

Computation of the Effective Solid Angle for Gas Scattering Experiment

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A simple numerical integration method is presented to calculate the effective solid angle for a correlation experiment using a gas target. The method is described for the case of a double slit system using a front aperture composed of two parallel edges of infinite height and a rear (detector) rectangular aperture. It is possible to calculate the angular spread for each telescope. The method is applicable even when the beam line does not intersect the center of the rotation of the telescopes. A FORTRAN program is presented in the appendix.

KEY WORDS: Gas target/ Solid angle/ Angular correlation/

1. INTRODUCTION

In nuclear scattering experiments with gas targets, the target thickness is defined by a pair of collimators in front of each telescope. For each telescope we have a certain section of the target which is "seen" with 100% efficiency (umbra) and an upper and lower penumbra. Since the situation for a correlation experiment using a gas target is very complicated we propose a numerical integration method.

The method described in the following section permits us to calculate the angular spread for each collimator. This is important for the theoretical analysis of the experimental data. Since this method is applicable for the case that the beam line does not intersect the center of the rotation of the telescopes we can examine the influence of the finite size of the beam.

2. THE METHOD OF CALCULATION

In this section the method of calculation of the effective solid angle is given for the case of a double slit system using a front aperture composed of two parallel edges of infinite height and a rear (detector) rectangular aperture. The top view of the situation is given in fig. 1. The meanings of the symbols are as follows (see fig. 1).

$2b_1$ the width of the first collimator.

$2b_2$ the width of the second collimator.

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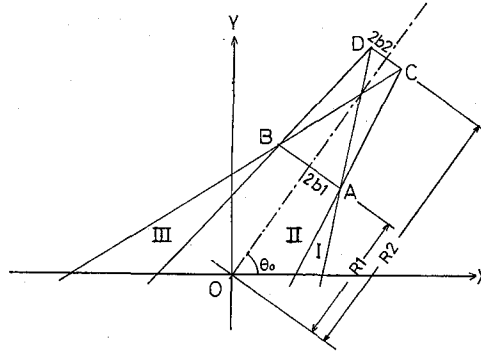


Fig. 1. Top view of the telescope for the explanation of the meanings of the symbols.

- l_2 the height of the second collimator.
- O the center of the rotation of the telescope.
- R_1 the distance between the first collimator AB and O.
- R_2 the distance between the second collimator CD and O.
- θ_0 the angle between X-axis and the center line of the slit system.
- I and III the upper and lower penumbra region.
- II the umbra region.

Writing c for $\cos \theta_0$ and s for $\sin \theta_0$, the X and Y co-ordinates of A, B, C, D are given as

$$\begin{aligned}(X_A, Y_A) &= (R_1 c + b_1 s, R_1 s - b_1 c), \\(X_B, Y_B) &= (R_1 c - b_1 s, R_1 s + b_1 c), \\(X_C, Y_C) &= (R_2 c + b_2 s, R_2 s - b_2 c), \\(X_D, Y_D) &= (R_2 c - b_2 s, R_2 s + b_2 c).\end{aligned}$$

Let a point P lie on the beam line. We can calculate the solid angle from P as follows. We can get which region (I, II, III) P exists in. If P is in the region I, the solid

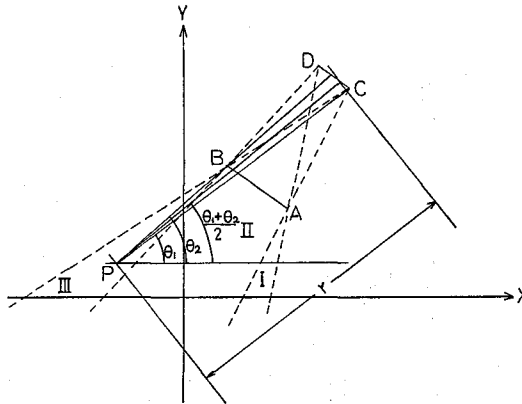


Fig. 2. Top view of the telescope showing the contribution to the solid angle from a point P on the X-Y plane.

