ZERODEE

A computer code for
0-D stability analysis

Version 1.4

by CryoSoft

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CryoSoft

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Introduction

ZERODEE is a computer program for the (parametric) analysis of the stability margin of conductors. It is based on a local balance of heat capacities, i.e. a 0-D model of the cable. The typical conductor, with the geometry indicated in Fig. 1, is approximated lumping each component (helium, cable and jacket) into a single degree-of-freedom. Note that although in principle the helium cross section is subdivided in a portion in the cable bundle and a portion within the cooling hole, the temperature of both portions is considered to be the same (and the helium cross section lumped into a single value).

The set of equations solved by the program is then:

$$A_{St}C_{St}\frac{dT_{St}}{dt} = \dot{q}_{St} + \dot{q}_{Joule} - p_{St,He}h_{St,He}\left(T_{St} - T_{He}\right) - p_{St,Ja}h_{St,Ja}\left(T_{St} - T_{Ja}\right) \tag{1}$$

$$A_{Ja}C_{Ja}\frac{dT_{Ja}}{dt} = -p_{Ja,He}h_{Ja,He}\left(T_{Ja} - T_{He}\right) - p_{St,Ja}h_{St,Ja}\left(T_{Ja} - T_{St}\right) \tag{2}$$

$$A_{He}C_{He}\frac{dT_{He}}{dt} = \dot{q}_{Ja} + p_{St,He}h_{St,He}\left(T_{St} - T_{He}\right) + p_{Ja,He}h_{Ja,He}\left(T_{Ja} - T_{He}\right) \tag{3}$$

where the subscripts refer to the strands (St), jacket (Ja) or helium (He) in the conductor. The three components, with cross section A, have heat capacities C that are computed for each cable component as the sum of stabilizer and superconductor (strands), steel and insulation (jacket), and the full helium cross section. A flag allows to compute the helium heat capacity either under constant pressure conditions, or under constant density conditions, thus simulating two extreme processes in a stability transient.

The components are thermally coupled through convection on wetted surfaces (or contact perimeters) p with a surface heat transfer coefficient h. For the definition of the heat transfer coefficient, the following expressions have been used:

$$h_{St,He} = h_{He}$$

$$h_{Ja,He} = \frac{h_{Ja}h_{He}}{h_{Ja} + h_{He}}$$

$$h_{St,Ja} = \frac{h_{Ja}h_{Co}}{h_{Ja} + h_{Co}}$$

where the following definition has been used for the heat transfer coefficient to helium:

$$h_{He} = \max\left\{h_{Ks}, h_{Kt}\right\}$$

$$h_{Kt} = \frac{h_K h_t}{h_K + h_t}$$

$$h_{Ks} = \frac{h_K h_{ss}}{h_K + h_{ss}}$$

$$h_K = 200\left(T_{St} + T_{He}\right)\left(T_{St}^2 + T_{He}^2\right)$$

$$h_t = \sqrt{\frac{K\rho C_p}{\pi t}}$$

where K is the thermal conductivity of helium, ρ is its density, and C_p is the specific heat at constant pressure and h_{ss} is the user's defined steady state heat transfer coefficient. For the thermal contacts of strands and jacket the following empirical definitions have been used:

$$h_{Ja} = \frac{2K_{SS}}{t_{SS}}$$

$$h_{Co} = 1000$$

where K_{SS} is the thermal conductivity of stainless steel and t_{SS} is the thickness of the jacket.

During an evolution, an initial energy input in the strands Φ_{St} or in the jacket Φ_{Ja} causes the cable to transit to the normal state. The system of equations above is solved by an implicit, linearised, first order accurate algorithm that is unconditionally stable. Adaptive time stepping, based on a limit on the maximum change in the solution, is used. The user can select the minimum and maximum allowed time steps to be taken, thus allowing for a limited control on the actual time stepping.

