超导体磁通穿透，交流损耗 ANSYS 仿真程序免费下载

说明：

为感谢全球同仁对原力超导一如既往的支持，值此公司成立 5 周年之际，原力超导公布基于 Resistive Adaption Algorithm (RAA)方法的超导磁体交流损耗 ANSYS 仿真源代码，**欢迎国内外同行免费使用传播。**

该程序基于清华大学顾晨老师提出的 Resistive Adaption Algorithm (RAA) 算法开发，后经原力超导公司赖凌峰博士修订升级。算法的基本原理是通过迭代求解超导体离散化电阻率矩阵，逼近临界态模型[1,2,3]，仿真磁通穿透和电流分布历史过程，通过磁场穿透微观历史过程计算磁体 I-V 曲线、交流损耗、磁体屏蔽电流等宏观电磁性能。算法已在国内外多家实验室得到应用。

本期发布的代码总计超过 1000 行，采用 ANSYS-APDL 语言编写，并配有详细的中英文注释和使用说明。线圈激励采用“场-路”耦合加载方式，可实现多匝并联条件下的激励加载，还可以结合限流器、SMES 等实现电路联合仿真。初学用户只需设置带材 Ic(B)特性和线圈参数，就可以得到磁体交流损耗并可直观观察线圈每匝导线上的磁通穿透过程，以及伴生涡流损耗、耦合损耗、磁体剩余磁场等。经过 1-2 天简单学习，即可获得超导磁体交流损耗计算能力。

需特别说明的是，本次发布的计算模型采用临界态模型条件下的简化方法,只需知道峰值电流就可以获得交流损耗，是一种快捷获得线圈交流损耗的方法[2]。程序目前最大支持 20 个单饼构成磁体的建模计算，总匝数不建议超过 500。原力超导已研发完整的计算模型配备海量匝数线圈解耦算法，配备计算交流损耗精确值的下降沿算法和 power law 模型下的算法，如有进一步需求，请与原力超导公司联系。

本次公开的源代码是开发团队对超导电磁物理模型深刻理解条件下和对 ANSYS 电磁仿真功能熟练掌握条件下综合应用的体现。但由于开发团队水平有限、时间仓促，源代码难免有不够优化之处，欢迎同行批评指正，改进升级。源代码参数众多，使用过程如遇问题，请耐心阅读帮助文件和参考文献。

为了验证仿真有效性，原力超导提供完整的超导体交流测试解决方案，提供基于电测法与热测法的超导体、超导磁体交流损耗及交流磁化率测试系统与服务，可实现 AC-AC 激励条件下的各种测试；此外，我公司还同步提供磁性材料磁导率，BH 曲线，交直流磁滞回线测试设备和服务。

培训：

1. 原力超导将于 2019 年暑假提供超导体交流测试专题培训活动，届时将开展交流损耗仿真集中培训，同期开展交流损耗，交流磁化率测试学习活动。活动具体时间将通过网页，微信，邮件多种方式通知，敬请留意。
2. 感兴趣的学生请加赖凌峰博士微信号(han3do)，视具体需求，定期开展网络培训。

