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**A ONE-DIMENSIONAL DISK MODEL SIMULATION
FOR KLYSTRON DESIGN***

by

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1. Preface

In 1982, one of the authors (Okazaki), of Toshiba Corporation, wrote a "one-dimensional, rigid-disk model" computer program <1> to serve as a reliable design tool for the 150 MW klystron development project. This is an introductory note for the users of this program.

While reviewing the so-called disk programs^{1,2} presently available, hypotheses such as gridded interaction gaps, a linear relation between phase and position, and so on, were found. These hypotheses bring serious limitations and uncertainties into the computational results. JPNDISK was developed to eliminate these defects, to follow the equations of motion as rigorously as possible, and to obtain self-consistent solutions for the gap voltages and the electron motion.

Although some inaccuracy may be present in the relativistic region, JPNDISK, in its present form, seems a most suitable tool for klystron design; it is both easy and inexpensive to use.

The following features are present in JPNDISK:

- 1) A full time-stepping formulation³ is used to integrate the equation of motion, from the entrance to the exit of the drift tube.
- 2) A gridless gap³ is assumed. A Gaussian function formulation, developed by Prof. T. Wessel-Berg, simulates the field distribution.
- 3) Relativistic effects are included in the equation of motion.
- 4) The space charge field is computed, with corrections for relativistic effects, as given Dr. P. Tallerico.²

<1> This program is presently called "DISK" by the SLAC klystron group. The "DISK" model is used in many programs; to avoid confusion, it seems advisable to give it a different name. In this note, it is called "JPNDISK".

In addition, to accommodate new ideas for high efficiency klystrons, the following features have been introduced:

- 5) A klystron with a double output gap can be simulated, using an impedance matrix⁴ to define the coupling between the two gaps.
- 6) A second (or higher) harmonic cavity can be included in the simulation.

The JPNDISK program is now on the public disk of the klystron group, and has been used by people designing a high power klystron.

2. Algorithm

The algorithm used in the JPNDISK program to obtain a self-consistent solution of the electron motion and the gap voltages is as follows:

- 1) Read out the input data from the defined disk file.
- 2) Set the initial values of the gap voltages at small fixed values.
- 3) Integrate the equation of motion for each disk, from the entrance to the exit of the drift tube, summing the induced current for each cavity.
- 4) Expand the induced current into Fourier components.
- 5) Compute the gap voltages, using the gap impedances and the fundamental or harmonic component of the induced current, as obtained in 4).
- 6) Using the new values of the gap voltages, compute as in 3), but taking the space charge forces into consideration.

Following this, compute steps 4), 5) and so on, until all of the gap voltages have converged. As it is reasonable to believe that the gap voltages near the input of the tube converge faster than those at the penultimate or output gap, convergence is examined for only one gap at the input end during one iteration cycle. If the voltage has converged, the next iteration step is started from the next cavity, the voltage of which will be used to test convergence in the next iteration step. Thus, computation time is saved.

When the voltage of the output gap has converged, the program leaves that

iteration loop and the computation of the electric and kinetic efficiency starts; this is followed by a graphic display of the computational results. Fig. 1 show the flow-chart of the JPNDISK program.

3. Working Equations

In this section, the working equations of JPNDISK are explained.

3.1 DISKS

As described in the preface, the program simulates the one-dimensional motion of rigid disks. Each disk is infinitely thin in the direction of travel and has an electric charge, q , where

$$q = \frac{-I_0}{f_{op} N_d}$$

Here, I_0 is the beam current, f_{op} is the operating frequency, and N_d is the number of disks. The mass of each disk is

$$m = \frac{q}{e} m_0$$

where e is the charge of the electron and m_0 its rest mass.

3.2 EQUATION OF MOTION

Taking the relativistic mass factor into account, the equation of motion for each disk is:

$$\left(1 - \left(\frac{v}{c_0}\right)^2\right)^{-3/2} \dot{v} = - \left|\frac{q}{m}\right| E_z$$

where c_0 is the speed of light, and v is the axial velocity of the disk. The dot represents time differentiation. E_z , the electric field in the z direction (direction of electron travel), includes both the cavity circuit field E_c , and the space charge field E_s . These will be discussed below.

