International Journal of Research in Advent Technology, Vol.6, No.11, November 2018
E-ISSN: 2321-9637
Available online at www.ijrat.org

Effect of Ferrofluid on Quality Factor of Printed Spiral Winding (PSW) Structures

Vilas V. Sarwadnya[1], Rajashree V. Sarwadnya[2], Shambhunath G.Kahalekar[3]
Department of Electrical Engineering[1,2,3],SGGSIE&T, Nanded[1,2,3]
Email: vsarwadnya@yahoo.co.in[1],rvsarwadnya@sggs.ac.in[2],sgk@yahoo.com[3]

Abstract-The need towards higher power density, compact size and lighter weight of the energy converter is an area of research now-a-days. Space, biomedical, electric vehicles and various energy scavenging applications are some of the prime one. The light weight inductors and transformers used in high frequency Megahertz (MHz) range are major components on which overall volume and weight of circuits depends. Quality factor and the hollow winding structure decide the foot prints area required. The air cored coils are mainly preferred due to absence of magnetic material in MHz applications and hence such structures were well studied earlier. But, poor magnetic coupling, EMI (Electromagnetic Interference) and higher temperatures affect badly the performance of such structures. The use of ferrofluid can well improve the performance. In this paper, various coil structures in the form of printed spiral winding placed in ferrofluid are studied. The magnetic property of ferrofluids helps in improving the performance of a coil.

Index Terms- Ferrofluid, hollow Planar Spiral Winding, Quality factor.

1. INTRODUCTION

Inductors and capacitors play important role as energy storage elements in various circuits mainly the DC-DC converters. Higher the switching frequency, lower will be L and C requirements [1]. This will automatically reduce the size and weight of the overall circuit used in Biomedical and space applications. The planar air cored inductors are well tested and accepted. In the coils having spiral nature, inner turns are prone to higher eddy current losses as compared to outer turns. The inner turn provides higher ac resistance while outer turns are having lesser one. Studies on quality factor of hollow spiral winding structure have been reported by Yipeng Su [2]. The use of ferrofluids will further help to improve its performance.

Research on coreless printed circuit board (PCB) inductors and coreless PCB transformers have been reported in the literature [3-5]. DC-DC power supplies using these elements for optimal design have been reported [6-8]. The coreless operation is able to provide the low volume circuit implementation. [9].The coils are having rectangular cross section and spiral in nature.

2. PRINTED SPIRAL WINDING STRUCTURE

2.1:construction

The winding under study is having 10 turns. R_{in} (internal radius of the coil) while R_{out} is the outer radius of the coil, s is the spacing between the adjacent tracks, h is the track height and w is the width of the track as shown in Fig. 1.

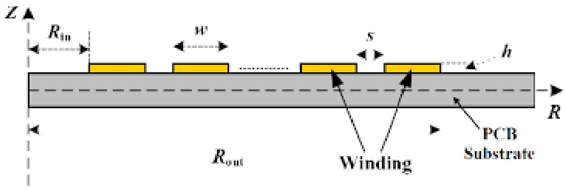

Fig. 1. The coil winding structure shown in 2D axi arrangement.

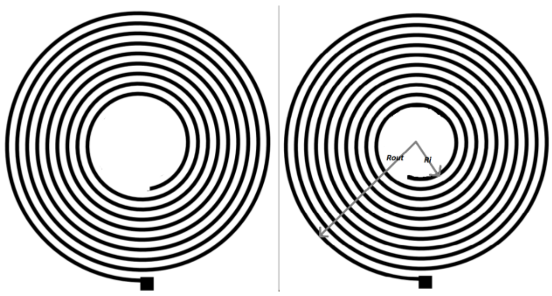

Fig. 2. Hollow (9 turn) and Full(10 turn) winding structures.

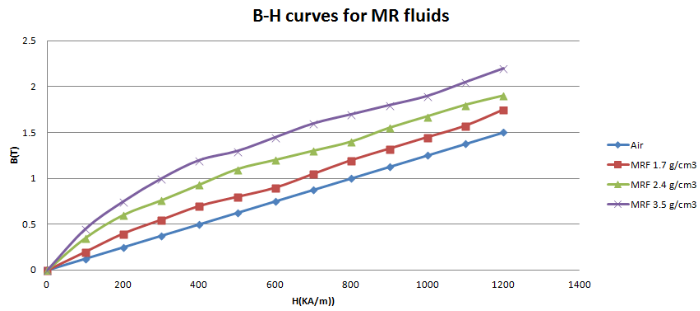

Fig. 3. B-H curve of the Ferrofluids [9]

