How Does Changing the PWM Duty Cycle Affect the Magnetic Field Strength and Core Saturation Behavior of an Electromagnet With and Without a Soft Iron Core?

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Around 40% of electromagnet coil failures result from overheating-induced enamel degradation. Implementing a current limit as the magnetic core saturates can reduce this overheating and prevent energy waste. The purpose of this project is to analyze the non-linear relationship between current and magnetic field, identify the core's saturation point, and calculate its permeability. To investigate this saturation curve, a microcontroller generated 5kHz PWM signals to precisely regulate the average electrical current with a MOSFET. This experiment involved two trials, one with a soft iron core inserted in the wound coil, and the other with the iron core removed (air core). A magnetometer and current monitor system, calibrated to capture a wide span of field intensities, recorded the magnetic flux density alongside current sensors. Analysis of the current and flux density data identified the exact saturation point of the iron core. In the soft iron core electromagnet, flux density rose rapidly with initial current increases, then decelerated and leveled off at saturation. In contrast, an air core model demonstrated a slow, linearly proportional increase in flux density without saturating. The finding suggests that adding a current cap of 2 Amps, for this case, instead of 5A max, reduces power consumption by 60% while only sacrificing less than 25% of the magnetic flux density. This principle can be applied to real world electromagnetic devices such as industrial solenoids and electric motors. Therefore, applying a precise current cap to electromagnet coils prevents unnecessary energy waste and mitigates material degradation.

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