Modeling and measurement of the voltage signal in HTS flux pumps

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Introduction

A novel, optimized and fast method for 2D modeling of flux pump

A realistic 2D model of dynamo-type flux pump based on Minimum Electro Magnetic Entropy Production method (MEMEP 2D)

Study of the influence of airgap on open-circuit DC voltage of flux pump

2D Modeling Method

based on Minimum Electro Magnetic Entropy Production method

$$\mathbf{E}(\mathbf{J}) = -\dot{\mathbf{A}} - \nabla\varphi$$

Vector Potential   Scalar Potential

$$L = \int_S ds \left[\frac{1}{2}\frac{\Delta \mathbf{A}_J}{\Delta t}\Delta \mathbf{J} + \frac{\Delta \mathbf{A}_a}{\Delta t}\Delta \mathbf{J} + U(\mathbf{J})\right] \quad U(\mathbf{J}) = \int_0^J \mathbf{E}(\mathbf{J}').d\mathbf{J}'$$

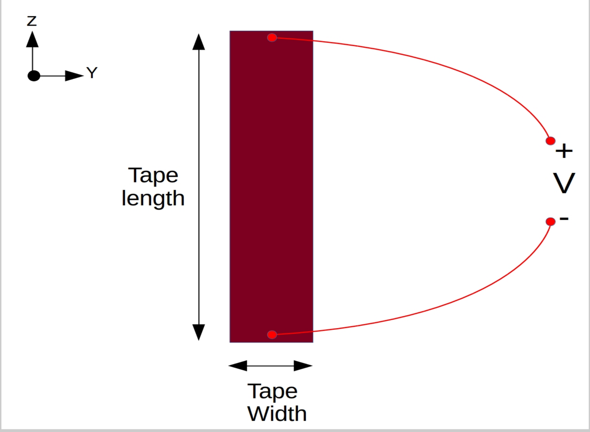
Vector Potential due to current density   Vector Potential due to applied field

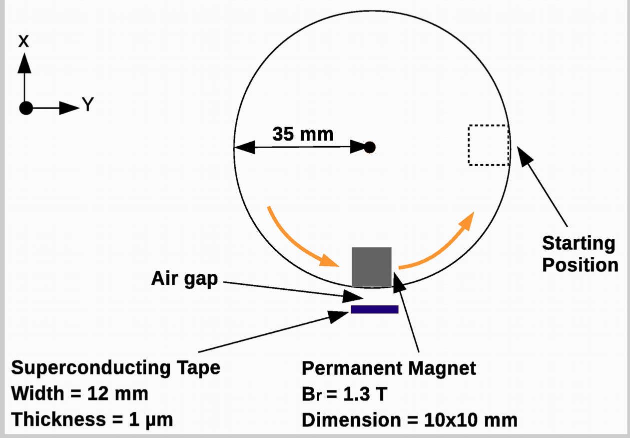
Isotropic power law

$$\mathbf{E}(\mathbf{J}) = E_c \left(\frac{|\mathbf{J}|}{J_c}\right)^n \frac{\mathbf{J}}{|\mathbf{J}|}$$

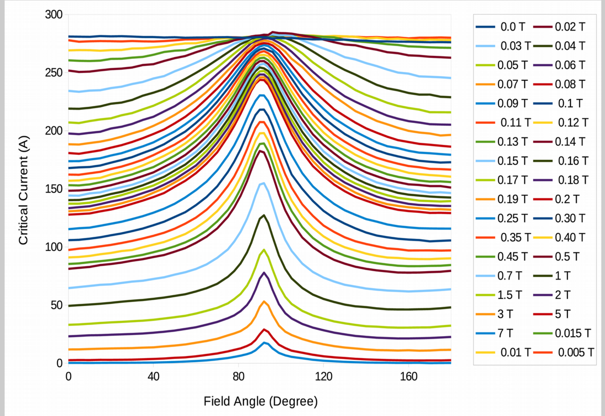
$$V = -\left(\frac{\partial \varphi}{\partial z}\right).l$$

Tape length





$I_c(B,\theta)$ experimental data at 77°K [1]



