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Modelling stator width effects in a HTS dynamo

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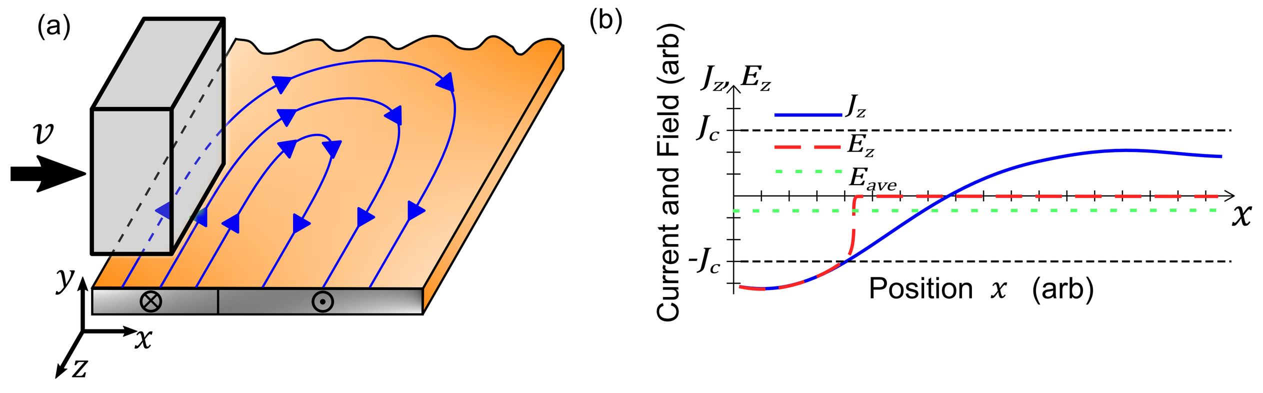
HTS dynamos generate DC voltage [1]



DC voltage is caused by over-critical currents flowing in the HTS stator [2].

These currents experience a non-linear resistivity such that the electric field is biased in one direction.

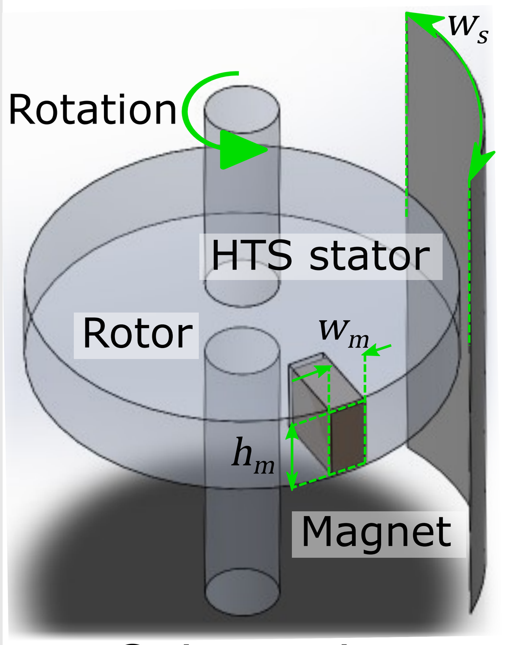
This bias stems from the fact that eddy currents are largest underneath the magent.

In normal conductors, Ohm's law insures that the average electric field through the cross section, E_{ave}, is proportional to the net current.

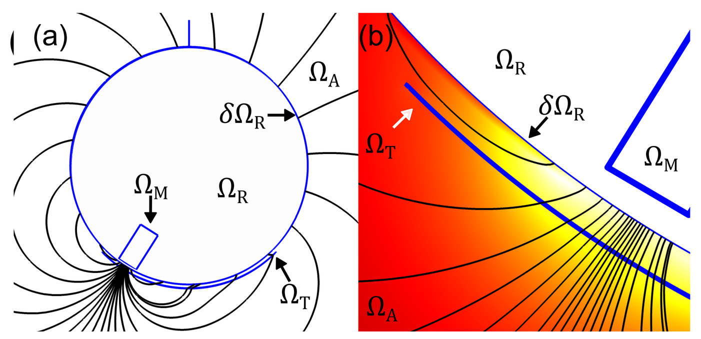
Hence the average electric field in a normal dynamo is always zero in open circuit.

