(Beam Cavity Interaction)

A COMPUTER PROGRAM FOR TRANSIENT ELECTROMAGNETIC FIELDS OF BUNCHED BEAMS IN ACCELERATORS
**BCI USER’S GUIDE**

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1. Introduction

The computer program BCI solves Maxwell's equations approximately in the time domain for structures with cylindrical symmetry using a finite integration method, see Refs 1-5. The excitation can be given by bunches of charged particles moving or axis at an arbitrary speed. The shape of the bunch as well as the shape of the accelerator component can be defined by the user. Since BCI includes an open boundary condition in the longitudinal direction, it is for example possible to compute the electromagnetic fields in a cavity with infinitely long beam tubes on both sides.

The output of the program contains the electromagnetic field as a function of time and the coordinates r and z, the displacement current, the charge distribution on the walls, the stored energy in the electric and magnetic fields and the wake potential inside and behind the bunch. The graphical output contains electric field lines and displacement current lines.

The main application of the program is to compute the total energy loss of a bunched beam passing an accelerating structure as a function of its bunch length and the computation of the wake potential inside a beam. Other results which may be obtained include fundamental beam loading, higher mode impedance (as a function of bunch length) and the fundamental resonant frequency of a cavity.

The program is written in FORTRAN and available on IBM and CDC. There is only one version, with a maximum mesh size of 20,000 points though this may be easily altered in the source. The typical cpu time consumption is between 20 s and 10 min and depends strongly on the amount of graphical output and line printer output.

In order to familiarize the reader with the use of BCI we will describe the procedure using two realistic accelerating cavities with cylindrical symmetry. All the input data have to be written in free (*) format (except one namelist input). MKSA units are used throughout unless otherwise specified.

Copies of this write-up and the program may be obtained from:

CERN, Computer Program Library, CH1211 Geneva 23
code=T310, name=BCI

Copies of this write-up may also be obtained from:

CERN, Secretariat ISR, CH1211 Geneva 23
code: CERN/ISR-TH/80-45
2. The physical problem

Two different standing wave cavities are used as examples. Their shapes are given in Fig.1 and Fig.2 (example A, Fig.1, is a 200 MHz cavity proposed for the p-anti p project of CERN, see Ref 7, example B, Fig.2, is a single cell of the LEP cavity, see Ref. 6).

In example A we wish to know what happens if a Gaussian bunch with r.m.s length 7.0cm travels along the z-axis at the speed of light.

In example B we wish to know the effect of a sinusoidal bunch having a line-charge density as a function of the bunch coordinate s (see Fig.3):

\[ q(s) = \begin{cases} 0, & s \leq -0.4 \text{ m} \\ \cos(\pi s/0.8m), & -0.4 \text{ m} \leq s \leq 0.4 \text{ m} \\ 0, & s > 0.4 \text{ m} \end{cases} \]

This bunch has the speed of \(0.995 \times c\).

3. Preparation of the input data

To illustrate the use of BCI a complete list of all input data for both examples will be given, followed by the produced line printer and graphical output.

The first input datum is a namelist input $PARAM. All the other input data are divided into groups, each group initialized by a keyword: $KEYWORD. The order of the groups must not be changed although some may be omitted. Each group consists of a keyword and some numerical or literal data.

For both examples we wish to know:

a) the electromagnetic field induced 
b) the energy gain of particles inside the bunch 
   (wake field) due to the induced self-fields 
c) the total energy lost by the bunch 
d) for example, B in addition, the wake field behind the bunch, i.e. for a total range of 1.6m.
4. The input data for example A

For a normal job using Gaussian bunches the $\$P\$A\$R\$M\$ input is not important. More details see example B and chapters 6 and 16. Thus we use as first input line:

$\$P\$A\$R\$M\$ $\$E\$N\$D$

1. Keyword=$TEXT$

If $TEXT$ is specified the input line following it will be taken as identifier for the dataset.

Example:

$TEXT$
TEST1 EXAMPLE A, SPS 200 MHZ CAVITY TEST1

2. Keyword=$BOUNDARY$

This keyword is used to define the boundary conditions at the outmost mesh lines. It is followed by an input line containing the integers IRU,IZL,IZR. IRU indicates the boundary condition at the radial end of the structure and may have the values 1 or 2. IZL and IZR define the boundary conditions at the left and right end of the mesh and may have the values 1,2 or 3.

1 means an infinitely conducting wall (E-tangential = zero)
2 means an infinitely permeable wall (H-tangential = zero)

3 means an open boundary condition (infinite tube)

Using IRL=IZL=3 are no longer needs tapers to simulate the infinite tube.

In our example the data are:
Example:

$BOUNDARY$
1,3,3

3. Keyword=$MESH$ (** Necessary **)

$MESH$ is followed by a card giving the number of mesh lines in the r and z direction (NR,NZ). The next card gives the total radius of the structure (called "radius" in the following) and the total length respectively ( called "gaplength" further on )

Example:

$MESH$
50,91
0.490 0.900

4. Keyword=$CAVITYSHAPE$ (** Necessary **)

This keyword is used to input the shape of a full structure without making any use of symmetries. Although this is unnecessarily complicated as example A has a symmetry plane, this procedure will be used now for demonstration. A symmetric input set will be described in chapter 5 together with example B.
The shape of the required structure is defined by one or several polygons represented by the coordinates \((r,z)\) of their vertices. The orientation of each polygon must be clockwise. Any part of a polygon may be either a straight line or a part of a circle. If two subsequent vertices are to be connected with a part of a circle, an additional data card has to be inserted between them containing two real numbers: RKIND, RRADIUS. RKIND must be -1.0 or -2.0 indicating a circular connection which is respectively less than or greater than half a circle. RRADIUS gives the radius of the circle. If RRADIUS is negative a convex circle will be used with the radius -RRADIUS. If RRADIUS is positive a concave circle will be used with the radius RRADIUS. Convex and concave is always with respect to the inner area of the polygon.

BCI searches all crossing points of the input shape with the mesh lines and shifts these points towards the nearest mesh points. Thus the input shape will be replaced by another polygon along mesh lines and diagonals of single cells.

The inner area of this generated polygon will then be filled with a material of the conductivity KAPPA in \(\text{A/Vm}\). KAPPA must be the first data card after the keyword $CAVITYSHAPE$. If KAPPA is zero, the material for filling is vacuum ("air"). If KAPPA is equal 9999.0 an infinitely conducting material will be used.

There are two different ways for the input of a cavity shape:

a) KAPPA = 0.0

If KAPPA is zero the interior region (all mesh cells) will be preset entirely with infinitely conducting metal. Following polygons will then overwrite this default by filling the inner area(s) with air. This way of defining the cavity shape is always useful if the r-z area of the cavity is simply connected. This procedure cannot be used for structures with a finite conductivity.

b) KAPPA .NE. 0.0

If KAPPA is not zero the interior region (all mesh cells) will be preset with vacuum and the following polygons will overwrite this default by filling the inner area(s) with metal of the conductivity KAPPA. This way of input of the cavity shape is useful if some independent subregions of metal exist in the r-z plane. A nonzero KAPPA which is not 9999.0 does not change the boundary conditions at the outmost mesh lines. There, an infinitely conducting or permeable material or an open tube will always be assumed, as defined by the data after $BOUNDARY$ or by the default. Finite conductivity and an open boundary condition are not
allowed at the same time. To generate a finite conductivity on the entire cavity boundary a strip of metal has to be used between the boundary of the cavity and the boundary of the mesh (at least 2 or 3 mesh steps).

In general "filling with air" is easier to use and so we do in example A:

Example:

$CAVITYSHAPE
0.00
0.00 0.000
0.070 0.000
-1.000 0.000
0.089 0.0289
-1.000 0.000
0.200 0.000
-1.000 0.000
0.120 0.119
0.200 0.119
0.290 0.119
-1.000 0.119
0.490 0.519
0.490 0.519
-1.000 0.200
0.290 0.761
0.200 0.761
-1.000 0.080
0.120 0.761
0.089 0.611
-1.000 0.01
0.070 0.615
0.070 0.900
0.000 0.900
0.000 0.000
9999.9999.

The last two numbers 9999.9999. must be given to tell BCI that this is the end of the input polygons.

5. Keyword = $TIMESTEP

The following card contains four integers:

MT NT N$F N$S

MT is the number of time steps to be processed.

NT is the number of time steps necessary for a particle in the bunch (or the whole bunch) to move one mesh step in z direction. Due to stability criterions, MT has to fulfill the condition:

MT .GT. SQRT( 1 + (z-step)/(min. r-step) )/BETA

Together with an open boundary condition MT has to be greater than:

MT .GT. sinh(pi/2)*sqrt(1+...)/BETA

i.e. at least 3. For more details see Refs 1,5. BCI uses in addition a safety factor of 10/9. If MT is too small it will be increased and a WARNING will be printed. Usually for relativistic charges (BETA=1.) MT can be set to its minimum 2 (or 3 together with an open boundary condition).

N$F is the first time step where one wishes a printout or a graphical output.

N$S is the interval in time steps between successive line printer or graphical output. An example would be:

$TIMESTEP
15 2 10 2

These data would cause an output at the time steps:

1 (default), 10, 12, 14, 15 (default)
If $\text{TIMESTEP}$ is not specified, BCI will take the smallest possible value for MT. NT will be calculated to allow sufficient time for the bunch to pass the entire structure. A print will be done at some suitable intervals. The easiest way to begin is to omit this keyword and to use the defaults.

6. **Keyword=\$SPEED**

This keyword allows the input of the speed of the beam in units of $c$ (velocity of light). It is followed by a line giving this speed BETA. An example might be:

\texttt{\$SPEED 0.75}

If this keyword and BETA are omitted, the speed of light will be assumed. It should be mentioned that the total cpu time goes like $1/\text{BETA}$, since one needs more time to allow a bunch to pass a given structure if the bunch is slow.

7. **Keyword=\$BEAM**

The use of the keyword \$BEAM enables a bunch with a Gaussian line-charge density to be specified. The following card contains the r.m.s. length SIGMA of the bunch and an integer ISIG, the number of standard deviations used in both directions from the bunch centre. The coordinate of the line-charge density is s. In example A the following data cards are used:

\texttt{\$BEAM 0.074}

BCI will now use the line-charge density $q(s)$ given by:

\[
q(s) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{s^2}{2\sigma^2}\right), \quad \sigma = 0.07, \quad \sigma \leq 0.28
\]

If \$BEAM is not used, the MAIN program calling BCI must provide a subroutine function SHAPE(S) returning a line-charge density in \text{As/m} to BCI. An example of such an user-defined bunch shape will be given together with example B in the next chapter.

8. **Keyword=\$WAKE**

This keyword is used to produce a wake field computation. Wakefield in our context is the integrated longitudinal electric field at a fixed point in the bunch over all the times when this point is inside the structure. The wake field has the dimension VOLT and is the energy gain of particles as a function of their position along the bunch. The coordinate system $(u)$ used for the wake field starts at the first particle which enters the structure and $u$ is always positive. With $u$ as coordinate for the wake field $W(u)$ and $s$ as coordinate for the bunch shape, the situation
would be the one shown in Fig.4. The bunch and the wake field coordinates have the dimension meter.

To perform such a wake field calculation a certain number of time steps is needed to allow all the particles to pass the entire structure. If no time steps were specified, BCI will use an appropriate number. If by the use of $\text{TIMESTEP}$ an insufficient number of time steps was specified, the wake field will be calculated only for those particles which have left the structure at the last time step. Otherwise the full range for the wake field will automatically be the same as the full range where the line-charge density was defined as not zero. For a Gaussian bunch the wake field will be computed in a range of $u=(0.0--2\times ISIGMA)$. For a user-defined bunch shape the wake field range is $u=(0.0--2\times SBEG)$. The wake field at $u=0$ is the energy gain of the first particle in the bunch, sitting at the bunch coordinate $s=ISIGMA$ or $s=SBEG$ (for user defined bunches) respectively.

There is a similar keyword to allow computations of wake fields far behind the driving bunch which will be described in the next chapter together with example B.

9.Keyword=$\text{PLOT}$ ( or $\text{SPLOT}$ )
This keyword may be used to generate graphical output at the same time steps as a line printer output will appear.

The following card contains the integer number $\text{NPLT}$. If $\text{NPLT}$ is positive, $\text{NPLT}$ defines the number of field lines to be plotted between the first particle and the last particle in the bunch. For $\text{NPLT}=10$ and a total charge of 1As there will always be a flux of 0.1As between two fieldlines. Due to electromagnetic effects higher charge densities may be generated and thus the number of field lines plotted will increase. A positive $\text{NPLT}$ always generates field lines proportional to the field strength.

If $\text{NPLT}$ is negative the fixed number $-\text{NPLT}$ of field lines will be plotted independent of the actual field strength. This is useful if one excites a cavity with a very long bunch to get the fundamental mode. In this case a positive $\text{NPLT}$ would result in plots containing none or only some field lines.

After this card some of the following ones may be given in arbitrary order:
- CURPLOT produces plots of displacement current lines
- EPLT produces field lines of the electric field
- BEAMSHAPE plot of the current distribution on the axis
- MESH plot of the mesh at the first time step
- CAVITYUSED the input cavity shape and the approximated shape in the mesh are not always the same. Therefore
one may get a plot of the actual cavity shape used in the program. The input shape will be used in all field plots and will plotted at the first time step anyway.

**MESHCAVU**
combined plot of the mesh and the cavity used

**MESHCAVI**
combined plot of the mesh and the input cavity

**CAVICAVU**
combined plot of the input and the cavity used

**PLOT RANGE**
this keyword allows the use of an arbitrary graphical device. It is followed by a data card giving the range in the output medium in which a plot should appear. The line contains:

**XMIN,XMAX,YMIN,YMAX**

- **X** is the coordinate in which the paper is rolled. This data word may be omitted together with the data card. In this case default ranges are used as they exist in the CERN graphic packages (Raster:=0,1023,/X/0,1023,)
- A 1:1 correspondence between the physical dimensions and the graphical output is obtained for any device range as long as the units in the device itself are the same in x and y.

If **@FLOT** is used instead of **FLOT** the cpu time of the plotting routines will be about 15 percent less but the fieldlines will no longer end exactly on mesh lines. If a lot of graphical output is to be produced this keyword should be used.

Since the new input data set is to be checked before doing actual calculations, all plots which may help to find errors in the input data should be ordered. So we take:

**$PLT**
15
**EPLT**
**CURPLOT**
**BEAMSHAPE**
**MESH**
**CAVITYUSED**
**MESHCAVU**
**CAVICAVU**

**10. KEYWORD=PRINT**

Some of the following words may be used, in arbitrary order, to generate a line printer output of the quantities specified at the previously defined time steps:

- **ER** radial electric field
- **EZ** longitudinal electric field
- **EZBEAM** longitudinal electric field on the axis
- **H** azimuthal magnetic field
- **RCUR** radial total (displacement) current
- **ZCUR** longitudinal total (displacement) current
- **PRIMCUR** primary current on the axis produced by the beam
- **ENERGY** electric, magnetic and total energy in the cavity
The output ordered by ENERGY can be used to compute the total energy lost by the bunch into the cavity and a loss parameter k-tot. The total energy W01T after the bunch has left the structure divided by the total charge squared of the bunch (see printout under BEAMCHECK) yields the total loss parameter ktot in V/Coulomb. The total energy lost by the bunch is not necessarily the same as the energy lost into the cavity whenever open boundary conditions are used. Thus one always should use for loss calculations the wake field and the stored energy. For bunches longer than the cut off frequency of the beam tube or for closed cavities the energy lost should be, within 1 percent, equal to the energy stored in the cavity.

In order to illustrate the program all possible line printer output should be shown. Thus the data cards are:

$PRINT
ER
EZ
EZBEAM
H
ZCUR
RCUR
PRIMCUR
ENERGY
CHARGE
CURPLOT
EPLT

distribution of the charges on the mesh points including parasitic charges due to rounding errors. Very useful to check the program: the total charge must always be zero within the accuracy of the word length of the computer in use compared with the total charge in the driving bunch.

CURPLOT
simulation of lines of total current (Hxr=const)

EPLT
plot simulation of electric field lines
11. **Keyword**: !$END$

This keyword stops the input stream and starts the calculation.

The complete set of the input data for example A is now:

```plaintext
$SPARM $END
$TEXT
TEST1 EXAMPLE A, SPS 200 MHZ CAVITY TEST1
$BOUNDARY
1 3 3
$MESH
50.91
0.490 0.900
$CAVITYSHAPE
0.00
0.000 0.000
0.070 0.285
-1.0.01
0.089 0.289
0.120 0.199
-1.0.080
0.200 0.119
0.290 0.119
-1.0.200
0.490 0.319
0.490 0.581
-1.0.200
0.290 0.781
0.200 0.781
-1.0.000
0.120 0.701
0.089 0.611
-1.0.01
0.070 0.615
0.070 0.900
0.000 0.900
0.000 0.000
9999.9999.
$BEAM
0.074
$WAKE
$PLOT
15
EPILOT
CURPLOT
BEAMSHAPE
$END
```
5. The input data for example B

Since a non-Gaussian bunch is to be used in example B, the half length of the user defined bunch shape has to be defined via the $\$P$ARM$ namelist input. The first particle entering the cavity is sitting at $s=$SBEG$=0.4m$, see Fig. 3. Thus the first input line is:

$\$P$ARM$ SBEG$=0.4$ $\$END$

Only the keywords and data different from example A will be described here.