No. of turns	R_{in} (mm)	R_{out} / R_{in}	L (µH)	R_{ac} (Ω)	Q_{air}	$Q_{Ferrofluid}$
R_{out} = 15 mm, h = 105 µm, w = 1mm, s = 0.5mm						
10	0.5	0.0333	1.1	0.08906	7.73	11.27
9	2	0.1333	1.09	0.0868	7.88	11.49
8	3.5	0.2333	1.06	0.08267	8.02	11.70
7	5	0.3333	9.86E-07	0.07706	8.04	11.73
6	6.5	0.4333	8.80E-07	0.07007	7.89	11.51
5	8	0.5333	7.41E-07	0.06171	7.54	11.00
4	9.5	0.6333	5.75E-07	0.05201	6.95	10.13
3	11	0.7333	3.96E-07	0.04095	6.08	8.86
2	12.5	0.8333	2.21E-07	0.02852	4.87	7.10
1	14	0.9333	7.53E-08	0.01476	3.20	4.67

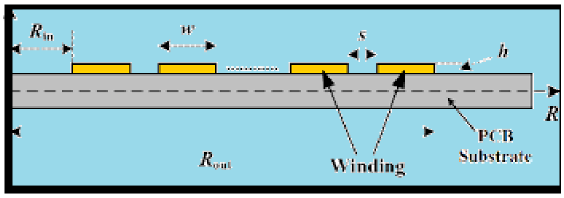

Fig. 4. The coil winding structure shown in 2D axi arrangement dipped in ferrofluid

R_{in} and R_{out} are to be chosen in correct way to have better Q (quality factor of the coil) with lesser ac resistance. Different turns of the conductor are studied. The coil under study is having 10 turns and with conductor width w = 1.0 mm, spacing s = 0.5mm, track height h = 105 µm, R_{out} = 15 mm Fig(2). It is tested for air media and ferrofluid dipped condition. Ferrofluid is a suspension of magnetic particles in a nonmagnetic liquid medium. Its material properties, such as viscosity, stress, and magnetic permeability, are continuously varied by the magnitude of externally applied magnetic fields. Fig(3) shows B-H curve.

The inner turns are removed one by one and hollow winding is obtained. Its inductance and the ac resistance have been calculated in each case using FEA tool. In this work, we are trying to see the dependency of the number of coil turns and the inductance so formed. If the turns are reduced from maximum to minimum, the inductance value decreases also ac resistance varies. The quality factor which is ratio of inductive reactance to ac resistance of the coil also changes.Fig(4) shows coil arrangement with ferrofluid.

Table 1. The variation of Quality factor at 100 kHz in the absence (air cored)and in presence of ferrofluid

The hollow windings will able to have higher quality factor as seen from the graph. Also the presence of ferrofluid will improve the inductance. As seen from the B-H curve the ferrofluid have higher permeability as compared to air. Hence higher inductance will be obtained. Fig. 5. shows coil quality factor variation with (R_{in} / R_{out}) ratio for both air cored and Ferrofluid dipped coil.

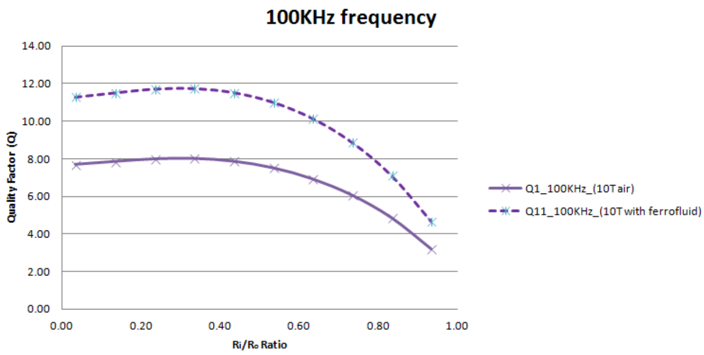

Fig. 5. The coil quality factor variation with (R_{in}/ R_{out}) ratio (air cored and Ferrofluid dipped coil)

Obviously use of ferrofluids will improve the performance. There are different density wise Ferrofluids available and the B-H curve is plotted for different density ferrofluids. [10]

Table 2. The variation of quality factor (500KHz)

*2.2 Simulation:*The FEA tool COMSOL Multiphysics [11] is used for calculating R_{ac} and inductance of the coil r of turns increases the value of inductance and consequently the quality factor, the presence of ferrofluid additionally increases the inductance by a factor of 47% as the permeability of used ferrofluid is 1.47.Fig(5) shows relationship graph at 100KHz. show that the full turn (10Turn)coil will have larger inductance but the quality factor will be lower one as compared to hollow winding.The q factor is better for 0.33 to 0.53for 100 KHz frequency.

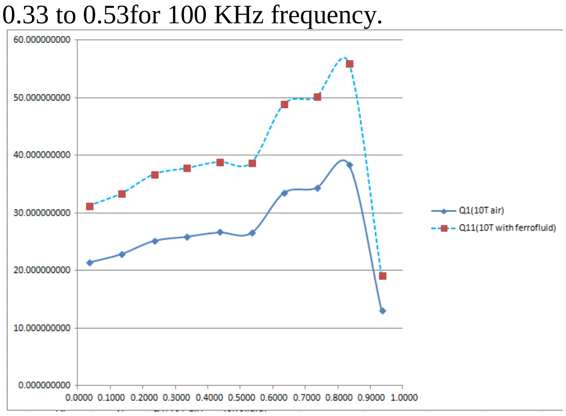

Fig.6. The coil quality factor variation w.r.t (R_{in} / R_{out}) ratio at 500 kHz (air cored and Ferrofluid dipped coil)

Fig.6. Shows coil quality factor variation w.r.t (R_{in} / R_{out}) ratio at 500 kHz .Both air cored and Ferrofluid dipped coil are simulated at 500 kHz. It will be concluded that the Quality factor improves greatly at higher value 3 to 4 times as compared to 100 KHz. Hence it is better to use such structures at high frequencies.