As this effect is caused by eddy currents, the width of stator in which they can flow, has a critical effect on the generative and resistive mechanisms.

Stator width model



Schematic



2D FEM model

To calculate the value of E_{ave} through the cross section we use a H-formulation [3], [4] model to solve Ampere and Faraday's laws.

$$\nabla \times \vec{H} = \vec{J} \qquad \nabla \times \vec{E} = \partial_t \vec{B}$$

$$\rho \vec{J} = \vec{E} \qquad \mu \vec{H} = \vec{B}$$

We modify the model used in [2] to accommodate wider stators. The stator is conformed to be concentric with the rotor with a flux gap g of 2 mm.

We use the E-J power law [5] to represent the non-linear resistivity of the stator. And use J_c data derived from 42 mm wide AMSC HTS wire [6].

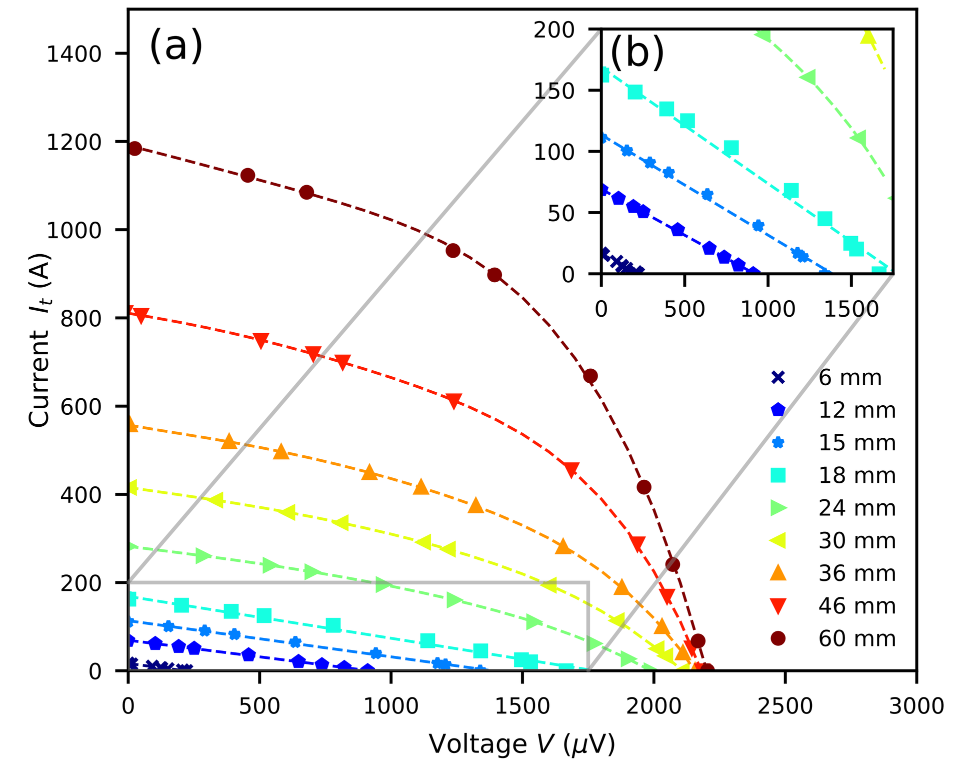
$$\rho = \frac{E_0}{J_c}\left(\frac{J_z}{J_c}\right)^{n-1}$$

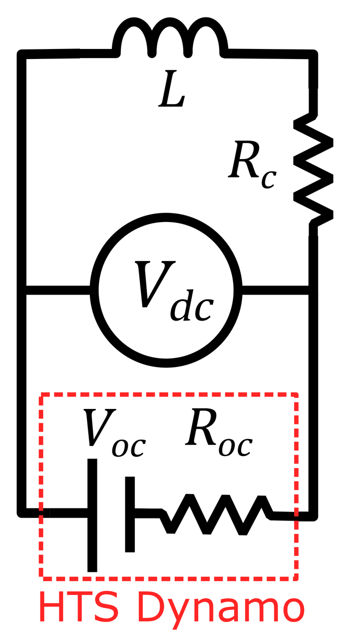
We run models for stator widths w from 6 mm to 60 mm, or 1-10 times the magnet width w_m = 6 mm.

