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Ac Hysteresis Loop Depending on the Phase Angle of the Higher Harmonic Induction

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For the design of high efficiency electric machines, analysis of higher harmonic frequency components of the magnetic induction is necessary. We have measured ac magnetic properties of non-oriented silicon steel under harmonic frequencies ranging from 3rd (180 Hz) to 9th (540 Hz) and harmonic amplitude components from 10 % to 50 % of the total amplitude (B_{max} = 1.5 T). From the experiment, it is found that, if the magnetic induction waveform has above 9th harmonic frequency components of the magnetic induction, the core losses only depended on the harmonic amplitude component, but if harmonic frequency becomes lower than 9th harmonic frequency, the core losses depend on the phase angle and the harmonic amplitude, and phase angle should be considered in the design of electric machine.

1. Introduction

In electric machines, higher harmonic frequency components of the magnetic induction are always generated during ac magnetization of magnetic cores. These higher harmonic frequency components of magnetic induction increase core loss and the analysis for the higher harmonic frequency components of magnetic inductions are important in the design of the high efficiency electric machines.

For the high efficiency electric machine design, core loss has been analyzed using superposition principle of higher harmonic frequency components of magnetic induction without the consideration of their phase angles [1, 2].

In this work, we have analyzed the ac hysteresis loop properties depending on phase angle of the given single higher harmonic frequency component of magnetic induction.

2. Construction of Measuring System

For the generation of the magnetic induction including higher harmonic frequency component with different phase angles, we have constructed a double yoke type single sheet core loss tester of which speciemen size is 8 cm × 8 cm including arbitrary waveform synthesizer (hp1445) and a 2-channel transient recorder (hp1429), which were controlled by VXI-bus of the VXI system (hp75000), and a feed-back system for the waveform of the induced voltage from secondary winding is the same as the output voltage of the arbitrary waveform synthesizer [3]. A waveform was numerically programmed by the instrument controller (hp745) and the waveform data were transferred to the arbitrary waveform synthesizer via IEEE-488bus. Magnetic induction $B(t)$ and magnetic field strength $H(t)$ were digitized using 2-channel transient recorder and data were transferred to the instrument controller via IEEE-488 bus. Fig. 1 shows schematic diagram of the constructed measuring system in this work.

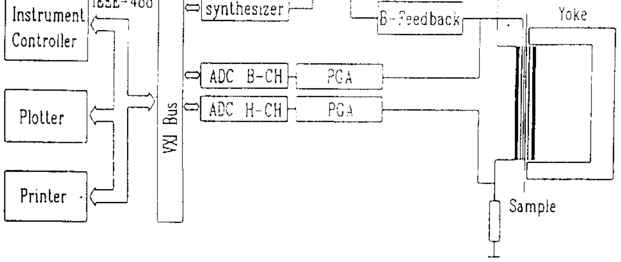


Fig. 1. Schematic diagram of constructed equipment for measuring ac magnetic properties, which depend on the phase angle of the higher harmonic frequency component of magnetic induction.