2. Keyword=$\$BOUNDARY$
Since we use tapers on both ends of the cavity this keyword would be meaningless. It is omitted together with its data card.

3. Keyword=$\$MESH$

XXX it is strongly recommended not to use this keyword XXX
This keyword allows the creation of a mesh which is not uniform in the r direction. This may be useful to get a better approximation of structures with boundary lines which are not parallel to mesh lines. This keyword is followed by the r values $r(i=1...NR)$ of all the horizontal mesh lines instead of the total radius of the structure. The step size in z has always to be constant and cannot be changed by this keyword. Thus the total length of the structure follows, as before, after the last radial coordinate. The first radial coordinate has to be zero. All the others may be given in an arbitrary order. Thus it is easy to add afterwards some radial mesh lines without retyping these data cards. An example for this cavity (which is not supposed to be the best or even a good one) would be:

$\$MESH$
36,63
0.0,01,02,03,04,05,06,07,076,082,
0.088,094,1.11,12,13
0.14,15,16,17,18,19,2,21,22,23,24,25,
0.26,27,28
0.288,292,298,304,308
0.62 = total length GAP

4. Keyword=$\$CAVITYSHAPE$
Since almost all accelerating cavities have a symmetry plane in the middle of a cell, a second possibility exists to input such a cavity shape making use of this symmetry. Using $\$CAVITYSHAPE$ one only needs to input the left half of the cavity. The full cavity will be used automatically. The total length of the structure must still be the one of the full cell as there exists no field symmetry in the time domain. An input using "filling with metal" would need the following data cards:
In general it is "safer" to use an odd number NZ of mesh lines in z direction when symmetric input data are used. In this case both halves of the structure are divided by a z=const mesh line in the middle. If an even number NZ is used problems may occur due to rounding errors and the cavity shape used has to be checked carefully.

6. Keyword=$\text{SPEED}$

To input the speed of 0.995c we use the two cards:

```
$\text{SPEED}
0.995
```

7. Keyword=$\text{BEAM}$

This keyword has to be omitted when line-charge densities are user defined.

8. Keyword=$\text{SWAKE}$

Instead of $\text{SWAKE}$ we use $\text{SWAKE}$ to compute the wake field far behind the bunch. The next two cards contain the real numbers:

```
UBF, UBT
ZCF, ZCT
```

UBF (U Bunch From) is the first coordinate in the wake field coordinate system which starts at the first particle entering the cavity and increases to later particles (coordinate=\(u\), dimension=\(\text{meter}\)). The point UBF=0 corresponds to the point \(s=0\) in the bunch-shape coordinates.

UBT (U Bunch To) is the last coordinate and thus the range in which the wake field is to be computed is now defined as (UBF, UBT).

ZCF (Z Cavity From) and

ZCT (Z Cavity To) define a range in the cavity coordinates. Only in this range will the longitudinal electric field be taken into account for the wake field integral. Usually the entire cavity length is used and so the data for a wake field in example B would be:

```
$\text{SWAKE}
0.00 1.60
0.00 0.62
```
Using $SWAKE$ is slightly more complicated than the use of $SAKE$. One has in addition to estimate the number of time steps which are needed to complete this wake field calculation. One way would be to run BCI in TEST mode and to read the information (NTW=number of time steps needed for wake). We shall do so in this case. However there also exists a simple rule to calculate the number of time steps NT:

\[
NT = \left( GAP + UBT \right) \times MT / DDZ
\]

- GAP= total length of the structure
- UBT= last wake field coordinate in meter
- MT = number of time steps/cell advance (2,3,4,..)
- DDZ = step size of the mesh in z = GAP/(NZ-1)

In example B the result would be NT=444 with GAP=.62m, UBT=1.6m, DDZ=.01m and assuming that MT=2 is sufficient for stability. This is not very useful since we do not know yet MT. If MT is too small the range of the wake field (UBT) will be reduced stepwise until the number of time steps previously defined (or the default) is sufficient to perform a complete wake field in the final range of u.

For all the other keywords similar data may be used as in example A. Only NPLT will be used negative here to get a fixed number of field lines.

The complete set of the input data for example B is now:
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5. How to run BCI on CERN IBM

The subroutines of BCI are compiled and available from the LINK library CR.PUB.PRO.PGMLIB. (To use BCI on CDC, see chapter 15.) BCI may then be called as a subroutine in a short MAIN program (the reason for this is to allow the possible provision of a user bunch shape subroutine):

CALL BCI

data cards on G.SYSIN stream.
The first data card(s) is in NAMELIST format and may contain any of the following parameters:

$PARM SBEG=value,NREC=value,NSAV=value,NREP=value,
NWAK=value,TEST=value,NTADD=value $END

SBEG is the equivalent to ISIG used for Gaussian bunches. A user defined bunch will be considered nonzero only in the range of s between -SBEG and +SBEG. The particle sitting at +SBEG will be the first one in the cavity. Since SBEG is used ONLY for user defined bunches, more details will be given later in this chapter together with example B.

NREC,NSAV,NREP and NTADD are used to generate subsequent jobs or to restart a job after an abnormal end. These facilities will be described in chapter 8.

NWAK is used to save information and a computed wake field for further use. For details see chapter 8 and 9.

TEST is an integer defining the mode in which BCI is to be used. TEST=0 means a normal production run. TEST=1 (or any integer) will cause the TEST mode to be active. This TEST mode should always be used when a new input data set has been created since under PRODUCTION mode only some of the input data will be printed.

There are some more parameters which may be changed in the namelist input. Since this is usually not necessary, these other parameters are explained in Appendix B, chapter 16.
6.1 Run of BCI for example A and output

The following JOB including the MAIN routine and some job control language (CERN) is used (Note: the procedure automatically includes the CERN program library as LLB6):

```
//WEITEST1 JOB
// EXEC NFORTCLG,ILB1='CR.PUB.PRO.PGMLIB',
// GRGN=800K
//C.SYSP DD *
CALL BCI
STOP
END

//G.SYSP DD *
$SPRAM ITEST=1 $END
$TEXT
TESTI EXAMPLE A, SPS 200 MHZ CAVITY TESTI
$BOUNDARY
1.333
$MESH
50.91
0.490 0.900
$CAVITYSHAPE
0.00
0.000 0.000
0.070 0.000
0.070 0.285
-1.0,0.01
0.089 0.289
0.193 0.199
-1.0.0.000
0.200 0.119
0.290 0.119
-1.0.200
0.490 0.519
0.490 0.581
-1.0.200
0.290 0.781
0.290 0.781
-1.0.0.000
0.120 0.701
0.089 0.611
-1.0.0.01
0.070 0.615
0.070 0.900
```

0.000 0.900
0.000 0.000
9999,9999.
$BEAM
0.07,4
$SHAKE
$PLOT
15
EPLT
CURL
BEAMSHP
MESH
CAVITYUSED
MESHCAV
MESHCAVU
CAVICAVU
$PRINT
ER
EZ
EZBEAM
H
ZCUR
RCUR
PRIMCUR
ENERGY
CHARGE
CURL
EPLT
$END

The line printer output is given on the following pages.
BCI USER'S GUIDE

&PARM
SBEG= 0
NTADD= 0
NREC= 0
NSAV= 0
NREP= 0
NWAK= 0
IEST= 1
LBOX1= T
LBOX2= T
LBOX3= T
LTEXT= T
LSMOTH=F
QFX1=.5000000007E-01
QFX2=.5000000007E-01
QFY1=.5000000007E-01
QFY2=.149999976
QFY3=.149999976
QFY4=.5000000007E-01
&END

PAM SOURCE= BCI 1.00 802511 15.20 CERN PROGRAM LIBRARY BCI= T310

CALL OF BCI( FIRST PARTICLE ENTERS AT (SBEG): SEE BELOW
RECOVER FROM FILE (NREC): NO RECOVERING
SAVE RESULTS INTO FILE (NSAV): NO SAVING
TIME STEPS TO ADDED (NTADD): --
SAVE WAVEFIELD INTO FILE (NWAK): NO SAVING
TEST MODE (IEST= 1) : TEST

******************************************************************************

* TEST1 EXAMPLE A, SPS 200 MHZ CAVITY TEST1 *
******************************************************************************

** BCI ** BEAM-CAVITY INTERACTION PROGRAM FOR CYLINDRICALLY SYMMETRIC
CAVITIES OF ARBITRARY SHAPE AND BEAMS OF ARBITRARY SHAPE ON THE AXIS

JOB DATE:26/11/80 JOB TIME:10.40.27 JOB NAME:WEITEST1 BCI-LEVEL(25/11/80)

** BCI ** SIMULATION FOR CHECKING INPUT DATA, NO CALCULATION OF FIELDS
BOUNDARY CONDITIONS
UPPER : IU = 1 (E-TANGENTIAL=ZERO)
LEFT : IZL = 3 (OPEN)
RIGHT : IZR = 3 (OPEN)

NUMBER OF MESH LINES IN R : NR = 50
NUMBER OF MESH LINES IN Z : NZ = 91
NUMBER OF MESH POINTS : NP = 4556
TOTAL LENGTH OF THE STRUCTURE : GAP = 9.0000E-01(M)
TOTAL RADIUS OF THE STRUCTURE : RAD = 4.9000E-01(M)

R'(M) -VALUES (GENERATED)
0.0 0.0100 0.0200 0.0300 0.0400 0.0500 0.0600 0.0700 0.0800 0.0900 0.1000 0.1100 0.1200 0.1300 0.1400
0.1500 0.1600 0.1700 0.1800 0.1900 0.2000 0.2100 0.2200 0.2300 0.2400 0.2500 0.2600 0.2700 0.2800 0.2900
0.3000 0.3100 0.3200 0.3300 0.3400 0.3500 0.3600 0.3700 0.3800 0.3900 0.4000 0.4100 0.4200 0.4300 0.4400
0.4500 0.4600 0.4700 0.4800 0.4900

Z/(M) -VALUES (GENERATED)
0.0 0.0100 0.0200 0.0300 0.0400 0.0500 0.0600 0.0700 0.0800 0.0900 0.1000 0.1100 0.1200 0.1300 0.1400
0.1500 0.1600 0.1700 0.1800 0.1900 0.2000 0.2100 0.2200 0.2300 0.2400 0.2500 0.2600 0.2700 0.2800 0.2900
0.3000 0.3100 0.3200 0.3300 0.3400 0.3500 0.3600 0.3700 0.3800 0.3900 0.4000 0.4100 0.4200 0.4300 0.4400
0.4500 0.4600 0.4700 0.4800 0.4900

MATERIAL DISTRIBUTION, FILLING WITH VACUUM

INPUT: (R,Z) (I,J)
( 0.0 ; 0.0 ) ( I; J )
( 7.0000E-02; 2.8500E-01) ( 8; 30) SHIFTED TO ( 7.0000E-02; 2.9000E-01)
( 8.9000E-02; 2.8500E-01) ( 10; 30) SHIFTED TO ( 9.0000E-02; 2.9000E-01)

*** AUTOMESH BEGIN ***
THE LAST TWO POINTS ARE TO BE CONNECTED BY A CIRCLE

CIRCLE TO BE PROCESSED BY AUTOMESH:
FROM=( 7.0000E-02; 2.8500E-01)
TO=( 8.9000E-02; 2.8500E-01)
USING A CONCAVE CIRCLE, RADIUS= 1.0000E-02M
KIND OF ANGLE (-I==0-PI; 2==IP=2-PI) IKIND=-1
REPLACED BY A POLYGON OF 8 SEGMENTS

MESH-POLYGON GENERATED:

<table>
<thead>
<tr>
<th>I</th>
<th>R(I)</th>
<th>J</th>
<th>Z(J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>6.99999E-02</td>
<td>30</td>
<td>2.90000E-01</td>
</tr>
<tr>
<td>9</td>
<td>8.00000E-02</td>
<td>30</td>
<td>2.90000E-01</td>
</tr>
<tr>
<td>10</td>
<td>9.00000E-02</td>
<td>30</td>
<td>2.90000E-01</td>
</tr>
</tbody>
</table>

*** AUTOMESH END ***
BCI USER’S GUIDE

INPUT: (R,Z) (I,J)
===> (1.2000E-01; 1.9900E-01) (13; 21) SHIFTED TO (1.2000E-01; 2.0000E-01)

*** AUTOMESH BEGIN ***

THE LAST TWO POINTS CANNOT BE CONNECTED USING EQUAL NUMBERS
OF STEPS IN R AND Z. STRAIGHT LINE HAD TO BE REPLACED.

VERTICES TO BE PROCESSED BY AUTOMESH:
FROM = (8.90000E-02; 2.89000E-01)
TO = (1.20000E-01; 1.99000E-01)

SUB-POLYGON GENERATED:

<table>
<thead>
<tr>
<th>I</th>
<th>R(I)</th>
<th>J</th>
<th>Z(J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>9.00000E-02</td>
<td>30</td>
<td>2.90000E-01</td>
</tr>
<tr>
<td>10</td>
<td>9.00000E-02</td>
<td>30</td>
<td>2.90000E-01</td>
</tr>
<tr>
<td>10</td>
<td>9.00000E-02</td>
<td>29</td>
<td>2.80000E-01</td>
</tr>
<tr>
<td>11</td>
<td>1.00000E-01</td>
<td>28</td>
<td>2.70000E-01</td>
</tr>
<tr>
<td>11</td>
<td>1.00000E-01</td>
<td>27</td>
<td>2.60000E-01</td>
</tr>
<tr>
<td>11</td>
<td>1.00000E-01</td>
<td>26</td>
<td>2.50000E-01</td>
</tr>
<tr>
<td>12</td>
<td>1.10000E-01</td>
<td>25</td>
<td>2.40000E-01</td>
</tr>
<tr>
<td>12</td>
<td>1.10000E-01</td>
<td>24</td>
<td>2.30000E-01</td>
</tr>
<tr>
<td>12</td>
<td>1.10000E-01</td>
<td>23</td>
<td>2.20000E-01</td>
</tr>
<tr>
<td>13</td>
<td>1.20000E-01</td>
<td>22</td>
<td>2.10000E-01</td>
</tr>
<tr>
<td>13</td>
<td>1.20000E-01</td>
<td>21</td>
<td>2.00000E-01</td>
</tr>
<tr>
<td>13</td>
<td>1.20000E-01</td>
<td>21</td>
<td>2.00000E-01</td>
</tr>
</tbody>
</table>

*** AUTOMESH END ***

and so on ........................

INPUT: (R,Z) (I,J)
(7.0000E-02; 9.0000E-01) (8; 91)
(0.0; 9.0000E-01) (1; 91)
(0.0; 0.0) (15; 91)

THE INNER AREA IS: 3.060E-01 MM² (3060.0 CELLS)
BCI USER'S GUIDE

NUMBER OF TIME STEPS / CELL : MT = 3
VELOCITY OF THE BUNCH / C : BETA = 1.00000E+00
DISTANCE FROM C : 1-BETA = 0.0
CALCULATED ENERGY : GAMMA = 9.99999E+69
TIME-STEP VALUE : DT = 1.11111E-11(S)
TIME FOR A PARTICLE TO PASS : PT = 3.00288E-09(S)
DT-STATES FOR A PARTICLE TO PASS : NPT = 27
CONDUCTIVITY OF THE METAL : KAPPA = INFINITE
SIGMA OF THE GAUSSIAN BUNCH : SIG = 7.00000E-02(M)
NUMBER OF STAND.DIV. USED : ISIG = +/- 4
FIRST PARTICLE ENTERS AT : SBE = 2.80000E-01(M)
DT-STATES FOR THE BUNCH TO PASS : NPTB = 439

NUMBER OF TIME STEPS (DEFAULT) : NT = 504
FIRST PRINT/PLOT AT (DEFAULT) : NSF = 50
THEN EVERY NNS STEPS (DEFAULT) : NNS = 50
NUMBER OF UNKNOWN ER : NER = 3038
NUMBER OF UNKNOWN EZ : NEZ = 3046
NUMBER OF UNKNOWN H : NH = 3086

INPUT-DATA FOR WAKEFIELD CALCULATION:

WAKEFIELD BETWEEN THE BUNCH COORDINATES : UBF = 0.0 (M)
AND UBT = 5.60000E-01(M)
WAKEFIELD BETWEEN THE CAVITY COORDINATES : ZCF = 5.00000E-03(M)
AND ZCT = 8.95000E-01(M)
NUMBER OF WAKEFIELD POINTS : NW = 57
NUMBER OF TIME STEPS NEEDED FOR WAKE : NTW = 438
**Beamcheck:**

A Gaussian bunch is used between the bunch coordinates ± Sbeg = ± 2.80000E-01 (m)

<table>
<thead>
<tr>
<th>± 6.00E+00</th>
<th>± 5.00E+00</th>
<th>± 4.00E+00</th>
<th>± 3.00E+00</th>
<th>± 2.00E+00</th>
<th>± 1.00E+00</th>
<th>± 0.0E+00</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Max. Charge-Density: 5.699E+00 (AS/m) ; Greatest Step: 4.906E-01 (AS/m) ; Conv.: WC = 0.086 ; Total Charge: 9.99952E-01 (AS)
BCI USER'S GUIDE

TEST1 EXAMPLE A, SPS 200 MHZ CAVITY TEST1
TIME STEP= 1 TIME(H)= 1.0 TIME(ER,EZ)= 1.5 ZB(HEAD)= 5.000E-03M ZB(CENTER)= -2.750E-01M ZB(END)= -5.550E-01M
REAL TIME= 1.112E-02 NANOSECONDS

and so on

TEST1 EXAMPLE A, SPS 200 MHZ CAVITY TEST1
TIME STEP= 500 TIME(H)= 500.0 TIME(ER,EZ)= 500.5 ZB(HEAD)= 1.665E+00M ZB(CENTER)= 1.385E+00M ZB(END)= 1.105E+00M
REAL TIME= 5.559E+00 NANOSECONDS

--> BUNCH OUTSIDE THE CAVITY

TEST1 EXAMPLE A, SPS 200 MHZ CAVITY TEST1
TIME STEP= 504 TIME(H)= 504.0 TIME(ER,EZ)= 504.5 ZB(HEAD)= 1.675E+00M ZB(CENTER)= 1.395E+00M ZB(END)= 1.115E+00M
REAL TIME= 5.604E+00 NANOSECONDS

--> BUNCH OUTSIDE THE CAVITY

BCI WOULD PROBABLY RUN WITHOUT ERROR
The graphical output produced is shown in Figs 5-10. The quality of the cavity shape approximation is quite good and since the TEST run was successful, a production run may now follow using the JOB listed below. In order to reduce the amount of printout we will use the keyword $TISTEP to generate output only for two time steps. The additional data cards are

$TISTEP
504 3 252,252

The printout will be given here only for the time step 252 and not in the full cavity range. The graphical output is shown in Figs 11-13.