3.3 CAVITY CIRCUIT ELECTRIC FIELD

The field E_c , due to the cavity circuit, is expressed as:

$$E_c = f_n V_n \cos(\omega_n t + \Theta_n)$$

where

$$V_n = - \int_{-\infty}^{+\infty} E_c dz$$

is the voltage across the n -th gap and ω_n is the angular frequency of the gap voltage. If the cavity is tuned to the second harmonic frequency, $\omega_n = 2\pi(2f_{op})$. t is the time variable. Θ_n is the phase of the gap voltage, relative to the phase of the input gap voltage. f_n is the normalized field distribution function. This function can be a square function, an hyperbolic function, etc., as in many other programs. In this program, f_n is a Gaussian function:

$$f_n(z) = \frac{1}{\sqrt{\pi}} k \exp(-k^2(z - z_n)^2)$$

where

$$k^2 = (a^2 - b^2 + 4\delta^2 \ell_g^2)^{-1},$$

a is the radius of the drift tube, b is the beam radius, and δ^2 represents a coefficient expressing the shape of the nose tip; i.e., blunt or sharp. Usually, δ^2 is in the range of 1/4 to 1/6. ℓ_g is half the length of the gap, while z_n specifies the position of the gap center. This formulation was developed by Prof. T. Wesselberg. It is believed that, in case of low $\beta_e = \omega/v$, this approximation results in a reliable representation of the coupling coefficient, M .

3.4 SPACE CHARGE FIELD

Using a Green's function method,² the space charge field at z_0 , due to a disk at z_i , is found to be:

$$E_s = -2 \frac{\rho_0}{\epsilon_0} \frac{v}{f_{op} N_d} \sum_i \sum_{\ell} \left(\frac{J_1(\mu_1 a)}{(\mu_1 a) J_1(\mu_1 a)} \right)^2 \exp\left(-\frac{\mu_1(z_i - z_0)}{\gamma_e}\right) \text{sgn}(z_i - z_0)$$

where ρ_0 is the average charge density of the beam, ϵ_0 is the dielectric constant of the vacuum, J_1 is the Bessel function of first kind and zero order, $(\mu_1 a)$ is the

root of $J_0(\mu_1 a) = 0$, and γ_e is the radial propagation factor. The summation over i is taken for ± 0.5 of the beam wavelength.

3.5 INDUCED CURRENT

The induced current in the n -th gap, at time t , is computed as follows:

$$\begin{aligned} I_{ind,n}(t) &= \int_{-\infty}^{+\infty} \rho v f_n dz \\ &= \sum_i^i q_i v_i f_n(z_i) \end{aligned}$$

where ρ is the charge density. A conventional Fourier expansion is used to extract the fundamental and harmonic components.

3.6 GAP IMPEDANCE

Z_n , the gap impedance of n -th gap, as seen from the drift tube is given by:

$$Z_n = \frac{(R/Q)_n Q_n}{1 + jQ_n \left(\frac{f_{op}}{f_{r,n}} - \frac{f_{r,n}}{f_{op}} \right)},$$

where $(R/Q)_n$ is the characteristic impedance of the n -th cavity, Q_n is the loaded Q of the n -th cavity, j is the unit imaginary number, and $f_{r,n}$ is the resonant frequency of n -th cavity.

Q_n is computed from the relation:

$$Q_n = \frac{Q_{e,n}}{1 + (R/Q)_n Q_{e,n} G_{b,n}}$$

$Q_{e,n}$ is the external Q of n -th cavity, which is measurable, and $G_{b,n}$ is the beam conductance, as derived from linear theory:

$$G_{b,n} = \frac{I_0 \sin \frac{1}{2} \Theta_{t,n}}{2V_0 \frac{1}{2} \Theta_{t,n}} \left(\frac{\sin \frac{1}{2} \Theta_{t,n}}{\frac{1}{2} \Theta_{t,n}} - \cos \frac{1}{2} \Theta_{t,n} \right)$$

Here, V_0 is the DC accelerating voltage of the electron beam, and Θ_n is the effective transit angle for the n -th gap:

$$\Theta_{t,n} = \omega_n \frac{d_n}{v}$$

The effective gap distance, d_n , is defined by:

$$d_n = \sqrt{\pi} / k ,$$

where k is the coefficient appearing in the Gaussian function defined previously.

3.7 GAP VOLTAGE

The gap voltage is derived from the induced current and the gap impedance:

$$V_n = I_{ind,n}^m Z_n ,$$

where, $I_{ind,n}^m$ is the m th Fourier component of the induced current of the n -th cavity; m is 1 for those cavities resonant at the fundamental frequency and 2 for the 2nd harmonic cavities.