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angle is defined by the two points A and D, if in the region II, by C and D and if in the region III, by B and C. For example let P be in the region III, that is B and C are the two points which define the solid angle, and we define θ_1 and θ_2 as (see fig. 2)

$$\theta_1 = \arctan \{(Y - Y_C)/(X - X_C)\},$$

$$\theta_2 = \arctan \{(Y - Y_B)/(X - X_B)\}.$$

Then $(\theta_2 - \theta_1)$ turns to be the angular spread for the point P to see the rear slit in the X-Y plane. Defining r as the distance between P and the intersection of the line through P with an angle of inclination $(\theta_1 + \theta_2)/2$ which is the mean angle for the point P to see the telescope, and the segment CD, the solid angle from the point P is given as

$$\Delta\Omega = (\theta_2 - \theta_1) l_2 / r.$$

In the case of an angular correlation measurement we have to get the values $\Delta\Omega$ for the two detectors and multiply them to have the solid angle $\Delta\Omega_1 \Delta\Omega_2$.

To calculate the solid angle for one detector or for the coincidence measurement with two detectors, we proceed as follows. We divide the segment of the beam line which is seen simultaneously by the two telescopes into small sections and compute the contribution of each section to the solid angle $\Delta\Omega$ (for a single measurement) or $\Delta\Omega_1 \Delta\Omega_2$ (for a coincidence measurement). By adding the contributions of each section we get the total solid angle multiplied by the length of the target. Since the solid angle from any point can be calculated the method is applicable even when the beam line shifts from the X-axis. In the case that the finite size of the beam cannot be neglected, the solid angle can be calculated by dividing the cross section perpendicular to the beam line into small sections and adding the contributions from each section.

Fig. 3 shows an illustration of the effect of the shift of the beam line. The first telescope is set at 12.5° with $2b_1 = 3.75$ mm, $2b_2 = 2.50$ mm, $R_1 = 81.1$ mm, $R_2 =$

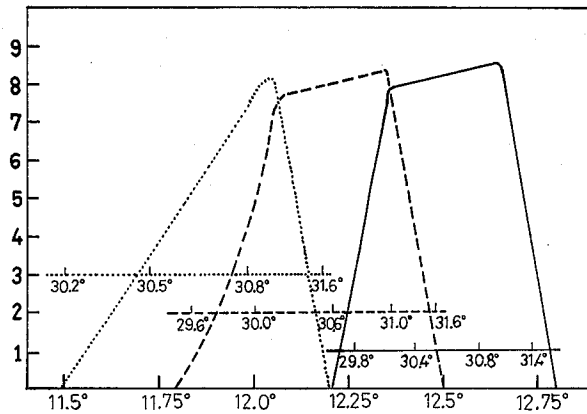


Fig. 3. Angular spread for a coplanar angular correlation experiment for the cases that the shift of the beam line is 0 mm (the solid line), 1 mm (the dashed line) and 2 mm (the dotted line). The abscissa represents the weighting factor in arbitrary units. The ordinate represents the angle of the first telescope. The angle of the second telescope is given for each spectrum.

257.5 mm, $l_2=6.4$ mm. The second telescope is set at 30.6° with $2b_1=3.23$ mm, $2b_2=3.50$ mm, $R_1=80.2$ mm, $R_2=258.6$ mm, $l_2=6.5$ mm. The solid angles for the cases that the shift of the beam line is 0 mm, 1 mm and 2 mm are 7.56×10^{-7} (sr 2 ·mm), 7.31×10^{-7} (sr 2 ·mm) and 4.02×10^{-7} (sr 2 ·mm) respectively. The solid angle is very much affected when the shift of the beam line amounts to 2 mm for the setting of this illustration.

3. PROGRAM

In appendix a program written in FORTRAN which calculates the effective solid angle for coplanar correlation experiment using a gas target and the slit system of a front aperture composed of two parallel edges of infinite height with a rear rectangular aperture for each telescope.

