A new Version of the Full-wave ICRH Code FISIC for Plasmas with Non-circular Flux Surfaces

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ABSTRACT

A user's manual for a new version of the FISIC code which is now applicable to arbitrary (toroidal) geometry is presented. It contains a description of the input parameters and quantities as well of all subroutines and a list of all common blocks.

1. Introduction.

To simulate ICRF heating experiments in Tokamak plasmas the FISIC code solves the integro–differential wave equation in the finite Larmor radius approximation in fully toroidal geometry. The code models the electromagnetic wave field as well as antenna coupling and power deposition profiles in axisymmetric plasmas.

A detailed description of the physical model and the numerical method including a discussion of the validity of the approximations which have been made and of the convergence properties can be found in [1], [2] and [3]. The last two references, however, refer to an older version which assumes that the magnetic flux surfaces have circular, concentric cross sections. The MHD–equilibrium and the flux surfaces used in the new version are described in [1]. The correct expressions for the differential operators in the underlying model in terms of the metric coefficients as introduced in [1] are given in the descriptions of the routines *DPLEPL*, *ROTEPS*, *ROTEET*, *ROTEPA* and *DIVE* in chapter 3.

A description and "user manual" of the older version of the code can be found in [4]. Besides the more general geometry, which requires also the specification of some new input quantities, the structure of the new version is also slightly different. It still consists of three sets of routines which shall be called in the following program FISIC, program BALANCE and program DPROF. The first program initialises the code, evaluates the stiffness matrix and solves the linear system, i.e. computes the poloidal spectra of the electromagnetic wavefield at the radial gridpoints and stores them as well as the input quantities and some plasma parameters and profiles externally on Cray–disc. They will be read by the program BALANCE. It is thus made shure that the programs FISIC and BALANCE assume the same input and profiles. Moreover some output and plots of quantities characterising the plasma can be obtained. The program FISIC can also be run without evaluating the stiffness matrix and solving the linear system. It is then just a test program which might be used to facilitate the adjustment of certain parameters. Consequently in this case no data are stored externally.

Upon reading the data provided by the program FISIC the program BALANCE evaluates the power deposition profiles and the antenna load due to one toroidal

mode and stores them together with some other quantites externally. These data will be used by the program DPROF which evaluates the total energy balance, i.e. the sum over all toroidal modes. (The programs FISIC and BALANCE treat per run only one toroidal mode to be specified). Moreover the electric wavefield can be visualised in various plots. Since this diagnostic requires much less CPU–time, it can also be done without evaluating the power balance and consequently without providing any external data sets.

The program DPROF finally reads for a ICRH scenario the data sets provided by previous runs of BALANCE and evaluates the total power balance and deposition profiles summed over all toroidal modes excited by the antenna.

The code is designed in such a way that the parts which require most of the CPU–time, i.e. the program FISIC and the part of the program BALANCE which evaluates the power deposition profiles for a single toroidal mode, are independent of the toroidal spectrum of the antenna current, so that once the programs FISIC and BALANCE have been run for several toroidal modes n_φ, a simulation of different antenna types can be done without major additional effort.

The rest of this report is organised as follows: In the next chapter the Fortran PARAMETERs and the input quantities to be specified by the user are dicussed. In chapter 3 the routines used in the program FISIC are described. Most of these routines are also called in the program BALANCE. The additional routines used in BALANCE are discussed in chapter 4, the additional routines in DPROF in chapter 5. Finally chapter 6 contains a list of all common blocks and says in which routines they are referenced.

2. Parameters and input variables for the programs FISIC and BALANCE.

With the exception of those variables, which are needed to control the plotting of certain quantities (NAMELIST *IPLOTF*) and the diagnostic (NAMELIST *DIAGF*), the input variables of the code are read once in the program FISIC as NAMELIST *INPUT*. Temperature and density profiles are specified in the routine *PROINI*, the poloidal spectrum of the antenna current in the routine *ANTC*, the toroidal spectrum in the routine *TORSP*. Moreover some integer numbers used to dimension arrays must be specified as Fortran PARAMETERs.

2.1. FORTRAN PARAMETERS.

The following Fortran PARAMETERs have to be specified first:

NM Number of poloidal modes N_m; The largest prime factor of *NM* must not exceed 19. This condition arises from the FFT–Routine used to reconstruct the electromagnetic field after its Fourier modes have been evaluated. On the Cray X–MP memory space sets an upper limit of $NM \leq 108$. Odd numbers might be preferred so that there are as many positive as negative modes in the sample.

NTT Number of poloidal gridpoints N_p used for the poloidal integration of resonant terms by FFT. *NTT* must be a potency of 2 and larger than $2 \cdot NM$, a typical value is $NTT = 128$.

NTTS Number of poloidal gridpoints N_{ps} used for the poloidal integration of nonresonant terms by FFT.*NTTS* must be a potency of 2, *NTTS*=8 or 16 should ensure sufficient resolution.

NELM Parameter used for dimensioning of radial arrays. Must be equal or larger than the actually used number of finite elements N_{elem} which is evaluated in the routine *MESH*.

NGAUS Number of Gauss points N_g used in the radial integration per finite element. A typical value is $NGAUS = 3$.

NVRB Number of variables N_{vrb}; $NVRB = 2$ unless one changes the code so that all three components of the electric wavefield are explicit variables.

NPROF Number of radial gridpoints for spline interpolation of density and temperature profiles and poloidal component of the static magnetic field.

NMHD Number of gridpoints for spline interpolation of the radial functions which determine the MHD equilibrium.

Then the PARAMETERS *NUP2=NM/2, NTT2=NTT/2, NTTS2=NTTS/2* and $NELM1 = NELM + 1$ are evaluated.

2.2. VARIABLES TO BE READ AS NAMELIST INPUT.

The following input variables specifying basic plasma and Tokamak properties as well as some adjustable parameters are read by FISIC as NAMELIST *INPUT* :

$NSPEC$	Number of ion species, must be smaller than 5.
$DENEC$	Central electron density $n_e(0)$, in electrons per cubic cm.
$DENIC(I),\ I = 1, NSPEC$	Relative densities of the ion species in %, must add up to 100. Firts species should be the majority
$ATM(I),\ I = 1, NSPEC$	Atomic mass number of the ion species.
$AZI(I),\ I = 1, NSPEC$	Atomic charge number of the ion species.
$TEMPEC$	Central electron temperature $T_e(0)$, in eV.
$TEMPIC(I),\ I = 1, NSPEC$	Central ion temperatures $T_i(0)$, in eV.
RT	R_T, distance plasma center–vertical axis (large radius), in cm.
RW	r_W, distance plasma center–wall at low field side (l.f.s.), in cm.
$RANT$	r_{Ant}, distance plasma center–antenna at l.f.s., in cm.
$RPLAS$	a, distance plasma center–separatrix or limiter at l.f.s., in cm.
$RSHIFT$	Shafranov–shift of the magnetic axis from $R = R_T$, in cm.
$ZELLIP(1)$	Ellipticity of the flux surfaces at the magnetic axis
$ZELLIP(2)$	Ellipticity of the outer magnetic flux surface (at the wall).
$ZTRIAN$	Triangularity of the outer magnetic flux surface (at the wall).
ALC	Effective poloidal propagation length $\sqrt{LC}$ of the antenna.
$BZERO$	Strength B_0 of the toroidal magnetic field at the plasma center, in Gauss.
$AJTOR$	Toroidal plasma current I_{tor}, in Ampère.

$FREQCY$	applied Frequency ν, in Hz.
$NPHI$	Toroidal mode number n_φ.
EPS	Parameter ϵ to adjust the "stoch." IBW damping, should be of order 1.
XSI	Parameter χ to determine the effective collisional frequency so that sufficient resolution of ion cyclotron resonances is ensured, should be of order 1.

Moreover the NAMELIST $INPUT$ contains the following integer variables to control different options :

$IRES1 = 1/0$	Fundamental cyclotron resonance/ no fundamental cyclotron resonance of any ion species lies in the plasma. In the latter case, the corresponding term is treated as local operator and in the power balance the evaluation of the absorption due to ICD at the fundamental resonance is omitted. The default value should be $IRES1 = 1$.
$IRES2 = 1/0$	Harmonic cyclotron resonance/ no harmonic cyclotron resonance of any ion species lies in the plasma. In the latter case the power balance does not evaluate the absorption due to ICD at the harmonic resonance. The default value should be $IRES2 = 1$.
$ISTOCH = 1/0$	"Stochastic" IBW damping included/ not included, should be 1 if an IBW might be excited.
$IBND = 1/0$	Contributions due to the ion FLR current in the boundary terms at the antenna included/not included. The difference between these two options is very small, the first one is the correct one from the physical point of view, the latter is simpler.
$IFLR = 1/0$	Ion FLR current included/ not included. In the latter case a specification of $IRES2$ and $IFLR$ is not neccessary. The default value should be $IFLR = 1$.
$ISOL$	If $ISOL$=0 the stiffness matrix is not evaluated and the linear system not solved. The program is then just a test routine to evaluate certain plasma parameters and to draw the plots specified by the NAMELIST $IPLOTF$.

2.3. VARIABLES TO BE READ AS NAMELIST IPLOTF.

The following plots can be obtained (x denotes here the horizontal coordinate in the equatorial plane). They are controlled by a set of variables which is read by FISIC as well as by BALANCE as NAMELIST *IPLOTF* :

$IOUT$	If $IOUT = 0$ no output will be given and the parameters described in the following have no meaning.
$ITEPL \neq 0$	$T_e(x)$.
$ITIPL = I$	$T_i(x)$ for the I–th ion species.
$IDPL \neq 0$	$n_e(x)$.
$IQPL \neq 0$	$q(\psi)$; This plot can be used to estimate for which poloidal modes $k_{\parallel}^{m,n_\varphi} \simeq (n_\varphi + m/q)/R_T$ is equal to zero.
$IXEPL \neq 0$	$x_{0,e}^{m=0}(x)$; This quantity is important to estimate kinetic damping through electrons.
$INB \neq 0$	$k_{\perp BW} \cdot \rho_i(\psi)$ at the high field side; This plot should facilitate the adjustment of the parameter ϵ in the "stoch." IBW damping term: The IBW is usually completely absorbed before $\epsilon(k_{\perp BW}\rho_i(\psi))^2 \gtrsim 1.3$.
$IPLF \neq 0$	Plot of the magnetic flux surfaces.
$ISPR \neq 0$	$\tilde{S}(x)$; This plot shows if and where an ion–ion hybrid resonance or an Alfv'en resonance $n_{\parallel}^2 = \tilde{S}$ lie within the plasma.
$ILPR \neq 0$	$\tilde{L}(x)$; This plot shows the position of ion cyclotron resonances as well as of the cut–off $n_{\parallel}^2 = \tilde{L}$ associated with an ion–ion hybrid resonance.
$IRPR \neq 0$	$\tilde{R}(x)$; This plot can be used to estimate the position of the low density cut–off $n_{\parallel}^2 = \tilde{R}$.
$ILAMPR \neq 0$	$\tilde{\lambda}_2(x)$, shows the position of second harmonic ion cyclotron resonances.
$ILPT \neq 0$	$\tilde{L}(\vartheta)$ at $\psi = PSIPLT$ and its Fourier transform.
$ILAMPT \neq 0$	$\tilde{\lambda}_2(\vartheta)$ at $\psi = PSIPLT$ and its Fourier transform.
$PSIPLT$	Flux surface for the two plots described above.

