Comparison of Linear Superconducting Magnetic Bearings using Isotropic and Anisotropic Materials

Wenjiao Yang[1], Guangtong Ma[1], Loïc Quéval[2],

1. Applied Superconductivity Laboratory, State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu, China
2. Group of Electrical Engineering - Paris, UMR CNRS 8507, CentraleSupélec, Univ. Paris-Sud, Univ. Paris-Saclay, Sorbonne Univ., Gif-sur-Yvette, France

MT 26 International Conference on Magnet Technology, Vancouver, Canada | 2019

Thu-Mo-Po4.13-01 [97]

Purpose

Explore the influence of HTS materials anisotropy on the performance of superconducting magnetic bearings.

Modeling

We consider a linear superconducting magnetic bearing (LSMB) consisting of an HTS assembly and a permanent magnet guideway.

Permanent magnet guideway model

What: Permanent magnets arranged in Halbach array
How: 2D **A**-formulation (magnetostatic) FE model

HTS assembly model

What: HTS isotropic/anisotropic bulk
How: 2D **H**-formulation FE model

- isotropic bulk model: use only one current constraint for whole HTS domain

$$\iint_s J_z \, ds = 0$$

- anisotropic bulk model: devide the bulk into subdomains, use a mapped mesh with one element in the thickness and apply one current constraint per subdomain so that $J_{c,axis} = 0$.

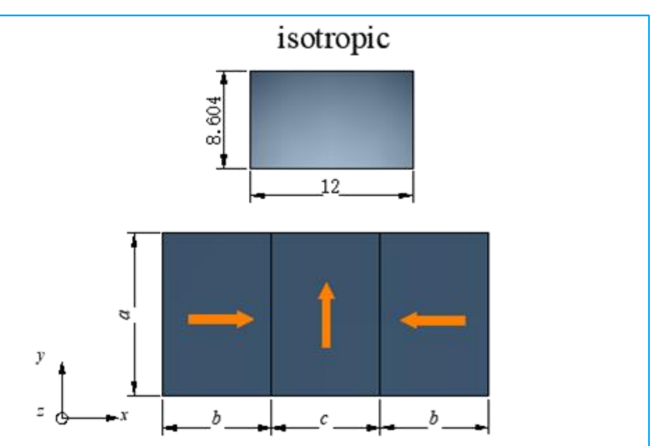


Fig. 1a - LSMB with isotropic material.

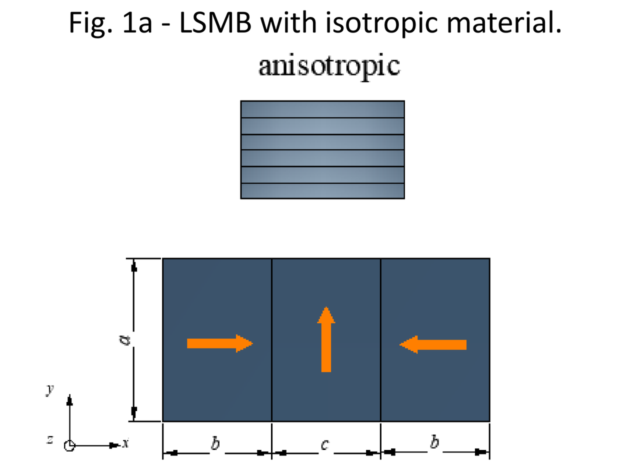


Fig. 1b - LSMB with anisotropic material.

Observation

ZFC100 sequence

(a) Zero field cooling at 100 mm
(b) Vertical displacement downward to 5 mm
(c) Vertical displacement upward.

FC25-LD10 sequence

(a) Field cooling at 25 mm
(b) Vertical displacement downward to 5 mm
(c) Lateral displacements to ±10 mm.

