Research on Polymer-Bonded Magnetic Materials for a buck converter

Kai Ding, K.W.E.Cheng, Wei-Tai Wu, Daohong Wang

***Abstract*--There is currently a need of magneto-electrical apparatus such as inductor and transformer that operate at hundreds of kHz up to several MHz, or even higher frequency. The material based on polymer-bonded magnetic powder has a feature of the magnetic property and can be used as the power transformer, electromagnetic interference shielding, and power inductor, etc. It is so promising that this material has been found good results for power conversion and screening. In this work, a magnetic ring core was fabricated using the composite of the magnetic powder and polymer, nickel, rare earth materials and poly(methyl methacrylate) (PMMA). This ring core was used as the output filter in a buck converter, and the electrical properties were studied.**

***Index Terms*-- buck converter, magnetic material, polymer, transformer**

I. Introduction

IN recent years, the advanced properties of polymer bonded magnetic materials continue to be attractive to researchers. These magnetic materials, which are composed of magnetic powder and polymer matrix, combine attractive magnetic properties with superior shaping capabilities. Other advantages of the polymer-bonded magnets are lighter weight, unlimited magnet lengths, and, in many cases, improved cost effectiveness due to net-shape manufacturing[1]-[4].

Soft ferromagnetic materials are those magnetic materials with high permeability, low coercivity and low hysteresis loss, which can be used to amplify the flux density generated by a magnetic field. There are many types of soft ferromagnetic materials; usually, for the power converter application, they could be ferrites (like Ni-Zn ferrites, and Mn-Zn ferrites, etc.), the alloy containing Fe, Co, Ni and other elements (like FeNi alloy, and silicon steel sheet, etc.), and polymer-bonded magnetic materials which are composed of polymer matrix and magnetic powder (like polymer -bonded MSS magnetic powder, polymer -bonded MPP magnetic powder, polymer bonded Fe-Ni powder, etc.), etc. The available range of magnetic properties of soft magnetic materials is continually being expanded. This amounts to reduction in coercivity, increase in permeability and consequently a decrease in hysteresis loss. These advantages make them very popular for the application in power conversion. One of the applications is to produce inductor cores or transformer cores for the power converter. And the loss for the magnetic device usually accounts for 30-40% of the total losses of the converter.[5]-[10]

Conventional magnetic material suffers from a number of disadvantages including limited size, brittle, high loss, and high cost, etc. Particularly, for the application in high power conversion (> 20 kw system), it becomes very difficult and much expensive to fabricate the transformer or inductor cores required. However, polymer-bonded magnets can be produced by traditional polymer processing methods, which offer significant advantages in respect to shaping and cost.[11]

In power conversion, the loss mainly derives from the loss in the conductor and that in the core. The loss in the conductor (winding) is the resistive loss because of the passing current through the winding, and it will increase dramatically with increasing frequency due to the high-frequency current distributed in the conductor. The losses in the magnetic core usually include the hysteresis loss, eddy loss, and residue loss. The hysteresis loss is the dominant loss when working at the lower frequency (below 50 kHz, hysteresis/eddy loss < 20%), and the eddy loss becomes more important at the higher frequency (above 500 kHz, hysteresis/eddy loss > 60%). The introduction of polymer bonded soft magnetic materials in the core could lower the eddy loss to some extent, thus could extend their applications to a broader range at high frequency area.

This paper is to investigate the electrical properties of a polymer bonded magnetic material applied in power conversion. The polymer bonded magnetic material was prepared by a common mixing method namely "melt mixing method", and then was molded into ring shape. This ring core was used as the inductor, which is used as the output filter in a buck converter. It is envisioned that the present studies may bring some insight into the application of the polymer bonded magnetic material.

II. Fabrication of Magnetic Composite

The filler of the composite materials were cobalt powders (spherical, diameter < 18 μm) or nickel powders (spherical, diameter < 4 μm). Their surfaces were treated by titanic coupling agent (1.5% weight of filler) to enhance dispersing the magnetic powders and improving the consistent between magnetic powders and the polymer. Poly(methyl methacrylate) (PMMA) was used as the polymer matrix.

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III. THE POLYMER BONDED MAGNETIC RING CORE

A Polymer bonded ring core which consist of Nickel micro –powder(18%), Rare Earth Materials(76%) and PMMA is used for analysis. The outer and inner diameters of the core are 3cm and 1.2cim respectively. The height is 1.1cm. Fig.1 shows the core wounded by 150 turns of winding. It can be seen that the core is very similar to other ferrite or powder iron. The strength of the core is also very high but not brittle as the ferrite and powder iron. The inductance of the core wounded by 150turns was measured at 100 kHz, the wounded core has a low relative permeability of 3, and the measured inductance is 87uH.

