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HEBT Emittance programs: LINEM and EMIT

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Introduction

Program LINEM, written in Fortran IV for the PDP10 computer, collects data on the phase-space density distribution of protons from the 200 MeV injector for the AGS and then extracts pertinent parameters from the data. The point of measurement is at the plane of the scanning slits (sometimes indicated as SEM 7 on drawings) just downstream of BMV. LINEM is liberally divided into subroutines which the operator calls into use when prompted for a mode selection by the Teletype. The program prompts the operator for all input data or control information, which is given in free format. Emitt is essentially the same program, which scans a pre-set phase space region and goes through a fixed sequence of modes, with a mimimum of operator action being required. LINEM.SAV and EMITT.SAV are on the disk, area [25, 25]. There is a copy of the source programs LINEM.F4 and EMITT.F4 on Dectape, reel #46 and, currently, in area [25, 50] (Password T50).

I. Typical User Sequence

For ease of reference, the reader may refer to the Appendix for a typical sequence of LINEM commands and data entered by the operator to measure the emittance. Underlined characters are those entered by the operator, and the symbol ↓ denoted Carriage Return. Program EMITT is very similar, but requires fewer operator actions. Details of the various programmed operations may be found in the following sections.

II. Initializing

Upon entering the program, the user is reminded how he can get a list of the various modes available, that numerical data is entered in free form (i.e., any character not properly belonging to a number field terminates the character string), that horizontal or vertical plane is specified by hitting H or V, and that questions should be affirmed with a Y (anything else, such as carriage return, means No). Then the program asks where the output should be directed: directly to the LPT?, to the JET?, to the DSK?, or to a DTA? (It is recommended that one temporarily store printer output on the DSK or DTA to avoid tying up the printer during the emittance scan and analysis. A subsequent Mode 14 or 15 selection will print the output).

After specifying the output device, the user is given the opportunity to save existing output on that device (e.g., if thr PDD-10 caused an exit to monitor mode and LINEM cannot be continued, one can restart LINEM and at this point answer Y). The end of printing is signified by ::::End File:::

Next, the operator is asked if he wishes to recover the most recent previously gathered emittance data from the DSK. (The files RHOH.DAT and RHOV.DAT are used to store horizontal and vertical data respectively in area [25, 25]. Each file contains 1063 binary words of PDP-10 memory). After this, a Mode selection is requested to which the user responds with an integer from 1 to 15. These Modes are described in the following sections. If data was recovered from DSK, the user would proceed exactly as if he had just completed the Mode 3 emittance scanning operation.

III. Mode 1: (List Modes)

Types out list of Modes.

IV. Mode 2: (Change)

Allows user to make changes in certain basic information, such as distance from slit to picket fence or calibration factors for position indicating potentiometers.

