Technical Report

Technology Trends of Ferrite Cores and Their Applications

TDK Corporation Katsushi Yasuhara

Dempa Shimbun High-Technology January 7, 2010 Edition

1. IEEE milestone recognition

In October 2009, the "Development of Ferrite Materials and their Applications" by TDK and the Tokyo Institute of Technology was recognized as an "IEEE Milestone" by the IEEE, which is the world's largest academic society for electrical and electronics engineers. IEEE Milestones give recognition to key historical achievements in the electrical and electronics engineering fields that contribute to society and toward development of the industry. Since it was established in 1983, over 80 achievements from around the world have been recognized. Ferrite development makes the tenth achievement from Japan to be recognized in addition to developments such as the Tokaido Shinkansen and the VHS format.

Ferrite is a unique magnetic compound invented in Japan. It was invented in 1930 by Dr. Yogoro Kato and Dr. Takeshi Takei who belonged to the electrical and electronics engineering department at the Tokyo Institute of Technology. At that time, applications for ferrite were unknown. In 1937, TDK began mass production of ferrite cores called "Oxide Cores" for use in radios. Afterward, based on the unique characteristics of ferrite, it began to be used for various electrical components such as inductors, coils, antennas, deflection yokes, transformers, and EMC management components. This greatly contributed toward the development of electrical devices. Still now, ferrite is an essential material for the electronics industry. The "Development of Ferrite Materials and their Applications" was therefore recognized as an IEEE milestone because ferrite has greatly contributed to new products and new technologies according to current needs even 80 years after its invention.

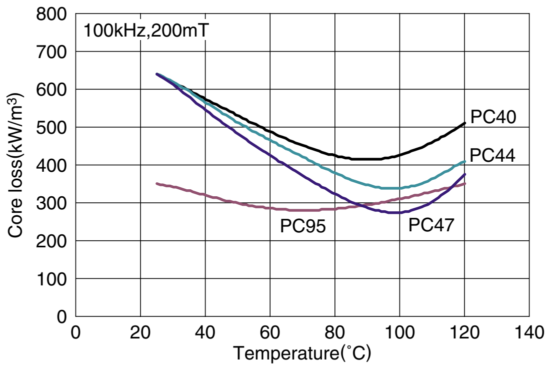
A sense of crisis has been increasing globally due to global warming. Therefore, people are aware of the need to reduce greenhouse gas emissions. Improving fuel efficiency and use of electronics in transportation equipment such as hybrid vehicles are typical examples. Electronic devices are expected to save energy and resources. As a result, electronic devices have become smaller, lighter, and more efficient. Solar energy generation is more commonly used as an environmentally friendly energy source. Required characteristics for electrical components and materials have become more varied. TDK has been developing ferrite that is compatible for various usages. Here, the latest technical trends related to ferrite for power systems and noise suppression will be explained.

2. Ferrite for power transformers

The characteristics of MnZn ferrite include low magnetic anisotropy and large spontaneous magnetization. Because of this, it has low loss and a high saturation flux density, which makes it optimal for power transformers.

Figure 1 shows the core loss temperature characteristics of this ferrite for various switching power sources.

Figure 1 Correlation between ferrite core loss and temperature for switching power sources



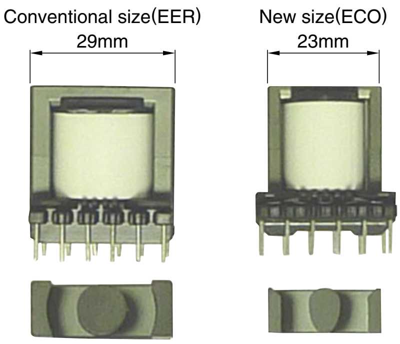
In 1981, PC40 was made into a commercial product and became the de facto standard. This was later developed into PC44 and PC47. PC95 was made as a commercial product to meet requirements for low loss over a wide temperature range for vehicle electronic devices and the high power density of the power module. PC95 has been used in the main transformers of main power sources and module power sources of EVs. It has been contributing toward improved power efficiency and

TDK

controlling temperature increase.

Circuit types, input/output, and specifications for drive frequencies, and the operating environment temperature of power sources differ according to the usage. Therefore, the required characteristics of ferrite materials also differ. Flyback systems are the simplest and most common type of circuits that use few components. Flyback transformers need to use high-saturation flux density materials because magnetic saturation limits size minimization. TDK has improved the existing PC47 to develop a high-saturation flux density ferrite material that can allow for better direct current superimposition. By changing the core size and bobbin configuration, we have been able to create the ECO series of small transformers for flyback power sources that are compatible with major safety standards throughout the world. The ECO series products are 20% smaller and 45% lighter than our conventional products (Figure 2).