The models are then run at a constant rotational frequency of 38.25 Hz.

Finally the current through the cross section of the conductor is integrated and constrained to be equal to the transport current.

DC Characterization

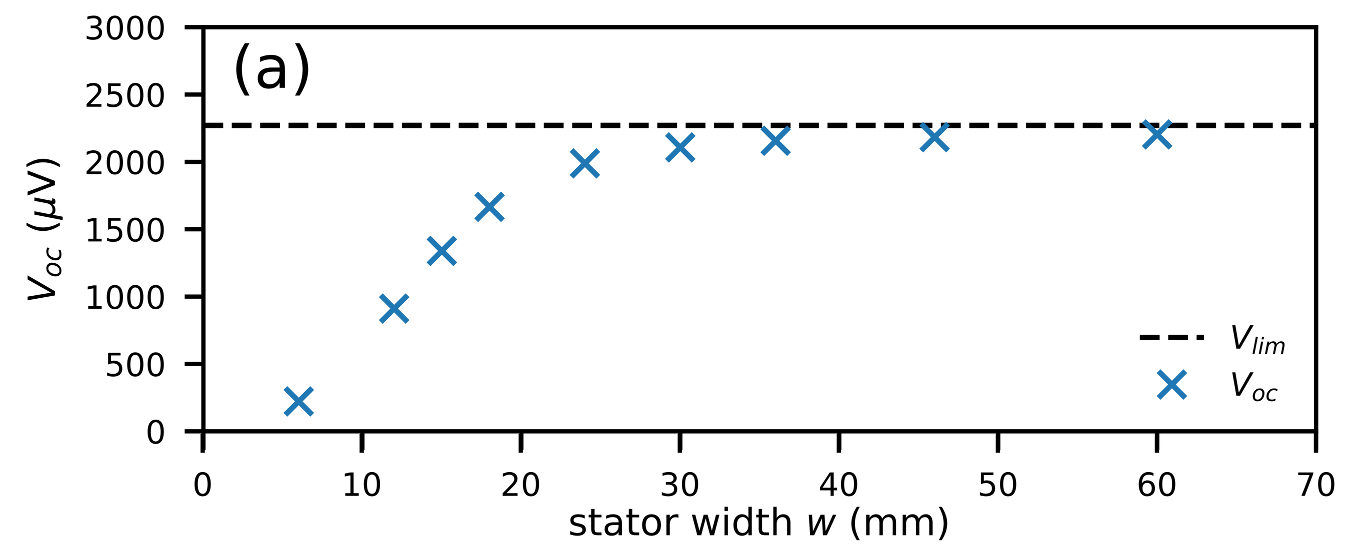




The model results can be understood with respect to the DC parameters (cycle averages).

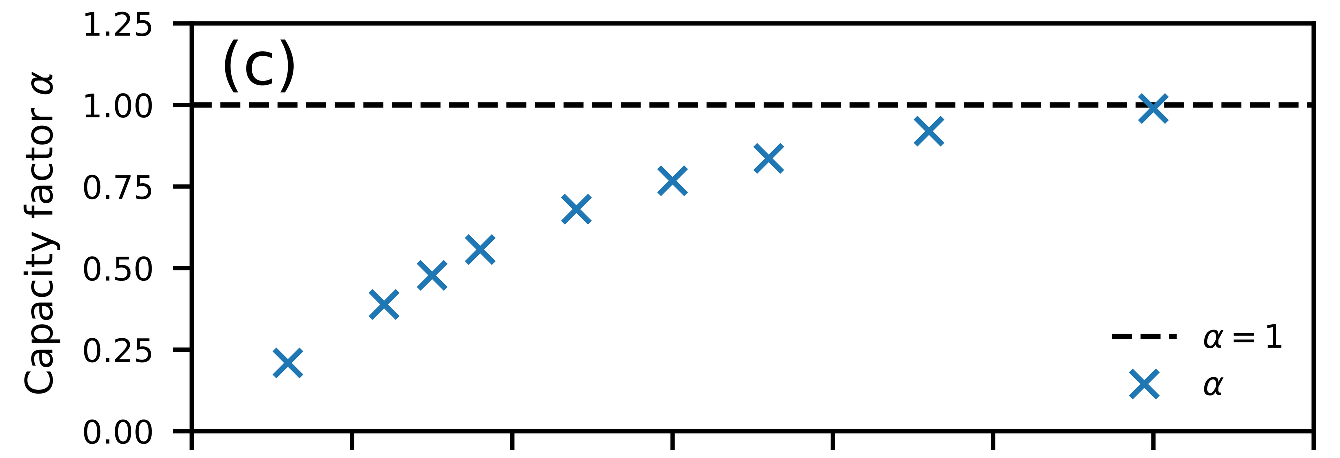
This produces I-V characteristics [7] that show the evolution of the output voltage vs driven current.