V. Mode 3: (Scan)

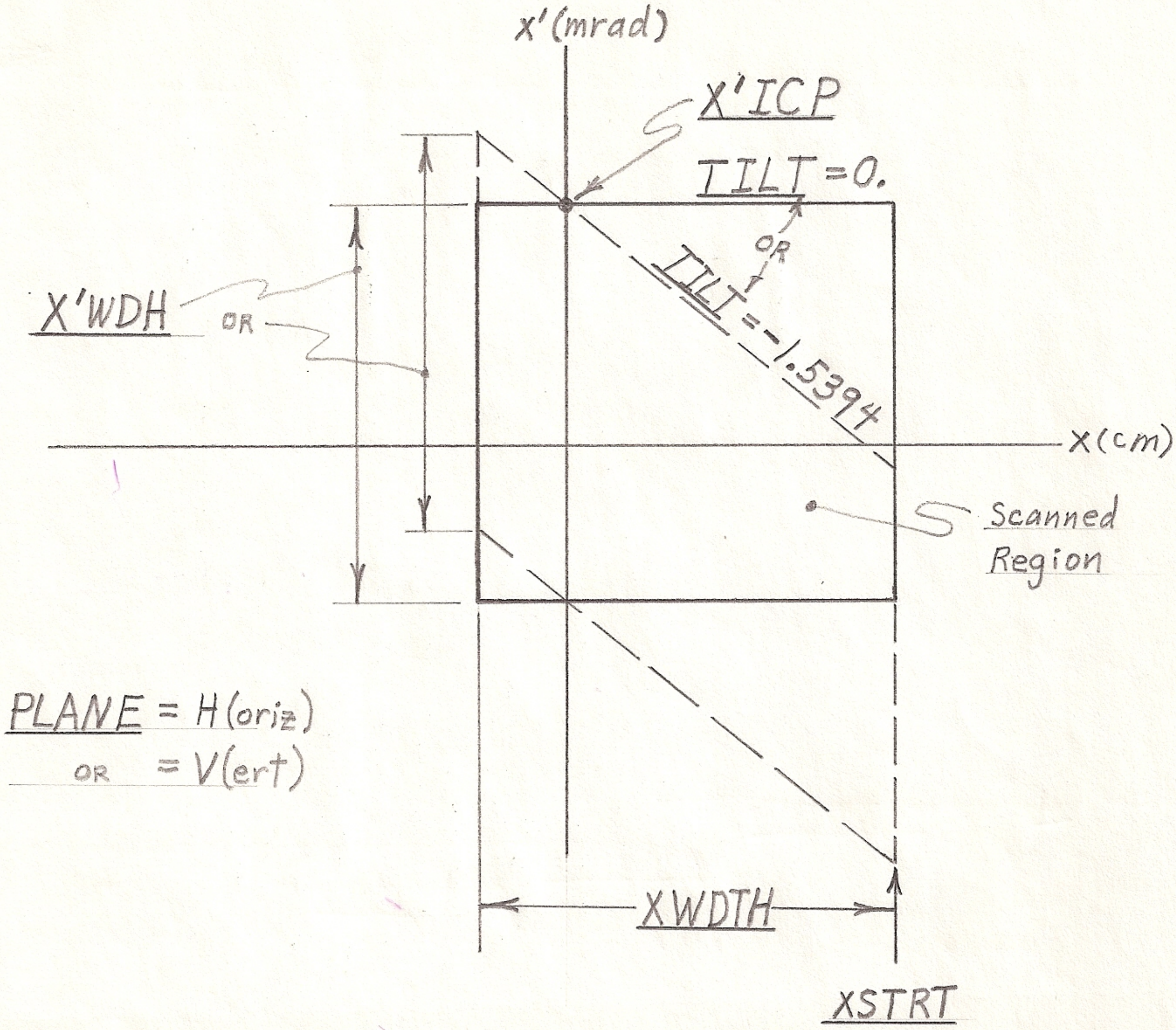
After warning the user that this Mode overwrites previous data, and giving him a chance to make a new Mode selection, this subroutine checks the status of the scanning slits and wire array. If the CoNTRL is not ReMOTE, that switch can only be set at the A10 house. If SLIT or WIRE is not PARKeD, the AGS operator can manually park them at the DATACOM panel, channel 037.

Before going past this point, the user should be sure that the program OPER is running in the PDP-10 and that the PDP-8 is functioning. In addition, make sure no one is using the ORBIT program at the same time, since ORBIT and LINEM share common flags in OPER.

Next, the phase space area to be framed by the scan is specified by the operator in response to 6 queries by the program. The parameters requested are defined in Figure 1.