The input quantities are the $2b_1$, $2b_2$, R_1 , R_2 , l_2 for each telescope and the parameters A and B for the equation of the beam line

$$Y=AX+B$$

and the radius of the beam R, which is 0.0 if the beam can be represented by a straight line, and DX, DR which are the length of the small section along the beam line (DX) and that of perpendicular to the beam axis (DR) and TH(1), TH(2) which are the polar angles of two detectors. The program gets the input parameters from a file whose name is given from the key board.

The program permits us to calculate the influence of the finite size of the beam if we input R and DR. The weighting function is assumed to be

$$\text{SQRT}\{R^2-(XR)^2\}$$

where XR is the distance from the center line of the beam.

The contribution for the effective solid angle together with the angle and the angular spread for each small section to see each telescope are represented in a matrix form. They are useful for theoretical calculation taking account of the experimental angular setting.

APPENDIX

SOURCE.FOR

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C      COMPUTATION OF SOLID ANGLE FOR GAS TARGET SCATTERING EXPERIMENT
C      CODED BY T. SEKIOKA AT HIMEJI INSTITUTE OF TECHNOLOGY JAN.88
COMMON B1(2), B2(2), R1(2), R2(2), FL2(2), FNAME, FONAME
DIMENSION OMEGA(500), ANG(2,500), SMD(500,2), ARNG(2,2)
X,AANG(2),BB1(2), BB2(2),TH(2),SAG(2),AANGR(2),DANG(2,500)
CHARACTER*64 FNAME, FONAME
C      WEIT IS A RADIAL FUNCTION OF BEAM INTENSITY DISTRIBUTION.
      WEIT(R,XR)=SQRT(R*R-XR*XR)
      PAI=3.141593
      RTI=PAI/180.0
      WRITE(*,950)
950  FORMAT(' ENTER INPUT FILE NAME (OR SPACE) - '
X*n)
      READ(*,910) FNAME
910  FORMAT(A)
      WRITE(*,940)
940  FORMAT(' ENTER OUTPUT FILE NAME - '
X*n)
      READ(*,910) FONAME
      OPEN(4,FILE=FONAME,STATUS='NEW')
      IF(FNAME .EQ. ' ') GO TO 200
      OPEN(3,FILE=FNAME)
210  READ(3,*,END=900) BB1(1),BB2(1),R1(1),R2(1),FL2(1)
      WRITE(*,6999) BB1(1),BB2(1),R1(1),R2(1),FL2(1)
      WRITE(4,6999) BB1(1),BB2(1),R1(1),R2(1),FL2(1)
6999  FORMAT(1H , '2B1,2B2,R1,R2,FL2 FOR LEFT ',6F7.2)
      IF (BB1(1) .EQ. 0.0) GO TO 900
      READ(3,*,END=900) BB1(2),BB2(2),R1(2),R2(2),FL2(2)
      WRITE(*,6996) BB1(2),BB2(2),R1(2),R2(2),FL2(2)
      WRITE(4,6996) BB1(2),BB2(2),R1(2),R2(2),FL2(2)
6996  FORMAT(1H , '2B1,2B2,R1,R2,FL2 FOR RIGHT ',6F7.2)
310  READ(3,*,END=900) ARCT, B, R, DX, DR
      WRITE(*,6998) ARCT, B, R, DX, DR
      WRITE(4,6998) ARCT, B, R, DX, DR
      IF (DX .EQ. 0.0) GO TO 210
410  READ(3,*,END=900) TH(1), TH(2)
      WRITE(*,6997) TH(1),TH(2)
      WRITE(4,6997) TH(1),TH(2)
      IF (TH(1) .EQ. 0.0) GO TO 310
      IF (TH(2) .EQ. 0.0) GO TO 310
6998  FORMAT(1H , 'ARCT, B, R, DX, DR ',5F7.3)
6997  FORMAT(1H , 'THETA(1)=',F8.3, ' THETA(2)=',F8.3)
      GOTO 750
200  WRITE(*,6001)
      READ(*,*) BB1(1),BB2(1),R1(1),R2(1),FL2(1)
      WRITE(*,6999) BB1(1),BB2(1),R1(1),R2(1),FL2(1)
      WRITE(4,6999) BB1(1),BB2(1),R1(1),R2(1),FL2(1)
      IF (BB1(1) .EQ. 0.0) GO TO 900
      WRITE(*,6002)
      READ(*,*) BB1(2),BB2(2),R1(2),R2(2),FL2(2)
6001  FORMAT(1H , ' 2B1 2B2 R1 R2 L2 FOR LEFT COUNTER')
6002  FORMAT(1H , ' 2B1 2B2 R1 R2 L2 FOR RIGHT COUNTER')
      WRITE(*,6996) BB1(2),BB2(2),R1(2),R2(2),FL2(2)
      WRITE(4,6996) BB1(2),BB2(2),R1(2),R2(2),FL2(2)
300  WRITE(*,6003)
      READ(*,*) ARCT, B, R, DX, DR
6003  FORMAT(1H , '(EQ. OF BEAM LINE Y=TAN(ARCT)*X+B, R=RADIUS, IF=0 LINE)'
X, ' DX OR DR =LENGTH OF SEGMENT'/
X, ' ARCT B R DX DR')
      WRITE(*,6998) ARCT, B, R, DX, DR