获取方式：

1．通过原力超导网站 www.eastfs.com，链接超导交流实验室自行下载。

2．联系赖凌峰博士 lailingfeng@eastfs.com，邮件索取。

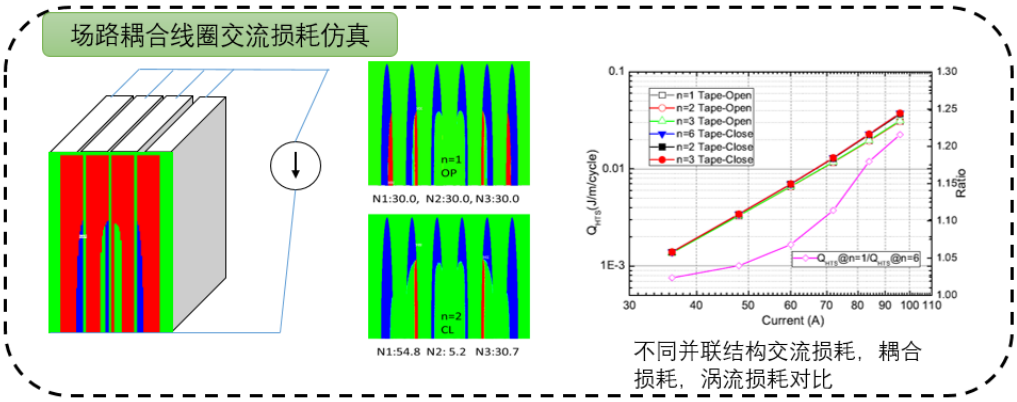
参考文献

1. Chen Gu, Timing Qu, Xiaofen Li, and Zhenghe Han, “Simulation of Current Profile and AC Loss of HTS Winding Wound by Parallel-Connected Tapes” ,*IEEE Trans. Appl. Supercond.*, 2014, vol.24, pp. 8200708
2. Chen Gu, Timing Qu, XiaoFen Li, and Zhenghe Han “AC losses in HTS Tapes and Devices With Transport Current Solved Through the Resistivity-Adaption Algorithm” *IEEE Trans. Appl. Supercond.*, 2013, vol.23, pp. 8201708
3. Chen Gu, and Zhenghe Han “Calculation of Ac Loss in HTS Tape with FEA Program ANSYS” *IEEE Trans. Appl. Supercond.*, 2005, vol.15, pp.2859-2862
4. Lingfeng Lai; Chen Gu; Timing Qu; Min Zhang; Yanqing Li; Rui Liu; Tim Coombs; Zhenghe Han,” Simulation of AC Loss in Small HTS Coils With Iron Core ” *IEEE Trans. Appl. Supercond.* 2015, Vol. 25, pp. 4700905
5. Lingfeng Lai; Timing Qu; Chen Gu,Nannan Hu Song Meng; Zhaoyang Zhong; Zhenghe Han "Study of AC Loss and Temperature Distribution of a BSCCO Coil Cooled in Liquid Nitrogen or Using a Cryocooler," IEEE Trans. Appl. Superond., vol. 26, no. 4, 2016
6. D.-X Chen and C. Gu “Transport AC loss in a cylinder with power-law current-voltage characteristic” *Appl.* Phys. Lett. vol. 86, p. 252504, 2005.
7. D.-X.Chen and C. Gu “Voltage-current curves of a cylinder with a power law E(J)” *Appl. Phys. Lett.* vol.88, p.112508, 2006.
8. D.-X. Chen and C. Gu “A universal formulation for the transport V(I) curve of a superconducting cylinder with a power law E(J)” *J. Appl. Phys.*, vol. 101 pp. 123921.1-123921.5. 2007.