Some of the quantities are evaluated assuming $k_{\|} = n_{\varphi}/R$, i.e. for the poloidal mode $m = 0$. The last two plots give also some information if the poloidal mesh is dense enough to resolve the ion cyclotron resonances and can therefore be used to adjust the parameter χ.

2.4. VARIABLES TO BE READ AS NAMELIST DIAGF.

To control the diagnostic and which plots of the wavefield and the deposition profiles shall be drawn, the following variables are read by BALANCE as NAMELIST $DIAGF$:

$IEPLT = 0/1$	No plot/ plot of $E_\pm$ in the equatorial plane.
$NMPL,\ NMPL < 5$	Number of plots of the poloidal spectrum $E_+(m)$ and its Fourier transform $E_+(\vartheta)$ for fixed flux surfaces $\psi = PSIMPL$ to be specified. These plots are particularly useful to check the convergence in the poloidal direction, i.e. if NM has been chosen large enough.
$PSIMPL(I),\ I = 1, NMPL$	specifies flux surfaces for the above plots
$IHL(IC) = 0/1$	Determines if the contour lines of the component specified by IC shall be plotted.
$IC = 1$	$\mathrm{Re}(E_x)$
$IC = 2$	$\mathrm{Im}(E_x)$
$IC = 3$	$\mathrm{Re}(E_y)$
$IC = 4$	$\mathrm{Im}(E_y)$
$IC = 5$	$\mathrm{Re}(E_+)$
$IC = 6$	$\mathrm{Im}(E_+)$
$IC = 7$	$\mathrm{Re}(E_-)$
$IC = 8$	$\mathrm{Im}(E_-)$
$IC = 9$	$\lvert E_\perp \rvert$
$IC = 10$	$\lvert E_x \rvert$
$IC = 11$	$\lvert E_y \rvert$
$IC = 12$	$\lvert E_+ \rvert$
$IC = 13$	$\lvert E_- \rvert$
	Plotted is the region $XMIHL < x < XMAHL$, $YMIHL < y < YMAHL$, in cm.

E_x and E_y denote here the horizontal and vertical component of the perpendicular

electric field $E_\perp$. The units of the electric field is V/cm, normalised to an total antenna current of 1 Ampére.

$IBAL = 0/1$	If $IBAL = 0$ the part of the program which evaluates the deposition profiles and requires much more CPU–time than the other parts, will not be executed. In this case the variables discussed in the following need not to be specified.
$ITABL = 0/1$	No plot/plot of $dP_{ABS}(x)/(\psi\, d\psi\, d\vartheta)$ in the equatorial plane.
$IABPL = 0/1$	No plot/plot of $dP_{ABS}(\psi)/(\psi\, d\psi)$ integrated over magnetic flux surfaces.
$ISYM$	should be equal 0. $ISYM \neq 0$ causes a slightly different form of the local power deposition due to parallel kinetic flux terms.
$IDSAV$	If $IDSAV \neq 0$ the total antenna load and deposition profiles due to this toroidal modes are, together with the radial mesh and a few other parameters, stored externally for the program $DPROF$. The unit number for this data set is 11.

3. Description of the routines in FISIC.

Some of these routines will also be called in BALANCE and DPROF.

MAIN

reads the input quantities (NAMELIST $INPUT$) and the variables used to control the output (NAMELIST $IPLOTF$). Moreover charge neutrality is ensured. Then the subroutine $FISIC$ is called.

FISIC(IOUT, ISOL)

This subroutine first initialises the code by calling the routines $PARA$, $PROINI$, $MHDINI$, $MESH$, $GAUS$, $INIFFT$ and $ANTC$. Then, if $ISOL \neq 0$, the routines $STORE$ and $MASTSOL$ are called. $STORE$ stores some of the previously evaluated quantities, which will be used by the program $BALANCE$, externally to make sure that FISIC and BALANCE use the same data. $MASTSOL$ eval-

uates the stiffnes matrix, the right hand side of the set of equations, solves the linear system and stores the solution externally. If $ISOL = 0$ the program can be used just as test routine. If $IOUT \neq 0$ the subroutine $OUTPUT$ will be called which controls the output and provides the various plots specified by the variables in the NAMELIST $IPLOTF$.

PARA

evaluates the electron and ion plasmafrequencies $OMPE = \omega_{pe}$ and $OMPI(I) = \omega_{pi}; I = 1, NSPEC$, cyclotron frequencies $OMCE = \Omega_{ce}$ and $OMCI(I) = \Omega_{ci}; I = 1, NSPEC$ and thermal velocities $VTHE = v_{the}$ and $VTHI(I) = v_{thi}; I = 1, NSPEC$ at the plasma center and $OM = \omega = 2\pi\nu$. Moreover $PSIANT = \psi_{Ant}$, which labels the flux surface, in which the antenna's central conductor lies and $PSIPL = \psi_{pl}$ which is the flux surface in which the limiter or separatrix lie, are evaluated (this part might be changed if a new form an representation of the flux surfaces is chosen). Note that $\psi = 0$ corresponds to the magnetic axis and $\psi = 1$ to the vacuum vessel.

PROINI

evaluates density and temperature profiles on an equidistant radial mesh with $NPROF$ gridpoints $(PSIPRO(I); I = 1, NPROF)$ and initialises a cubic spline interpolation using the subroutine $CUBSPL$. The resulting spline tables are $TNE(I,4); I = 1, NPROF$ for the density $(TTE(I,4); I = 1, NPROF)$ for the electron temperature and $(TTI(I,4,IS); I = 1, NPROF; IS = 1, NSPEC)$ for the ion temperature profiles. Moreover $(PJAVG(I); I = 1, NPROF)$, which is proportional to $T_e^{3/2}$ and will be used to evaluate the poloidal component of the static magnetic field, is computed on the same gridpoints. In the present version the following form for the various radial profiles $f(r)$ has been assumed:

$$f(r) = \begin{cases} f(0) - (f(0) - f(a)) \left(\psi/\psi_{pl}\right)^{\gamma}, & \text{if } \psi < \psi_{pl} \\ f(a) \cdot e^{-\frac{\psi-\psi_{pl}}{1-\psi_{pl}} \cdot (r_W - a)/\lambda}, & \text{if } \psi > \psi_{pl} \end{cases}$$

The following quantities must be specified:

$RDPL$; $RTEPL$;	$f(a)/f(0)$, relative values of the
$RTIPL(I)$,	density, electron temperature and ion temperatures
$I = 1, NSPEC$	at $\psi = \psi_{pl}$ compared to the central values.
$DEXP$; $TEEXP$;	Exponents γ of the various profiles for $\psi \leq \psi_{pl}$.
$TIEXP(I)$, $I = 1, NSPEC$	
$EDFLD$; $ETEFLD$;	Exponential decay lengths λ in the scrape off layer, in cm.
$ETIFLD(I)$, $I = 1, NSPEC$	

<u>$CUBSPL(H, C, NSP)$</u>

This subroutine initialises the cubic spline interpolation of a function on NSP equidistant points (distance=H). Upon entry the values at the gridpoints must be given as array $(C(I,1); I = 1, NSP)$. Upon exit the coefficients needed for of the spline interpolation are tabulated in the array $(C(I,J); I = 1, NSP; J = 1,4)$.

<u>$VALSPL(H, C, NSP, I, JDERIV)$</u>

This function evaluates the cubic spline interpolation of the $(JDERIV - 1)$'th derivative of the funtion whose spline coefficients are given by $(C(I,J); I = 1, NSP;$ $J = 1,4)$. I is the index of the gridpoint which is just below the reference point and H is the distance between this gridpoint and the reference point.

<u>$MHDINI$</u>

Initialisation of the MHD equilibrium. This subroutine evaluates first the radial functions $\Delta(\psi)$, $\rho(\psi)$, $D(\psi)$ and $\sigma(\psi)$ on the $NMHD$ equidistant gridpoints $(PSIMHD(I); I = 1, NMHD)$ and the coefficients $(BX0(I,J)$, $BX1(I,J)$, $BX2(I,J)$ and $BZ0(I,J)$; $I = 1, NMHD; J = 1,4)$ of their cubic spline interpolations using the subroutine $CUBSPL$. Then the volume elements $VOLUME(I) = \int d\vartheta R(\psi) J(\psi)$, the safety factor $PQR(I) = q(\psi)$ and the function $f_p(\psi)$, which is defined by $B^{pol} = \frac{N_T}{J}\frac{R_T}{R} \cdot f_p(\psi) \cdot B_0$, where $B_0 = BZERO$ denotes the toroidal magnetic field strength at $R = R_T$, are evaluated on the $NPROF$ radial gridpoints $(\psi = PSIPRO(I); I = 1, NPROF)$. For $f_p(\psi)$ the cubic spline coefficients $(TQR(I,J); I = 1, NPROF; J = 1,4)$ are computed using $CUBSPL$. The evaluation of these radial functions involves poloidal integrations within the flux surfaces, which are carried out using Simpson's rule. For this integration the metric coefficients N_T, J and R are needed in each flux surface ψ at certain angles ϑ.

To evaluate these quantities (and others) the subroutine $SMHD(PSI)$ is called once per surface $PSI = \psi$ and then $COORDS(THETA)$ is called for each angle $THETA = \vartheta$.

SMHD(PSI)

This subroutine evaluates the spline interpolations of $\Delta(\psi)$, $\rho(\psi)$, $D(\psi)$ and $\sigma(\psi)$ as well as their first and second derivatives at $\psi = PSI$ using $VALSPL$. These quantities are called $SBX0(I)$, $SBX1(I)$, $SBX2(I)$ and $SBZ0(I)$, respectively, where $(I-1;\ I = 1,3)$, labels the order of derivatives.