The program then initiates scanning devices in the 200 MeV proton beam via the PDP-10 AGS operating program OPER and a PDP-8 which acts as the interface between the AGS and PDP-10.* A subsection of the PDP-8 monitor program receives starting point and range data and then carries the scan through to completion. Simply put, a moveable slit samples a 1.0 mm section of beam in the given plane (horizontal or vertical) while an array of 30 secondary emission detectors (10 mil wires) farther downstream simultaneously samples the angular distribution of the transmitted protons. These 30 proton density measurements are stored in the PDP-8 for each slit position. Up to 29 positions may be covered, spaced 1.0 mm apart. In addition, the slit and wire array positions are read from linear potentiometers and the total linac current, for normalization, is read from a current transformer. The time required for an emittance scan in one plane is 2 to 3 minutes. One slit position is measured on each AGS pulse, and about half of the time is required to move the devices to their starting positions. When the PDP-8 signals completion, SCAN retrieves and unpacks these 957 pieces of data using two of the OPER system subroutines.

* See J. Smith and R. Warkentien for details of OPER and the PDP-8 monitor programs.



Framing Parameters Fig. 1

These parameters are quantized internally by the program in units of 0.1 cm for x parameters, amd 0.1539 mrad for x' parameters. TILT is restricted to 0. or - 1.539 mrad/cm. At present, TILT = - 1.539 is appropriate for the convergent Horizontal distribution at the slit, while TILT = 0. is best for the less strongly divergent Vertical distribution.

After typing out the quantized values actually used, the program asks if it is indeed OK to block the beam. If Yes, the scan begins; if No, a pseudo-distribution for testing is put into the density array RHO. The status of HEBT quads Q15 - Q23, steering dipoles HS1-HS4, and VS1-VS4 is typed out. The program then asks for a snooze period (should be about 180 seconds) during which it checks for completion of the scan every 5 seconds. When done, the time is recorded and the park status of the slit and wire array devices is checked. Usually, one would proceed to data analysis before they are completely parked, but in special cases one may choose to keep checking until they reach park. At this point, another subroutine is automatically entered which is described under Mode 5.

VI. Mode 4 (PSEUDO RHO)

The user may select this mode to put in an artificial density distribution $\rho(x, x')$ for test purposes. Linac currents and slit and wire positions are also simulated. Here again, Mode 5 is entered automatically.

VII. Mode 5 (RENORMALIZ)

Immediately after a SCAN or PSEUDO operation, this subroutine is called. It first outputs the raw data; i.e., the linac current measured for each slit position, the measured position of the slit and of the first wire of the detector array, and the measured density distribution. All of these are given exactly as received from the PDP-8 scanning program. (The user can have the ρ array displayed on the TTY if he wishes. This is only practical if the TTY is fast and the array small). This density array is scanned to find the minimum voltage recorded for each wire of the array. This minimum is taken to be the electrical offset for that wire's associated electronics, and is subtracted from all the readings on that wire. Then, all the resultant density values are divided by the corresponding linac current for each slit position.

At this point, if one has reason to know (e.g., from earlier scan results) that certain wires are dead, he may have those wires smoothed over either by CALC DEAD WIRES? Y↓ (which doesn't work very well!) or by SPCFY DEAD WIRES? Y↓. In the latter case, terminate the list of dead wires by WIRE NO. = 0. The operator can then enter a background, as a percentage of the maximum value of $\rho(x,x')$, which he wishes to subtract. This "subtraction" always leaves $\rho(x,x') \geq 0$. Conventionally, a background of 5% has been entered since May 1973. (The beam emittance areas derived depend rather sensitively on this subtraction). The ρ array is then normalized to unit integral over the entire parallelogram scanned in the x-x' plane. The peak value of ρ and the location of the peak is then typed, as well as the first and second moments of $\rho(x,x')$. Finally, the normalized version of $\rho(x,x')$ is printed (and typed on request). This array, along with the parameters needed to reconstruct the measurement, is stored on DSK under RHOH.DAT or RHOV.DAT at this time. It can be recovered by the proper response when starting the program at a subsequent time.

The smoothing over (i.e., interpolation between wires adjacent to a dead wire) does not handle adjacent dead wires correctly by a single calculation. One can approximate the correct result by manually selecting Mode 5 one or two more times after its first (automatic) call. In this case, one would not, of course, respecify single dead wires already given, nor subtract background again. Alternatively, one might use Mode 5 to examine the effect of different background subtractions on the emittance results.