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WRITE(4,6998) ARCT, B, R, DX, DR
IF (DX .EQ. 0.0) GO TO 200
400 WRITE(*,6004)
6004 FORMAT(1H , 'TH1 TH2 IF INPUT=0 GO TO SET OF BEAM LINE')
READ(*,*) TH(1), TH(2)
WRITE(*,6997) TH(1), TH(2)
WRITE(4,6997) TH(1), TH(2)
IF (TH(1) .EQ. 0.0) GO TO 300
IF (TH(2) .EQ. 0.0) GO TO 300
750 CONTINUE
A=TAN(ARCT*RTI)
B1(1)=0.5*BB1(1)
B1(2)=0.5*BB1(2)
B2(1)=0.5*BB2(1)
B2(2)=0.5*BB2(2)
IF (R .EQ. 0.0) GO TO 500
IF (DR.EQ. 0.0) GO TO 500
FR=R/DR
NR=FR
IF(NR .GT. 500) NR=500
FNR=NR
DDR=R/FNR
SRWEIT=0
SMG=0.0
SAG(1)=0.0
SAG(2)=0.0
WRITE(*,6110) R,DDR
WRITE(4,6110) R,DDR
6110 FORMAT(1H , 'CALCULATION OF FINITE SIZE OF BEAM. R=', F6.3
X, ' DDR=', F5.3)
DO 1000 KR=1, NR
FKR=KR
XR=(FKR-0.5)*DDR
RWEIT=WEIT(R,XR)
SRWEIT=SRWEIT+RWEIT
BR=B+XR*SQR(1+A*A)
CALL SLDANG(A,BR,DX,DDDX,TH,ANG,DANG,
X DOMEA,AANG,SMEGA(KR,1),KMAX,ILL)
ARNG(1,1)=AANG(1)
ARNG(1,2)=AANG(2)
IF(ILL .EQ. 0) GO TO 610
WRITE(*,6901) ILL
610 CONTINUE
WRITE(*,6100) XR,KR,SMEGA(KR,1), AANG(1), AANG(2)
WRITE(4,6100) XR,KR,SMEGA(KR,1), AANG(1), AANG(2)
BR=B-XR*SQR(1+A*A)
CALL SLDANG(A,BR,DX,DDDX,TH,ANG,DANG,
X DOMEA,AANG,SMEGA(KR,2),KMAX,ILL)
ARNG(2,1)=AANG(1)
ARNG(2,2)=AANG(2)
IF(ILL .EQ. 0) GO TO 620
WRITE(*,6901) ILL
620 CONTINUE
WRITE(*,6100) -XR,KR,SMEGA(KR,2), AANG(1), AANG(2)
WRITE(4,6100) -XR,KR,SMEGA(KR,2), AANG(1), AANG(2)
6100 FORMAT(1H , 'XR=', F8.4, ' SMEGA(' , I3, ')=' , E13.6
X, ' AANG1=' , F10.5, ' AANG2=' , F10.5)
SMG=SMG + RWEIT*(SMEGA(KR,1)+SMEGA(KR,2))*0.5
SAG(1)=SAG(1) + RWEIT*(ARNG(1,1)+ARNG(2,1))*0.5
SAG(2)=SAG(2) + RWEIT*(ARNG(1,2)+ARNG(2,2))*0.5