COORDS(THETA)

After $SMHD(PSI)$ has been called, $COORDS(THETA)$ can be used to evaluate the horizontal and vertical coordinates $UX = x$, $UZ = y$, the distance from the vertical axis $URHS = R_T + x$, the metric coefficients $ANTAU = N_\tau$, $AJ = J$, $AG = G$ and the derivatives $DXPSI = \frac{dx}{d\psi}$, $DXTH = \frac{dx}{d\vartheta}$, $DZPSI = \frac{dz}{d\psi}$, $DZTH = \frac{dz}{d\vartheta}$, $DNTAUP = \frac{1}{N_\tau}\frac{dN_\tau}{d\psi}$, $DJP = \frac{1}{J}\frac{dJ}{d\psi}$, $DNTAUT = \frac{1}{N_\tau}\frac{dN_\tau}{d\vartheta}$, $DJT = \frac{1}{J}\frac{dJ}{d\vartheta}$, $DGT = \frac{dG}{d\vartheta}$, $DTAUP = \frac{d\tau}{d\psi}$, $DTAUT = \frac{d\tau}{d\vartheta}$ at the position $\psi = PSI$, $\vartheta = THETA$. τ denotes an angle defined by $\cos\tau = \frac{1}{N_\tau}\frac{dz}{d\vartheta}$, $\sin\tau = -\frac{1}{N_\tau}\frac{dx}{d\vartheta}$.

SURF(PSI)

This subroutine evaluates the following surface quantities at $\psi = PSI$: Density $DENS$, electron temperature $TEMPE$, ion temperatures $(TEMPI(I); I = 1, NSPEC)$, $O2P = \frac{\omega_{pe}^2}{\omega^2}$, $(OMP2(I) = \omega_{pi}^2; I = 1, NSPEC)$, elctron and ion thermal velocities $VTE = v_{the}$ and $(VT(I) = v_{thi}; I = 1, NSPEC)$, electron and ion β, $BETAE = \frac{v_{the}^2}{c^2}\frac{\omega_{pe}^2}{\Omega_{ce}^2}$ and $(BETAI(I) = \frac{v_{thi}^2}{c^2}\frac{\omega_{pi}^2}{\Omega_{ci}^2},\ I = 1, NSPEC)$ as well as $BP0 = f_p$ and $BP1 = \frac{df_p}{d\psi}$ (cfr. description of $MHDINI$) and the effective collision frequencies $ANU1$, $ANU2$, $ANUE$, which will be used to evaluate the terms describing ICD at fundamental and harmonic resonance and ELD, respectively. In the present version they are all given by $\omega\frac{\chi 2\pi\psi r_W}{N_p R_T}$. If $IRES1 = 0$ or $IRES2 = 0$ we set $ANU1 = 0$ or $ANU2 = 0$, respectively. To compute some of these quantities the subroutine $VALSPL$ is called.

BFIELD

This subroutine can be called after $SMHD(PSI)$ and $COORDS(THETA)$ have been called to evaluate the following quantities at the position $\psi = PSI$, $\vartheta =$

$THETA$: The angle $\Theta = TETA$, which is defined by $\tan\Theta = B^{pol}/B^{tor}$, as well as $SINT = \sin\Theta$, $ACOST = \cos\Theta$, $TETADP = \frac{d\Theta}{d\psi}$, $TETADT = \frac{d\Theta}{d\vartheta}$ and the relative strength of the static magnetic field $BM = |\vec{B}|/B_0$ where B_0 denotes the strength of the toroidal field at $R = R_T$.

MESH

evaluates the radial gridpoints ($PSIME(I)$; $I = 1, N1$) with $PSIME(1) = 0$, $PSIME(N1) = 1$ and $JANT$ where $PSIME(JANT) = PSIME(JANT + 1) = \psi_{Ant}$. In the present version the number of gridpoints which are actually used is $N1 = NELM + 1$, the number of elements is $NELEM = NELM$ and $JANT = NELM - NANT$. $NANT$ is specified at the beginning of this routine. For $0 < \psi < \psi_{Ant}$ ($JANT - 1$ elements) and $\psi_{Ant} < \psi < 1$ ($NANT$ elements) the mesh is equidistant. Moreover the equidistant poloidal meshs ($AT(IT)$; $IT = 1, NTT$) and ($ATS(IT)$; $IT = 1, NTTS$) are computed.

GAUS

computes points $GF(I)$ and weights $GD(I)$ for Gauss–integration on $NGAUS$ points per finite element and the values of the cubic hermitean interpolating functions and their derivatives at these points. $FINTL(I, J, IG)$ denotes a function centered at the left, $FINTR(I, J, IG)$ at the right side of en element. The first index, I, is 1 for the function and 2 for its derivative, the second, J, labels the function and the third the Gauss point, where the value is computed.

INIFFT

initialises the two fast Fourier transforms (FFT's) used to carry out the poloidal integrations on NTT and $NTTS$ gridpoints. The cosine and sine tables are computed by the Cray– routine $CFFT2$.

FFTDIR(CFFT)

This subroutine evaluates the FFT of the array $CFFT(I)$, $I = 1, NTT$ on NTT points. It calls the Cray– routine $CFFT2$. Upon exit the spectrum is ordered in such a way that the negative modes come first.

FFTS(CFFT)

This subroutine does the same as $FFTDIR(CFFT)$, only for a smaller number of points $NTTS$.

ANTC

The central conductor of the antenna is assumed to lie in a magnetic flux surface at $\psi = \psi_{Ant}$ and the current flows perpendicular to the static magnetic field. We assume that the poloidal current distribution $J^{\#}(\vartheta)$ has the same form for all values of n_φ. $ANTC$ evaluates the arrays $CFJ(I)$, $I = 1, NTT$ and $CFXJ(I)$, $I = 1, NTT$ which are proportional to $J^{\#}(\vartheta)$ and $N_\tau J \cdot J^{\#}(\vartheta)$ at the NTT poloidal gridpoints used for the ϑ–integration, respectively. In the present version two common types of low field side antennas have been provided : If $IPOL = 1$ the feeders are at the end and the antenna is operated in "push–pull" (even current profile). If $IPOL = -1$ the feeders are in the equatorial plane and the current profile is odd. In both cases the antenna extends up to $\vartheta = \pm TMAX$. If $IRESA = 1$ the antenna is assumed to be resonant at the applied frequency and the value of ALC read at the beginning will in general be changed accordingly. For other antenna types CFJ and $CFXJ$ must be specified explicitely by the user. Furthermore the maximum current in the antenna (at the shorts) $AIANT$ is evaluated. This quantity will be used later to compute the antenna load. Finally the poloidal spectra of $J^{\#}$ and $N_\tau J \cdot J^{\#}$ are evaluated by calling $FFTDIR(CFJ)$ and $FFTDIR(CFXJ)$. To compute N_τ and J the routines $SMHD(PSIANT)$ and $COORDS(THETA)$ are also called.

STORE

This subroutine stores the input quantities, the quantities computed in $PARA$, the tables for the various spline interpolations, the radial mesh and the poloidal antenna spectrum externally on Cray–disc. The unit identifier is 9. These quantities will be read by BALANCE to evaluate the power balance and the energy deposition profiles.

MASTSOL

This routine is the "master routine" for the solution of the linear system using external storage facilities. Enbedded are the sets of routines which provide the (block–tridiagonal) stiffness matrix and the right hand side. To minimise the number of I/O operations the code keeps in general more than one pair of block rows of the stiffness matrix or its L/U decomposition (this is the minimum requirement) in the central memory. To optimise the use fo the central memory one has to specify

by $KILWOR$ the central memory available and by $KILPRGR$ the memory required by the code *excluding* the memory used for two blockrows. For example on the Cray $KILWOR$ is identical to the $REGION$ number specified in the job control cards and $KILPRGR$ is basically a known function of NM, NTT, $NVRB$. From the subroutine called directly or indirectly by $MASTSOL$ we shall discuss here only those which have no relation to the solution of the linear system, i.e. the routines which provide the r.h.s. and the block rows of the stiffness matrix. The solution, i.e. the poloidal spectrum of the electric field, is finally obtained in the routine $RSOLV$ and stored externally on the same Cray disc which has already been used by $STORE$. The external unit identifier is 9. Note that the solution is given "backwards", i.e. the electric field components associated with the last meshpoint are evaluated and stored first. This has to be taken into account when the solution is read by BALANCE.

$\underline{RHS(CRHS, NBG, IR)}$

This subroutine is called by $CONX$ to provide the right hand side $CRHS(I)$, $I = 1, NBG$ corresponding to the IR'th block row. NBG is the rank of one block given by $NBG = 2 \cdot NVRB \cdot NM$. In the present version of the code, where one assumes that the central conductor of the antenna lies within the flux surface at $\psi = \psi_{Ant} = PSIME(JANT)$ and the currents in the feeders and shorts are neglected, this array is zero except for $IR = JANT$

$\underline{BLOX(JPSI, NBG, LBH, A)}$

This subroutine provides the $JPSI$'th block row $(A(I,J);\ I = 1, NBG;\ J = 1, LBH)$ of the block–tridiagonal stiffness matrix, $LBH = 3 \cdot NBG$. Let us first consider the situation if $JPSI$ is neither 1, which is at the magnetic axis, nor $JANT$, which is at the inner side of the antenna, nor $N1$, which is at the wall. Note that the evaluation of the stiffness matrix proceeds elementwise whereas the left part of the $JPSI$'th block row is evaluated in the finite element inside, the right block in the finite element outside of $\psi = PSIME(JPSI)$ and the middle block contains contributions from both. Therefore $BLOX$ evaluates also the the matrices $CMML$ and $CML0$ which are the left block and the contributions of this finite element to the middle block of the next block row. Hence at the beginning of $BLOX$, the left block of A is set equal to $CML0$ and the middle block is set

equal to $CMML$ which have been computed in the previous run of $BLOX$. Then the contributions of the new finite element to the middle block are added and the right block as well as the new matrices $CMML$ and $CML0$ are evaluated. At the first call of $BLOX$, i.e. if $JPSI$=1, all elements of $CMML$ and $CML0$ are of course zero. If $JPSI \neq JANT$ and $JPSI \neq N1$ the calculation of the various blocks involves a Gauss–integration within the (radial) interval between $\psi = PSIME(JPSI)$ and $\psi = PSIME(JPSI+1)$. This integration is done after the poloidal integration, which is computed in the subroutine $OP(PSI)$, has been carried out on the flux surfaces given by the Gauss–points. The routine OP evaluates basically the auxiliary matrix $CO(IDER, JDER, IVRB, IM, JM, JVRB)$ (cfr. description of $OP(PSI)$) which is then contracted with the various interpolating functions to give the correponding block matrices. If $JPSI = JANT$ the situation is different since $PSIME(JANT) = PSIME(JANT + 1) = \psi_{Ant}$ and instead of evaluating the contributions to the stiffness matrix in the usual way, the matching conditions at the antenna must be imposed. The "natural" conditions, i.e. the jump of $B_{\|}$ and the continuity of the kinetic flux associated with the ion FLR–current through the antenna flux surface, are imposed in the routine $BNDAFP$, which directly manipulates the matrices A and $CMML$. At the antenna one must also impose the continuity of E_η which is an "essential" boundary condition. This is done explicetely by changing some rows of the $(JANT + 1)$'th block row. At the wall, i.e. for $JPSI = N1$, the kinetic and electromagnetic flux terms vanish and one must only impose the essential boundary condition $E_\eta = 0$. To do this some rows of the $N1$'th block row are changed.