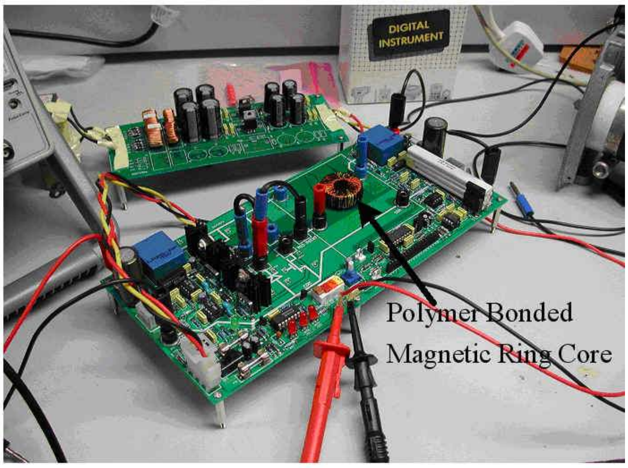


Fig.1. Photo of the experiment configuration.

IV. APPLICATION OF A BUCK CONVERTER

A. *Buck Converter*

The buck or step-down converter regulates the average DC output voltage at a level lower than the input or source voltage. This is accomplished through controlled switching where the DC input voltage is turned on and off periodically, resulting in a lower average output voltage. The buck converter is commonly used in regulated DC power supplies like those in computers and instrumentation. The buck converter is also used to provide a variable DC voltage to the armature of a DC motor for variable speed drive applications[12]. As shown in Fig.2, the characteristic of buck converters, in general, is that the DC output waveform is less than the DC input waveform. A buck converter that does not employ a transformer as an isolation stage is referred to as a non-isolated buck converter. The non-isolated buck converter typically includes switching circuitry coupled to an input source of electrical power. The switching circuitry includes at least one active switch. The switching circuitry is coupled to an output inductor and output capacitor which provides the DC output waveform (i.e., an output voltage) at an output of the non-isolated buck converter[13].

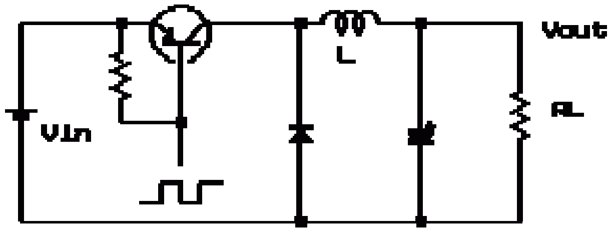


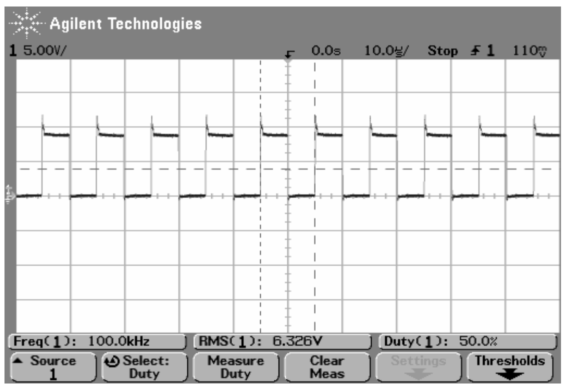
Fig.2 Buck converter

B Experiment

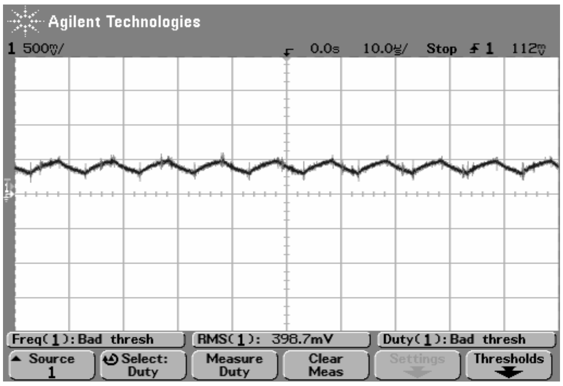
The buck converter shown in Fig.2 was constructed; the inductor based on the polymer-bonded magnetic material was used in the experiment. The electrical specification of the converter is shown in table I. The polymer-bonded magnetic ring core inductor was used as the output filter in the experiment shown in Fig.1. The switching frequency is 100 kHz; the switch duty ratio of the buck converter was set to 50% and 75% respectively. A variable load resistor was used as the load. The load resistor was adjusted to 10ohm. The experiment waveforms are shown in Fig.3 and Fig.4. Fig.3(a) and Fig.4(a) show the PMW signal. For the inductor current measurement, calibration of the current sensors is such that for 1A flowing through the sensor, the output is 0.5V. The signal is amplified by a factor of 2 as shown in Fig.3(b) and Fig.4(b). The capacitor current is measured across a series resistor of 0.1ohm. Hence the actually value of capacitor current is 10 times the value as shown in Fig.3(c) and Fig.4(c).