The gap voltage, V_1 , for the input cavity, is computed from the available input power, P_a :

$$V_1 = \left(\frac{8P_a}{Q_1(R/Q)_1} Z_1 Z_1^* \right)^{1/2}$$

Here, $*$ represents complex conjugation.

In the case of a double-gap output cavity, the above expression has to be modified:

$$\begin{pmatrix} V_{n,1} \\ V_{n,2} \end{pmatrix} = \begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} \begin{pmatrix} I_{ind,n,1}^1 \\ I_{ind,n,2}^1 \end{pmatrix}$$

where, $V_{n,m}$ means the voltage of the m -th gap of the n -th cavity and similarly for $I_{ind,n,m}^1$. The elements of the 2×2 Z -matrix can be determined by measurements.

3.8 EFFICIENCY

This program computes two kinds of efficiency: the kinetic efficiency and the electronic efficiency.

This kinetic efficiency, η_k , is obtained from the change in the kinetic energy of the electrons between the inlet and the outlet of the output gaps:

$$\eta_k = 1 - \frac{\sum_i^j \gamma_i(z_2) - 1}{\sum_i \gamma_i(z_1) - 1}$$

Here, γ is the relativistic mass factor, z_1 and z_2 are the positions of the input and output, respectively.

The electronic efficiency, η_e , is given as:

$$\eta_e = \frac{\sum_n^n V_n I_{ind,n}^1}{2V_0 I_0} ,$$

where V_0 is the *dc* beam voltage.

3.9 NORMALIZATION

All quantities used in the program are normalized according to the following scheme: (barred variables are normalized quantities)

- a. Axial position \bar{z}

$$\bar{z} = \frac{z}{\lambda_e}$$

where,

$$\lambda_e = \frac{u_0}{f_{op}}$$

is the beam wavelength, and u_0 is the *dc* beam velocity.

- b. Time \bar{t}

$$\bar{t} = f_{op} t$$

- c. Force \bar{F}

$$\bar{F} = \frac{\eta}{u_e f_{op}} \frac{E_z}{\gamma^3} \equiv \left(\frac{d^2 \bar{z}}{d \bar{t}^2} \right)$$

where η is the charge to mass ration of the electron.

All other quantities are normalized by introducing the variables shown above.

4. Input Data

Table 1 is an example of an input file, in this case, for the 150MW klystron with a double output gap. This example is due to T. Lee.

The corresponding variables and FORTRAN formats are shown in Table 2. The functions that describe the input data are shown in Table 3.

5. Execution

S. Hutton of SLAC wrote a universal EXEC program, named RUN, which makes it very easy to use the JPNDISK program. The sequence that one uses is:

1. Make an input data file, as shown in chapter 4 on your disk. (Assume it is named as: FN FT FM)
2. GIME KLYGRP 210
3. RUN DISK FN FT FN (options: BATCH TIME HOLD VERSATEC TEKTRONIX, etc. More information is available in HELP RUN, or RUN?)

That's all one has to do.

The machine time for a typical computation of a 5 cavity klystron is about 2 min. or less, using the IBM3081 VM/CMS system of SLAC.

6. Output Displays

Computational results are summarized in two forms: output from the line printer and also in graphic printouts. The graphics are available from either the Versatec or the Tektronics machines.

Graphic displays

- 1) Phase diagram, which shows the deviation of each disk from its *dc* location.

- 2) Fundamental and second harmonic components of beam current, *vs* axial position, z .
- 3) Merit figure, defined by Mihran, *vs* z .
- 4) Velocity spread of beam *vs* z .
- 5) Induced current in the output gap, and its Fourier components, as functions of time.
- 6) Energy distribution of the spent beam.
- 7) Applegate chart in the vicinity of the output gap.
- 8) Electric field distribution in the output gap.
- 9) Amplitude and phase of the output gap voltage and current. (In case of multi-output gap only)

Figure 2, Fig. 3, and Fig. 4 show examples of the output graphics for the input data in chapter 4.

Printouts

- 1) Gap voltage and phase.
- 2) Fourier components of the induced currents in all cavities.
- 3) Efficiencies. (kinetic and electronic)

Fig. 5 and Fig. 6 show examples of the printouts.

7. Comparison with Experiments

A comparison with the experimental results is presented here, in order to emphasize the capability of the JPNDISK program. The available test data at SLAC covered four klystrons: the PEP, the XK-5, the 150MW, and the 5045. All are 5 cavity klystrons, except the 5045. The operating beam voltage ranges from 62 KV for the PEP klystron, to 450KV for the 150MW klystron. The perveance varies from 0.74 for the PEP klystron, to 2.14 for the XK-5. Thus, Klystrons designed to be operated in a variety of conditions were analyzed.