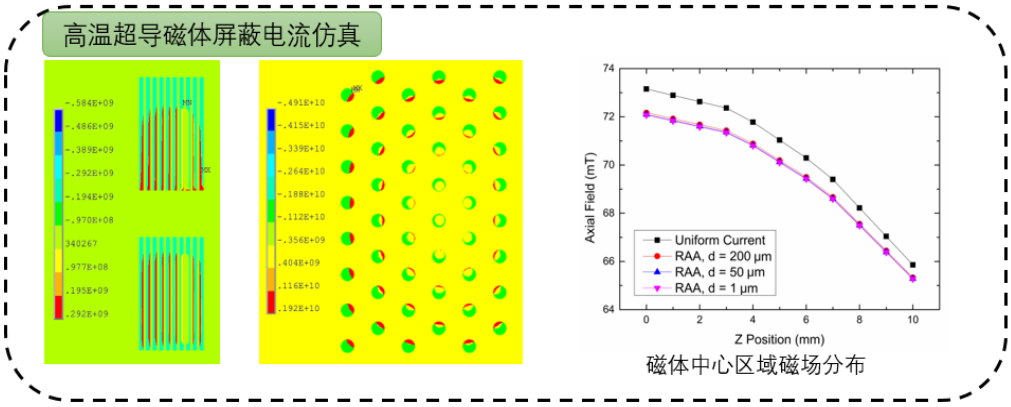
致谢：

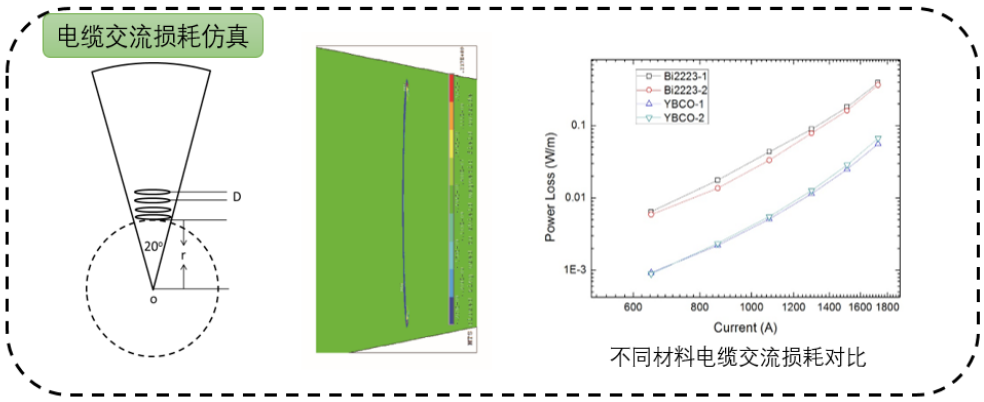
感谢云南电网电科院提供部分仿真计算平台和实验验证平台。

典型应用实例：



不同并联结构交流损耗，耦合损耗，涡流损耗对比





FREE use-Flux penetration; AC loss simulation code by ANSYS

To thank our colleagues all over the world for their continuous support for the development of Beijing Eastforce Superconducting Technology Co., Ltd., on the occasion of our 5th anniversary, the company releases ANSYS simulation source code of AC loss of superconductor magnet based on Resistive Adaption Algorithms (RAA) . And we welcome free use and dissemination by domestic and foreign counterparts.

The code is based on Resistive Adaption Algorithms (RAA) proposed by Gu Chen from Tsinghua University. It was revised and upgraded by Dr. Lai Lingfeng from Beijing Eastforce Superconducting Technology Co., Ltd. The basic principle of the algorithm is to solve the discrete resistivity matrix of superconductors iteratively, approximate the critical state model [1,2,3]. The macro-electromagnetic properties such as I-V curve, AC losses and screen current can be calculated through the micro-history process of magnetic field penetration. The algorithm has been used in many laboratories worldwide.

The code of current version has more than 1000 lines, written in ANSYS-APDL language, with detailed Chinese and English annotations and instructions. Coil excitation adopts "field-circuit" coupling loading mode, which can realize joint simulation with fault current limiter and SMES in the grid. Users only need to set the Ic (B) characteristics of the tape and the coil parameters to get the AC loss and the flux penetration in each turn.

It should be noted that the simplified method under the condition of critical state model is adopted in this released code. The AC loss can be obtained only by knowing the peak current. It is a fast method to obtain the AC loss of coil but will sacrifice accuracy to some extent[2]. As many as 10 double pancake coils can be built in the model. The total turn number should be less than 500. The full RAA code can calculate the AC loss of the coils that have more than 10,000 turns, can calculate precise AC loss by integrating serial states along the descendent process, but due to the complexity of the code, it has not been released this time. Users who want the full RAA code, please contact the EASTFORCE.

To verify the simulation results, EASTFORCE provides a complete AC testing solution for superconductors. The AC loss and AC susceptibility testing system for tape, cable and magnet based on Electrical and thermal methods are provided. All kinds of testing under AC-AC excitation conditions can be realized. It also provides magnetic material permeability, BH curve, AC and DC hysteresis loop testing equipment and services.

Training program:

1. In the summer vacation of 2019, EASTFORCE will provide special training program. The specific time of the event will be notified by web page, Wechat and email.
2. We will provide online training program when necessary. Please contact Dr. Lai Wechat (han3do).

