"MPCG" for Large-Current Using Ultra Low Loss Dust Material "SENNTIX" Formed by One-Piece Construction

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Abstract

Recently, the performance of electronic equipment has been advancing rapidly and function availability has been increasing. This trend is of particular importance in the case of compact equipment such as notebook PCs, where a reduction in voltages in order to reduce the power consumption has resulted in an increase in the current flowing through the power lines. This has made it necessary for the inductors to be capable of dealing satisfactorily with the high-current supply and to improve the power loss characteristic. NEC TOKIN has started development of low-loss magnetic core materials that can improve power conversion efficiency and has produced an ultra low loss dust material for inductors, named "SENNTIX." "SENNTIX" is a metallic glass dust powder that features both a high saturated magnetic flux density that is proper to metallic materials and a stable amorphous structure proper to metal glass composite materials. There is no magnetic saturation under a high-current supply and it can therefore significantly reduce magnetic loss resulting from the effect of the core material. NEC TOKIN's low-loss choke coils of the MPCG Series use the low-loss metallic glass composite material "SENNTIX" as the core material and offer a high power conversion efficiency reflecting the low loss characteristic of the material. We are now advancing the application and deployment of "SENNTIX" in power components with the aim of providing solutions for power supply systems issues of electronic equipment that is subjected to increasing power loads. This policy will enable energy saving and control of heat generation as well as improvements in the power integrity.

Keywords

metallic glass, low loss, dust core, inductor, choke coil, DC/DC converter

1. Introduction

As a result of the evident advancement of ubiquitous technology, information equipment applications, including those for notebook PCs are making significant progress and their power consumptions are increasing more and more.

The inductor materials used in the DC/DC converters for the power supplies of cellular phones and notebook PCs are shifting greatly from the previously used ferrite materials to metal alloy materials with higher saturated magnetic flux density. This practice is enabling prevention of the magnetic saturation caused by the increased power loads.

Following this trend, the supply of a high-speed, high-quality energy and the control of power consumption become big problems along with it in CPU. The achievement of a high level of power efficiency in the power supply circuit has become a high-priority issue.

At NEC TOKIN, we observed the loss characteristic of metal inductors as well as their high-current compatibility and have developed "SENNTIX," which is a new low-loss metallic glass composite material that can compactly achieve high-efficiency inductors for low-voltages and high-current power supplies for mobile notebook PCs, etc. This paper describes the characteristics of "SENNTIX" and introduces the MPCG-Series of high-current compatible, low-loss choke coils that use "SENNTIX" as the core material.

2. Development Background

"SENNTIX" is an ultra low-loss type metallic glass composite dust material with an excellent loss characteristic that has been implemented by applying our inherited magnetic technology. Our aim in this development has been to improve the power supply efficiency of switched power supplies by improving the loss characteristic of the cores used in the inductors.

In general, an inductor for use in a power supply circuit with a high DC is required to achieve a specified current smoothness and a constant voltage. In order to achieve this, a compacted metal dust core is used, which is fabricated by the integral molding of crystalline metal powder with a high saturated magnetic flux density, such as Fe powder or Fe-Si powder together with resin. However, since the main component of the crystalline Fe-based metal dust materials is iron, they present big magnet loss (hysteresis loss) due to magnetocrystalline anisotropy and magnetostriction derived from the crystalline structure, regardless of their high-saturation magnetic flux densities. As a result, when they are used in inductor cores, they become a non-negligible factor; depraving the power efficiency of the power supply circuitry.

Based on the knowledge that an amorphous crystalline structure can decrease the magnetocrystalline anisotropy of metallic materials, Fe-or Co-type amorphous materials have been put to practical use. However, there have been problems in the practicality of these materials because necessitates an advanced rapid quenching process in manufacturing [1)].

Also, some materials featuring low magnetostriction have been put to practical use, including crystalline materials such as Fe-Si-Al (Sendust [*1]) and 80Ni-Fe (Permalloy) as well as amorphous metallic materials such as Co amorphous materials. However, these materials are not suitable for the inductors used in high-current power supply circuitry because their low saturated magnetic flux densities easily cause magnetic saturation under high-current supply loads.

