MEMEP 3D Software Instructions and Help

Contents

1. Software Downloading Links

Three-dimensional (3D) electro-magnetic modeling tool for superconductors and normal conductors using the Minimum Electro-Magnetic Entropy Production (MEMEP) variational principle (https://doi.org/10.1016/j.jcp.2017.05.001).

Webpage link to original code: https://github.com/epardov/MEMEP3Dtool

The modified version of the code includes modeling of dynamo-type flux pump and a superconducting magnetic bearing (SMB).

Webpage link to the modified code: https://htsmodelling.com/model-files

Licence

2. Authors and Affiliations

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Date: 01.11.2024

The names and details about authors cannot be removed. Further development of the code is allowed. You may add the details about future co-authors.

3. Citations

If you use this code or data generated by this code, please cite the following:

[1] E. Pardo and M. Kapolka "3D computation of non-linear eddy currents: variational method and superconducting cubic bulk" 2017 J. Comput. Phys., 344:339–363, https://doi.org/10.1016/j.jcp.2017.05.001

[2] M. Kapolka and E. Pardo "3D modelling of macroscopic force-free effects in superconducting thin films and rectangular prisms" 2019 Supercond. Sci. Technol., 32:054001, https://doi.org/10.1088/1361-6668/ab016a

[3] A. Ghabeli, E. Pardo, M. Kapolka, “3D Modeling of a Superconducting Dynamo-Type Flux Pump”, Scientific Report, 11(1):10296, 2021, https://doi.org/10.1038/s41598-021-89596-4

[4] P. Zhou, A. Ghabeli, M. Ainslie, F. Grilli, “Characterization of flux pump-charging of high-temperature superconducting coils using coupled numerical models”, Supercond. Sci. Technol., 2023, 36(11):115002, https://doi.org/10.1088/1361-6668/acf739

[5] A. Ghabeli, G. Fuchs, J. Hänisch, P. Zhou, O. de Haas, A. Morandi, F. Grilli, "3D modeling and measurement of HTS tape stacks in linear superconducting magnetic bearings", Supercond. Sci. Technol., 2024, 37 (6):065003, https://doi.org/10.1088/1361-6668/ad3c9a

4. Description of the Input Parameters

Currently, only thin film and bulk models in Cartesian coordinate system with hexahedral cells are supported. The modeling tool can take the following configurations into account:

- Hexahedral bulk superconductor: https://doi.org/10.1088/1361-6668/aa69ed

- Rectangular thin film (hexahedral superconductor with one element in the thickness): https://doi.org/10.1016/j.jcp.2017.05.001

- Multi-filamentary superconductor with normal conductor in between, where each filament is an hexahedron: https://arxiv.org/abs/1605.09610

- Stacks of tapes with several elements in the thickness: https://doi.org/10.1088/1361-6668/ab5aca

- Thin film disks, cylinders or spheres: https://doi.org/10.1016/j.jcp.2017.05.001

The input parameters need to be set in the `input.txt` file in the main folder. The input examples are in the `Input_example` folder. You may edit and save the input file `input.txt` to change the parameters, or replace the input files from another folder (keep the name as input.txt).

The parameters highlighted in Blue were added in the modified version of the code for modeling the dynamo-type flux pump and superconducting magnetic bearing (SMB) cases. The ones in Red belong to the original code.

x[m]: width of the sample

xl[m]: width of the metallic part in the sample between two filaments (shape == 3 only; see below for the 'shape' description)

y[m]: length of the sample

z[m]: thickness of the sample

full_matrix: interaction matrix: 0 - with symmetry for uniform mesh, 1 - without symmetry for nonuniform mesh (check RAM memory usage for more than 31x31x31 elements)

nsucx[-]: number of the cells along the x axis in the superconducting material

nncx[-]: number of normal conductor joints in the striated tape along the x axis (shape == 3 only)

ncy[-]: number of the cells along the y axis

ncz[-]: number of the cells along the z axis (thin film approximation ncz=1) or total number of elements for stack (only in shape=4)

n_tapes[-]: number of superconducting layers in the stack (only for shape=4)

nc_tape[-]: number of cells per superconducting layer in the stack (only in shape=4)

nc_gap[-]: number of gaps between superconducting layers in the stack (only in shape=4)

d_tape[m]: thickness of the superconducting layer in the stack (only in shape=4)

d_gap[m]: thickness of the gap in the stack (only in shape=4) elc[-]: 0 disable/1 enable, elongated cells in the long sample with aspect ratio greater than 2

tol_elc[-]: tolerance criterion for average vector potential of elongated cells (0.001-default)

Bamax[T]: maximum amplitude of the applied magnetic field (times the void permeability)