The power transfer characteristics of the klystrons, computed with the JP-

NDISK program, are shown in Fig. 7 through Fig. 10. The operation conditions are given in the figure captions.

The computation results on the saturation efficiency show good agreement for the PEP and 150MW klystrons, although they tend to predict a higher gain than observed.

In the case of the XK-5 klystron, the agreement of both gain and efficiency are excellent.

However, the 5045 klystron, designed with the JPNDISK program, shows a rather large discrepancy from the calculated efficiency. Although the reason is not clear so far, it may be attributed to the 5045's high gain design (6 cavities). It should be recalled that the 5045, at this stage, needs critical focusing control because of instabilities.

Concluding this comparison, one sees that the JPNDISK program has accurately predicted the efficiency of 5 cavity klystrons. In the case of a 6-cavity klystron, more experimental and theoretical work should be done.

Acknowledgement

The JPNDISK program was developed and studied in the course of the 150MW klystron development project, in collaboration by SLAC, KEK, MELCO and TOSHIBA Corporation. The authors wish to thank their many colleagues who took an interest in or supported this project.

Many thanks are owed to Dr. G. Konrad and Mr. T. Lee of the Klystron Department of SLAC for their encouragement and useful advice.

The kind advice and many useful discussions with Prof. B. Lippmann and his assistance with language problems are also greatly appreciated.

References

1. T. G. Mihran : IEEE Trans., ED-14, No. 4, (1967), p.201.
2. P. J. Tallerico : IEEE Trans., ED-18, No. 6, (1971), p.374.
3. T. Kageyama : IEEE Trans., ED-24, No. 1, (1977), p. 3.
4. Y. X. Zhao : IEEE Trans., ED-29, No. 2 (1982), p. 316.

TABLE 1. INPUT DATA OF THE JPNDISK PROGRAM

150MW 2P1 DISK						
450.	603.	2856.	0.	0.0187	0.013	-0.85 100.
24	30	18	1			
1	1	1	1	-1	-1	
150.	2000.	2000.	2000.			
95.	75.	89.	109.			
0.0157	0.0104	0.0158	0.0157	0.0197	0.0197	
0.0	0.135	0.270	0.568	0.682	0.7505	
4.	9.	14.	84.	0.	0.	
800.	0.	800.	0.			
800.	0.	800.	0.			
200.						

TABLE 2. CORRESPONDING VARIABLES AND FORMAT

VARIABLES							FORMAT
TITLE							(5A4)
EB A1	FMHZ	FCARRI	RDRFT	RBEAM	BETA	PIN	(8F8.4)
NDISK	NSTEP	ITERMX	IPLOT	IDEBUG			(515)
TYPE ₁	TYPE ₂	TYPE ₃	TYPE ₄	TYPE ₅	TYPE ₆		(8I8)
QE ₁	QE ₂	QE ₃	QE ₄	QE ₅	QE ₆		(8F8.4)
RBQ ₁	RBQ ₂	RBQ ₃	RBQ ₄	RBQ ₅	RBQ ₆		(8F8.4)
GAPD ₁	GAPD ₂	GAPD ₃	GAPD ₄	GAPD ₅	GAPD ₆		(8F8.4)
GAPZ ₁	GAPZ ₂	GAPZ ₃	GAPZ ₄	GAPZ ₅	GAPZ ₆		(8F8.4)
DEL _{F1}	DEL _{F3}	DEL _{F4}	DEL _{F5}	DEL _{F6}			(8F8.4)
ZZ ₁₁	FAI ₁₁	ZZ ₁₁	ZZ ₁₂	FAI ₁₂			(8F8.4)
ZZ ₂₁	FAI ₂₁	ZZ ₂₂	FAI ₂₂				(8F8.4)
PIN							(F8.4)