Figure 2 Flyback power source transformers

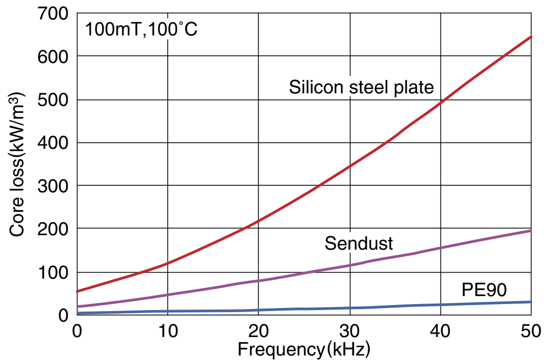


Flat-panel TVs have now replaced CRT TVs, and these have become larger, thinner, and more energy efficient. As a result, high-efficiency and low noise resonance systems have become more commonly used for main power sources*1. In order to produce small, thin, and efficient resonance transformers, it is necessary to reduce temperature increases. We have developed ferrite materials with low loss at temperature environments where transformers are used, and have developed commercial resonance transformers that are only 10mm thick (on the substrate) based on optimization of core and bobbin sizes and winding techniques. We have also developed a PFC inductor (choke for improving the power factor) that is only 10mm thick on the substrate by using high-saturation flux density ferrite mentioned in the above.

3. Ferrite for reactors use with high-power units

In solar power generation systems, DC power is generated by solar batteries, which is then converted to AC power using a power conditioner and used to power general household devices. In many countries, usage of new energies has been promoted based on political policies. As a result, the market for solar power generation systems has suddenly increased throughout the world. Power conditioners consist of a converter that increases the DC voltage, and an inverter that converts the DC to AC. Reactors are used for booster circuits and inverter smoothing. Reactors used in high-power units require a core material with a high-saturation flux density and low iron loss. Currently, operating frequencies are from 15 to 20kHz, which is relatively low, so metal cores with a higher saturation flux densities are often used. Figure 3 shows a comparison of core loss frequency characteristics for a metal magnetic material and ferrite (PE90). Large PE90 cores have low loss and a high saturation flux density and can be used for reactors with a rated current of 10A. When the operating frequency is 16kHz, PE90 core loss is about 1/14th that of silicon steel plates, and about 1/3rd that of sendust. When PE90 is used as the core material in reactors for inverter smoothing, the total loss from iron loss and copper loss can be reduced by about 33% over that of silicon steel plates and about 30% over that of sendust.

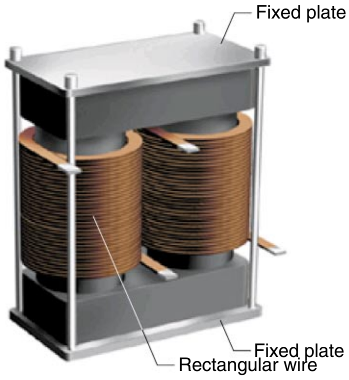
Figure 3 Comparison of core loss frequency characteristics



In recent years, high-power IGBTs (Insulated Gate Bipolar Transistors) have been improved with lower loss and higher speeds. Therefore, it is expected that switching frequencies for power conditioners will be able to be increased to 30 to 50kHz. When a higher frequency is achieved, the required magnetic flux density becomes smaller, so it will become possible to reduce the size and to utilize the advantages of ferrite's low loss even more. Figure 4 shows an example of a reactor configuration. Two wound cylindrical cores are installed between plate-like cores. Inductance is adjusted using the air gap between the cylindrical cores and plate cores. Ferrite's ability to easily be molded and processed into various shapes makes it possible to create optimal designs.

*1 July 28, 2008 issue of Nikkei Electronics, P.111-114

Figure 4 Reactor configuration



4. Ferrite for power inductors

Inductors used in the power systems of mobile phones, portable music players, and digital still cameras must be small, thin, and efficient and have high DC superimposition characteristics. The configuration uses direct winding to the drum core, so NiZn ferrite with high volume resistivity is mainly used. The core material must have high saturation flux density and have low loss, and it should also have a high mechanical strength.
Table 1 shows the characteristics of the High Bs series used for TDK power inductors. It can be said that there is a tradeoff relationship between the saturation flux density and initial permeability or core loss.
Therefore, materials with high Bs and low loss have continued to be developed. In order to make smaller and thinner inductors, it is necessary to use smaller, thinner ferrite cores with improved dimension accuracy.
Because of the advancement of comprehensive processing techniques, from materials and granules to molding and firing, cores can now be created that are compatible with 1005 size products using a powder molding process.