//WEITST2 JOB
/EXEC NFORTCLG,LLB='CR.PUB.PRO.PGMLIB',
// GRGN=800K,
//C.SYSIN DD *
CALL BCI
STOP
END

/}
//G.SYSIN DD *
$SPARM SEND
$TEXT
TEST2 EXAMPLE A, SPS 200 MHZ CAVITY TEST2
$BOUNDARY
1.3,3
$SMESH
50,91
0.490 0.900
$CAVITYSHAPE
0.00
0.000 0.000
0.070 0.000
0.070 0.285
-1.0.0.01
0.089 0.289
0.120 0.199
-1.0.080
0.200 0.119
0.290 0.119
-1.1.290
0.490 0.319
0.490 0.581
-1.1.200
0.290 0.781
0.200 0.781
-1.1.0.080
0.120 0.701
0.089 0.611
-1.1.0.01
0.070 0.615
0.070 0.900
0.000 0.900
0.000 0.000
9999.9999.
$TISTEP
504 3 252,252
$BEAM
0.07,4
$SWALE
$PLOT
15
$PLOT
BEAMSHAPE
$PRINT
ER
E
EZONE
ZCUR
RCUR
PRIMCUR
ENERGY
CHARGE
CURPLOT
EPLLOT
SEND
/}
&PARM
SBEG= .0
NTADD= 0
NREC= 0
NSAV= 0
NREP= 0
NWAK= 0
ITEST= 0
LBOX1= T
LBOX2= T
LBOX3= T
LTEST= T
LSMOTH=F
QFX1= .500000007E-01
QFX3= .500000007E-01
QFY1= .500000007E-01
QFY2= .149999976
QFY4= .149999976
QFY5= .500000007E-01
&END

PAM SOURCE= BCI     1.00     802511 15.20 CERN PROGRAM LIBRARY BCI= T310

CALL OF BCI
FIRST PARTICLE ENTERS AT (SBEG) : SEE BELOW
RECOVER FROM FILE (NREC) : NO RECOVERING
SAVE RESULTS INTO FILE (NSAV) : NO SAVING
TIME STEPS TO ADDED (NTADD) : --
SAVE WAKEFIELD INTO FILE (NWAK) : NO SAVING
TEST MODE (ITEST= 0) : PRODUCTION

******************************************************************************
******************************************************************************
******************************************************************************
******************************************************************************

* TEST2 EXAMPLE A, SPS 200 MHZ CAVITY TEST2
******************************************************************************
******************************************************************************
******************************************************************************
******************************************************************************

******************************************************************************
******************************************************************************
******************************************************************************
******************************************************************************

!!! BCI !!! BEAM-CAVITY INTERACTION PROGRAM FOR CYLINDRICALLY SYMMETRIC
CAVITIES OF ARBITRARY SHAPE AND BEAMS OF ARBITRARY SHAPE ON THE AXIS


BOUNDARY CONDITIONS   UPPER : IRU =  1 (E-TANGENTIAL=ZERO)
                      LEFT : IZL =  3 (OPEN)
                      RIGHT : IZR =  3 (OPEN)

NUMBER OF MESH LINES IN K : NR =  50
NUMBER OF MESH LINES IN Z : NZ =  91
NUMBER OF MESH POINTS : NP =  4550
TOTAL LENGTH OF THE STRUCTURE : GAP =  9.00000E-01(M)
TOTAL RADIUS OF THE STRUCTURE : RAD =  4.90000E-01(M)
MATERIAL DISTRIBUTION, FILLING WITH VACUUM

INPUT:  (R,Z)  (I,J)
( 0.0 ; 0.0 ) ( 1 ; 1 )
( 7.0000E-02; 0.0 ) ( 8 ; 1 )
( 7.0000E-02; 2.8500E-01 ) ( 8; 30 ) SHIFTED TO ( 7.0000E-02; 2.9000E-01 )
===>> CONNECTION BY A CIRCLE, IKIND=-1 RADIUS=1.4000E-02M
===>> ( 8.9000E-02; 2.8900E-01 ) ( 10; 30 ) SHIFTED TO ( 9.0000E-02; 2.9000E-01 )
===>> ( 1.2000E-01; 1.9700E-01 ) ( 13; 21 ) SHIFTED TO ( 1.2000E-01; 2.0000E-01 )
===>> CONNECTION BY A CIRCLE, IKIND=-1 RADIUS=8.4000E-02M
===>> ( 2.0000E-01; 1.1900E-01 ) ( 21; 15 ) SHIFTED TO ( 2.0000E-01; 1.2000E-01 )
===>> ( 2.9000E-01; 1.1900E-01 ) ( 30; 13 ) SHIFTED TO ( 2.9000E-01; 1.2000E-01 )
===>> CONNECTION BY A CIRCLE, IKIND=-1 RADIUS=2.0000E-01M
===>> ( 4.9000E-01; 3.1100E-01 ) ( 50; 33 ) SHIFTED TO ( 4.9000E-01; 3.2000E-01 )
===>> ( 4.9000E-01; 5.8100E-01 ) ( 50; 53 ) SHIFTED TO ( 4.9000E-01; 5.8000E-01 )
===>> CONNECTION BY A CIRCLE, IKIND=-1 RADIUS=2.6000E-01M
===>> ( 2.9000E-01; 7.8000E-01 ) ( 30; 79 ) SHIFTED TO ( 2.9000E-01; 7.8000E-01 )
===>> ( 2.0000E-01; 7.8000E-01 ) ( 21; 79 ) SHIFTED TO ( 2.0000E-01; 7.8000E-01 )
===>> CONNECTION BY A CIRCLE, IKIND=-1 RADIUS=1.0000E-02M
===>> ( 1.2000E-01; 7.0100E-01 ) ( 13; 71 ) SHIFTED TO ( 1.2000E-01; 7.0000E-01 )
===>> ( 8.9000E-02; 6.1100E-01 ) ( 10; 62 ) SHIFTED TO ( 9.0000E-02; 6.1000E-01 )
===>> CONNECTION BY A CIRCLE, IKIND=-1 RADIUS=1.0000E-02M
===>> ( 7.0000E-02; 6.1500E-01 ) ( 8; 63 ) SHIFTED TO ( 7.0000E-02; 6.2000E-01 )
( 0.0 ; 9.0000E-01 ) ( 1 ; 9 )
( 0.0 ; 0.0 ) ( 1 ; 1 )

TIME STEPS TO BE PROCESSED : NT = 504
NUMBER OF TIME STEPS / CELL : MT = 3
FIRST PRINT/PLOT AT TIME STEP : NSF = 252
THEN EVERY NNS TIME STEPS : NNS = 252
VELOCITY OF THE BLNCH / C : BETA = 1.00000E+00
DISTANCE FROM C : 1-BETA = 0.0
CALCULATED ENERGY : GAMMA = 9.99999E+69
TIME-STEP VALUE : DT = 1.11111E-11(S)
TIME FOR A PARTICLE TO PASS : PT = 3.00303E-09(S)
DI-STEP FOR A PARTICLE TO PASS : NPT = 271
CONDUCTIVITY OF THE METAL : KAPPA = INFINITE
SIGMA OF THE GAUSSIAN BUNCH : SIG = 7.00000E-02(M)
NUMBER OF STAND.DEV. USED : ISIG = 4
FIRST PARTICLE ENTERS AT : SBEC = 2.80000E-01(M)
DI-STEP FOR THE BUNCH TO PASS : NPTB = 439
NUMBER OF UNKNOWN ER : NER = 3016
NUMBER OF UNKNOWN EZ : NEZ = 3016
NUMBER OF UNKNOWN H : NH = 3080
INPUT-DATA FOR WAKEFIELD CALCULATION:

WAKEFIELD BETWEEN THE BUNCH COORDINATES \( \text{UBF} = 0.0 \) \( \text{(M)} \)
AND \( \text{UBT} = 5.60000E-01 \) \( \text{(M)} \)

WAKEFIELD BETWEEN THE CAVITY COORDINATES \( \text{ZCF} = 5.00000E-03 \) \( \text{(M)} \)
AND \( \text{ZCT} = 8.95000E-01 \) \( \text{(M)} \)

NUMBER OF WAKEFIELD POINTS \( \text{NW} = 57 \)
NUMBER OF TIME STEPS NEEDED FOR WAKE \( \text{NTW} = 438 \)

$\text{PLOT:}$
Plot of electric field-lines
Field lines/total bunch charge: \( \text{NPLOT} = 15 \)
Plot of beam shape under the field-plot

$\text{PRINT:}$
Printout of primary current
Printout of radial electric field
Printout of longitudinal electric field
Printout of E/Z on the axis, inside the beam
Printout of azimuthal magnetic field
Printout of radial total currents
Printout of longitudinal total currents
Printout of the total energy in the cavity
Printout of parasitic and primary charges
Plot simulation of total current lines
Plot simulation of electric field lines

**********>> Computation time control
Entry = end of input
**********>> Time-step it = 0 CPU-time used so far = 3.876 \( \text{s} \) CPU-time left = 112.5 \( \text{s} \)

BEAMCHECK:
A Gaussian bunch is used between the bunch coordinates \( \pm 2.80000E-01 \) \( \text{(M)} \)
Max. charge-density: \( 5.699E+00 \) \( \text{(As/M)} \); Greatest step: \( 4.906E-01 \) \( \text{(As/M)} \); Conv.: \( \text{WC} = 0.086 \); Tot. charge: \( 9.99952E-01 \) \( \text{(As)} \)
BCI USER'S GUIDE

RADIAL

TOTAL CURRENT/(1.44600E+09A)

Z/(M)= 0.0 0.010 0.020 0.030 0.040 0.050 0.060 0.070 0.080 0.090 0.100 0.110 0.120 0.130 0.140 0.150 0.160 0.170 0.180 0.190
R/(M) 0.495 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.475 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

LONGITUDINAL TOTAL CURRENT/(1.70524E+09A)

Z/(M)= 0.005 0.015 0.025 0.035 0.045 0.055 0.065 0.075 0.085 0.095 0.105 0.115 0.125 0.135 0.145 0.155 0.165 0.175 0.185 0.195
R/(M) 0.495 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.485 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

RADIAL

ELECTRIC FIELD/(2.04424E+13V/M)

Z/(M)= 0.0 0.010 0.020 0.030 0.040 0.050 0.060 0.070 0.080 0.090 0.100 0.110 0.120 0.130 0.140 0.150 0.160 0.170 0.180 0.190
R/(M) 0.495 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.475 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

LONGITUDINAL ELECTRIC FIELD/(1.02114E+12V/M)

Z/(M)= 0.005 0.015 0.025 0.035 0.045 0.055 0.065 0.075 0.085 0.095 0.105 0.115 0.125 0.135 0.145 0.155 0.165 0.175 0.185 0.195
R/(M) 0.495 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.480 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

EZ INSIDE THE BEAM AT R=0/(1.02114E+12V/M)

Z/(M)= 0.005 0.015 0.025 0.035 0.045 0.055 0.065 0.075 0.085 0.095 0.105 0.115 0.125 0.135 0.145 0.155 0.165 0.175 0.185 0.195
R/(M) 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

TOTAL CHARGE IN (AS) :

CAVITY= 9.999E-01 WALL=-9.999E-01 ERROR= 1.252E-06

CHARGE ON THE MESH POINTS/(7.92521E-02AS)

Z/(M)= 0.0 0.010 0.020 0.030 0.040 0.050 0.060 0.070 0.080 0.090 0.100 0.110 0.120 0.130 0.140 0.150 0.160 0.170 0.180 0.190
R/(M) 0.490 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.480 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

- - -
TOTAL CURRENT-LINES=2*M_PI*X ON THE MESH POINTS/(1.70603E+09A)

Z/(M)= 0.0 0.010 0.020 0.030 0.040 0.050 0.060 0.070 0.080 0.090 0.100 0.110 0.120 0.130 0.140 0.150 0.160 0.170 0.180 0.190
R/(M)
0.490 xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx
0.480 xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx

EPSNULXE-LINES=2*M_PI*X*INTEGRAL(X*DCT) ON THE MESH POINTS/( 1.00001E+00AS)

Z/(M)= 0.0 0.010 0.020 0.030 0.040 0.050 0.060 0.070 0.080 0.090 0.100 0.110 0.120 0.130 0.140 0.150 0.160 0.170 0.180 0.190
R/(M)
0.490 xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx
0.480 xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx xxxxxxx

PLOT:
MINMAX OF EPSNULXE = D -LINES : 4.8040E-10(AS) 1.00001E+00(AS)
MINMAX OF EPSNULXE = D -LINES PLOTTED: 5.33317E-02(AS) 9.66620E-01(AS)
CHARGE-FLUX BETWEEN TWO LINES: 6.66634E-02(AS) NUMBER OF LINES PLOTTED: 15

XXXXXXXXX>> COMPUTATION TIME CONTROL ENTRY-END OF TIME LOOP
XXXXXXXXX>> TIME-STEP IT= 252 CPU-TIME USED SO FAR= 22.40 S CPU-TIME LEFT= 94.00 S

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX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The total energy after the bunch has left the cavity is printed. Dividing WIOT=1.5490E11 VAS by the total charge squared yields a total loss parameter: ktot (SIGMA=7.0cm) = 0.1549 V/µC. In order to get the function ktot(SIGMA) one has to run BCI with different bunches. One should check at least two steps for the stored energy after the bunch has left the structure. In an open structure it might be necessary to "wait" a certain time after the bunch has left in order to reach a steady distribution. (Some fields may leak out through the tubes!)

+++++++++++++++ COMMENT ++++++++++++++++++++++++
TEST2 EXAMPLE A. SPS 200 MHz CAVEITY TEST2

(w)=WAKEFIELD=ENERGY GAIN \( \text{in} \) \( \text{MeV} \)

(\( \nu \))=AS A FUNCTION OF THE BUNCH COORDINATES IN \( \text{m} \).