Download path:

1. Fill in the download application form and download through the Force Superconducting Website. www.eastfs.com
2. Contact Dr. Lai by email:lailingfeng@eastfs.com

Reference:

1. Chen Gu, Timing Qu, Xiaofen Li, and Zhenghe Han, "Simulation of Current Profile and AC Loss of HTS Winding Wound by Parallel-Connected Tapes", IEEE Trans. Appl. Supercond., 2014, Vol. 24, PP. 8200708
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6. D. -X Chen and C. Gu "Transport AC loss in a cylinder with power-law current-voltage characteristic" Appl. Phys. Lett. Vol. 86, P. 252504, 2005.
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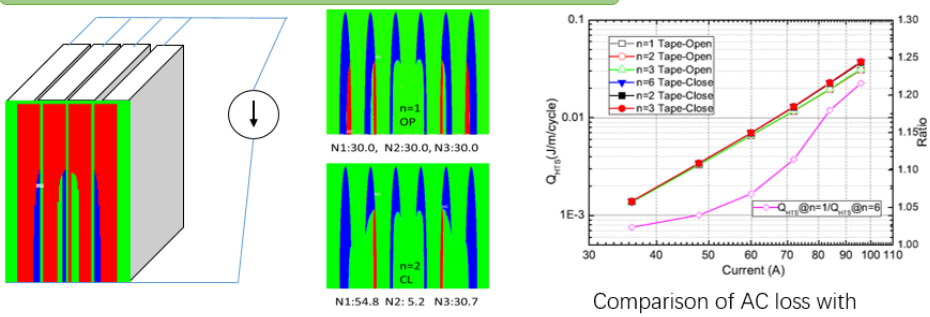
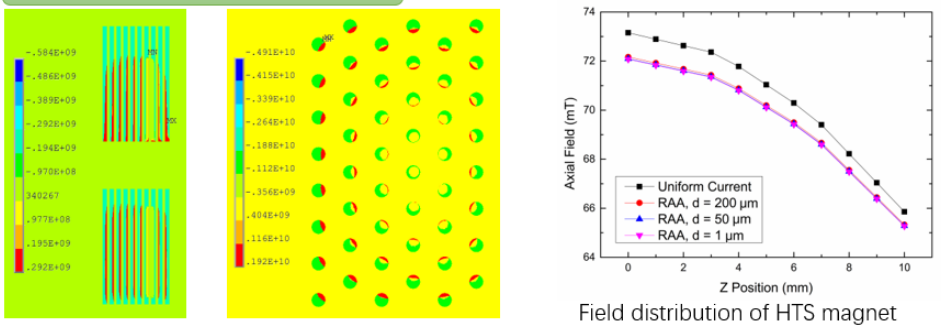
Typical applications：

"Circuit-field" coupling simulation of AC loss of coil



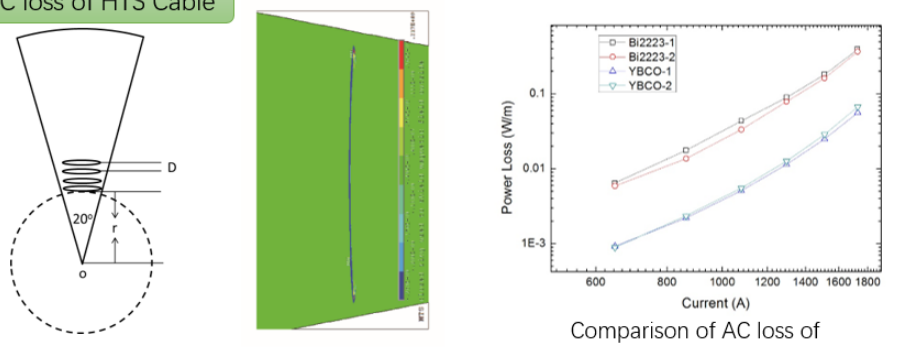
Comparison of AC loss with different connection structure.

Screen current of HTS magnet



Field distribution of HTS magnet considering screen current.

AC loss of HTS Cable



Comparison of AC loss of cables with different materials