The evolution of the system is followed until quench or recovery can be decided. Time limit, as set by the user, is signalled by an error condition when reached. The decision on recovery or quench is based on the following algorithm:

- recovery if $t > \tau_q$ and $V \le V_{max}$
- quench if ($t > \tau_q$ and $T_i > T_c$) or ($t > 1.5\ \tau_q$ and ($V > V_{max}$ or $\frac{dV}{dt} > 0$))

where τ_q is the heating time (in s), V is the resistive voltage (in V/m) and $\frac{dV}{dt}$ is its time derivative, V_{max} is the user's selected voltage threshold for quench detection (in V/m), T_c is the critical temperature (in K).

An external loop keeping track of the energy input in the system is adjusting automatically searching for the energy margin between an upper and a lower bound determined by the user. Again, an error condition signals the fact that the energy boundaries are too tight (and the actual energy margin is below or above the bracket).

As a final feature, the program loops on the input file to search for new cases. The input data needs to be modified only for what concerns the changing parameters, all other data are maintained equal to those read for the previous case. A storage file stocks the results of the cases, and a post-processor, reading the results stored, allows the creation of tables for plotting of the energy margin versus a parameter (within the definition of allowed parameters in the post-processor).

The input of the processor has been thought for maximum compatibility with the 1-D analysis code *GANDALF*, so that *ZERODEE* can be effectively used as a preliminary tool for a more sophisticated analysis.

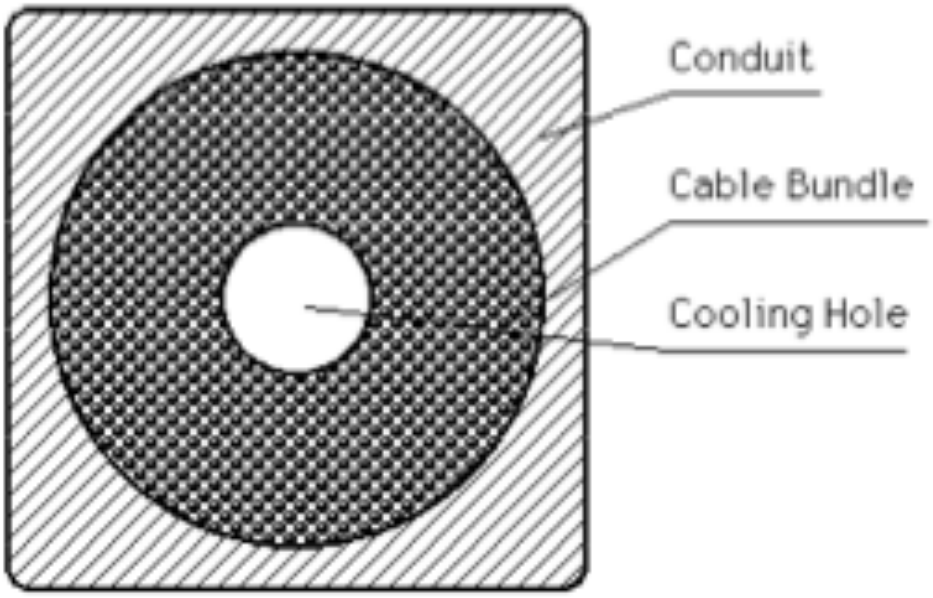

Figure 1. General geometry of a conductor considered in *ZERODEE*.

Code Structure

Main solver

This is the portion performing the calculation and generating the results. The code performs input and output on the following files

File Name	Usage
input file	Input of the data for the run. The user is prompted for the file name at the start of the run
`zerodee.store`	Binary storage for post-processing
`zerodee.output`	Output of the results

The binary storage is used for post-processing by the program *ZERODEEP* (see later for its description).

Note: FORTRAN unit numbers above 50 are reserved for internal use

Material properties

The main solver needs to be linked to a set of routines for the calculation of the material properties of solid materials and helium. As these routines are at the lowest level in the code execution, their efficiency is of paramount importance. A set of routines is provided by default with the program. These can be easily changed provided that the calling arguments are respected (and obviously units !) and keeping in mind the requirements on the code efficiency. For the complete list of the property functions, please refer to the *SOLIDS* [1] and *He_tables* [2] manuals.

