INT 144/88

PROGRAMME ISTART 3

Courant d'accrochage d'un gyrotron travaillant en mode TE_{mp1}

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TABLE DES MATIERES

1. BUT DU PROGRAMME ISTART3

Dessiner le courant d'accrochage en fonction du champ magnétique statique B_0, pour différents modes TE.

2. MODELE ET EQUATIONS UTILISEES

Le calcul analytique est basé sur les hypothèses suivantes:

Champ électrique dans la cavité cylindrique [1]:

$$\underline{E} = (E_r \hat{r} + E_\phi \hat{\phi})\, e^{i(\omega t + \psi)} \qquad \text{avec:}$$

$$\begin{cases} E_r = i \dfrac{m}{k_\perp r} E_0 f(z)\, J_m(k_\perp r)\, e^{-im\phi} \\ E_\phi = E_0 f(z)\, J'_m(k_\perp r)\, e^{-im\phi} \end{cases}$$

A un instant donné, le champ électrique physiquement mesurable est la partie réelle de $\underline{E}$.

$k_\perp = \dfrac{\gamma_{mp}}{a}$ $\qquad$ γ_{mp} : $p^{\text{ième}}$ zéro non nul de $J'_m(x)$

a = rayon de la cavité

Le champ E a un profil supposé gaussien selon z, l'axe du faisceau d'électrons:

$$f(z) = \exp\left[-\left(\frac{2z}{L}\right)^2\right]$$

L = longueur d'intéraction
1.201·FWHM de f(z)

Le faisceau électronique est caractérisé par sa tension V_0, son anisotropie $\alpha = \beta_\perp / \beta_{//}$, son rayon R_e.

La longueur d'intéraction normalisée est définie par: $\mu = \pi \dfrac{\beta_\perp^2}{\beta_{//}} \dfrac{L}{\lambda}$

Pour une bonne efficacité dans le régime non-linéaire (soft excitation region), il faut prendre $\mu \simeq 9$ (cf Fig.3 de ref [1]).

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[1] Generalized Nonlinear Harmonic Gyrotron Theory,
B.G. Danly and R.J. Temkin, PFC, MIT, April 85.

Le "detuning" normalisé est défini par

$$\Delta = \frac{2}{\beta_\perp^2}\left(1 - \frac{n\Omega_0}{\gamma_0 \omega}\right) \qquad \text{avec } \Omega_0 = \frac{eB_0}{m_e} \quad ; \quad \gamma_0 = 1 + \frac{eV_0}{m_e c^2}$$

$$\text{d'où } B_0 = \frac{m_e}{n\cdot e}\gamma_0 \omega\left(1 - \frac{\beta_\perp^2}{2}\Delta\right) \qquad \beta_{//} = \sqrt{\frac{1-\gamma_0^{-2}}{1+\alpha^2}} \quad ; \beta_\perp = \alpha \beta_{//}$$

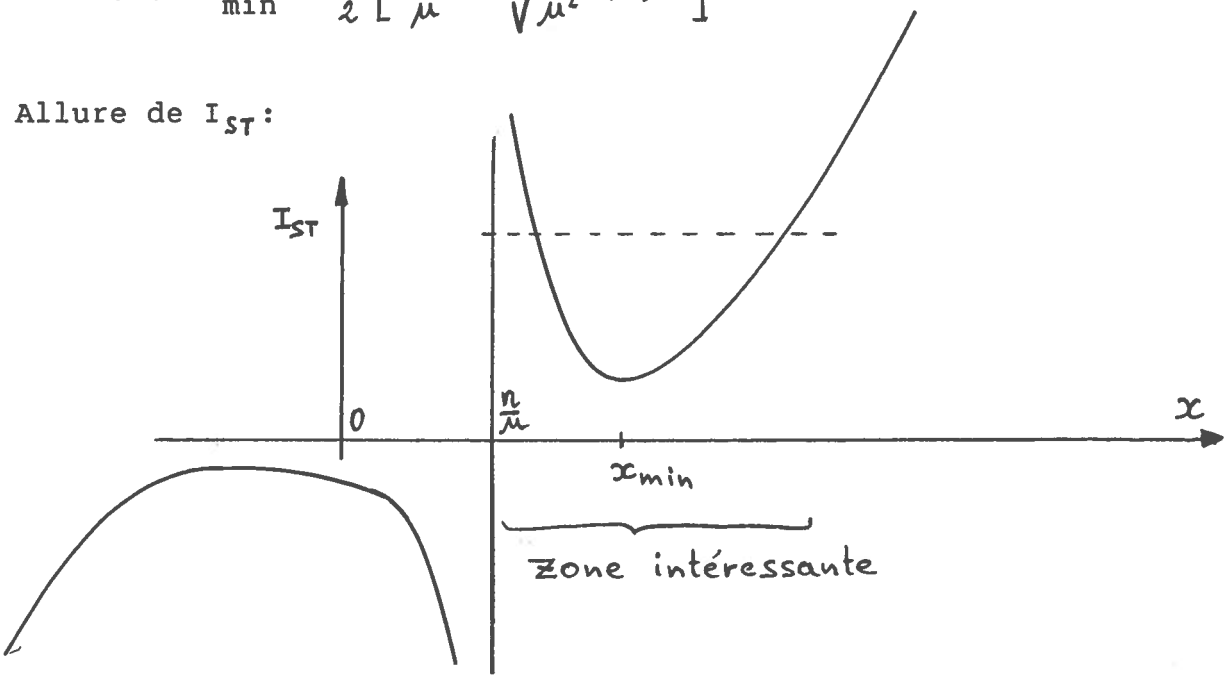
n = n° de l'harmonique: 1, 2...

Le courant d'accrochage normalisé est alors donné par

$$I_{ST}(\Delta, \mu) = \frac{4}{\pi \mu^2} \cdot \frac{e^{2x^2}}{\mu x - n} \qquad \text{avec } x = \frac{\mu \Delta}{4}$$

Minimum: $x_{min} = \frac{1}{2}\left[\frac{n}{\mu} + \sqrt{\frac{n^2}{\mu^2} + 1}\right]$

Allure de I_{ST}:



Le courant normalisé est relié au courant en Ampères via:

$$I = \left(\frac{2}{\pi}\right)^{\frac{5}{2}} \frac{e}{\varepsilon_0 m_e c^3} \frac{Q_{mp} I_A}{\gamma_0} \beta_\perp^{2n-6} \left(\frac{\lambda}{L}\right)\left(\frac{n^n}{2^n n!}\right)^2 \frac{J_{m\pm n}^2(k_\perp R_e)}{(\nu_{mp}^2 - m^2) J_m^2(\nu_{mp})}$$

Q_{mp} = facteur de qualité du mode TE_{mp1}

$J_{m\pm n}$: le signe dépend de la polarisation du mode ($\pm im\phi$).
Donc pour $m \neq 0$, il y aura 2 courbes $I_{ST}(B_0)$.

λ = longueur d'onde de l'onde e.m. dans le vide

3. FICHIER DE DONNEES

Variable

NCAS	Nombre de cas à étudier
N	N° d'harmonique (1, 2,...)
MM(1 à NCAS)	Index azymuthal (0, 1,...)
PP(1 à NCAS)	Index radial (1, 2,...)
LL(1 à NCAS)	Longueur d'intéraction [m]
QQ(1 à NCAS)	Facteur de qualité
V0	Tension d'accélération du faisceau [V]
ALPHA	Anisotropie
RE	Rayon du faisceau [m]
A	Rayon de la cavité [m]
BMIN, BMAX	Limites du champ magnétique [Tesla] (dessin)
IAMAX	Limite max du courant [A] (calcul et dessin)

Exemple:

```
M I T   1 4 0   G H Z   G Y R O T R O N
=======================================
 $MODES
 NCAS = 3, N=1,
 MM(1)=0, PP(1)=3, QQ(1)=1450., LL(1)=0.0120,
 MM(2)=2, PP(2)=3, QQ(2)=1400., LL(2)=0.0120,
 MM(3)=5, PP(3)=2, QQ(3)=1300., LL(3)=0.0120,
 V0=65000., ALPHA=1.5, RE=0.00182, A=0.00347,
 BMIN=5.2, BMAX=6.0, IAMAX=3.5,
 $END
```

4. Benchmark

Avec les données précédentes, on trouve:

			Expérimental [2]	
Mode	I	B	I	B
(0,3,1)	0.46	5.564	0.4	5.58
(2,3,1)	0.52	5.430		
(-2,3,1)	0.45	5.449	0.4	5.41
(5,2,1)	1.34	5.735		
(-5,2,1)	0.30	5.735		
	[A]	[Tesla]	[A]	[Telsa]

L'accord est excellent. Les légères différences s'expliquent par la dispersion du faisceau, dont le programme ne tient pas compte, et par le facteur de qualité qui n'a pas été mesuré à 140 GHz.