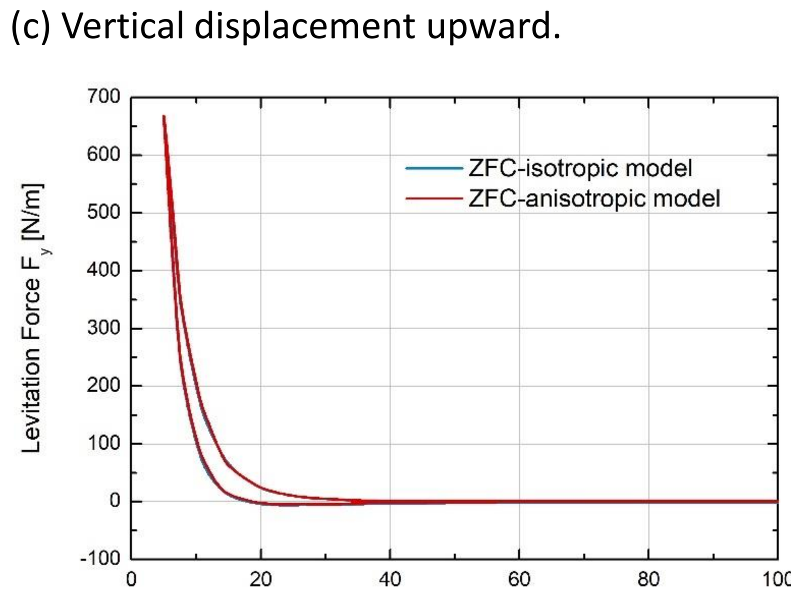


Fig. 2a - Levitation force calculated for the ZFC100 sequence.

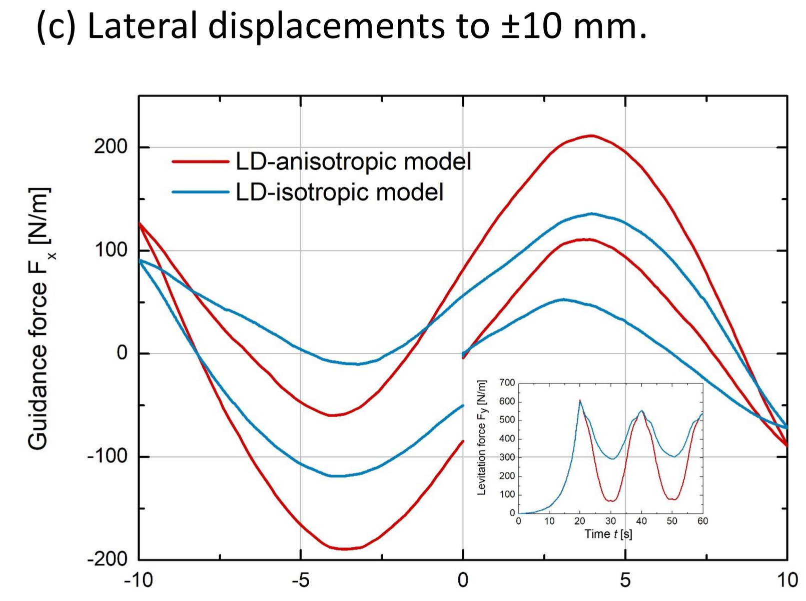


Fig. 2b - Guidance forces for the FC25-LD10 sequence. Inset: Levitation force.

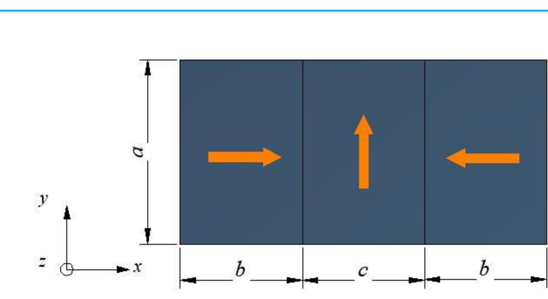
Conclusion

(a) For vertical movement, there is no difference between isotropic and anisotropic materials
(b) For lateral movement, the levitation and guidance forces are very different between isotropic and anisotropic materials.
But how to compare isotropic and anisotropic materials in a "fair" way ? ⇨ Optimization !