VIII. Mode 6 (ONE CONTUR)

This mode finds the intersection contour of $\rho(x,x')$ with a plane parallel to the (x-x') plane but above it by an amount specified by the operator as a percentage of ρ max. The coordinate points and the area of the contour are stored internally for later display (see Modes 7 and 9).

IX. Mode 7 (N CONTOURS)

This mode causes automatically repeated calls to three different modes. Starting at a chosen percentage of ρ max, the operator may cause up to 10 contours to be found by Mode 6, the height of the contour plane decreasing by a factor of 3/4 each time. Ellipses are fitted to these contours, and the contours and ellipses plotted on the LPT and TTY if desired. In the plots, x's represent empirical data, while .'s represent fitted ellipse data.

Area, fractional beam content, and ellipse shape parameters are given in all cases, and a summary of the information generated is always typed. Interpolated ellipse parameters are given for fractional beam contents of 50% and 80%, and the behavior of β, α, and area/π are plotted as functions of beam content.

X. Mode 8 (ELLIPS FIT)

This is the ellipse fitting mode. If selected manually, it fits an ellipse to the contour whose points were placed in a storage list (VTX) by a Mode 6 just preceding Mode 8. Modes 7 & 10 leave other data in VTX, and should not intervene between manual calls to Modes 6 and 8. The prescription for fitting is to define a residual $R=\Sigma(Ai-1)^2$ where 1 represents the area of the fitted ellipse and A_i is the relative area of an ellipse of the same shape and center passed through the contour coordinate point (x_i, x_i'). R is minimized by setting $\partial R/\partial\alpha_j=0$, where α_j are the 5 parameters specifying the ellipse. The calculation is similar to a least squares polynomial fit. The ellipse center is first approximated by the mean of the contour vertices. Corrections to this come out of the minimization and converge to $<$ 1/2 the grid spacings of $\rho(x,x')$ in a few passes. If convergence should not occur in 5 tries, the ellipse center is taken as the original mean of the contour vertices. The fit may fail if the points on the contour are so placed as to lead to a hyperbolic rather than elliptical curve, or if the matrix inversion in solving for the 5 parameters fails because there are too few contour points ($<$ 5). Points on the fitted ellipse are calculated and put into a list ELLPTS for later plotting.

XI. Mode 9 (PLOT CNTUR)

This mode uses a subroutine which can be manually selected to plot the contour points in VTX and the ellipse points in ELLPTS. Either VTX or ELLPTS may be suppressed if desired. (ELLPTS will be undefined, or will be an earlier fit, if the ellipse fitting attempt failed). The same subroutine is called internally by Modes 7, 10, & 11 to plot other data put into VTX and ELLPTS. Consequently, manual use of Mode 9 should generally immediately follow Mode 6 or Mode 8.

XII. Mode 10 (PROFILE)

Profiles of the beam may be obtained. The user specifies a slit (spatial) or wire (angular) profile when prompted. He further specifies the consecutive wire or slit position, respectively, to be summed in the profile distribution, and indicates whether the plot should be sent to the TTY. Note that for the wire profile, the projection into the x' axis is made in the direction of TILT (see Fig. 1), and is not necessarily perpendicular to the x' axis.

XIII. Mode 11 (RMS ELLIPS)

A so called RMS ellipse is derived from the 1st and 2nd moments of $\rho(x,x')$ already calculated in Mode 5. The ellipse equation is:

$$\gamma(x-\bar{x})^2+2\alpha(x-\bar{x})(x'-\bar{x}')+\beta(x'-\bar{x}')^2=\varepsilon$$

where in $\beta\gamma-\alpha^2=1$ and $\varepsilon=$ Area/π.