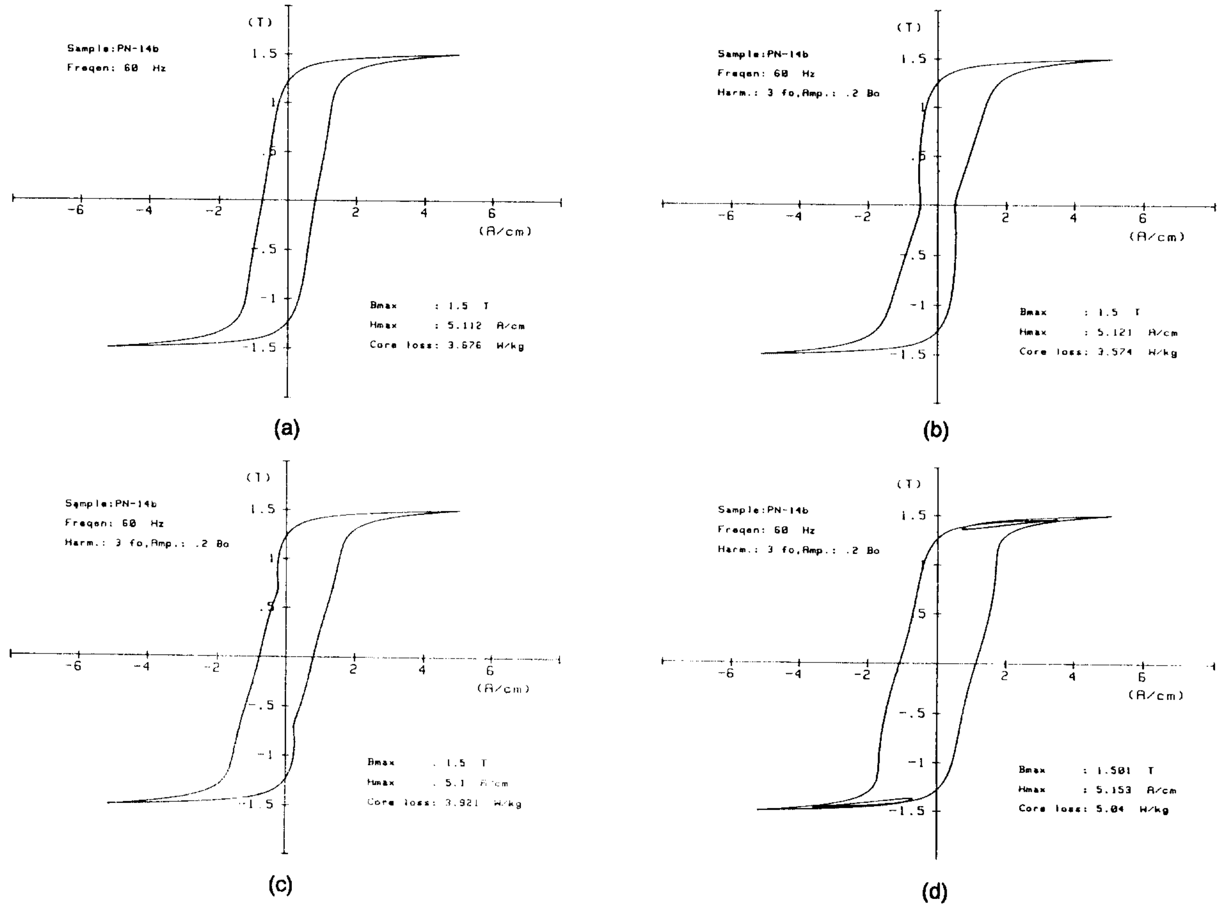
3. Results and Discussion

Fig. 2 shows ac hysteresis loops of non-oriented silicon steel at magnetizing frequency of 60 Hz, including 3rd harmonic frequency component (180 Hz) of magnetic induction which has different phase angle from 0° to 180° with the step of 90° and harmonic amplitude was 20 % of the total amplitude of the magnetic induction. Fig. 3 shows ac hysteresis loops for the same condition as that in Fig. 2 except harmonic amplitude component of magnetic induction of 50 %. From the experiment, we can see that ac hysteresis loop and core loss are strongly dependent on the phase angle of harmonic frequency component of magnetic induction. If the 3rd harmonic frequency component of magnetic induction affected near the coercive field strength region of ac hysteresis loop, the core loss was decreased, but near the saturation magnetic induction region of ac hysteresis loop, the core loss was increased. This effect was increased remarkably, if harmonic amplitude component of magnetic induction was increased. Fig. 4 shows the change of ac hysteresis loops based on the phase angle change from 0° to 180° for the case of 9th harmonic frequency component of magnetic induction and the harmonic amplitude was 50 % of the total amplitude of the magnetic induction. In 9th harmonic case, the ac hysteresis loop shapes are different under different phase angles but the corresponding core loss changes were very small.

