) equivalent in producing flux in both shape and magnitude, this is illustrated in Fig. 1 where the flux lines of PM and a coil are compared. Therefore, by arranging coils in a halbach array raw, a strong and weak sides are expected. Fig. 2 presents an FEA model showing the flux lines of halbach PM and coil.

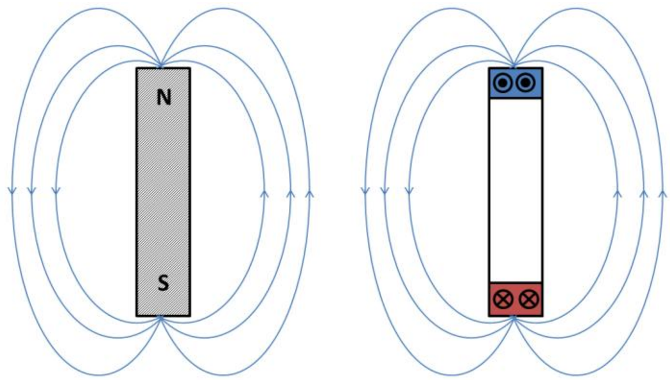


Fig. 1 DC coil equivalent of permanent magnet.

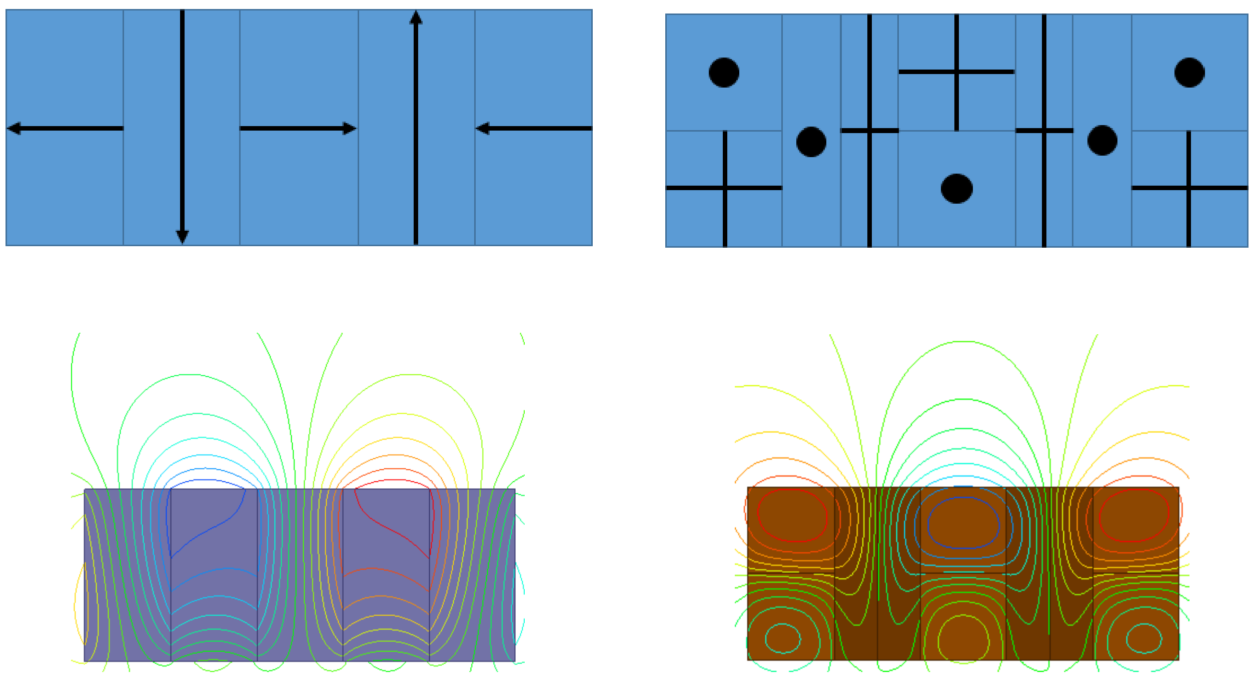
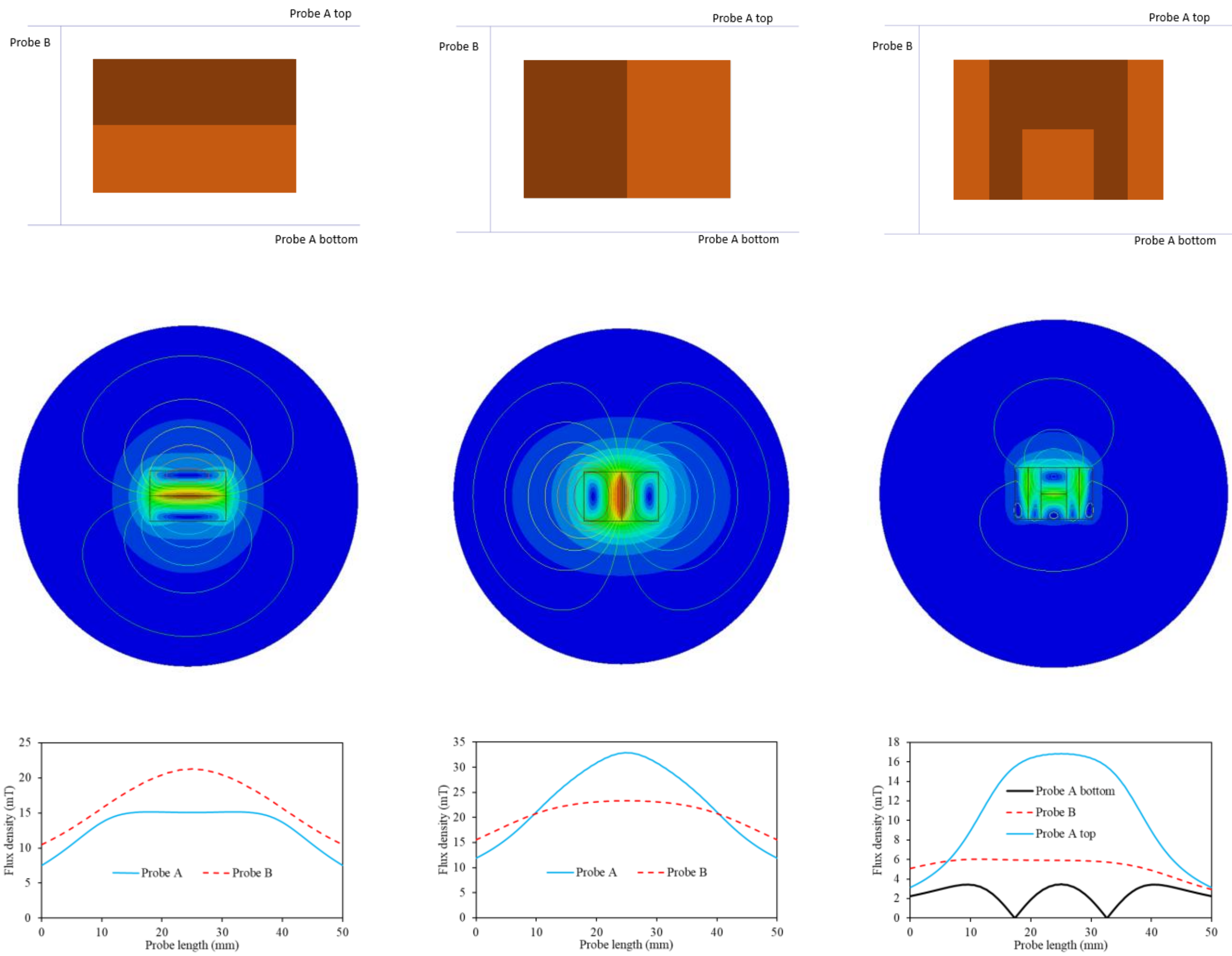


Fig. 2 Halbach array PM and coil. (a) Halbach PM orientation (b) Halbach PM equipotential (c) Halbach coil winding arrangement (d) Halbach coil equipotential.