The relations are:

$$\bar{x} = \langle x\rangle$$
$$\bar{x}' = \langle x'\rangle$$
$$\beta\varepsilon = \langle x^2\rangle - \langle x\rangle^2$$
$$\alpha\varepsilon = \langle xx'\rangle - \langle x\rangle.\langle x'\rangle$$
$$\gamma\varepsilon = \langle x'^2\rangle - \langle x'\rangle^2$$

Where $\langle x^m x'^n\rangle \equiv \iint x^m x'^n \, \rho(x,x') \, dx \, dx'$

These parameters are printed, together with the fractions of beam contained by various ellipses of the same shape but different areas.

XIV. Mode 12 (SPARE MODE)

XV. Mode 13 (PARK ALL)

This sets an abort flag which will sometimes cause unparked devices to be parked. It is not infallible.

XVI. Mode 14 (PRINT)

The output information will be printed on the LPT or JET as desired if, at the beginning, the user chose to put it on DSK or DTA.

If the printer is unavailable, a message is typed, and the operator may try again (after a built-in 10 second wait) or go back to other mode selections and try printing again later.

XVII. Mode 15 <u>(EXIT)</u>

This mode executes the same print out function as <u>Mode 14</u>, but then exits to the Monitor.

XVIII. <u>Program EMITT</u>

EMITT is a streamlined, pre-set version of LINEM which requires fewer operator responses to obtain fairly complete emittance data. When prompted, the operator selects the plane to be scanned. Subroutine SCAN is preset with:

XSTRT = 1.5 cm.
XWDTH = 2.9 cm.
X'ICP = 1.69 mrad.
X'WDH = 3.23 mrad.
TILT = 0. (For Vert.),-1.539 (For Hor.).

The angular width X'WDH = 3.23 mrad is employed to limit data collection to the first 22 wires. Some malfunction of the electronics gives erroneous readings on wire numbers 23 through 30 (at this date). Should this or any other pre-set parameter require changing, one should go to subroutine SCAN in the source program EMITT.F4 and change the statement DATA (SCNDT(L),L=1,5)/1.5, 2.9, 1.69, 3.23, 0./ as required.

XIX. <u>Recompilation and Loading</u>

If either LINEM or EMITT must be recompiled and/or reloaded, the sequence is (as of this date):

```
.R LOADER
*/1H
*SYS: COMM1
*/-H
*DSK:  LINEM, UNPACK
*SYS:  LIB/L
*LPT:  ← /-V/F/M
*ALTMODE
```

UNPACK. REL is in DSK area [25,50] and also on DECTAPE #46. This sequence produces a load map on the LPT. It is assumed that system subroutines LINK, SNOOZE, DUMPI, LPTAVA, JETAVA, and ERASE (for EMITT only) are on SYS:LIB. If trouble is encountered, see John Smith about possible system changes.

xx. External Use Of Stored Emittance Data

As mentioned in Section II, the complete emittance data may be retrieved from the DSK files RHOH.DAT or RHOV.DAT (horizontal or vertical respectively). This data consists of 1063_{10} binary words. It can be read from DSK by these FORTRAN statements:

```
DIMENSION CONSTS (40), DAY (2), RHO (960), SLPOS (30), WPOS 930)
CALL IFILE (1, 4HRHOH)
READ (1) (CONSTS (I), I=1,40), DAY (1), DAY (2), HOUR,
1 (RHO (I), I=1, 960), (SLPOS (1), WPOS (I), I=1, 30)
```

The date and time of measurement are in ASCII code in DAY (1), DAY (2), and HOUR. The density array RHO should be treated as a two dimensional array RHO (I,J) with dimensions ID and JD.

ID = CONSTS (18)

JD = CONSTS (19)

Then the effective location (I,J) is:

LOC = I+ID*(J-1).

The coordinates corresponding to the density RHO(LOC) are then as follows. The spatial (or slit) position is:

X = SLPOS(J)

The position of the first wire of the picket fence corresponding to this same slit position is:

WPOS(J)

Then the corresponding slope to be used is:

X' =(-TM11*SLPOS(J)+WPOS(J))TM12 - FLOAT(I-1)*DSS.

where TM11 = CONSTS(5),TM12 = CONSTS(6) and DSS = CONSTS(28).