Bamax1[T]: maximum amplitude of the applied magnetic cross-field (times the void permeability)

Bshape[-]: waveform of the applied field : 0-sinusoidal, 1-ramp down followed by cross-field of Bamax1 (amplitude of the cross-field) and fi1 (angle of the cross-field), 2-constant ramp (triangular)

Btrape[-]: 0 disable/1 enable, calculation of the magnetic field outside of the sample in a certain plane (B-plane)

Ismax[A]: transport current in y direction

rcx_plane[m]: the center position of the B-plane, x component (only in shape=4 and Btrape=1)

rcy_plane[m]: the center position of the B-plane, y component (only in shape=4 and Btrape=1)

rcz_plane[m]: the center position of the B-plane, z component (only in shape=4 and Btrape=1)

x_plane[m]: width of the B plane (only in shape=4 and Btrape=1)

y_plane[m]: length of the B plane (only in shape=4 and Btrape=1)

z_plane[m]: thickness of the B plane (only in shape=4 and Btrape=1)

ncx_plane[-]: number of the cells in the B plane along the x axis (only in shape=4 and Btrape=1)

ncy_plane[-]: number of the cells in the B plane along the y axis (only in shape=4 and Btrape=1)

ncz_plane[-]: number of the cells in the B plane along the z axis (only in shape=4 and Btrape=1)

theta[degree]: angle of the applied magnetic field from the x axis to the y axis

fi[degree]: angle of the applied magnetic field from z axis to the x axis

fi1[degree]: angle of the applied cross magnetic field from z axis to the x axis of amplitude Bamax1 (above) and frequency f1 (below). The cross-field is usually perpendicular to the applied magnetic field (fi).

uni[-]: type of the mesh: 1-uniform (default)

rel[-]: type of power-law E(J) relation: 1-isotropic, 2-Jc(B) of Kim analytical model, 3-Jc(B,theta) interpolated from measured data in JcBload.txt file, 4-with force-free anisotropy (https://doi.org/10.1088/1361-6668/ab016a).

nB[-]: 0 disable/1, enable power-law n(B) interpolated from measured data

measured_points[-]: Jc(B) data, number of magnetic field angles (only in rel=3)

measured_fields[-]: Jc(B) data, number of magnetic field amplitudes per one angle (only in rel=3)

sym[-]: type of minimization: 0-without sectors and symmetry, 1-sectors (default), 2-sectors with symmetry (odd input number of cells in each direction only and only rel=1!)

Ec[V/m]: critical electric field of the power-law E(J) relation

Jo[A/m2]: critical current density (ignored if rel=3,4)

Jol[A/m2]: current density for normal conducting material, defined as Jol=Ec/rho with rho being the resistivity of the normal conducting material (only in shape=1,2,3,4)

rhoR[ohm*m]: effective resistivity of the normal conducting material between filaments (only in shape=3)

dl[m]: width of the normal conducting joint (only in case=3)

Jcpa[A/m2]: parallel critical current density (only rel=4)

Jcpe[A/m2]: perpendicular critical current density (only rel=4)

Bo[T]: characteristic magnetic field for the Kim model

N[-]: power law exponent (ignored if nB=1)

Nl[-]: power law exponent for metallic material (1-default)

m[-]: Kim model exponent

f[Hz]: frequency of the applied field of amplitude Bamax (above)- in the case of flux pump is the frequency of each PM- in the case of SMB is the frequency of one cycle

f1[Hz]: frequency of the applied cross-field of amplitude Bamax1 (see above; only in shape=4)

ns[-]: number of time steps per cycle

step[-]: total number of time steps

tolJ[-]: tolerance of the current density (1e-4 default)

shape[-]: geometry of the sample: 0-square/rectangular, 1-disk/ball, 2-cylinder, 3-tape with filaments, 4-stack of tapes

num_threads[-]: number of parallel computing threads (recommended to be the same as the number of threads of the computer)

op_Mag[-]: Option for using permanent magnet (PM) as external source of magnetic field: 0-Without PM , 1-With PM (case of dynamo flux pump and SMB)

Loc_Mag[-]: Option for moving path of PM: 1-Linear movement of PM (SMB), 2- Circular movement of PM (dynamo flux pump)

Br_Mag[T]: magnetization of PM

ml[m]: length of PM in z direction

md[m]: diameter of PM in x and y direction (cylindrical magnet)

nlm[-]: number of loops for making PM (higher loop -> higher accuracy)

Zmi[m]: starting position of PM in z direction in linear movement

Zme[m]: ending position of PM in z direction in linear movement

Rm[m]: Outer radius of PM surface in circular moving path

Xcm[m]: x-coordinate of the center of the circular moving path or center of the PM in SMB

