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Signal Transmission Properties of the Inductive Coupler using the High Permeability Magnetic Materials

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Abstract

We observed the application possibility of inductive coupler for the underground high-voltage power line communication by means of analysis of signal transmission characteristics and magnetic properties on annealing temperatures for high-permeability Fe-base amorphous alloys. The best electromagnetic and transmission characteristics were shown in nano-crystalline precipitated alloy annealed at temperature 510 ℃. The transmission characteristics in the low-frequency band depend on permeability of magnetic core materials and its properties of high-frequency band can be improved by impedance matching. Using the high pass filter embedded in the coupler, other noise signal band except for communication signals could be cut off.

Key Words : Power line communication, Nano-crystalline, Inductive coupler, Signal transmission

1. INTRODUCTION

For the smooth operations of PLC(Power Line Communication), the communication signals must be transmitted with minimal losses to the user's modem. But, the properties of signals passed the power transformer go bad by loss of signals in the high-frequency band. The PLC coupler which has selective ability to pass the communication signals only in the high-voltage power line is a critical part of PLC and plays an important role on improvements of transmission qualities[1,2]. It is possible to group couplers into two types which are inductive and capacitive coupler. In the case of capacitive coupler, it has excellent transmission properties because of connecting directly to the power cable, but it cannot but show limited applications due to the difficulties and dangers of setting to the cable and high prices of its body. Otherwise, inductive type can be installed easily around cable and shows good frequency characteristics, for example, insertion loss is <-5 dB in the 2~30 MHz frequency range.

The transmission characteristics of inductive coupler consist of magnetic material characteristics and characteristics of high-frequency band. Magnetic material must have high permeability with high saturation flux density (B_s) and be set up annealing conditions for minimizing high frequency loss. On the other hand, characteristics of high-frequency band must be set up core lamination method, winding method of signal lines and impedance matching technique. The coupler plays a role passing on the signal carried by the power frequency wave. However, it also carries other noise signals which give rise to do malfunction of equipment.

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So, It is necessary to cut off noise signal frequency band[2].

In this study, electro-magnetic properties of magnetic material on various annealing conditions and transmission characteristics using these materials are investigated.

2. EXPERIMENTS

After winding the Fe-base alloy ribbons in the form of ring core with automatic winding machine whose bore size is enough to apply to high-voltage underground power cable (cross section area : 325 mm^2), these cores were annealed at the temperature range 480 ~ 550 ℃, 1 hour in N_2 gas and rising temperature rate is 1 ℃/min.

Crystal structure changes with annealing temperatures investigated with XRD The micro-structure and Laue pattern were studied by TEM Permeability and power loss were measured by Impedance Analyser (Agilent, 4294A) and B-H Analyzer (IWATSU, SY-8232).

In order to improve high frequency transmission properties the impedance matching circuit and the high pass filter cutting off noise signal band were embedded in the coupler as shown in Fig. 1.

Signal attenuation(S21) and Impedance changes were measured using Network Analyzer(HP, 8751A).

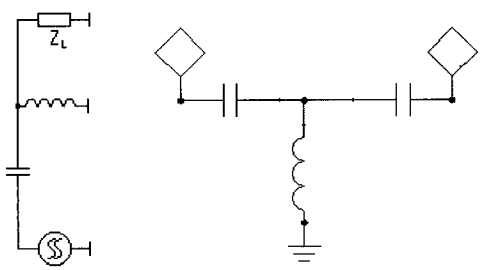

Fig. 1. (a) Impedance matching and (b) high pass filter circuit.

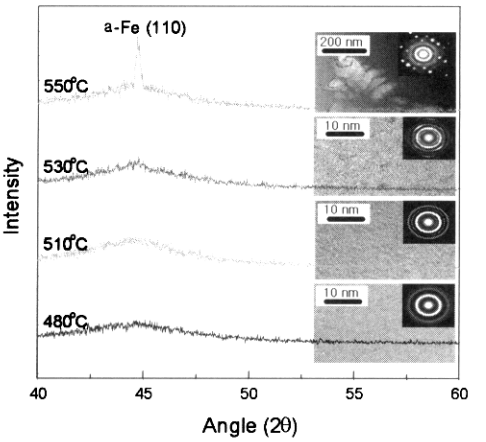

Fig. 2. XRD patterns and TEM images shown micro-structure changes of the Fe-base amorphous alloy with annealing temperatures.

