ELECTRON BEAM DENSITY OF CRYEBIS FRECH 2 ELECTRON GUN

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Abstract.

This report gives a method to calculate by computer -programming the FRECH II- electron beam density. This method consists in taking current measurements on a 1/10 mm tungsten-wire, to determine the electron-beam density profile.

Résumé.

Ce rapport décrit la méthode employée pour trouver la densité du faisceau électronique issu du canon FRECH II. Il décrit le programme de calcul réalisé qui, à partir des mesures du profil de faisceau sur un fil de 1/10 mm, permet le calcul de la densité.

I. Apparatus.

In this study we use the Frost-type electron gun (1) scale 2. It consists of a cathode, a focusing electrode (Wehnelt) and an anode as shown in figure (1). This gun is magnetically shielded. The distances between gun-shielding and cathode-wehnelt could be adjusted by sensitive micrometers.

Around the cathode there is a small coil for cancelling residual magnetic field. The gun and its support (A) Fig.(2) are placed in front of a solenoid (B) that gives more than 5200 gauss for electron beam confinement.

The electron current is measured on a Faraday cup (C) with wires that can be moved in the three dimensions.

The vacuum is obtained by two cryogenic pumps that uses liquid He or N_2. The two pumps (D and E) have pumping speeds of 300 and 400 litres/sec respectively. On using liquid helium the apparatus operates four days while for liquid nitrogen it works one and half day only. After continuous operation for three weaks the pressure reaches 5.10^{-10}mm Hg when the cathode is cold and 2.10^{-9}mm Hg under operation.

The filament is heated by a 20 KHz 7.1 V-13A supply. The cathode temperature reaches 1100°C.

For electron beam extraction, a pulse generator (2) with amplitudes of 10 KV-2 A and pulse width 20 μs is used on the cathode. The anode is kept at zero potential. The wehnelt is at the cathode potential.

The beam tester as shown in figure (3) consists of a diaphragm in front of two wires of thickness 0.1mm perpendicular to each other and a cooled collector put at the end of a rod that moves in the three directions by micrometers. The study of the electron beam profile is made by the use of the two wires. An x-y recorder is used to draw the electron beam profile by moving one wire across the beam axis.

The electron currents on the diaphragm, the two wires and the collector are measured through a 10Ω resistance on an oscilloscope. The wires are polarized with respect to the collector Fig.(4) to avoid the secondary electrons emissions.

II. DENSIT program.

First of all, we control that the vertical and the horizontal wires give the same profile. Then, we can calculate the density. If the profile is not exactly symmetrical which is the general case, then we calculate the density for each half part of the profile. This is made by the DENSIT computer program that we now briefly describe.

1. In this program, we calculate the average electron density in electron beam cross-section (BJBAR). The experimental electron density distribution profile do not gives the true value since the beam is distributed along the length of the wire.

By using the experimental profile, we calculate its total area by using simpson's rule

$$\text{Area} = \frac{h}{3}\,(Y_o+4Y_1+2Y_2+4Y_3+2Y_4 \cdots +2Y_{n-2}+4Y_{n-1}+Y_n)$$

where Y_o, Y_1, $Y_2 \cdots Y_n$ are Y values corresponding to equal displacement h in the X-direction.

2. In this method the profile Fig.(5) is devided into vertical elements by the lines Y_1, Y_2, $Y_3 \cdots Y_n$.

The ratio between each small area and the total area multiplied by the total electron current gives the current distribution in each element. To eliminate mistakes due to the reading, we utilise the mean value between two successive points (B1 or B2) which are called BM1 and BM2 which corresponds to the values before and after the maximum value (NMAXI) respectively. The values BM1 and BM2 are arranged for computer calculations, and called BI(IA) where IA = 1,2, 3...,NMAXI.

3. The second part of this program devides the cross-section of the electron beam into small areas which are calculated and has special indices to be arranged in a matrix.

First the cross-section is divided into vertical areas as shown in Fig.(6) which are called S(N,NMAX). SS(N,NMAX) is the area of the sector.

In calculation of the next vertical element the area of the first element is substracted which is called (SIG) where

$$SIG = SIG + S(N,NMAX)$$

$$SS(N,NMAX) = \frac{r^2}{2}\left(\frac{\pi\alpha}{180} - \sin\alpha\right) \qquad \text{Ref.(3)}$$

$$S(N,NMAX) = \frac{\pi r^2}{2} - \frac{r^2}{2}\left(\frac{\pi\alpha}{180} - \sin\alpha\right) - SIG$$

where $\frac{\pi r^2}{2}$ is the total area, α the angle of the sector. SIG = 0 in the first calculation.