Airgap[m]: gap length from the tape surface to magnet surface in circular moving path (along z-axis)

thm0[degree]: starting position of PM in circular moving path (with respect to θ=90)

Nmag[-]: number of PMs per disc distributed evenly in the circle

Nrotor[-]: number of rotor disks each one containing Nmag PMs: 1 or 2

Drotor[m]: distance between the centers of the two rotor discs (only for N_rotor = 2)

Jz_limit[-]: limits the current in z direction by making Jz=0 for modeling tape stacks: 0 or 1

SMB[-]: option for using SMB: 1 with SMB, 2 without SMB

5. Instructions for Running 3D MEMEP Code in Ubuntu OS

The code is prepared for Linux (or Unix) operating system and compiles well with all versions of compilers. In the program, we set it to run with compiler g++ -11. However, you can easily modify the compiler version or type by going to `compile.bsh` file in the main folder of the program.

Note: This FEM code is optimized to run on Ubuntu, but you can also use it on other operating systems like Windows 11, as long as you compile it correctly. Just make sure any extra software or libraries needed by the code are set up on your system.

Step 1: Downloading the Code

Download the original MEMEP 3D code from the following repository:
https://github.com/epardov/MEMEP3Dtool

Or the modified one including the dynamo flux pump and SMB:

https://htsmodelling.com/model-files

Step 2: Setting up the Environment

Before running the code, follow these steps to set up your system:

- Installing Ubuntu OS

Install any version of Ubuntu Os.

- Installing C++ Compiler

Install any version of C++ compiler. In this software we use g++ -11.

1. Open a terminal (press **Ctrl + Alt + T**) and run the following commands to add the Ubuntu Toolchain PPA, which contains newer compiler versions:

   ```
   sudo add-apt-repository ppa:ubuntu-toolchain-r/test
   ```

   ```
   sudo apt update
   ```

2. Install compiler:

   ```
   sudo apt install g++-11
   ```

3. Set g++ 11 as the Default. If you have other versions installed and want to make g++ 11 the default, use:

   ```
   sudo update-alternatives --install /usr/bin/g++ g++ /usr/bin/g++-11 11
   ```

   ```
   sudo update-alternatives --config g++
   ```

4. Verify the version:

```
g++ --version
```

- Installing the GSL Library

The GSL library provides mathematical functions used by the code (only for modeling the permanent magnet).

Run the following command in the terminal:

```
sudo apt-get install libgsl-dev
```

Step 3: Compiling and Running the Code

- Compiling the Code

1. Open a terminal in the main folder of the code.
2. Run the following command to compile the code:

```
bash compile.bsh
```

Note: Make sure the terminal address is in the main folder. To change the terminal's current directory, use the cd command followed by the folder path:

```
cd /path/to/folder
```

Example:

```
cd /home/admin/Documents
```

Tip: You can see the folder's current path by pressing Ctrl + L.

If the compilation succeeds, the terminal will proceed to the next line without any error messages.

- Running the Code

Run the following command to execute the code and see the program check in the terminal environment:

```
./main
```

Or to see the program check in the `output.txt` file in the main folder including AC loss and computing time at the end of file.

```
./main > output.txt
```

There are more files with detailed data results and debugging information. It is recommended to use the Gnuplot graphs (after installing Gnuplot software) to see the detailed results.

Step 4: Postprocessing and Viewing Results

1. Navigate to the `data` folder, which contains the output files in `.txt` format.
2. Use Gnuplot to run the `.plt` files in the `data` folder.
3. The results will be saved as `.pdf`, `.jpeg`, or other file formats in the same folder.
4. You can edit the `.plt` files using a text editor to customize your plots.

Examples:

Run the following commands in terminal in order to see the related results. You will need to previously install the GNU software gnuplot.

- Geometry:

```
gnuplot g_1.plt
```

- Screening current density:

```
gnuplot 2Dz.plt
```

Choose options in the `2Dz.plt` or `3Dz.plt` files: Jx, Jy, J, Bz,...: 0 disable/1 enable to see the corresponding quantities.