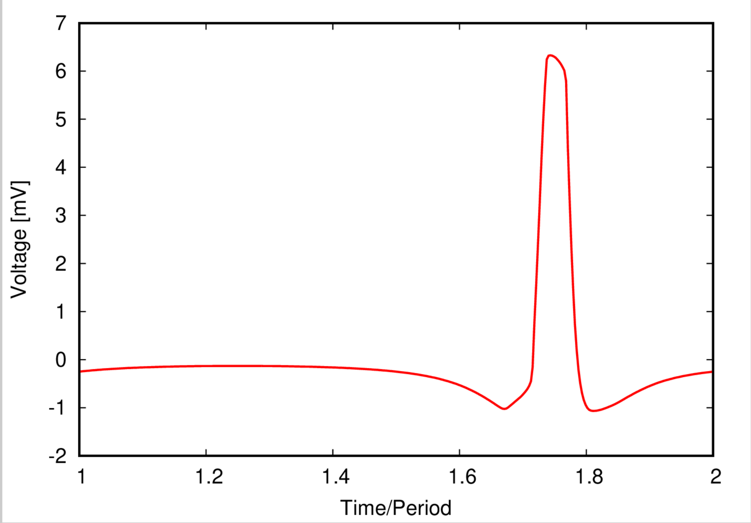
Calculation of open-circuit DC voltage

$$V_{dc} = f\int_0^{1/f} V(t)\,dt$$

Modeling Results for Main Behavior

Results for airgap 3.3 mm and frequency 12.3 Hz

Open-circuit output voltage



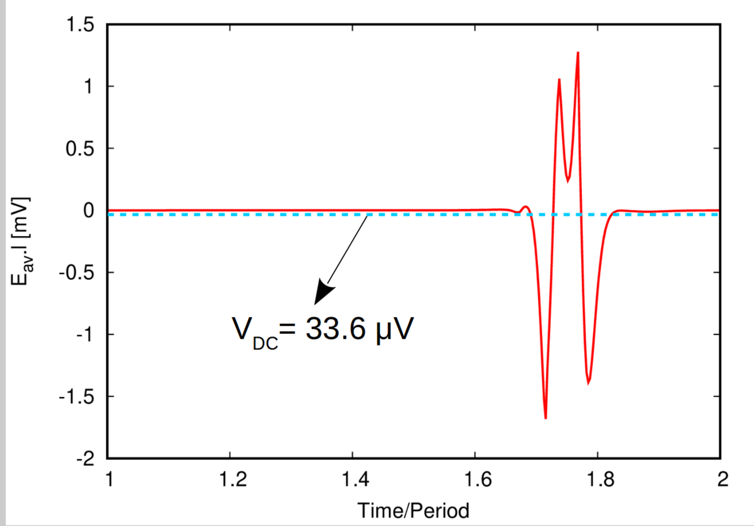
Non-linear resistivity of HTS tape causes DC voltage

$$E_{av}(\mathbf{J}) = \frac{1}{S}\int_S ds\,\mathbf{E}(\mathbf{J})$$

$$V_{dc} = fl\int_0^{1/f}[\partial_t \mathbf{A} + \mathbf{E}(\mathbf{J})]dt = fl\int_0^{1/f}\mathbf{E}_{av}(\mathbf{J})dt$$

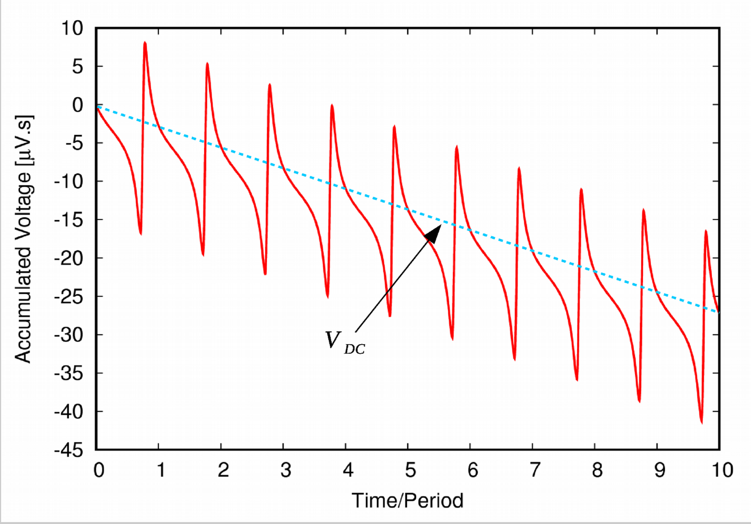
For linear materials

$$E_{av}(\mathbf{J}) = \frac{1}{S}\int_S ds\,\rho\,\mathbf{J} = \frac{1}{S}\rho\int_S ds\,\mathbf{J} = 0 \Rightarrow V_{dc} = 0$$



Accumulated DC voltage can charge magnets

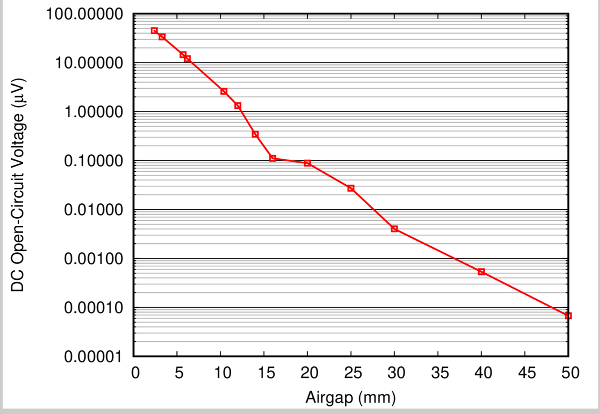
$$V_{accumulated}(t) = \int_0^t V_{dc}(t')\,dt'$$