4. The next step is to subdevide the cross-section area into circular areas in a manner as shown in fig.(7) each surface element is called A(I,J).

The area A(I,J) is calculated by substraction between two successive columns in the same vertical element e.q. A(1,6) = S(1,6) - S(1,5).

The arrangement of elements of area A(I,J) are changed to the arrangement B(IR,JRZ) as shown in fig.(7).

5. By using the values of B and the currents BI(IA) the UNIVAC subroutine SEQL(NMAX,B,BI) solve the following system of linear equations

$$I_1 = J_1\ B_{11} + J_2\ B_{12} + J_3\ B_{13} + J_4\ B_{14} + J_5\ B_{15} + J_6\ B_{16}$$

$$I_2 = J_2\ B_{22} + J_3\ B_{23} + J_4\ B_{24} + J_5\ B_{25} + J_6\ B_{26}$$

$$I_3 = J_3\ B_{33} + J_4\ B_{34} + J_5\ B_{35} + J_6\ B_{36}$$

$$I_4 = J_4\ B_{44} + J_5\ B_{45} + J_6\ B_{46}$$

$$I_5 = J_5\ B_{55} + J_6\ B_{56}$$

$$I_6 = J_6\ B_{66}$$

This system of linear equations has this arrangement up to the vslue of NMAXI in the program. In these equations I_1, I_2... represents BI(IA) and J_1,J_2,J_3... represents BI(II) SEQL inverse the B-matrix, and give the calculated solutions of the density in BI(II) where II=1,NMAXI.

6. The area of the circular sections SAB(1), SAB(2)... are calculated. These areas are added successively and called SINT(1), SINT(2)... as shown in Fig.(8).

where

$$SINT(1) = SAB(1)$$
$$SINT(2) = SAB(1)+SAB(2)$$
$$SINT(3) = SAB(1)+SAB(2)+SAB(3)$$
$$\vdots$$
$$SINT(NMAXI) = \frac{\pi R^2}{2}$$

For calculation of the average electron density we use the equation

$$BJBAR(NJ) = \frac{BJBAR(NJM1).SINT(NJM1)+SAB(NJ).BI(NJ)}{SINT(NJ)}$$

where BJBAR is the average electron density
SINT(NJM1) is the area corresponding to (NJM1)
SAB(NJ) is the circular area corresponding to (NJ)
BI(NJ) is the calculated density BI(II)
NJM1 = NJ-1

With this program the average electron density is calculated for each half part of the profile.

III. Results.

The electron distribution profile of the electron beam extracted from the electron gun FRECH II is measured by a beam tester and drawn on a X-Y recorder Fig.(9) shows the electron average density (A/cm^2) on the two sides of the beam calculated by the UNIVAC computer.

The experimental conditions for the electron beam profile are

V_{ex} = 10 KV
I = 2.15 A
B = 5200 gauss
2B1 = 50 gauss

The difference between the two curves shows a small dissymetry of the beam which has to be corrected by a small displacement of the gun.

Conclusion.

The DENSIT program, which gives rapidly the density in the center of the beam, and the density on its both sides, is a good way to study and to optimize the electron guns.

References

1) R.Frost, O.Pursl, Watkins Johnson C O. Palo Alto California N°AF33 (616) 6441 (1962).

2) Ch.Goldstein, A.Serafini (Bilan des essais sur le canon FRECH1 et définition du canon FRECH2 de la source CRYEBIS). IPNO-76-07, Orsay (1976).

