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R.F. NOTE #103

Contents:

1. An Electrostatic Stored Energy Subroutine for Poisson at NSCL

In order to attempt to more accurately model non-uniform structures such as this generation of cyclotron dees or coupling devices, etc., use of a computer code appears most desirable. Poisson solves the two-dimensional electrostatic problem, but unfortunately did not yield the electrostatic stored energy per unit meter or radian as an available output. Since knowledge of the potential on the boundaries along with the stored energy is sufficient information to determine the capacitance and characteristic impedences per meter or radian, the stored energy is an important output.

A routine has been written and successfully tested for various known geometries. The subroutine is placed at the end of Poisson 5 and is tentatively called "Energ." The routine is set up for multiple dielectrics, whose material characteristics (ϵ_r, μ_r) are specified in the Poisson input data file. μ_r is not used in the routine currently. Should no dielectrics be specified, it defaults to $\epsilon_r = 1$, $\mu_r = 1$. The actual position for the control constants in the con array have not been formally specified by the accelerator group here, but we have tentatively used:

Con(33) = N ==> N materials are specifed in the input data file.

Example:

```
* 33 2 S
1 10. 1.
2 1.  1.
```

"* 33 2 S" means 2 lines to be read in
"1 10. 1." means material number 1 has $\epsilon_r = 10.0$, $\mu_r = 1.0$.
"2 1. 1." means material number 2 has $\epsilon_r = 1.0$, $\mu_r = 1.0$.

Con(125) = 1 ==> compute stored energy
= 0 ==> don't

The routine uses a simple iteration to solve the relationship:

$$U = \frac{\epsilon_r \epsilon_0}{2} \int_V |E|^2 dV$$

Let: A_n = Area of the nth triangle

E_n = The average total electric field magnitude in the nth triangle.

then:

xy case:

$$\frac{U}{meter} \simeq \sum_{n=1}^{N} \frac{\epsilon_0 \epsilon_r}{2} E_n^2 A_n$$

rz case:

$$\frac{U}{radian} \simeq \sum_{n=1}^{W} \frac{\epsilon_0 \epsilon_r}{2} E_n^2 A_n r_n$$

where: r_n = the average radius in the nth triangle

A copy of subroutine Energ is included is Appendix A. and numbers for the four following cases comparing theory to the computed value is contained in Appendix B.

a) Parallel plates (xy case)
b) 1/4 coaxial cross-section in r, ø (xy case)
c) Coaxial section in r, z (rz case)
d) 1/4 coaxial cross-section in r, z (hemisphere)

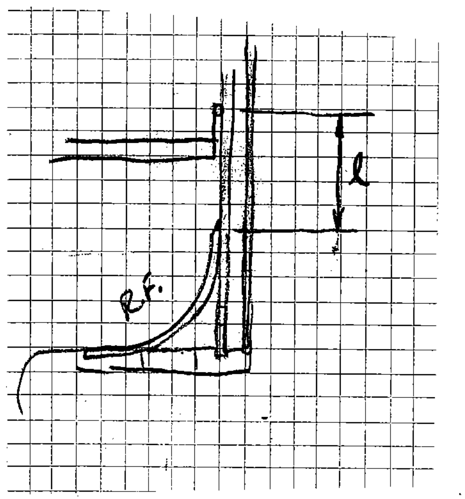
The error appears to fall in the ≦ ± .1% range. The xy cases run very fast, whereas the rz cases approximately triple the running time. Any suggestions to boost the accuracy or speed are welcome.

2. K500 Transrex Crowbar Upgrade

A new crowbar unit has been installed in the transrex. This unit is self-contained and can be replaced as a module. A work order has been placed in the electronic shop to build another one for a spare. In the future, if the crowbar fails we will fix it on the bench. This unit fires with a hydrogen thyratron versus a Krytron pac. This means spare parts are now easy to get and keep in stock.

This unit is wired to directly fire off the mainline current transducer, and from the the crowbar eletronics board for the remote current transducers. Hence we should receive two trigger pulses for any remote arc. The unit has worked very well during preliminary on-line tests. One annoyance is the fact that it fires simply due to the supply being switched off with no inputs connected. We haven't figured out how to solve that yet, although it poses no real problem.