Airgap Dependence of DC Voltage

Results for frequency 12.3 Hz

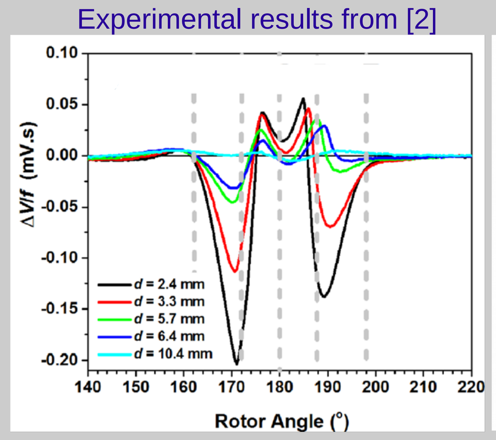
DC voltage decreases with increasing airgap and never vanishes



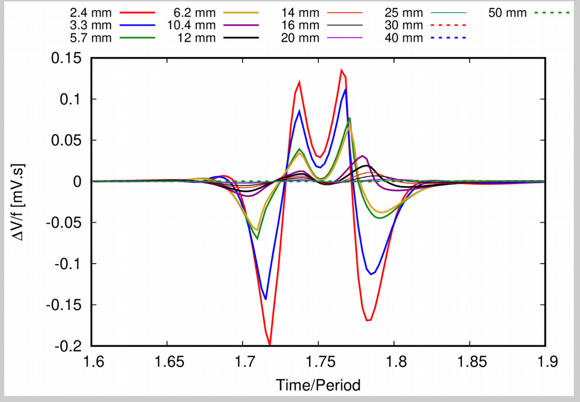
Same qualitative bahavior as measurements

$\Delta V = V_{77^\circ K} - V_{300^\circ K}$

Experimental results from [2]

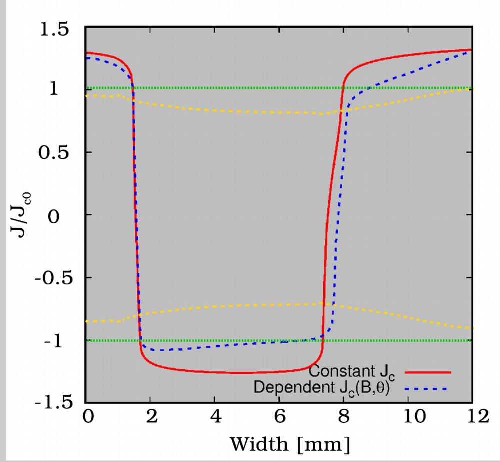


Modeling Results

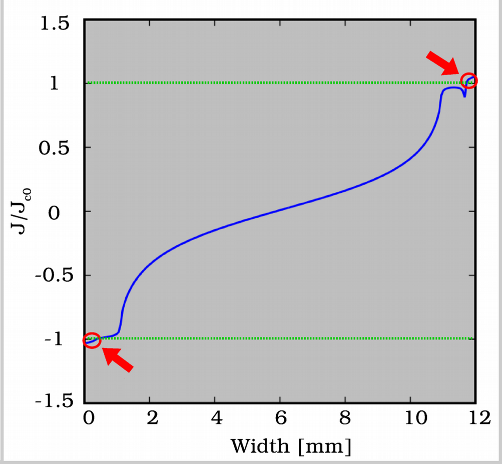


Overcritical regions cause DC voltage

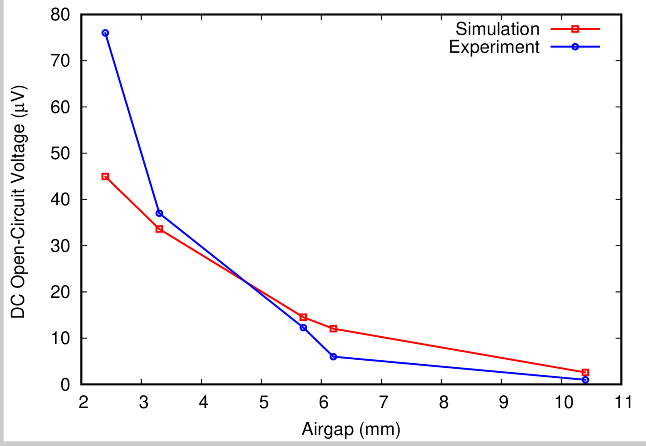
3.3 mm



50 mm



Modeling has good agreement with experiments in [2]



CONCLUSION

Good agreement between modeling results and measurements in different airgaps

Fastest realistic model of a flux pump can be realized using MEMEP 2D method

DC voltage generation in flux pump does not vanish even in large airgaps

References

[1] R. Mataira, M. Ainslie, R. Badcock, and C. Bumby, "Origin of the dc output voltage from a high-tc superconducting dynamo," Applied Physics Letters, vol. 114, no. 16, p. 162601, 2019.

[2] C. Bumby, Z. Jiang, J. Storey, A. Pantoja, and R. Badcock, "Anomalous open-circuit voltage from a high-tc superconducting dynamo," Applied Physics Letters, vol. 108, no. 12, p. 122601, 2016.

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