II. COMAPRING CONVETIONAL AND HALBACH ARRAY WINDING

A comparison between the Halbach array coil and two conventional coils, the first is horizontally wound and the second is vertically wound. Fig. 3 presents the horizontal (H), vertical (V), and Halbach (HAL) coils. Halbach coil is a rearrangement of the conventional coils, therefore the same current density and size can be maintained. The three coils have the same size, current density, number of turns, and current. Fig. 3 presents the equipotential and flux density of the three coils and the flux density along A and B probs. By comparing the flux density at probes A and B in the three coils, it can be seen that higher magnetic field density is found in the H and V coils compared to HAL. However, the inductance of the H, V and HAL are respectively. To study the Halbach coil further, a ferromagnetic core forming a magnetic circuit with airgap has been placed around the three coils as shown in Fig. 4. An AC current waveform is injected in the three coils, the waveform has 50Hz frequency and 1A peak current. Fig. 4 presents the flux density and equipotential distribution in the coils and the flux density along the probes A and B. Fig. 5 presents the flux-linkage induced in the secondary coil (shown in Fig. 4). Table I lists the main coil parameters. It can be seen that the HAL coil in a ferromagnetic core can produce the same level of flux-linkage with that of the H coil, however, lower inductance in HAL coil making the power factor of the HAL coil higher than H as shown in Table I.



H, L 156mH　　　V, L 248mH　　　Hal, L 63mH

Fig. 3 Structure, flux density and equipotential, and flux density along the probes. (a) Horizontal coil (b) Vertical coil (c) Halbach coil.