3. K500 --> K800 INNER CONDUCTOR COOLING



Although the highest power density (W/in^2) on the inner conductor occurs at the highest frequency and thus occurs when "l" is the shortest, the hottest temperature on the I.C. will occur when "l" is at some point where it isn't being effectively influenced by the conductive cooling of the "cooled" I.C. on the non-R.F. side. Just looking at the geometry and data leads one to a guess of about 5 to 10 inches -- I'll use 10".

$$\frac{M}{\theta} = 1.3 \frac{V^{.8}}{D^{.2}}$$

$M = 65 \frac{W}{in^2}$ (at 10")

$V = .75 \frac{ft}{sec}$ (at 3 GPM - uppers)

$D = 3.86\varnothing$

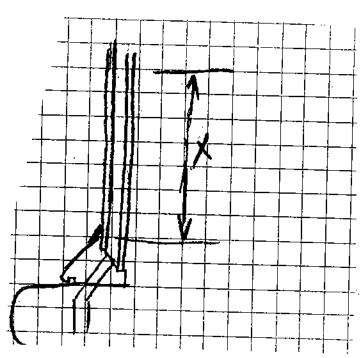
$$\frac{65}{\theta} = 1.3 \frac{(.75)^{.8}}{(3.86)^{.2}}$$

$$\frac{65}{\theta} = .7883$$

$$\theta = 82^{\circ}C$$

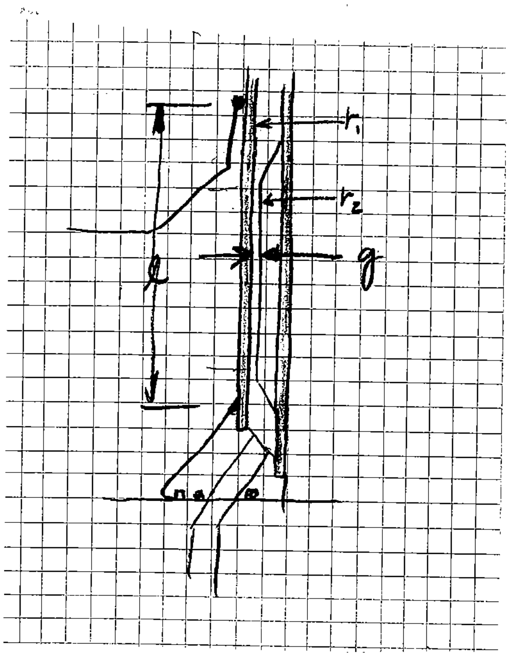
So if I find a place on the K800 stem design where the $\theta = 82^{\circ}C$ at its designed flow, this should be where the "expansion" should occur to start increasing the velocity for the remainder of the length where the W/in^2 increases. This assumes simply that because the K500 works at this temperature, the K800 should also. (From a previous calculation, I see that at 19MHz the $\theta = 81^{\circ}C$ = close enough.)

19 MHz = X = (83.3 - 10.2) - 51.3 = 21.80" (See Fig. 1.)



To maintain the 82°C for the remainder of the length "l" what will the velocity need to be at the worst heating case?

Assume worst heating to occur when l = 10".



10" = 40 $\frac{W}{in^2}$ (see Fig. 1)

$\frac{M}{\theta} = 1.3 \frac{V^{.8}}{D^{.2}}$

M = 40

θ = 82

V = ?

D = 7.725

$\frac{40}{82} = 1.3 \frac{V^{.8}}{(7.725)^{2}}$

$.5648 = V^{.8}$

$V = .49 \frac{ft}{sec}$ @ 1GPM

$1GPM = 2.23 \times 10^{-3} \frac{ft^3}{sec}$

$A = 2.23 \times 10^{-9} \div .49 = 4.55 \times 10^{-3}$ $ft^2 = .655$ in^2 @ 1GPM