Here it is clear that for larger stator widths the I-V curves become highly non-linear, deviating from the typical behaviour.



Of particular interest is the fact that the open circuit voltage V_{oc} increase to some limiting value V_{lim}.

This suggests that narrow stators do not effectivelty capture the available *emf*; thus implying a minimum effcient stator width.

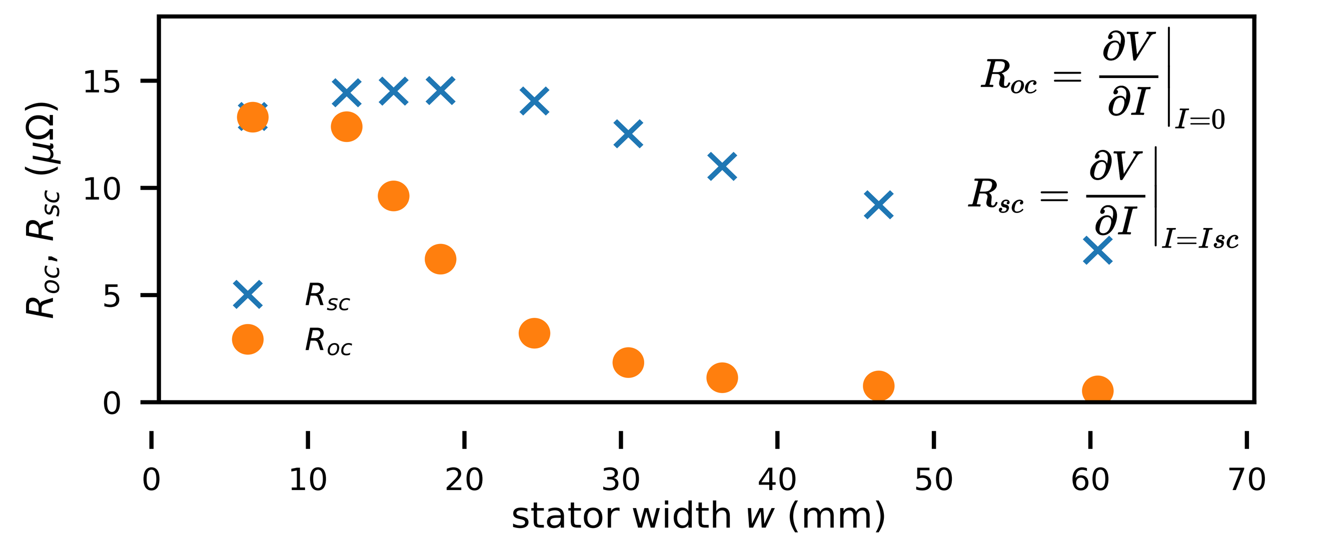


We can also define the capacity factor: $\alpha = \dfrac{I_{sc}}{I_{c,min}}$

Where $I_{c,min}$ is the lowest critical current value during the device cycle, and I_{sc} is the short circuit current. α clearly shows that the stator must be aproaching its own flux flow regiem, even away from the magnet's influence.