<u>$OP(PSI)$</u>

This subroutine evaluates the matrix $CO(IDER, JDER, IVRB, IM, JM, JVRB)$ at the radial position $\psi = PSI$. After the poloidal integration has been carried

out, the stiffness matrix can be written as:

$$S(m',\beta,k,j;m,\alpha,l,i) = \int d\psi \left\{ h_{k,j}(\psi) S_1(\psi;m'\beta;m,\alpha) h_{l,i}(\psi) \right.$$
$$+ h_{k,j}(\psi) S_2(\psi;m',\beta;m,\alpha) \frac{dh_{l,i}}{d\psi}(\psi)$$
$$+ \frac{dh_{k,j}}{d\psi}(\psi) S_3(\psi;m',\beta;m,\alpha) h_{l,i}(\psi)$$
$$\left. + \frac{dh_{k,j}}{d\psi}(\psi) S_4(\psi;m',\beta;m,\alpha) \frac{dh_{l,i}}{d\psi}(\psi) \right\}$$

where m, α label the mode and component of the electric field, m', β those of the testfunction and $(h_{k,j},\ h_{l,i};\ k,l = 1,2)$ denote the two cubic hermitean interpolating functions centerd at the j'th and i'th radial gridpoint. CO represents now the matrices $S_1 - S_4$: m, α correspond to the indices ($JM = m+NUP2+1$; $NUP2 = NM/2$), $JVRB = 1$ if $\alpha = \psi$ and $JVRB = 2$ if $\alpha = \eta$; m', β correspond in an analog way to $IM, IVRB$ and for S_1 one has $IDER = 1$, $JDER = 1$, for S_2 $IDER = 1$, $JDER = 2$, for S_3 $IDER = 2$, $JDER = 1$ and for S_4 $IDER = 2$, $JDER = 2$. The multiplication with the interpolating functions and the radial integration are carried out in $BLOX$. In OP and the routines called by this subroutine the contributions to the stiffness matrix due to the various terms are evaluated on a flux surface and the poloidal integration is done by means of the FFT on NTP gridpoints. For terms describing ion cyclotron damping, which might be resonant within the plasma, $NTP = NTT$, for the other terms $NTP = NTTS$. In general each term can be decomposed in a differential operator, which acts in a symmetric way on the electric field as well as on the test functions, and an integral operator along magnetic field lines, i.e. a non local part which depends not only on ψ, ϑ but also on $k_{\|}^{m} = \frac{n_\varphi}{R}\cos\Theta + \frac{m}{N_\tau}\sin\Theta$ and hence on m. At the beginning OP calls the routines $SURF$ and $SMHD$ to evaluate surface quantities. The routine $METT$, which evaluates certain metric coefficients and the magnetic field at the NTP gridpoints within a flux surface is called for $NTP = NTT$ before the contributions due to the resonant terms (ICD) are evaluated and for $NTP = NTTS$ before the other terms are treated. The array ($CR(IT)$; $IT = 1, NTT$) containes the product of the Jacobian and the dielectric tensor element $\hat{R}$, which is evaluated by the function $RTEN$. The subroutine $TENST$ computes the array CXT which contains, for a given m, the

values of one of the nonlocal functions $\hat{L}$, $\hat{\lambda}_2$, $\hat{\lambda}_0$ or $i\mathrm{Im}n_{\|}^2/\hat{P}$ specified in the argument list, on NTP polodal gridpoints (if the poloidal component of $\vec{B}$ is neglected, i.e. if $AJTOR = 0$, CXT is independent of m). The contribution due to the zero'th order Larmor radius perpendicular current, which does not involve any differential operators, can be evaluated immediatly by calling for each value of m $TENST$ to compute the nonlocal function $\hat{L}$ at the poloidal gridpoints and carrying out the poloidal integration using the FFT. Note that the m'th mode of $E_{\psi,\eta}$ corresponds for geometric reasons to the $(m+1)$'th mode of E_+. Some terms contain differential operators as well as a nonlocal functions like the terms describing ICD at the harmonic resonance, electron TTMP (which is, however, neglected if $\psi < \psi_{Ant}$) and, in our approximation where $E_{\|}$ is expressed in terms of the perpendicular components, electron Landau damping. In these cases the functions $DPLEPL$, $ROTEPA$, $DIVE$ are called first to compute the coefficients $(CD(IT, IVRB, I);\ IT = 1, NTP;\ IVRB = 1, NVRB;\ I = 1, 3)$ of the differential operators $\sqrt{2}\partial_+ E_+$, $(\vec{\nabla} \times \vec{E})_{\|}$, $\vec{\nabla} \cdot \vec{E}$, respectively. CD is generally defined as follows:

$$\begin{aligned} \mathcal{D}\vec{E} =& CD(IT,1,1) \cdot E_\psi + CD(IT,1,2) \cdot \frac{\partial}{\partial \vartheta} E_\psi + CD(IT,1,3) \cdot \frac{\partial}{\partial \psi} E_\psi \\ &+ CD(IT,2,1) \cdot E_\eta + CD(IT,2,2) \cdot \frac{\partial}{\partial \vartheta} E_\eta + CD(IT,2,3) \cdot \frac{\partial}{\partial \psi} E_\eta \end{aligned}$$

where $\mathcal{D}$ stands for some differential operator. In $DIFF$ the "dyadic product" of these coefficients with their hermitean conjugate which act on the testfunctions, is evaluated and multiplied with the local Jacobian. Then $TENST$ is called for each m to evaluate $\hat{\lambda}_2$, $1+2\cdot\hat{\lambda}_0$ and $\mathrm{Im}(k_{\|}^2/\hat{P})$ on NTP poloidal gridpoints, respectively. Again, note that the m'th mode of $E_{\psi,\eta}$ corresponds for geometric reasons to the $(m+2)$'th mode of $\partial_+ E_+$. In $OPADDT$ the nonlocal factor is combined with the differential part and, after poloidal integration using the FFT, the contribution to CO is added. The contributions due to $(\vec{\nabla} \times \vec{E})_\psi$, $(\vec{\nabla} \times \vec{E})_\eta$ and, if $\psi > \psi_{Ant}$, $(\vec{\nabla} \times \vec{E})_{\|}$ do not contain any nonlocal operators. Hence they can be evaluated and added to CO for all m at once by calling $OPADD$ after $DIFF$ and $ROTEPS$, $ROTET$, $ROTEPA$ have been called, respectively.

<u>$METT(ATT, NTP)$</u>

This subroutine can be called after $SMHD(PSI)$ and $SURF(PSI)$ have been

executed to evaluate metric tensor elements and their derivatives as well as the magnetic field on the NTP poloidal angles ($\vartheta = ATT(I);\ I = 1, NTP$) within the flux surface $\psi = PSI$. The resulting arrays contain the following quantities: $BF = |\vec{B}|/B_0$, $SINTT = \sin\Theta$, $ACST = \cos\Theta$, $AJAC = R \cdot J$, $AJT = J$, $AGT = G$, $ANTT = N_\tau$, $R1 = 1/R$, $DR1RT = \frac{1}{R}\frac{\partial R}{\partial \vartheta}$, $DR1RP = \frac{1}{R}\frac{\partial R}{\partial \psi}$, $DN1NP = \frac{1}{N_\tau}\frac{\partial N_\tau}{\partial \psi}$, $TETAT = \Theta$, $DTDP = \frac{\partial \Theta}{\partial \psi}$, $DTDT = \frac{\partial \Theta}{\partial \vartheta}$, $DN1JT = \frac{\partial}{\partial \vartheta}\frac{J}{N_\tau}$, $DN1GT = \frac{1}{J}\frac{\partial}{\partial \vartheta}\frac{G}{N_\tau}$, $DTAUTT = \frac{\partial \tau}{\partial \vartheta}$, $DTAUPT = \frac{\partial \tau}{\partial \psi}$. To compute these arrays the routines $COORDS$ and $BFIELD$ are called for ($\vartheta = ATT(IT);\ IT = 1, NTP$).

$\underline{TENST(CTEN, PSI, M, NPHI, NTP)}$

This subroutine evaluates the array ($CXT(IT);\ IT = 1, NTP$) which contains the values of the external function $CTEN$ at the NTP angles ϑ in the flux surface $\psi = PSI$. $CTEN$ stands for one of the functions $CL(B, AKP, PSI)$, $CLAM(B, AKP, PSI)$, $CLAMS(B, AKP, PSI)$, $CLAM0(B, AKP, PSI)$, or $CP(B, AKP, PSI)$. This requires to calculate first the arguments, i.e. $AKP = \cos\Theta\frac{n_\varphi}{R} + \sin\Theta\frac{m}{N_\tau}$ and $B = |\vec{B}|/B_0$ where $n_\varphi = NPHI$, $m = M$ and the other quantities have already been computed in $METT$.

$\underline{RTEN(B)}$

This subroutine can be called after $SURF(PSI)$ has been called to evaluate the dielectric tensor element $\hat{R}$ within the flux surface $\psi = PSI$ for the relativ magnetic field strength $B = |\vec{B}|/B_0$.

$\underline{CL(B, AKP, PSI)}$

After $SURF(PSI)$ has been executed to evaluate surface quantities this function can be called to compute $\hat{L}$ for a given relative magnetic field strength $B = |\vec{B}|/B_0$ and parallel wavenumber $AKP = k_\parallel$.Collisional damping is included assuming an effective collisional frequency $\nu = ANU1$. This routine calls the subroutine $CZETA$ which evaluates the Fried-Conte Zeta-function for a complex argument.

$\underline{CLAM(B, AKP, PSI)}$

This function evaluates $\hat{\lambda}_2$. The arguments are the same as for CL. As effective collisional frequency $\nu = ANU2$ is inserted. $CLAM$ also refers to $CZETA$.

$CLAMS(B, AKP, PSI)$

This function calls first $CLAM$ to evaluate $\hat{\lambda}_2$ and then, if the ratio of imaginary to real part of $\hat{\lambda}_2$ is smaller than some value $AKRIT$, CST to add the term describing stochastic damping of the ion Bernstein wave. In the present version this term is adiabatically switched on.

$CST(B, AKP, PSI, RLAM)$

This function evaluates the term describing stochastic damping of the IBW. $RLAM$ is the real part of $\hat{\lambda}_2$ which must have been evaluated before. The other arguments are the same as in CL and $CLAM$. The functions CL and $RTEN$ are called to estimate the wavelength of the IBW using an approximate root of the dispersion relation. The expression also involves the ion Larmor radius of the first ion species.

$CLAM0(B, AKP, PSI)$

This function evaluates $1 + 2 \cdot f(\psi) \cdot \mathrm{Im}(\hat{\lambda}_0)$ where $f(\psi)$ denotes a function which goes between $\psi = \psi_{pl}$ and $\psi = \psi_{Ant}$ adiabatically to zero. Outside $\psi = \psi_{Ant}$ the electron TTMP is neglected. In practice $CLAM0$ is therefore only called if $\psi < \psi_{Ant}$.