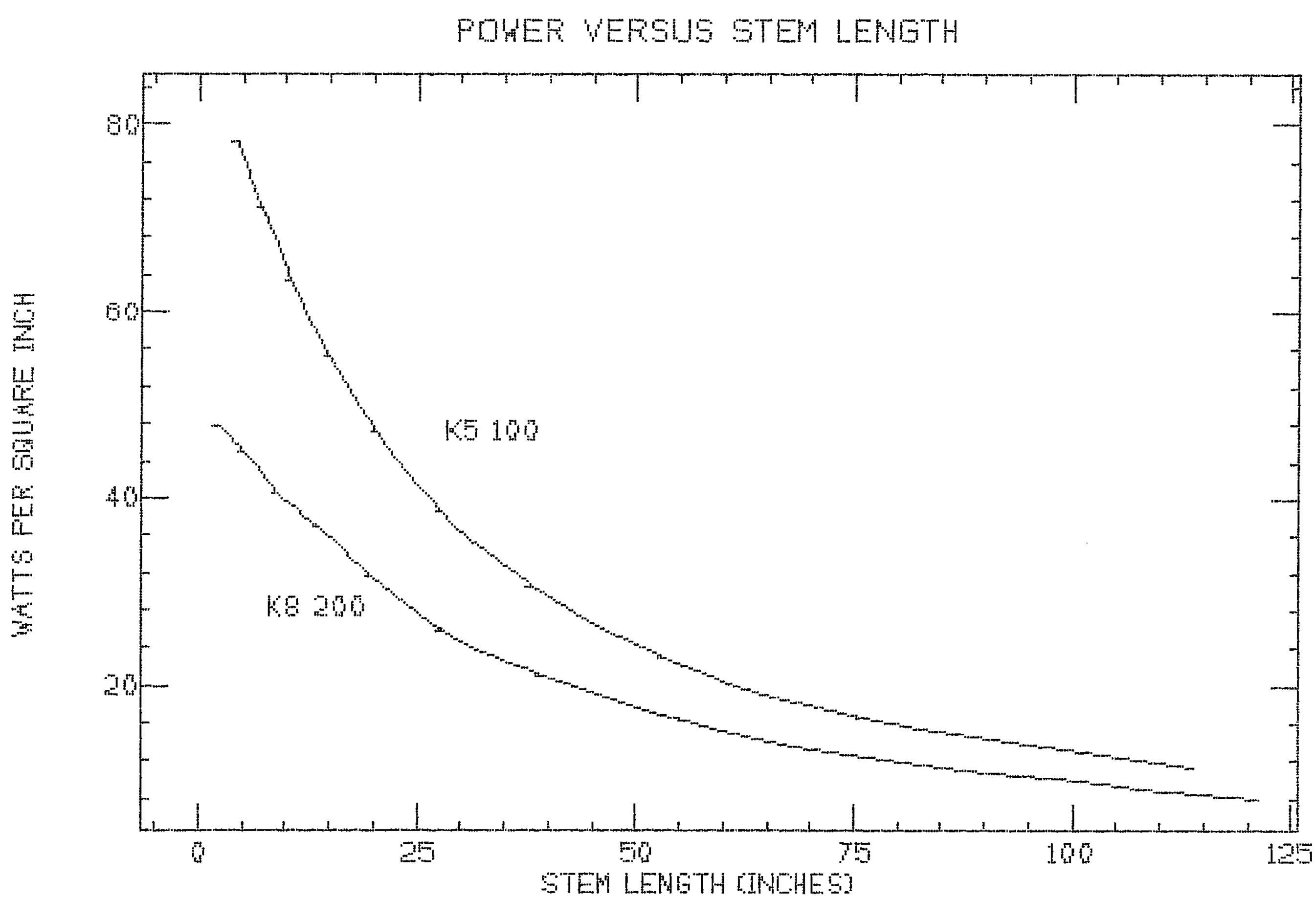
$r_1 = 3.86$ $r_2 = ?$

$A = 9.12$ $in^2 = \pi(r_1^2 - r_2^2)$

$\frac{9.17}{\pi} = 14.92 - r_2^2$

$r_2 = 3.46"$

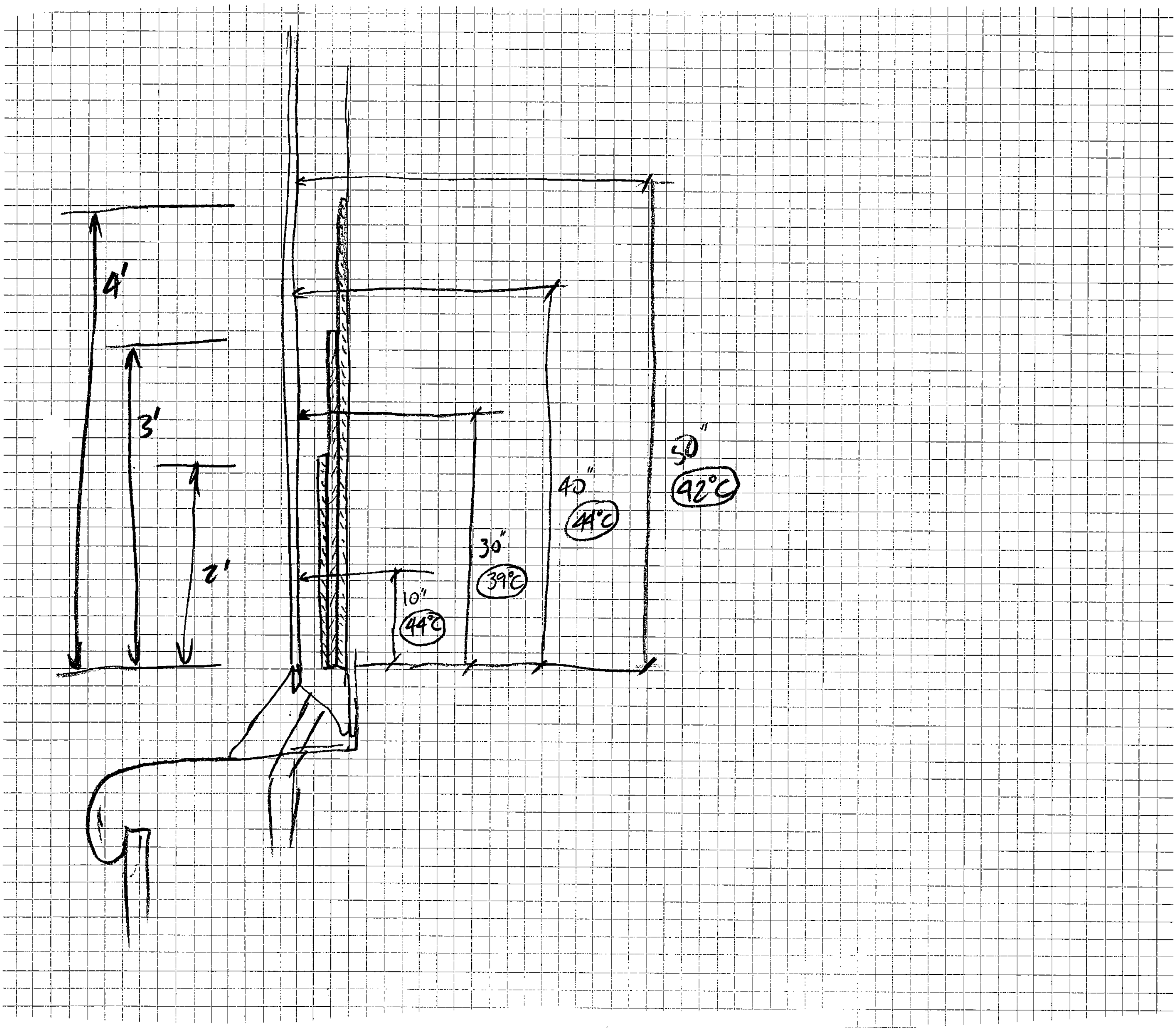
g = .40" to maintain 82°C @ 14GPM



POWER VERSUS STEM LENGTH
WATTS PER SQUARE INCH
80
60
40
20
K5 100
K8 200
0
25
50
75
100
125
STEM LENGTH (INCHES)

(FIG 1)

Making a water path as shown, with three $\frac{1}{8}$" thick rolled sheets tack-welded into place, results in DT's as shown. (Calculations on pp. 5 & 6.)



@ 10″

if gap is .175

$r_1 = 3.86$ $r_2 = 3.68$ $A = 4.26 in^2$ $(299 \times 10^{-2} ft^2)$

$1 \text{ GPM} = 2.23 \times 10^{-3} \frac{ft^3}{sec}$

$\frac{(2.23 \times 10^{-3})}{V} \div V = (2.99 \times 10^{-2})$

$V = .0746 \frac{ft}{sec}$ @ 1GPM

$V = 1.04 \frac{ft}{sec}$ @ 14GPM

$\frac{M}{\pi} = 1.3 \frac{V^{.8}}{D^{.2}}$

$M = 40$

$\pi = ?$

$V = 1.04$

$D = 7.725$

$\frac{40}{\pi} = 1.3 \frac{(1.04)^{.8}}{(7.725)^{.2}}$