Optimization

Parametrization

Dimensions of HTS bulk : fixed
Dimensions of PM guideway : 3 parameters



Objective and constraints

ZFC100 sequence

We look for the PM guideways that minimize the cost of the PM guideway and maximize the levitation force:

minimize ($f_1(a, b, c), f_2(a, b, c)$),
with $f_1(a, b, c) = a(2b+c)\gamma_{PM}$,
$f_2(a, b, c) = -F_y(t=95\ s)$,

where the price of PM γ_{PM} is set as 250 $k€/m^3$.

FC25-LD10 sequence

We look for the PM guideways that minimize the cost of the PM guideway and maximize the lateral force, with a constraint on the minimum levitation force:

minimize ($f_1(a, b, c), f_2(a, b, c)$),
subject to ($c_1(a, b, c) < 0$),
with $f_1(a, b, c) = a(2b+c)\gamma_{PM}$,
$f_2(a, b, c) = -F_x(t=40\ s)$,
$c_1(a, b, c) = 250 - \min(F_y(t>20\ s))$.

Optimization algorithm

Multi-objective Particule Swarm Optimization (MOPSO), 100 particules, 25 generations.

Results and discussion

ZFC100 sequence

For the given permanent guideway topology, and for this sequence:

(a) In agreement with the preliminary observations, no difference between isotropic and anisotropic materials;
(b) Levitation force is a logarithmic function of the cost. The slope of the Pareto front is steep at first and then decreases gradually to zero;
(c) This can be explained by looking at the current penetration: gradual from the bottom and sides;
(d) The bulk is never fully penetrated: the quantity of HTS material could be reduced.

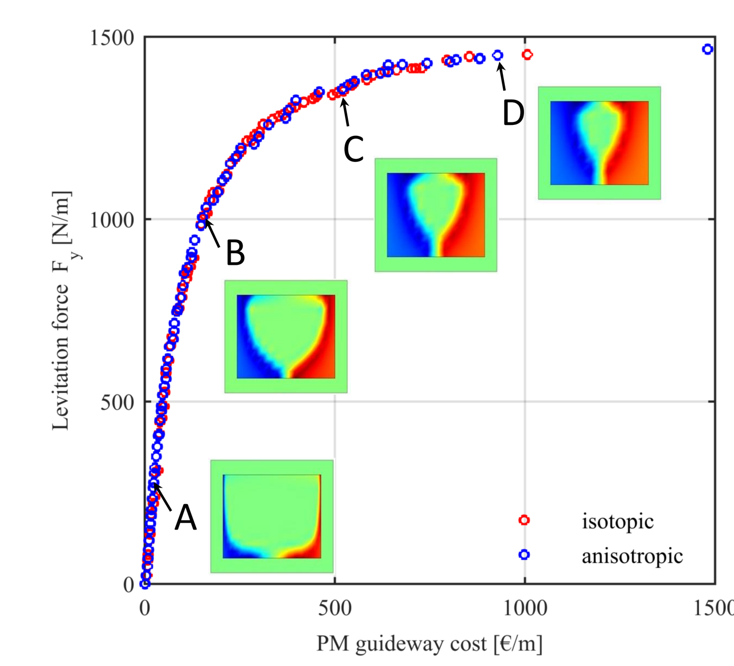


Fig. 3a - Pareto optimal solutions of the bi-objective optimization for the ZFC100 sequence.

FC25-LD10 sequence

For the given permanent guideway topology, and for this sequence:

(a) Guidance force is a logarithmic function of the cost.
(b) Isotropic material offers higher guidance force than anisotropic material.
(c) Isotropic model is always stable ($x < 0, F_x > 0$);
(d) Anisotropic model is always unstable ($x < 0, F_x < 0$);

What if the lateral displacement amplitude is reduced ? ⇨ FC25-LD5 sequence.