To deal with the above problems, we have succeeded to develop a Fe-based metallic glass dust material "SENNTIX" featuring a high saturated magnetic flux density that can correspond to the large-current supply and an extremely low hysteresis loss (particularly the crystal magnetic anisotropy magnetocrystalline anisotropy) that can minimize the inductor loss.

We have thus enabled commercialization of the MPCG Series of new low-loss choke coil capable of improving the power loss characteristic of power inductors for use in large-current supply environments.

3. Ultra Low Loss Inductor Material "SENNTIX"

"SENNTIX" is a metallic glass material using Fe as its main component in an amorphous structure, which has a DSC (Differential Scanning Calorimeter) profile as shown in **Fig. 1** . "SENNTIX" presents a wide supercooled liquid region which is peculiar to the metallic glass and an amorphous structure with excellent stability [2)] .

These characteristics have allowed us to achieve both the high saturated flux magnetic density of an Fe-type soft magnetic material and the excellent low-loss characteristic of an amorphous material.

The power loss in a metal magnetic core can be expressed in a simplified form using the following formula:

$$P_{LOSS} = Wh \cdot f + We \cdot f^2 \quad (1)$$

Here, P_{LOSS} is the total power loss of the metal magnetic core, Wh is the hysteresis loss component that represents the magnetic loss, We is the eddy current loss component that represents the electrical loss, and f is the input waveform frequency when the core is used in an inductor.

Theoretically, amorphous materials do not have magnetocrystalline anisotropy. In fact, however, manifestations of anisotropy derived from the fabrication conditions such as the temperature gradient in quenching have been reported. "SENNTIX" is a metallic glass material with very low magnetic anisotropy (Ku), and using it as the material for inductors has made it possible to significantly reduce the hysteresis loss component that can be expressed in the following

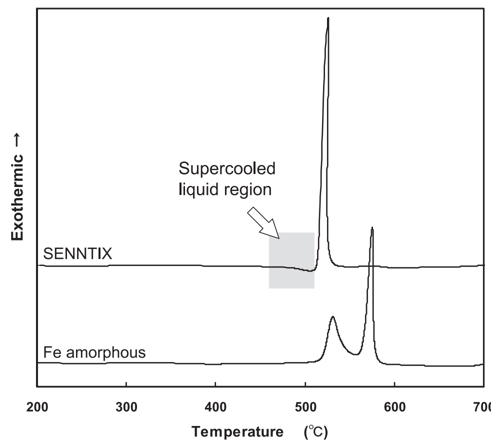

Fig. 1 DSC profile of SENNTIX.

*1 "Sendust" is a registered trademark of the National University Corporation Tohoku University.

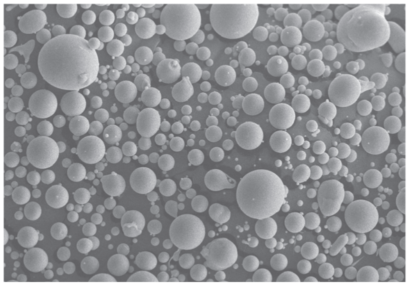

Photo 1 SEM micrograph of SENNTIX.

formula:

$$Wh = 4\,Ch \cdot B \cdot 2Ku/Is \quad \text{- (2)}$$

Here, *Wh* is the hysteresis loss component, *Ku* is the magnetic anisotropy constant derived from the crystalline structure arrangement, *Ch* is the coefficient determined by the hysteresis curve, *B* is the magnetic flux density and *Is* is the saturation magnetization [3)].

Photo 1 shows an SEM micrograph for the “SENNTIX” powder. It shows that this dust powder features both a spherical shape and a very small grain diameter.

