

Physics Module Equations

Revision: 2/2012 by L. Carlson

Code Version: ASC v.35

Code Modules: *inpar.txt* & *inpar2.txt* (input files), *corona* (plasma equilibrium look-up table), *makefile* (instructions to build the executable), *PlasmaPhysics.exe* (executable), *runphysics.sh* (run command shell), *sysplas_PC.F* (source code)

History: Z. Dragojlovic received from the author C. Kessel 3/2007

Module note: The physics module is the first module that must be complete when running the Aries Systems Code. The physics module must be compiled on a Linux machine with g++ and gfortran compilers. See “How to run the ASC v.4.pdf” for instructions to install these compilers.

[For instructions on how to run the physics module and on the nomenclature used, see Z. Dragojlovic 5/2009 “[ASC_User_Manual_Dragojlovic.pdf](#)”]

Physics Equations

The specific equations contained in the source code *sysplas_PC.F* are lengthy and beyond the scope of this overview document. For details regarding the equations, the author C. Kessel or the systems code administrator should be contacted. The physics module is described in detail in the physics section of the Fusion Engineering and Design journal article by Z. Dragojlovic, et al “[An Advanced Computational Algorithm for systems analysis of tokamak power plants](#),” FED 85 (2010) 243-265.

“Inpar” and “inpar2” files

The files with user-specified parameters are called “inpar” (fixed parameters) and “inpar2” (scanned parameters). To find viable plasmas for use in the power plant model, certain plasma parameters must be scanned. Each parameter is defined by the number of samples to scan, the initial value and the final value. Parameters that do not have a scan range in *inpar2* will be set at the fixed value, as defined in *inpar*. In the example *inpar2* file below, “nbt” (toroidal field at plasma major radius *r*) is scanned from 4.0 to 9.0 in 11 steps (4.0, 4.5, 5.0 ... 8.5, 9.0). “Betan” is scanned from 0.04 to 0.06 in 5 steps. The resolution of the scan range gauges how many points must be calculated and this must be considered for computer CPU time. It is best to start with a broad and coarse scan area, then, when areas of interest are identified, narrow down the range and increase the resolution for a more detailed analysis.

```
&inpar2
nbt =      11
bts =      4.0
btf =      9.0
nbetan =   5
betans =   0.04
betanf =   0.06...
```

Running the Physics Module

Once all the input files are prepared, the code is compiled using the *make* file. The compiler used is *gfortran* (new 2/2012 “*lff95*” *Lahey-Fujitsu Fortran*), which creates a *PlasmaPhysics.exe* file. Next, the code run from the terminal by the *runphysics.sh* shell script. As each combination of

scans is completed, the code adds the data to the output file named “sysout.” The plasmas that remain from the scan are self-consistent and satisfy the power and particle balance. The specifics are described by 55 parameters, as shown below in the tables.

The output file of the physics module then becomes the input file for the engineering module (aries.cpp files...).

Physics Output File Parameters

plasma major radius	r(i)
plasma aspect ratio (R/a)	asp(i)
toroidal field at plasma major radius r	bt(i)
plasma current	aip(i)
normalized beta	betan(i)
q95	qmhd(i)
q-cylindrical	qcyl(i)
plasma triangularity	delta(i)
exponent on plasma density profile	an(i)
exponent on plasma temperature profile	at(i)
ratio of line ave plasma density to Greenwald density	fracgw(i)
fusion gain (Pfusion/Pauxiliary)	ap(i)
plasma elongation (kappa)	ak(i)
H98(y,2) multiplier on energy confinement scaling	hfactor(i)
current diffusion time	tauj(i)
energy confinement time	taue(i)
ratio of effective particle confinement time to energy confinement time	tpote(i)
volume average electron density	xne(i)
volume average temperature	tempave(i)
flattop time	tflat(i)
L to H mode threshold power	pltoh(i)
average neutron wall load at plasma surface	xnwall(i)
bremssstrahlung radiation loss	pbrem(i)
bootstrap current fraction	fbs(i)
current drive efficiency	etacd(i)
power into plasma from generic heating/CD source	powcd(i)
total power into plasma for power balance	paux(i)
cyclotron radiation loss	pcycl(i)
ohmic power in plasma	pohm(i)
line radiation loss	pline(i)
fast alpha beta	betaf(i)
effective charge	zeff(i)
ratio of plasma temperature at center to edge	trat(i)
ratio of plasma density at center to edge	drat(i)
heating/CD power from source 1	powcd1(i)
heating/CD power from source 2	powcd2(i)
heating/CD power from source 3	powcd3(i)