TABLE 3. MEANINGS OF THE VARIABLES

TUNAME	Tube name or title (no more than 20 char.)	
EB	Beam voltage	
AI	Beam current	(A)
FMHZ	Frequency	(MHz)
FCARRI	Not used in this program, set= 0.	(MHz)
RDRFT	Drift radius	(m)
BETA	Radial beam coupling constant (if beta < 0, BETA is calculated)	
PIN	Available input power	(W)
NDISK	Number of disks,	(max = 32)
NSTEP	Integration steps per rf cycle, (usually 25 to 40)	(max = 50)
ITERMX	Maximum number of iterations	
IPLT	= 0 : Tektronix 4013 ≠ 0 : Versatec plotter	
TYPE(M)	Cavity gap type (integer) 1 : Fundamental mode cavity 2 : Second harmonic cavity 3 : Third harmonic cavity (if any) -4 : Output gap 0 : Unused cavity	
QE(M)	External Q of the m - th cavity	
RBQ(M)	R/Q of the m - th cavity	
GAPD(M)	Gap distance (actual length)	(m)
GAPZ(M)	The position of the m - th gap center measured from the center of the input gap	(m)
DELFM)	Detuned freq. minus operation freq.	(MHz)
ZZ(I, J)	Impedance matrix of output gap; if all impedances = 0., no energy exchange calc.	(ohm)
FAI(I, J)	Phase of impedance of output gap	(deg.)
PIN	Available input power for further comp. PIN is not given or is negative, comp. stops	(W)

Figure Captions

1. Flowchart of the JPNDISK program.
 - m : Cavity number where the iteration starts
 - k : Iteration cycle number
 - η : Relaxation factor (default=0.6)
 - δ : Convergence criterion (default=0.004)
 - MCAV : Number of cavities
2. Graphic display (No. 1) from JPNDISK (Phase diagram, Beam RF current, and Velocity spread).
3. Graphic display (No. 2) from JPNDISK (Induced current, Spent beam energy, Applegate chart, Electric field).
4. Graphic display (No.3) from JPNDISK (Induced current and Voltage of the output gap).
5. An example of the printouts. (The first page from the 3800)
6. An example of the printouts. (The last page from the 3800)
7. Output efficiency of PEP2A klystron. Comparison of the results from computation and experiment. 62kV, 11.5A, $P_{\mu} = 0.74$, Freq. 353.2MHz
8. Output efficiency of XK-5 klystron. Comparison of the results from computation and experiment. 270kV, 300A, $P_{\mu} = 2.14$, Freq. 2856MHz.
9. Output efficiency of 150MW klystron. Comparison of the results from computation and experiment. 450kV, 600A, $P_{\mu} = 1.99$, Freq. 2856MHz.
10. Output efficiency of 50MW klystron. Comparison of the results from computation and experiment. 320kv, 362A, $P_{\mu} = 2.00$, Freq. 2856MHz.

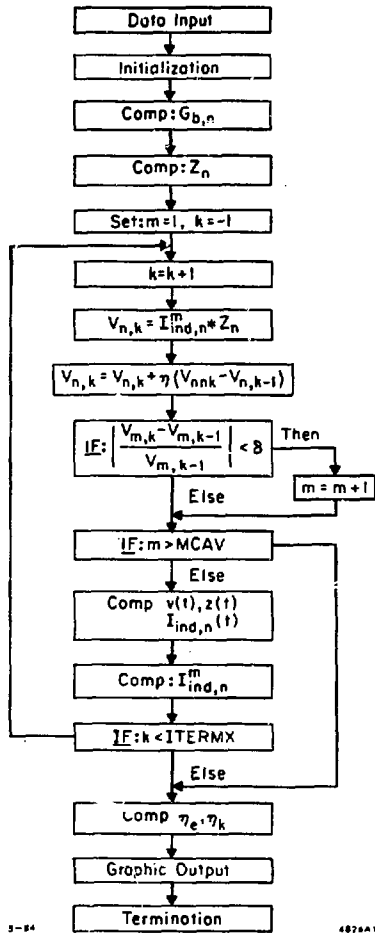


Fig. 1

150MW 2PI DISK

EB=450.0KV F=2856.0 MHz A=0.0187 H B=0.0130 M
 IK=603.0 A ITER = 13 NSTEP = 30 NDISK = 24
 PO= 100.0 V BETA= 0.91 $\lambda_q = 1.680$ M

GAPZ	0.0	0.135	0.270	0.566	0.682	0.751
DF	0.0	0.0	14.0	64.0	0.0	0.0
SE	150.0	2000.0	2000.0	2000.0	0.0	0.0
R70	65.0	75.0	86.0	104.0	0.0	0.0
GAP0	0.0157	0.0198	0.0198	0.0157	0.0107	0.0107
VGAP	1.88	0.70	50.44	203.57	425.65	425.65
PE-V	0.000	0.002	0.014	0.133	0.302	0.088

