Independence of the Dynamic Magnetic Loss from Temperature

H. Saotome and H. Ohta
Faculty of Engineering, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba 263-8522, Japan

Ferrite power loss consists of four parts: the hysteresis, eddy current, equivalent dielectric, and dynamic magnetic losses. The eddy current and dielectric losses are negligible in ferrites compared to the other two losses. It is well known that the hysteresis loss is constant with respect to the exciting frequency but is dependent on temperature. It was previously reported by one of the authors that the dynamic magnetic loss is dominant in the high frequency excitation region. This paper shows that the dynamic magnetic loss is independent of temperature. We experimentally verified this with Mn-Zn and Ni-Zn ferrite cores that were magnetized by rectangular waveform voltages.

Key words: ferrite, Mn-Zn, Ni-Zn, iron loss, dynamic magnetic loss, B-H loop, temperature

1. Introduction

Ferrite cores are mainly used for high frequency electric power converters, especially in DC-DC converters where their switching frequencies are usually around 100 kHz. This is because the eddy current loss in ferrites is negligible even when excited at such high frequencies. Ferrite power loss can be divided into four parts: the hysteresis, eddy current, equivalent dielectric, and dynamic magnetic losses. The equivalent dielectric loss for Ni-Zn ferrites is negligible because of their low permittivity, and it is quite small for Mn-Zn ferrites if they are excited at a frequency less than 1 MHz. Accordingly, the hysteresis and dynamic magnetic losses, defined by the area of B-H loops, are of great interest for applications in electric power converters.

The shape and area of a B-H loop changes with an increase of the maximum magnetic induction, $B_m$, or the exciting frequency, in other words, the time derivative of the magnetic induction, $dB/dt$. The hysteresis loss ($J/m^2$) is defined by the minimum B-H loop area with respect to the exciting frequency when $B_m$ is kept constant. Then the hysteresis loss can be expressed as a function of $B_m$. It is also well known that the hysteresis loss has temperature dependence even when $B_m$ is constant.

In this paper, we experimentally determine whether the dynamic magnetic loss depends on temperature similar to the hysteresis loss using Mn-Zn and Ni-Zn ferrites.

2. Dynamic magnetic loss and its measurement

First, we must clarify the differences in the area surrounded by a B-H loop, the hysteresis, and dynamic magnetic losses by using Fig. 1, which shows a typical B-H loop. When a ferrite core is excited at a high frequency, such as 100 kHz, we obtain the B-H loop that corresponds to the iron loss, depicted by the solid line in Fig. 1. When we decrease the frequency with constant $B_m$, the B-H loop reduces its width to the hysteresis loop depicted by the broken line in Fig. 1. In other words, the B-H characteristics obtained at very low frequencies (less than 1 kHz) are independent of frequency and referred to as the hysteresis loop. The dynamic magnetic loss (the hatched area in Fig. 1) is obtained by subtracting the hysteresis loss from the iron loss when
excited at a high frequency. In this study, ferrites were excited by rectangular waveform voltages because we wanted to measure the iron loss with a constant $dB/dt$, whereas $dB/dt$ varies during one period in sinusoidal voltages.

With the low and high frequency measurements, we used an analogue amplifier and a full bridge inverter to apply rectangular waveform voltages to ferrite cores as shown in Figs. 2(a) and 2(b). In practice, the utilization of an amplifier or inverter is appropriately chosen whether $dB/dt$ is smaller or larger than 100 mT/µs, respectively. The exciting current, $i_1$, is calculated from the measured voltage, $v_s$, across a shunt resistor with a resistance of $R_s$, and a compensation for the voltage of the stray inductance, $l_s$, from the resistor.

In the experimental setup shown in Fig. 2(a), the voltage signal waveform generated by a function generator (F.G.) was compensated in order to obtain rectangular waveform excitation voltages. When the function generator outputs a rectangular waveform signal to the amplifier, the excitation voltage, $v_2$, detected by a secondary coil, deteriorates as shown in Fig. 3. From the increase in $v_s$, $v_2$ reduces with an increase in $i_1$. From the data of $v_2$ and $i_1$ shown in Fig. 3, the function generator signal was modified as shown in Fig. 4(a). This obtains a precise rectangular waveform excitation voltage, $v_2$, as shown in Fig. 4(b). Although signal modification is necessary for low frequency excitations, it is not needed for high frequency excitations because $i_1$ is small enough to neglect the deviation of $v_2$ from the rectangular waveform for short periods. For high frequency rectangular waveform voltage excitations, the analogue amplifier is not suitable because of its limit in response time. Accordingly, we used the inverter shown in Fig. 2(b) for the high frequency excitations.

In this paper, we verify whether the dynamic magnetic loss depends on temperature. We took measurements at room temperature and around zero degrees Centigrade. To perform the low temperature experiment, the cores listed in Table 1 were totally submerged in distilled water which was surrounded by ice as shown in Fig. 5. The duration of the excitation was short enough to keep the change in temperature less than 1 °C.

### Table 1  Toroidal core dimensions (mm).

| Material | Inner diameter | Outer diameter | Height |
|----------|----------------|----------------|--------|
| Mn-Zn    | 7.0            | 14.2           | 3.4    |
| Ni-Zn    | 9.7            | 19.6           | 4.3    |

3. Experimental results

Figs. 6(a) and 6(b) show $B$-$H$ loops at room and low temperatures where $B_m$ is a constant 200 mT. Eleven $B$-$H$ loops are shown in each of the figures with a $dB/dt$ of 10,
The smallest and largest loops correspond to 10 mT/μs and 1,000 mT/μs, respectively. Because the B-H loops measured at 5 mT/μs at room and low temperatures overlap the smallest loops in Figs. 6(a) and 6(b), we can determine that the smallest loops are the hysteresis loops which do not decrease in area with a further decreasing dB/dt. Comparing the hysteresis loops at room and low temperatures, we found that the hysteresis loss at low temperature is larger than that at room temperature.

When dB/dt is greater than 10 mT/μs, the area of the B-H loops, the dynamic magnetic loss, expands with an increase of dB/dt at both room and low temperatures. Fig. 7 shows the iron loss, w (J/m³), of the Mn-Zn core with respect to dB/dt at room and low temperatures when B_m is kept constant at 100, 200, 300, and 400 mT. We observed that the difference in iron loss between the room and low temperature measurements with the same B_m are almost constant and independent of dB/dt. Therefore, the dynamic magnetic loss depending on dB/dt is independent of temperature and the differences are simply caused by the temperature dependence of the hysteresis loss.

Similar experiments were implemented for the Ni-Zn ferrite core listed in Table 1 and the results are shown in Fig. 8. Because the magnetization characteristics of the Ni-Zn core differ from the Mn-Zn core and thus the output voltage of the inverter is limited, the measurement range is smaller than in Fig. 7. However, we found that the dynamic magnetic loss for the Ni-Zn ferrite core is independent of temperature as well.

The experimental results shown in Figs. 7 and 8 lead us to study their physical mechanism from the point of view of Landau-Lifshitz-Gilbert equation.

4. Conclusions

We experimentally determined that the dynamic magnetic loss for ferrites is independent of temperature, whereas the hysteresis magnetic loss depends on temperature. This fact suggests that the mechanisms of the hysteresis and dynamic magnetic losses might be physically different.

Authors plan to verify whether the discovered property of ferrite is consistent at high temperature, for the next work.

References

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