$\pi = 44°C$

==

@ 30″ gap = .30 $W = 24 \frac{W}{in^2}$

$r_1 = 3.86$, $r_2 = 3.56$, $A = 6.99 in^2$ $(4.86 \times 10^{-2} ft^2)$

$V = \frac{2.23 \times 10^{-3}}{4.86 \times 10^{-2}} \times 14 = .64 \frac{ft}{sec}$

$\frac{24}{\pi} = 1.3 \frac{(.64)^{.8}}{(7.725)^{.2}}$

$\pi = 39°C$

@ 40″ gap = .425 $W = 21 \frac{W}{in^2}$

$r_1 = 3.86$ $r_2 = 3.44$ $A = 9.63 in^2$ $(6.69 \times 10^{-2} ft)$

$$V = \frac{2.23 \times 10^{-3}}{6.69 \times 10^{-2}} \times 14 = .47 \frac{ft}{sec}$$

$$\frac{21}{\pi} = 1.3 \frac{(.47)^{.8}}{(7.725)^{.2}}$$

$$\pi = 44°C$$

==

@ 50″ gap = .55 $W = 16 \frac{W}{in^2}$

$r_1 = 3.86$ $r_2 = 3.31$ $A = 12.39 in^2$ $(8.60 \times 10^{-2} ft^2)$

$$V = .36 \frac{ft}{sec}$$

$$\frac{16}{\pi} = 1.3 \frac{(.36)^{.8}}{(7.725)^{.2}} = 42°C$$

==

* @10″ gap = .55 $M = 40 \frac{W}{in^2}$ $A = 8.60 \times 10^{-2} ft^2$

$$V = .36 \frac{ft}{sec}$$

$$\frac{40}{\pi} = 1.3 \frac{(.36)^{.8}}{(7.725)^{.2}} = 104°C$$ = no "bump"