Fig. 5 shows core loss dependence on phase angle of the harmonic frequency component of magnetic induction under different harmonic frequencies from 3rd (180 Hz) to 9th (540 Hz) and harmonic amplitude component from 10 % to 50 % of the total amplitude (B^{max} = 1.5 T). From Fig. 5, we can see that core losses strongly depend on phase angle and harmonic amplitude in lower harmonic frequency component of magnetic induction. However as the harmonic frequency becomes higher, the core losses becomes a weak function of the phase angle while strongly dependent on harmonic amplitude. From this experimental result, if waveform of magnetic induction in electric machine have higher harmonic frequency component of magnetic induction, phase angle should be considered when frequency components are below 9th harmonic frequency.

Conclusion

Higher harmonic frequency components of the magnetic induction are always generated in electric machines and the core loss analysis for the higher harmonic frequency component of magnetic inductions is important in the design of high efficiency electric machines. From the experimental results, we can see that core losses only depend on the harmonic amplitude component when the magnetic induction waveform has above



(a) (b) (c) (d)

Fig. 2. Ac hysteresis loops dependence on phase angle of the 3rd harmonic frequency component of magnetic induction (20 % of B_{max} = 1.5 T); a) without higher harmonic, b) phase angle of 0°, c) phase angle of 90°, d) phase angle of 180°.