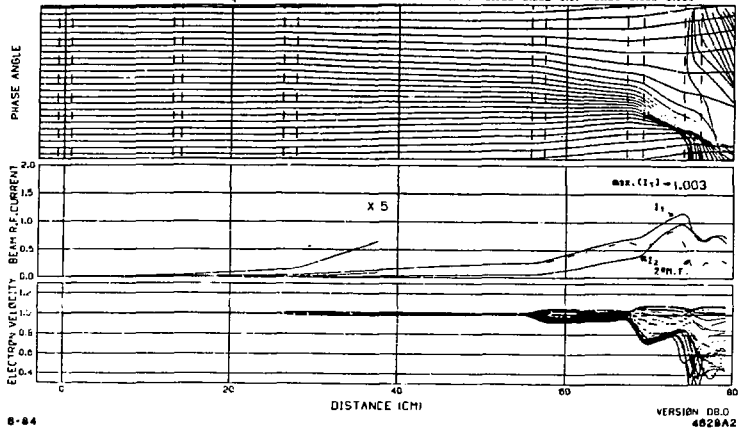


Fig. 2

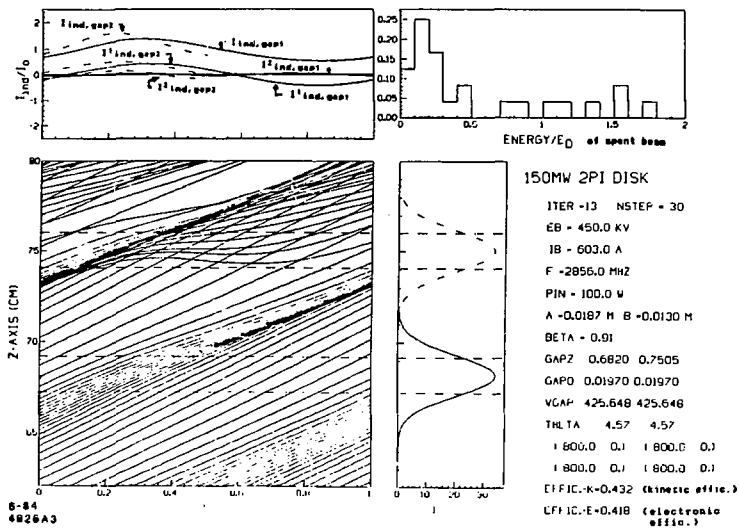


Fig. 3

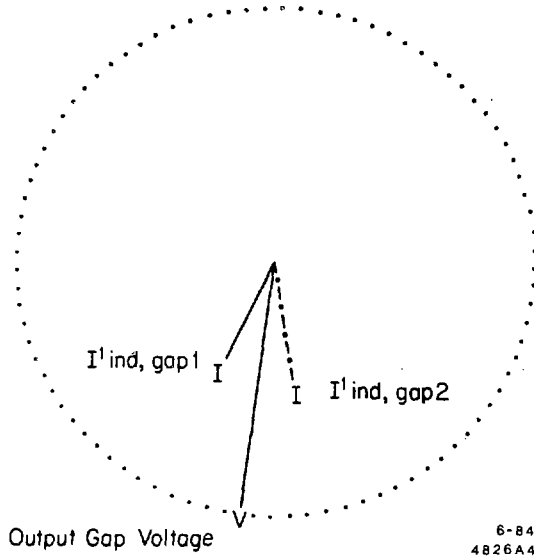


Fig. 4

```

DISK MODEL SIMULATION INCLUDING ENERGY EXCHANGE PROCESS IN MULTI-OUTPUT GAPS          VERSION 08.0          COMMENTS
***** 150MHz CPI DISK ***** ( 5 CAVITY KLYSTROM )
IB = 450.0 KV      AJ = 603.0 A      F = 2856.0 MHZ      FCARRI = 0.0 MHZ
RDPFI = 0.0187 M  RDEAM = 0.0130 M  HT = 0.033333  BETA = 0.914
GMPSA = 0.7008   G4RDB = 0.4886

NCISK = 24      NSTEP = 30      NGAP = 2      ITERNO = 25      PLOT = VERSATEC
-----
      1      2      3      4      5      6      7      8
QE      150.0  2000.0  2000.0  2000.0  0.0    0.0    0.0    0.0
R/D      95.0   75.0   89.0   109.0  0.0    0.0    0.0    0.0
GAPD (M) 0.0157  0.0104  .0158  0.0157  0.0197  0.0197  0.0    0.0
GAPZ (M) 0.0    0.1350  0.2700  0.5660  0.6820  0.7505  0.0    0.0
DELTA (MHZ) 4.0    9.0    14.0   84.0   0.0    0.0    0.0    0.0
ZGAP(DMM) 4.4    5.9    5.2    1.8    0.0    0.0    0.0    0.0
QT      47.1   90.4   70.6   58.1   0.0    0.0    0.0    0.0
FREQ-L   2860.0  2865.0  2870.0  2960.0  2856.0  2856.0  0.0    0.0
-----
***** IMPEDANCE MATRIX *****
      ( 800.0 , 0.0 | 1 800.0 , 0.0 ) (
      ( 800.0 , 0.0 | 1 800.0 , 0.0 ) (
SIGM = 1.8806      UZ = 0.2539E+09      YBZ = 0.1125E+02      BETAE=0.70678E+01      DELSQ=0.1667
OMGP = 0.942640E+10  DMGQ = 0.244917E+10      REDF = 0.2598197      REDUCED PLASMA WAVE LENGTH= 1.679841 M
FIH = 103.0 I M |
***** ITER = 0 *****
      (iteration cycle number)          (starting cavity No. of iteration)
-----
      2      3      4      5      6      7      8