Input Variables

The following table contains the input variables, their physical dimensions, default value and meaning for the *ZERODEE* processor. They have been kept compatible with the input to *GANDALF* as far as possible. The input of *ZERODEE* is done using the FORTRAN instruction `NAMELIST`. The namelist is called `INDATA`. A sample input file is reported in the end of the manual. Note that the first line in the input file is read-in as the problem title.

Conductor cross section composition and properties

Variable	Type	Units	Default	Meaning
AHEH	R	(m^2)	0.0	Helium hole cross section. This variable can be set to 0.0 to eliminate the double flow features. In this case the *ZERODEE* model is identical to that for a single flow channel CICC
AHEB	R	(m^2)	0.0	Helium bundle cross section
ASC	R	(m^2)	0.0	Superconductor cross section
AST	R	(m^2)	0.0	Stabilizer cross section
AJK	R	(m^2)	0.0	Jacket cross section
AIN	R	(m^2)	0.0	Insulation cross section

WARNING ! Note that the *ZERODEE* model needs a positive heat capacity for all three cable components. This implies that the following constraint must be satisfied :

$$\begin{aligned} AHEH + AHEB &> 0 \\ AST + ASC &> 0 \\ AJK + AIN &> 0 \end{aligned}$$

Variable	Type	Units	Default	Meaning
ISC	I	(-)	0	Superconductor type: (<0) user's defined through external functions UserDensity , UserSpecificHeat, UserCriticalTemperature, UserCriticalCurrent, , UserCurrentSharing (4001) standard NbTi (4002) standard Nb3Sn

IJK	I	(-)	0	Jacket material: (1001) Silver (1002) Aluminium (1003) Copper (1005) Titanium (2112) Copper-30%Nickel (2113) Copper-45%Nickel (Monel) (2201) Haynes C276 (Hastelloy-C276) (2202) SMC Ni-Cr 718 (Inconel 718) (2203) SMC Ni 908 (Incoloy 908) (2301) Stainless Steel AISI-304 (2302) Stainless Steel AISI-316 (2401) Ti-6%Al-4%V
IST	I	(-)	0	Stabilizer material: (1001) Silver (1002) Aluminium (1003) Copper
IIN	I	(-)	0	Insulating material: (3001) Alumina (3002) Epoxy Resin (3003) G10/G11 warp (3004) G10/G11 parallel (3005) Polyimide (Kapton)
EPSLON	R	(-)	0.0	Total longitudinal strain in the superconductor in operating condition. Its value is assumed constant during the transient
E0	R	(V/m)	0.0	Electric field criterion for the definition of the resistive transition at the critical current. E0 is needed if the user chooses to model the electric field E in the superconductior by the power law: $E = E_0\left(\frac{I}{I_c}\right)^n$, where I is the current in the superconductor and I_c is the critical current. This model is used for a choice of NPOWER below 250 (see below).
NPOWER	I	(-)	0	Exponent of the power-law used to model the longitudinal electric field in the superconductor (see above). The power law is used only for values of $0 < \text{NPOWER} \leq 250$. For NPOWER > 250 a sharp transition is assumed (zero resistance below I_c, infinite resistance above I_c), which does not require the definition of E0.
RRR	R	(-)	0.0	Residual resistivity ratio for stabilizer

PHTC	R	(m)	0.0	Perimeter used for heat transfer calculation among the strands and the *bundle* helium channel. This perimeter is usually a fraction (e.g. 5/6) of the total wetted perimeter p_B of the strands in the conductor. The correction factor takes into account that the wetted surface can be reduced in a compated conductor.
PHTCJ	R	(m)	0.0	Perimeter used for heat transfer calculation between the conductor strands and the jacket. Although the heat transfer between the strands and the jacket is more likely to be governed by the contact heat resistance, it is treated as a convective heat transfer with *wetted* perimeter PHTCJ between the two components.
PHTJ	R	(m)	0.0	Perimeter used for heat transfer calculation between the jacket and the *bundle* helium channel. The heat transfer coefficient used over this perimeter is computed by the routine EXTHJB
THJ	R	(m)	0.0	Thickness of the jacket used in the calculation of the effective thermal resistance between the jacket and the *bundle* helium channel.