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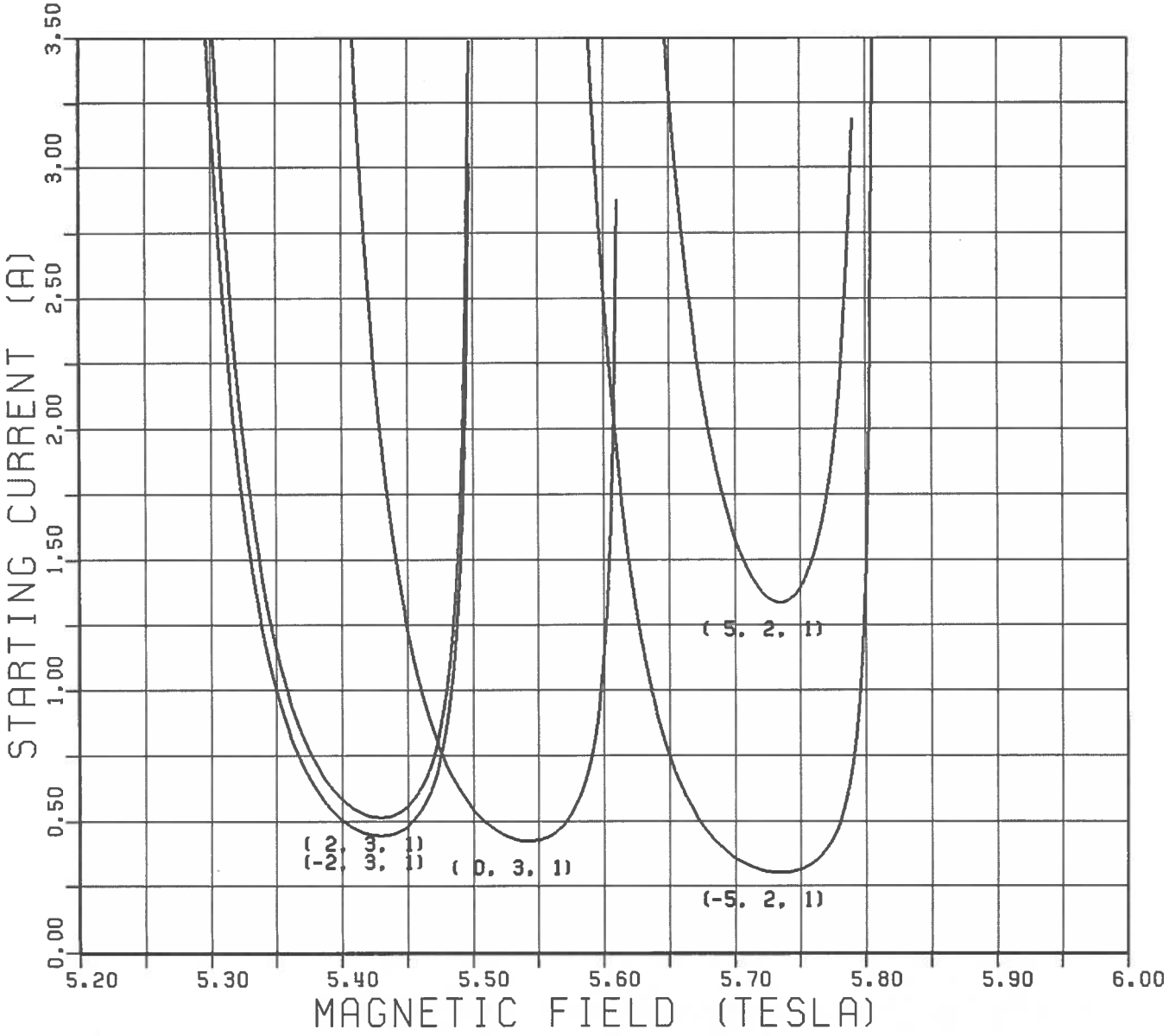
[2] High Efficiency Operation of a 140 GHz Gyrotron, K.E. Kreisher, J.B. Schutkeker, R.J. Temkin, and W.J. Mulligan, Proc. 8th Int. Conf. on MM Waves, Miami, 1983.

M I T 1 4 0 G H Z G Y R O T R O N

CRPP - 88/07/09. 10.59.30.
GYROTRON PROJECT

STARTING CURRENT VERSUS STATIC MAGNETIC FIELD PROGRAM ISTART3

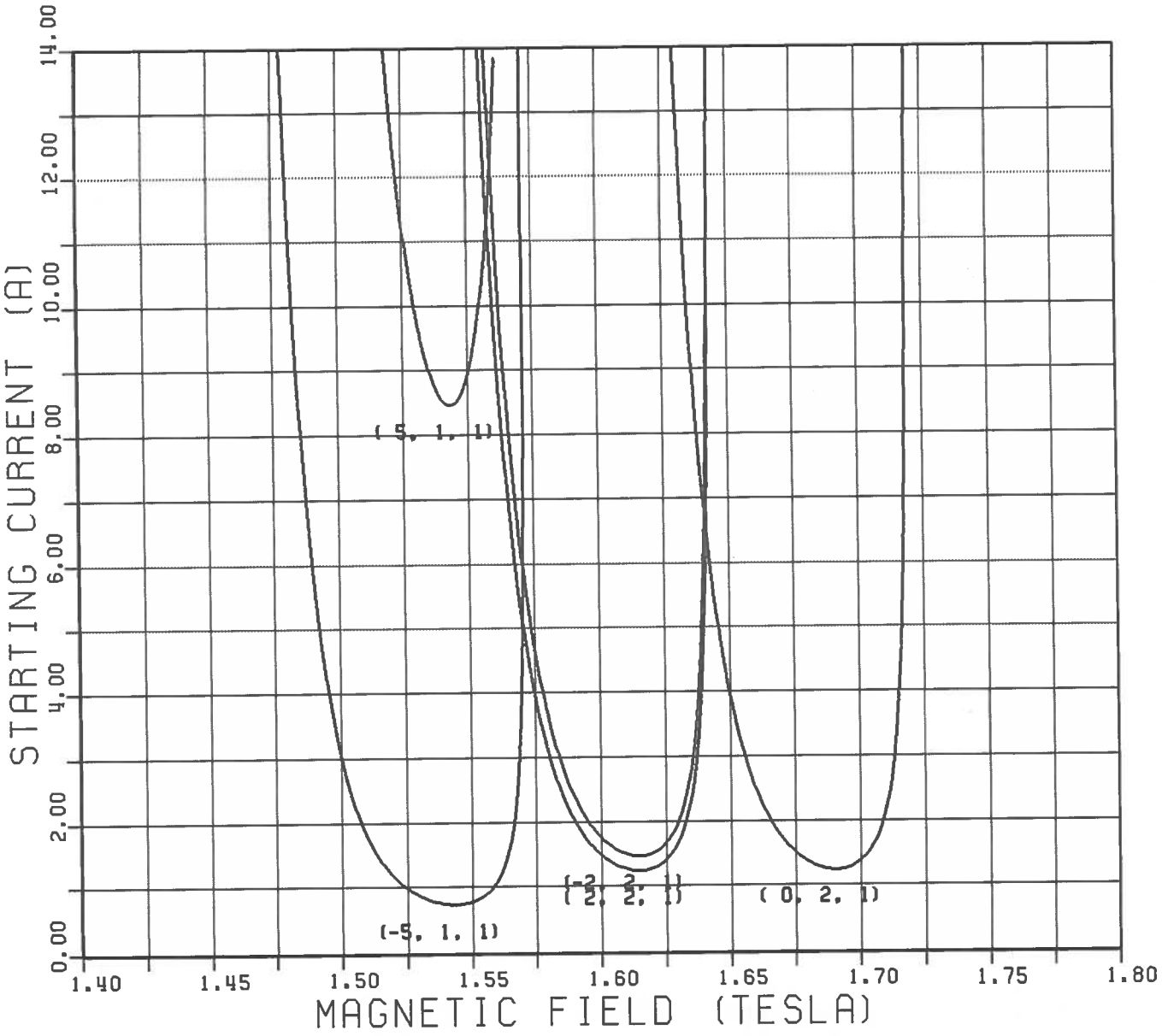


RESONATOR RADIUS: 3.47 MM
GAMMA0: 1.1272
ALPHA: 1.5000
BEAM VOLTAGE: 65.00 KV
ANNULAR BEAM RADIUS: 1.82 MM
HARMONIC # : 1