4. K500 - K800 STEM CURRENT DENSITY

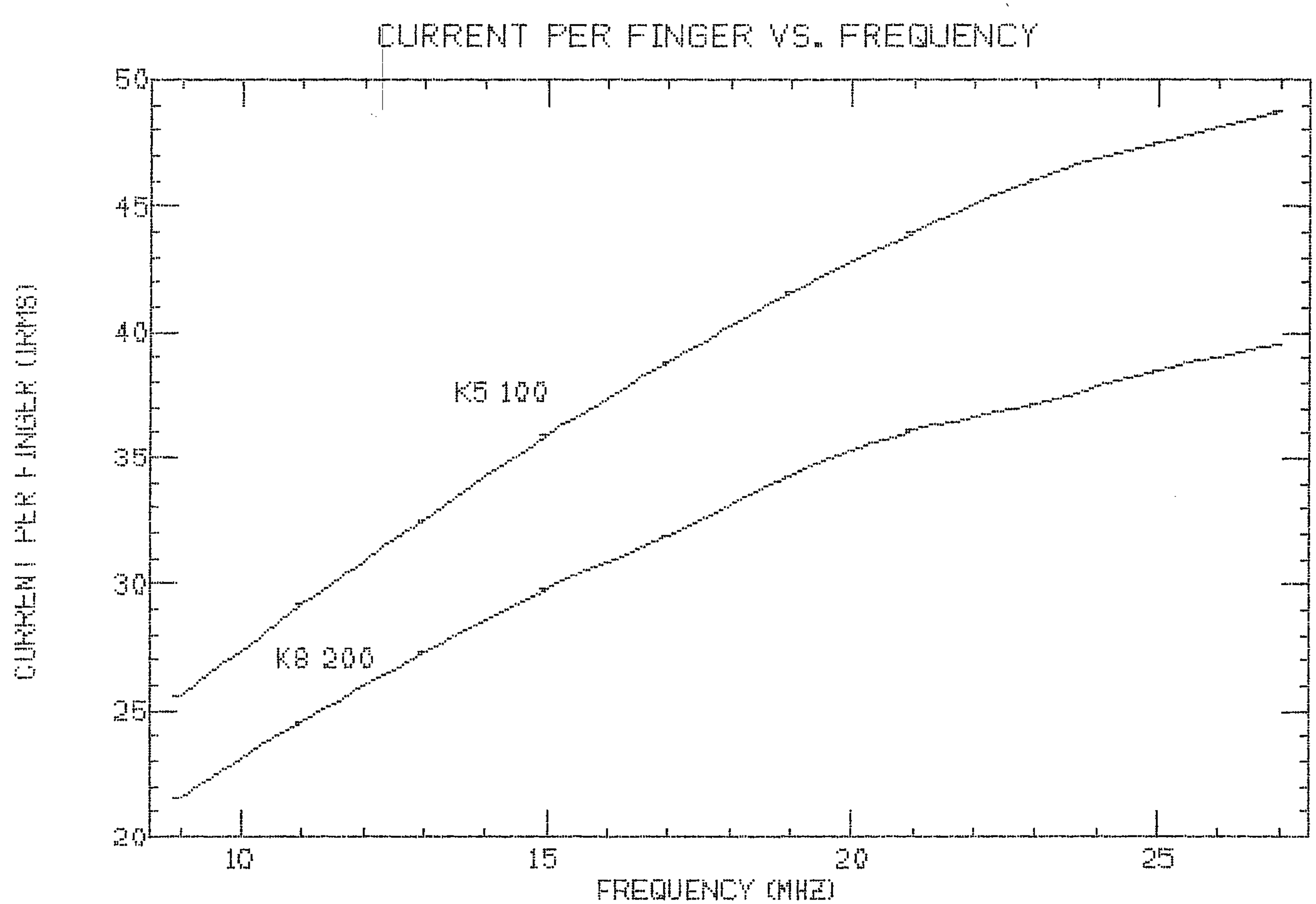
The K500 currently uses pneumatic pistons applying pressure to an R.F. current connection from inner stem to sliding short. The K800 design is attempting to use fingers in this equivalent location. In order to test the feasibility of this design, a 30MHz quarter-wave coaxial resonator was constructed. Application of 75 watts of R.F. power resulted in approximately 45 amps RMS flow on a single finger, accomplishing the current node. The test ran for more than 24 uninterrupted hours with the finger occasionally bumped. No discoloration or damage to the finger was observed. A finger was also tested at greater than 100 amps RMS at 60 Hz, with no damage or excess temperature observed.