(\( \times \))=BUNCH SHAPE

<table>
<thead>
<tr>
<th>( E )</th>
<th>( \nu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 5.00\times10^1 )</td>
<td>( 0.0 )</td>
</tr>
<tr>
<td>( -5.00\times10^1 )</td>
<td>( 0.0 )</td>
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<tr>
<td>( -1.00\times10^1 )</td>
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<tr>
<td>( -1.50\times10^1 )</td>
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<tr>
<td>( -2.50\times10^1 )</td>
<td>( 0.0 )</td>
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</table>

\( 1.00\times10^1 \) \( 2.00\times10^1 \) \( 3.00\times10^1 \) \( 4.00\times10^1 \) \( 5.00\times10^1 \)
### List of Calculated Wakefield in Volt as a Function of the Wakefield Coordinate \( u \) in Meter

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<tr>
<th>( u/M )</th>
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<th>5.0000E-02</th>
<th>6.0000E-02</th>
<th>7.0000E-02</th>
<th>8.0000E-02</th>
<th>9.0000E-02</th>
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<tr>
<td>( \text{WAKE/V} )</td>
<td>-1.8745E+09</td>
<td>1.7242E+09</td>
<td>-1.2630E+09</td>
<td>1.6120E+09</td>
<td>-9.9866E+08</td>
<td>1.8578E+09</td>
<td>-8.1389E+08</td>
<td>1.9060E+09</td>
<td>-1.0746E+09</td>
<td>1.3751E+09</td>
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</table>

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<th>1.3000E-01</th>
<th>1.4000E-01</th>
<th>1.5000E-01</th>
<th>1.6000E-01</th>
<th>1.7000E-01</th>
<th>1.8000E-01</th>
<th>1.9000E-01</th>
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<td>( \text{WAKE/V} )</td>
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<td>-9.3117E+08</td>
<td>-6.2345E+09</td>
<td>-6.5762E+09</td>
<td>-1.4104E+10</td>
<td>-1.8046E+10</td>
<td>-2.8816E+10</td>
<td>-5.1257E+10</td>
<td>-6.2116E+10</td>
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<th>2.9000E-01</th>
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<tbody>
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<td>-8.0287E+10</td>
<td>-9.4469E+10</td>
<td>-1.1372E+11</td>
<td>-1.2891E+11</td>
<td>-1.4750E+11</td>
<td>-1.6063E+11</td>
<td>-1.7656E+11</td>
<td>-1.8566E+11</td>
<td>-1.9701E+11</td>
<td>-2.0123E+11</td>
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<td>-2.0668E+11</td>
<td>-2.0746E+11</td>
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<td>-1.9117E+11</td>
<td>-1.8404E+11</td>
<td>-1.7353E+11</td>
<td>-1.6439E+11</td>
<td>-1.5254E+11</td>
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</table>

|------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|

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<tbody>
<tr>
<td>( \text{WAKE/V} )</td>
<td>-5.8056E+10</td>
<td>-5.3336E+10</td>
<td>-4.8562E+10</td>
<td>-4.4797E+10</td>
<td>-4.0324E+10</td>
<td>-3.7041E+10</td>
<td>-3.2947E+10</td>
</tr>
</tbody>
</table>

**Total Energy Gain of the Bunch**: \(-1.55095E+11\) V/AS

**BCI Ended Without Error**
The wake field multiplied by the line charge density integrated over the entire bunch yields the total energy lost by the bunch. This number is printed above.

By the law of energy conservation the energy lost by the bunch should be exactly the sum of the energy stored in the cavity and the energy radiated into the beam tubes. Since the bunch length used in this example is longer than the beam tube radius, there is not much energy radiated into the tubes. The stored energy has been printed above:

\[ \text{WTOT} = 1.5490 \text{E11 VAs} \]

The energy lost by the bunch is:

\[ \text{WLOST} = 1.5509 \text{E11 VAs} \]

The difference is thus 0.12 percent.

The comparison between these two numbers, which are computed independently, is very useful and should always be made. If one uses very long bunches, producing almost pure inductive wake fields, the accuracy of the integrated wake field goes down (but not the accuracy of the stored energy!), since the product of an odd function with an even one is integrated.

6.2 Run of BCI for example B and output

In the second example a non-Gaussian bunch is to be used and the cosine like bunch has to be defined by the following function subroutine:

FUNCTION SHAPE(S)
  DATA A /0.8/ , PI /3.1415/
  SHAPE = COS ( PI * S / A ).
  RETURN
END

This function will return the line-charge density in As/m to BCI. There is no need to treat the range of s outside +/- SBEG = +/-0.4m because this is done automatically by BCI. Calling BCI with SBEG=0.4 in the $PARM namelist will ensure that the function SHAPE will be called only between -0.4m and +0.4m.

It should be mentioned here again that two different coordinate systems are used. The s-system for the line-charge density in the range +/- SBEG and the u-system for the wake field starting with zero at the first particle which enters the cavity. This first particle sits at \( u=0 \) and at \( s=SBEG \). The last particle in the bunch sits at \( u=2 \times SBEG \) and at \( s=-SBEG \), see Fig 4.
The complete program to test the second example is now:

```plaintext
//WEITEST3 JOB
// EXEC NFORTCLG,ILB1='CR.FUB.PRO.PGMLIB',
// GRGN=800K
//C.SYSIN DD *
  CALL BCI
  STOP
END
FUNCTION SHAPE(S)
  DATA A /0.8/, PI /3.1415/
  SHAPE = COS ( PI *S / A )
  RETURN
END
//G.SYSIN DD *
$PARM SBEG=0.4, ITEST=1 $END
$TEXT
TEST3 EXAMPLE B, LEP 353MHZ CAVITY TEST3
$MESH
36, 63
  0.0, 01, 02, 03, 04, 05, 06, 07, 076, 082, 088, 094, 1, 11, 12, 13
  0.14, 15, 16, 17, 18, 19, 2, 21, 22, 23, 24, 25, 26, 27, 28
  0.286, 292, 298, 304, 308
  0.62
$CAVITY3SHAPE
  99999.0
  0.0000 0.0000
  0.3080 0.0000
  0.3080 0.1720
  0.3053 0.1720
  0.2740 0.1860
  -1.0 0.0030
  0.2700 0.1155
  0.1020 0.1155
  -1.0 0.0010
  0.0980 0.1170
  0.0690 0.1660
  -1.0 -0.0100
  0.0500 0.1620
  0.0500 0.0500
  0.0000 0.0000
  99999.9999
$SPEED
  0.995
$SPEED
  0.00 1.6
  0.00 0.62
$SLOT
15
EPLOT
BEAMSHAPE
```

Mesh
CAVITY3SHAPE
MESHCAVI
MESHCAVU
CAVICAVU
PRINT
ER
EZ
EZBEAM
H
RCUR
ZCUR
PRIMCUR
CURPLOT
EPLOT
CHARGE
ENERGY
$END

The printout follows on the next pages and the graphical output produced is given in the figures 14-19.
BCI USER'S GUIDE

&PARM
SBEG= .399999976
NTADD= 0
NREC= 0
NSAV= 0
NRDP= 0
NWAK= 0
ITEST= 1
LBOX1= T
LBOX2= T
LBOX3= T
LTEXT= T
LSMOOTH= F
QFX1= .500000007E-01
QFX3= .500000007E-01
QFY1= .500000007E-01
QFY2= .149999976
QFY4= .149999976
QFY5= .500000007E-01
&END

PAM SOURCE= BCI 1.00 802511 15.20 CERN PROGRAM LIBRARY BCI= T310

CALL OF BCI ( FIRST PARTICLE ENTERS AT (SBEG) = 4.000000E-01M
RECOVER FROM FILE (NREC) = NO RECOVERING
SAVE RESULTS INTO FILE (NSAV) = NO SAVING
TIME STEPS TO ADDED (NTADD) = --
SAVE WAKEFIELD INTO FILE (NWAK) = NO SAVING
TEST MODE (ITEST = 1) = TEST

****************************************************************************
* TEST3 EXAMPLE B, LEP 353MHZ CAUTITY TEST3
*
****************************************************************************

** BCI ** BEAM-CAVITY INTERACTION PROGRAM FOR CYLINDRICALLY SYMMETRIC
CAVITIES OF ARBITRARY SHAPE AND BEAMS OF ARBITRARY SHAPE ON THE AXIS


** BCI ** SIMULATION FOR CHECKING INPUT DATA, NO CALCULATION OF FIELDS
BOUNDARY CONDITIONS
  UPPER : IRU = 1 (E-TANGENTIAL=ZERO)
  LEFT : IDL = 1 (E-TANGENTIAL=ZERO)
  RIGHT : IZR = 1 (E-TANGENTIAL=ZERO)
NUMBER OF MESH LINES IN R : NR = 36
NUMBER OF MESH LINES IN Z : NZ = 63
NUMBER OF MESH POINTS : NP = 2268
TOTAL LENGTH OF THE STRUCTURE : GAP = 6.20000E-01(M)
TOTAL RADIUS OF THE STRUCTURE : RAD = 3.08000E-01(M)
R(M) - VALUES
0.0 0.0100 0.0200 0.0300 0.0400 0.0500 0.0600 0.0700 0.0760 0.0820 0.0880 0.0930 0.1000 0.1100 0.1200
0.1300 0.1400 0.1500 0.1600 0.1700 0.1800 0.1900 0.2000 0.2100 0.2200 0.2300 0.2400 0.2500 0.2600 0.2700
0.2800 0.2900 0.3000 0.3100 0.3200 0.3300 0.3400 0.3500 0.3600 0.3700 0.3800 0.3900 0.4000 0.4100 0.4200
0.4300 0.4400 0.4500 0.4600 0.4700 0.4800 0.4900 0.5000 0.5100 0.5200 0.5300 0.5400 0.5500 0.5600 0.5700
0.5800 0.5900 0.6000 0.6100 0.6200

SYMOMETRIC HALF CELL INPUT IS USED

MATERIAL DISTRIBUTION, FILLING WITH METAL OF INFINITE CONDUCTIVITY

INPUT : (R,Z) (I,J)
0.0 0.0
3.08000E-01 0.0
36 1

==>> (3.08000E-01; 1.72000E-01) (36; 13)
SHIFTED TO (3.08000E-01; 1.70000E-01)

==>> (3.05000E-01; 1.72000E-01) (35; 13)
SHIFTED TO (3.04000E-01; 1.70000E-01)

==>> (2.74000E-01; 1.18000E-01) (30; 13)
SHIFTED TO (2.70000E-01; 1.20000E-01)

Automesh Begins

The last two points are to be connected by a circle.

Circle to be processed by Automesh:

FRO M = (2.74000E-01; 1.18000E-01)
T O = (2.70000E-01; 1.15500E-01)
 USING A CONCAVE CIRCLE, RADIUS = 3.00000E-03M
KIND OF ANGLE (-1==0-PI; 2==PI-2*PI) IKIND=-1
REPLACED BY A POLYGON OF 4 SEGMENTS

Mesh-Polygon Generated:

I R(I) J Z(J)
30 2.70000E-01 13 1.20000E-01

Automesh Ends

and so on...

The inner area is: 3.493E-02 MM2 (412.5 cells)
**WARNING**

MI = 2 was too small, now increased to MI = 4

NUMBER OF TIME STEPS / CELL : MT = 4

VELOCITY OF THE BUNCH / C : BETA = 9.95000E-01

DISTANCE FROM C : 1-BETA = 5.00000E-03

CALCULATED ENERGY : GAMMA = 1.00125E+01

TIME-STEP VALUE : DT = 8.38102E-12(S)

TIME FOR A PARTICLE TO PASS : PT = 2.07849E-09(S)

DT-STEPS FOR A PARTICLE TO PASS : NPT = 249

CONDUCTIVITY OF THE METAL : KAPPA = INFINITE

An external line-charge density has been specified

DT-STEPS FOR THE BUNCH TO PASS : NPTB = 569

NUMBER OF TIME STEPS (DEFAULT): NT = 654

FIRST PRINT/PLOT AT (DEFAULT): N5F = 65

THEN EVERY N55 STEPS (DEFAULT): N55 = 65

NUMBER OF UNKNOWN ER : NER = 1325

NUMBER OF UNKNOWN EZ : NEZ = 1350

NUMBER OF UNKNOWN H : NH = 1360

Input-data for wakefield calculation:

Wakefield between the bunch coordinates UBFB = 0.0 (M)

And UBTB = 1.60000E+00(M)

Wakefield between the cavity coordinates ZCF = 5.00000E+03(M)

And ZCT = 6.15000E+01(M)

Number of wakefield points NW = 161

**WARNING**

The number of wake points is now reduced to NW = 102

**WARNING**

The total wake-calculation would need 888-DT-steps NT = 654 is not enough and UBT had to be changed last bunch coordinate changed to 1.01000E+00(M)

Number of time steps needed for wake NTW = 888
COMPUTATION TIME CONTROL  ENTRY=END OF INPUT
TIME-STEP IT= 0  CPU-TIME USED SO FAR= .6182 S  CPU-TIME LEFT= 11.93 S
BCI USER'S GUIDE

TEST3 EXAMPLE B, LEP 353MHZ CAVITY TEST3
TIME STEP= 1 TIME(H)= 1.0 TIME(ER,EZ)= 1.5 ZB(HEAD)= 5.00E-03M ZB(CENTER)= -3.950E-01M ZB(END)= -7.950E-01M
REAL TIME= 8.381E-03 NANOSECONDS


--------> COMPUTATION TIME CONTROL  ENTRY=END OF TIME LOOP
--------> TIME-STEP IT= 1 CPU-TIME USED SO FAR= 1.136 S CPU-TIME LEFT= 11.45 S


and so on


--------> COMPUTATION TIME CONTROL  ENTRY=END OF TIME LOOP
--------> TIME-STEP IT= 654 CPU-TIME USED SO FAR= 654.5 S CPU-TIME LEFT= 11.38 S


WARNING
THE WAKEFIELD COMPUTATION HAS NOT BEEN COMPLETED!
THE NUMBER OF TIME STEPS EXECUTED SO FAR IS LESS THAN NTF= 388

WARNING
THE WAKEFIELD COMPUTATION HAS NOT BEEN COMPLETED!
THE NUMBER OF TIME STEPS EXECUTED SO FAR IS LESS THAN NTF= 388

BCI WOULD PROBABLY RUN WITHOUT ERROR
The graphical output produced is shown in Figs 14-19. The cavity shape approximation is good enough for demonstration; and since the TEST run was successful a production run may now follow using the JOB listed below.

The total number of time steps needed for a complete wake field computation is given in the above printout by NTW (TOTAL NUMBER OF TIMESTEPS NEEDED FOR WAKE = 388). Since the default value was not sufficient we have to add a $TIMESTEP input. The integer MT has to be at least 4 to fulfill the stability criterion, s. printout. In order to reduce the amount of printout we will order printout only for two time steps. The additional data cards are

$TIMESTEP
388 4 444,444
The printout will be given here only for the time step 444 and not in the full cavity range. The graphical output is shown in Figs 20-22.

//WGETEST4 JOB
// EXEC NFDRTCLG,LLB1='CR.PUB.PRO.PCMLIB'
//C.SYSIN DD *
CALL BCI
STOP
END
FUNCTION SHAPE(S)
SHAPE=COS(3.1415*S/0.8)
RETURN
END
/*
// G.SYSIN DD *
$SPARM $SEG=0.4 $END
$TEXT
TEST4 EXAMPLE B, LEP 353MHZ CAVITY TEST4
$S$MESH
36,63

0.0, 01.02, 03.,04.,05.,06.,07.,086.,082.,088.,094.,11.12
0.14., 15.16., 17., 18., 19.21., 22.23.,24.,25.,26.,27.,28
0.286.,292.298.,304.,308
0.62
$CAVITYSHAPE
9999.0
0.0000 0.0000
0.0380 0.0000
0.0380 0.1720
0.3053 0.1720
0.2740 0.1180
-1.0 0.0030
0.2700 0.1155
0.1020 0.1155
-1.0 0.0000
0.0000 0.1170
0.0690 0.1660
-1.0 0.0100
0.0570 0.1620
0.0570 0.0500
0.0000 0.0000
9999.9
9999.
$STIMESTEP
9999 4 444,444
$SPEED
0.995
$WAKE
0.00 1.5
0.00 0.52
$PLOT
-15
EPLT
BEMSHAPE
$PRINT
ER
EZ
EZBEAM
H
ENERGY
RUR
ZCUR
CHARGE
EPLT
CURPLOT
$END
/*
//G.FT11F001 DD DSN=&amp;DISPLY,DISP=(NEW,PASS);
// LABEL=(.,OUT), UNIT=SCR,SPACE=(CYL,(1,1),NLSE)
//PLOT EXEC CCPLT,LR=MM175,TR=MM175
BOUNDARY CONDITIONS
UPPER : IRU = 1 (E-TANGENTIAL=ZERO)
LEFT : IZL = 1 (E-TANGENTIAL=ZERO)
RIGHT : IZR = 1 (E-TANGENTIAL=ZERO)
NUMBER OF MESH LINES IN R : NR = 36
NUMBER OF MESH LINES IN Z : NZ = 63
NUMBER OF MESH POINTS : NP = 2268
TOTAL LENGTH OF THE STRUCTURE : GAP = 6.20000E-01(M)
TOTAL RADIUS OF THE STRUCTURE : RAD = 3.08000E-01(M)
R(M) -VALUES
0.0  0.0100  0.0200  0.0300  0.0400  0.0500  0.0600  0.0700  0.0760  0.0820  0.0880  0.0940  0.1000  0.1100  0.1200
0.1300  0.1400  0.1500  0.1600  0.1700  0.1800  0.1900  0.2000  0.2100  0.2200  0.2300  0.2400  0.2500  0.2600  0.2700
0.2800  0.2860  0.2920  0.2980  0.3040  0.3080

SYMMETRIC HALF CELL INPUT IS USED

MATERIAL DISTRIBUTION, FILLING WITH METAL OF INFINITE CONDUCTIVITY

INPUT: (R,Z) (I,J)
( 0.0 ; 0.0 ) ( 1; 1)
( 3.0800E-01; 0.0 ) ( 36; 1)

===> ( 3.0800E-01; 1.7200E-01 ) ( 36; 18) SHIFTED TO ( 3.0800E-01; 1.7000E-01)

===> ( 3.0530E-01; 1.7200E-01 ) ( 35; 18) SHIFTED TO ( 3.0400E-01; 1.7000E-01)