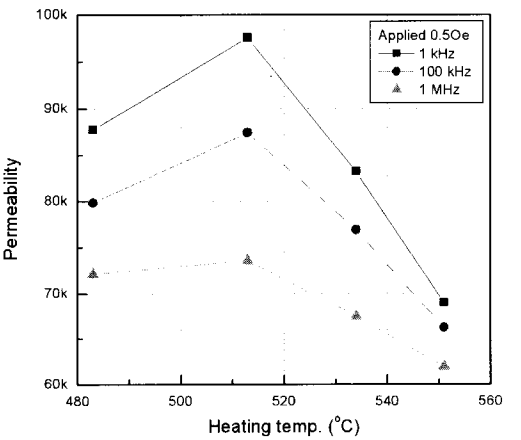

Fig. 3. Variations of magnetic permeability of core materials with annealing temperature.

3. RESULTS AND DISCUSSION

Figure 2 shows X-ray Diffraction(XRD) patterns and TEM micro-structures images of Fe-base amorphous alloys with annealing temperatures. Over the annealing temperature 510 ℃ nano-size α-Fe crystallites start to precipitate. As increasing the temperature, intensities of (110) diffractions were increased.

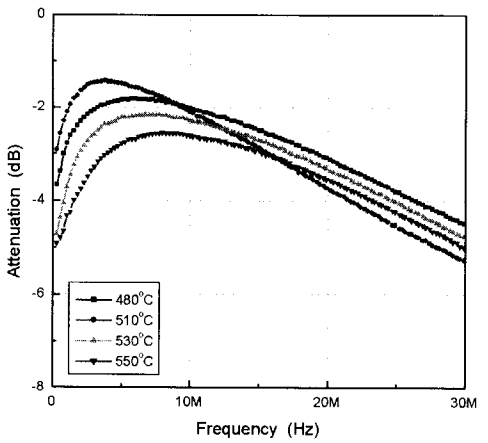

Fig. 4. Signal attenuation characteristics with annealing temperatures of magnetic cores.

Figure 3 shows magnetic permeability variation with annealing temperatures. In the temperature 510 ℃ the largest value of permeability was obtained, but further increasing the temperature reduces the permeability. This means that domain wall pinning effect does not effect on magnetic anisotropy due to the grain sizes of under 10 nm of Fe crystallite precipitated over the 510 ℃ are smaller than domain wall thickness.

Figure 4 shows characteristics of insertion loss of couplers with various annealing temperatures of magnetic core material. Coupler whose core was annealed at temperature 510 ℃ shows the lowest attenuation and the attenuation was increased as the annealing temperature of core increased. This is well coincidence with the permeability changes of core materials as shown in Fig. 3. Therefore, it is considered that the insertion loss of inductive couplers are governed by magnetic permeability of its core material. But, In the high frequency band over the 10 MHz, dependances on permeability were not be shown and the values of losses are almost same.

On other hands, even through the attenuation level is below -5 dB all over the frequency range, the steep worse of high frequency attenuation must be corrected because that the coupler for PLC should have the attenuation level below -5 dB in the range 2 ~ 30 MHz.

Figure 5 shows Impedance curve change before and after introducing matching circuits. Before the matching, the impedance approaches 50 ohm at about 30 MHz as shown in Fig. 5 (a), then it went away from 50 ohm. But, After inserting the matching circuit as shown in (b),