Operating conditions

Variable	Type	Units	Default	Meaning
IOP0	R	(A)	0.0	Initial operating current in the coil
IOPFUN	I	(-)	0	Flag used to specify the behaviour of the operating current in time: (-1) user's defined. through external function EXTI to be linked with the code (0) constant in time
IBIFUN	I	(-)	0	Flag used to specify the behaviour of the magnetic field in time and space (-1) user's defined, through external function EXTB to be linked with the code (0) constant in time at the value BISS and BOSS (1) Proportional to the current in time. At any time the field is the sum of the steady state value BISS and of the transient value proportional to the operating current BITR
BISS	R	(T)	0.0	Value of the steady state component of the magnetic field
BITR	R	(T)	0.0	Value of the transient component of the magnetic field

Initial and flow boundary conditions

Variable	Type	Units	Default	Meaning
INTIAL	I	(-)	0	Flag used to specify the initial and boundary conditions for the transient. (1) initial pressure and temperature are given, open system assumed. The thermodynamic process is at constant pressure. (4) initial pressure and temperature given, closed system assumed. The thermodynamic process is at constant volume.
PREINI	R	(Pa)	0.0	initial pressure
TEMINI	R	(K)	0.0	initial temperature
HSS	R	(W/m^2K)	0.0	steady state heat transfer coefficient

External heating

Variable	Type	Units	Default	Meaning
IQFUN	I	(-)	0	Flag used to specify the heating input (-1) through external function EXTQ (0) square wave in time. The power is input for a time TAUQ
E0MIN	R	(J/m)	0.0	Minimum linear energy density input in the conductor (lower bound for stability margin search)
E0MAX	R	(J/m)	0.0	Maximum linear energy density input in the conductor (upper bound for stability margin search)
TAUQ	R	(s)	0.0	Heating time when IQFUN=0. The power is applied for 0 < t < TAUQ. Note that if IQFUN = -1 (user's defined energy input) TAUQ is still used in the recovery/quench decision, and must therefore give the maximum time scale of the energy input

Time stepping and quench/recovery decision

Variable	Type	Units	Default	Meaning
TIMLIM	R	(s)	0.0	Maximum time for the time integration (time limit)
VMAX	R	(V/m)	0.0	Voltage threshold used to determine the quench or recovery condition during an evolution. The conductor recovers if after the heating time TAUQ the resistive voltage is below the threshold VMAX, while it has quenched if the voltage is above VMAX (see the quench/recovery decision algorithm described in the introduction)
STPMIN	R	(s)	0.0	minimum allowed time step
STPMAX	R	(s)	0.0	maximum allowed time step

The input file consists in general of a title card, followed by an arbitrary number of input data sets (cases). *ZERODEE* loops on the input cases automatically, solving all of them. Note that in the input phase the previous value of the parameters is retained (if not explicitly given in the new case). Therefore the input of new cases with a change in a single parameter is extremely simplified (the namelist for the case contains the single parameter to be changed). See in the example section for a real input case.

External Routines

The following sections describe routines that are provided as an interface for the user to improve the modelling capabilities of *ZERODEE*. These routines are provided as dummy (void) procedures, in the case that they are not needed for the standard execution of the code.

Note: FORTRAN unit numbers above 50 are reserved for internal use

Coil current

```
SUBROUTINE EXTI          (TIME   ,TSTEP ,IOP0   ,RSSTNC,IOP    )
```

Compute the operating current as an arbitrary function of time and coil resistance.

