TRANS_HEAT (A code for Transient Heat Conduction Analysis in Superconducting Cavities)

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Abstract

This code is developed for transient heat conduction analysis in superconducting cavities. 17 parameters can be input. The transient temperature distribution on the inner and outer wall, heat production and Q_0 can be printed out. This code can be used to analyze the cavity behaviors for any kinds of transient and static heat load condition e.g. high pulsed-power processing, laser light induced e^- emission.

1 Introduction

This code based on program HEAT[1] is developed for transient heat conduction analysis in superconducting cavities.

A vector algorithm, which calculation is proportional to the number of mash points, has been developed for solving two dimensional nonlinear transient diffusion equations.

A finite cylindrical disk of thickness Z and radius R bounded by liquid helium on the lower surface and by a uniform of field on the top surface is assumed. A defect is on the center of the top surface, so the transient heat conduction equation can be written in the cylindrical coordinates as

$$rCv\frac{\partial T}{\partial t} = \frac{\partial}{\partial r}rK\frac{\partial T}{\partial r} + r\frac{\partial}{\partial z}K\frac{\partial T}{\partial z} + rP \qquad (1)$$

where Cv is heat capacity, K is thermal conductivity, P heat production from rf field and absorption by helium. The heat flow on the rim of the disk is assumed to be zero:

$$\frac{\partial}{\partial r}T(R, z, t) = 0; \quad z \leq Z \qquad (2)$$

This is similar to the case of uniform defects in which the distance between defects is equal to 2R.

The disk is divided into a series of $M \times N$ ring-like elements of average radius $(m - \frac{1}{2})\Delta r$, thickness $\Delta z = Z/N$, and width $\Delta r = R/M$. By using finite difference method, the temperature distribution $T(r, z, t)$ can be represented as:

$$T^l_{mn} \equiv T(m, n, l); \quad m = 1, \ldots M; \quad n = 1, \ldots N$$

and the partial differential equation (2.1) can be reduced to a algebraic equation. The method for solving this equation is described in Ref.[2]

The heat capacity, thermal conductivity and heat production change rapidly with temperature, so the equation (1) is highly nonlinear and the mathematical instability is easy to happen during the solving process.

In TRANS_HEAT the deviation of the temperature distribution between two iteration

$$EX = \sum_{m,n}^{M,N}(T^{l+1}_{mn} - T^l_{mn})^2 \qquad (3)$$

is used to determine automatically the appropriate the length of the time step. However, the value of EX must be input. If EX is too large, instability will happen and the execution of the code will be stopped. In this case a prompt to reduce EX will be printed out.

The quench occurs when heat production is larger than $1w/mm^2$, otherwise the steady state can be reached if the ratio of heat absorption by helium to heat production is larger than 85%. If more accurate results are needed, then this ratio can be increased, but it may take more computation time.

This code has been written in FORTRAN77, which contains about 1100 lines, consists of 47 subroutines and uses double precision. To run this code do not need any other library, but if the Engineering and Scientific Subroutine Library(ESSL)[3] is used, the calculation efficiency can be improved especially for vector computation.

The dynamic storage allocation has also been used. There is a big array IA(400000). All arrays for the storage of mesh data are stored sequentially in IA(400000) according their real sizes determined by input. 2M storage is required to run this code, which allows about 10000 mesh points. In order to change the scale of calculation, only the dimension of IA needs to be changed. For example, decreasing this value it can be run on the microcomputer, or increasing this value the problem of larger mesh points can be solved.

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This code will be further developed to analyze the transient atomic diffusion. Thus the precipitation of hydrogen, oxygen and carbon etc. on the niobium surface even the electron emission in superconducting cavities can be analyzed by using this code[2,4,5].

In this version of the code, heat capacity and thermal conductivity above 20K, and n.c. resistance of niobium are assumed to be constant. In future we need to know various properties, including thermodynamic, of niobium and other materials from low temperature to high temperature.

2 Input data

Only one list-directed READ is in the code. The list consists of 17 parameters:

1. Disk radius R [m]
2. Disk thickness Z [m]
3. No. of radius step M [integer]

   The length of radius step Δr=R/M
4. No. of thickness step N [integer]

   The length of thickness step Δz=Z/N
5. Thermal conductivity type NT

   NT=1: RRR=20 (WAH CHANG)
   NT=2: RRR=40 (KBI)
   NT=3: RRR=120 (HERAEUS)
   NT=4: RRR=30000 (GLANDUN)
   NT=5: AN OLD THERMAL CONDUCTIVITY REPORTED BY CERN
   NT=6: RRR=300 (WASSERBACH)
   NT=7: RRR=500 (THEORETICAL)
   NT=8: RRR=1000 (THEORETICAL)
   NT=9: RRR=2000 (THEORETICAL)
   NT=10: 30 RRR NIOBIUM WITH LOW PHONON CONTRIBUTION
   NT=11: 30 RRR NIOBIUM WITH FLAT PHONON CONTRIBUTION
   NT=12: 30 RRR NIOBIUM WITH HIGH PHONON CONTRIBUTION
6. Kapitza resistance type NK

   NK=1: UNANNEALED NIOBIUM
   NK=2: ANNEALED NIOBIUM
   NK=3: NUCLEATE BOILING HELIUM
   NK=4: SUBCOOLED HELIUM
   NK=5: HELIUM EXCHANGE
7. Field type NH

   NH=0: H=HMAX; $t \geq 0$
   NH=1: H=200+HMAX$\cdot 10^{-5}$t
   HN=2: Test experiment (Some intermediate results are printed out)
8. Magnetic field HMAX [G]
9. Defect resistance RD [Ω]
10. Defect size MD [integer]

    The radius of the defect a=MD·R/M (The defect-free case:MD=0)
11. n.c. resistance of Nb RN [Ω]
12. Helium bath temperature TBATH [K]
13. R.F. Frequency F [GHz]
14. The maximum No. of iteration ITR
15. The exactness of iteration EX

$$EX = \sum_{m,n}^{M,N} (T_{mn}^{l+1} - T_{mn}^{l})^2$$

16. Coefficient of initial time step C1

$$\Delta t = c1 \cdot \Delta z^2 \cdot C_v(T_1)/K(T_1)$$

    where $T_1 = T(1,1)$

    If C1 is too small, the underflow may happen; inversely, instability may happen.
17. Residual resistance RS [Ω]

These 17 parameters(some of them can be revised) can be input repeatedly. The execution of the code will not be stopped until the end of input data. Therefore. the whole Q curve can be obtained by executing the code once.

3 Output data

1. Print out the input data
2. The maximum used element in IA(MU)

   If MU is large than 400000, the code will be stopped. Thus the dimension of IA must revised to larger than MU.
3. The transient temperature distribution at inner wall

$$T_S(r,0,t) \equiv TS(M,L)$$

4. The transient temperature distribution at outer wall

$$T_B(r,Z,t) \equiv TB(M,L)$$

5. Temperature distribution on disk at steady state or quench T(M,N)
6. Accumulated time at time step t(L)
7. Heat production at time step P(L) [w/mm^2]
8. Q_0 at the time step Q(L)

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References

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