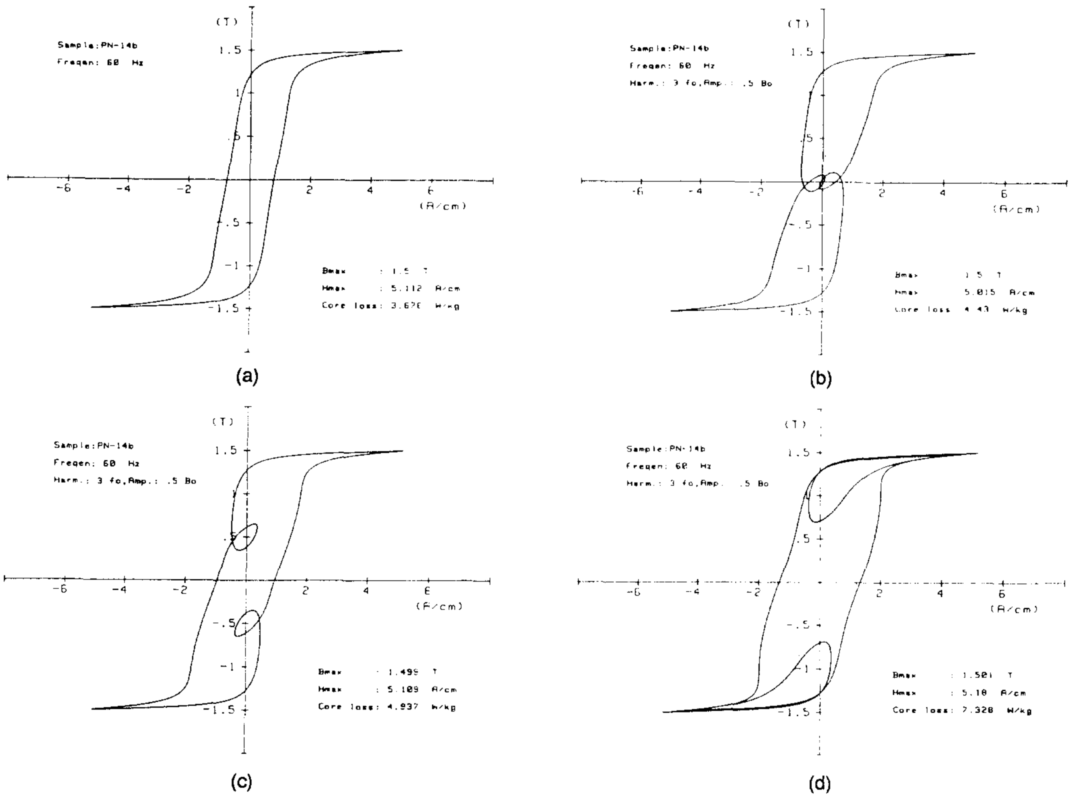


Fig. 3. Ac hysteresis loops dependence on phase angle of the 3rd harmonic frequency component of magnetic induction (50 % of B_{max} = 1.5 T); a) without higher harmonic, b) phase angle of 0°, c) phase angle of 90°, d) phase angle of 180°.

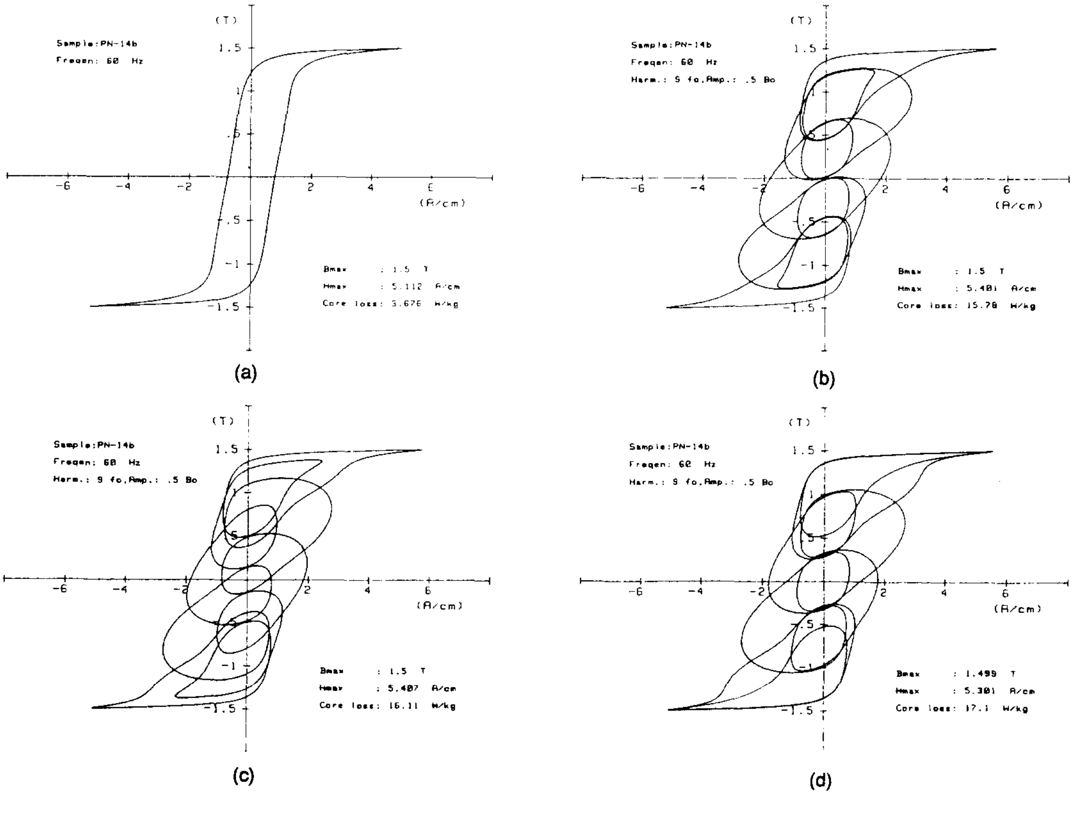


Fig. 4. Ac hysteresis loops depend on the phase angle of the 9th harmonic frequency component of magnetic induction (50 % of B_{max} = 1.5 T); a) without higher harmonic, b) phase angle of 0°, c) phase angle of 90°, d) phase angle of 180°.

