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Practical Estimation of Losses in a HTS Dynamo

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Efficient High Current Supply for HTS Coils

HTS dynamos enable DC HTS coils to be powered without physical connections through the cryostat wall.

Power is transmitted into the cryogenic environment by a time varying magnetic field, which is self rectified in the dynamo stator to produce a DC output current.

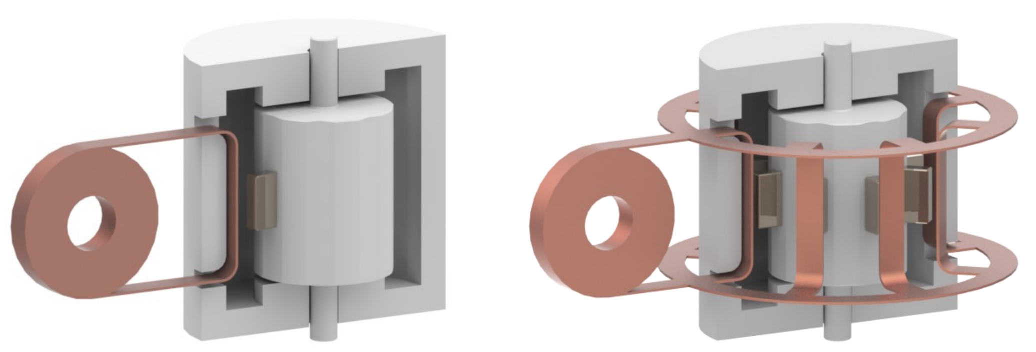
These devices remove the need for copper current leads to penetrate the cryostat, and thereby reduce the cooling power required to operate HTS magnet coils.

The work presented here measures the efficiency of a “Squirrel Cage” HTS dynamo delivering up to 1700 A.

The total power required to operate a 2 W, 1000 A HTS coil using the HTS dynamo is compared to the total power required to operate the same coil using standard HTS coil supply methods.

Dynamo Hardware

The HTS dynamo consists of a permanent magnet attached to a rotating shaft, and one or more HTS stators arranged so the field of the permanent magnet sweeps across the stator during rotation. The gap between the magnet and stator may contain the wall of the cryostat, leaving the rotating components at room temperature while the HTS stators are kept cryogenic.



In this work, the efficiency of an eight stator, four magnet dynamo was measured by monitoring the shaft torque and dynamo DC output voltage across a range of rotational speeds and dynamo output currents.

The power supplied to the dynamo is the shaft power delivered from an ambient temperature motor to the rotating magnets:

$$P_{in} = \omega\tau$$

The power supplied by the dynamo to the HTS circuit is the electrical power at the dynamo output terminals:

$$P_{out} = VI$$

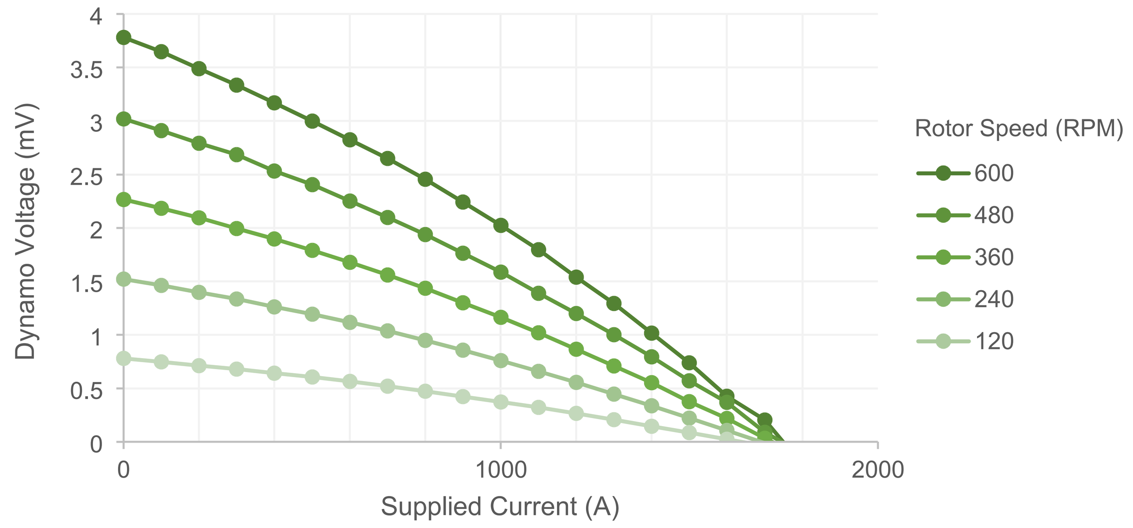
The efficiency of the dynamo is calculated as the ratio of output power to the input power:

$$\eta = P_{out}/P_{in}$$

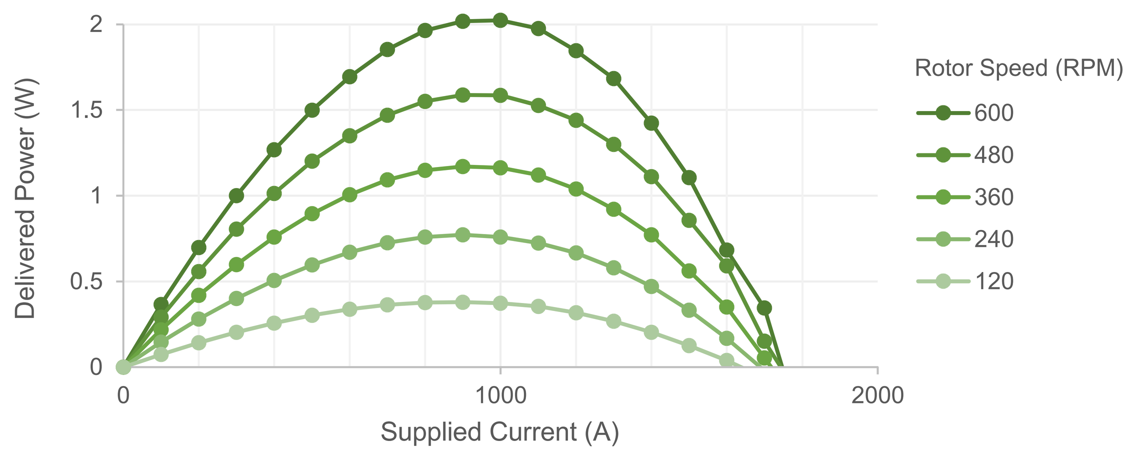
The power loss in the dynamo occurs wholly inside the cryogenic environment as heating of the HTS stator. The dynamo losses are therefore equivalent to the thermal load that would be imparted on an attached cryocooler by the dynamo operation.

Results

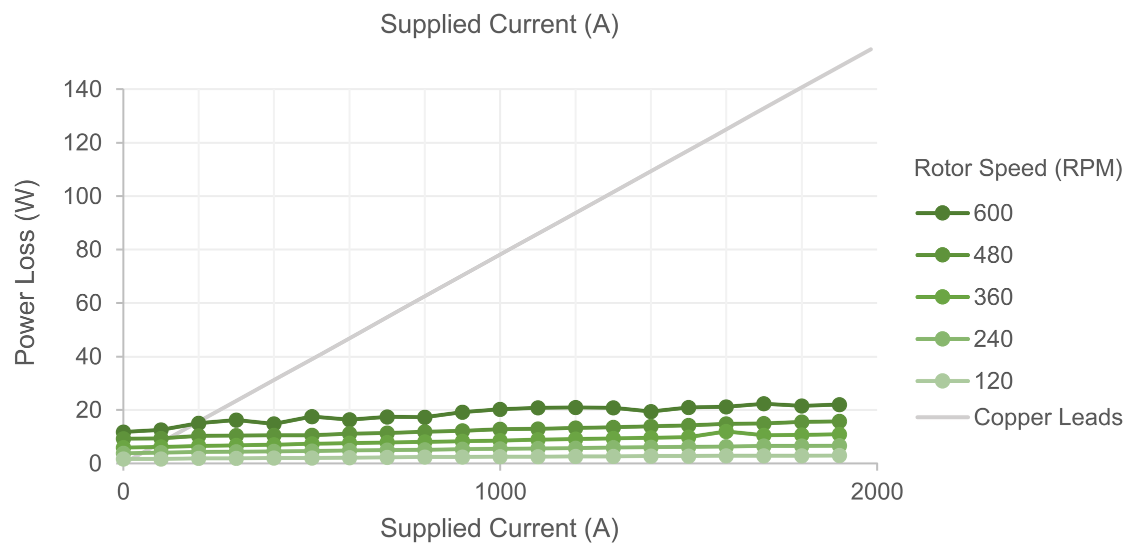
As larger currents are produced in the HTS circuit by the dynamo, the voltage across the output terminals decreases as shown by the VI relationship.