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1000 CONTINUE
    TOMEA=SMG/SRWEIT
    AANG(1)=SAG(1)/SRWEIT
    AANG(2)=SAG(2)/SRWEIT
    WRITE(*,6200) TOMEA, AANG(1),AANG(2)
    WRITE(4,6200) TOMEA, AANG(1),AANG(2)
6200 FORMAT(' TOMEA=',E13.6, ' ATH1=',F10.5,' ATH2=',F10.5)
    IF (FNAME .EQ. ' ') GO TO 400
    GO TO 410
500 CONTINUE
    CALL SLDANG(A,B,DX,DDX,TH,ANG,DANG,
    X DOMEA,AANG,SOMEA,KMAX,ILL)
    WRITE(*,6120) KMAX,DDX
    WRITE(4,6120) KMAX,DDX
6120 FORMAT(1H,'KMAX=',I3,' LENGTH OF SEGMENT=',F7.5)
    IF(ILL .EQ. 0) GO TO 600
    WRITE(*,6901) ILL
    GO TO 900
600 CONTINUE
    NKMAX=KMAX/5
    DO 550 NK=1, NKMAX
    NK5=(NK-1)*5
    WRITE(*,6310) NK5,(DOMEA(J),J=(NK-1)*5+1,NK*5)
    WRITE(*,6320) (ANG(1,J),DANG(1,J),J=(NK-1)*5+1,NK*5)
    WRITE(*,6320) (ANG(2,J),DANG(2,J),J=(NK-1)*5+1,NK*5)
    WRITE(4,6310) NK5,(DOMEA(J),J=(NK-1)*5+1,NK*5)
    WRITE(4,6320) (ANG(1,J),DANG(1,J),J=(NK-1)*5+1,NK*5)
    WRITE(4,6320) (ANG(2,J),DANG(2,J),J=(NK-1)*5+1,NK*5)
550 CONTINUE
    NK5=NKMAX*5
    IF(NK5 .GE. KMAX) GO TO 560
    WRITE(*,6310) NK5,(DOMEA(J),J=NK5+1,KMAX)
    WRITE(*,6320) (ANG(1,J),DANG(1,J),J=NK5+1,KMAX)
    WRITE(*,6320) (ANG(2,J),DANG(2,J),J=NK5+1,KMAX)
    WRITE(4,6310) NK5,(DOMEA(J),J=NK5+1,KMAX)
    WRITE(4,6320) (ANG(1,J),DANG(1,J),J=NK5+1,KMAX)
    WRITE(4,6320) (ANG(2,J),DANG(2,J),J=NK5+1,KMAX)
6310 FORMAT(1H,I3,5E15.6)
6320 FORMAT(1H,3X,5(F8.3,'( ',F5.3,' ')))
560 CONTINUE
    WRITE(*,6250) SOMEA, AANG(1), AANG(2)
    WRITE(4,6250) SOMEA, AANG(1), AANG(2)
6250 FORMAT(' SOMEA=',E13.6,' AANG1=',F8.3,' AANG2=',F8.3)
6901 FORMAT(' ERROR ILL=',I2)
    IF (FNAME .EQ. ' ') GO TO 400
    GO TO 410
    CLOSE(3,STATUS='KEEP')
    CLOSE(4,STATUS='KEEP')
900 CONTINUE
    STOP
    END