===> ( 2.7400E-01; 1.1600E-01 ) ( 30; 13) SHIFTED TO ( 2.7000E-01; 1.2000E-01)

===> ( 2.7000E-01; 1.1550E-01 ) ( 30; 13) SHIFTED TO ( 2.7000E-01; 1.2000E-01)

===> ( 1.0200E-01; 1.1550E-01 ) ( 13; 13) SHIFTED TO ( 1.0000E-01; 1.2000E-01)

CONNECTION BY A CIRCLE, IKIND= -1 RADIUS= 3.0000E-03M

===> ( 9.8000E-02; 1.1700E-01 ) ( 13; 13) SHIFTED TO ( 1.0000E-01; 1.2000E-01)

===> ( 9.8000E-02; 1.6600E-01 ) ( 8; 18) SHIFTED TO ( 7.0000E-02; 1.7000E-01)

CONNECTION BY A CIRCLE, IKIND= -1 RADIUS= 1.0000E-02M

===> ( 5.0000E-02; 1.6200E-01 ) ( 6; 17) SHIFTED TO ( 5.0000E-02; 1.6000E-01)

( 5.0000E-02; 5.0000E-02 ) ( 6; 6)
( 0.0 ; 0.0 ) ( 1; 1)
TIME STEPS TO BE PROCESSED : NT = 888
NUMBER OF TIME STEPS / CELL : MT = 4
FIRST PRINT/ PLOT AT TIME STEP : NSF = 444
THEN EVERY NSS TIME STEPS : NSS = 444
VELOCITY OF THE BUNCH / C : BETA = 9.9560E-01
DISTANCE FROM C : 1-BETA = 5.0000E-03
CALCULATED ENERGY : GAMMA = 1.00125E+01
TIME-STEP VALUE : DT = 8.3810E-12 (s)
TIME FOR A PARTICLE TO PASS : PT = 2.07849E-09 (s)
DT- STEPS FOR A PARTICLE TO PASS : NPT = 249
CONDUCTIVITY OF THE METAL : KAPPA = INFINITE

AN EXTERNAL LINE-CHARGE DENSITY HAS BEEN SPECIFIED

DT- STEPS FOR THE BUNCH TO PASS : NPTB = 569
NUMBER OF UNKNOWN ER : NER = 1325
NUMBER OF UNKNOWN EZ : NEZ = 1350
NUMBER OF UNKNOWN H : NH = 1360

INPUT-DATA FOR WAKEFIELD CALCULATION:

WAKEFIELD BETWEEN THE BUNCH COORDINATES UBF = 0.0 (M)
AND UBT = 1.60000E+30 (M)
WAKEFIELD BETWEEN THE CAVITY COORDINATES ZCF = 5.00000E-03 (M)
AND ZCT = 6.15000E-11 (M)
NUMBER OF WAKEFIELD POINTS NW = 161
NUMBER OF TIME STEPS NEEDED FOR WAKE NTW = 888

$PLOT:
PLOT OF ELECTRIC FIELD-LINES
ABSOLUTE NUMBER OF FIELD LINES: NPLT = 15
PLOT OF BEAM SHAPE UNDER THE FIELD- PLOT

$PRINT:
PRINTOUT OF RADIAL ELECTRIC FIELD
PRINTOUT OF LONGITUDINAL ELECTRIC FIELD
PRINTOUT OF EZ ON THE AXIS, INSIDE THE BEAM
PRINTOUT OF AZIMUTHAL MAGNETIC FIELD
PRINTOUT OF RADIAL TOTAL CURRENTS
PRINTOUT OF LONGITUDINAL TOTAL CURRENTS
PRINTOUT OF THE TOTAL ENERGY IN THE CAVITY
PRINTOUT OF PARASITIC AND PRIMARY CHARGES
PLOT SIMULATION OF TOTAL CURRENT LINES
PLOT SIMULATION OF ELECTRIC FIELD LINES

************ COMPUTATION TIME CONTROL ENTRY=END OF INPUT
************ TIME-STEP IT = 0 CPU-TIME USED SO FAR = 0.5503 S
CPU-TIME LEFT = 115.8 S
SHAPE OF THE BUNCH IN (AS/M) AS A FUNCTION OF $S$ IN THE RANGE $+/\pm 4.00E-01(M)$ \*\* FRONT ON THE RIGHT HAND SIDE \*\*

and so on

MAX. CHARGE-DENSITY: 1.000E+00(AS/M); GREATEST STEP: 3.926E-02(AS/M); CONV.: WC=0.039; TOT. CHARGE: 5.09242E-01(AS)

TEST4 EXAMPLE B, LEP 353MHZ CAVITY TEST4
TIME STEP= 1 TIME(H)= 1.0 TIME(ER,EZ)= 1.5 ZB(HEAD)= 5.000E-03M ZB(CENTER)= -3.950E-01M ZB(END)= -7.950E-01M
REAL TIME= 8.381E-03 NANOSECONDS

TEST4 EXAMPLE B, LEP 353MHZ CAVITY TEST4
TIME STEP= 444 TIME(H)= 444.0 TIME(ER,EZ)= 444.5 ZB(HEAD)= 1.105E+00M ZB(CENTER)= 7.050E-01M ZB(END)= 3.050E-01M
REAL TIME= 3.721E+00 NANOSECONDS

ENERGY/(VAS) IN THE CAVITY: WELE= 9.2723E+09 WMag= 3.4518E+09 WTOT(IT-0.5)= 1.7259E+09 WTOT(IT)= 8.0879E+09
BCI USER'S GUIDE

RADIAL TOTAL CURRENT/(2.75352E+08A)

<table>
<thead>
<tr>
<th>Z/(M)</th>
<th>R/(M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.010 0.020 0.030 0.040 0.050 0.060 0.070 0.080 0.090 0.100 0.110 0.120 0.130 0.140 0.150 0.160 0.170 0.180 0.190</td>
</tr>
<tr>
<td>0.308</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 -0.27 -0.03 -0.03</td>
</tr>
<tr>
<td>0.306</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 -0.29 -0.02 -0.02</td>
</tr>
</tbody>
</table>

LONGITUDINAL TOTAL CURRENT/(2.75352E+08A)

<table>
<thead>
<tr>
<th>Z/(M)</th>
<th>R/(M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005</td>
<td>0.015 0.025 0.035 0.045 0.055 0.065 0.075 0.085 0.095 0.105 0.115 0.125 0.135 0.145 0.155 0.165 0.175 0.185 0.195</td>
</tr>
<tr>
<td>0.308</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 -0.27 -0.29 -0.32</td>
</tr>
<tr>
<td>0.304</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 -0.29 -0.00 -0.00</td>
</tr>
</tbody>
</table>

RADIAL ELECTRIC FIELD/(3.13373E+12V/M)

<table>
<thead>
<tr>
<th>Z/(M)</th>
<th>R/(M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.010 0.020 0.030 0.040 0.050 0.060 0.070 0.080 0.090 0.100 0.110 0.120 0.130 0.140 0.150 0.160 0.170 0.180 0.190</td>
</tr>
<tr>
<td>0.306</td>
<td>XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX -0.00 -0.00</td>
</tr>
<tr>
<td>0.301</td>
<td>XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX 0.00 0.00 0.00</td>
</tr>
</tbody>
</table>

LONGITUDINAL ELECTRIC FIELD/(2.79759E+12V/M)

<table>
<thead>
<tr>
<th>Z/(M)</th>
<th>R/(M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005</td>
<td>0.015 0.025 0.035 0.045 0.055 0.065 0.075 0.085 0.095 0.105 0.115 0.125 0.135 0.145 0.155 0.165 0.175 0.185 0.195</td>
</tr>
<tr>
<td>0.304</td>
<td>XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX 0.00 0.00 0.00</td>
</tr>
</tbody>
</table>

EZ INSIDE THE BEAM AT R=0./(2.79759E+12V/M)

<table>
<thead>
<tr>
<th>Z/(M)</th>
<th>R/(M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005</td>
<td>0.015 0.025 0.035 0.045 0.055 0.065 0.075 0.085 0.095 0.105 0.115 0.125 0.135 0.145 0.155 0.165 0.175 0.185 0.195</td>
</tr>
<tr>
<td>0.0</td>
<td>-0.01 -0.01 -0.01 -0.01 -0.01 -0.01 -0.01 -0.01 -0.01 -0.01 -0.01 -0.01 -0.01 -0.01 -0.01 -0.01 -0.01 -0.01</td>
</tr>
</tbody>
</table>

TOTAL CHARGE IN (AS): CAVITY=1.618E-01 WALL=-1.618E-01 ERROR=1.132E-06

CHARGE ON THE MESH POINTS/(3.46524E+02AS)

<table>
<thead>
<tr>
<th>Z/(M)</th>
<th>R/(M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.010 0.020 0.030 0.040 0.050 0.060 0.070 0.080 0.090 0.100 0.110 0.120 0.130 0.140 0.150 0.160 0.170 0.180 0.190</td>
</tr>
<tr>
<td>0.308</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.01</td>
</tr>
<tr>
<td>0.304</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.04 -0.00 -0.00</td>
</tr>
</tbody>
</table>
TOTAL CURRENT-LINES = 2*PI*R*XH ON THE MESH POINTS

\[ Z/(M) = 0.0 \quad 0.010 \quad 0.020 \quad 0.030 \quad 0.040 \quad 0.050 \quad 0.060 \quad 0.070 \quad 0.080 \quad 0.090 \quad 0.100 \quad 0.110 \quad 0.120 \quad 0.130 \quad 0.140 \quad 0.150 \quad 0.160 \quad 0.170 \quad 0.180 \quad 0.190 \]

\[ R/(M) = 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \]

EPNSLXE-LINES = 2*PI*R*INTEGRAL(H*DT) ON THE MESH POINTS

\[ Z/(M) = 0.0 \quad 0.010 \quad 0.020 \quad 0.030 \quad 0.040 \quad 0.050 \quad 0.060 \quad 0.070 \quad 0.080 \quad 0.090 \quad 0.100 \quad 0.110 \quad 0.120 \quad 0.130 \quad 0.140 \quad 0.150 \quad 0.160 \quad 0.170 \quad 0.180 \quad 0.190 \]

\[ R/(M) = 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \quad 0.308 \]

PLOT:

\[ \text{MINMAX of EPNSLXE} = 3.49382E-01(AS) \quad 7.46861E-01(AS) \]

\[ \text{MINMAX of EPNSLXE plotted} = 3.61803E-01(AS) \quad 7.34435E-01(AS) \]

\[ \text{Number of lines plotted:} = 15 \]

TEST4 EXAMPLE B, LEP 353MHZ CAVITY TEST4

TIME (S)= 888 TIME (H)= 888.0 TIME (ER, E2)= 888.5 ZB (HEAD) = 2.215E+00M ZB (CENTER) = 1.815E+00M ZB (END) = 1.415E+00M

REAL TIME = 7.442E+00 NANOSECONDS

---> BUNCH OUTSIDE THE CAVITY

ENERGY/(JAS) IN THE CAVITY: WELE = 3.9943E+08 WMAE = 5.1659E+09 WTOT(IT=0.5) = 5.5393E+09 WTOT(IT) = 5.5399E+09
TEST4 EXAMPLE B. LEP 353MHZ CAVITY TEST4

(W)=WAKEFIELD=ENERGY GAIN IN (V) AS A FUNCTION OF THE BUNCH COORDINATES IN (M), (*)=BUNCH SHAPE

1.00E+11

5.00E+10

0.0

-5.00E+10

-1.00E+11

0.0  2.00E-01  4.00E-01  6.00E-01  8.00E-01  1.00E+00  1.20E+00  1.40E+00
### List of Calculated Wakefield in Volt as a Function of the Wakefield Coordinate U in Meter

<table>
<thead>
<tr>
<th>U/M</th>
<th>0.0</th>
<th>1.0000E-02</th>
<th>2.0000E-02</th>
<th>3.0000E-02</th>
<th>4.0000E-02</th>
<th>5.0000E-02</th>
<th>6.0000E-02</th>
<th>7.0000E-02</th>
<th>8.0000E-02</th>
<th>9.0000E-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAKE/V</td>
<td>1.3616E+10</td>
<td>-2.3009E+10</td>
<td>9.9166E+09</td>
<td>-1.6915E+10</td>
<td>7.1253E+09</td>
<td>-1.6735E+10</td>
<td>4.4334E-09</td>
<td>-1.9698E+10</td>
<td>-1.5012E+09</td>
<td>-1.9894E+10</td>
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</tbody>
</table>

<table>
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<tr>
<th>U/M</th>
<th>1.0000E-01</th>
<th>1.1000E-01</th>
<th>1.2000E-01</th>
<th>1.3000E-01</th>
<th>1.4000E-01</th>
<th>1.5000E-01</th>
<th>1.6000E-01</th>
<th>1.7000E-01</th>
<th>1.8000E-01</th>
<th>1.9000E-01</th>
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</thead>
</table>

and so on ........................

<table>
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<tr>
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<th>1.0000E+00</th>
<th>1.0100E+00</th>
<th>1.0200E+00</th>
<th>1.0300E+00</th>
<th>1.0400E+00</th>
<th>1.0500E+00</th>
<th>1.0600E+00</th>
<th>1.0700E+00</th>
<th>1.0800E+00</th>
<th>1.0900E+00</th>
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</thead>
</table>

<table>
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<tr>
<th>U/M</th>
<th>1.1000E+00</th>
<th>1.1100E+00</th>
<th>1.1200E+00</th>
<th>1.1300E+00</th>
<th>1.1400E+00</th>
<th>1.1500E+00</th>
<th>1.1600E+00</th>
<th>1.1700E+00</th>
<th>1.1800E+00</th>
<th>1.1900E+00</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>U/M</th>
<th>1.2000E+00</th>
<th>1.2100E+00</th>
<th>1.2200E+00</th>
<th>1.2300E+00</th>
<th>1.2400E+00</th>
<th>1.2500E+00</th>
<th>1.2600E+00</th>
<th>1.2700E+00</th>
<th>1.2800E+00</th>
<th>1.2900E+00</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>U/M</th>
<th>1.3000E+00</th>
<th>1.3100E+00</th>
<th>1.3200E+00</th>
<th>1.3300E+00</th>
<th>1.3400E+00</th>
<th>1.3500E+00</th>
<th>1.3600E+00</th>
<th>1.3700E+00</th>
<th>1.3800E+00</th>
<th>1.3900E+00</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>U/M</th>
<th>1.4000E+00</th>
<th>1.4100E+00</th>
<th>1.4200E+00</th>
<th>1.4300E+00</th>
<th>1.4400E+00</th>
<th>1.4500E+00</th>
<th>1.4600E+00</th>
<th>1.4700E+00</th>
<th>1.4800E+00</th>
<th>1.4900E+00</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAKE/V</td>
<td>-1.3979E+10</td>
<td>-2.8425E+10</td>
<td>-2.5490E+10</td>
<td>-2.4564E+10</td>
<td>7.8768E+09</td>
<td>-1.9316E+10</td>
<td>1.7864E+10</td>
<td>-1.2942E+10</td>
<td>2.8194E+10</td>
<td>-7.1483E+09</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>U/M</th>
<th>1.5000E+00</th>
<th>1.5100E+00</th>
<th>1.5200E+00</th>
<th>1.5300E+00</th>
<th>1.5400E+00</th>
<th>1.5500E+00</th>
<th>1.5600E+00</th>
<th>1.5700E+00</th>
<th>1.5800E+00</th>
<th>1.5900E+00</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAKE/V</td>
<td>3.7936E+10</td>
<td>4.9737E+08</td>
<td>4.7459E+10</td>
<td>5.2700E+09</td>
<td>5.6610E+10</td>
<td>1.1020E+10</td>
<td>6.4203E+10</td>
<td>1.6125E+10</td>
<td>6.9485E+10</td>
<td>2.0382E+10</td>
</tr>
<tr>
<td>U/M</td>
<td>1.6000E+00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WAKE/V</td>
<td>7.4744E+10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Energy Gain of the Bunch = -5.54030E+09 VAS**

**BCI Ended Without Error**

*Some text is not clearly visible or legible.*
9.3) we give on the following page the result of the same run as before but using LSMOTH=.TRUE.

As can be seen in the printout above, the stored energy in the cavity and the integrated wake field (energy lost by the bunch) are the same: WTOT=WL0SS=5.54E9 VAs. In order to get the loss parameter k=tot in V/pC one has to divide this number by the charge squared and by 10**12.

The calculated wake field in the last example is oscillating with a rather high amplitude. This is caused by two facts:

a) the derivatives of the bunch shape function are not small enough at the ends of the bunch.

b) forcing a bunch of charged particles to go through an infinitely conducting wall at the speed of light is physically problematic. The field strength at both ends goes to infinity and thus the wake field contains terms of +infinite-infinite.

In order to avoid such oscillations one can either restrict the wake field range in the cavity (see $WAKE, ZCF,ZCT) or smooth the wake field by setting LSMOTH=.TRUE. in the $SPARM namelist input.