MODE TE	L [MM]	Q	FREQUENCY [GHZ]
(0, 3, 1)	12.0	1450.	139.888
(2, 3, 1)	12.0	1400.	137.083
(5, 2, 1)	12.0	1300.	144.651

42 GHZ GYROTRON

STARTING CURRENT VERSUS STATIC MAGNETIC FIELD PROGRAM ISTART3



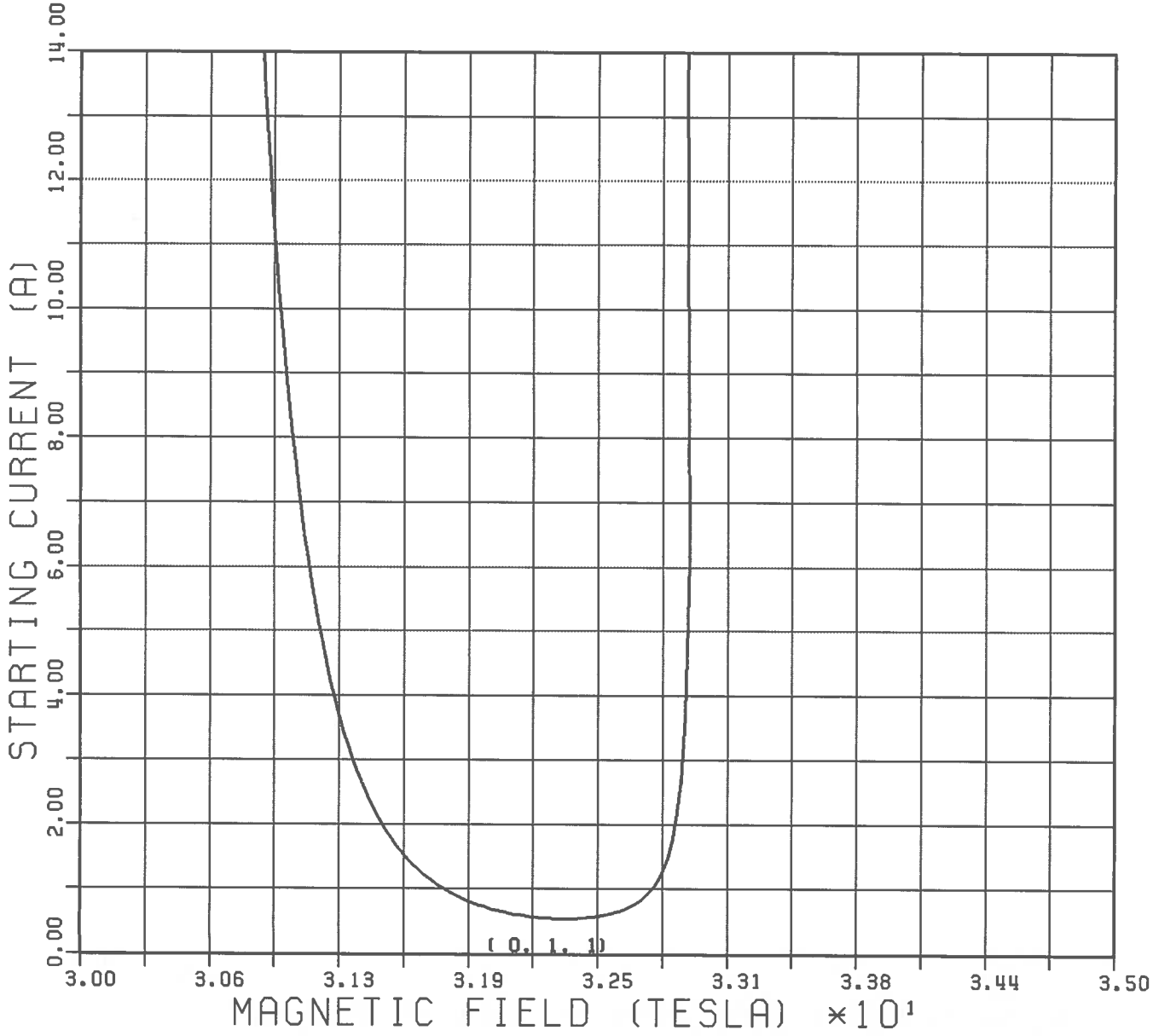
RESONATOR RADIUS: 8.00 MM
GAMMA0: 1.1566
ALPHA: 1.5000
BEAM VOLTAGE: 80.00 KV
ANNULAR BEAM RADIUS: 6.00 MM
HARMONIC # : 1

MODE TE	Q	FREQUENCY [GHZ]
(0, 2,1)	618.	41.842
(2, 2,1)	556.	39.997
(5, 1,1)	503.	38.264

8 GHZ GYROTRON

CRPP - 88/07/05. 08.46.34.
GYROTRON PROJECT

STARTING CURRENT VERSUS STATIC MAGNETIC FIELD PROGRAM ISTART3



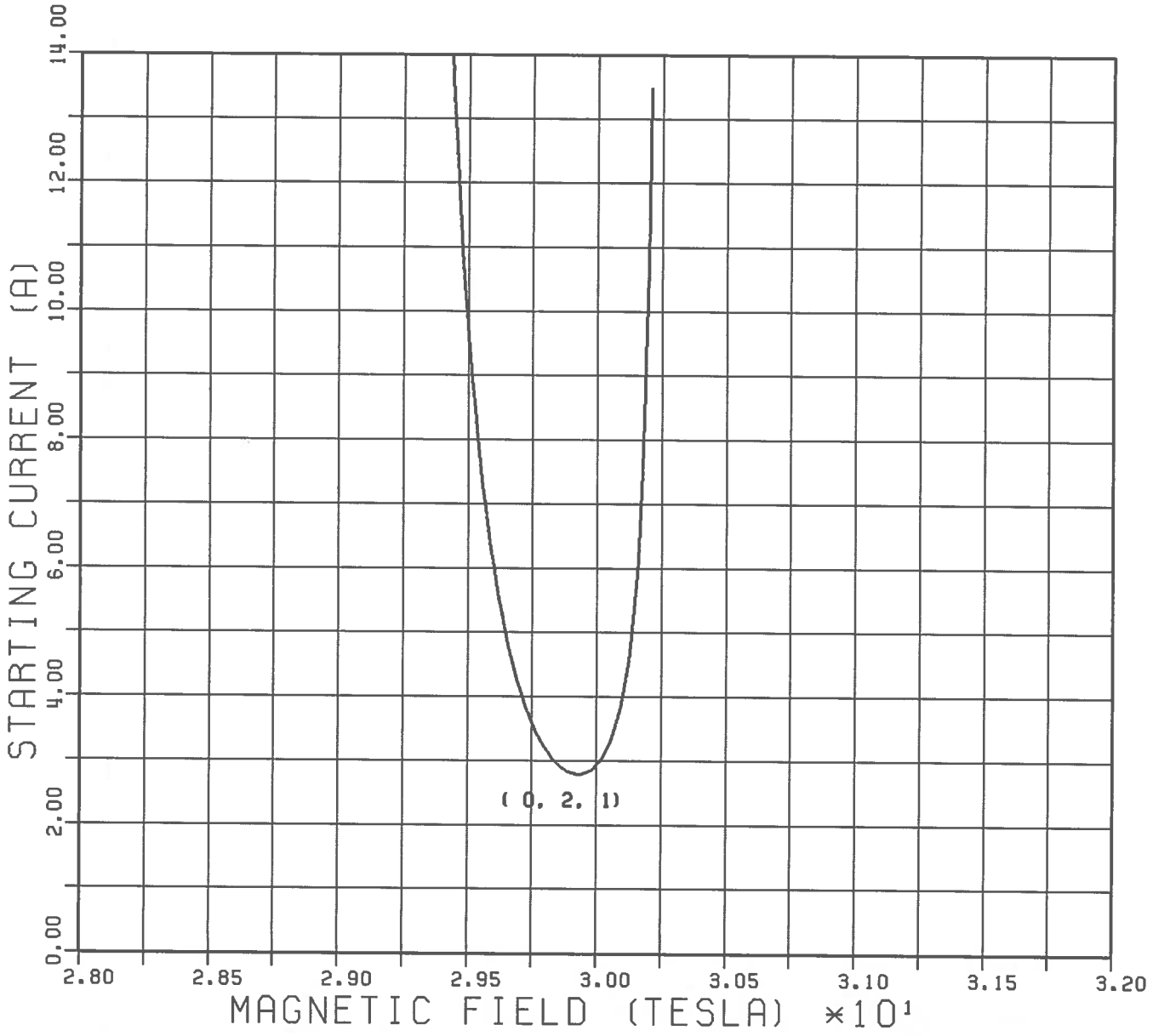
RESONATOR RADIUS: 22.80 MM
GAMMA0: 1.1566
ALPHA: 1.8900
BEAM VOLTAGE: 80.00 KV
ANNULAR BEAM RADIUS: 11.18 MM
HARMONIC # : 1

MODE TE	Q	FREQUENCY [GHZ]
(0, 1,1)	227.	8.019

8 GHZ GYROTRON

CRPP - 88/07/05. 09.00.47.
GYROTRON PROJECT

STARTING CURRENT VERSUS STATIC MAGNETIC FIELD PROGRAM ISTART3



RESONATOR RADIUS: 22.80 MM
GAMMA0: 1.1566
ALPHA: 1.8900
BEAM VOLTAGE: 80.00 KV
ANNULAR BEAM RADIUS: 11.18 MM
HARMONIC # : 2

MODE TE	Q	FREQUENCY [GHZ]
(0, 2,1)	200.	14.681

APPENDICE A

Sortie des résultats (Fichier de sortie)

Pour tourner le programme SUR CYBER (NOS)

```
GET,ISTART3/UN=AP1.
FTN5,I=ISTART3,L=0,ANSI=0.
LIBRARY,MAPP5.
LGO,IST140,OUTPUT.
RASTER.
ROUTE,GLDX.
```

PROGRAM ISTART3 88/07/11. 10.17.21.