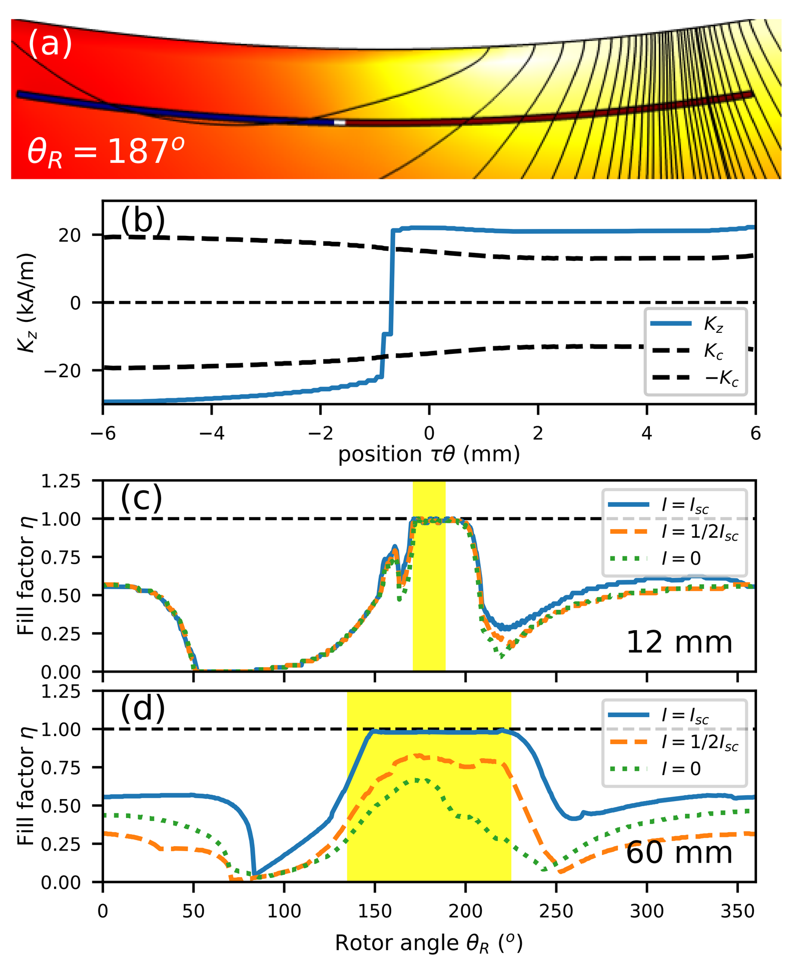
This is strong evidence that the combination of high output voltage and low internal resistance effects means that HTS dynamos need not be a bottle neck in system design.

95% Reduction in Internal Resistance



Between 12 and 30 mm, the differential resistance at open circuit R_{oc} has droped by an order of magnitude. This suden drop and the more stable value of R_{sc} suggest that a large resistive mechanism exists in narrow tapes at any current

Current over filling



As the magent passes over a narrow 12 mm stator, the induced electric fields drive the whole tape over the critical current. This has two effects: one it adds an electric field in the disipitive polarity (the reverese current). And two, the reverse current competes for space with the generative polarity (forward current), again reducing the average electric field. If the stator can be made wide enough, this can be avoided.

We can define a fill-factor η that captures the fraction of the the stator over J_c

$$K_z(\theta) = \int_{\tau-b}^{\tau+b} J_z(r,\theta)dr \qquad u(\theta) = \begin{cases} 1, \text{if } |K_z| > K_c \\ 0, \text{otherwise} \end{cases}$$

$$K_c(\theta) = \int_{\tau-b}^{\tau+b} J_c(r,\theta,B,\theta_B)dr \qquad \eta = \frac{1}{w_s}\int_{-w_s/2\tau}^{w_s/2\tau} u(\theta)d\theta$$

Looking at the evolution of this fill factor, we can clearly see that the 12 mm stator is full of over currents for any amount of transport current. However for the 60 mm stator, even at 1/2 of I_{sc}, the stator is still not completely full of over-currents logically implying that more current can be added

Conclusions

Increasing stator width not only increases the current carying capacity I_{sc} of the HTS dynamo but critcally increases the output voltage V_{oc} as well. This increase is accomanied by a sharp reduction in the differential resistance of the device at open circuit R_{oc}, indicating that a resistive mechanism is present in narrow stators but not in wider ones. This mechanism, where eddy currents are pinched in the narrow stator exists even without transport current, and also has the effect of reducing V_{oc} from it optimum. However, this mechanism can be completely avoided, upto some opperating current, by using sufficiently wide stators. This supports creating high current dynamos for low inductance highly parallel coils.

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