We are now proceeding with the design of a new R.F. sliding short for a test to be performed on one of the K500 dee resonators. This short will use fingers to make connection to the inner stem. We intend to run these fingers for an undetermined period (possibly indefinitely) to further test the feasibility for this application. Results of this test will be used to modify the K800 sliding short design if necessary.

The finger we use is approximately 1 inch long. .18 inch wide and .015 inch thick. It is constructed of beryllium copper and Ag plated to a thickness of .75 mills. The top of the finger which accomplishes the sliding connection has affixed to it a hemisphere with a .16 inch radius constructed of a silver graphite material. The silver graphite material is 99% Ag and 1% C. These fingers come in a strip in which they are spaced at five fingers per inch.

The inner stem diameter on the K500 cyclotron is 4.125 inches and the K800 will have a 8.125 inch diameter stem. This corresponds to about 64 fingers total, making a connection to the K500 inner stem and 127 to the K800 inner stem. Figure 2 now shows the calculated current per finger for the K500 with 100kV dee peak and the K800 with 200kV dee peak.

The maximum current occurs for both machines at the high frequency side (27MHz), where the K500 has 48.72 amps per finger @ 100kV dee and the K800 has 39.6 amps @ 200kV dee. The maximum operationally observed steady state voltage handling capability of the K500 has been about 85kV peak at 22MHz. This corresponds to about 45 amps per finger.


CURRENT PER FINGER VS. FREQUENCY
CURRENT PER FINGER (ARMS)
FREQUENCY (MHZ)
K5 100
K8 200
50
45
40
35
30
25
20
10
15
20
25

(FIG. 2)