A1

ZEROES OF DERIVATIVES OF BESSEL FUNCTIONS

```
J'(  0,  5) = 16.47063005   ITER=  4
J'(  0,  4) = 13.32369194   ITER=  4
J'(  0,  3) = 10.17346814   ITER=  3
J'(  0,  2) =  7.01558667   ITER=  4
J'(  0,  1) =  3.83170597   ITER=  4
J'(  1,  5) = 14.86358863   ITER=  4
J'(  1,  4) = 11.70600490   ITER=  4
J'(  1,  3) =  8.53631637   ITER=  4
J'(  1,  2) =  5.33144277   ITER=  4
J'(  1,  1) =  1.84118378   ITER=  4
J'(  2,  5) = 16.34752232   ITER=  4
J'(  2,  4) = 13.17037086   ITER=  4
J'(  2,  3) =  9.96946782   ITER=  4
J'(  2,  2) =  6.70613319   ITER=  4
J'(  2,  1) =  3.05423693   ITER=  4
J'(  3,  5) = 17.78874787   ITER=  4
J'(  3,  4) = 14.58584829   ITER=  5
J'(  3,  3) = 11.34592431   ITER=  4
J'(  3,  2) =  8.01523660   ITER=  4
J'(  3,  1) =  4.20118894   ITER=  4
J'(  4,  5) = 19.19602880   ITER=  5
J'(  4,  4) = 15.96410704   ITER=  5
J'(  4,  3) = 12.68190844   ITER=  4
J'(  4,  2) =  9.28239629   ITER=  4
J'(  4,  1) =  5.31755313   ITER=  4
J'(  5,  5) = 20.57551452   ITER=  5
J'(  5,  4) = 17.31284249   ITER=  5
J'(  5,  3) = 13.98718863   ITER=  4
J'(  5,  2) = 10.51986087   ITER=  4
J'(  5,  1) =  6.41561638   ITER=  5
```

M I T 1 4 0 G H Z G Y R O T R O N

```
$MODES
NCAS    = 3,
MM      = 0, 2, 5, 0, 0, 0, 0, 0, 0, 0,
PP      = 3, 3, 2, 0, 0, 0, 0, 0, 0, 0,
QQ      = .145E+04, .14E+04, .13E+04, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
LL      = .12E-01, .12E-01, .12E-01, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
N       = 1,
BMIN    = .52E+01,
BMAX    = .6E+01,
IAMAX   = .35E+01,
```

A2

```
V0      = .65E+05,
ALPHA   = .15E+01,
RE      = .182E-02,
A       = .347E-02,
$END
GAMMA0 =   1.12720
BETA PERP =    .383971
BETA PARA =    .255981
CONST =    .238402E-03
```

MODE TE(0, 3,1)

```
QUALITY FACTOR =        1450.00
INTERACTION LENGTH=    .120000E-01
NUMP   =        10.1735
JM (NUMP) =     -.249705
KPERP*RE        5.33594
LAMBDA  =         .214309E-02
JMPN    =      -.346123
FREQUENCY  =          .139888E+12
MU      =        10.1317
XMIN    =        .551780
```

	BO [TESLA]	IA START [A]
1	.5616E+01	.1418E+02
2	.5613E+01	.4760E+01
3	.5611E+01	.2878E+01
4	.5608E+01	.2074E+01
5	.5606E+01	.1628E+01
6	.5603E+01	.1346E+01
7	.5601E+01	.1152E+01
8	.5598E+01	.1011E+01
9	.5596E+01	.9041E+00
10	.5593E+01	.8205E+00
11	.5591E+01	.7536E+00
12	.5588E+01	.6992E+00
13	.5586E+01	.6542E+00
14	.5583E+01	.6167E+00
15	.5581E+01	.5850E+00
16	.5578E+01	.5581E+00
17	.5576E+01	.5352E+00
18	.5574E+01	.5156E+00
19	.5571E+01	.4987E+00
20	.5569E+01	.4843E+00
21	.5566E+01	.4720E+00
22	.5564E+01	.4615E+00
23	.5561E+01	.4526E+00
24	.5559E+01	.4452E+00
25	.5556E+01	.4391E+00
26	.5554E+01	.4342E+00
27	.5551E+01	.4304E+00
28	.5549E+01	.4276E+00
29	.5546E+01	.4258E+00
30	.5544E+01	.4249E+00
31	.5541E+01	.4249E+00
32	.5539E+01	.4258E+00
33	.5536E+01	.4274E+00
34	.5534E+01	.4299E+00
35	.5531E+01	.4332E+00

A3

36	.5529E+01	.4372E+00
37	.5526E+01	.4421E+00
38	.5524E+01	.4477E+00
39	.5522E+01	.4542E+00
40	.5519E+01	.4615E+00
41	.5517E+01	.4696E+00
42	.5514E+01	.4786E+00
43	.5512E+01	.4885E+00
44	.5509E+01	.4993E+00
45	.5507E+01	.5111E+00
46	.5504E+01	.5239E+00
47	.5502E+01	.5379E+00
48	.5499E+01	.5529E+00
49	.5497E+01	.5691E+00
50	.5494E+01	.5866E+00
51	.5492E+01	.6054E+00
52	.5489E+01	.6257E+00
53	.5487E+01	.6474E+00
54	.5484E+01	.6708E+00
55	.5482E+01	.6958E+00
56	.5479E+01	.7228E+00
57	.5477E+01	.7517E+00
58	.5474E+01	.7827E+00
59	.5472E+01	.8159E+00
60	.5470E+01	.8517E+00
61	.5467E+01	.8900E+00
62	.5465E+01	.9312E+00
63	.5462E+01	.9754E+00
64	.5460E+01	.1023E+01
65	.5457E+01	.1074E+01
66	.5455E+01	.1129E+01
67	.5452E+01	.1188E+01
68	.5450E+01	.1252E+01
69	.5447E+01	.1320E+01
70	.5445E+01	.1394E+01
71	.5442E+01	.1474E+01
72	.5440E+01	.1560E+01
73	.5437E+01	.1652E+01
74	.5435E+01	.1752E+01
75	.5432E+01	.1861E+01
76	.5430E+01	.1978E+01
77	.5427E+01	.2105E+01
78	.5425E+01	.2242E+01
79	.5422E+01	.2391E+01
80	.5420E+01	.2553E+01
81	.5418E+01	.2728E+01
82	.5415E+01	.2918E+01
83	.5413E+01	.3126E+01
84	.5410E+01	.3351E+01
85	.5408E+01	.3597E+01

MAPPED - VECTOR

*****PLOT OPTIONS IN EFFECT*****

MODEL	=	8224	,XMIN	=	.00	,XMAX	= 100.00
YMIN	=	.00	,YMAX	=	58.51	,MSGLVL	= 1
XSTART	=	.00	,YSTART	=	.00	,SCALE	= 1.00
XFACT	=	1.00	,YFACT	=	1.00	,UNITS	= 2.54
STRIP	=	58.52	,STRIPO	=	.00	,SPACE	= 10.16
PAPIER	=	0	,FC	=	1		

MODE TE(2, 3,1)

QUALITY FACTOR = 1400.00

INTERACTION LENGTH= .120000E-01
NUMP = 9.96947
JM (NUMP) = .254744

ROTATING MODE: 1
KPERP*RE 5.22894
LAMBDA = .218694E-02
JMPN = .320362
FREQUENCY = .137083E+12
MU = 9.92851
XMIN = .552890

A4

	BO [TESLA]	IA START [A]
1	.5502E+01	.1717E+02
2	.5500E+01	.5765E+01
3	.5497E+01	.3486E+01
4	.5495E+01	.2512E+01
5	.5492E+01	.1973E+01
6	.5490E+01	.1632E+01
7	.5487E+01	.1397E+01
8	.5485E+01	.1225E+01
9	.5483E+01	.1096E+01
10	.5480E+01	.9945E+00
11	.5478E+01	.9136E+00
12	.5475E+01	.8476E+00
13	.5473E+01	.7932E+00
14	.5470E+01	.7477E+00
15	.5468E+01	.7093E+00
16	.5465E+01	.6768E+00
17	.5463E+01	.6490E+00
18	.5460E+01	.6252E+00
19	.5458E+01	.6048E+00
20	.5455E+01	.5874E+00
21	.5453E+01	.5724E+00
22	.5450E+01	.5597E+00
23	.5448E+01	.5489E+00
24	.5445E+01	.5400E+00
25	.5443E+01	.5326E+00
26	.5441E+01	.5266E+00
27	.5438E+01	.5220E+00
28	.5436E+01	.5187E+00
29	.5433E+01	.5165E+00
30	.5431E+01	.5154E+00
31	.5428E+01	.5154E+00
32	.5426E+01	.5165E+00
33	.5423E+01	.5185E+00
34	.5421E+01	.5215E+00
35	.5418E+01	.5254E+00
36	.5416E+01	.5303E+00
37	.5413E+01	.5362E+00
38	.5411E+01	.5430E+00
39	.5408E+01	.5508E+00
40	.5406E+01	.5597E+00
41	.5403E+01	.5695E+00
42	.5401E+01	.5804E+00
43	.5399E+01	.5924E+00
44	.5396E+01	.6055E+00
45	.5394E+01	.6198E+00
46	.5391E+01	.6353E+00
47	.5389E+01	.6521E+00
48	.5386E+01	.6703E+00
49	.5384E+01	.6899E+00
50	.5381E+01	.7111E+00
51	.5379E+01	.7338E+00
52	.5376E+01	.7583E+00
53	.5374E+01	.7846E+00