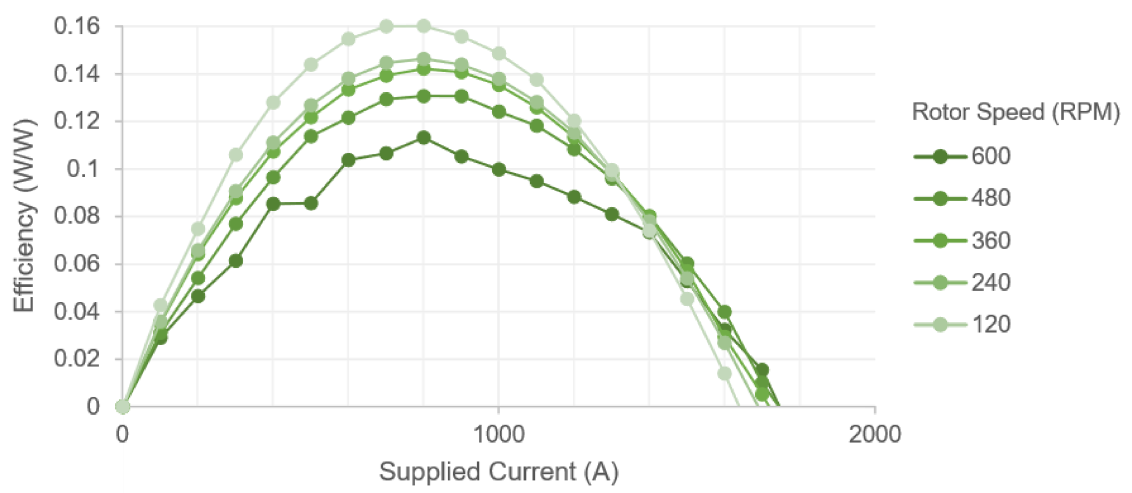
The output power of this HTS dynamo was found to be 2 W at the maximum speed tested. The optimum operating point in terms of power delivered to the HTS circuit occurs at 1000 A.



The varying magnetic field of the dynamo produces AC loss in the HTS. These losses produce heat in the cryogenic environment. The losses in a pair of 1 m long copper leads optimised for each supplied current, as calculated using the method from [2], are also plotted.



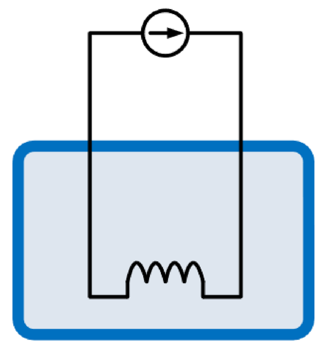
Across the speed range tested the efficiency of the HTS dynamo is between 10 and 16%. As shown in the above plot, the power required to provide 1000 A in the cryogenic environment is significantly less than is required using the standard method.



1 kA HTS Coil Supply Comparison

Using the HTS dynamo power and efficiency data found experimentally, the total power required to operate a HTS coil energised via the dynamo can be calculated. The total power required running the same coil energised using the standard method of copper leads and an ambient current source is also calculated.