List of variables:

Variable	Type	I/O	Units	Meaning
TIME	R	I	(s)	Real time in the integration
TSTEP	R	I	(s)	Time step to be taken
IOP0	R	I	(A)	Initial current (t=0)
RSSTNC	R	I	(Ohm/m)	Coil resistance per unit length
IOP	R	O	(A)	Coil current

Magnetic field

```
SUBROUTINE EXTB          (TIME   ,IOP    ,B      )
```

Compute the magnetic field as an arbitrary function of time and current

List of variables:

Variable	Type	I/O	Units	Meaning
TIME	R	I	(s)	Real time in the integration
IOP	R	I	(A)	Coil current
B	R	O	(T)	Magnetic field

External heat input

```
SUBROUTINE EXTQ          (TIME  ,TSTEP ,EO   ,TAUQ  ,
                          QFLUXC,QFLUXJ)
```

Compute the heat perturbation as an arbitrary function of time and space. The routine returns the value of the heating flux in the conductor QFLUXC or in the jacket QFLUXJ at the time TIME. Note that the parameter TAUQ read-in from the input namelist (see input parameters list) is passed to the routine (as *trimming* value) although it is in effect not used in the main program (but can be used in principle in EXTQ). The variable E0 is the trial linear energy density (J/m) that must be input in total in the conductor, as determined by the solver in its search for the energy margin. This means that the time dependence of the heat fluxes must be such that their time integral is E0. Finally, in the recovery/quench check, TAUQ is used as the maximum time over which heating takes place. This means that after TAUQ the heating must be off (or negligible) for the check in the solver to be valid.

List of variables:

Variable	Type	I/O	Units	Meaning
TIME	R	I	(s)	Real time in the integration
TSTEP	R	I	(s)	Time step to be taken
E0	R	I	(J/m)	Linear energy density for trial evolution
TAUQ	R	I	(s)	Heating time (as from input)
QFLUXC	R	O	(W/m)	Heating linear flux in the conductor
QFLUXJ	R	O	(W/m)	Heating linear flux in the jacket

Electrical and thermal properties of user's defined materials

These functions substitue the default material properties in case of negative material flag ISC.

Density

```
FUNCTION UserDensity    (Material ,T)
```

Used to compute the density of a user's defined material

List of variables:

Variable	Type	I/O	Units	Meaning
Material	I	I	(-)	Material flag, as from input
T	R	I	(K)	temperature
UserDensity	R	O	(Kg/m^3)	density

Specific heat

```
FUNCTION UserSpecificHeat     (Material ,T   ,B   ,ANGLE ,EPSLON)
```

Used to compute the specific heat of a user's defined material

List of variables:

Variable	Type	I/O	Units	Meaning
Material	I	I	(-)	Material flag, as from input
T	R	I	(K)	temperature
B	R	I	(T)	Magnetic field
ANGLE	R	I	(degrees)	angle of magnetic field w/r to direction normal to the current flow
EPSLON	R	I	(-)	longitudinal strain
UserSpecificHeat	R	O	(J/Kg K)	specific heat

Critical current density

```
FUNCTION UserCriticalCurrentDensity (Material ,T  ,B ,ANGLE ,
                          EPSLON)
```

Used to compute the critical current density of a user's defined superconducting material

List of variables:

Variable	Type	I/O	Units	Meaning
Material	I	I	(-)	Material flag, as from input
T	R	I	(K)	temperature
B	R	I	(T)	Magnetic field
ANGLE	R	I	(degrees)	angle of magnetic field w/r to direction normal to the current flow
EPSLON	R	I	(-)	longitudinal strain
UserCriticalCurrentDensity	R	O	(A/m^2)	critical current density

Critical temperature

```
FUNCTION UserCriticalTemperature    (Material ,B ,ANGLE ,EPSLON)
```

Used to compute the critical temperature of a user's defined superconducting material

List of variables:

Variable	Type	I/O	Units	Meaning
Material	I	I	(-)	Material flag, as from input
B	R	I	(T)	Magnetic field
EPSLON	R	I	(-)	longitudinal strain
ANGLE	R	I	(degrees)	angle of magnetic field w/r to direction normal to the current flow
UserCriticalTemperature	R	O	(K)	critical temperature