54	.5371E+01	.8128E+00
55	.5369E+01	.8432E+00
56	.5366E+01	.8757E+00
57	.5364E+01	.9106E+00
58	.5361E+01	.9481E+00
59	.5359E+01	.9883E+00
60	.5357E+01	.1031E+01
61	.5354E+01	.1078E+01
62	.5352E+01	.1127E+01
63	.5349E+01	.1181E+01
64	.5347E+01	.1238E+01
65	.5344E+01	.1300E+01
66	.5342E+01	.1366E+01
67	.5339E+01	.1438E+01
68	.5337E+01	.1514E+01
69	.5334E+01	.1597E+01
70	.5332E+01	.1686E+01
71	.5329E+01	.1782E+01
72	.5327E+01	.1886E+01
73	.5324E+01	.1998E+01
74	.5322E+01	.2118E+01
75	.5319E+01	.2249E+01
76	.5317E+01	.2390E+01
77	.5315E+01	.2543E+01
78	.5312E+01	.2708E+01
79	.5310E+01	.2888E+01
80	.5307E+01	.3082E+01
81	.5305E+01	.3294E+01
82	.5302E+01	.3523E+01

AS

ROTATING MODE:-1
KPERP*RE 5.22894
LAMBDA = .218694E-02
JMPN = -.344363
FREQUENCY = .137083E+12
MU = 9.92851
XMIN = .552890

	BO [TESLA]	IA START [A]
1	.5502E+01	.1486E+02
2	.5500E+01	.4989E+01
3	.5497E+01	.3017E+01
4	.5495E+01	.2174E+01
5	.5492E+01	.1708E+01
6	.5490E+01	.1412E+01
7	.5487E+01	.1209E+01
8	.5485E+01	.1061E+01
9	.5483E+01	.9484E+00
10	.5480E+01	.8607E+00
11	.5478E+01	.7907E+00
12	.5475E+01	.7336E+00
13	.5473E+01	.6865E+00
14	.5470E+01	.6471E+00
15	.5468E+01	.6139E+00
16	.5465E+01	.5857E+00
17	.5463E+01	.5617E+00
18	.5460E+01	.5411E+00
19	.5458E+01	.5235E+00
20	.5455E+01	.5083E+00
21	.5453E+01	.4954E+00
22	.5450E+01	.4844E+00
23	.5448E+01	.4751E+00
24	.5445E+01	.4673E+00
25	.5443E+01	.4609E+00
26	.5441E+01	.4558E+00
27	.5438E+01	.4518E+00

28	.5436E+01	.4489E+00
29	.5433E+01	.4470E+00
30	.5431E+01	.4461E+00
31	.5428E+01	.4461E+00
32	.5426E+01	.4470E+00
33	.5423E+01	.4487E+00
34	.5421E+01	.4513E+00
35	.5418E+01	.4547E+00
36	.5416E+01	.4590E+00
37	.5413E+01	.4641E+00
38	.5411E+01	.4700E+00
39	.5408E+01	.4767E+00
40	.5406E+01	.4844E+00
41	.5403E+01	.4929E+00
42	.5401E+01	.5023E+00
43	.5399E+01	.5127E+00
44	.5396E+01	.5240E+00
45	.5394E+01	.5364E+00
46	.5391E+01	.5498E+00
47	.5389E+01	.5644E+00
48	.5386E+01	.5801E+00
49	.5384E+01	.5971E+00
50	.5381E+01	.6154E+00
51	.5379E+01	.6351E+00
52	.5376E+01	.6563E+00
53	.5374E+01	.6790E+00
54	.5371E+01	.7035E+00
55	.5369E+01	.7297E+00
56	.5366E+01	.7579E+00
57	.5364E+01	.7881E+00
58	.5361E+01	.8205E+00
59	.5359E+01	.8553E+00
60	.5357E+01	.8927E+00
61	.5354E+01	.9328E+00
62	.5352E+01	.9758E+00
63	.5349E+01	.1022E+01
64	.5347E+01	.1072E+01
65	.5344E+01	.1125E+01
66	.5342E+01	.1182E+01
67	.5339E+01	.1244E+01
68	.5337E+01	.1311E+01
69	.5334E+01	.1382E+01
70	.5332E+01	.1459E+01
71	.5329E+01	.1542E+01
72	.5327E+01	.1632E+01
73	.5324E+01	.1729E+01
74	.5322E+01	.1833E+01
75	.5319E+01	.1946E+01
76	.5317E+01	.2069E+01
77	.5315E+01	.2201E+01
78	.5312E+01	.2344E+01
79	.5310E+01	.2499E+01
80	.5307E+01	.2668E+01
81	.5305E+01	.2851E+01
82	.5302E+01	.3049E+01
83	.5300E+01	.3265E+01
84	.5297E+01	.3500E+01
85	.5295E+01	.3755E+01

A6

MODE TE(5, 2,1)

QUALITY FACTOR = 1300.00
INTERACTION LENGTH= .120000E-01
NUMP = 10.5199

JM (NUMP) = -.261092

ROTATING MODE: 1
KPERP*RE 5.51762
LAMBDA = .207252E-02
JMPN = .188849
FREQUENCY = .144651E+12
MU = 10.4766
XMIN = .549998

A7

	BO [TESLA]	IA START [A]
1	.5808E+01	.4476E+02
2	.5805E+01	.1502E+02
3	.5803E+01	.9081E+01
4	.5800E+01	.6542E+01
5	.5798E+01	.5137E+01
6	.5795E+01	.4247E+01
7	.5793E+01	.3634E+01
8	.5791E+01	.3188E+01
9	.5788E+01	.2850E+01
10	.5786E+01	.2586E+01
11	.5783E+01	.2375E+01
12	.5781E+01	.2204E+01
13	.5778E+01	.2062E+01
14	.5776E+01	.1943E+01
15	.5773E+01	.1843E+01
16	.5771E+01	.1758E+01
17	.5768E+01	.1686E+01
18	.5766E+01	.1624E+01
19	.5763E+01	.1571E+01
20	.5761E+01	.1525E+01
21	.5758E+01	.1486E+01
22	.5756E+01	.1453E+01
23	.5753E+01	.1425E+01
24	.5751E+01	.1402E+01
25	.5748E+01	.1382E+01
26	.5746E+01	.1367E+01
27	.5743E+01	.1355E+01
28	.5741E+01	.1346E+01
29	.5738E+01	.1341E+01
30	.5736E+01	.1338E+01
31	.5733E+01	.1338E+01
32	.5731E+01	.1340E+01
33	.5728E+01	.1346E+01
34	.5726E+01	.1353E+01
35	.5723E+01	.1364E+01
36	.5721E+01	.1377E+01
37	.5718E+01	.1392E+01
38	.5716E+01	.1410E+01
39	.5714E+01	.1430E+01
40	.5711E+01	.1453E+01
41	.5709E+01	.1479E+01
42	.5706E+01	.1507E+01
43	.5704E+01	.1539E+01
44	.5701E+01	.1573E+01
45	.5699E+01	.1610E+01
46	.5696E+01	.1651E+01
47	.5694E+01	.1695E+01
48	.5691E+01	.1742E+01
49	.5689E+01	.1794E+01
50	.5686E+01	.1849E+01
51	.5684E+01	.1908E+01
52	.5681E+01	.1972E+01
53	.5679E+01	.2041E+01
54	.5676E+01	.2115E+01
55	.5674E+01	.2195E+01

56	.5671E+01	.2280E+01
57	.5669E+01	.2371E+01
58	.5666E+01	.2470E+01
59	.5664E+01	.2575E+01
60	.5661E+01	.2688E+01
61	.5659E+01	.2810E+01
62	.5656E+01	.2940E+01
63	.5654E+01	.3080E+01
64	.5651E+01	.3231E+01
65	.5649E+01	.3393E+01
66	.5646E+01	.3567E+01

A8

ROTATING MODE:-1
KPERP*RE 5.51762
LAMBDA = .207252E-02
JMPN = .396118
FREQUENCY = .144651E+12
MU = 10.4766
XMIN = .549998

	BO [TESLA]	IA START [A]
1	.5808E+01	.1017E+02
2	.5805E+01	.3414E+01
3	.5803E+01	.2064E+01
4	.5800E+01	.1487E+01
5	.5798E+01	.1168E+01
6	.5795E+01	.9652E+00
7	.5793E+01	.8260E+00
8	.5791E+01	.7247E+00
9	.5788E+01	.6479E+00
10	.5786E+01	.5879E+00
11	.5783E+01	.5399E+00
12	.5781E+01	.5008E+00
13	.5778E+01	.4686E+00
14	.5776E+01	.4416E+00
15	.5773E+01	.4189E+00
16	.5771E+01	.3996E+00
17	.5768E+01	.3832E+00
18	.5766E+01	.3691E+00
19	.5763E+01	.3570E+00
20	.5761E+01	.3467E+00
21	.5758E+01	.3378E+00
22	.5756E+01	.3303E+00
23	.5753E+01	.3239E+00
24	.5751E+01	.3186E+00
25	.5748E+01	.3142E+00
26	.5746E+01	.3107E+00
27	.5743E+01	.3080E+00
28	.5741E+01	.3060E+00
29	.5738E+01	.3047E+00
30	.5736E+01	.3041E+00
31	.5733E+01	.3041E+00
32	.5731E+01	.3047E+00
33	.5728E+01	.3059E+00
34	.5726E+01	.3076E+00
35	.5723E+01	.3100E+00
36	.5721E+01	.3129E+00
37	.5718E+01	.3164E+00
38	.5716E+01	.3204E+00
39	.5714E+01	.3251E+00
40	.5711E+01	.3303E+00
41	.5709E+01	.3361E+00
42	.5706E+01	.3426E+00
43	.5704E+01	.3497E+00
44	.5701E+01	.3575E+00
45	.5699E+01	.3660E+00