Appendix A

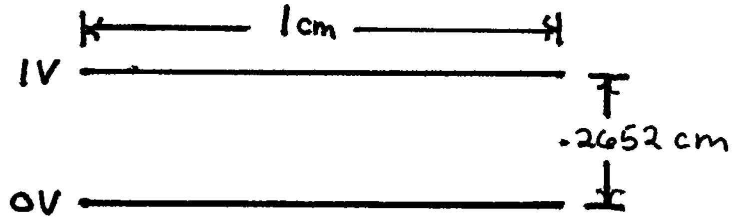
```
      SUBROUTINE ENERG
C
      DOUBLE PRECISION A
      COMPLEX BZERO
      COMMON /XB/X(1),/YB/Y(1),/A1/A(1),/I1/INDEX(1)
      COMMON /REGB/M0,MAT(30),DEN(30),AREA(30),IREGN(30)
      COMMON /LSDB/REEL,IMAG,BZERO,W2ND,KINDS(15),POINT(20),
     X      WEIGHT(20),XEDIT,YEDIT
      COMMON /EPMU/ZEPS,EPS(11),ZFMU,FMU(11)
      COMMON /PROB/CON(125)
        INTEGER C1,C2,C3,K,L,NZ,LOC,NM1,NM6,PERM
        REAL*8 ER,EZ,ET,R1,R2,R3,FACT,EPSI,FMUI
C
      EQUIVALENCE (LMAX,CON(3)),(CLIGHT,CON(58)),
     X            (IMAX,CON(5)),(KMAX,CON(4))
     X           ,(MASK37,CON(116)),(NOT,CON(33))
     X           ,(ERG,CON(72)),(ICYLIN,CON(19))
     X           ,(PERM,CON(33))
C
      LAND(IWORD,MASK)=IWORD.AND.MASK
      ISR(IWORD,IBITS)=JISHFT(IWORD,-IBITS)
C
        ERG=0.0
        IF(PERM.EQ.0)GO TO 6
        DO 4 L=1,PERM
          CALL FREE(3,MATER,1,EPSIL,1,FLOMU,1)
          EPS(MATER)=EPSIL
          FMU(MATER)=FLOMU
    4   CONTINUE
C
C     ********** FIND THE FIELD COMPONENTS EX,EY OR POTENTIAL   ********
C     ********** ASSOCIATED WITH A GIVEN TRIANGLE.  ALSO FIND   ********
C     ********** THE TRIANGLE AREA.                             ********
C
    6 KMAX1=KMAX-1
      IROW=IMAX-1
C
      DO 110 L=1,LMAX
        IROW=IROW+2
        NOD=LAND(L,1)
C
        DO 100 K=1,KMAX1
          IROW=IROW+1
          NM1=MAT(LAND(ISR(INDEX(IROW),20),MASK37))
          NM6=MAT(LAND(ISR(INDEX(IROW),15),MASK37))
          IF(NM1.EQ.0 .OR. NM1.GE.6) GO TO 10
          EPSI=EPS(NM1)
          FMUI=FMU(NM1)
          IF((PERM.EQ.0).AND.(NM1.EQ.1)) THEN
            EPSI=1.0
            FMUI=1.0
          END IF
          IUP=IROW+IMAX+NOD
          C1=IROW
          C2=IROW+1
          C3=IUP
          AREMU=ATU(C1,C3)
          R1=X(C1)
          R2=X(C2)
```

```
      R3=X(C3)
      IF(ICYLIN.EQ.1) GO TO 5
      CALL BXYTRI(C1,C2,C3,AX,AY)
      NUP=1
      GO TO 20
 5    CALL CWORK(C3,0)
      NUP=1
      GO TO 30
C
10    IF(NM6.EQ.0 .OR. NM6.GE.6) GO TO 100
      EPSI=EPS(NM6)
      FMUI=FMU(NM6)
      IF((PERM.EQ.0).AND.(NM6.EQ.1)) THEN
        EPSI=1.0
        FMUI=1.0
      END IF
      IDN=IROW-IMAX+NOD
      C1=IROW
      C2=IROW+1
      C3=IDN
      AREMU=ATL(C1,C3)
      R1=X(C1)
      R2=X(C2)
      R3=X(C3)
      IF(ICYLIN.EQ.1) GO TO 15
      CALL BXYTRI(C1,C2,C3,AX,AY)
      NUP=0
      GO TO 20
15    CALL CWORK(C3,0)
      NUP=0
      GO TO 30
C
C    ************ FIND THE TOTAL ELECTRIC FIELD ASSOCIATED WITH *******
C    ************ A TRIANGLE IN X,Y SPACE                       *******
C
20    ET=SQRT(AX*AX+AY*AY)
C
C    ************ COMPUTE THE TRIANGLE ENERGY IN X,Y SPACE AND  ******
C    ************ ADD TO THE SUM                                ******
C
      ERG=ERG+AREMU*ET*ET*(1/(2*36*3.1415E+9))*EPSI
      GO TO 40
C
C    ************ COMPUTE THE TRIANGLE ENERGY IN R,Z SPACE AND  ******
C    ************ ADD TO THE SUM                                ******
C
30    NZ=0
      FACT=3.0
      IF(R1.EQ.0.0) THEN NZ=NZ+1
      IF(R2.EQ.0.0) THEN NZ=NZ+1
      IF(R3.EQ.0.0) THEN NZ=NZ+1
      IF(NZ.EQ.2) THEN FACT=2.0
      ER=REAL(BZERO)
      EZ=AIMAG(BZERO)
      ET=SQRT(ER*ER+EZ*EZ)
      ERG=ERG+AREMU*ET*ET*(1/(2*36*3.1416E+9))*.01*(R1+R2+R3)/FACT
     +*EPSI
C
C    *****************************************************************
C
```

```
  40    IF(NUP.EQ.1) GO TO 10
 100    CONTINUE
        IROW=IROW+1
 110  CONTINUE
C
      RETURN
      END
```

Appendix B

Case a: <u>Parallel Plates</u> (xy)
(Cartesian)



Theory: $U = \frac{1}{2}CV^2 = 16.670\, pJ./meter$

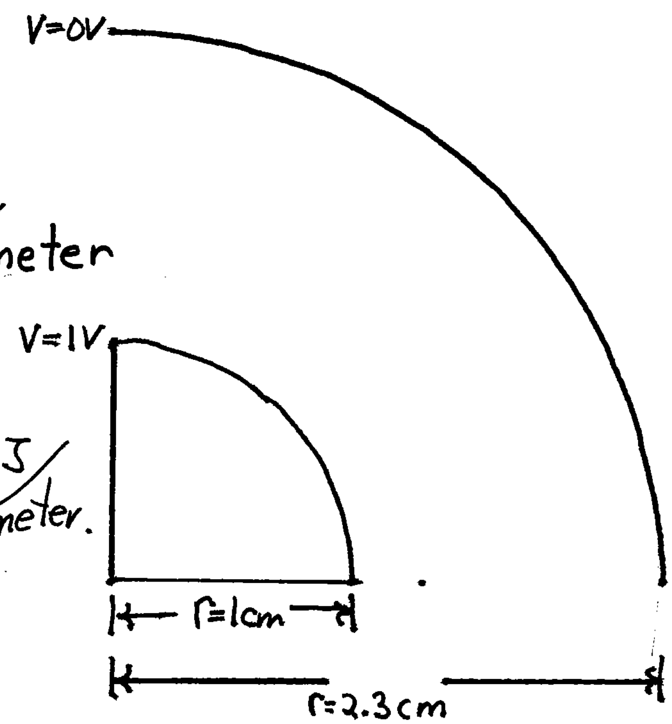
Poisson Energ. $U = 16.671\, pJ./meter$.