V GAP  0.1876E+04  0.4000E-03  0.4000E-03  0.4000E-03  0.0    0.0    0.0
THETA  0.0        0.0        0.0        0.0        0.0    0.0    0.0
-----
HT      : Time step
GAPSA  : Gamma = RDEFT
GAPDB  : Gamma = RDEAN
Gamma  : Radial propagation factor
NGAP   : Number of output gaps

ZGAP   : Gap impedance
QT      : Total Q
FREQ-L : Resonant frequency

SIGM   : Relativistic mass factor
UZ     : DC beam velocity
YBZ    : 1/beam wavenumber
BETAE  : Beam propagation factor
DELSQ  : delta of Gaussian function
OMGP   : Plasma angular frequency
DMGQ   : Reduced DMGP
REDF   : DMSC/DMGP

V GAP   : Gap number
THETA   : Gap voltage          6-84
                                           4826A10

```

Fig. 5

***** ITER #12 *****

MEAN = 4

	1	2	3	4	5	6	7	8
VGAP	0.1876E+04	0.9702E+04	0.5044E+05	0.2036E+06	0.4255E+06	0.4255E+06	0.0	0.0
THETA	0.0	1.739	3.827	1.520	4.573	4.573	0.0	0.0

FOURIER COMPONENTS AND PHASES OF INDUCED CURRENT

	1	2	3	4	5	6		
0	0.911 (0.0)	0.911 (0.0)	0.911 (0.0)	0.911 (0.0)	0.913 (0.0)	0.913 (0.0)		Gap number
1	0.000 (3.214)	0.003 (1.2231)	0.016 (3.227)	0.107 (0.237)	0.424 (4.250)	0.502 (-1.431)		Induced current
2	0.000 (2.646)	0.000 (-1.072)	0.000 (2.529)	0.016 (0.215)	0.055 (2.713)	0.152 (3.412)		Fundamental component
3	0.000 (2.323)	0.000 (1.064)	0.000 (-0.615)	0.001 (-0.952)	0.011 (2.145)	0.034 (2.563)		2nd harmonic component
4	0.000 (2.063)	0.000 (3.129)	0.000 (1.224)	0.000 (4.260)	0.002 (-0.613)	0.007 (1.178)		3rd harmonic component
							amplitude	4th harmonic component
							phase/rad	

***** ITER #13 *****

MEAN = 5

	1	2	3	4	5	6	7	8
VGAP	0.1876E+04	0.9702E+04	0.5044E+05	0.2036E+06	0.4255E+06	0.4255E+06	0.0	0.0
THETA	0.0	1.739	3.827	1.520	4.573	4.573	0.0	0.0