    SUBROUTINE SLDANG(A,B,DX,DDX,TH,ANG,DANG,
    X DOMEA,AANG,SOMEA,KMAX,ILL)
    COMMON B1(2), B2(2), R1(2), R2(2), FL2(2)
    DIMENSION DOMEA(500), ANG(2,500), AANG(2),TH(2)
    1,XA(2),YA(2),XB(2),YB(2),XC(2),YC(2),XD(2),YD(2)
    2,NCH(2),AL(2),BL(2),CL(2,4),DL(2,4),NREG(2)
    3,DMG(2),SANG(2),XISC(2,4),THR(2),ANGCA(2),DANG(2,500)
    DO 10 J=1,500

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DOMEGA(J)=0.0
ANG(1,J)=0.0
ANG(2,J)=0.0
DANG(1,J)=0.0
DANG(2,J)=0.0
10 CONTINUE
PAI=3.141593
RTI=PAI/180.0
THR(1)=TH(1)*RTI
THR(2)=TH(2)*RTI
ILL=0
DO 100 I=1,2
C=COS(THR(I))
S=SIN(THR(I))
XA(I)=R1(I)*C + B1(I)*S
YA(I)=R1(I)*S - B1(I)*C
XB(I)=R1(I)*C - B1(I)*S
YB(I)=R1(I)*S + B1(I)*C
XC(I)=R2(I)*C + B2(I)*S
YC(I)=R2(I)*S - B2(I)*C
XD(I)=R2(I)*C - B2(I)*S
YD(I)=R2(I)*S + B2(I)*C
AL(I)=(YD(I)-YC(I))/(XD(I)-XC(I))
BL(I)=(YC(I)*XD(I)-XC(I)*YD(I))/(XD(I)-XC(I))
CL(I,1)=(XD(I)-XA(I))/(YD(I)-YA(I))
DL(I,1)=(YD(I)*XA(I)-XD(I)*YA(I))/(YD(I)-YA(I))
CL(I,2)=(XC(I)-XA(I))/(YC(I)-YA(I))
DL(I,2)=(YC(I)*XA(I)-XC(I)*YA(I))/(YC(I)-YA(I))
CL(I,3)=(XD(I)-XB(I))/(YD(I)-YB(I))
DL(I,3)=(YD(I)*XB(I)-XD(I)*YB(I))/(YD(I)-YB(I))
CL(I,4)=(XC(I)-XB(I))/(YC(I)-YB(I))
DL(I,4)=(YC(I)*XB(I)-XC(I)*YB(I))/(YC(I)-YB(I))
DO 200 J=1,4
IF(I.EQ.1) XISC(I,J)=(B*CL(I,J) + DL(I,J))/(1-A*CL(I,J))
IF(I.EQ.2) XISC(I,J)=(-B*CL(I,J) + DL(I,J))/(1+A*CL(I,J))
200 CONTINUE
NCH(I)=1
IF (XISC(I,2) .LT. XISC(I,3)) NCH(I)=2
IF (NCH(I) .EQ. 1) GO TO 100
XISC(I,3)=BBB
XISC(I,3)=XISC(I,2)
XISC(I,2)=BBB
100 CONTINUE
DO 119 I=1,2
C WRITE(*,6997) I,(XISC(I,J),J=1,4)
6997 FORMAT(1H ,'XISC I='I2,2X,4F10.5)
C WRITE(*,6995) I,(CL(I,J),J=1,4)
6995 FORMAT(1H ,'CL I='I2,2X,4F10.5)
C WRITE(*,6994) I,(DL(I,J),J=1,4)
6994 FORMAT(1H ,'DL I='I2,2X,4F10.5)
C WRITE(*,6993) A, B
6993 FORMAT(1H ,'A=',F10.5,' B=',F10.5)
119 CONTINUE
XBIGIN=XISC(1,4)
IF (XISC(1,4) .LT. XISC(2,4)) XBIGIN=XISC(2,4)
XEND=XISC(1,1)
IF (XISC(2,1) .LT. XISC(1,1)) XEND=XISC(2,1)
XREG=XEND-XBIGIN
C WRITE(*,6996) XBIGIN,XEND
6996 FORMAT(1H ,'XBIGN=',F10.5,' XEND=',F10.5)