Current sharing temperature

```
FUNCTION UserCurrentSharing   (Material ,B ,ANGLE ,EPSLON,JOP   )
```

Used to compute the current sharing temperature of a user's defined superconducting material

List of variables:

Variable	Type	I/O	Units	Meaning
Material	I	I	(-)	Material flag, as from input
B	R	I	(T)	Magnetic field
ANGLE	R	I	(degrees)	angle of magnetic field w/r to direction normal to the current flow
EPSLON	R	I	(-)	longitudinal strain
JOP	R	I	(A/m^2)	operating current density
UserCurrentSharing	R	O	(K)	current sharing temperature

Error Codes

A limited number of checks are performed in the input phase to insure that the data set is consistent and that the memory requirements for the solution of the problem do not exceed the availability. An error message is printed on the main output unit in case that one of these checks is not passed. The error message gives a numeric code which corresponds to the following table:

Code	Error	Meaning and corrective action
10	ISC >= 0 and ISC ≠ valid option	The flag for the superconductor type has a wrong value. Correct ISC in input
11	IST >= 0 and IST ≠ valid option	The flag for the superconductor type has a wrong value. Correct IST in input
12	IJK >= 0 and IJK ≠ valid option	The flag for the superconductor type has a wrong value. Correct IJK in input
13	IIN >= 0 and IIN ≠ valid option	The flag for the superconductor type has a wrong value. Correct IIN in input
14	IOPFUN ≠ 0 and IOPFUN ≠ -1	The flag for the current behaviour has a wrong value. Correct IOPFUN in input
15	IBIFUN ≠ 0 and IBIFUN ≠ -1 and IBIFUN ≠ 1	The flag for the field behaviour has a wrong value. Correct IBIFUN in input
17	INTIAL ≠ 1 or INTIAL ≠ 4	The flag for the initial condition has a wrong value. Correct INTIAL in input
18	IQFUN < -1 or IQFUN > 1	The flag for the heating input has a wrong
32	ASC<0 or AST<0 or AJK<0 or AIN<0	A negative value for an area has been given in input. Correct the input value
33	ASC>0 and AST<=0	The conductor is not stabilized. Specify a non-negative stabilizer area AST in input
34	AHE <=0	No helium present in the cable. Specify a non-negative helium area AHE in input

36	PHTC < 0 or PHTJ < 0 or PHTCJ < 0	Negative wetted perimeter. Specify a non-negative wetted perimeter PHTC or PHTJ or PHTCJ in input
37	NPOWER <= 0	Negative or zero exponent for electric field power law. Specify a positive exponent NPOWER in input
38	E0 <= 0	Negative or zero electric field limit for the electric field power law. Specify a positive E0 in input
50	PREINI <= 0	Negative or zero initial pressure. Specify a non-negative helium pressure PREINI in input
51	TEMINI <= 0	Negative or zero initial temperature. Specify a non-negative helium temperature TEMINI in input
53	E0MIN >= E0MAX	The boundaries for the energy margin search are not valid. Specify a valid energy interval
54	VMAX <=0	The voltage threshold is negative or zero. Specify a non-negative voltage threshold VMAX in input
55	TAUQ <=0	The heating time or time scale is negative or zero. Specify a non-negative heating time TAUQ in input
56	TIMLIM <= TAUQ	The time limit for the integration is smaller or equal to the heating time or time scale. Specify a value of TIMLIM larger than the heating time TAUQ in input
62	Input error	The input file is empty or a read-in error was found
72	Matrix factorization error	The system matrix is singular and cannot be factorized during the inversion process
74	TIME > TIMLIM	Time limit reached in the integration
75	ETRY = E0MAX	The upper boundary for the energy margin search is too low. Increase E0MAX
76	ETRY = E0MIN	The upper boundary for the energy margin search is too high. Decrease E0MIN