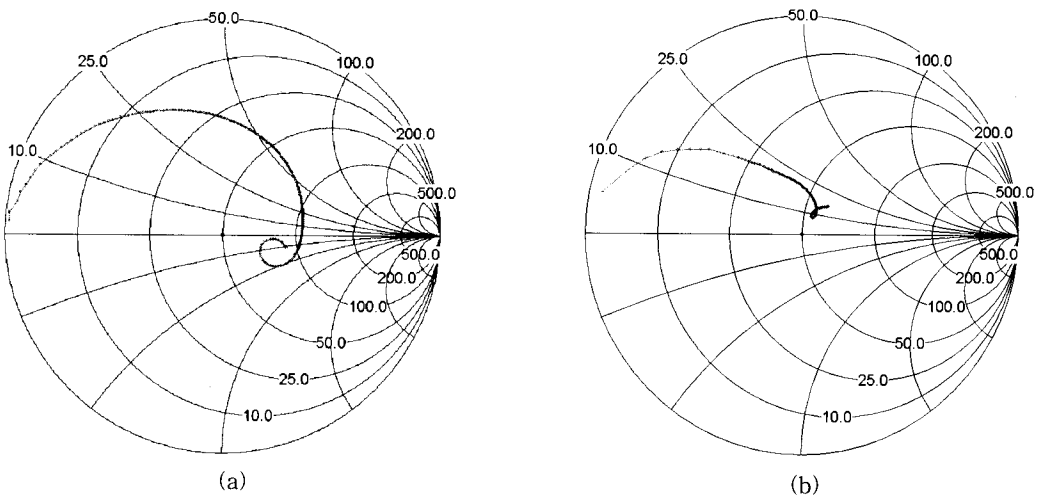

Fig. 5. Influence of matching circuit on the impedance : (a) Before the impedance matching, (b) After the impedance matching.

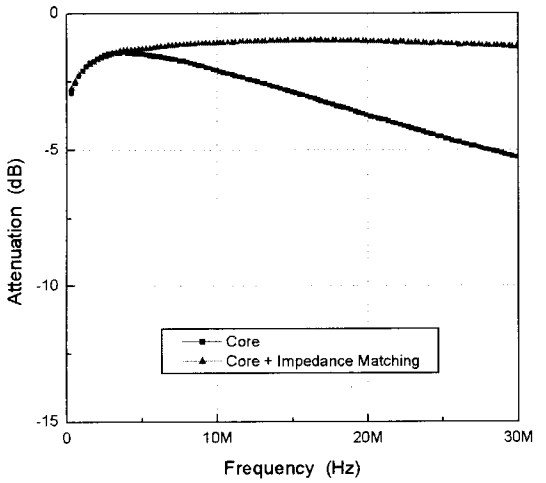

Fig. 6. Changes of signal attenuation curve by the impedance matching.

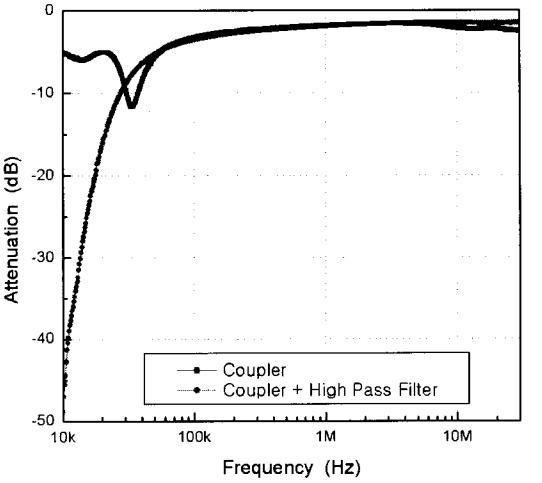

Fig. 7. Effects of high pass filter on the transmission characteristics.

the matching was well established in the frequency range 35 ~ 40 MHz.

Figure 6 shows the changes of signal attenuations of the coupler due to introduction of matching circuit. Although impedance matching was performed in the range 35 ~ 45 MHz in the Fig. 4, the improvement of signal characteristics was accomplished markedly and was uniform in all the range over 5 MHz. Therefore, basically, the transmission characteristics of inductive coupler depends on magnetic properties of core, but it was thought that the transmission characteristics in high-frequency range in which magnetic properties do not affect were dominated by impedance matching.

Figure 7 shows effects of high pass filter on the transmission characteristics of coupler. Because the other low frequency band also carry noise signals which give rise to do malfunction of equipment, it is necessary to cut off noise signal frequency band under 100 kHz as shown in Fig. 7.

4. CONCLUSION

We report a study on the transmission characteristics of inductive couplers using amorphous magnetic alloy cores in order to set up fabrication conditions of inductive coupler.

1. The best electromagnetic and transmission characteristics were shown in nano-crystalline precipitated alloy annealed at temperature 510 ℃.

2. The transmission characteristics of inductive coupler in low frequency band depend on magnetic permeabilities of core materials and that in high-frequency range in which magnetic properties do not affect could be improved by impedance matching.

3. Embedding the high pass filter in the coupler, noise signal frequency band except for communication signal band could be cut off.

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