A9

46	.5696E+01	.3752E+00
47	.5694E+01	.3852E+00
48	.5691E+01	.3960E+00
49	.5689E+01	.4077E+00
50	.5686E+01	.4202E+00
51	.5684E+01	.4338E+00
52	.5681E+01	.4483E+00
53	.5679E+01	.4640E+00
54	.5676E+01	.4808E+00
55	.5674E+01	.4988E+00
56	.5671E+01	.5182E+00
57	.5669E+01	.5390E+00
58	.5666E+01	.5613E+00
59	.5664E+01	.5853E+00
60	.5661E+01	.6110E+00
61	.5659E+01	.6386E+00
62	.5656E+01	.6683E+00
63	.5654E+01	.7002E+00
64	.5651E+01	.7344E+00
65	.5649E+01	.7712E+00
66	.5646E+01	.8109E+00
67	.5644E+01	.8535E+00
68	.5641E+01	.8994E+00
69	.5639E+01	.9488E+00
70	.5637E+01	.1002E+01
71	.5634E+01	.1060E+01
72	.5632E+01	.1122E+01
73	.5629E+01	.1189E+01
74	.5627E+01	.1261E+01
75	.5624E+01	.1339E+01
76	.5622E+01	.1424E+01
77	.5619E+01	.1516E+01
78	.5617E+01	.1615E+01
79	.5614E+01	.1723E+01
80	.5612E+01	.1840E+01
81	.5609E+01	.1967E+01
82	.5607E+01	.2105E+01
83	.5604E+01	.2255E+01
84	.5602E+01	.2418E+01
85	.5599E+01	.2596E+01
86	.5597E+01	.2790E+01
87	.5594E+01	.3002E+01
88	.5592E+01	.3233E+01
89	.5589E+01	.3486E+01
90	.5587E+01	.3762E+01