- AC loss:

```
gnuplot loss.plt
```

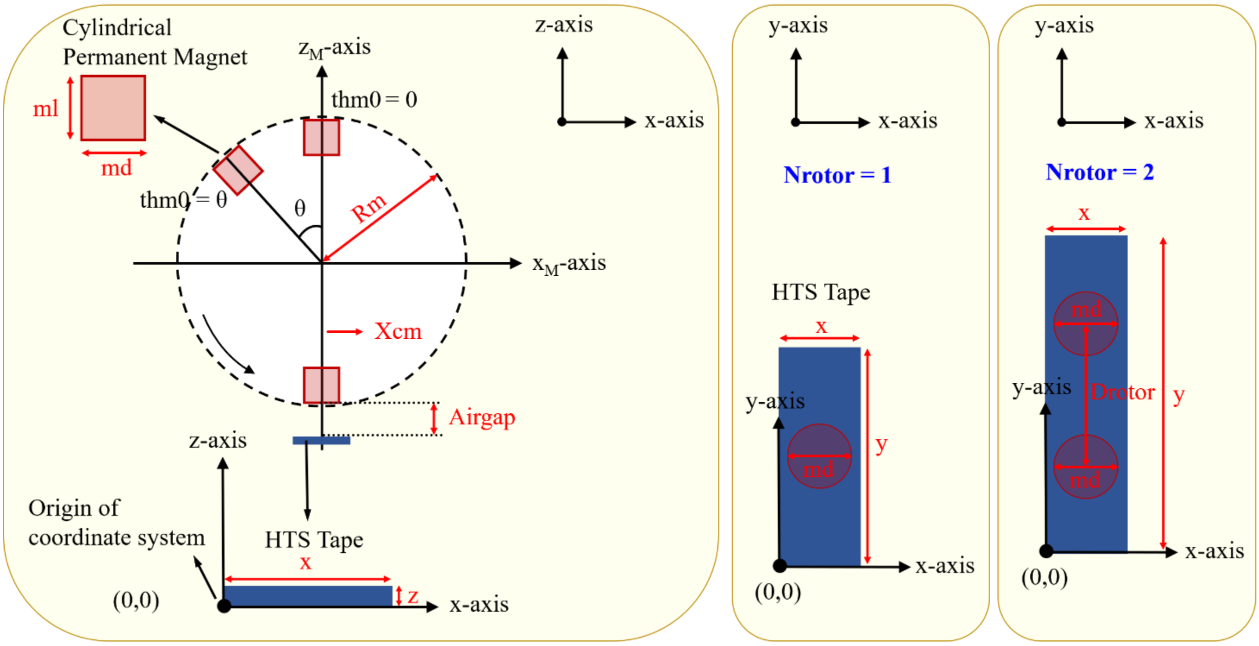
-Parameters related to flux pump or SMB

Go to `data` folder and open the `Flux_Pump.txt` file. There are 14 columns showing the following parameters:

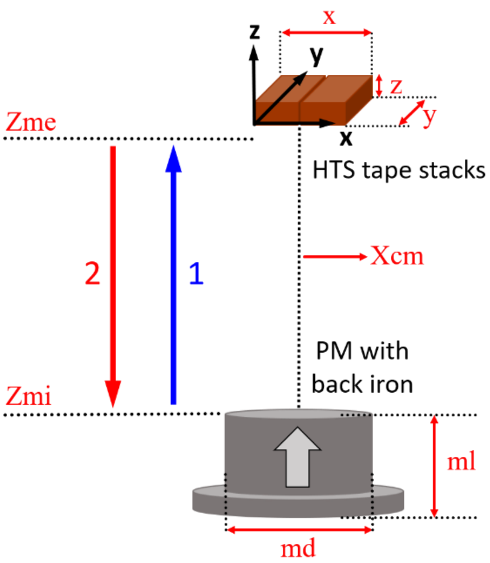
# Columns	Parameter	Definition
1	it	time step no
2	t [s]	time
3	Eav.l [V]	resistive voltage ((Eq(7) of Ref [3]))
4	Ee.l [V]	(Eav+DAs+DAa).l, electrostatic voltage
5	DeltaV.l [V]	(Eav+DAs).l (Eq(11) of Ref [3])
6	DAa.l [V]	inductive voltage (due to PM field)
7	DAs.l [V]	induced voltage due to tape screening current
8	Eav_c.l [V]	same as Eav.l, but in the center of tape (see Fig.4(c) of Ref[3])
9	DAs_c.l [V]	same as DAs.l, but in the center of tape (see Fig.4(c) of Ref[3])
10	DeltaV_c.l [V]	same as DeltaV.l, but in the center of tape (see Fig.4(c) of Ref[3])
11	DeltaZ [mm]	separation between PM and superconductor domain
12	Fx [N]	Lorentz force between PM and superconductor domain in z direction
13	Fy [N]	Lorentz force between PM and superconductor domain in y direction
14	Fz [N]	Lorentz force between PM and superconductor domain in z direction