The Variation of the H (magnetic strength) AT/m is shown in fig.7. It is obviously higher at central area. This convex uneven nature will lead to higher eddy current loss at the central (inner) turns.

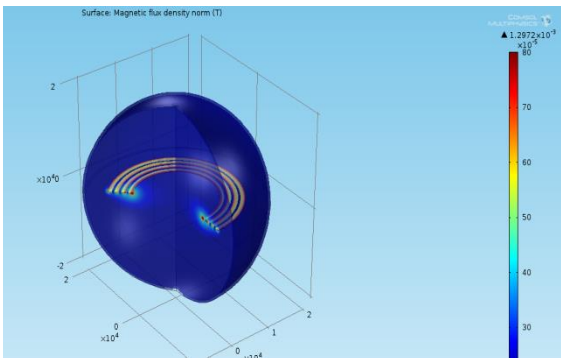

Fig. 7. Variation of the magnetic field strength

No. of turns	**R_{in} (mm)**	**R_{out} / R_{in}**	**L uH**	**Rac**	**Q(Air)**	**Q FF**
R_{out} = 15 mm, h = 105 µm, w = 1mm, s = 0.5 mm						
10	0.5	0.0333	1.0611	0.15526	21.47431	31.3095
9	2	0.1333	1.0580	0.14500	22.92576	33.4257
8	3.5	0.2333	1.0553	0.13150	25.21532	36.7639
7	5	0.3333	9.6500	0.11690	25.93695	37.8160
6	6.5	0.4333	8.6400	0.10170	26.69309	38.9185
5	8	0.5333	7.2840	0.08601	26.60891	38.7957
4	9.5	0.6333	5.6600	0.06980	33.55418	48.922
3	11	0.7333	3.9050	0.05300	34.41657	50.1793
2	12.5	0.8333	2.1700	0.03565	38.41205	56.0047
1	14	0.9333	7.4300	0.01775	13.15214	19.1758

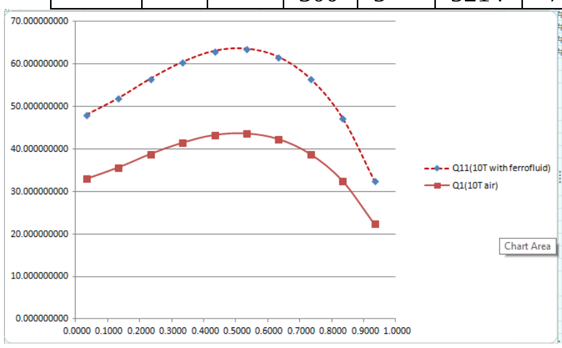

Fig. 8. Variation of quality factor at 1MHz

Fig. 8. Shows coil quality factor variation w.r.t (Ri/Rout) ratio at 1 MHz .Both air cored and Ferrofluid dipped coil are simulated at 1 MHz.It will be concluded that the Quality factor improves but not greatly as higher value .Hence it is clear that now the rise is not high as ealier.

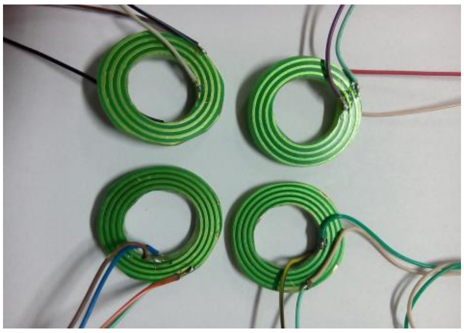

Fig. 9. PCB windings constructed in LAB.

The PCB winding are constructed as shown.Fig.9. The Hollow winding structures for three Turn coil is shown. Copper tracks are formed using etching process. The winding parameters are measured practically using LCRQ (HP 4284 A) meter.

Fig. 10. Practically testing the parameters in HF lab.

It is also important to see the temperature variation of such coil under test. Fig.(11)The FLIR IR camera is used for the purpose. The higher temperature rise can be reduced by cooling property of ferrofluid. Such nature will obviously help to improve the performance at Higher frequencies.

Fig. 11. Measurement of the temperature using FLIR IR camera

3.Conclusion:

Use of ferrofluids obtained from Charother University (Gujrat,India) was done.It is clear that in all cases the performance (quality factor) improved greatly. Hence we will able to improve total performance of the inductors and transformers

4.Acknowledgments

We would like to acknowledge Dr. R.V. Upadhyay and Ms. Kinnari Parekh, Charother University, Gujrat, India for their support for providing us the ferrofluid samples.

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