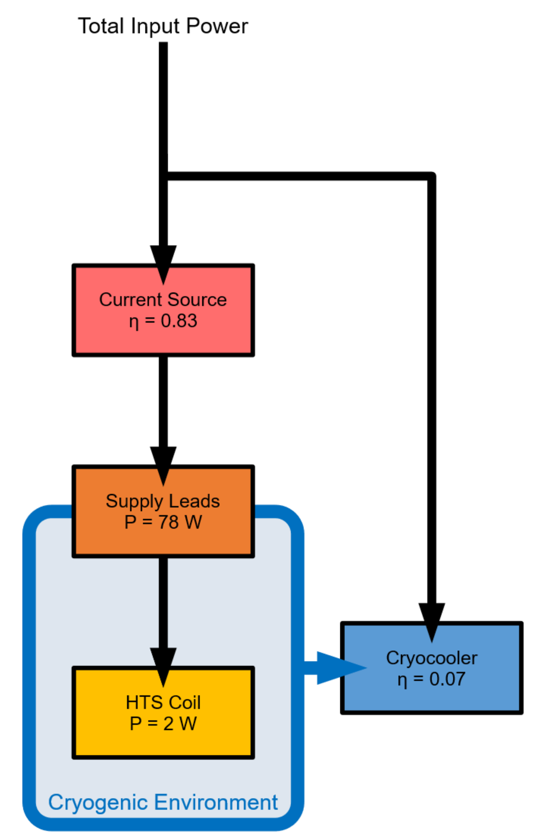
Conventional Supply



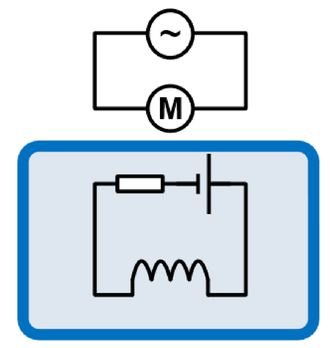
The conventional method to supply HTS coils uses an ambient temperature constant current source, connected in series with the coil via copper supply leads. The copper supply leads introduce heat to the cryogenic environment through resistive heating.

The power required to operate the coil is the sum of the supply leads and coil power, multiplied by the efficiency of the current supply.

The total power required for cooling is the sum of the supply lead power and coil power, multiplied by the efficiency of the cryocooler.



Supply via Dynamo

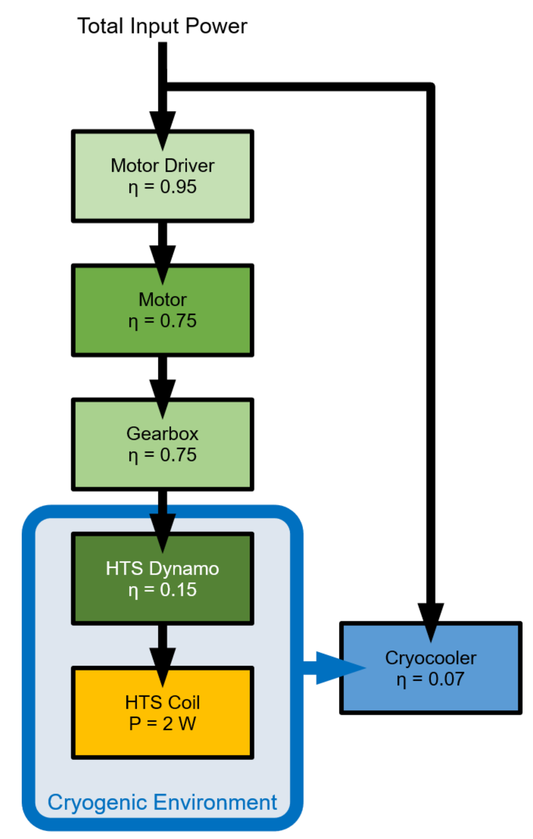


Supplying the same coil with a dynamo uses an ambient temperature motor and gearbox to drive the dynamo rotor. The HTS dynamo stator completes the coil superconducting circuit inside the cryogenic environment without needing resistive components.