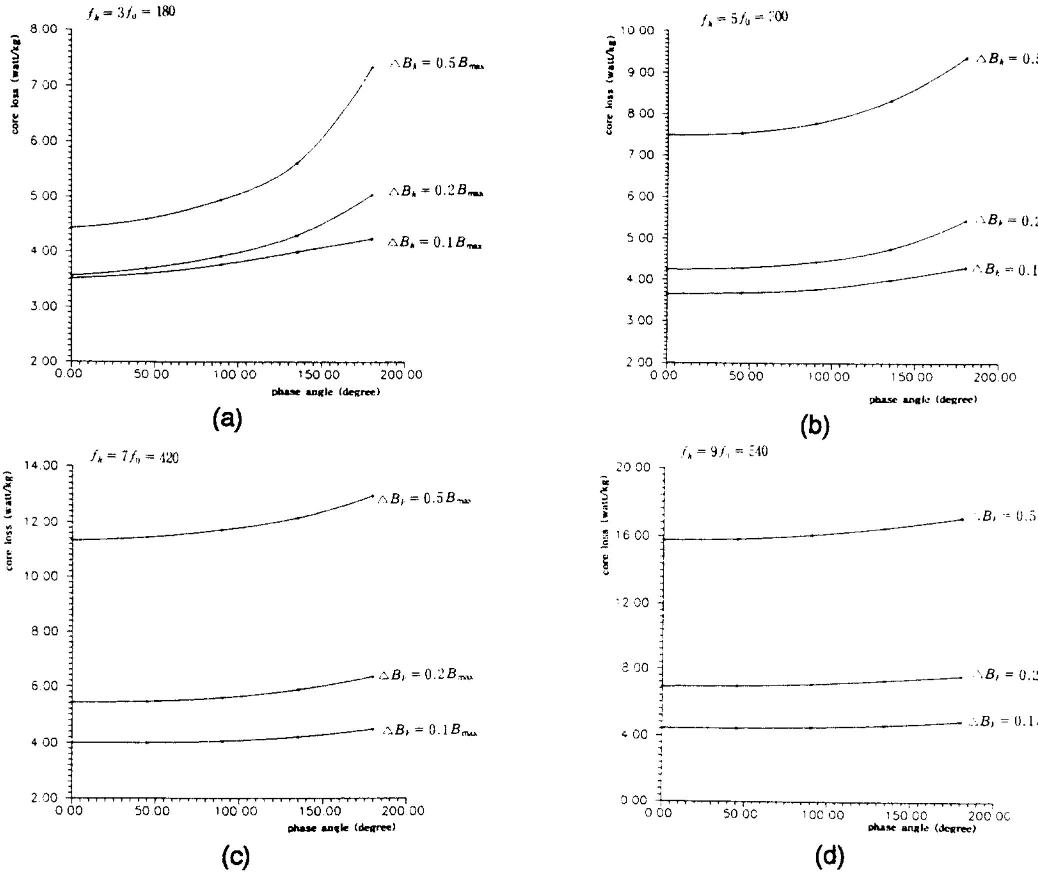


Fig. 5. Core loss depend on the phase angle of the higher harmonic frequency components of magnrtic induction; a) for 3rd harmonic, b) for 5th harmonic, c) for 7th harmonic, and d) for 9th harmonic case.

9th harmonic frequency components of magnetic induction. As the harmonic frequency becomes lower than 9th harmonic frequency, the core losses depend on the phase angle and the harmonic amplitude. Thus, the phase angle should be carefully considered in the design of electric machines.

For the further work, the analytical description for higher harmonic frequency components of the magnetic induction is recommended, but it is very difficult due to the nonlinear and hysteresis properties of magnetic materials.

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References

[1] H. L. Schenk et al., IEEE Trans on Magn., **MAG-17**, 3385 (1981).
[2] F. Fiorillo et al., IEEE Trans on Magn., **MAG-26**, 2559 (1981).
[3] D. Son et al., J. of Korean Magnetics Society **Vol. 5**, 395 (1995).