# Time-domain effects in the magnetic response of Fe-based nanocrystalline cores

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We studied the time- and frequency-domain response of superparamagnetic cores using high-frequency reflectometry and transformer-based magnetization measurements. Our Fe-based nanocrystalline alloys based on $Fe_{73.5}Si_{15.5}Cu_1Nb_3B_7$ are commonly used in variable frequency drive systems as electromagnetic interference (EMI) noise absorbers. We discuss the relevance of the particle size on the superparamagnetic versus soft-ferromagnetic behavior as well as the distinction between DC and dynamic hysteresis. We demonstrate using a continuous wave radiofrequency study that the superparamagnetic cores display dynamic hysteretic effect, while having a zero DC coercivity. We identify the properties of the initial and the descending branch of the hysteresis loops under a gated radiofrequency excitation. These properties may be vital for devices operated under rapidly varying conditions including sudden jumps in exciting current magnitude or its frequency.

*Keywords:* Fe-based soft magnetic alloys; stress annealing; dynamical hysteresis; initial magnetization curve

The application area of Fe-based soft magnetic toroidal cores is constantly increasing in different industry sectors. From current sensing applications like residual current devices (RCDs) or energy meters, till electromagnetic interference (EMI) noise absorbers, the FINEMET-type nanocrystalline cores made of $Fe_{73.5}Si_{15.5}Cu_1Nb_3B_7$ or similar alloys have a huge market potential in our increasingly electrified world. The high Curie temperature over 500°C is beneficial for applications with high service temperatures like automotive or aerospace. Although most applications entail the handling of a constant amplitude AC electromagnetic radiation, in several instances rapidly changing field amplitudes are present. Examples include rapid switch on-off applications and the use of the filters under electrostatic discharge conditions. Then, the conventional continuous wave approach to the electromagnetic behaviour of the magnetic cores breaks down and a study of the transients is required.

Here we study the transient response of FINEMET-type cores, whose magnetic and mechanical properties are thoroughly characterized including the high-frequency characteristics by the methods described in Ref. 1. We show that the switch-on and switch off transients have markedly different behaviour from the excitations with continuous waves, which must be considered in the design of devices employing these cores. Our results show for the first time that stress annealed cores with high uniaxial magnetic anisotropy have zero DC coercivity, which is consistent with superparamagnetism.

We measured the transfer function through the cores, whose dynamics response is known [1]. We used a conventional transformer setup using 10 turns for both the primary and secondary coils. The primary coil is driven with an RF amplifier which delivers the exciting current, whose magnitude is monitored using a serial shunt resistor. The secondary coil detects the induced voltage which is proportional to the time derivative of the core’s magnetization.

Figure 1 shows in time domain the detected voltage and the driving current.

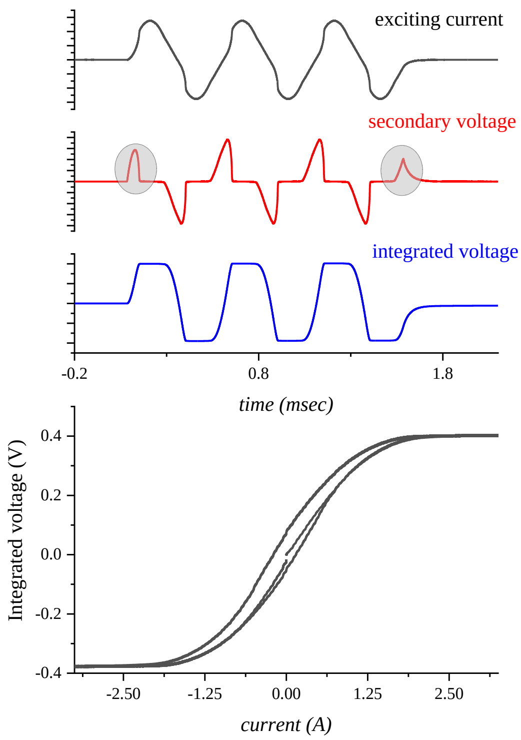


**Figure 1:** Top panel: The time domain data on the transferred voltage, its integral and the exciting current. Bottom panel: The integral of the transferred voltage as a function of the exciting current. Note the clearly distinguishable initial and return curves.

The integral of the detected transferred voltage is proportional to the core’s magnetization as dictated by the Faraday induction law. The bottom panel of Fig. 1. also shows the dynamic hysteresis curves as obtained from the time domain data. The initial and return magnetization curves are clearly distinguishable.

[1] F. Zamborszky et al. JMMM **564**, 170027 (2022).