$CP(B, AKP, PSI)$

This function calculates $i\frac{c^2}{\omega^2}\mathrm{Im}\left((k_{\parallel}^m)^2/\hat{P}\right)$. The arguments are the same as in CL. The effective collisional frequency is $ANUE$, as evaluated in $SURF$. $CZETA$ is called to evaluate the derivative of the Zeta function of a complex argument.

$CZETA(CX, CZ0, CZ1, CZ2, CZ3)$

This subroutine evaluates the plasma dispersion relation $CZ0$ and its derivatives up to the third order ($CZ1$, $CZ2$, $CZ3$) for complex argument CX. It was originally developed at PPPL.

$DPLEPL(NPHI, NTP)$

This subroutine evaluates the coefficients CD (cfr. description of OP) of the

differential operator

$$\sqrt{2}\partial_+ E_+ = \frac{1}{\sqrt{2}}\Bigg\{\frac{N_\tau}{J}\frac{\partial}{\partial\psi}\left(E_\psi + iE_\eta\right)$$
$$+\left(i\frac{\cos\Theta}{N_\tau} - \frac{G}{JN_\tau}\right)\frac{\partial}{\partial\vartheta}\left(E_\psi + iE_\eta\right)$$
$$+\Bigg[\frac{i}{N_\tau}\left(\cos\Theta\left(\frac{1}{R}\frac{\partial R}{\partial\vartheta} + \frac{1}{J}\frac{\partial J}{\partial\vartheta} - \frac{1}{N_\tau}\frac{\partial N_\tau}{\partial\vartheta}\right) + \frac{\partial\cos\Theta}{\partial\vartheta}\right)$$
$$+\frac{N_\tau}{J}\left(\frac{1}{R}\frac{\partial R}{\partial\psi} + \frac{1}{N_\tau}\frac{\partial N_\tau}{\partial\psi} + 2i\frac{\partial\tau}{\partial\psi}\right)$$
$$-\frac{G}{JN_\tau}\left(\frac{1}{R}\frac{\partial R}{\partial\vartheta} + \frac{N_\tau}{G}\frac{\partial}{\partial\vartheta}\left(\frac{G}{N_\tau}\right) + 2i\frac{\partial\tau}{\partial\vartheta}\right)$$
$$+\frac{n_\varphi}{R}\sin\Theta - \frac{2\cos\Theta}{N_\tau}\frac{\partial\tau}{\partial\vartheta}\Bigg]\left(E_\psi + iE_\eta\right)\Bigg\}$$

at NTP poloidal angles using the quantities evaluated previously in $METT$ on a given flux surface.

<u>$ROTEPS(NPHI, NTP)$</u>

This subroutine evaluates the coefficients CD (cfr. description of OP) of the differential operator

$$(\vec{\nabla}\times\vec{E})_\psi = \left(-i\frac{n_\varphi}{R}\cos\Theta - \frac{1}{RN_\tau}\frac{\partial}{\partial\vartheta}(R\sin\Theta)\right)E_\eta$$
$$-\frac{\sin\Theta}{N_\tau}\frac{\partial}{\partial\vartheta}E_\eta$$

<u>$ROTEET(NPHI, NTP)$</u>

This subroutine evaluates the coefficients CD (cfr. description of OP) of the differential operator

$$(\vec{\nabla}\times\vec{E})_\eta = \left(i\frac{n_\varphi}{R}\cos\Theta + \frac{\sin\Theta}{J}\frac{\partial}{\partial\vartheta}\left(\frac{J}{N_\tau}\right)\right)E_\psi$$
$$+\frac{\sin\Theta}{N_\tau}\frac{\partial}{\partial\vartheta}E_\psi$$
$$+\Bigg\{\frac{N_\tau}{J}\left[\frac{\partial\Theta}{\partial\psi} + \sin\Theta\cos\Theta\left(\frac{1}{R}\frac{\partial R}{\partial\psi} - \frac{1}{N_\tau}\frac{\partial N_\tau}{\partial\psi}\right)\right]$$
$$-\frac{G}{JN_\tau}\left[\frac{\partial\Theta}{\partial\vartheta} + \sin\Theta\cos\Theta\left(\frac{1}{R}\frac{\partial R}{\partial\vartheta} - \frac{N_\tau}{G}\frac{\partial}{\partial\vartheta}\left(\frac{G}{N_\tau}\right)\right)\right]\Bigg\}E_\eta$$

$ROTEPA(NPHI, NTP)$

This subroutine evaluates the coefficients CD (cfr. description of OP) of the differential operator

$$
\begin{aligned}
(\vec{\nabla} \times \vec{E})_{\parallel} = & \left(i\frac{n_\varphi}{R}\sin\Theta - \frac{\cos\Theta}{J}\frac{\partial}{\partial\vartheta}\left(\frac{J}{N_\tau}\right)\right) E_\psi \\
& - \frac{\cos\Theta}{N_\tau}\frac{\partial}{\partial\vartheta}E_\psi \\
& + \left\{ \frac{N_\tau}{J}\left[\sin^2\Theta\frac{1}{R}\frac{\partial R}{\partial\psi} + \cos^2\Theta\frac{1}{N_\tau}\frac{\partial N_\tau}{\partial\psi}\right] \right. \\
& \left. - \frac{G}{JN_\tau}\sin^2\Theta\frac{1}{R}\frac{\partial R}{\partial\vartheta} + \cos^2\Theta\frac{1}{J}\frac{\partial}{\partial\vartheta}\left(\frac{G}{N_\tau}\right)\right\} E_\eta \\
& - \frac{G}{JN_\tau}\frac{\partial}{\partial\vartheta}E_\eta \\
& + \frac{N_\tau}{J}\frac{\partial}{\partial\psi}E_\eta
\end{aligned}
$$

$DIVE(NPHI, NTP)$

This subroutine evaluates the coefficients CD (cfr. description of OP) of the differential operator

$$
\begin{aligned}
\vec{\nabla}\cdot\vec{E} = & \left\{ \frac{N_\tau}{J}\left[\frac{1}{R}\frac{\partial R}{\partial\psi} + \frac{1}{N\tau}\frac{\partial N_\tau}{\partial\psi}\right] - \frac{G}{JN_\tau}\frac{1}{R}\frac{\partial R}{\partial\vartheta} + \frac{1}{J}\frac{\partial}{\partial\vartheta}\left(\frac{G}{N_\tau}\right)\right\} E_\psi \\
& - \frac{G}{JN_\tau}\frac{\partial}{\partial\vartheta}E_\psi \\
& + \frac{N_\tau}{J}\frac{\partial}{\partial\psi}E_\psi \\
& + \frac{1}{N_\tau}\left\{ \cos\Theta\left[\frac{1}{R}\frac{\partial R}{\partial\vartheta} + \frac{1}{J}\frac{\partial J}{\partial\vartheta} - \frac{1}{N_\tau}\frac{\partial N_\tau}{\partial\vartheta}\right] + \frac{\partial\cos\Theta}{\partial\vartheta} - i\frac{n_\varphi}{R}\sin\Theta\right\} E_\eta \\
& + \frac{\cos\Theta}{N_\tau}\frac{\partial}{\partial\vartheta}E_\eta
\end{aligned}
$$

$DIFF(AJAC, NTP)$

This subroutine evaluates the array ($CDD(IT, IVRB, JVRB, I, J)$; $IVRB = 1, NVRB$; $JVRB = 1, NVRB$; $I = 1, 3$; $J = 1, 3$) which is the "dyadic product" of $CD(IT, JVRB, J)$ and $(CD(IT, IVRB, I))^*$ times the local Jacobian ($AJAC(IT)$; $IT = 1, NTP$). The array CD has been prviously evaluated in $DPLEPL$, $ROTEPS$, $ROTEET$, $ROTEPA$ or $DIVE$.

$\underline{OPADD(NTP)}$

This subroutine is called to add the contributions from those terms which involve only differential operators to CO. First the Fourier transform of $CDD(IT, IVRB, JVRB, I, J)$ is computed for all values of $IVRB$, $JVRB$, I, J. Since this routine deals only with non resonant terms, i.e. CDD is always given on $NTP = NTTS$ poloidal gridpoints, this is done by $FFTS$. Then $\frac{\partial}{\partial \vartheta}$, if applied on $\vec{E}$, can be substituted by im and, if applied on the testfunction, by $-im'$ and the addition of the contribution to CO is straightforward.

$\underline{OPADDT(JM, NTP, FFT)}$

This subroutine computes for a given poloidal mode $m = JM - NM/2 - 1$ the contributions to CO from those terms which contain a nonlocal function, whose values $(CXT(IT);\ IT = 1, NTP)$ have been calculated in $TENST$, as well as a differential operator, whose coefficients $CDD(IT, IVRB, JVRB, I, J)$ have been evaluated in $DIFF$. First $(CXT1(IM);\ IM = 1, NTP)$, the Fourier transform of CXT, is evaluated. The fast Fourier transform FFT used in this subroutine ($FFTS$ or $FFTDIR$) is specified as external in the argument list when calling $OPADDT$. Then for each combination of $IVRB$, $JVRB$ the array $(CDDT(IM, I, J); IM = 1, NTP)$ is evaluated. If $CDD(IT, IVRB, JVRB, I, J)$ is constant within a flux surface, i.e. independent of IT, $CDDT(IM, I, J)$ is the product of $CDD(1, IVRB, JVRB, I, J)$ and $CXT1(IM)$. Otherwise $CDDT(IM, I, J)$ is the Fourier transform of the product of $CDD(IT, IVRB, JVRB, I, J)$ and $(CXT(IT);\ IT = 1, NTP)$. The addition of the corresponding contributions to CO is then analog to what is done in $OPADD$.

$\underline{BNDAFP(NBG, LBH, A, CMML)}$

This subroutine computes the contributions to the stiffness matrix due to the "natural" matching conditions at the antenna (and Faraday shield). First the routines $SURF$ and $SMHD$ are called at $\psi = PSIANT$. Then, after $METT$ has been called, the coefficients CD of $(\vec{\nabla} \times \vec{E})_{\|}$ are evaluated in $ROTEPA$, multiplied with the surface element, and Fourier transformed using $FFTDIR$. To implement the jump of $B_{\|}$ at the antenna, $(\vec{\nabla} \times \vec{E})_{\|}$ in the inner side's boundary term is expressed in terms of variables at the outer side. The contribution due to the antenna current goes as source term in the r.h.s. and does not change the

stiffness matrix. If $IBND = 0$ the contributions due to the ion FLR current to the boundary terms are neglected. Otherwise this contribution to the inner side's boundary term is expressed in terms of variables at the outer side and vice versa. To do this the coefficients of the differential part of these terms are evaluated in $DPLEPL$ and multiplied with the local surface element and the nonlocal function $\hat{\lambda}_2$ (plus, if $ISTOCH \neq 0$, the stochastic damping term of the IBW) is computed for each m on NTT poloidal gridpoints by calling $TENST$. The evaluation of the resulting contributions to the stiffness matrix, i.e. to A and $CMML$ is then analog to what is done in $OPADDT$.