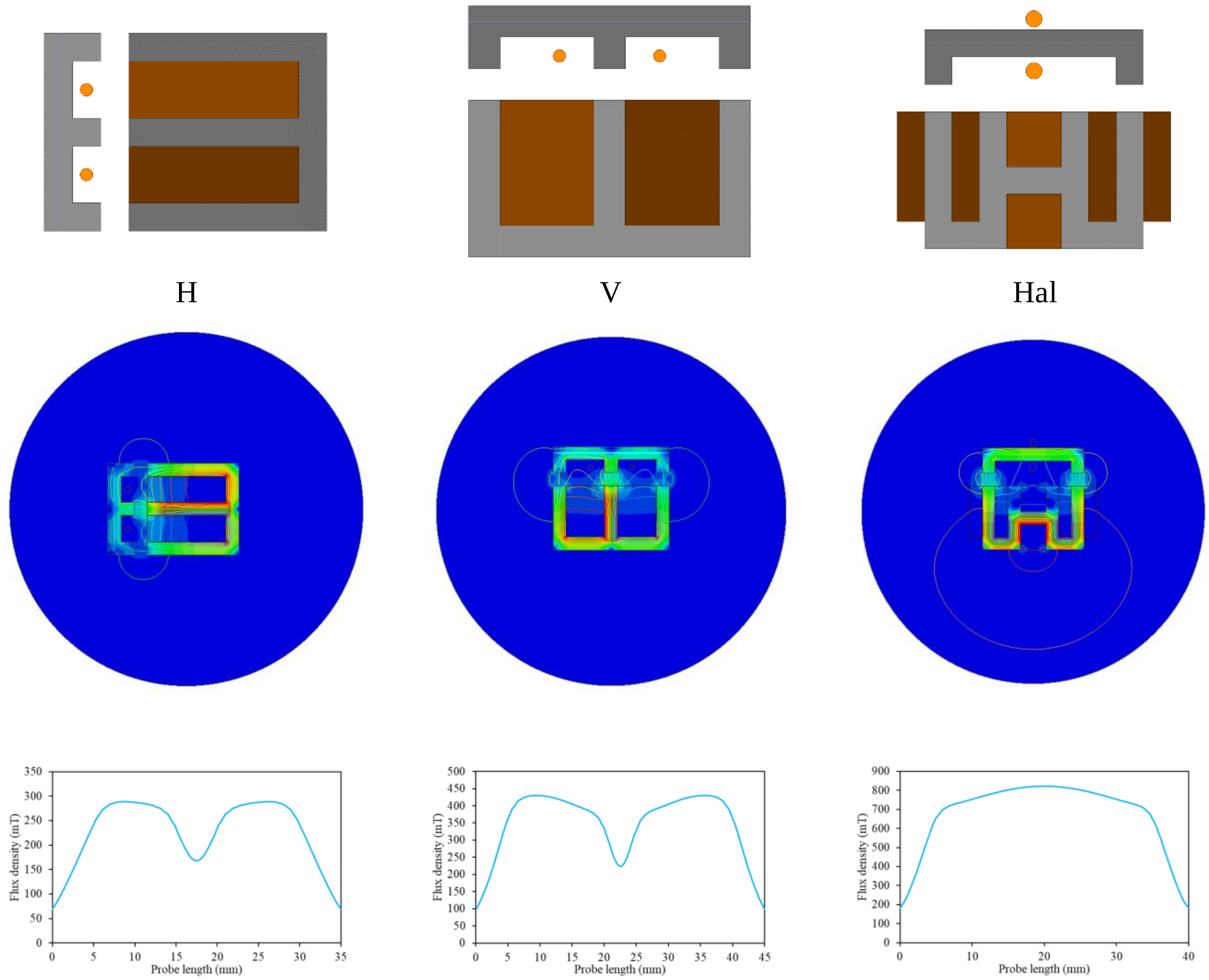


Fig. 4 Structure, flux density and equipotential, and flux density along the probes. (a) Horizontal coil core (b) Vertical coil core (c) Halbach coil core.

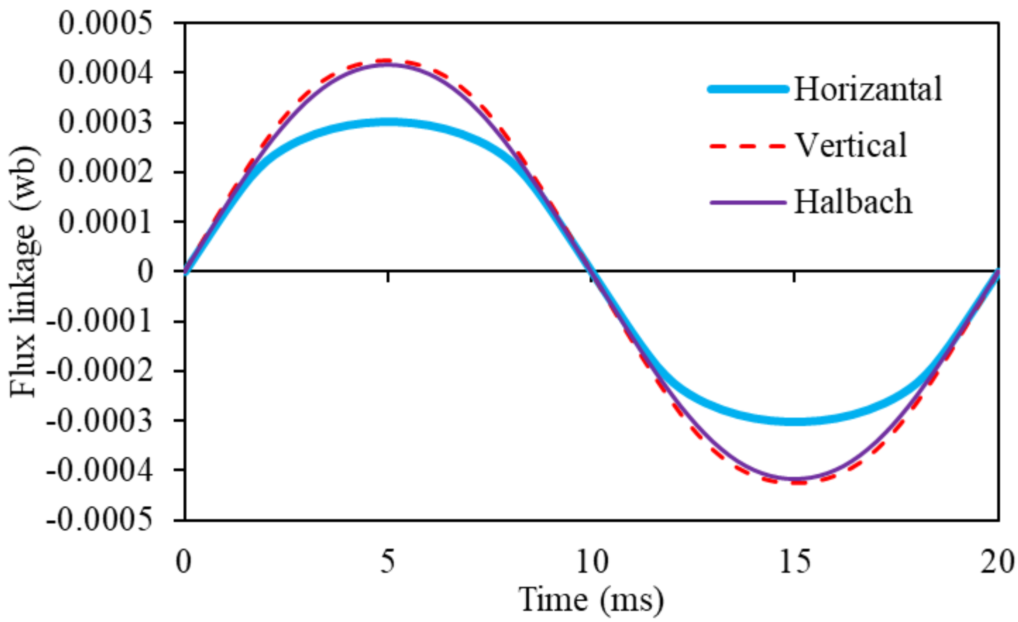


Fig. 5 Flux-linkage predicted at the secondary coil.