3) I.N.Bronstein (Aide-mémoire de mathématiques), p.250 (1963).

```
CDD R 021731 IPRAD      DBLE R 021103 VALMAX      CODE R 021563 XT        DRCD R 12161
100 R 009144 Z

      DIMENSION Y(100),Z(100),ST(50,50),S(50,50),A(50,50),B1(100),
     1B2(100),SA(100),SINT(100),PJRAP(100),PR(100),G(23,23),DT(46),
     2PM1(100),PM2(100),XI(23),XJ(46)
      READ 10,N,PAS,COUR,DMAX
      READ 5,(Y(I),I=1,N)
      PRINT30,(Y(I),I=1,N)
      J=1
      AIRE1=0.
   10 AIRE1=AIRE1+Y(J)
      PRINT60,AIRE1
      J=J+1
      IF(J.LE.N) GO TO 10
      J=2
      AIRE2=0.
   15 AIRE2=AIRE2+Y(J)
      PRINT61,AIRE2
      J=J+2
      IF(J.LT.N) GO TO 15
      J=3
      AIRE3=0.
    8 AIRE3=AIRE3+Y(J)
      PRINT 62,AIRE3
      J=J+2
      IF(J.LT.N) GO TO 8
      AIRE=PAS/3.*(AIRE1+3.*AIRE2+AIRE3)
      PRINT 11,AIRE
      NVMAX=1
      VALMAX=Y(1)
      DO 50 IND=1,500
      IF(Y(IND)-VALMAX) 50,51,52
   51 NVMAX=NVMAX+1
      GO TO 50
   52 VALMAX=Y(IND)
      INDMAX=IND
   50 CONTINUE
      PRINT19,VALMAX,INDMAX
      DO 70 IA=1,N
      Z(IA)=(Y(IA)/AIRE)*COUR
      PRINT 75,Z(IA)
   70 CONTINUE
      DO 80 IA=1,INDMAX
      IC=INDMAX+1-IA
      B1(IA)=Z(IC)
      PRINT 85,B1(IA)
   80 CONTINUE
      LL=INDMAX-1
      DO 81 IA=1,LL
      PM1(IA)=(B1(IA)+B1(IA+1))/2.
      PRINT 86,PM1(IA),IA
   81 CONTINUE