TABLE I
The Electrical Specification of the buck converter

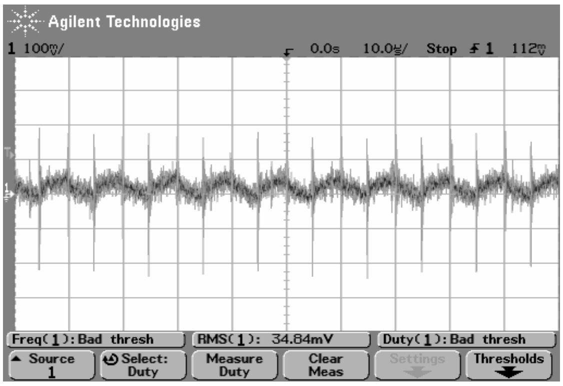
Operation	Specification
Input Voltage Vin	15V
Output Voltage Vout	0-15V
Output Power Po	0-15W
Switching Frequency fs	100kHz
Polymer Inductor	87uH
Output Capacitor	680uF



(a)

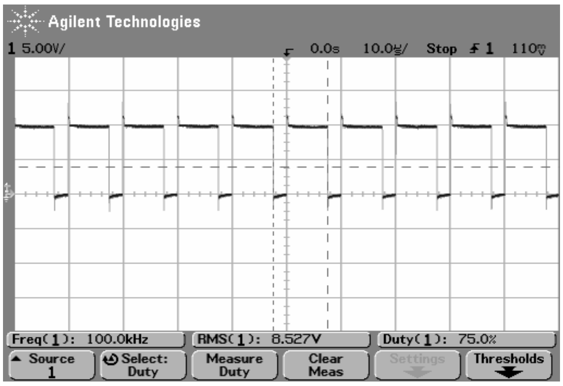


(b)

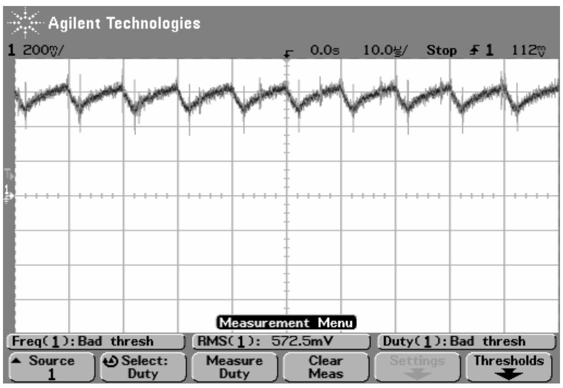


(c)

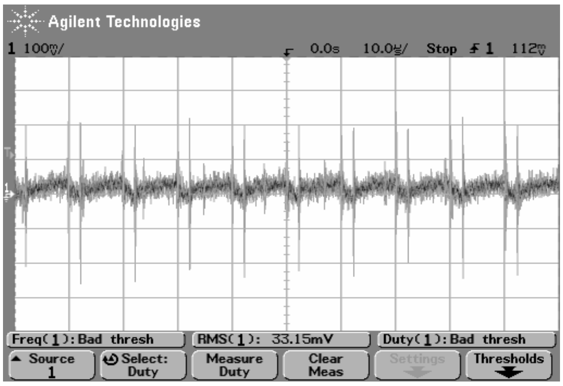
(a) PWM signal (b) Inductor current(500mV/1A) (c) Output capacitor current(100mV/1A)
Fig.3 Experiment results (Duty ratio=50%)



(a)



(b)



(c)

(a) PWM signal (b)Inductor current(200mV/400mA) (c) Output capacitor current(100mV/1A)
Fig.4.Experiment results (Duty ratio=75%)

V. ACKNOWLEDGMENT

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VI. CONCLUSION

Polymer bonded magnetic materials offers many advantages compared to the conventional type of magnetic materials in respect to shape, and cost, etc. A polymer bonded magnetic material was developed. The fillers of the composite were nickel powders (18% in weight) and rare earth compounds (76% in weight), and PMMA was used as the polymer matrix. A buck converter using an inductor core based on the materials had been prototyped. The experimental results indicate that the material may be suitable for making inductor core.

VII. REFERENCES

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