For the application of “SENNTIX” powder in inductor cores, the sphericity and diameter of the particle are optimized to improve the packing density. In addition, the eddy current loss is shown by the following formula. And the eddy current loss produced when current flows through the core or individual metal grains is also reduced.

$$We = \pi^2 \cdot d^2 \cdot B^2 / c \cdot \rho \quad \text{- (3)}$$

Here, *We* is the eddy current loss component, *d* is the particle diameter, *B* is the magnetic flux density, *c* is the constant determined by the particle shape, and *ρ* is the volume resistivity [4)].

Table 1 shows electromagnetic characteristics in the bulk status of “SENNTIX” and a Fe-type soft magnetic material. It shows that “SENNTIX” is a soft magnetic material providing both a high saturation magnetic flux density and a high

Table 1 Electromagnetic characteristics of SENNTIX.

Characteristic / Material	Saturated magnetic flux density *Bs* [T]	Relative permeability *μ* 100 kHz	Coercive force *Hc* [A/m]	Electrical resistivity *ρ* [μΩ-cm]
SENNTIX	1.3	6000	2.0	130
Pure iron	2.2	≦200	64	10
6.5% Si-Fe	1.8	1600	20	80
Fe amorphous	1.5	2900	3.0	115

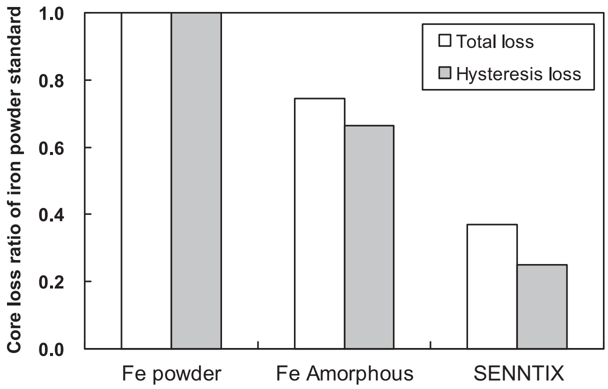

Fig. 2 Comparison of loss between SENNTIX and Fe-type soft magnetic dust materials.

magnetic permeability. Specifically, the saturated magnetic flux density of *Bs* =1.3T, which can correspond enough to the large-current supply and a relative permeability of μ = 6000.

In addition, the volume resistivity value is higher than for other Fe-type soft magnetic materials and it is also expected that the eddy current loss, which was caused in each microscopic dust particle, will be reduced when the material is fabricated into the core.

Furthermore, in “SENNTIX” which has high stability in amorphous structure, composition of low magnetocrystalline anisotropy the coercive force is low, as a result the hysteresis loss also has been decreased.

This also means that it is a soft magnetic material that is extremely suitable for use in inductors that handle high power.

Fig. 2 shows the results of a loss comparison between “SENNTIX” and Fe-type amorphous dust material (at 50mT, 300kHz). It shows that the loss of “SENNTIX” is 1/2 compared with a iron powder, is 1/3 and a very low loss compared with Fe-type amorphous material. This is an effect of the reduced hysteresis loss. Such a low-loss characteristic may be because “SENNTIX” can maintain the amorphous state stably thanks to the wide supercooled liquid region proper to a metallic glass composite. As a result, it has thought an inhibition of the manifestation of the magnetocrystalline anisotropy that might lead to an increased hysteresis loss.

4. Low–Loss Choke Coils “MPCG Series”

Similarly to the MPC Series that has already been commercialized, the MPCG series is choke coil formed by one-piece construction method that are made by pressurizing a coil obtained by winding a flat rectangular wire edgewise with "SENNTIX" that can correspond to a large-current (**Photo 2** , **Table 2** , **Table 3**).

MPCG is a choke coil that can provide an unprecedented high efficiency characteristic of excellent low loss by having adopted "SENNTIX" (featuring both high saturation magnetic flux density and a low-loss characteristic) for the magnetic material compared with our previous products.