Error = +.01 %.

Case b: <u>1/4 Coaxial Section in r, φ</u> (xy).
(Cartesian).

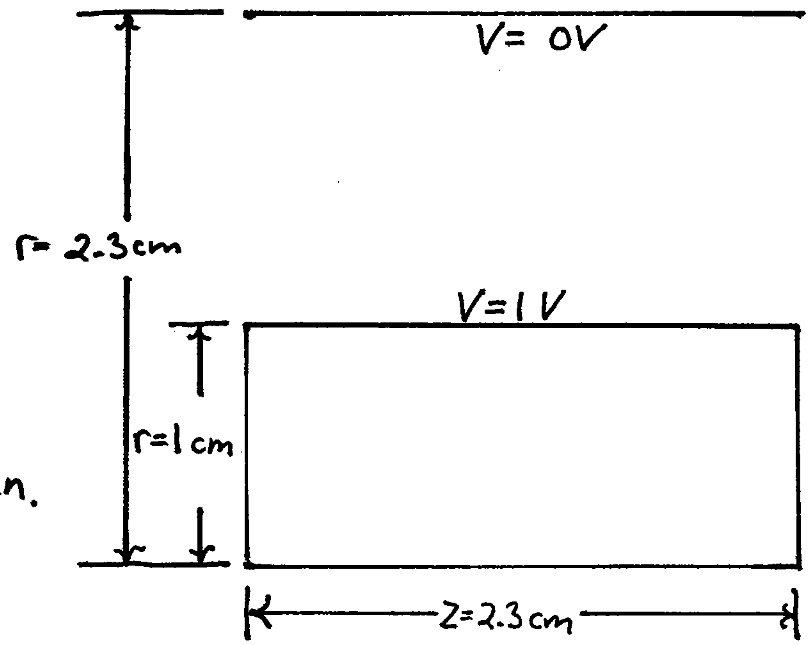
Theory: $U = 8.3376\, pJ/meter$

Poisson Energ.
$U = 8.3382\, pJ/meter$.



error = +.01 %.

Case c: Coaxial Section in r, z (Cylindrical)



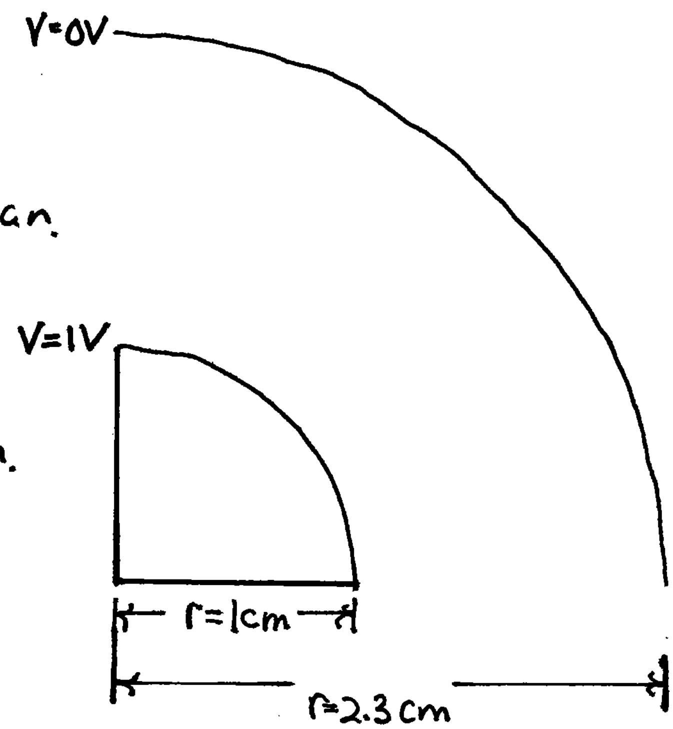
Theory: $U = .12208\ pJ/\text{radian}$.

Poisson Energ.

$U = .12212\ pJ/\text{radian}$.

error = +.03 %.

Case d: 1/4 Coaxial Crossection in r z. (hemisphere) (Cylindrical)



Theory: $U = 7.8217 \times 10^{-14}\ J/\text{radian}$.

Poisson Energ:

$U = 7.8243 \times 10^{-14}\ J/\text{radian}$.

error = +.03%