6. Help for Geometry of Input Data

6.1. Dynamo-type flux pump

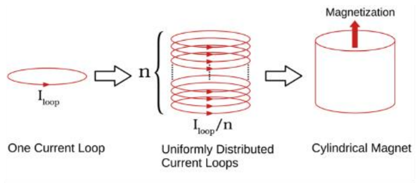


6.2. SMB

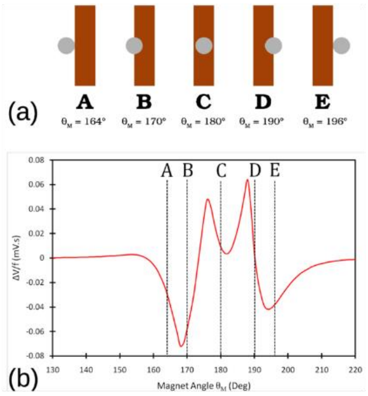


7. Examples of Solved Cases

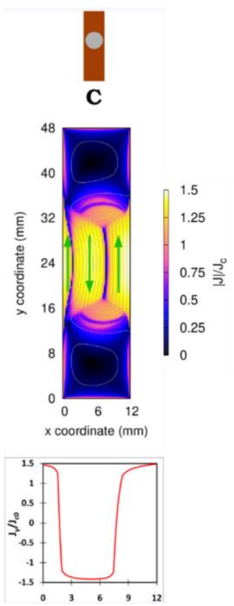
7.1. HTS dynamo-type flux pump with a single PM



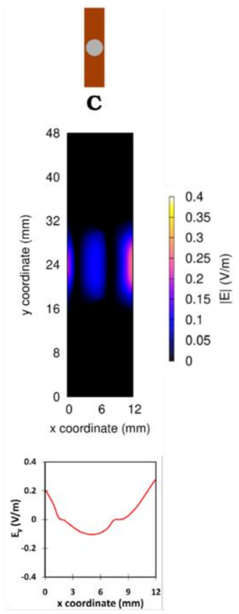
Process of modeling a 3D cylindrical magnet



Frequency-normalized ΔV versus magnet angle θ_M for airgap of 3.3 mm



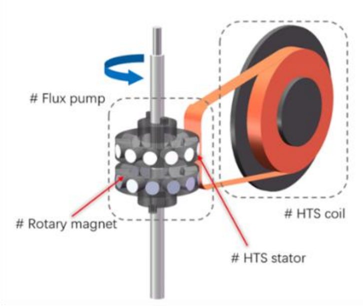
Screening current when PM traverses the tape



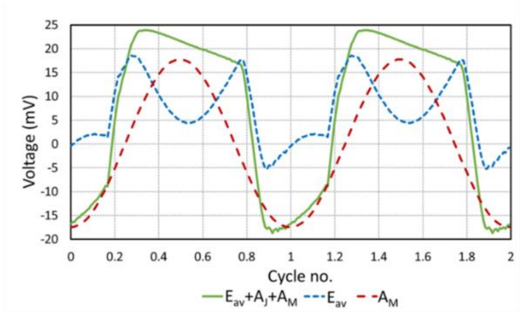
Electric field when PM traverses the tape

A. Ghabeli et al, Scientific Report, 2021

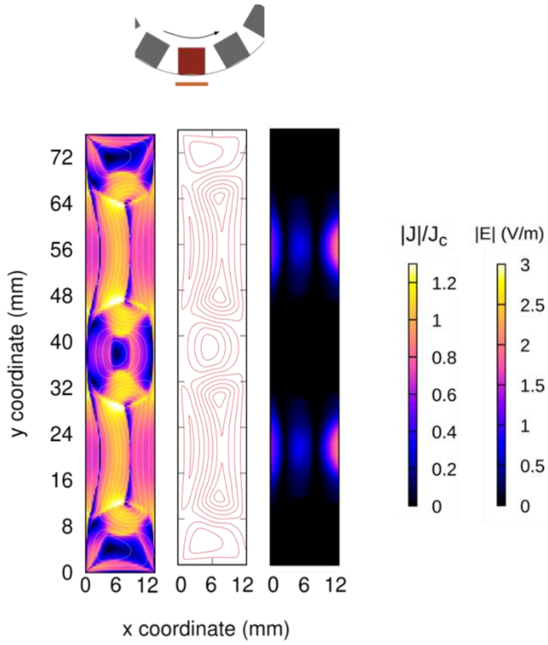
7.2. HTS dynamo-type flux pump with two rotor disks and 24 PMs



Configuration of the HTS coil charged by a dynamo-type flux pump with 2 discs each one containing 12 PMs



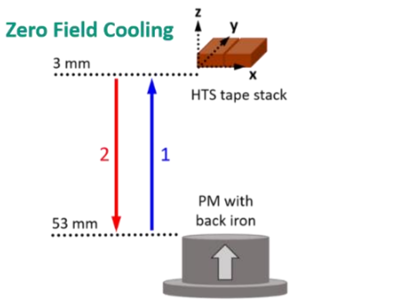
Calculated total output voltage , resistive voltage, and inductive voltage of the HTS dynamo.
Case of the 1 mm flux gap and 600 Hz