DIMENSIONS DU DESSIN: X MINIMUM = .00 X MAXIMUM = 29.00
Y MINIMUM = .00 Y MAXIMUM = 21.00

DO=-LONG/-OT,ARG=-COMMON/-FIXED,CS= USER/-FIXED,DB=-TB/-SB/-SL/-ER/-ID/-PMD/-ST,-AL,PL=5000
FTN5,I=ISTART3,L=LIS,ANSI=0,LO=S/-A,PN.

```
      PROGRAM ISTART3(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C     COMPUTATION OF THE STARTING CURRENT OF A CONVENTIONAL GYROTRON
C     PLOT ON VERSATEC (CYBER)
C
C     - MODE TE(M,P,1)   (SIMPLE CAVITY)
C     - ANALYTICAL APPROXIMATION (LINEAR REGIME)
C     - MKSA UNITS
C     - DOCUMENTATION: INT 144/88
C
C     ANDRE PERRENOUD      CRPP/EPFL    VERSION 1    04 JULY 1988
C-----------------------------------------------------------------------
C     PARAMETERS
C     ----------
C     NMAX            MAX NUMBER OF MODES
C     NPOINT          MAX NUMBER OF B FIELD POINTS
C     MMAX            MAX AZYMUTHAL INDEX     ( MMAX < 51 )
C     IPMAX           MAX RADIAL INDEX
C
C     INPUT DATA
C     ----------
C     NCAS            NUMBER OF MODES TO BE COMPUTED
C     MM(1...NCAS)    AZYMUTHAL INDEX
C     PP(1...NCAS)    RADIAL INDEX
C     QQ(1...NCAS)    QUALITY FACTOR OF MODE TE(M,P,1)
C     LL(1...NCAS)    INTERACTION LENGTH OF MODE TE(M,P,1)
C     N               HARMONIC #   (MAX 3)
C     A               RADIUS OF RESONATOR (CYLINDRICAL CAVITY)
C     BMIN            LOWEST VALUE OF B FIELD  (FOR THE PLOT)
C     BMAX            HIGHEST VALUE            ( "   "   "  )
C     IAMAX           HIGHEST VALUE OF CURRENT ( "   "   "  )
C     V0              BEAM VOLTAGE
C     ALPHA           BEAM ANISOTROPY  (VPERP/VPARA)
C     RE              BEAM RADIUS
C-----------------------------------------------------------------------
C
      PARAMETER (NMAX=10, NPOINT=200, MMAX=5, IPMAX=5)
      INTEGER P, PP
      REAL IAMAX, IA, MU0, L, LL, NFAC(10), LAMBDA, MU, KRE,
     *     KPERP, NUMP, JMNUMP, JMPN, IST
      DIMENSION B0(NPOINT), IA(NPOINT), BJZP(MMAX+1,IPMAX+2), BJ(50)
      CHARACTER DATE*10,TIME*10,DATE1*10,TIME1*10, LABEL*80
C
      COMMON /TITRE1/ LABEL(2)
      COMMON /TITRE2/ DATE1,TIME1
      COMMON /BEAM/   V0, ALPHA, RE, GAMMA0
      COMMON /CAVITY/ A, M, P, N, ISIG
      COMMON /MODE/   NCAS, MM(NMAX), PP(NMAX), QQ(NMAX), LL(NMAX),
     *                FREQ(NMAX)
      COMMON /PAGE/   XA4,YA4,DXL,DXR,DYU,DYD, CH, X0,Y0,AXEX,AXEY
C
      NAMELIST /MODES/ NCAS, MM, PP, QQ, LL, N, BMIN,BMAX, IAMAX,
     *                 V0, ALPHA, RE, A
C-----------------------------------------------------------------------
C
C  1. CAS STANDARD (BENCHMARK)
C
      DATA LABEL(1)/'M I T   1 4 0   G H Z   G Y R O T R O N'/
      DATA LABEL(2)/'======================================='/
```

```
      DATA NCAS/3/, N/1/
      DATA MM(1), PP(1), QQ(1), LL(1)/0, 3, 1450., 0.015/
      DATA MM(2), PP(2), QQ(2), LL(2)/2, 3, 1400., 0.015/
      DATA MM(3), PP(3), QQ(3), LL(3)/5, 2, 1300., 0.015/
      DATA V0, ALPHA, RE, A/ 65000., 1.5, 1.82E-03, 3.47E-03/
      DATA BMIN, BMAX, IAMAX/ 5.2, 6.0, 3.5/
C
      DO 10 NC= NCAS+1, NMAX
      MM(NC)=0
      PP(NC)=0
      QQ(NC)=0.
10    LL(NC)=0.
C-----------------------------------------------------------------------
C
C  2. CONSTANTS
C
      DATA CLIGHT/2.99792458E+08/
      DATA EMASS,ECHARG/9.1093897E-31, 1.60217733E-19/
      PI    = ACOS(-1.)
      MU0   = 4.E-07*PI
      EPS0 = 1./(MU0*CLIGHT**2)
C
      JFAC=1
      DO 15 I=1,10
      JFAC=JFAC*I
15    NFAC(I)=JFAC
C
      DATE1=DATE()
      TIME1=TIME()
      WRITE(6,100) DATE1,TIME1
100   FORMAT('1'////' PROGRAM ISTART3',4X,2A10/
     *                ' ================'//)
C
      WRITE (6,105)
105   FORMAT (' ZEROES OF DERIVATIVES OF BESSEL FUNCTIONS'/)
      CALL BEPZERO(BJZP,MMAX,IPMAX)
C-----------------------------------------------------------------------
C
C  3. READ INPUT DATA
C
      READ (5,'(A)') LABEL
      WRITE (6,'(//1X,A/1X,A/)') LABEL
      READ (5,MODES)
      WRITE (6,MODES)
C
      GAMMA0 = 1. + (ECHARG*V0)/(EMASS*CLIGHT**2)
      BPARA  = SQRT ((1.-1./GAMMA0**2)/(1.+ALPHA**2))
      BPERP  = ALPHA * BPARA
      WRITE (6,110) 'GAMMA0 =',GAMMA0
110   FORMAT (1X,A,G14.6)
      WRITE (6,110) 'BETA PERP =', BPERP
      WRITE (6,110) 'BETA PARA =', BPARA
C
      CF = SQRT((2./PI)**5)
      CF = CF *ECHARG/(EPS0*EMASS*CLIGHT**3)
      WRITE (6,110) 'CONST =', CF
      CF = CF/GAMMA0*BPERP**(2*N-6)
      CF = CF*(N**N/(2**N *NFAC(N)))**2
C-----------------------------------------------------------------------
C
C  4.  CALCULS
```

```
121           C
122                 IF (N .GT. 3) STOP ' N TOO LARGE'
123                 IFIRST = 1
124                 DO 490 NC=1,NCAS
125                 M = MM(NC)
126                 P = PP(NC)
127                 Q = QQ(NC)
128                 L = LL(NC)
129                 IF (M .GT. MMAX) STOP ' M TOO LARGE'
130                 IF (P .GT. IPMAX) STOP ' P TOO LARGE'
131                 NUMP = BJZP(M+1,P)
132                 CALL BESSEL (M, NUMP,BJ)
133                 JMNUMP = BJ(M+1)
134           C
135                 WRITE (6,120) M,P
136           120   FORMAT (///' MODE TE(',I2,',',I2,',1)'/' ------------------'/)
137                 WRITE (6,110) ' QUALITY FACTOR =   ', Q
138                 WRITE (6,110) ' INTERACTION LENGTH=', L
139                 WRITE (6,110) ' NUMP  =    ', NUMP
140                 WRITE (6,110) ' JM (NUMP) = ', JMNUMP
141           C
142                 CF1 = CF*Q/((NUMP**2 - M**2)*JMNUMP**2)
143                 NSIG = 2
144                 IF (M.EQ.0) NSIG=1
145                 DO 480 NS=1,NSIG
146                 ISIG = 3 - 2*NS
147                 MN = M + ISIG*N
148                 KPERP = NUMP/A
149                 KRE   = KPERP*RE
150                 LAMBDA= 2.*PI/KPERP
151                 IF (M.NE.0 ) WRITE (6,435) ISIG
152           435   FORMAT (/'  ROTATING MODE:',I2)
153                 WRITE (6,110) ' KPERP*RE  ', KRE
154                 WRITE (6,110) ' LAMBDA  =   ', LAMBDA
155                 CALL BESSEL(MN,KRE,BJ)
156                 JMPN = BJ(MN+1)
157                 WRITE (6,110) ' JMPN  =    ', JMPN
158                 CF2 = CF1*JMPN**2 *(LAMBDA/L)
159                 OMEGA = KPERP*CLIGHT
160                 FREQ(NC) = OMEGA/(2.*PI)
161                 WRITE (6,110) ' FREQUENCY  =   ', FREQ(NC)
162                 MU = PI * BPERP**2/BPARA * (L/LAMBDA)
163                 WRITE (6,110) ' MU    =    ', MU
164                 XM = N/MU
165                 XMIN = 0.5*(XM + SQRT(XM**2 + 1.))
166                 WRITE (6,110) ' XMIN  =    ', XMIN
167           C-----------------------------------------------------------------------
168           C
169           C  5. COMPUTES POINTS (B0, IA) FOR X > XM
170           C
171                 DX = (XMIN-XM)/30.
172                 DX2 = DX
173                 J = 1
174           425   DX2 = DX2/2.
175                 X =XM + DX2
176           430   DELTA = 4.*X/MU
177                 B0(J) = EMASS/ECHARG*GAMMA0*OMEGA*(1. - 0.5*BPERP**2 *DELTA)/N
178                 IST = 4./(PI*MU**2) * EXP(2.*X**2) /(MU*X - N)
179                 IA(J) = IST/CF2
180                 IF (J.EQ.1 .AND. IA(J).LT.IAMAX) GOTO 425
181                 IF (IA(J).GT.IAMAX .AND. X.GT.XMIN) GOTO 440
```

```
      182                 IF (J.GE.NPOINT) GOTO 440
      183                 J=J+1
      184                 X=X+DX
      185                 GOTO 430
      186           440   WRITE (6,445)
      187           445   FORMAT (/10X,'B0 [TESLA]   IA START [A]'/)
      188                 WRITE (6,450) (J1, B0(J1), IA(J1), J1=1,J)
      189           450   FORMAT (I5,2E15.4)
      190           C-------------------------------------------------------------------------
      191           C
      192           C  6. PLOT ON VERSATEC
      193           C
      194                 IF (IA(1).GT.IAMAX .AND. IA(2).LT.IAMAX) THEN
1     195                   B0(1) = B0(2) + (IAMAX-IA(2))*(B0(1)-B0(2))/(IA(2)-IA(1))
1     196                   IA(1) = IAMAX
1     197                 ENDIF
      198                 IF (IA(J).GT.IAMAX .AND. IA(J-1).LT.IAMAX) THEN
1     199                   B0(J) = B0(J-1) - (IAMAX-IA(J-1))*(B0(J-1)-B0(J))/
1     200                *                    (IA(J)-IA(J-1))
1     201                   IA(J) = IAMAX
1     202                 ENDIF
      203                 CALL PLOTST(B0,IA,J, BMIN,BMAX,IAMAX,IFIRST)
      204           C
      205           480   CONTINUE
      206           490   CONTINUE
      207                 CALL TITLE
      208                 CALL PLOT(0.,0.,999)
      209                 STOP
      210                 END
```

```
      SUBROUTINE BEPZERO(BJZP,M,N)
C
C     COMPUTES THE ZEROES OF THE DERIVATIVES OF BESSEL FUNCTION
C     OF INTEGER ORDER (M=0,1,2...5)
C
C     ON RETURN: BJZP(K+1, L) = LTH ZERO OF J'K(X)   (L = 1,2 3...N)
C
      PARAMETER (EPS=1.E-12, MMAX=5, IPMAX=5)
C
      DIMENSION BJZP(MMAX+1,IPMAX+2), BJ(50)
C
      PI =ACOS(-1.)
      IF (M.GE.0 .AND. M.LE.MMAX) GOTO 5
      WRITE (6,1) M
1     FORMAT (' SUBROUTINE BEPZERO CALLED WITH M=',I3)
      STOP
5     IF (N.GE.1 .AND. N.LE.IPMAX) GOTO 10
      WRITE (6,2) N
2     FORMAT (' SUBROUTINE BEPZERO CALLED WITH N=',I3)
      STOP
C
C     FIND ROOTS USING NEWTON ALGORITHM FOR J'M(X)=0
C
10    DO 30 IM=0,M
      DO 30 IN=N,1,-1
C
      IF (IN.GE.N-1) THEN
C                              USE ASYMPTOTIC ROOTS AS STARTING VALUES
1       X0 = PI/4. * (2*IM + 4*IN -3)
1       IF (IM.EQ.0) X0 = X0 + PI
1     ELSE
1       X0 = 2*BJZP(IM+1,IN+1) - BJZP(IM+1,IN+2)
1     ENDIF
      ITER=0
C
C     NEWTON SCHEME: X1 = X0 - JM'(X0)/JM"(X0)
C
15    CALL BESSEL(IM+2,X0,BJ)
      BJM    = BJ(IM+1)
      BJMP   = -BJ(IM+2) + IM/X0*BJM
      BJMP1P = -BJ(IM+3) + (IM+1)/X0*BJ(IM+2)
      BJM2P  = -BJMP1P + IM/X0*(BJMP - BJM/X0)
      X1 = X0 - BJMP/BJM2P
      ITER = ITER +1
      IF (ABS(X1-X0) .LT. EPS) GOTO 20
      X0=X1
      IF (ITER.LT.50) GOTO 15
      WRITE (6,16) IM,IN
16    FORMAT (' NO CONVERGENCE REACHED FOR M=',I3,'  N=',I3)
      X1=0.
20    BJZP(IM+1,IN)=X1
      WRITE (6,17) IM,IN,X1,ITER
17    FORMAT (' J''(',I3,',',I3,') =',F12.8,'  ITER=',I3)
30    CONTINUE
      END
```

```
      SUBROUTINE BESSEL(LMAX,X,BJ)
C
C     CALCULATE BESSEL FUNCTIONS BY BACKWARD RECURSION
C
C     ON RETURN: BJ(1)=J0(X), BJ(2)=J1(X), ... BJ(LMAX+1)=BJLMAX(X)
C
C
      PARAMETER (XMIN=.00001,XMAX=100.,MSTART=200,DEL=1.E-60)
      DIMENSION TEMP(MSTART),BJ(*)
C
      IF (ABS(X).GT.XMIN) GOTO 20
      IF (ABS(X).GT.XMAX) STOP 'BESSEL: ARGUMENT TOO BIG'
      IF ( LMAX .GT.50  ) STOP 'BESSEL: ORDER TOO BIG'
      BJ(1)=1.
      IF (LMAX.EQ.0) RETURN
      DO 10 L=1,LMAX
10    BJ(L+1)=X/FLOAT(2*L)*BJ(L)
      RETURN
C
20    LSTART=2*(5*INT(ABS(X))+(LMAX+1)/2+10)+1
C.....ORDER OF HIGHEST BESSEL FUNCTION IS EVEN TO GUARANTEE CORRECT
C.....PARITY (JN(X) = (-1)**N *JN(-X) )
      IF (LSTART.GT.MSTART) LSTART=MSTART
      TEMP(LSTART)=DEL
      TEMP(LSTART-1)=DEL*FLOAT(2*(LSTART-2))/X
      TS=TEMP(LSTART)**2
      DO 30 L=LSTART-1,2,-1
      TEMP(L-1)=FLOAT(2*(L-1))/X*TEMP(L)-TEMP(L+1)
30    TS=TS+TEMP(L)**2
      TS=1./SQRT(TEMP(1)**2+2.*TS)
      DO 40 L=1,LMAX+1
40    BJ(L)=TS*TEMP(L)
      RETURN
      END
```

```
      1                 SUBROUTINE PLOTST(B0,IA,J, BMIN,BMAX,IAMAX,IFIRST)
      2           C
      3                 COMMON /PAGE/   XA4,YA4,DXL,DXR,DYU,DYD, CH, X0,Y0,AXEX,AXEY
      4           C
      5                 REAL B0(*), IA(*), IAMAX
      6                 INTEGER P
      7                 CHARACTER T*20
      8           C
      9                 COMMON /CAVITY/ A, M, P, N, ISIG
     10           C
     11                 DATA XA4,YA4/29.,21./, DXL,DXR,DYU,DYD/3.,2.,2.5,3./, CH/0.2/
     12                 DATA X0,Y0,AXEX,AXEY/3.,2.5,16.,14./
     13           C
     14                 IF (IFIRST.EQ.0) GOTO 25
     15                 CALL PLOTS ('VERSATEC',100.,8224,0,1)
     16           C
     17                 CALL FRAME(BMIN,BMAX,0.,IAMAX, X0,Y0,AXEX,AXEY)
     18                 CALL CHPEN(3)
     19                 IFIRST=0
     20           C
     21           25    CONTINUE
     22                 IPEN=3
     23                 DO 30 K=1,J
     24                 CURR=IA(K)
     25                 IF (CURR.LT.0. .OR. CURR.GT.IAMAX) GOTO 30
     26                 XX = X0 + (B0(K)-BMIN)/(BMAX-BMIN) * AXEX
     27                 YY = Y0 + CURR/IAMAX * AXEY
     28                 CALL PLOT(XX,YY,IPEN)
     29                 IPEN=2
     30           30    CONTINUE
     31           C
     32                 SMIN=1.E+20
     33                 DO 40 K=1,J
     34                 IF (IA(K).LT.SMIN) THEN
1    35                   NN=K
1    36                   SMIN=IA(K)
1    37                 ENDIF
     38           40    CONTINUE
     39                 XX = X0 + (B0(NN)-BMIN)/(BMAX-BMIN) * AXEX   -1.2
     40                 YY = Y0 + IA(NN)/IAMAX * AXEY  -0.5
     41                 WRITE (T,50) ISIG*M, P
     42           50    FORMAT('(',I2,',',I2,', 1)')
     43                 CALL SYMBOL(XX,YY,0.2,T,0.,10)
     44                 RETURN
     45                 END
```

```
 DO=-LONG/-OT,ARG=-COMMON/-FIXED,CS= USER/-FIXED,DB=-TB/-SB/-SL/-ER/-ID/-PMD/-ST,-AL,PL=5000
 FTN5,I=ISTART3,L=LIS,ANSI=0,LO=S/-A,PN.

 1                    SUBROUTINE FRAME(BMIN,BMAX,ISMIN,ISMAX)
 2                    COMMON /PAGE/   XA4,YA4,DXL,DXR,DYU,DYD, CH, X0,Y0,AXEX,AXEY
 3              C
 4                    REAL ISMIN,ISMAX
 5              C
 6                    DATA MASK/O"5252525252525252"/
 7              C
 8              C     CH = CHARACTER HEIGHT
 9              C
10              C     A4 FRAME
11              C
12                    CALL CHPEN(2)
13                    CALL PLOT(0.     ,1.     ,3)
14                    CALL PLOT(0.     ,0.     ,2)
15                    CALL PLOT(1.     ,0.     ,2)
16                    CALL PLOT(XA4-1.,0.     ,3)
17                    CALL PLOT(XA4    ,0.     ,2)
18                    CALL PLOT(XA4    ,1.     ,2)
19                    CALL PLOT(XA4-1.,YA4    ,3)
20                    CALL PLOT(XA4    ,YA4    ,2)
21                    CALL PLOT(XA4    ,YA4-1.,2)
22                    CALL PLOT(0.     ,YA4-1.,3)
23                    CALL PLOT(0.     ,YA4    ,2)
24                    CALL PLOT(1.     ,YA4    ,2)
25              C
26              C     AXES AND GRID
27              C
28                    DB=(BMAX-BMIN)/AXEX
29                    CALL AXIS(X0,Y0,AXEX,0.,BMIN,DB,'MAGNETIC FIELD (TESLA)',22)
30              C
31                    DIS=(ISMAX-ISMIN)/AXEY
32                    CALL AXIS(X0,Y0,AXEY,90.,ISMIN,DIS,'STARTING CURRENT (A)',-20)
33                    CALL CHPEN(3)
34                    CALL PLOT(X0,Y0,3)
35                    CALL PLOT(X0,Y0+AXEY,2)
36                    CALL PLOT(X0+AXEX,Y0+AXEY,2)
37                    CALL PLOT(X0+AXEX,Y0,2)
38                    CALL PLOT(X0,Y0,2)
39                    CALL CHPEN(2)
40                    IAXEX=AXEX
41                    IAXEY=AXEY
42                    CALL GRID(X0,Y0,IAXEX,1.,IAXEY,1.,MASK)
43                    RETURN
44                    END
```