Table I main design parameters of the three coils.

Parameter	Horizontal	Vertical	Halbach
Width (mm)	50	45	50
Height (mm)	35	40	40
Length (mm)	100	100	100
Airgap (mm)	5	5	5
Copper area (mm2)	600	600	600
Total core area (mm2)	875	825	850
Current (A)	1	1	1
Turns	3000	3000	3X1000
Resistance (ohm)	206.4	206.4	206.4
Inductance (H)	3.33	2.62	1.83
Impedance	1066.31	848.58	610.83
Power factor	0.19	0.24	0.33
Power (W)	206.4	206.4	206.4
Peak flux (wb)	0.000302	0.000424	0.000415

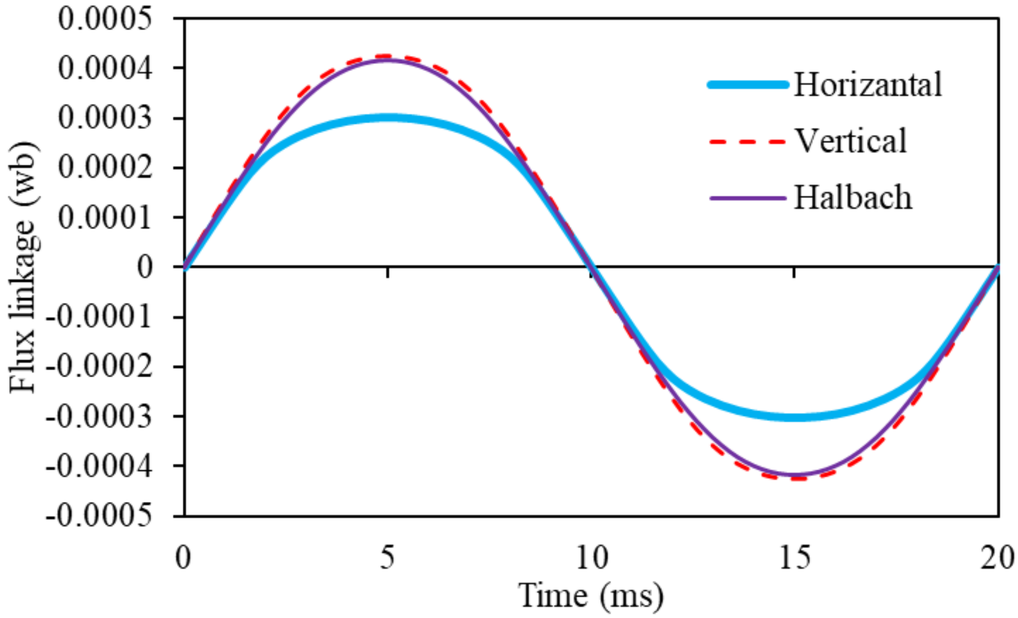


Fig. 5 Flux-linkage predicted at the secondary coil.

V. CONCLUSION

Halbach array winding has been studied in this paper. Several comparisons between Helbach array coil and conventional coils under different conditions have been reported. From the comparisons, it has been concluded that Halbach array winding can produce relatively high magnetic field and lower inductance and therefore higher power factor compared to the conventional coils.

REFERENCES

1. J. Mallinson, "One-sided fluxes -- A magnetic curiosity?," in IEEE Transactions on Magnetics, vol. 9, no. 4, pp. 678-682, December 1973.
2. K. Halbach, "Strong Rare Earth Cobalt Quadrupoles," in IEEE Transactions on Nuclear Science, vol. 26, no. 3, pp. 3882-3884, June 1979.