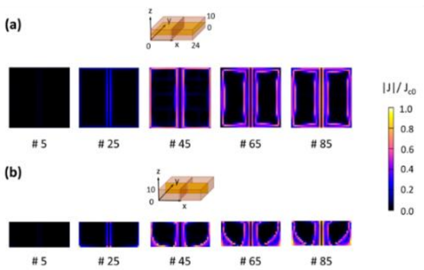


Current modulus maps (left side), the corresponding current lines (middle), and electric field modulus maps (right side) in the stator when PM traverses the tape

P. Zhou etal, Supercond. Sci. Technol., 2023

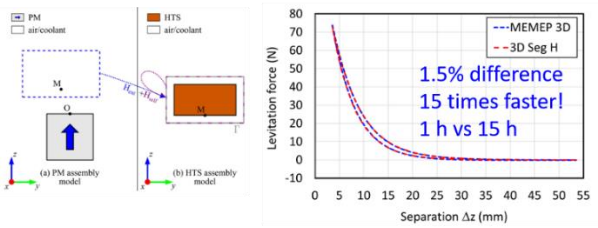
7.3. SMB in zero field cooling case



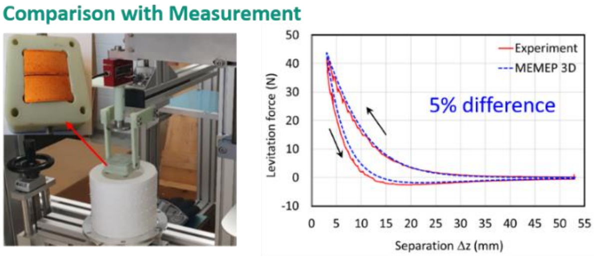


Screening current distribution in ZFC mode for various time steps during the first cycle

Comparison with 3D segregated H-formulation method (COMSOL Multiphysics)



Comparison with Measurement



A. Ghabeli, et al, Supercond. Sci. Technol., 2024

8. Parameter Selection Guide for Each Case

Necessary parameters (green), optional but not required parameters (yellow), and unusable parameters (red) are highlighted here for modeling of each case. The numbers in front of some inputs are the necessary or suggested parameters for modeling each case.

8.1. Dynamo-type flux pump

x[m]: width of the sample

xl[m]: width of the metallic part in the sample between two filaments (shape == 3 only; see below for the 'shape' description)

y[m]: length of the sample

z[m]: thickness of the sample

full_matrix: 0

nsucx[-]: number of the cells along the x axis in the superconducting material

nncx[-]: number of normal conductor joints in the striated tape along the x axis (shape == 3 only)

ncy[-]: number of the cells along the y axis

ncz[-]: number of the cells along the z axis (thin film approximation ncz=1) or total number of elements for stack (only in shape=4)

n_tapes[-]: number of superconducting layers in the stack (only for shape=4)

nc_tape[-]: number of cells per superconducting layer in the stack (only in shape=4)

nc_gap[-]: number of gaps between superconducting layers in the stack (only in shape=4)

d_tape[m]: thickness of the superconducting layer in the stack (only in shape=4)

d_gap[m]: thickness of the gap in the stack (only in shape=4)

elc[-]: 0

tol_elc[-]: tolerance criterion for average vector potential of elongated cells (0.001-default)

Bamax[T]: maximum amplitude of the applied magnetic field (times the void permeability)

Bamax1[T]: maximum amplitude of the applied magnetic cross-field (times the void permeability)

Bshape[-]: waveform of the applied field : 0-sinusoidal, 1-ramp down followed by cross-field of Bamax1 (amplitude of the cross-field) and fi1 (angle of the cross-field), 2-constant ramp (triangular)

Btrape[-]: 0 disable/1 enable, calculation of the magnetic field outside of the sample in a certain plane (B-plane)

Ismax[A]: transport current in y direction

rcx_plane[m]: the center position of the B-plane, x component (only in shape=4 and Btrape=1)

rcy_plane[m]: the center position of the B-plane, y component (only in shape=4 and Btrape=1)

rcz_plane[m]: the center position of the B-plane, z component (only in shape=4 and Btrape=1)

x_plane[m]: width of the B plane (only in shape=4 and Btrape=1) y_plane[m]: length of the B plane (only in shape=4 and Btrape=1)

z_plane[m]: thickness of the B plane (only in shape=4 and Btrape=1)

ncx_plane[-]: number of the cells in the B plane along the x axis (only in shape=4 and Btrape=1)

ncy_plane[-]: number of the cells in the B plane along the y axis (only in shape=4 and Btrape=1)

ncz_plane[-]: number of the cells in the B plane along the z axis (only in shape=4 and Btrape=1)

theta[degree]: angle of the applied magnetic field from the x axis to the y axis

fi[degree]: angle of the applied magnetic field from z axis to the x axis

fi1[degree]: angle of the applied cross magnetic field from z axis to the x axis of amplitude Bamax1 (above) and frequency f1 (below). The cross-field is usually perpendicular to the applied magnetic field (fi).