5. Ferrite for noise suppression

Noise suppression using ferrite is done by (1) reflecting noise using L components and impedance, (2) converting noise to heat and absorbing it using R components, and (3) shielding emission noise.
The most common noise suppression method is reflecting noise using impedance*2.
Table 2 shows the characteristics of TDK's ferrite HF series for noise suppression. This series includes MnZn ferrite for low frequencies and NiZn ferrite for high frequencies so that a wide range of frequencies can be

*2 Shinichiro Ito: Basics Related to Noise Suppression Using Ferrite, Monthly issue EMC, No.256, P.107-119(2009)

Table 1 Material characteristics of the High Bs series used for power inductors

Material			L7H	L13H	L14H	L2H	L9H
Adaptive frequency			0.05 to 1MHz	0.05 to 1.5MHz	0.05 to 3MHz	0.05 to 2MHz	0.05 to 3MHz
Initial permeability	μi		800±25%	500±25%	300±25%	400±25%	200±25%
Relative loss factor	tan δ/μi	[$\times10^{-6}$]	<12(0.05MHz)	<55(0.05MHz)	<160(0.1MHz)	<15(0.05MHz)	<35(0.05MHz)
			<80(1MHz)	<65(1MHz)	<90(2MHz)	<65(2MHz)	<65(3MHz)
Relative temperature factor (μi)	αμir	[$\times10^{-6}$/℃]	7 to 15	15 to 25	25 to 40	15 to 35	20 to 30
Curie temperature	Tc	[℃]	>180	>250	>250	>250	>300
Saturation flux density	Bs	[mT]	390(4kA/m)	460(4kA/m)	480(4kA/m)	430(4kA/m)	500(12kA/m)
Volume resistivity	ρv	[Ω · m]	10^5	10^5	10^5	10^5	10^5
Bulk density	db	[Mg/m³]	5.1	5.2	5.2	5.1	5.2

Table 2 Material characteristics of the HF series for noise suppression

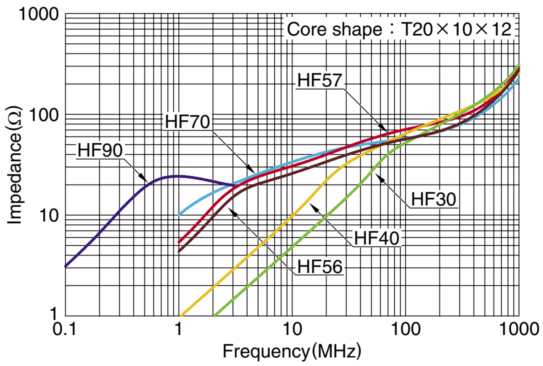
Material			HF90	HF70	HF57	HF40	HF30
Material type			MnZn	NiZn	NiZn	NiZn	NiZn
Initial permeability	μi		5000	1500	600	120	45
Relative temperature factor (μi)	α_F	[$\times10^{-6}$/℃]		1 to 3	3 to 5	8 to 18	5 to 15
Curie temperature	Tc	[℃]	>180	>100	>180	>250	>300
Saturation flux density	Bs	[mT]	480	280	400	410	320
Volume resistivity	ρ_v	[Ω · m]	0.3	10^5	10^5	10^5	10^5
Bulk density	d_b	[Mg/m³]	4.8	5.0	5.0	5.0	5.0
Adaptive frequency*			to 1MHz	to 500MHz	to 500MHz	to 600MHz	to 1GHz
				Radiation noise suppression	Radiation noise suppression	Radiation noise suppression	Radiation noise suppression
Main usage			Noise terminal voltage	Noise terminal voltage			
			Noise voltage	Noise voltage			

* The adaptive frequency is an estimated value.

TDK

covered (150kHz to 1GHz). Integrated and divided type cores that are compatible with round and flat cables and connectors are available. Our lineup also includes the HS series (μi=5500 to 12000) for common mode chokes with different amounts of initial permeability. To suppress noise, it is vital to select the proper ferrite material, core size, and number of windings so that large impedance can be acquired at the frequency band of the noise that needs to be removed. Figure 5 shows an example of impedance frequency characteristics according to each material. HF90 is designed to have a μ" peak at 500kHz so that high impedance can be achieved in the AM radio frequency band. HF90 is effective for suppressing noise from over 100kHz to a few MHz where NiZn ferrite is not effective, and is also effective for suppressing noise on inverter circuits. Replacing metal magnetic materials also helps to reduce costs.

Figure 5 Impedance frequency characteristics of ferrite used for noise suppression



On the other hand, bead cores can be used to absorb noise using ferrite R components. Noise is reflected at a low frequency because reluctance is dominant. However, R components are dominant at higher frequencies, so noise can be absorbed. This makes it important to select the proper material with high R (μ") at the frequency band where the noise that needs to be absorbed exists in order to absorb the noise effectively. This same principle applies to ferrite radio wave absorbers. NiZn ferrite used for bead cores has high intrinsic resistivity, so insulation processing is not necessary between the core and wires.

6. Conclusion

In this document, only some ferrite core products were explained. There are a wide range of ferrite application fields such as laminated chip inductors. Ferrite is a key material for cutting-edge electronic devices, which are used for a variety of purposes and are continuing to advance. TDK will continue to provide new solutions to save energy and resources, and to improve reliability of electrical devices by fully utilizing original materials, process techniques, and evaluation techniques.

• Please note that the articles from the January 7, 2010 Edition of the Dempa Shimbun contained in this chapter have been edited by our company.