Design and performance of a “squirrel-cage” dynamo-type HTS flux pump

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HTS Dynamo Flux Pumps

- HTS magnet coils cannot be operated in persistent mode.
- Require DC current injection from external current supply via metal current leads.
  - Conducting current leads bridge between room temperature and cryogenic environment
- Parallel high-speed motors (no injection = dissipation)
- Alternative approach: Dynamo-type HTS flux pumps can inject DC current into a series-connected superconducting coil (inductive load) without physical electrical connections.
  - Employs mechanically-rotating permanent magnets which pass over coated conductor tape (stator wire).
  - Behaves like a DC voltage source: output voltage V_SC and internal resistance R_SC [1–4].
  - DC voltage arises due to partial rectification of the induced ac output. This is caused by circulating supercurrents which ‘short-circuit’ the coil in the high field region directly opposite the rotor magnet [4].
- The internal resistance (R_SC) of an HTS dynamo limits its maximum output current (I_SC). R_SC can be reduced by adding additional stator wires in parallel.
  - Here we investigate the effect of changing the ratio of number of rotor magnets to number of stator wires for a cylindrical ‘squirrel-cage’ stator geometry.
  - A programmable DC current supply is used to characterise the output of the dynamo across a range of operating currents and frequencies (see [3, 7]).

Design of experimental “squirrel-cage” dynamo

- Device employs a stator geometry of 8 parallel HTS tapes connected at either end by a superconducting ring-bus. The 8 stator tapes are mounted upon a cylindrical iron stator yoke which is arranged coaxially with the rotor.
  - Parallel HTS stator tapes: 12 mm ReBCO coated conductor (Superpower Inc, self-field (SFSF) = 260 A @ 77K).
  - HTS dual-ring bus and flyleads: 10 mm ReBCO coated conductor (Fujikura, self-field (SFSF) = 490 A @ 77 K).

Current-voltage output characteristics

Measuring the V_SC relationship of the dynamo provides three key parameters which fully describe the output of the dynamo at a given rotor speed: V_SC is the open-circuit voltage, given by the x-intercept R_SC. I_SC is the internal resistance due to ac losses [5], obtained from the slope of the linear fit. I_SC is the short-circuit current (the maximum current that could be delivered into a fully-superconducting load). This is given by the y-intercept of the linear fit.

These 3 parameters are related by:

\[ V_{SC} = I_{SC} \times R_{SC} \]

For I_SC = 67 A we measure output currents up to 700 A. This is the limit of our measurement system. Extrapolations of each line indicate substantially higher currents can be achieved. For n_ROT = 8, the maximum measured output current is reduced and this is exacerbated at higher rotor speeds. This is probably due to the much higher magnet frequencies seen by each stator tape, resulting in local heating of the HTS wires. [6, 7]

Effect of magnet ratio on output parameters

The Flux Pump output is strongly dependent on the ratio of magnet number, n_MAG, to number of parallel stator wires, n_ROT (= 8 in this work).

- If n_MAG < n_ROT, the critical current of the superconducting return path is no longer sufficient to fully short-circuit the magnet-driven emf.
- If n_MAG ≥ n_ROT, R_SC is also approximately proportional to rotor speed. Thus plotting R_SC/N_ROT collapses all the data onto a single line.

The optimal ratio of magnets to stator wires for 8 stators will depend on application requirements:

\[ n_MAG > n_ROT \]

Summary

The HTS dynamo behaves as a simple DC voltage source with open-circuit voltage V_SC and internal resistance R_SC. R_SC is proportional to both rotor speed and magnet number. Multiple parallel stator wires lead to low internal resistance of < 3.5 μΩ for all speeds with n_ROT ≤ 8.

To date, the maximum measured current from this device is 700 A, but this is limited by experimental equipment. Linear extrapolations indicate maximum output currents of up to 1.3 kA could be achieved.

References