Fig. 3 shows the improvement of the power load efficiency confirmed by the use of "SENNTIX" as the material for the core of our metal composite choke coil (MPC1040LR56). The graph shows that the use of "SENNTIX" has improved the effective efficiency all over the load current range from 0.1A to 10A. In particular, in the low-current range below 5A where the hysteresis loss has occupied an important share, the

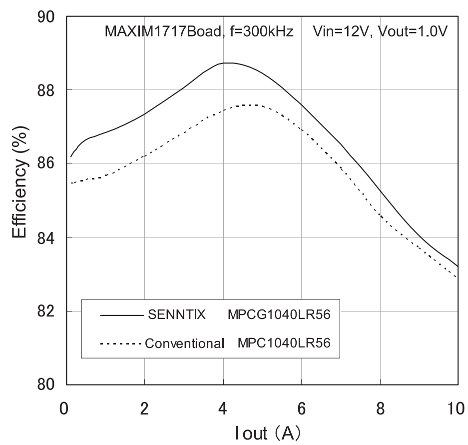

Fig. 3 Power load efficiency characteristic.

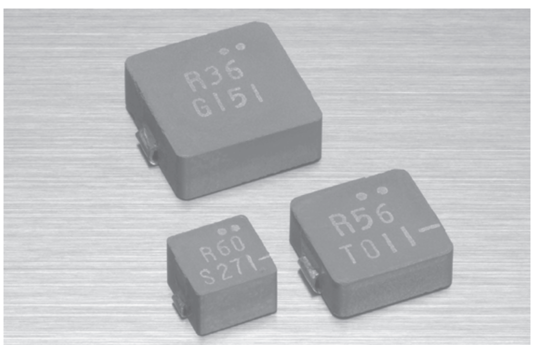

Photo 2 External view of low-loss choke coil "MPCG" products.

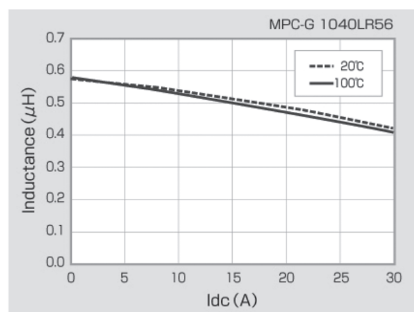

Fig. 4 DC-superposed characteristic.

Table 2 Construction of the MPCG Series.

	MPCG Series
Coil	Flat Copper Wire
Core	Fe-based Metallic Glass Powder
Molding	Pressurization Molding
Terminals	Direct Terminals

Table 3 Dimensions and electrical characteristics of MPCG Series.

Name	Dimensions [mm]	L [μH] at 100 kHz	Rdc [mΩ]	Rated Current [A]
MPCG0730LR20	7.0max×8.0max× 3.0Hmax	0.20 ±20%	1.20 ±10%	17.5
MPCG0740LR42	7.0max×8.0max× 4.0Hmax	0.42 ±20%	1.55 ±7%	20.0
MPCG1040LR36	10.3max×11.5max× 4.0Hmax	0.36 ±20%	1.05 ±15%	25.5
MPCG1040LR45		0.45 ±20%	1.10 ±15%	25.0
MPCG1040LR56		0.56 ±20%	1.30 ±15%	23.0

efficiency has been improved by more than 1.5%. This means that the use of the MPCG Series of low-loss choke coils in notebook PCs can be expected to improve the standby time, etc.

Fig. 4 shows the DC-superposed characteristic of the MPCG1040LR56. It shows that "SENNTIX" as a Fe-basedmetallic glass composite material presents a stable temperature characteristic without being saturated, even under large current supply conditions above 20A. The MPCG Series of low-loss choke coils can thanks to their low loss characteristic correspond enough to large currents and provide an optimum solution for the design of high-efficiency power supply circuitry.

5. Conclusion

We are concentrating to develop low-loss magnetic materials with the aim of improving the energy efficiency of the mobile electronic equipment that currently leads the information society.

In this context, by improving their magnetic permeability we are implementing more compact, low-loss inductors than were hitherto in use. In this way we will continue to able to offer optimum solutions to our customers.

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