Using these relationships, an external program, such as ORTHO, could be arranged to transform the density matrix to some other point in the HEBT line where one might wish, for example, to make an accurate calculation of the beam profile.

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APPENDIX

LINEM: TYPICAL TTY-OPERATOR INTERACTION

```
.LOGIN
JOB 6 50603  AGS  (RJW) TTY4
#25,25
PASSWORD: OPER
1326    19-JUN-73       TUE
5.06 NOTICE 18JUN73
I) TO REPORT SYSTEM BUGS PROMPTLY, TYPE "R GRIPE" AND GIVE YOUR GRIPE.
II) KNOWN BUGS IN 5T0603:
        (1) LOADER "HANGS UP" WHEN DOING A FORTRAN LIBRARY SEARCH.
                USE THE /-V SWITCH WHEN LOADING FORTRAN FILES FOR NOW.

.RUN LINEM


MODE 1 TYPES LIST OF MODES

NUMERICAL DATA IS FREE FORM.

HIT H OR V FOR DESIRED PLANE

QUESTIONS: HIT Y FOR YES

OUTPUT DESTINATION
LPT?

JET?

DSK? Y

OUTPUT FILE IS LNMOT.DAT

SAVE EXISTING OUTPUT?

RECOVER EMITT DATA FROM DSK?

MODE-3

WARNING. SCAN OVERWRITES RHO. CONTINUE? Y

CNTRL      RMOTE

WIRE       PARKD

SLIT       PARKD
```

APPENDIX

LINEM: TYPICAL TTY-OPERATOR INTERACTION

```
XSTRT=1.5

XWDTH=2.9

X'ICP=1.7

X'WDH=3.23

TILT =Ø.

PLANE=V


VALUES USED.
XSTRT=     1.5000
XWDTH=     2.9000
X'ICP=     1.6933
X'WDH=     3.2328
TILT =     Ø.ØØØØ
PLANE-VERT
WIRE START=     2.6000

OK TO BLOCK LINAC BEAM? Y

VERT  SCAN START ON 19-JUN-73 AT 13:28

HEBT MAGNETS
      RDNG     COMM               RDNG     COMM
Q15  =    Ø        Ø       HS1  =    Ø        Ø
Q16  =    Ø        Ø       HS2  =    Ø        Ø
Q17  =    Ø        Ø       VS1  =    Ø        Ø
Q18  =3231         Ø       VS2  =    Ø        Ø
Q19  = 576         Ø       $$$$$=    Ø        Ø
Q2Ø  =    8        Ø       HS3  =    Ø        Ø
Q21  =    4        Ø       HS4  =    Ø        Ø
Q22  =   32        Ø       VS3  =   32        Ø
Q23  =1865         Ø       VS4  =3779         Ø
CONTINUE SECONDS =180


VERT  SCAN DONE  ON 19-JUN-73 AT 13:31


CNTRL      RMOTE

WIRE       PARKD

SLIT  NOT  PARKD
CONTINUE? Y

USE MEASD SLIT AND WIRE POSITIONS?Y
```