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        IF(XREG .GT. 0.0) GO TO 300
        WRITE(*,6901)
6901  FORMAT(' XREG<0.0. ERROR')
        ILL=1
        RETURN
300  CONTINUE
        FX=XREG/DX
        NX=FX+1
        IF(NX .GT. 500) NX=500
        FNX=NX
        DDX=XREG/FNX
        NREG(1)=3
        NREG(2)=3
        DO 400 I=1,2
        IF(XBIGIN .GT. XISC(I,3)) NREG(I)=2
        IF(XBIGIN .GT. XISC(I,2)) NREG(I)=1
400  CONTINUE
        SANG(1)=0.0
        SANG(2)=0.0
        SS=0.0
        SSA=0.0
        DO 1000 KX=1, NX
        FKX=KX
        X=XBIGIN+(FKX-0.5)*DDX
        Y=A*X + B
        ANGCA(1)= ATAN(A)/RTI
        ANGCA(2)=-ATAN(A)/RTI
        DO 2000 I=1,2
        IF (I .EQ. 2) Y=-Y
        IF (X .GE. XISC(I,NREG(I))) NREG(I)=NREG(I)-1
        GOTO (2100,2200,2300) NREG(I)
2100  CONTINUE
        TH1=ATAN((YA(I)-Y)/(XA(I)-X))
        TH2=ATAN((YD(I)-Y)/(XD(I)-X))
        GOTO 2500
2200  CONTINUE
        GOTO (2210,2220) NCH(I)
2210  TH1=ATAN((YC(I)-Y)/(XC(I)-X))
        TH2=ATAN((YD(I)-Y)/(XD(I)-X))
        GOTO 2500
2220  TH1=ATAN((YA(I)-Y)/(XA(I)-X))
        TH2=ATAN((YB(I)-Y)/(XB(I)-X))
        GOTO 2500
2300  CONTINUE
        TH1=ATAN((YC(I)-Y)/(XC(I)-X))
        TH2=ATAN((YB(I)-Y)/(XB(I)-X))
        GOTO 2500
2500  CONTINUE
        THE=0.5*(TH1+TH2)
        DTHE=0.5*(TH2-TH1)
        CTAN=COS(THE)/SIN(THE)
        YIS=(AL(I)*X+BL(I)-AL(I)*CTAN*Y)/(1-CTAN*AL(I))
        R=ABS((YIS-Y)/SIN(THE))
        DMG(I)=FL2(I)*(TH2-TH1)/R
        ANG(I,KX)=THE/RTI - ANGCA(I)
        DANG(I,KX)=DTHE/RTI
C      WRITE(*,6998) I,DMG(I),TH2/RTI,TH1/RTI,NREG(I)
6998  FORMAT(1H , 'I=',I2,' DMG=',E13.6,' TH2=',F10.5
        X,' TH1=',F10.5,' NREG=',I2)
2000  CONTINUE

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      DOMEGA(KX)=DMG(1)*DMG(2)
      SANG(1)=SANG(1) + ANG(1,KX)*DOMEGA(KX)
      SANG(2)=SANG(2) + ANG(2,KX)*DOMEGA(KX)
      SS=SS + DOMEGA(KX)*DDX*SQRT(1.0+A*A)
      SSA=SSA + DOMEGA(KX)
C      WRITE(*,6999) KX, DOMEGA(KX)
6999  FORMAT(' DOMEGA(',I3,')=',E13.6)
1000  CONTINUE
      AANG(1)=SANG(1)/SSA
      AANG(2)=SANG(2)/SSA
      SOMEGA=SS
      KMAX=NX
      DDDX=DDX*SQRT(1.0+A*A)
      RETURN
      END
```