OUTPUT

This subroutine controls the output and plotting of plasma parameters as specified by the data listed in the NAMELIST $IPLOTF$. It refers to the plotting routines $GPLOT$, $GPLOT3$ and $PLOTF$.

$GPLOT(X, Y1, Y2, NN, XTEXT, NXT, YTEXT, NYT, IPLOT)$

$(X(I);\ I = 1, NN)$ contains the x-values, $Y1(I);\ I = 1, NN$ contains the y-values of a first function which is plotted solid. Moreover, if $IPLOT \neq 1$ the function whose values are given in the array $(Y2(I);\ I = 1, NN)$ is plotted dashed. This is usually done to visualise real an imaginary part of a complex function. $XTEXT$ is a character string of NXT digits which specifies the text printed at the x–axis. $YTEXT$ is a character string of NYT digits which specifies the text printed at the y–axis. $GPLOT$ calls various ERLGRAPH–routines.

$GPLOT3(X, Y1, Y2, NN, XTEXT, NXT, YTEXT, NYT, ZTEXT1, NZ1, ZTEXT2, NZ2, ZNUM, IPLOT)$

This subroutine is similar to $GPLOT$ but it has the additional feature of printing a number specified by $ZNUM$. $ZTEXT1$ is character string of $NZ1$ digits specifying the text which shall be written before the number and $ZTEXT2$ is a character string of $NZ2$ digits specifying the text which shall be written behind the number (in general a unit). $GPLOT3$ calls various ERLGRAPH–routines.

$PLOTF$

This is a subroutine to plot magnetic flux surfaces $\psi = const$. The distance between two adjacent flux surfaces to be plotted is given by $DPSI$, the number of poloidal points used to plot a surface is specified as PARAMETER NN. $PLOTF$

calls $SMHD$ and $COORDS$ and some ERLGRAPH–routines.

4. Description of additional routines used in the program BALANCE.

MAIN

first reads the variables which control the diagnostic (NAMELIST $DIAG$). Then the quantities provided by the program FISIC, i.e. the quantities written by $STORE$ and the solution of the linear system as written by $RSOLV$ are read from the external Cray disc. The external unit identifier is 9. After some normalisation, the spectrum of of the electromagnetic wavefield is then given by the arrays (in arbitrary units): $CPSI(IR,IM) = E_\psi^m(\psi)$, $CDPSI(IR,IM) = \frac{\partial}{\partial\vartheta}E_\psi^m(\psi)$, $CETA(IR,IM) = E_\eta^m(\psi)$, $CDETA(IR,IM) = \frac{\partial}{\partial\vartheta}E_\eta^m(\psi)$ where $m = IM - NM/2 - 1$ and $\psi = PSIME(IR)$. Moreover the equidistant poloidal grids $(AT(IT);\ IT = 1, NTT)$ and $(ATS(IT);\ IT = 1, NTTS)$ are evaluated.

BALANCE(IOUT, IBAL, IDSAV)

First the quantities needed for the Gaussian integration are evaluated by calling $GAUS$ (the number $NGAUS$ of Gauss points per finite element does not have to be the same as in FISIC). Then, if $IOUT \neq 0$, $INIFFT$ and $OUTPUT$ are called. The initialisation of the FFT's $FFTDIR$ and $FFTS$ is only neccessary if $IOUT \neq 0$ because $OUTPUT$ is the only subroutine in BALANCE which calls these routines. After this $ANTP$ is called to compute the contribution $RRANT$ of the toroidal mode $n_\varphi = NPHI$ to the total antenna load. Moreover $PANT$, which is proportional to the contribution of n_φ to the power launched by the antenna is evaluated. These two quantities are evaluated *without*taking into account the toroidal spectrum of the antenna current. If $IBAL \neq 0$ $PABS$ is called to compute the power deposition profiles and the total power balance. If $IDSAV \neq 0$ $STORED$ is called to store the results of this routine externally on Cray disc. They can be used later by the program DPROF to evaluate the total antenna load, power deposition profiles and power balance (summed over toroidal modes n_φ).

ANTP(PANT, RRANT)

This subroutine evaluates first $PANT$, which is proportional to the contribution of the toroidal wavenumber n_φ to the power radiated by an antenna, whose current

has a toroidal spectrum in which all modes n_φ are equally strong represented. Then $RRANT$, which is the contribution of n_φ to the antenna load in Ω, is evaluated under the same assumption. To obtain the real contribution $RRANTN$ to the antenna load, $RRANT$ is multiplied with the factor $GNPHI \cdot GNPHI$ where the relative weight $GNPHI = g_{n_\varphi}$ of the toroidal mode n_φ of the antenna current is evaluated in $TORSP$ for a given antenna type. $RRANTN$ is printed in the output of $BALANCE$. $GNPHI$ is also used to normalise $AIANT$ which will be used in $DIAG$ to compute the field strength of the contribution due to the toroidal mode n_φ to the electric wave field in V/cm for a toroidal spectrum of the antenna current as specified in $TORSP$.

TORSP(GNPHI)

This subroutine evaluates the weight $GNPHI = g_{n_\varphi}$ of the toroidal mode n_φ in the spectrum of the antenna current for a given antenna type. g_{n_φ} is normalised in such a way that $\sum_{n_\varphi} g_{n_\varphi} = 2\pi$.

DIAG

This subroutine provides the diagnostic of the electromagnetic wavefield. Which plots will be made is determined by the variables read as NAMELIST $DIAG$. To reconstruct the wavefield from their Fourier modes, the inverse Fourier transform $FFTREV$ is called. The field components are normalised in such a way that they give the contribution of the toridal mode $n_\varphi = NPHI$ to the electric wavefield in V/cm for a total antenna current of 1 Ampére and a toroidal current spectrum as specified in $TORSP$. In the plots which show $E_+(\vartheta)$ within a magnetic flux surface additional points between the poloidal gridpoints are evaluated by calling $VALSPL$ after a cubic spline interpolation has been initialised by $CUBSPL$. The plots showing the electromagnetic field in the equatorial plane are done on the radial grid– and Gauss–points. To compute the horizontal gridpoints needed for these plots and $\sin\tau$ and $\cos\tau$ which are used to evaluate the perpendicular components E_x and E_y, the routines $SMHD$ and $COORDS$ are called. The plots are finally executed by calling $GPLOT3$. To get the contour plots first the array RE, which containes the values of the field component specified in the NAMELIST $DIAG$ on $NM + 1$ poloidal times $NELEM \cdot (NGAUS + 1) + 1$ radial gripoints, is evaluated. This array will be used by the FUNCTION $ZREX$ which computes

the value of this component at a position given by the horizontal and vertical coordinates x and y. $ZREX$ is an argument of the subroutine $ERLHL$ which provides the plots of contour lines. Before $ERLHL$ is called the ERLGRAPH routine $MINMAX$ evaluates the minimum and maximum values $ZMIHL$ and $ZMAHL$ of RE and hence of the function $ZREX$ to be plotted for $\psi < \psi_{pl}$. This information will be used to determine the values for the contour lines to be plotted. If $ZMIHL$ and $ZMAHL$ were evaluated within the entire plasma, the plot would be dominated by the field in the vicinity of the antenna. $DIAG$ also calls the routine $EANT$ which evaluates the average strength of the square of the electromagnetic wave field in front of the antenna. This quantity might be useful to analyse the impurity production in front of the antenna during ICRH.

$FFTREV(CFFT)$

This subroutine is used to reconstruct the electromagnetic wavefield on a flux surface from a given poloidal spectrum ($CFFT(IM)$; $IM = 1, NM$). Upon exit $CFFT$ containes the values at NM equidistant poloidal angles. $FFTREV$ calls the NAGLIB–routine $C06ECF$ to compute the FFT on NM points.

$ZREX(X,Y)$

This function computes the values of a function specified by the array ($RE(IT, IR)$; $IT = 1, NM+1$, $IR = 1, NELEM \cdot (NGAUS+1)+1$) at the position given by the horizontal and vertical coordinates $x = X$ and $y = Y$. The array RE, which has been computed in $DIAG$, contains the values of this function on $NM+1$ equidistant poloidal gridpoints (the first is at $\vartheta = 0$, identical with the last at $\vartheta = 2\pi$) times $NELEM \cdot (NGAUS + 1) + 1$ radial meshpoints given by the array RR. The subroutine ZRT is called to evaluate the indices $IPSI$ and IT of the closest flux surface $RR(IPSI)$ and poloidal angle $\vartheta = 2\pi\frac{(IT-1)}{NM}$. $ZREX$ is then computed using a linear interpolation. If $IGUESS = 0$, which means that the point $x = X, y = Y$ lies outside the vacuum vessel (cfr. $INVERT$) $ZREX(X,Y) = 0$.

$ZRT(X,Y,IPSI,DPSI,IT,DT,IGUESS,RR,NR,NT)$

Unless $IGUESS = 0$, which means that the point $x = X, y = Y$ lies outside the vacuum vessel (cfr. $INVERT$), this subroutine evaluates the indices $IPSI$ and IT so that $RR(IPSI) < \psi < RR(IPSI+1)$ and $IT\frac{2\pi}{NT} < \vartheta < (IT+1)\frac{2\pi}{NT}$ where $RR(IR)$, $IR = 1, NR$ is an array which labels the flux surfaces, $RR(1) = 0$

and $RR(NR) = 1$, and $\psi = PSI, \vartheta = TETA$ are evaluated in $INVERT$ and correspond to the horizontal and vertical coordinates $x = X, y = Y$. Moreover the relative distances $DPSI = (PSI - RR(IPSI))/(RR(IPSI+1) - RR(IPSI))$ and $DT = (TETA - 2\pi\frac{IT}{NT}) \cdot \frac{NT}{2\pi}$ are computed.

$\underline{INVERT(XX, ZZ, PSI, THETA, IGUESS)}$

This subroutine evaluates which flux surface $\psi = PSI$ and angle $\vartheta = THETA$ correspond to a point which is given by $R = RT + XX = R_T + x$ and the vertical coordinate $ZZ = y$. If this point lies outside the vacuum vessel, $IGUESS$ is set equal 0, otherwise $IGUESS = 1$. Since it is in general not possible to invert the representation of the flux surfaces $x(\psi, \vartheta)$, $y(\psi, \vartheta)$ analytically, ψ and ϑ are evaluated iteratively. This requires an initial guess which is evaluated under the assumption of circular flux surfaces whose Shavranov–shifts are a quadratic function of ψ. The iteration involves then calls of the routines $SMHD$ and $COORDS$.

