

Magnetic loss versus frequency in non-oriented steel sheets and its prediction: minor loops, PWM, and the limits of the analytical approach

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The Pulse Width Modulation (PWM) technique is commonly adopted to supply modern high-speed electrical machines. The involved fundamental frequency is generally in the kilohertz range, with switching frequencies of several tens of kilohertz, as allowed by the new SiC or AsGa based power transistors modules. Switching does introduce minor loops in the major hysteresis cycle, with durations of the order of 100 μ s or lower and ensuing magnetization dynamics likely affected by strong skin effect. However, since these minor loops have relatively small amplitude, their constitutive equation can possibly be described by an equivalent permeability (real or complex), depending on the mean slope of the minor loop and its static energy loss. By retrieving this permeability, the classical loss is straightforwardly calculated by analytical solution of the Maxwell's equations. In this work, we measure and calculate, according to the quasi-linear approximation for the minor loops, the magnetic energy losses of 0.2 mm thick non-oriented Fe-Si 3% sheets subjected to PWM induction waveform. Minor loop peak amplitudes ranging between 50 mT and 0.2 T and frequencies up to 10 kHz are investigated. The results are shown to comply to good extent with the proposed model, the predicting uncertainty being lower than 5%.