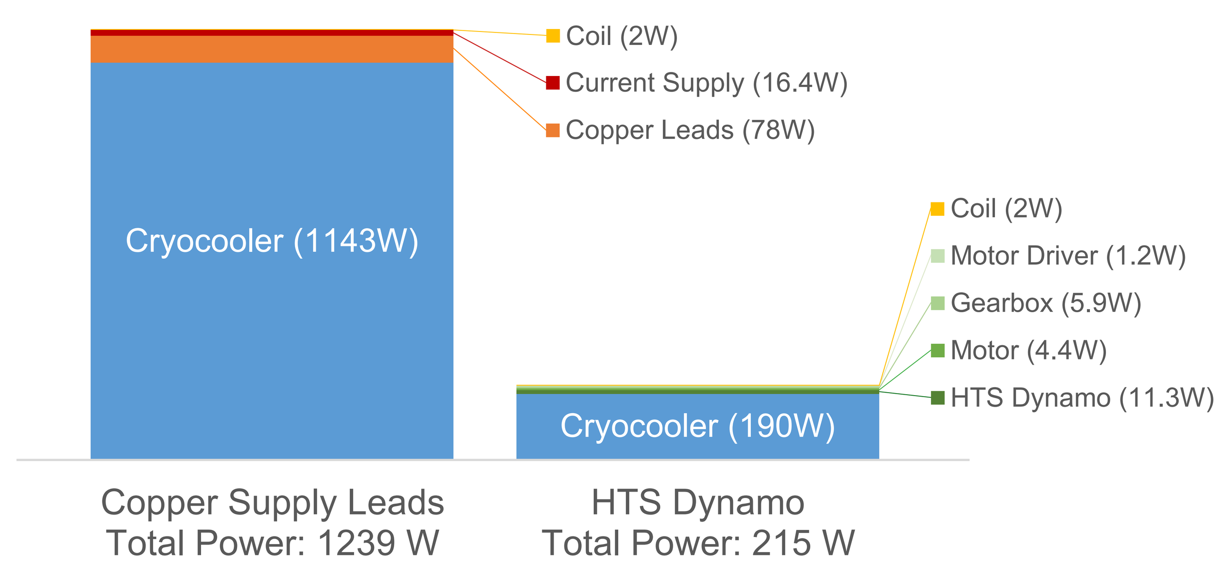
This enables the HTS coil to be operated in quasi-persistent mode.

The power required to operate the coil is the coil power divided by the product of the efficiencies of the components in the supply chain.

The total power required for cooling is the sum of the coil power and the power loss in the HTS dynamo.



75% Reduction in HTS Coil Cryogenic Load



The total power, including cryocooler power, required to supply a 1000 A at 77 K with 2 W is significantly reduced when a HTS dynamo is used as the constant current supply.

References

1. Hamilton, Kent, Andres E. Pantoja, James G. Storey, Zhenan Jiang, Rodney A. Badcock, and Chris W. Bumby. "Design and performance of a “squirrel-cage” dynamo-type HTS flux pump." *IEEE Transactions on Applied Superconductivity* 28, no. 4 (2018): 1-5.
2. McFee, Richard. "Optimum input leads for cryogenic apparatus." *Review of Scientific Instruments* 30, no. 2 (1959): 98-102.
3. Mataira, R. C., M. D. Ainslie, R. A. Badcock, and C. W. Bumby. "Origin of the DC output voltage from a high-Tc superconducting dynamo." *Applied Physics Letters* 114, no. 16 (2019): 162601.
4. Hamilton, Kent, Andres E. Pantoja, James G. Storey, Zhenan Jiang, Rodney A. Badcock, and Chris W. Bumby. "Asynchronous Magnet–Stator Topologies in a Squirrel-Cage Superconducting Dynamo." *IEEE Transactions on Applied Superconductivity* 29, no. 5 (2019): 1-5.
5. Walsh, Rowan Martin, Christopher William Bumby, Rodney Alan Badcock, Robert Andrew Slade, Zhenan Jiang, Kent Anthony Hamilton, and Michael Graeme Fee. "Superconducting current pump." U.S. Patent 9,972,429, issued May 15, 2018.
6. Bumby, C. W., Zhenan Jiang, J. G. Storey, A. E. Pantoja, and R. A. Badcock. "Anomalous open-circuit voltage from a high-T c superconducting dynamo." *Applied Physics Letters* 108, no. 12 (2016): 122601.
7. Bumby, Chris W., Rodney A. Badcock, Hae-Jin Sung, Kwang-Min Kim, Zhenan Jiang, Andres E. Pantoja, Patrick Bernardo, Minwon Park, and Robert G. Buckley. "Development of a brushless HTS exciter for a 10 kW HTS synchronous generator." *Superconductor Science and Technology* 29, no. 2 (2016): 024008.
8. Hoffmann, Christian, Donald Pooke, and A. David Caplin. "Flux pump for HTS magnets." *IEEE Transactions on Applied Superconductivity* 21, no. 3 (2010): 1628-1631.