$\underline{ERLHL(ZREX, XMIN, XMAX, YMIN, YMAX, ZMIHL, ZMAHL, IC)}$

This subroutine draws contour lines of the function $z(x, y) = ZREX(X, Y)$ in the area $XMIN < x < XMAX$, $YMIN < y < YMAX$. The levels are equidistant between $ZMIHL < z < ZMAHL$. If $ZMIHL < 0$, the absolute values of positive and negative levels are equal and the contour lines corresponding to negative values are plotted dashed, the others solid. If $ZMIHL > 0$, i.e. if all levels are positive, the contour lines corresponding to levels between $z = 0$ and $z = ZMAHL/2$ are plotted dashed, the others solid. The number of contour lines to be plotted is less or equal to $NCTR$. Before the actual plotting begins, $ERLHL$ computes the array $(ZXY(IX, IY);\ IX = 1, NXT;\ IY = 1, NYT)$ which containes the values of the function $ZREX$ on a cartesian grid of NXT and NYT equidistant horizontal and vertical meshpoints between $XMIN, XMAX$ and $YMIN, YMAX$. The plot routines are from the ERLGRAPH–package. The quantity IC determines the description of the plot, i.e. it says which component of the electric field is being plotted. Finally, the vacuum vessel is plotted if it lies within the region $XMIN < x < XMAX$, $YMIN < y < YMAX$.

$\underline{EANT(CX, CY, NR, NM1)}$

This subroutine evaluates the average electric field at the antenna, i.e. the integral $\int_{-\vartheta_m}^{\vartheta_m} |E_x|^2 + |E_y|^2 d\vartheta$ at the inner and outer side of the antenna. $\vartheta_m = TM$ is

specified at the beginning of the routine and should be about equal to the poloidal extension of a low field side antenna. For other antenna types this routine might be slightly changed. ($CX(IR,IT)$ and $CY(IR,IT)$; $IR = 1,NR$, $IT = 1,NM1$) are the perpendicular field components as evaluated in $DIAG$.

$PABS(PANT)$

This subroutine evaluates the power deposition profiles and the total power balance for the toroidal mode $n_\varphi = NPHI$. Computed are the arrays ($ABSI1(IEL,IT)$, $ABSI2(IEL,IT)$, $ABST(IEL,IT)$, $ABSET(IEL,ITS)$, $ABSEL(IEL,ITS)$, and $ABI1(IEL)$, $ABI2(IEL)$, $AS(IEL)$, $ABET(IEL)$, $ABEL(IEL)$; $IEL = 1,NELEM$, $IT = 1,NTT+1$, $ITS = 1,NTTS+1$), which contain the local power deposition due to ICD at fundamental and harmonic resonance, stochastic damping of the IBW, electron TTMP and Landau damping averaged over the IEL'th finite element at the poloidal angle $\vartheta = 2\pi(IT-1)/NTT$ or $\vartheta = 2\pi(ITS-1)/NTTS$ or averaged over a magnetic flux surface, respectively. They are all given in $\%/cm^3$ of the power radiated in the toroidal mode $n_\varphi = NPHI$. Hence the sum of the quantities $AI1TOT$, $AI2TOT$, $ASTOT$, $AETTOT$, $AELTOT$, which are obtained from the local power deposition profiles by integration over all space, should be 100. For this normalisation the quantity $PANT$ which has been evaluated previously in $ANTP$ is needed. The evaluation of the deposition profiles involves already an averaging within the finite elements which is done by means of a Gaussian integration. For this purpose the arrays $CEPSI(IM)$, $CDEPSI(IM)$, $CEETA(IM)$ and $CDEETA(IM)$ which contain the poloidal spectra E_ψ^m, $\frac{dE_\psi^m}{d\psi}$, E_η^m and ($\frac{dE_\eta^m}{d\psi}$; $m = IM-NM/2-1$) are evaluated at the flux surfaces given by the Gauss points. Then $SURF$ and $SMHD$ are called to evaluate surface quantities and $METT$ is called to compute certain quantities needed in the following routines on NTT or $NTTS$ poloidal angles. The array ($CDE(IM)$; $IM = 1,NM$), which contains in general the poloidal spectrum of a differential operator applied on the electric wavefield times the factor $e^{im\vartheta}$, is calculated for a given poloidal angle for the various damping mechanisms. With the exception of the term describing ICD at the fundamental resonance, which does not contain any differential operators, this is done by calling one of the routines $DPLEPL$, $ROTEPA$, or $DIVE$ to evaluate the auxiliary array CD (cfr. description of OP) which contains the

coefficients of the various differential operators. The nonlocal part is given by the array $CIT(IM)$, whose elements are computed by calling one of the functions CL, $CLAM$, CST, $CLAM0$, CP for each poloidal mode m and multiplied with the local Jacobian times the factor $AJKORR$, which contains the normalisation and the weight for the Gauss integration. Note that to the m'th mode of $E_{\psi,\eta}$ corresponds the $(m+1)$'th or $(m+2)$'th mode of E_+ or $\partial_+ E_+$, respectively. Finally at each poloidal gridpoint the subroutine $SUMOD$ is called to sum over poloidal modes and add the contribution from this Gauss point to the integral over the finite element. The remaining integrals over ϑ to obtain the arrays $ABI1(IEL)$, etc., and the sum over finite elements to get $AI1TOT$, etc., are then straightforward. Finally, to obtain a power densitiy, the arrays are divided by the volume over which their elements have been evaluated.

$\underline{SUMOD(ABS, CD, CT, NM, ISYM)}$

This subroutine evaluates the sum over NM poloidal modes and adds it to ABS. $(CD(IM);\ IM = 1, NM)$ containes the factor due to the (differential) expression involving the electromagnetic wave field and $(CT(IM);\ IM = 1, NM)$ the contribution from the nonlocal function for the poloidal mode $m = IM - NM/2_1$ at a given poloidal angle. If $ISYM = 0$ the expression added is

$$\sum_{IM,JM} \mathrm{Im}\,(CD^*(JM) \cdot CD(IM) \cdot CT(IM))\,,$$

for $ISYM = 1$ it is

$$\sum_{IM,JM} \mathrm{Re}\,(CD^*(JM) \cdot CD(IM) \cdot \mathrm{Im}(CT(IM)))$$

and for $ISYM = 2$, which should, however, never be used:

$$\sum_{IM} \mathrm{Re}\,(CD^*(IM) \cdot CD(IM) \cdot CT(IM))\,.$$

In general one should choose $ISYM = 0$. In this case the power balance is a consequence of the equations used when implementing the stiffness matrix. For $ISYM = 1$ this is no more exactely the case and a contribution due to an approximate parallel kinetic flux term, which does not neccessarily vanish upon poloidal integration, arises so that the power balance might be less accurate.

PPLOT(ISTOCH,IFLR)

This subroutine plots, using ERLGRAPH–routines, the power deposition profiles due to the various damping mechanisms in the equatorial plane. For $ISTOCH = 0$ and $IFLR = 0$ the curves for stochastic damping of the IBW and ICD at harmonic resonance, respectively, are not plotted.

PLOTTH(ISTOCH,IFLR)

This subroutine plots, using ERLGRAPH–routines, the over flux surfaces averaged power deposition profiles due to the various damping mechanisms. For $ISTOCH = 0$ and $IFLR = 0$ the curves for stochastic damping of the IBW and ICD at harmonic resonance, respectively, are not plotted.

STORED(RRANT)

This subroutine stores the following quantities which will be used by program *DPROF* on external Cray–disc (unit number 11): The variables in NAMELIST *INPUT*, the spline coefficients for the radial functions determining the MHD equilibrium, the local power deposition profiles, the results of the global power balance as well as the quantity *RRANT* as computed in *ANTP*.

5. Description of additional routines used in the program DPROF.

MAIN

This routine reads for each toroidal mode n_φ for which the program BALANCE has been run, the data which have been provided by *STORED*, from external Cray discs using the unit identifiers $IUNIT1$–$IUNIT9$ = 10–18. Hence in the present version up to 9 different toroidal mode numbers can be handled. It would be straightforward to enlarge this number. The number of toroidal modes from which the program shall actually evaluate the total power deposition profiles and power balance must be specified as PARAMETER *NNPHI* with $1 \leq NNPHI \leq 9$. Moreover the PARAMETERS *NR*, *NT*, *NTS* must be specified in such a way that they are larger than the maximum values of $NELEM(INPHI)$, $NTT(INPHI) + 1$ and $NTTS(INPHI) + 1$ used in any of the previous runs of BALANCE which provided the data read by DPROF. For the *INPHI*'s toroidal mode $RRANT(INPHI)$ is the contribution to the total antenna load up to the factor due to the toroidal spectrum of the antenna current and $AI1T(INPHI)$,

$AI2T(INPHI)$, $ASTT(INPHI)$, $AELT(INPHI)$, $AETT(INPHI)$ are the relative power absorbed due to ICD at fundamental and harmonic resonance, stochastic damping of the IBW, electron Landau damping and TTMP, respectively. The corresponding over flux surface averaged deposition profiles are given at the surfaces ($\psi = RR(IR, INPHI)$; $IR = 1, NELEM(INPHI)$) by the arrays $AI1(IR, INPHI)$, $AI2(IR, INPHI)$, $AST(IR, INPHI)$, $AEL(IR, INPHI)$ and $AET(IR, INPHI)$. The arrays $ABSI1(IR, IT, INPHI)$, $ABSI2(IR, IT, INPHI)$, $ABST(IR, IT, INPHI)$, $ABSEL(IR, ITS, INPHI)$, $ABSET(IR, ITS, INPHI)$ finally contain the local power deposition due to the above listed absorption processes at the poloidal angles ($\vartheta = AT(IT, INPHI)$; $IT = 1, NTT(INPHI)$) and ($\vartheta = ATS(ITS, INPHI)$; $ITS = 1, NTTS(INPHI)$) and flux surfaces ($\psi = RR(IR, INPHI)$; $IR = 1, NELEM(INPHI)$). In general one does not run the code for all n_φ's excited by the antenna but chooses a typical sample which should represent the whole spectrum. The number of toroidal modes which is thus represented by the $INPHI$'s data set must be specified as $WNPHI(INPHI)$. After a data set has been read, $TORSP$ is called to evaluate the weight $g_{n_\varphi} = GNPHI$ of the correponding mode $n_\varphi = NPHI$ in the toroidal spectrum of the antenna current. The quantity $WNPHI * GNPHI * GNPHI$ will be used as weight of this toroidal mode. First $RRANT(INPHI)$ is multiplied with this factor to give the contribution due to the toroidal modes represented by the $INPHI$'s data set to the total antenna load. $DPTOT$ evaluates then the total power balance and antenna load, DPT the over magnetic flux surfaces averaged deposition profiles and $DPXY$ the deposition profiles in the poloidal cross section.