uni[-]: 1

rel[-]: type of power-law E(J) relation: 1-isotropic, 2-Jc(B) of Kim analytical model, 3-Jc(B,theta) interpolated from measured data in JcBload.txt file, 4-with force-free anisotropy (https://doi.org/10.1088/1361-6668/ab016a).

nB[-]: 0 disable/1, enable power-law n(B) interpolated from measured data

measured_points[-]: Jc(B) data, number of magnetic field angles (only in rel=3)

measured_fields[-]: Jc(B) data, number of magnetic field amplitudes per one angle (only in rel=3)

sym[-]: 1

Ec[V/m]: critical electric field of the power-law E(J) relation

Jo[A/m2]: critical current density (ignored if rel=3,4)

Jol[A/m2]: current density for normal conducting material, defined as Jol=Ec/rho with rho being the resistivity of the normal conducting material (only in shape=1,2,3,4)

rhoR[ohm*m]: effective resistivity of the normal conducting material between filaments (only in shape=3)

dl[m]: width of the normal conducting joint (only in case=3)

Jcpa[A/m2]: parallel critical current density (only rel=4)

Jcpe[A/m2]: perpendicular critical current density (only rel=4)

Bo[T]: characteristic magnetic field for the Kim model

N[-]: power law exponent (ignored if nB=1)

Nl[-]: power law exponent for metallic material (1-default)

m[-]: Kim model exponent

f[Hz]: frequency of the applied field of amplitude Bamax (above)- in the case of flux pump is the frequency of each PM- in the case of SMB is the frequency of one cycle

f1[Hz]: frequency of the applied cross-field of amplitude Bamax1 (see above; only in shape=4)

ns[-]: number of time steps per cycle

step[-]: total number of time steps

tolJ[-]:1e-4

shape[-]: geometry of the sample: 0-square/rectangular, 1-disk/ball, 2-cylinder, 3-tape with filaments, 4-stack of tapes

num_threads[-]: number of parallel computing threads (recommended to be the same as the number of threads of the computer)

op_Mag[-]: 1

Loc_Mag[-]: 2

Br_Mag[T]: magnetization of PM

ml[m]: length of PM in z direction

md[m]: diameter of PM in x and y direction (cylindrical magnet)

nlm[-]: 400

Zmi[m]: starting position of PM in z direction in linear movement

Zme[m]: ending position of PM in z direction in linear movement

Rm[m]: Outer radius of PM surface in circular moving path

Xcm[m]: x-coordinate of the center of the circular moving path or center of the PM in SMB

Airgap[m]: gap length from the tape surface to magnet surface in circular moving path (along z-axis)

thm0[degree]: starting position of PM in circular moving path (with respect to θ=90)

Nmag[-]: number of PMs per disc distributed evenly in the circle

Nrotor[-]: number of rotor disks each one containing Nmag PMs: 1 or 2

Drotor[m]: distance between the centers of the two rotor discs (only for N_rotor = 2)

Jz_limit[-]: 0

SMB[-]: 0

8.2. SMB

x[m]: width of the sample

xl[m]: width of the metallic part in the sample between two filaments (shape == 3 only; see below for the 'shape' description)

y[m]: length of the sample

z[m]: thickness of the sample

full_matrix: 0

nsucx[-]: number of the cells along the x axis in the superconducting material

nncx[-]: number of normal conductor joints in the striated tape along the x axis (shape == 3 only) ncy[-]: number of the cells along the y axis

ncz[-]: number of the cells along the z axis (thin film approximation ncz=1) or total number of elements for stack (only in shape=4)

n_tapes[-]: number of superconducting layers in the stack (only for shape=4)

nc_tape[-]: number of cells per superconducting layer in the stack (only in shape=4)

nc_gap[-]: number of gaps between superconducting layers in the stack (only in shape=4)

d_tape[m]: thickness of the superconducting layer in the stack (only in shape=4)

d_gap[m]: thickness of the gap in the stack (only in shape=4)

elc[-]: 0

tol_elc[-]: tolerance criterion for average vector potential of elongated cells (0.001-default)

Bamax[T]: maximum amplitude of the applied magnetic field (times the void permeability)

Bamax1[T]: maximum amplitude of the applied magnetic cross-field (times the void permeability)