      MM=N-INDMAX+1
```

```
      DO 90 IA=1,NY
      R2(IA)=Z(N-IA+1)
      PRINT 95,R2(IA)
   90 CONTINUE
      KK=N-INRMAX
      DO 91 IA=1,KK
      RM2(IA)=(R2(IA)+R2(IA+1))/2.
      PRINT 96,RM2(IA)
   91 CONTINUE
      NMAXI=INRMAX-1
      DO 19 IA=1,NMAXI
      XI(IA)=RM1(IA)
      PRINT 191 ,IA,XI(IA)
   19 CONTINUE
      L=N+1
      DO 20 IA=INRMAX,L
      XJ(IA)=(R2(N-IA)
      IF(IA.NE.N) GO TO 150
  150 RM2(N-IA)=0.
      PRINT 200,IA,XJ(IA)
   20 CONTINUE
      IMIN=1
      IMAX=NMAXI
      DO 32 IK=1,2
      DO 33 IA=IMIN,IMAX
      IF(IK.EQ.1)  RI(IA)=XI(IA)
      IP=IA+NMAXI
      IF(IK.EQ.2)  RI(IA)=XJ(IP)
      PRINT 300,IA,RI(IA)
   33 CONTINUE
C               RMAX  =  RAYON MAXIMUM
      PI=3.1416
      R=RMAX
      NMAX=NMAXI
      DO 11 II=1,NMAXI
      DO 12 JJ=1,NMAXI
      B(II,JJ)=0.
      B(II,JJ)=0.
   12 CONTINUE
   11 CONTINUE
    8 RR(NMAX)=R
      R2=R**2
      R2S2=R2/2.
      SIG=0.
      TERAD=0.
C               CALCUL DES CARREAUX VERTICAUX
      DO 1 N=1,NMAX
      TERAD=TERAD+(RAS/R)
      TETA=ACOS(TERAD)*2.
      SS(N,NMAX)=R2S2*(TETA-SIN(TETA))
      S(N,NMAX)=PI*R2S2-SS(N,NMAX)-SIG
      SIG=SIG+S(N,NMAX)
    1 CONTINUE
      PRINT 1000,RR(NMAX)
      PRINT 1100,(SS(N,NMAX),S(N,NMAX),N=1,NMAX)
      R=R-RAS
      IF(R)777,4,7
```

```
      3   NMAX=NMAX-1