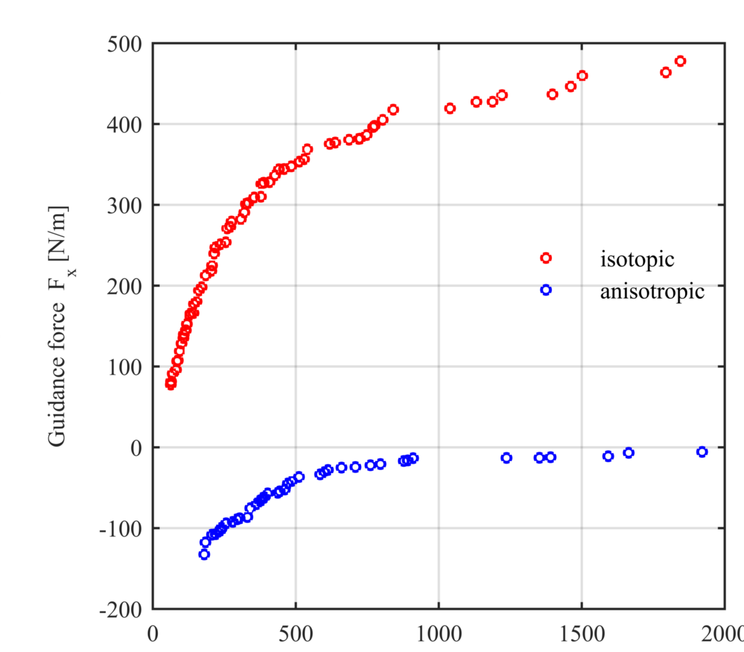


Fig. 3b - Pareto optimal solutions of the bi-objective optimization for the FC25-LD10 sequence.

FC25-LD5 sequence

For the given permanent guideway topology, and for this sequence:

(a) Isotropic model is unstable ($x < 0, F_x < 0$) at low cost, and stable ($x < 0, F_x > 0$) at high cost. For a smaller lateral displacement, one must spend more to obtain the same guidance force.
(b) Anisotropic model is hardly stable (x<0, Fx<0). Even for a large cost, the guidance force is almost zero;

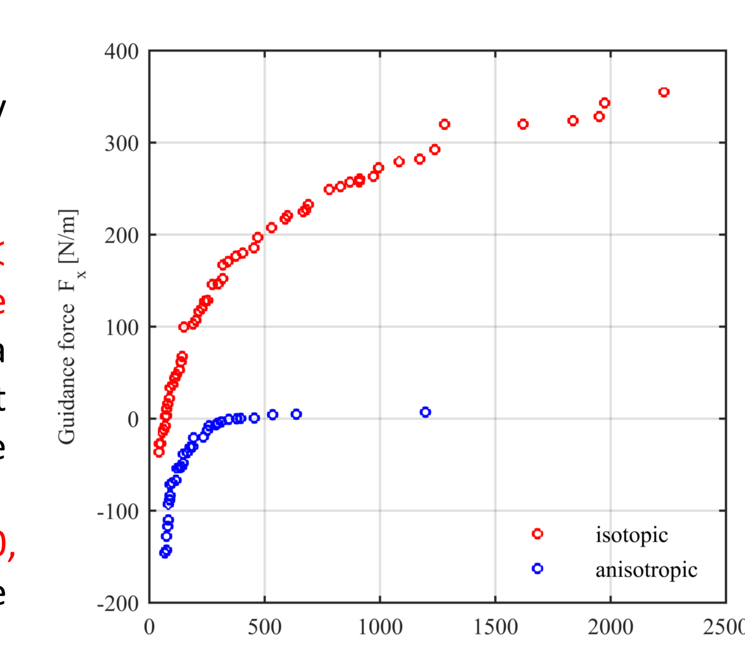


Fig. 3c - Pareto optimal solutions of the bi-objective optimization for the FC25-LD5 sequence.

Conclusion

In this work, a linear superconducting magnetic bearing with isotropic or an anisotropic material is studied. The performance of a bearing changes depending on the geometry of the PM guideway, and it's hard to draw a general conclusion for one given PM guideway. To deal with this issue, we use optimization. This allows us to compare different bearings (one using isotropic material and the other using anisotropic material) for a given set of requirements and constraints, and to draw general design guidelines for the future engineering applications:

General design guidelines

(a) For applications requiring only levitation force, both isotropic and anisotropic materials are suitable. Therefore the use of a stack of HTS tapes is recommended since it has the highest engineering critical current density.
(b) For applications requiring guidance force, anisotropic material can be unsuitable.