DO=-LONG/-OT,ARG=-COMMON/-FIXED,CS= USER/-FIXED,DB=-TB/-SB/-SL/-ER/-ID/-PMD/-ST,-AL,PL=5000
FTN5,I=ISTART3,L=LIS,ANSI=0,LO=S/-A,PN.

```
      SUBROUTINE TITLE
C
      PARAMETER (NMAX=10)
      COMMON /PAGE/    XA4,YA4,DXL,DXR,DYU,DYD, CH, X0,Y0,AXEX,AXEY
      COMMON /TITRE1/ LABEL(2)
      COMMON /TITRE2/ DATE1,TIME1
      COMMON /BEAM/    V0, ALPHA, RE, GAMMA0
      COMMON /CAVITY/ A, M, P, N, ISIG
      COMMON /MODE/    NCAS, MM(NMAX), PP(NMAX), QQ(NMAX), LL(NMAX),
     *                 FREQ(NMAX)
C
      INTEGER P, PP
      REAL LL
      CHARACTER T*80,DATE1*10,TIME1*10,LABEL*80
      YTOP=YA4-DYU
      CALL CHPEN(2)
      CALL SYMBOL(DXL,YTOP,CH,LABEL(1),0.,80)
      CALL SYMBOL(DXL,YTOP-2.*CH,CH,LABEL(2),0.,80)
      WRITE (T,100)
100   FORMAT ('STARTING CURRENT VERSUS STATIC MAGNETIC FIELD',5X,
     *        'PROGRAM ISTART3   ')
      CALL SYMBOL(DXL,YTOP-5.*CH,CH,T,0.,66)
C
      WRITE (T,1) DATE1,TIME1
1     FORMAT ('CRPP - ',2A10)
      CALL SYMBOL(0.8*XA4,YTOP,0.8*CH,T,0.,27)
      WRITE (T,2)
2     FORMAT ('GYROTRON PROJECT')
      CALL SYMBOL(0.8*XA4,YTOP-2.*CH,0.8*CH,T,0.,16)
C
      XT=X0+AXEX+1.
      YT=Y0+AXEY
      WRITE (T,3) A*1000.
3     FORMAT('RESONATOR RADIUS:',F7.2,' MM')
      CALL SYMBOL(XT,YT,CH,T,0.,27)
      YT=YT-2.*CH
      WRITE (T,7) GAMMA0
7     FORMAT('GAMMA0:',F7.4)
      CALL SYMBOL(XT,YT,CH,T,0.,14)
      YT=YT-2.*CH
      WRITE (T,8) ALPHA
8     FORMAT('ALPHA: ',F7.4)
      CALL SYMBOL(XT,YT,CH,T,0.,14)
      YT=YT-2.*CH
      WRITE (T,9) V0/1000.
9     FORMAT('BEAM VOLTAGE:',F6.2,' KV')
      CALL SYMBOL(XT,YT,CH,T,0.,22)
      YT=YT-2.*CH
      WRITE (T,10) RE*1000.
10    FORMAT('ANNULAR BEAM RADIUS:',F6.2,' MM')
      CALL SYMBOL(XT,YT,CH,T,0.,29)
      YT=YT-2.*CH
      WRITE (T,11) N
11    FORMAT('HARMONIC # :',I2)
      CALL SYMBOL(XT,YT,CH,T,0.,14)
C
      YT=YT-3.*CH
      T='   MODE          Q      FREQUENCY'
      CALL SYMBOL(XT,YT,CH,T,0.,33)
```

```
60                    YT=YT-2.*CH
61                    T='    TE                        [GHZ]  '
62                    CALL SYMBOL(XT,YT,CH,T,0.,33)
63                    DO 20 NC=1,NCAS
64                    YT=YT-2.*CH
65                    WRITE (T,21) MM(NC), PP(NC), QQ(NC), FREQ(NC)/1.E+09
66              21    FORMAT('(',I2,',',I2,',1) ',F10.0,2X,F9.3)
67              20    CALL SYMBOL(XT,YT,CH,T,0.,31)
68              C
69                    RETURN
70                    END
```