heating/CD power from source 4	powcd4(i)
impurity fraction 2 (fraction of electron density)	fimp1(i)
impurity fraction 3 (fraction of electron density)	fimp2(i)
impurity fraction 1 (fraction of electron density)	fimp3(i)
peak temperature	temp0(i)
external CD fraction of total plasma current	fcd(i)
total non-inductive current fraction of total plasma current	fni(i)
density fraction of He (fraction of electron density)	fhe(i)
density fraction of DT fuel (fraction of electron density)	fdt(i)
plasma stored energy	wtot(i)
poloidal flux swing required to raise plasma current	dfcs(i)
loop voltage in plasma	vloop(i)
density profile peak to volume average	dptav(i)
temperature profile peak to volume average	tptav(i)
poloidal beta	betap(i)
toroidal beta	betat(i)
alpha power in plasma	palpha(i)
ratio of loss power to L-H threshold power	ploplh(i)

This is the ORDER in which the physics file outputs the data into “sysout.data.” There are 55 parameters that describe the plasma.

1	Plasma major radius	R
2	Plasma aspect ratio	asp
3	Toroidal magnetic field at plasma major radius	B (Bt)
4	Plasma current	IP
5	Normalized beta	BetaN
6	Cylindrical safety factor	qcyl if +, q95 if -
7	MHD safety factor	qMHD
8	Plasma triangularity	"delta"
9	Exponent on plasma den profile	an
10	Exponent on plasma temp profile	at
11	Greenwald density fraction	fGW (Fracgw)
12	Fusion gain = Pfus/Paux	Ap (Q)
13	Plasma elongation	K (kappa)
14	Multiplier on energy confinement scaling	hfactor (H98)
15	Current diffusion time	Tau j
16	Energy confinement time	Tau e
17	Ratio of effective particle confinement to energy confinement time	tpote
18	Volume averaged electron density	Xne
19	Volume averaged temperature	Tave (Tempave)
20	Flat top time	tflat
21	L to H-mode threshold power	P LtoH

22	Average neutron wall load at plasma surface	Xwall
23	Bremsstrahlung radiation loss	Pbrem
24	Bootstrap current fraction	fBS (Fbs)
25	Current drive efficiency for generic heating/CD source	etacd (nCD)
26	Power from generic CD source	PCD
27	Total aux. power into plasma for power balance	Paux
28	Cyclotron radiation loss	Pcylc
29	Ohmic power in plasma	Pohm
30	Line radiation loss	Pline
31	Fast alpha beta	Betaf
32	Effective charge	Zeff
33	Ratio of plasma temp at center to edge	trat
34	Ratio of plasma density at center to edge	drat
35	Defining parameters for CD source 1	n1CD
36	Defining parameters for CD source 1	P1CD
37	Defining parameters for CD source 1	f1CD
38	Defining parameters for CD source 1	r1CD
39	Impurity fraction 1	fimp1
40	Impurity fraction 2	fimp2
41	Impurity fraction 3	fimp3
42	Peak temperature	To
43	External CD fraction of total plasma current	fCD
44	Total non-inductive fraction of total plasma current	fmi
45	Density fraction of Helium	fHe
46	Density fraction of DT fuel	fDT
47	Plasma stored energy	Wtot
48	Poloidal flux swing required to raise plasma current	dfcs
49	Loop voltage in plasma	Vloop
50	Density profile peak-to-volume average	dptav
51	Temp profile peak-to-volume average	tptav
52	Poloidal beta	betaP
53	Toroidal beta	betaT
54	Alpha power in plasma	Palpha
55	Ratio of loss power to L-H threshold power	ploplh

The following parameters are added to the output file after the completion of the engineering module. The nomenclature of the file is changed to sysoutsic.data or sysoutdcll.data

56	Plasma surface area	-
57	Peak magnetic heat field	Btmax
58	Heat flux on inboard divertor (ave)	Qdivinb
59	Heat flux on outboard divertor (ave)	Qdivoutb
60	Peak radiated heat flux on first wall	Qpeakrad
61	Net electric power	Pnelec
62	Recirculating power	Pecir
63	Thermal power	Pthermal

64	Cost of electricity	COE
65	Data point number from plasma physics output file	-
66-84	Filter flags, not in use	-
85	Location of point in the partial databases before combining	-
86	Location of point in raw database sysout.data	-