          IF(NMAX.GE.1) GO TO 3
C         CALCUL DES SURFACES TORQUES A(I,J)
C
      6   DO 6 I=1,NMAXI
          KI=NMAXI+2-I
          DO 7 J=NMAXI,I,-1
          JM=J-1
          KI=KI-1
          IF(I.EQ.J) GO TO 9
          A(I,KI)=S(I,J)-S(I,JM)
          IF(I.NE.JM) GO TO 7
          KI=KI-1
          A(I,KI)=S(I,JM)
          GO TO 7
      9   A(I,KI)=S(I,J)
      7   CONTINUE
      6   CONTINUE
          DO 40 IR=1,NMAXI
          IRZ=IR-1
          DO 41 JR=1,NMAXI
          JRZ=JR+IRZ
          IF(JRZ.GT.NMAXI) GO TO 41
          B(IR,JRZ)=A(IR,JR)
     41   CONTINUE
     40   CONTINUE
          DO 42 I=1,NMAXI
          PRINT 1007,I
          PRINT 1006,(I,KO,A(I,KO),B(I,KO),KO=NMAXI,1,-1)
     42   CONTINUE
          PRINT 1004,(BR(JJJ),BT(JJJ),JJJ=1,NMAXI)
C       BI REPRESENTE LA VALEUR NORMALISEE DES COURANTS
          CALL SECL(NMAXI,A,BT)
          PRINT 1002,(II,BT(II),II=1,NMAXI)
C       BI REPRESENTE ICI LES DENSITES CALCULEES
C
C
C       UN CERCLE EST REPRESENTE PAR        IIR+IIC=CONSTANTE
          DO 21 IIS=1,NMAXI
          SO=0.
          DO 22 IIC=1,NMAXI
          DO 23 IIR=1,NMAXI
          IF(IIC.GT.IIS) GO TO 23
          IF(IIR.GT.IIS) GO TO 23
          IF((IIS+1-IIC-IIR).EQ.0) GO TO 25
          GO TO 23
     25   SAB(IIS)=SO+A(IIC,IIR)
          SO=SAB(IIS)