Although it would be better to do this smoothing in a subsequent independent run of WAKPLO (see TEST9, chapter
TEST4 EXAMPLE B, LEP 353MHZ CAVITY TEST4

(W) = WAKEFIELD = ENERGY GAIN IN (V) AS A FUNCTION OF THE BUNCH COORDINATES IN (M), (x) = BUNCH SHAPE

\[ \begin{array}{cccccccc}
8.00E+10 & 8.00E-01 & 4.00E-01 & 6.00E-01 & 8.00E-01 & 1.00E+00 & 1.20E+00 & 1.40E+00 \\
6.00E+10 & 8.00E-01 & 4.00E-01 & 6.00E-01 & 8.00E-01 & 1.00E+00 & 1.20E+00 & 1.40E+00 \\
4.00E+10 & 8.00E-01 & 4.00E-01 & 6.00E-01 & 8.00E-01 & 1.00E+00 & 1.20E+00 & 1.40E+00 \\
2.00E+10 & 8.00E-01 & 4.00E-01 & 6.00E-01 & 8.00E-01 & 1.00E+00 & 1.20E+00 & 1.40E+00 \\
0.0 & 8.00E-01 & 4.00E-01 & 6.00E-01 & 8.00E-01 & 1.00E+00 & 1.20E+00 & 1.40E+00 \\
-2.00E+10 & 8.00E-01 & 4.00E-01 & 6.00E-01 & 8.00E-01 & 1.00E+00 & 1.20E+00 & 1.40E+00 \\
-4.00E+10 & 8.00E-01 & 4.00E-01 & 6.00E-01 & 8.00E-01 & 1.00E+00 & 1.20E+00 & 1.40E+00 \\
-6.00E+10 & 8.00E-01 & 4.00E-01 & 6.00E-01 & 8.00E-01 & 1.00E+00 & 1.20E+00 & 1.40E+00 \\
\end{array} \]
6.3 Access to the source of the test jobs

BCI is maintained at CERN by the PATCHY source maintenance system. The following two jobs will extract the IBM and CDC test jobs as a card image file.

IBM:

```plaintext
// JOB
// EXEC YPATCHY,PAMDNS='CR.PUB.PAM.PRO.BCI',
// ASMDSN='(NEW,CATLG,DELETE)',ASMUNT='SYSDA',
// ASMDSN='gg.uuu.BCITEST'
// Y.SYSIN DD *
+EXE.
+USE,P=IBM.
+USE,P=TEST. for all test jobs
or +USE,P=TEST,D=TESTi. for test job number i.
+PAM.
/*

This will catalog a file called gg.uuu.BCITEST containing the selected job or jobs.
```

CDC:

```plaintext
JOB.
ACCOUNT(.,)
FIND,ULIB,ID=PULIB.
LIBRARY,ULIB.
FIND,PAM,PROBCIPAM,ID=PROGLIB.
FILE,ASM,RT=Z,BT=C.
YPATCHY.
CATALOG,ASM,BCITEST,ID=duuuu,ST=CCQ,RP=999.
*XOR
+EXE.
+USE,P=CDC.
+USE,P=TEST. for all test jobs
or +USE,P=TEST,D=TESTi. for test job number i.
+PAM.
*XOR
*EOF

This will catalog an INTERCOM EDITOR file called BCITEST containing the job(s) selected.
```
7. Errors in the input data - inaccurate results

All input data are checked and it should be almost impossible to get the program running with unphysical data. The number of ERROR and WARNING messages is too high to give a complete list here.

Since BCI is a numerical mesh program, one should not believe all the results without some checking. Computing the total loss into a cavity as a function of bunchlength, one should always rerun at least one job with twice the mesh size. This should be done especially for relatively short bunches (NC greater than 0.1).

The computation of the wakefield also yields the energy lost by the bunch. For a closed cavity the energy lost by the bunch should be the same as the energy stored in the cavity. The same is approximately true for bunches longer than the beam tube radius. The difference between these two numbers should not be more than about 1 percent.

In an open structure the energy lost by the bunch is the sum of the energy stored in the cavity and the energy radiated into the beam tubes. Thus the radiated energy may be calculated from the difference between the lost and stored energy.

For very long bunches the wake field becomes almost inductive. Thus it is proportional to the derivative of the bunch shape. The wakefield in a bunch with a symmetric shape will thus be multiplied by an odd function and then be integrated. This reduces the accuracy of the integral and thus the accuracy of computed energy loss of the bunch. In those cases where the difference between the stored and lost energy is high for very long bunches, the accurate number is the stored energy, since this number is a result of an integration over all fields squared.

Another numerical inaccuracy exists in the wake field computation. Although a bunch does not have any wakefield in an infinitely long tube, the numerically computed wake field can never be exactly zero, see Ref. 5. If one is interested in wake fields inside short bunches, one should always do a second run which computes the wake field only in a tube of the same length and same mesh step size as used for the cavity. If this tube wake field is comparable to the cavity wake field one should increase the number of mesh points or use longer bunches.

If the wake field has too many wiggles, it may be artificially smoothed by setting LSMOTH=.T. in the $PARM namelist input or in a subsequent run of WAKPLO, see chapter 9.3. The default is .F.
An important parameter is the convergence parameter WC printed under BEAMCHECK. BCI does not accept a WC greater than 0.3. Although BCI runs with WC up to 0.3, an upper limit to get reasonable results is about 0.1, see Ref 2-4. In general WC increases if the bunchlength becomes too short compared to the step size in the z direction, i.e. there is a lower limit for the bunchlength in a given mesh.
A simple rule is: the sigma of a Gaussian bunch should be at least five times the step size in z direction. This corresponds to a value of 0.12 for WC.

A second important parameter is MT, the number of time steps needed for the bunch to move one step in the z direction. If MT is too small, the algorithm becomes unstable and the computed fields go to infinity. Usually MT is set by BCI and it is checked whether the stability criterion is fulfilled or not. For critical structures it may sometimes be necessary to choose a higher MT by using the keyword $TIMESTEP. Whenever the fields grow to infinity with increasing time steps, MT should be increased.

In order to avoid problems with the stability criterion on should use whenever possible equal steps in r and z direction ($MESH) and not the keyword $MESH. This is especially important together with open boundary conditions (IZL,IZR=3).

8. Saving and recovering with BCI

BCI has the following parameters in the $PARM namelist:
NREC , NSAV , NREP , NWAK , NTADD

NSAV is a logical file number in which all common blocks may be dumped during execution. The output is done by unformatted writing: WRITE(NSAV). If NSAV is zero nothing will be saved.

NREP is the frequency in units of time steps for saving the common blocks. NREP is meaningful only if NSAV is not zero. If a dump is to be done at each time step with printout, NREP may be set to 0 (default). If a dump is to be done only in case of an abnormal end, NREP may be set to 99999 or any big number.

NREC is a logical file number to input the contents of all common blocks of a preceding run which used NSAV unequal zero. In case of an abnormal end of a job one can restart the execution at the time step when the last saving was done in the preceding job. NREC and NSAV may also be used to generate a chain of jobs.

NWAK is a logical file number to save the calculated wake field together with other information. This output is used
later on by the MAJN program WAKPLO (see chapter 9.3) which allows one to mix the wake field with fundamental accelerating voltages and to generate graphical output. If NWAK is zero no wake field will be saved.

NSAV and NREC may be the same (on IBM) but NWAK must not be the same as NSAV or NREC.

NTADD is the number of time steps to be executed in a continuation run. NTADD is equal to NT by default, i.e. if NTADD is not specified, another NT time steps will be done.

To explain how such a save/recover operation works we use the following job with logical file number 2 for saving. With NREF=9999 a dump will be done only in case of an abnormal end.

```
//WEITEST5 JOB, WEILAND, TIME=(0, 15)
// EXEC /FORTCLG,
// LLIB='CR.PUB.FRO.PGMLIB',
// GRGN=800K
//G.SYS14 DD *
 CALL BCI
 STOP
 END
```

```
//G.SYS14 DD *
$PARAM NSAV=2, NREF=9999 $END
$TEXT
TEST5 EXAMPLE A, SPS 200 MHZ CAVITY TEST5
$BOUNDARY
1.3, 3
$MESH
50, 91
```

The following pages show the printout. The job was terminated to avoid an abnormal end and all common blocks have been saved.
BCI USER'S GUIDE

&PARM
SBEG= 0.0
NTADD= 0
NREC= 0
NSAV= 2
NREP= 9999
NWAK= 0
ITEST= 0
LBOX1= T
LBOX2= T
LBOX3= T
LTEXT= T
LSMOOTH=F
QFX1=.500000007E-01
QFX2=.500000007E-01
QFX3=.500000007E-01
QFY1=.149999976
QFY2=.149999976
QFY3=.500000007E-01

PAM SOURCE= BCI 1.00 802511 15.20 CERN PROGRAM LIBRARY BCI= T310

CALL OF BCI( FIRST PARTICLE ENTERS AT (SBEG) : SEE BELOW
RECOVER FROM FILE (NREC) : NO RECOVERING
SAVE RESULTS INTO FILE (NSAV) : 2
SAVE EVERY (NREP) TIME STEPS : 9999
TIME STEPS TO ADDED (NTADD) : --
SAVE WAKEFIELD INTO FILE (NWAK) : NO SAVING
TEST MODE (ITEST= 0) : PRODUCTION)

******************************************************************************
* TEST5 EXAMPLE A, SPS 200 MHZ CAVITY TEST5 *
* BEAM-CAVITY INTERACTION PROGRAM FOR CYLINDRICALLY SYMMETRIC *
* CAVITIES OF ARBITRARY SHAPE AND BEAMS OF ARBITRARY SHAPE ON THE AXIS *
******************************************************************************

BOUNDARY CONDITIONS UPPER : IRU = 1 (E-TANGENTIAL=ZERO)

and so on ..........................
BCI USER'S GUIDE

TEST5 EXAMPLE A, SPS 200 MHZ CAVITY TEST5
TIME STEP= 50 TIME(H)= 50.0 TIME(ER,EZ)= 50.5 ZB(HEAD)= 1.650E-01M ZB(CENTER)= -1.150E-01M ZB(END)= -3.950E-01M
REAL TIME= 5.559E-01 NANOSECONDS

************>> COMPUTATION TIME CONTROL ENTRY=END OF TIME LOOP
************>> TIME-STEP IT= 50 CPU-TIME USED SO FAR= 6.446 S CPU-TIME LEFT= 6.137 S

TEST5 EXAMPLE A, SPS 200 MHZ CAVITY TEST5
TIME STEP= 100 TIME(H)= 100.0 TIME(ER,EZ)= 100.5 ZB(HEAD)= 3.350E-01M ZB(CENTER)= 5.500E-02M ZB(END)= -2.250E-01M
REAL TIME= 1.112E+00 NANOSECONDS

************>> COMPUTATION TIME CONTROL ENTRY=END OF TIME LOOP
************>> TIME-STEP IT= 100 CPU-TIME USED SO FAR= 8.974 S CPU-TIME LEFT= 3.608 S

***ERROR***

JOB TERMINATED TO AVOID ABNORMAL END ENTRY=END OF TIME LOOP
************>> TIME-STEP IT= 112 CPU-TIME USED SO FAR= 9.398 S CPU-TIME LEFT= 2.985 S

************>> START OF SAVING INTO FILE 2
************>> END OF SAVING AT IT= 112

PROGRAM STOP - ERROR IN THE INPUT DATA

************

To continue this job we use NREC=2 and at the same time NSA=2. At the beginning the job will be restarted. The same file is then used for saving again. The frequency for saving is set to the default(0). After each printout the common blocks will then be saved. In addition we use the parameter NTADD to execute only 100 additional time steps. The continuation job is then:

```
//WEITEST6 JOB ,WEILAND,TIME=(0,10)
// EXEC NFORCLG,
// LLBI='CR.PUB.PRO.PGMLIB',
// GRGN=800K
//C.SYSIN DD *
CALL BCI
STOP
END

//G.SYSIN DD *
$PARAM NREC=2,NSAV=2,NREP=0,NTADD=100 $END
//G.FT02F001 DD DISP=SHR,DSN=gg.uuu.BCISAV
```
&PARN
SEBG= 0
NTADD= 100
NSAV= 2
NREP= 0
NWAK= 0
ITEST= 0
LBOX1= T
LBOX2= T
LBOX3= T
LTEXI= T
LSM011=F
QFX1=.500000007E-01
QFX2=.500000007E-01
QFX3=.500000007E-01
QFY1=.149999975
QFY2=.149999975
QFY3=.149999975

PAM SOURCE= BCI 1.00 802511 15.20 CERN PROGRAM LIBRARY BCI= T310

CALL OF BCI
FIRST PARTICLE ENTERS AT (SEBG): --
SAVE RESULTS INTO FILE (NSAV): 2
SAVE EVERY (NREP) TIME STEPS: BEFORE EACH PRINT/PRINT
TIME STEPS TO ADDED (NTADD): 100
SAVE WAKEFIELD INTO FILE (NWAK): NO SAVING
TEST MODE (ITEST= 0): PRODUCTION

*************** START OF RECOVERING FROM FILE 2
*************** END OF RECOVERING IT= 112

*******************************************************************************
* TESTS EXAMPLE A, SPS 200 MHZ CAVITY TESTS
*******************************************************************************

JOB IDENTIFICATION:
PRECEEDING JOB: NAME=WEITEST5 DATE=26/11/80 TIME=10.41.09
ACTUAL JOB: NAME=WEITEST6 DATE=26/11/80 TIME=11.01.14
BCI USER'S GUIDE

NUMBER OF TIME STEPS TO BE PROCESSED: 100

******************************************************************************

START OF SAVING INTO FILE 2

END OF SAVING AT IT= 113

******************************************************************************

TEST5 EXAMPLE A, SPS 200 MHZ CAVITY TEST5
TIME STEP= 113 TIME(H)= 113.0 TIME(ER.EZ)= 113.5 ZB(HEAD)= 3.750E-01M ZB(CENTER)= 9.500E-02M ZB(END)= -1.850E-01M
REAL TIME= 1.256E+00 NANoseconds

COMPUTATION TIME CONTROL ENTRY=END OF TIME LOOP
TIME-STEP IT= 113 CPU-TIME USED SO FAR= .3833 S CPU-TIME LEFT= 6.957 S

******************************************************************************

START OF SAVING INTO FILE 2

END OF SAVING AT IT= 150

******************************************************************************

TEST5 EXAMPLE A, SPS 200 MHZ CAVITY TEST5
TIME STEP= 150 TIME(H)= 150.0 TIME(ER.EZ)= 150.5 ZB(HEAD)= 4.950E-01M ZB(CENTER)= 2.150E-01M ZB(END)= -6.500E-02M
REAL TIME= 1.668E+00 NANoseconds

COMPUTATION TIME CONTROL ENTRY=END OF TIME LOOP
TIME-STEP IT= 150 CPU-TIME USED SO FAR= 2.314 S CPU-TIME LEFT= 5.026 S

******************************************************************************

ERROR

JOB TERMINATED TO AVOID ABNORMAL END ENTRY=END OF TIME LOOP
TIME-STEP IT= 192 CPU-TIME USED SO FAR= 4.372 S CPU-TIME LEFT= 2.968 S

******************************************************************************

START OF SAVING INTO FILE 2

END OF SAVING AT IT= 192

******************************************************************************

PROGRAM STOP - ERROR IN THE INPUT DATA
9. Subsequent analysis of BCI results

9.1 Fundamental mode and frequency

Although BCI is not designed to compute fundamental modes and frequencies, it is sometimes advantageous to get this information without using a second computer program. Since there is no (not yet) eigenvalue procedure in BCI, the fundamental mode is found by a simple trick. The structure is excited by a bunch with a standard deviation of about 1/4 of the expected wavelength. This bunch will excite (more or less) only the fundamental mode. After the bunch has left the structure the remaining field is the fundamental one.

The fundamental frequency may now be found by a computation of the wake field for some RF periods behind this long bunch. Since the wake field is just the fundamental loss parameter times a cosine function, one gets the wavelength by measuring the wavelength of the wake field printed.