EFFICIENCY(KINETIC) = 0.432

EFFICIENCY(ELECTRIC) = 0.418

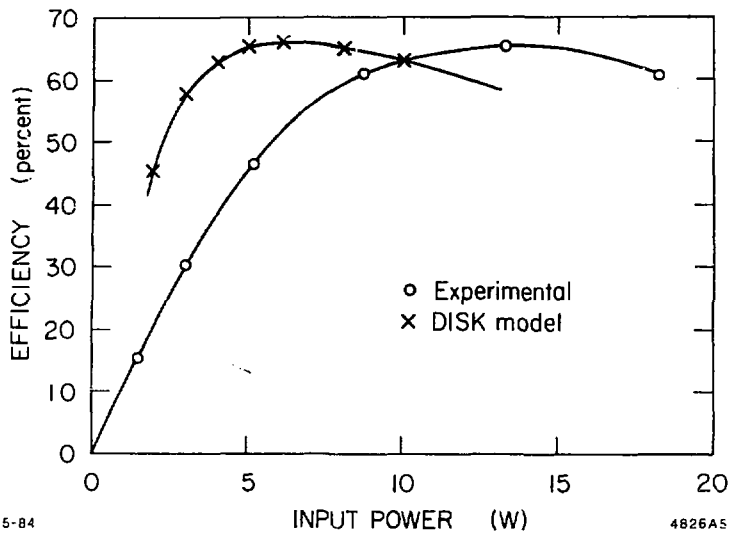
***** VT = 124.98 SEC *****

SUMMARY OF ERRORS FOR THIS JOB

ERROR NUMBER	NUMBER OF ERRORS
6-84	208
	359

4826A9

Fig. 6



5-84

4826AS

Fig. 7

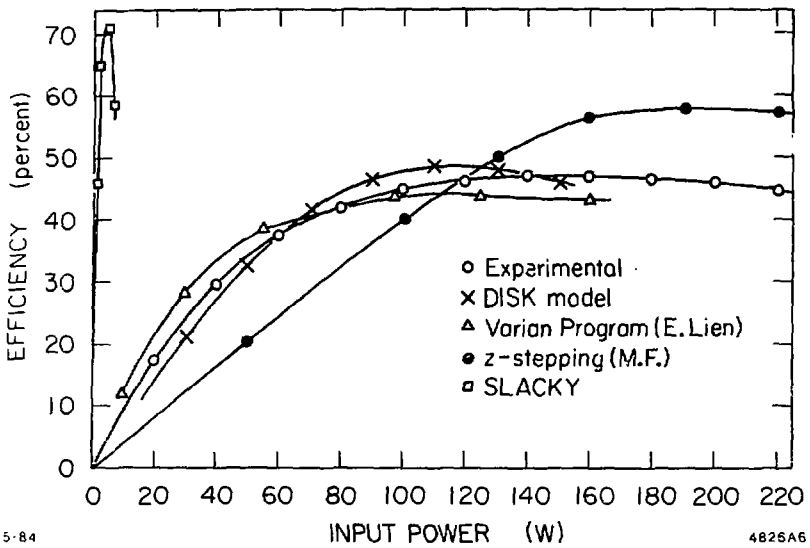


Fig. 8

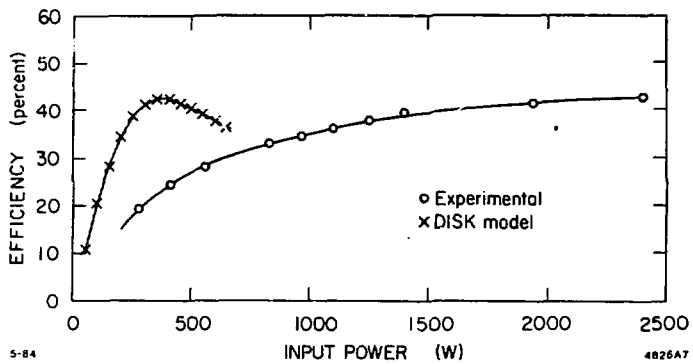
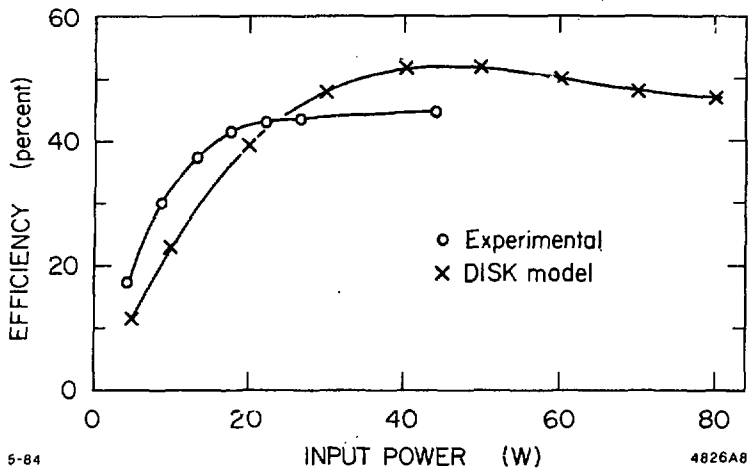


Fig. 9



5-84

4826A8

Fig. 10