     23   CONTINUE
     22   CONTINUE
     21   CONTINUE
          PRINT 1009,(KU,SAB(KU),KU=1,NMAXI)
C         VERIFICATION + SURFACES INTERMEDIAIRES
          SURF=0.
          DO 26 IA=1,NMAXI
          SURF=SURF+SAB(IA)
          SINT(IA)=SURF
```

```
   25    CONTINUE
         PRINT 1005,SUPF
         PRINT 1003,(SINT(IA),IA=1,NMAXI)
C
C        CALCUL DE LA DENSITE MOYENNE
C
         BJUAR(1)=BT(1)
         DO 27 NJ=2,NMAXT
         NC=NMAXT+1-NJ
         NJM1=NJ-1
         BJUAR(NJ)=(BJUAR(NJM1)*SINT(NJM1)+SAP(NJ)*BT(NJ))/SINT(NJ)
   27    CONTINUE
         PRINT 1004,(BJUAR(NJ),ET(NJ),NJ=1,NMAXT)
   32    CONTINUE
   15    FORMAT(2X,I2,2X,F4.2,2X,F4.2,2X,F4.2)
   30    FORMAT(2X,F15.8)
    5    FORMAT()
   60    FORMAT(F8.2)
   61    FORMAT(10X,F12.2)
   62    FORMAT(20X,F8.2)
   12    FORMAT(110),'APE =',E11.5)
   18    FORMAT(10X,F12.4,5X,I3)
   25    FORMAT(2X'Z='E11.4)
   65    FORMAT(2X'P)='F10.8)
   85    FORMAT(2X'PM1='E11.5,I3)
   95    FORMAT(2X'B2=',F10.5)
   35    FORMAT(2X'PM2=',E10.5)
  100    FORMAT(2X'IA=',I3,'      XT(IA)=',F10.5)
  200    FORMAT(2X'IA=',I3,'      YJ(IA)=',F10.5)
  300    FORMAT(2X'IA=',I3,'      BJ(IA)=',E10.5)
 1000    FORMAT(5X,F15.8,5X,F15.8)
 1001    FORMAT()
 1002    FORMAT(20X,T5,10X,E15.9)
 1003    FORMAT(70X,E15.9)
 1004    FORMAT(50X,E15.8)