APPENDIX

LINEM: TYPICAL TTY-OPERATOR INTERACTION

```
RAW DATA
AVG LINAC CURR=     1.   RMS DEV=     0.0
               1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
 1.     1.     1.     1.     1.     1.     1.     1.     1.

               1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
 1.

RHO MATRIX TO TTY?

CALC  DEAD WIRES?

SPCFY DEAD WIRES?Y

DEAD WIRE NO.=9

DEAD WIRE NO.=13

DEAD WIRE NO.=0

SUBTRACT RHOMAX TIMES F(%)=5.

BACKGROUND =  150.0000 SUBTRACTED FROM ARRAY ABOVE

VERT  RHO NORMALIZED BY LINAC CURRENTS AND TO UNIT TOTAL FLUX
RHOMAX=     3.0504
AT X=     0.1000 CM AT SLIT
   S=     0.1539 MRAD

MOMENTS:
X      BAR=  0.10000
X'     BAR=  0.15394
XSQD   BAR=  0.04512
XX'    BAR=  0.07695
X'SQD  BAR=  0.17936

RHO MATRIX TO TTY?

MODE-7

STARTING AT RHOMAX TIMES F(%)=88.89

FIT NO. OF CONTOURS N=10

EACH CONTOUR DATA TO TTY?

EACH CONTOUR PLOT TO TTY?
```

APPENDIX

LINEM: TYPICAL TTY-OPERATOR INTERACTION

VERT SUMMARY 19-JUN-73 13:31

	CONTOUR			ELLIPSE			
L	%	AREA/PI	%BEAM	BETA	ALPHA	AREA/PI	%BEAM
1	88.890	0.007	6.650	11.808	-1.806	0.009	10.696
2	66.668	0.042	31.026	7.951	-1.139	0.036	31.026
3	50.001	0.066	44.670	9.084	-1.544	0.076	46.948
4	37.500	0.115	65.431	9.349	-1.616	0.113	68.881
5	28.125	0.149	75.990	9.229	-1.576	0.146	75.990
6	21.094	0.179	82.597	9.400	-1.591	0.179	81.558
7	15.821	0.203	86.847	9.376	-1.571	0.208	86.422
8	11.865	0.252	93.261	9.329	-1.560	0.237	91.978
9	8.899	0.262	94.286	9.329	-1.552	0.265	94.928
10	6.674	0.292	96.504	9.361	-1.557	0.289	96.068

50.00 % OF TOTAL BEAM CONTAINED IN:
BETA = 8.42940 METRS
ALPHA= -1.38008
AR/PI= 0.07055 CM-MR

80.00 % OF TOTAL BEAM CONTAINED IN:
BETA = 9.53914 METRS
ALPHA= -1.63789
AR/PI= 0.16697 CM-MR

MODE-11

VERT RMS ELLIPSE	THIS AREA HOLDS	THIS % OF BEAM
XCTR = 0.10000 CM	0.01165	10.69592
X'CTR= 0.15394 MRAD	0.02330	17.93567
BETA = 9.68294 METRS	0.04660	36.47031
ALPHA= -1.65134	0.09320	55.54417
AR/PI= 0.04660 CM-MR	0.18640	82.59737

50.00 % OF TOTAL BEAM CONTAINED IN:
AR/PI= 0.07768 CM-MR

80.00 % OF TOTAL BEAM CONTAINED IN:
AR/PI= 0.17536 CM-MR

MODE-10

SLIT PROFILE? Y

SUM INCLUSIVE WIRE POSITIONS (I1,I2)=(1,22

PROFILE TO TTY?

APPENDIX

LINEM: TYPICAL TTY-OPERATOR INTERACTION

```
MODE-10

SLIT  PROFILE?

WIRE  PROFILE? Y

SUM INCLUSIVE SLIT  POSITIONS (I1,I2)=(1,30

PROFILE TO TTY?

MODE-14

PRINT ON JET?

:::::END FILE  :::::

RECOVER EMITT DATA FROM DSK?

MODE-15

PRINT ON JET?

:::::END FILE  :::::

EXECUTION TIME:          2 MIN. 54.23 SEC.
TOTAL ELAPSED TIME:      18 MIN. 0.57 SEC.

NO. OF ERRORS             ERROR TYPE
20              FLOATING UNDERFLOW

EXIT

.K/F
JOB 6, USER [25,25]  LOGGED OFF TTY4     1346  19-JUN-73
SAVED ALL 36 FILES (1010. DISK BLOCKS)
RUNTIME 2 MIN, 56.22 SEC
```