Bshape[-]: waveform of the applied field : 0-sinusoidal, 1-ramp down followed by cross-field of Bamax1 (amplitude of the cross-field) and fi1 (angle of the cross-field), 2-constant ramp (triangular)

Btrape[-]: 0 disable/1 enable, calculation of the magnetic field outside of the sample in a certain plane (B-plane)

Ismax[A]: transport current in y direction

rcx_plane[m]: the center position of the B-plane, x component (only in shape=4 and Btrape=1)

rcy_plane[m]: the center position of the B-plane, y component (only in shape=4 and Btrape=1)

rcz_plane[m]: the center position of the B-plane, z component (only in shape=4 and Btrape=1)

x_plane[m]: width of the B plane (only in shape=4 and Btrape=1)

y_plane[m]: length of the B plane (only in shape=4 and Btrape=1)

z_plane[m]: thickness of the B plane (only in shape=4 and Btrape=1)

ncx_plane[-]: number of the cells in the B plane along the x axis (only in shape=4 and Btrape=1)

ncy_plane[-]: number of the cells in the B plane along the y axis (only in shape=4 and Btrape=1)

ncz_plane[-]: number of the cells in the B plane along the z axis (only in shape=4 and Btrape=1)

theta[degree]: angle of the applied magnetic field from the x axis to the y axis

fi[degree]: angle of the applied magnetic field from z axis to the x axis

fi1[degree]: angle of the applied cross magnetic field from z axis to the x axis of amplitude Bamax1 (above) and frequency f1 (below). The cross-field is usually perpendicular to the applied magnetic field (fi).

uni[-]: 1

rel[-]: type of power-law E(J) relation: 1-isotropic, 2-Jc(B) of Kim analytical model, 3-Jc(B,theta) interpolated from measured data in JcBload.txt file, 4-with force-free anisotropy (https://doi.org/10.1088/1361-6668/ab016a).

nB[-]: 0 disable/1, enable power-law n(B) interpolated from measured data

measured_points[-]: Jc(B) data, number of magnetic field angles (only in rel=3)

measured_fields[-]: Jc(B) data, number of magnetic field amplitudes per one angle (only in rel=3)

sym[-]: 1

Ec[V/m]: critical electric field of the power-law E(J) relation

Jo[A/m2]: critical current density (ignored if rel=3,4)

Jol[A/m2]: current density for normal conducting material, defined as Jol=Ec/rho with rho being the resistivity of the normal conducting material (only in shape=1,2,3,4)

rhoR[ohm*m]: effective resistivity of the normal conducting material between filaments (only in shape=3)

dl[m]: width of the normal conducting joint (only in case=3)

Jcpa[A/m2]: parallel critical current density (only rel=4)

Jcpe[A/m2]: perpendicular critical current density (only rel=4)

Bo[T]: characteristic magnetic field for the Kim model

N[-]: power law exponent (ignored if nB=1)

Nl[-]: power law exponent for metallic material (1-default)

m[-]: Kim model exponent

f[Hz]: frequency of the applied field of amplitude Bamax (above)- in the case of flux pump is the frequency of each PM- in the case of SMB is the frequency of one cycle

f1[Hz]: frequency of the applied cross-field of amplitude Bamax1 (see above; only in shape=4)

ns[-]: number of time steps per cycle

step[-]: total number of time steps

tolJ[-]:1e-4

shape[-]: geometry of the sample: 0-square/rectangular, 1-disk/ball, 2-cylinder, 3-tape with filaments, 4-stack of tapes

num_threads[-]: number of parallel computing threads (recommended to be the same as the number of threads of the computer)

op_Mag[-]: 1

Loc_Mag[-]: 1

Br_Mag[T]: magnetization of PM

ml[m]: length of PM in z direction

md[m]: diameter of PM in x and y direction (cylindrical magnet)

nlm[-]: 400

Zmi[m]: starting position of PM in z direction in linear movement

Zme[m]: ending position of PM in z direction in linear movement

Rm[m]: Outer radius of PM surface in circular moving path

Xcm[m]: x-coordinate of the center of the circular moving path or center of the PM in SMB

Airgap[m]: gap length from the tape surface to magnet surface in circular moving path (along z-axis)

thm0[degree]: starting position of PM in circular moving path (with respect to θ=90)

Nmag[-]: number of PMs per disc distributed evenly in the circle

Nrotor[-]: number of rotor disks each one containing Nmag PMs: 1 or 2

Drotor[m]: distance between the centers of the two rotor discs (only for N_rotor = 2)

Jz_limit[-]: limits the current in z direction by making Jz=0 for modeling tape stacks: 0 or 1

SMB[-]: 1

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