 1005    FORMAT(100X,E15.9)
 1006    FORMAT(20X,T5,10X,I5,10X,F15.8,10X,F15.8)
 1007    FORMAT(30X,T5)
 1008    FORMAT(40X,T5,10X,E15.3)
  777    END

END OF COMPILATION:          NO  DIAGNOSTICS.

?Z SL72-9 02/14/76 09:58:48
PARIS)

S LIMITS     000000 043236     1177 IBANK WORDS DECIMAL
             040000 060674    10685 DBANK WORDS DECIMAL
NG ADDRESS  002113
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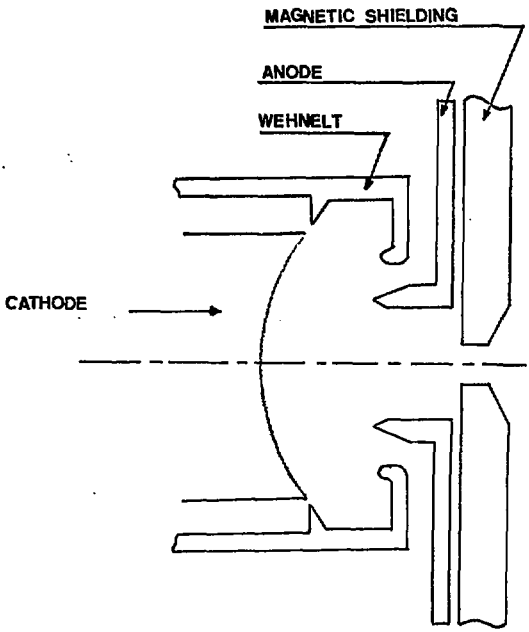
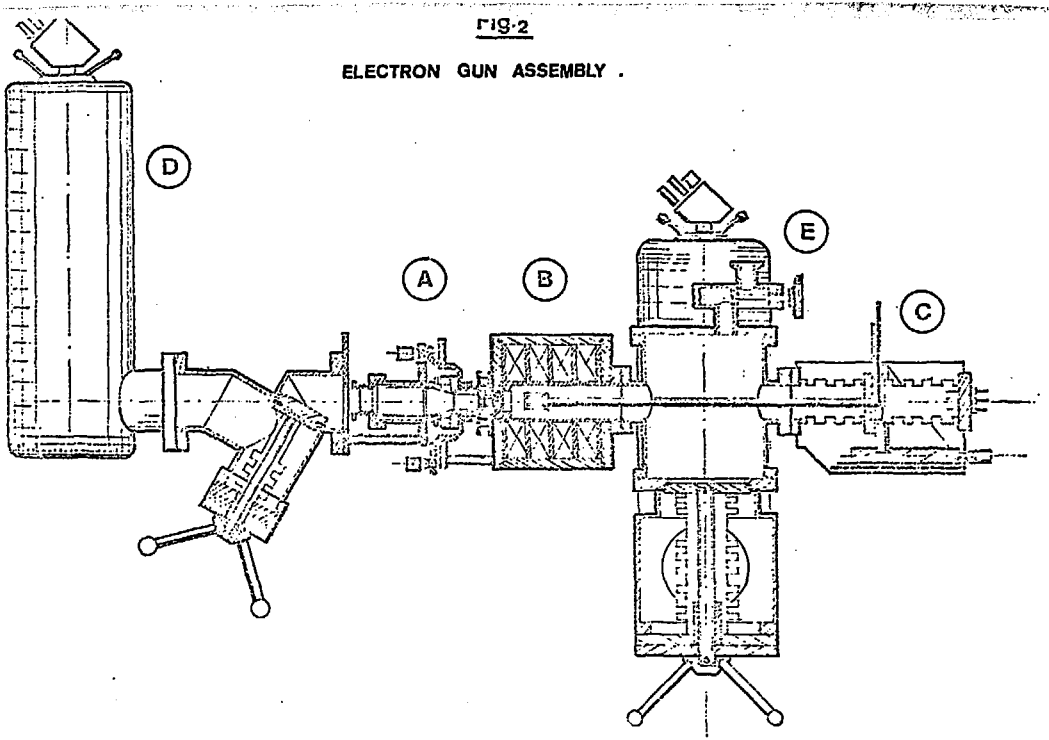


FIG. 1 ELECTRON GUN "FRECH2"

Fig·2

ELECTRON GUN ASSEMBLY .



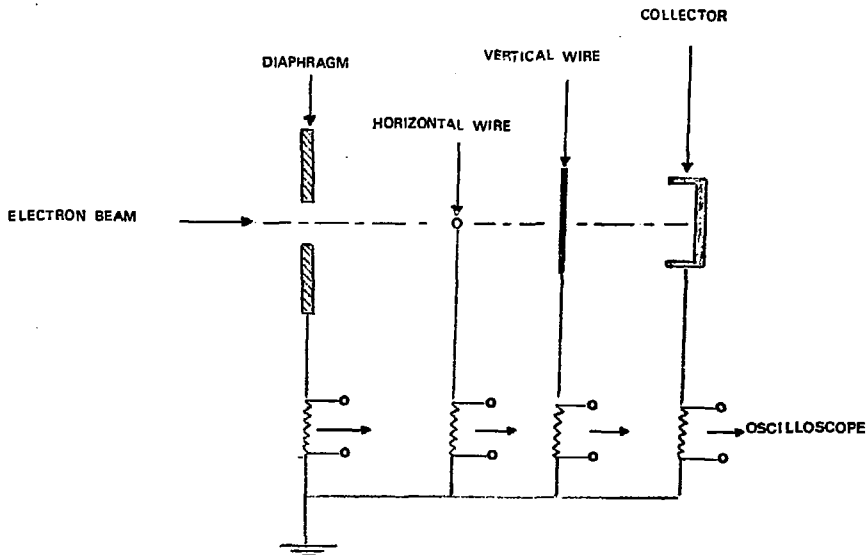


FIG.3_BEAM TESTER

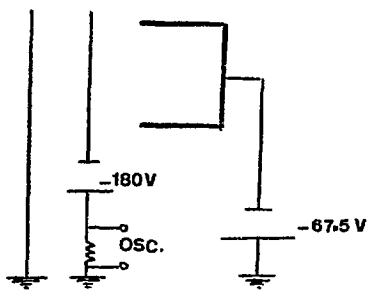


FIG.4 FARADAY CUP POLARISATION .

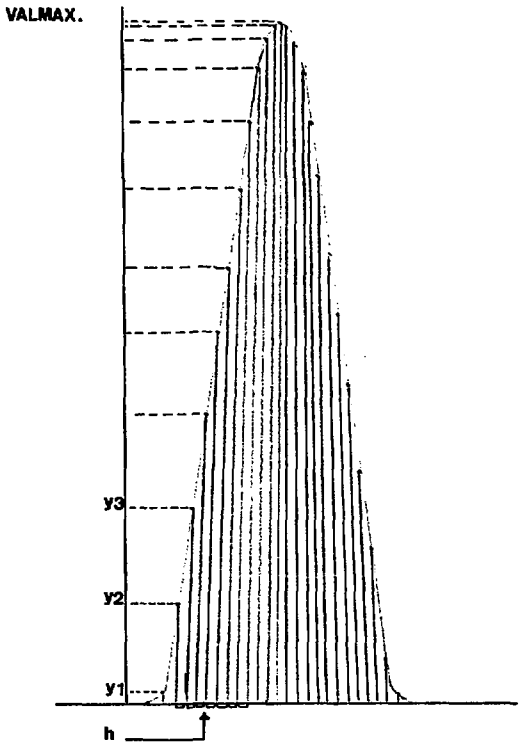


FIG.5 EXPERIMENTAL ELECTRON BEAM PROFILE.

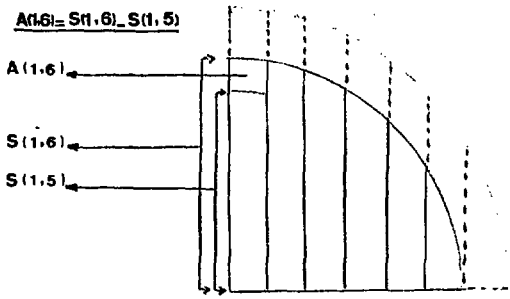


FIG.6 CALCULALATION OF A(IJ)

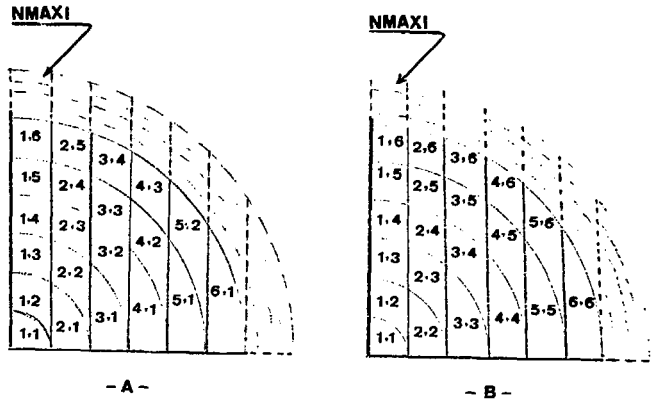


FIG.7. A(I,J) AND B(IR,JRZ)

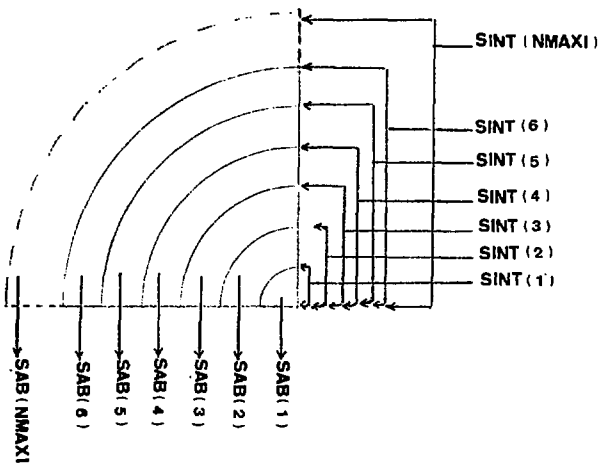


FIG.8 — RELATION BETWEEN SAB[IA] & SINT [IA]

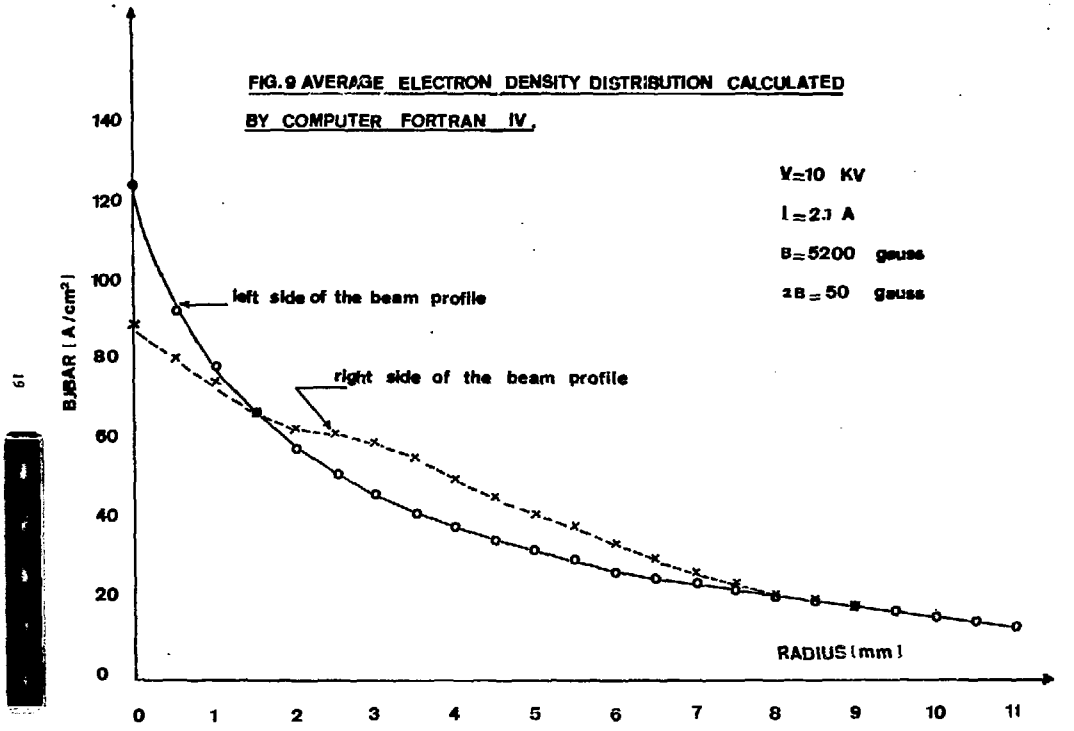


FIG. 9 AVERAGE ELECTRON DENSITY DISTRIBUTION CALCULATED
BY COMPUTER FORTRAN IV,
V=10 KV
I=2.1 A
B=5200 gauss
ΔB=50 gauss
left side of the beam profile
right side of the beam profile
BJBAR [A/cm²]
RADIUS [mm]
0
20
40
60
80
100
120
140
0
1
2
3
4
5
6
7
8
9
10
11