Post Processing

For post-processing of the results of *ZERODEE*, an easy to use interface has been written: *ZERODEEP*. This program reads the storage file and prompts, through a menu, for a selection of the variable to be considered as the independent parameter. An ASCII table is then created with the case number, the value of the parameter and the computed energy margin (in J/m and in mJ/cc referred to the strand cross section). The list of allowed parameters is shown in Fig. 3, where the menu list is reported. Selection is by numeric input.

```
    <<<      ZERO-DEEP     >>>
Enter Your Choice:
---------------------------------
Energy Margin as a function of:
( 1) ...... Superconductor area
( 2) ...... Stabilizer     area
( 3) ...... Helium         area
( 4) ...... Steady state h
( 5) ...... Strain
( 6) ...... Electric field E0
( 7) ...... Power law exponent
( 8) ...... Stabilizer RRR
( 9) ...... Field
(10) ...... Operating current
(11) ...... Pulse duration
(12) ...... Initial pressure
(13) ...... Initial temperature
---------------------------------
( 0) ...... END EXECUTION
---------------------------------
```

Figure 3. Menu for parameter selection in *ZERODEEP*.

References

[1] CryoSoft, *SOLIDS – Properties of Solid Materials*, Version 3.3, User's Manual, October 1999

[2] CryoSoft, *He_tables – Helium Properties*, Version 2.1, User's Manual, February 1999

Examples

Here are reported the input data for a sample run performed with the basic version of *ZERODEE* (i.e. without user's adaption, standard material properties) on a parametric analysis with the operating current as a parameter, and the results obtained using the post-processor *ZERODEEP*.

Input for a run with ZERODEE

```
ZERODEE Test Run for the manual
 &INDATA

      AHEH   =  19.6E-6, AHEB   =  71.4E-6,
      ASC    =  40.6E-6, AST    =  60.8E-6, AJK    =  73.5E-6,
      ISC    =     4002, RRR    =    100.0, AIN    =  61.0E-6,
      PHTC   =    0.330, PHTJ   =   5.1E-2, PHTCJ =   0.0E+0,
      E0     =   1.0E-4, NPOWER=       20, EPSLON=-0.250E-2,
      IIN    =       22, IST    =        1, IJK    =       13,

      INTIAL=         1,
      PREINI=  6.00E+5, TEMINI=      4.5,
      HSS    =      0.0,

      IOPFUN=         0,
      IOP0   =  8.00E+3,

      IBIFUN=         0,
      BISS   =     10.0, BITR   =       0.0,

      IQFUN  =         0,
      E0MIN  =     5.00, E0MAX  =   1000.00,
      TAUQ   =  10.0E-3,

      VMAX   =     1.0E-4,

      STPMIN=   1.0E-5, STPMAX=   1.0E-3,
      TIMLIM=      1.0
 &END
 &INDATA
      IOP0   =  7.00E+3,
 &END
 &INDATA
      IOP0   =  6.00E+3,
 &END
 &INDATA
      IOP0   =  5.00E+3,
 &END
 &INDATA
      IOP0   =  4.00E+3,
 &END
 &INDATA
      IOP0   =  3.00E+3,
 &END
 &INDATA
      IOP0   =  2.00E+3,
 &END
```

Post processor ZERODEEP

In accordance to the previous input, with operating current as a parameter, the following table was obtained with *ZERODEEP* (file `TEST.TABLES`) after responding to the menu prompt with the option "10" (`Operating current`). Note the value of energy margin in J/m converted in mJ/cc of strand (i.e. based on superconductor plus stabilizer cross section)

```
ZERODEE Test Run for the manual
 Case     Iop          dE (J/m)     dE (mJ/cc)
    1  8.00000E+03  7.25317E+01  7.15303E+02
    2  7.00000E+03  1.18687E+02  1.17048E+03
    3  6.00000E+03  1.55610E+02  1.53462E+03
    4  5.00000E+03  1.88647E+02  1.86043E+03
    5  4.00000E+03  2.24600E+02  2.21499E+03
    6  3.00000E+03  2.59580E+02  2.55996E+03
    7  2.00000E+03  2.98447E+02  2.94327E+03
```