We use example A with a bunch length of 0.35 m. The wake field is to be computed in a range of 0-10 m. After a TEST run (which gives the number of time steps necessary) we use the following job:

```//WEITTEST7 JOB, WEILAND, TIME=5
//EXEC NFORCLG,
//LLBL='CR.PUB.PRO.PGMLIB',
//GRSN=800K
//C.SYSIN DD M
CALL BCI
STOP
END
//G.SYSIN DD M
$SPARM $END
$TEXT
TEST7 EXAMPLE A, SPS 200 MHZ CAVITY TEST7
$BOUNDARY
1,3,3
$MESH
50,91
0.490 0.900
$CAVITYSHAPE
0.00
0.000 0.000
and so on, see job TEST1, TEST2
9999, 9999.
$TIMESTEP
3270 3 2270,200
$BEAM
0.35,4
$WAKE
0.00 10.00
0.00 0.90
$PRINT
ENERGY
$END
*/
```

The printout is given on the following pages. Measuring the wavelength in the wake field printout at the end of the job yields L=1.500 m. The frequency thus becomes 199.9 MHz.
CALL OF BCI
  FIRST PARTICLE ENTERS AT (SBEG) : SEE BELOW
  RECOVER FROM FILE (NREC) : NO RECOVERING
  SAVE RESULTS INTO FILE (NSAV) : NO SAVIN
  TIME STEPS TO ADDER (NTADD) : --
  SAVE WAKEFIELD INTO FILE (NZAK) : NO SAVING
  TEST MODE (ITEST= 0) : PRODUCTION

**************************************************************************
* TEST7 EXAMPLE A, SPS 200 MHZ CAVITY TEST7
* *
**************************************************************************
*
*B.C. BEAM-CAVITY INTERACTION PROGRAM FOR CYLINDRICALLY SYMMETRIC
CAVITIES OF ARBITRARY SHAPE AND BEAMS OF ARBITRARY SHAPE ON THE AXIS


BOUNDARY CONDITIONS
  UPPER : IRU =  1 (E-TANGENTIAL=ZERO)
  LEFT : IZL =  3 (OPEN)
  RIGHT : IZR =  3 (OPEN)

NUMBER OF MESH LINES IN R : NR =  50
NUMBER OF MESH LINES IN Z : NZ =  91
NUMBER OF MESH POINTS : NP = 4550
TOTAL LENGTH OF THE STRUCTS : GAP = 9.00000E-01(M)
TOTAL RADIUS OF THE STRUCTS : RAD = 4.90000E-01(M)
MATERIAL DISTRIBUTION, FILLING WITH VACUUM

INPUT: (R,Z) (I,J)
( 0.0 ; 0.0 ) ( 1; 1)
( 7.0000E-02; 2.8500E-01 ) ( 8; 1)
( 7.0000E-02; 2.8500E-01 ) ( 8; 39) SHIFTED TO ( 7.0000E-02; 2.9000E-01)
CONNECTION BY A CIRCLE, IKind = -1 RADIUS = 1.0000E-02 M

and so on ............

( 0.0 ; 0.0 ) ( 1; 1)

TIME STEPS TO BE PROCESSED : NT = 3276
NUMBER OF TIME STEPS / CELL : MT = 3
FIRST PRINT/PLT AT TIME STEP : NPT = 2276
THEN EVERY N$ TIME STEPS : N$ = 200
VELOCITY OF THE BUNCH / C : BETA = 1.00000E+00
DISTANCE FROM C : 1-BETA = 0.0
CALCULATED ENERGY : GAMMA = 9.99959E+69
TIME-STEP VALUE : DT = 1.11188E-11(S)
TIME FOR A PARTICLE TO PASS : PT = 3.00268E-09(S)
DT-STEPS FOR A PARTICLE TO PASS : NPT = 271
CONDUCTIVITY OF THE METAL : KAPPA = INFINITE
SIGMA OF THE GAUSSIAN BUNCH : SIG = 3.500000E-01(M)
NUMBER OF STAND.DEV. USED : ISIG = 4/- 4
FIRST PARTICLE ENTERS AT : SBEG = 1.40000E+00(M)
DT-STEPS FOR THE BUNCH TO PASS : NPTB = 1111
NUMBER OF UNKNOWN ER : NER = 3038
NUMBER OF UNKNOWN EZ : NEZ = 3046
NUMBER OF UNKNOWN H : NH = 3080

INPUT-DATA FOR WAKEFIELD CALCULATION:

WAKEFIELD BETWEEN THE BUNCH COORDINATES UBF = 0.0 (M)
AND UBT = 1.00000E+01(M)
WAKEFIELD BETWEEN THE CAVITY COORDINATES ZCF = 5.00000E+00(M)
AND ZCT = 8.95000E-01(M)
NUMBER OF WAKEFIELD POINTS NW = 1001
NUMBER OF TIME STEPS NEEDED FOR WAKE NTW = 3270

$PRINT:
PRINTOUT OF THE TOTAL ENERGY IN THE CAVITY

$************>> COMPUTATION TIME CONTROL ENTRY=END OF INPUT
$************>> TIME-STEP IT = 0 CPU-TIME USED SO FAR = 3.896 s CPU-TIME LEFT = 292.9 s

BEAMCHECK:
A GAUSSIAN BUNCH IS USED BETWEEN THE BUNCH COORDINATES +/- SBEG = +/- 1.40000E+00(M)
BCI USER'S GUIDE

MAX. CHARGE-DENSITY: 1.140E+00 (AS/M)  GREATEST STEP: 1.975E-02 (AS/M)  CONV.: WC=0.017  TOT. CHARGE: 9.99927E-01 (AS)

TEST7 EXAMPLE A, SPS 200 MHZ CAVITY  TEST7
TIME STEP = 1  TIME(H) = 1.0  TIME(ER,EZ) = 1.5  ZB(HEAD) = 5.000E-03M  ZB(CENTER) = -1.395E+00M  ZB(END) = -2.795E+00M
REAL TIME = 1.112E-02 NANOSECONDS

COMPUTATION TIME CONTROL  ENTRY=END OF TIME LOOP
TIME-STEP IT= 1  CPU-TIME USED SO FAR= 3.967  S  CPU-TIME LEFT= 292.8  S

TEST7 EXAMPLE A, SPS 200 MHZ CAVITY  TEST7
TIME STEP = 2270  TIME(H) = 2270.0  TIME(ER,EZ) = 2270.5  ZB(HEAD) = 7.565E+00M  ZB(CENTER) = 6.165E+00M  ZB(END) = 4.765E+00M
REAL TIME = 2.526E+01 NANOSECONDS

-- BUNCH OUTSIDE THE CAVITY

ENERGY/(VAS) IN THE CAVITY:  WELE= 1.7548E+09  WMAG= 1.1512E+10  WTOT(IT-0.5)= 5.7561E+09  WTOT(IT)= 1.2390E+10

COMPUTATION TIME CONTROL  ENTRY=END OF TIME LOOP
TIME-STEP IT= 2270  CPU-TIME USED SO FAR= 114.8  S  CPU-TIME LEFT= 181.9  S

and so on .................

TEST7 EXAMPLE A, SPS 200 MHZ CAVITY  TEST7
TIME STEP = 3270  TIME(H) = 3270.0  TIME(ER,EZ) = 3270.5  ZB(HEAD) = 1.089E+01M  ZB(CENTER) = 9.495E+00M  ZB(END) = 8.095E+00M
REAL TIME = 3.636E+01 NANOSECONDS

-- BUNCH OUTSIDE THE CAVITY

ENERGY/(VAS) IN THE CAVITY:  WELE= 1.2702E+10  WMAG= 4.6819E+08  WTOT(IT-0.5)= 1.3205E+10  WTOT(IT)= 1.3204E+10

COMPUTATION TIME CONTROL  ENTRY=END OF TIME LOOP
TIME-STEP IT= 3270  CPU-TIME USED SO FAR= 162.4  S  CPU-TIME LEFT= 134.4  S
## LIST OF CALCULATED WAKEFIELD IN VOLT AS A FUNCTION* OF THE WAKEFIELD COORDINATE U IN METER

<table>
<thead>
<tr>
<th>U/M</th>
<th>WAKE/V</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>-5.1457E+08,  4.2286E+08,  3.9820E+08,  3.2512E+08,  3.1404E+08,  3.0493E+08,  3.2140E+08,  4.0222E+08,  3.1675E+08</td>
</tr>
<tr>
<td>1.000E-01</td>
<td>1.100E-01,  1.200E-01,  1.300E-01,  1.400E-01,  1.500E-01,  1.600E-01,  1.700E-01,  1.800E-01,  1.900E-01</td>
</tr>
<tr>
<td>2.000E-01</td>
<td>2.100E-01,  2.200E-01,  2.300E-01,  2.400E-01,  2.500E-01,  2.600E-01,  2.700E-01,  2.800E-01,  2.900E-01</td>
</tr>
</tbody>
</table>

and so on ................

<table>
<thead>
<tr>
<th>U/M</th>
<th>WAKE/V</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.600E+00</td>
<td>9.610E+00,  9.620E+00,  9.630E+00,  9.640E+00,  9.650E+00,  9.660E+00,  9.670E+00,  9.680E+00,  9.690E+00</td>
</tr>
<tr>
<td>7.1879E+10</td>
<td>7.2095E+10,  7.3097E+10,  7.3108E+10,  7.3833E+10,  7.3617E+10,  7.4083E+10,  7.3636E+10,  7.3825E+10,  7.3147E+10</td>
</tr>
<tr>
<td>9.700E+00</td>
<td>9.710E+00,  9.720E+00,  9.730E+00,  9.740E+00,  9.750E+00,  9.760E+00,  9.770E+00,  9.780E+00,  9.790E+00</td>
</tr>
<tr>
<td>7.3574E+10</td>
<td>7.2175E+10,  7.1825E+10,  7.0701E+10,  7.0094E+10,  6.8753E+10,  6.7878E+10,  6.6327E+10,  6.5207E+10,  6.3452E+10</td>
</tr>
<tr>
<td>9.800E+00</td>
<td>9.810E+00,  9.820E+00,  9.830E+00,  9.840E+00,  9.850E+00,  9.860E+00,  9.870E+00,  9.880E+00,  9.890E+00</td>
</tr>
<tr>
<td>6.2067E+10</td>
<td>6.0143E+10,  5.8513E+10,  5.6463E+10,  5.4549E+10,  5.2274E+10,  5.0211E+10,  4.7769E+10,  4.5509E+10,  4.2941E+10</td>
</tr>
<tr>
<td>9.900E+00</td>
<td>9.910E+00,  9.920E+00,  9.930E+00,  9.940E+00,  9.950E+00,  9.960E+00,  9.970E+00,  9.980E+00,  9.990E+00</td>
</tr>
<tr>
<td>4.0487E+10</td>
<td>3.7788E+10,  3.5167E+10,  5.2378E+10,  2.9590E+10,  2.6719E+10,  2.3790E+10,  2.0866E+10,  1.7812E+10,  1.4884E+10</td>
</tr>
<tr>
<td>1.000E+01</td>
<td>1.1699E+10</td>
</tr>
</tbody>
</table>

TOTAL ENERGY GAIN OF THE BUNCH=-1.32442E+10VAS

---

* disclaimer: the asterisk (*) symbol is used to indicate that the data is approximate or estimated. 

---

**BCI ENDED WITHOUT ERROR**

---
9.2 Fundamental beamloading, higher mode losses

The loss into the cavity is proportional to the square of the total charge in the bunch. The charge independent loss parameter is thus obtained by dividing the stored energy by $Q^2$. In order to get the loss parameter in units of $V/pC$ one has to divide by $10^4 \times 12$. One also may get the loss parameter out of the amplitude of the wake field far behind the bunch, but in this case one has to divide only once by the charge, since the wake field is proportional to the total charge in the bunch.

Thus we finally get for the loss parameter:

$$k_{0}(V/pC) =$$
$$= (\frac{W_{tot}}{V_{As}}) \times$$
$$\times \exp(\omega e a 2 \times \sigma e a 2 / c \times 2) / \left(10^4 \times 12 \times (Q/As) \times (Q/As)\right)$$

Since the fundamental frequency is known from the job TEST7 and also the stored energy in the cavity, $k_{0}$ becomes:

$$k_{0} = 0.113 \ \frac{V}{pC}$$

For this calculation it is assumed that no higher mode has been excited by the bunch. This assumption can always be made if the exciting bunch is long enough. Since we now know the fundamental loss parameter, the higher mode losses may be obtained by using BCI with different bunchlengths and by subtracting the loss into the fundamental mode.

In example A we finally get:

$$k(\text{fundamental, 0cm}) = 0.113 \ \frac{V}{pC}$$
$$k(\text{fundamental, 7cm}) = 0.113 \ \frac{V}{pC}$$
$$k(\text{higher modes, 7cm}) = 0.052 \ \frac{V}{pC}$$
$$k(\text{all modes, 7cm}) = 0.155 \ \frac{V}{pC}$$

In order to get the total loss of a bunch one should always use the total energy printed (ENERGY,--> WTOT) and the integrated wake field.
9.3 Total energy gain including wake fields and accelerating voltages

Before we analyse a wake field we have to do a job which saves the information into the file NWAK. We set NWAK=3 in the $PARAM input and run the job:

```
//WEITEST8 JOB,WEILAND,TIME=2
// EXEC NFORICLG,
// LLBI='CR.PUB.PRO.PGMLIB',
// GRON=800K
//C.SYSIN DD *
CALL BCI
STOP
END
```

```
//G.SYSIN DD *
$PARAM NWAK=3 $END
$TEXT
TEST8 EXAMPLE A, SPS 200 MHZ CAVITY TEST8
$BOUNDARY
1,3,3
$MESH
50,91
0.490 0.900
$CAVITYSHAPE
0.00
0.000 0.000
0.070 0.000
0.070 0.285
-1.,0.01
0.089 0.289
0.120 0.199
-1.0.080
0.200 0.119
0.290 0.119
-1.0.200
0.490 0.319
0.490 0.581
-1.0.200
0.290 0.781
0.200 0.781
-1.0.080
0.120 0.701
0.089 0.611
-1.0.01
```

```
BCI USER'S GUIDE

SBEG=.0
NTADD=0
NREC=0
NSAV=0
NREP=0
NWAK=3
ITEST=0
LBOX1=1
LBOX2=1
LBOX3=1
LTEST=1
LSMTH=F
QFX1=.500000007E-01
QFX2=.500000007E-01
QFY1=.500000007E-01
QFY2=.149999976
QFY3=.500000007E-01

PAM SOURCE= BCI 1.00 802511 15.20 CERN PROGRAM LIBRARY BCI=T310

CALL OF BCI (FIRST PARTICLE ENTERS AT (SBEG) : SEE BELOW
RECOVER FROM FILE (NREC) : NO RECOVERING
SAVE RESULTS INTO FILE (NSAV) : NO SAVING
TIME STEPS TO ADDED (MTADD) : -
SAVE WAKEFIELD INTO FILE (NWAK) : 3
TEST MODE (ITEST) : PRODUCTION )

*****************************************************************************

TEST8 EXAMPLE A, SPS 200 MHZ cavity TEST8

*****************************************************************************

** BCI ** BEAM-CAVITY INTERACTION PROGRAM FOR CYLINDRICALLY SYMMETRIC
CAVITIES OF ARBITRARY SHAPE AND BEAMS OF ARBITRARY SHAPE ON THE AXIS

JOB DATE: 26/11/80  JOB TIME: 10.47.48  JOB NAME: WEITST8  BCI-LEVEL(25/11/80)

BOUNDARY CONDITIONS  UPPER : IRU = 1 (E-TANGENTIAL=ZERO)

and so on  ......................

*****************************************************************************

TEST8 EXAMPLE A, SPS 200 MHZ cavity TEST8
TIME STEP = 450  TIME(H) = 450.0  TIME(ER,EZ) = 450.5  ZB(HEAD) = 1.495E+00M  ZB(CENTER) = 1.215E+00M  ZB(END) = 9.350E-01M
REAL TIME = 5.003E+00 NANOSECONDS

--> BUNCH OUTSIDE THE CAVITY

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx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TEST8 EXAMPLE A, SPS 200 MHZ CAVITY TEST8

(W)=WAKEFIELD=ENERGY GAIN IN (V) AS A FUNCTION OF THE BUNCH COORDINATES IN (M), (X)=BUNCH SHAPE

5.00E+10

and so on as in JOB TEST2

-2.00E+11

-2.50E+11

0.0

1.00E-01

2.00E-01

3.00E-01

4.00E-01

5.00E-01

LIST OF CALCULATED WAKEFIELD IN VOLT AS A FUNCTION OF THE WAKEFIELD COORDINATE U IN METER

U/M = 0.0

WAKE/V = -1.8745E+09 1.7262E+09 -1.2630E+09 1.6122E+09 -9.9866E+08 1.8578E+09 -8.1389E+08 1.9060E+09 -1.0746E+09 1.3751E+09

and so on as in JOB TEST2


U/M = 5.0000E-01 5.1000E-01 5.2000E-01 5.3000E-01 5.4000E-01 5.5000E-01 5.6000E-01


TOTAL ENERGY GAIN OF THE BUNCH=-1.55095E+11 VAS

BCI ENDED WITHOUT ERROR
The following program is called WAKPLO and is independent of BCI, i.e. it does not call BCI subroutines. The input data have to be given in a $\text{SPARM}$ namelist. The parameters are:

- **VRFP** (0.0) peak voltage of the RF
- **ANGLE** (0.0) stable phase angle
- **QACT** (1.0) total charge to be used
- **FREQ** (0.0) frequency of the RF voltage in Hz
- **QVSYN** (0.0) synchrotron radiation losses
- **NCELL** (1) number of RF cells
- **LVLIN** (F) $T \Rightarrow$ RF voltage linear
- **LSMOTH** (F) $T \Rightarrow$ wake field will be smoothed, same procedure as in BCI itself
- **SHIFT** (0.0) distance between the first particle and the bunch centre (stable phase angle counted with respect to the bunch centre).

- **SCALE** (1.0) scale factor for all voltages
- **QXSHIF** (0.0) will be added to the bunch coordinates
- **QXSCAL** (1.0) scale factor for the particle position
- **LPRINT** (T) $T \Rightarrow$ produces line printer graph
- **LPLDT** (T) $T \Rightarrow$ produces a plot
- **LMAPX** (F) $T \Rightarrow$ x-axis rounded to even numbers
- **LMAPY** (T) $T \Rightarrow$ y-axis rounded to even numbers

The input data in this example are chosen as:

```
$SPARM
VRFP =2.0E6, ANGLE =130.0, FREQ =200.0E6, QACT =5.0E-6
SHIFT =0.28 , QXSHIFT=-0.28, QXSCAL=1.0 , LVLIN =.F.
LPLDT =.T .
$END
```

The output of this job and Fig. 23 now show the final energy potential inside the bunch, including the accelerating voltage and the synchrotron radiation losses.
*** BCI - WAKEFIELD PLOT/PRINT PROGRAM ****************************

********>>> START OF READING THE WAKEFIELD FROM FILE10
********>>> WAKEFIELD SUCCESSFULLY READ

WAKEFIELD TAKEN FROM JOB:

JOBNAME = WEXITEST8
JOB DATE = 26/11/80
JOBTIME = 10:47:48

STEP SIZE BETWEEN POINTS DDZ = 1.000E-02M
VELOCITY OF THE BUNCH VEL0 = 2.998E+08M/S
TOTAL CHARGE IN THE BUNCH QTOT = 1.000E+00AS
NUMBER OF WAKEFIELD VALUES NW = 57
NUMBER OF BUNCH SHAPE VALUES NB = 57

&PARM
VRFP = 2000000.00
ANGLE = 130.000000
FREQ = 200000000.
QVSYN = 1532000.00
NCELL = 1
LVLIN = F
LSMOTH = F
QACT = 499999997E-05
SHIFT = 279999971
SCALE = 1000000.00
QXSHIF = -279999971
QXSCAL = 1.00000000
LPL0T = T
LPRINT = T
LMAPX = F
LMAPY = F
&END
RF-PARAMETERS USED:

AMPLITUDE OF FUNDAMENTAL   VRF = 2.000E+06V
UNIT OF ALL ENERGIES   SCALE = 1.000E+06V
FREQUENCY   FREQ = 2.000E+08HZ
RADIATION LOSSES   QVSYN = 1.532E+06V
NUMBER OF CELLS/TURN   NCELL = 1
SHIFT IN RADIANTS TO 1. POINT   Θ = 2.800E-01M
PHASE ANGLE IN DEGREES   ANGLE = 130.00
ACTUAL BUNCH CHARGE   QACT = 5.000E-06AS

SHIFT IN X   = -2.800E-01M
SCALE IN X (XPLT=SCALE*X)   = 1.000E+00
SCALE IN X (X=SCALE*XPLT)   = 1.000E+00

LINEAR RF VOLTAGE   LVLIN = F
RF VOLTAGE AT SYN. POINT   VRF0 = 1.532E+06V
TIME DERIV. OF RF VOLTAGE   VDOT = -1.616E+15V/S
LONG. DERIV. OF RF VOLTAGE   VPRIM = -5.389E+06V/M

ENERGY BALANCE:

GAIN DUE TO ACC. RF = 1.467E+06 VAS
LOSS DUE TO WAKE = 7.755E+05 VAS
LOSS DUE TO RADIATION = 1.532E+06 VAS
TOTAL ENERGY GAIN = -8.400E+05 VAS

MINIMAX OF ALL VOLTAGES IN (VOLT*SCALE)

VRFMIN = -0.212E+01  VRFMAX = 0.468E+00
WAKMIN = -0.104E+01  WAKMAX = 0.953E-02
SUMMIN = -0.229E+01  SUMMAX = 0.465E+00

USED MINIMAX FOR PLOTTING:

XMIN = -0.28000E+00M  XMAX = 0.28000E+00M
YMIN = -0.25479E+01V  YMAX = 0.46779E+00V
5.0E-01
0.0
-5.0E-01
-1.0E+00
-1.5E+00
-2.0E+00
-2.50E+00
-3.00E-01
-2.0E-01
-1.00E-01
0.0
1.00E-01
2.00E-01

COMMENT: W=Wake field, V=RF voltage, S=sum=total voltage, B=Bunch shape

*** BCI - WAKEFIELD PLOT/PRINT PROGRAM *END*  ***********************************
10. Machine dependent subroutines

All externals are described in more detail in the source at the beginning of each subroutine.

The main group of external subroutines is the package for graphical output. All these subroutines are described in detail in the GD3, CERN program library J510, long write-up. We will give only a short list:

TVDRAW(X,Y,N)
draws a polygon along the N coordinates in X(N), Y(N)

TVRNG(2HX0,UX0,DX0)
sets up the correlation between the left bottom corner of a frame in user coordinates (UX0) and in the coordinates of the graphical device (DX0). This routine is called for all four corners with the arguments: 2HX0/X1/Y0/Y1 and the coordinates respectively.

TVBGH(II)
This routine initializes the graphical output and defines file II as intermediate storage file for the graphical output.

TVEND
This routine is the last one to be called. It closes the storage file.

TVNEXT(IFRAME)

Since the graphical output contains several frames, this routine has to be called to start a new one with the number IFRAME.

TVSET(5HSMALL) (6HMEDIUM)
By calling TVSET the size of the output character is chosen.

TVTEXT(X,Y,4HTEXT,4)
Starting at the point (X,Y) the text TEXT will be plotted. The last integer gives the number of output characters.

TVMTXT(X,Y,4HTEXT,4)
same as TVTEXT but the output is centered to (X,Y).

TVNUMB(X,Y,NUM,6H(F9.2),9)
Starting at the point (X,Y) the number NUM will be plotted using the FORMAT F9.2. The last integer gives the number of output characters.

The software version of the plotting routines use instead of TVSET, TVTEXT, TVMTXT the equivalent versions. Since this is of interest only for a user in CERN, the GD3 long write-up, J510, CERN program library, should be consulted if necessary. We will just give the list: TVORNT, TVMSS, TVMSSM. Details s. source listing.

In the MAIN program WAKPLO some other subroutines are used in addition. Since this program is strongly computer type dependent, we will also only give a short list:
BCI USER'S GUIDE

TVMODE
defines whether the user coordinate system or the device
coordinate system is in use.

TVMAP
determines the range of an array

TVGRPH
can draw curves with or without interpolation.

The subroutines MATE/PLOT1/PLOT2 exist in two versions,
ANSI and non-ANSI.

The non-ANSI versions use the bit-by-bit AND/OR
instruction together with masks to manipulate the bits. In
addition the masks may have to be changed depending if a
negative integer is stored as 1's or 2's complement. An IBM
and a CDC version of BCI exist in which all these
adjustments have been made.

In the ANSI version the bit manipulation is done by BCI
subroutines without any external functions. This version is
very cpu-time consuming (about 5\% more when
graphical output is produced) and should not be used unless
necessary. As long as no graphical output is to be
produced, the cpu time consumption of both versions is
almost the same.

Some information subroutines are called like:

DATIMH(DJOB, TJOB)
11. How to change the maximum number of mesh lines or mesh points

All dimensions have a nonzero last digit. Using a change operator with any editor one never gets into confusion with labels. Changing the number of mesh points from 20.004 to 10.004, the maximum number of radial lines from 501 to 301, the maximum number of longitudinal lines from 902 to 502 and the maximum number of wake field points from 5005 to 3003 would need the following commands:

change >5001< to >2501< 1/4 of the mesh point dimension  
change >10002< to >5002< 1/2 of the mesh point dimension  
change >20004< to >10004< mesh point dimension  
change >501< to >301< maximum number of r=const lines  
change >902< to >502< maximum number of z=const lines  
change >5005< to >3003< dimension of wake field array

These changes modify respectively the maximum numbers of mesh points, mesh lines and wake field points allowed by the program.

12. Layout of the graphical output.

Each single frame of the graphical output is divided into sub-boxes, see Fig.24. The fractional parts QFX1,QFX2,QFX3,QFY1,QFY2,QFY3,QFY4 and QFY5 are preset in the subroutine BCI. In order to change the layout of a picture one may change QFX1,QFX3,QFY1,QFY2,QFY4 and QFY5 in the $PARM namelist. This has to be done carefully!! The sums QFX1+QFX3 and QFY1+QFY2+QFY4+QFY5 must be less than 1. Other parameters to suppress the text and the boxes are described in Appendix B, chapter 16. The coordinates UX1,PX1 etc. are the coordinates in the user coordinate system and in the graphical device system. All these quantities are computed in the subroutine PLSCAL. To avoid confusion all the graphical operations are done in user coordinates.
13. BCI Reference card, short symbolic input data

// JOB.................. JOB control card
// EXEC NPORTCLG.LIB='CR.PUB.PRO.PGMLIB'........... compile, link, execute
//C.SYSIN DD *.............. Compiler input
CALL BCI
STDOUT
END
//G.SYSIN DD *.............. input data

$PARM
NSAV=7
NREP=0
    =9999
NREC=9
NUNIT=8
ITEST=0
    =1
NTADD=70
    =0
$SEEG=0.4
$END

$IDENTIFIER FOR THE DATA SET UP TO 72 CHARACTERS

$BOUNDARY
1,2,3

$MESH
50,91
0.490 0.900
OR
$$MESH
50,91
r(1),r(2),r(3),...r(50)
0.900

$CAVITYSHAPE

$CAVITYSHAPE

for input of the left half structure only

Conductivity of the inner area of the polygon
any number KAPPA, 9999.0 = infinite
first coordinates r1,z1
circle 0-π, concave, radius=0.01m

circle 0-π, convex, radius=0.05m

last point=first point
end of cavity shape input

specify time steps

total MT, per cell MT, first print NGF, frequency NGF

input of speed
speed in units of c

define a Gaussian bunch
sigma rms, use 4 sigmas in +/- direction

compute the wake field inside the bunch

compute the wake field between 0.15m, i.e. from the first particle on 15 m backwards

compute the electric field between 0. and 0.9m

in the cavity into account

produce graphical output

plot 15 proportional field lines

or 20 field lines for each plot
electric field

lines of total current

used mesh
cavity used in the mesh

input cavity and used cavity

mesh and input cavity

mesh and used cavity

beamshape

produce a line printer output

radial electric field

longitudinal electric field

ez on the axis

azimuthal magnetic field

charges on the mesh points

print plot of total current lines

print plot of electric field lines

energy in the structure

radial total currents

longitudinal total currents

That's it.
14. Literature


/3/ T. Weiland, Diffraction of electromagnetic waves on scatterers of arbitrary shape and arbitrary material. Kleinheubacher Berichte, FTZ-Darmstadt, 1980


/6/ The LEP Study Group, Design of a 22 to 130 GeV e+ e- colliding beam machine (LEP). CERN/ISR-LEP/79-33, 1979

/7/ T. Weiland, Higher mode losses in the PS cavity and in the SPS standing wave cavity. CERN/Lep-note 236, 1980, unpublished
15. Appendix A, BCI on the CERN CDC

The CDC version of BCI is also in a binary library in order to allow an optional user SHAPE routine. The user must provide a short main PROGRAM calling BCI and declaring the libraries:

PROBCILIB,ID=PROGLIB.
7600LIBRARY,ID=PROGLIB.

The PROGRAM card should have the form:

PROGRAM USEBCI (INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4,TAPE5
  ,TAPE11,DISPLAY
  ,TAPE1=INPUT,TAPE2=OUTPUT,TAPE11=DISPLAY)

The input is on TAPE1, the output on TAPE2 and the DISPLAY graphics file on TAPE11. For NWAK, NREC and NSAV one should use TAPE3, TAPE4 and TAPE5. The input data have the same form as for IBM.

The maximum number of mesh points is 20,000. Since the word length on CDC (60 bits) is almost twice as long as on the IBM, this program uses the SCM and LCM storage.
16. Appendix B: Additional parameters in $SPARM

In the first namelist input some more parameters may be changed:

LSMOOTH (def=F)
Setting LSMOOTH to .T. will cause an artificial smoothing of a computed wake field. This is done by the subroutine SMOOTH, which integrates the wake field locally and thus replaces a saw tooth wake function by a smooth one.

LBOX1 (def.=T.), LBOX2 (def.=T.), LBOX3 (def.=T.)
Setting these logical variables to .F. will suppress the boxes, which are drawn around the inner most picture.

LTEXT (def.=T.)
Setting LTEXT to .F. will suppress in all pictures but the first one the output of the time on top of the picture.

QFX1 (def.=0.05)
QFX3 (def.=0.05)
QFY1 (def.=0.05)
QFY2 (def.=0.15)
QFY4 (def.=0.15)
QFY5 (def.=0.05)

may be reset to change the layout of a picture. See Fig. 24 for definitions. QFX2 is calculated by BCI:

QFX2=1.-QFX1-QFX3 and QFY3 as well:
QFY3=1.-QFY1-QFY2-QFY4-QFY5. Thus one has to be careful to avoid negative values for QFX2 and QFY3!!

ITEST (def.=0)
for the normal TEST mode, ITEST may be set to any integer. Several special values of ITEST produce an immense amount of test output and should be avoided: 666,777,888 and 999.
// JOB
// EXEC NFORCLG,LLBI='CR.PUB.PRO.PGMLIB'
// $PARM
NSAV=7
NREP=0
  =88
  =9999
NREC=9
NWAK=8
ITEST=0
1
NTADD=70
  =50
SBEG=0.4
$END

job control card
compile, link, execute
Compiler input

input data

start of parameter input
save common blocks into file 7
do this before each printout
do this every 88 time steps
do this only just before an abnormal end
restart a preceding job, which dumped into file 9
save the wake field into file 8
production
TEST mode
when recovering, execute another 70 time steps
when recovering, execute another NT time steps
for user-defined bunches, nonzero in +/- 0.4 m
end of parameter input

$TEXT
IDENTIFIER FOR THE DATA SET UP TO 72 CHARACTERS

Keyword to give data identification
Identifier

$BOUNDARY
1,2,3

Keyword to input boundary conditions
IRU,IZL,IZR ; 1:Et=0, 2:Ht=0, 3:open

$MESH
50,91
0.490 0.900

Keyword for equidistant mesh
total radius, total length of the structure

OR

$SMESH
50,91
r(1),r(2),r(3),...,r(50)
0.900

Keyword for user input mesh
NR,NZ as before
r-values for the mesh lines
total structure length

$CAVITYSHAPE

Start of cavity shape input

for input of the left half structure only
Conductivity of the inner area of the polygon
any number KAPPA, 9999.0 = infinite
first coordinates r1,z1
circle 0-pi, concave, radius=0.01m
circle 0-pi, convex, radius=0.08m
$TIMESTEP 6360 4 200,200
$SPEED 1.0
$BEAM 0.09,4
$WAKE OR $WAKE + the data
$PLOT 15 or -20
EPLLOT CURPLOT MESH CAVITYUSED
CAVICAVU MESHCAV
MESHCAVU BEAMSHAPE
$PRINT ER EZ BEAM H
CHARGE CURPLOT EPLLOT ENERGY
RCUR ZCUR
$END

last point = first point
end of cavity shape input
specify time steps
total NT, per cell NT, first print NSF, frequency NSF
input of speed
speed in units of c
define a Gaussian bunch
sigma rms, use 4 sigmas in +/- direction
compute the wake field inside the bunch
compute the wake field between
0.15m, i.e. from the first particle on 15 m backwards
take the electric field between 0. and 0.9m
in the cavity into account
produce graphical output
plot 15 proportional fieldlines
or 20 fieldlines for each plot
electric field
lines of total current
used mesh
cavity used in the mesh
input cavity and used cavity
mesh and input cavity
mesh and used cavity
beamshape
produce a line printer output
radial electric field
longitudinal electric field
Ez on the axis
azimuthal magnetic field
charges on the mesh points
print plot of total current lines
print plot of electric field lines
energy in the structure
radial total currents
longitudinal total currents

That's it.
Fig. 3

\[ \frac{\lambda(s)}{A_s/m} \]

$\frac{s}{m}$
Fig. 4

Wake field $= W(u)$

Line charge density $= \lambda(s)$
Fig. 5

TEST1 EXAMPLE A, SPS 200 MHz CAVITY TEST1

JOBIDENTIFICATION  26/11/90  10.40.27  WEITEST1

INPUT CAVITY SHAPE
Fig. 6

MESH
Fig. 3

MESH - USED CAVITY
MESH - INPUT CAVITY
**Fig. 11**

<table>
<thead>
<tr>
<th>TEST2 EXAMPLE A, SPS 200 MHZ CAVITY TEST2</th>
</tr>
</thead>
<tbody>
<tr>
<td>JOBIDENTIFICATION</td>
</tr>
</tbody>
</table>

**INPUT CAVITY SHAPE**
Fig. 14

TEST3 EXAMPLE B, LEP 353MHz CAVITY TEST3

JOB IDENTIFICATION 26/11/80 10.38.24 WDETEST3

INPUT CAVITY SHAPE
Fig. 17

MESH - USED CAVITY
CAVITY USED - CAVITY INPUT
7.44 ns
Fig. 23

BCI - WAKE POTENTIAL PLOT PROGRAM

PARTICLE POSITION
Fig. 24

$\rightarrow X \ (UXM, PXM)$

$UXM, PXM$

$FY5$

$UY5, PY5$

$FY4$

$UY4, PY4$

$FY3$

$UY3, PY3$

$FY2$

$UY2, PY2$

$FY1$

$UY1, PY1$