<u>*DPTOT*</u>

This subroutine evaluates the total antenna load $RRANTT$ as well as the parts of the total power launched by the antenna which are absorbed due to ICD at the fundamental and harmonic resonance ($AI1TOT$ and $AI2TOT$), by electron TTMP and Landau damping ($AELTOT$ and $AETTOT$) and due to stochastic damping of the IBW ($ASTOT$).

<u>*DPT*</u>

This subroutine evaluates the over flux surfaces averaged power deposition profiles due to the various damping mechanisms. The arrays $AI1R(I)$, $AI2R(I)$,

$AELR(I)$ and $ASR(I)$ contain the profiles for ICD at fundamental and harmonic resonance, electron damping (TTMP+ELD) and stochastic damping of the IBW at the equidistant flux surfaces ($RP(I)$; $I = 1, NR$), respectively. They are all given in $\%/cm^3$ of the total power launched by the antenna. To obtain the quantities IR and DR needed for the linear interpolation of the various deposition profiles DPT calls the subroutine $R0$. The resulting deposition profiles are finally plotted by $PLOTTH$ (this subroutine is not identical with the subroutine $PLOTTH$ used in the program BALANCE).

$\underline{R0(R, IR, DR, RR, NR)}$

This subroutine evaluates for the point R the index IR of the array ($RR(I)$; $I = 1, NR$) so that $RR(I) < R < RR(I+1)$ and the relative distance $DR = (R - RR(I))/(RR(I+1) - RR(I))$.

$\underline{PLOTTH(AI1, AI2, AEL, AS, RP, NR)}$

This subroutine plots the deposition profiles whose values at the positions ($\psi = RP(I)$; $I = 1, NR$) are given by the arrays $AI1(I)$, $AI2(I)$, $AEL(I)$ and $AS(I)$ using plot routines from the packages LIBWOSS and GGLIB1.

DPXY

This subroutine evaluates the arrays ($ZI1XY(IX,IY)$, $ZI2XY(IX,IY)$, $ZETXY(IX,IY)$, $ZELXY(IX,IY)$, $ZTXY(IX,IY)$; $IX = 1,NX, IY = 1,NY$) which contain the local power deposition due to ICD at the fundamental and harmonic resonance, electron TTMP and Landau damping and stochastic damping of the IBW in $\%/cm^3$ of the total power launched by the antenna on a cartesian grid of NX times NY equidistant horizontal times vertical meshpoints in the poloidal crossection. $INVERT$ is called to evaluate the flux surfaces ψ and the poloidal angles ϑ corresponding to these meshpoints. $ZXYADD$ evaluates for the various profiles the with $RRANT(INPHI)$ weighted sum over toroidal modes. Finally the routine $PL3D$ is called to draw three–dimensional plots of the deposition profiles. $PL3D$ calls plot routines from the GGLIB1 package. To describe the plots and draw the axis, $DPXY$ calls also some routines from this library.

ZXYADD(Z, ABS, NR, NT, IR, DR, IT, DT, RRANT)

This subroutine computes by linear interpolation the value of a function which is given by the array ($ABS(I,J)$; $I = 1,NR; J = 1,NT$) at a position defined by IR, DR, IT, DT. IR and IT are the indices of the closest radial and poloidal meshpoints and DR and DT the relative radial and poloidal distances from this meshpoint to the point at which the function shall be evaluated. The resulting quantity is multiplied with $RRANT$ and added to Z.

6. List of all COMMON blocks referenced in the programs FISIC,BALANCE, DPROF.

COMMON /RAD/ FREQCY, ALC, NPHI
COMMON /PLAS/ ATM(4), AZI(4), DENIC(4), DENEC, TEMPIC(4), TEMPEC, RT, RANT, RW, RPLAS, BZERO, AJTOR, XSI, EPS, NSPEC, IRES1, IRES2, ISTOCH, IBND, IFLR, RSHIFT, ZTRIAN, ZELLIP(2)

are referenced in the routines *MAIN FISIC, PARA, SURF, PROINI, MHDINI, COORDS, INVERT, BFIELD, MESH, STORE, ANTC, OUTPUT, RTEN, CL, CLAM, CST, CLAM0, OP, BNDAFP,MAIN BALANCE, DIAG, PABS, ANTP, TORSP, STORED, MAIN DPROF, DPT, DPXY.*

PARAMETER (PI=3.1415926535898)
COMMON /MESH/ PSIME(NELM1), AT(NTT+1), ATS(NTTS+1), N1, NELEM, JANT
COMMON /GAUSS/ GD(NGAUS), GF(NGAUS)
COMMON /INTPOL/ FINTR(2,2,NGAUS), FINTL(2,2,NGAUS)

are referenced in *MESH, GAUS, BLOX, MASTSOL, STORE, RHS, ANTC, OUTPUT, OP, BNDAFP, MAIN BALANCE, DIAG, PABS, PPLOT, PLOTTH (BALANCE), ANTP, EANT, ZREX, STORED.*

COMMON /ANTC/ CFJ(NTT), CFXJ(NTT), AIANT

is referenced in *STORE, RHS, OUTPUT, MAIN BALANCE, DIAG, ANTP.*

COMMON /PARA/ OMCE, OMPE, OMC(4), OMP(4), VTHE, VTH(4), OM, A2, PSIPL, PSIANT

is referenced in *PARA, SURF, PROINI, MESH, STORE, ANTC, OUTPUT, RTEN, CL, CLAM, CST, CLAM0, CP, OP, BNDAFP, MAIN BALANCE, DIAG, PABS, ANTP.*

PARAMETER (NPROF=...)
PARAMETER (NMHD=...)
COMMON /PROTAB/ TNE(NPROF,4), TTE(NPROF,4), TTI(NPROF,4,4), TQR(NPROF,4), PSIPRO(NPROF), PJAVG(NPROF), VOLUME(NPROF), PQR(NPROF), DPSPRO
COMMON /MHDTAB/ BX0(NMHD,4), BX1(NMHD,4), BX2(NMHD,4), BZ0(NMHD,4), PSIMHD(NMHD), DPSMHD

are referenced in *SURF, PROINI, MHDINI, SMHD, COORDS, STORE, OUTPUT, MAIN BALANCE, PABS, STORED, MAIN DPROF, DPXY.*

COMMON /SURF/ DENS, TEMPE, TEMPI(4), O2P, OMP2(4), VTE, VT(4), BETAE, BETAI(4), BP0, BP1, ANU1, ANU2, ANUE
COMMON /MHDSUR/ SBX0(3), SBX1(3), SBX2(3), SBZ0(3)

are referenced in *SURF, MHDINI, SMHD, BFIELD, OUTPUT, RTEN, CL, CLAM, CST, CLAM0, CP, BNDAFP, PABS.*

COMMON /CCOORD/ UX, UZ, URHS
COMMON /COMTRD/ AJ, ANTAU, AG, DXPSI, DXTH, DZPSI, DZTH, DNTAUP, DJP, DTAUP, DTAUT, DNTAUT, DJT, DGT
COMMON /BFIELD/ BM, SINT, ACOST, TETA, TETADP, TETADT

are referenced in *MHDINI, COORDS, INVERT, BFIELD, METT, ANTC, OUTPUT, PLOTF, OP, BNDAFP, ERLHL, DIAG, PABS, PPLOT.*

COMMON /BMET/ BF(NTT), SINTT(NTT), ACST(NTT), ANTT(NTT), R1(NTT), AJAC(NTT), AJT(NTT), AGT(NTT), DR1RT(NTT), DR1RP(NTT), DN1NP(NTT), TETAT(NTT), DTDP(NTT), DTDT(NTT), DN1JT(NTT), DN1GT(NTT), DTAUTT(NTT), DTAUPT(NTT)

is referenced in *METT, OP, TENST, ROTEPS, ROTEET, ROTEPA, DIVE, DPLEPL, BNDAFP, PABS.*

COMMON /DIFF1/ CD(NTT,NVRB,3)

is referenced in *ROTEPS, ROTEET, ROTEPA, DIVE, DPLEPL, DIFF, BNDAFP, PABS.*

COMMON /DIFF2/ CDD(NTT,NVRB,NVRB,3,3)

is referenced in *OPADDT, DIFF, OPADD.*

COMMON /DTEN/ CXT(NTT)

is referenced in *OP, TENST, OPADDT, BNDAFP.*

COMMON /PRIV3/ CDDT(NTT,3,3),CXT1(NTT)

is referenced in *OPADDT, BNDAFP.*

COMMON /PRIV/ CO(2,2,NVRB,NM,NM,NVRB)

is referenced in *BLOX, OP, OPADDT, OPADD.*

COMMON /DIAG/ IEPLT, NMPL, PSIMPL(4), IHL(13), XMIHL, XMAHL, YMIHL, YMAHL, IBAL, ISYM, IDSAV, ITABPL, IABPL

is referenced in *MAIN BALANCE, DIAG, PABS.*

COMMON /CPLOT/ RE(NM1,NR),RR(NR)

is referenced in *DIAG, ZREX.*

COMMON /COMP/ CPSI(NELM1,NM), CPSID(NELM1,NM), CETA(NELM1,NM), CETAD(NELM1,NM)

is referenced in *MAIN BALANCE, DIAG, PABS, ANTP.*

COMMON /PROF/ ABSI1(NELM,NTT+1), ABSI2(NELM,NTT+1), ABSET(NELM,NTTS+1), ABSEL(NELM,NTTS+1), ABST(NELM,NTT+1)
COMMON /PROFT/ AI1(NELM), AI2(NELM), AET(NELM), AEL(NELM), AS(NELM), PSIP(NELM)
COMMON /ABSTOT/ AI1TOT, AI2TOT, AETTOT, AELTOT, ASTOT, TEST

are referenced in *PABS, PPLOT, PLOTTH, STORED.*

PARAMETER(NR=... ,NT=... ,NTS=... ,NNPHI=...)
COMMON /PROF/ ABSI1(NR,NT,NNPHI), ABSI2(NR,NT,NNPHI), ABST(NR,NT,NNPHI), ABSEL(NR,NTS,NNPHI), ABSET(NR,NTS,NNPHI), AI1(NR,NNPHI), AI2(NR,NNPHI), AST(NR,NNPHI), AEL(NR,NNPHI), AET(NR,NNPHI), RR(NR,NNPHI), AT(NT,NNPHI), ATS(NTS,NNPHI), AI1T(NNPHI), AI2T(NNPHI), ASTT(NNPHI), AELT(NNPHI), AETT(NNPHI),

RRANT(NNPHI)
COMMON /DIM/ NELEM(NNPHI), NTT(NNPHI), NTTS(NNPHI)

are referenced in *MAIN DPROF, DPTOT, DPT, DPXY.*

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[2] M. Brambilla, T. Krücken, Nuclear Fusion 28 (1988), p. 1813.

[3] T. Krücken, PhD–thesis, Ausbreitung und Absorption elektromagnetischer Wellen bei Ionenzyklotronresonanzheizung in Tokamakplasmen.

[4] T. Krücken, Report IPP 5/23 (1988).