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Frequency ramping effects on a dynamo-type HTS flux pump

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Flux pumps can inject high dc currents into superconducting coils, without requiring electrical connections between the cryogenic superconducting circuit and the room-temperature environment, thus significantly lowering the heat load on the cryogenic cooling system. Here we study a dynamo-type flux pump employing 2G ReBCO coated conductor wire at 77 K with multiple spinning Nd-Fe-B magnets and a soft ferromagnetic iron yoke, with all moving parts situated outside of the cryogenic environment. Dynamo-type flux pumps can be modelled as a DC voltage source with an internal resistance, where all output parameters are functions of the speed (frequency) of the spinning magnets. In this work we focus on the frequency dependence of the DC output voltage. From instantaneous traces of the generated voltage waveform, we observe three distinct frequency regimes of behaviour. We class them into regions of 'low', 'mid' and 'high' magnet frequency, depending on the magnitude of the DC open-circuit voltage and the shape of the voltage waveform. The voltage-generation mechanism is qualitatively understood at 'low' magnet frequencies, and in this regime the DC voltage increases proportional to frequency. However at 'mid' and 'high' magnet frequencies, the flux pump output deviates from this accepted model. In the 'mid' frequency regime, the DC output voltage is roughly constant with frequency, but is unstable. At 'high' frequencies, the DC voltage drops with increasing frequency following an approximately $1/f$ dependence. We have also studied the effects of ramping direction and rate, noting a high degree of reproducibility in the low and high frequency regimes, but complex unstable behaviour in the intermediate regime. We discuss our results in the context of self-heating due to emf-driven eddy-currents, leading to partial-quenching of the coated conductor wire. This becomes the dominant limiting factor in flux pump output at high frequencies, eventually suppressing the DC output altogether.

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