NAL LINAC CONTROL SYSTEM SOFTWARE

Robert W. Goodwin
National Accelerator Laboratory*
Batavia, Illinois 60510

ABSTRACT

A computer-based control system is being developed for the NAL 200-MeV linear accelerator. Software development is proceeding concurrently with the initial operating experience of the linac. Operator interaction includes the use of alphanumeric parameter displays with a keyboard as well as graphical displays of diagnostic data. On-line monitoring of accelerator parameters is provided. Operator control is implemented by a knob used in conjunction with a parameter display. Software organizational structure and operating framework of the system programs are described. Features of operating programs are discussed as they have been used during the early stages of linac operation.

In order to describe the linac control-system software, the operating environment must be established. The computer used is a XDS Sigma 2 with 32K of 16-bit memory, 20 I/O channels, 8 external priority interrupt levels, 2 real-time clocks, and hardware integer multiply/divide. Peripheral equipment includes a console teletype, 3-megabyte disk, magnetic-tape unit, card reader and line printer. Control-system interface equipment includes four 50 μsec 256 channel A/D differential multiplexers, 6 video matrix units used for multiplexing 150 inputs to 6 outputs, and a special "light link" interface[1] for communication of data via fiber optics between ground and the 850-kV Cockcroft-Walton high-voltage set. Control-console equipment, shown in Fig. 1, includes a CCI alphanumeric display with a keyboard and capability of displaying 24 lines of 40 characters each, 2 Tektronix 611 storage displays,[2] a trackball, a special numeric keyboard, a Tektronix 4601 hardcopy unit, a Tektronix 4501 scan converter, a set of sense switches, and a shaft encoder known as "the knob." Details of the computer hardware and interface equipment are described in another paper.[3] The operating console configuration as well as the control-system software have evolved largely from experiences gained in the past year from using this control system to help build the NAL linac.

The operating system provided by the manufacturer is the Real-Time Batch Monitor. RBM, a disk-based system, provides a foreground-background environment

*Operated by the Universities Research Association, Inc. under contract with the U. S. Atomic Energy Commission.

and a general re-entrant I/O system. Also included is a loader with overlay generation capability, a disk file editor, and a utility subsystem. Programming may be done in assembly language or in FORTRAN. A system generation package somehow puts it all together.

In the RBM environment, the memory is divided into several regions, shown in Fig. 2. The first of these contains the operating system. Next is a region used for a resident library of re-entrant subroutines shareable by any number of tasks. The Resident Foreground area contains tasks which are always resident in core and which are automatically loaded from disk each time the computer system is initialized, a procedure which requires about 5 seconds. A major use of this area in the control system is the Beam Interrupt Task, which is triggered 15 times a second, the operating pulse repetition rate for the linac. This task uses the A/D multiplexers to read the analog data, which is maintained in a data pool for use by any other program. It also provides a facility to continuously monitor particular analog or digital data points as specified by the operator. In addition, it "keeps an eye" on trackball motion and the numeric keyboard. The trackball is used for moving the cursor in the alphanumeric display, and the numeric keyboard is used for display selection. This task also will trigger the current application display program. The time required for executing the Beam Interrupt Task is about 12 msec.

The Monitor Message Task writes messages for the operator on one of the storage-display scopes as the monitor program detects analog data out of tolerance or digital data in the wrong state. The Keyboard Interrupt Task handles application program and alphanumeric display switching. The Motor Task uses a real-time clock to issue pulses to stepping motors at a rate of 200 pulses per second. Any reasonable number of motors may be driven simultaneously, during which time about 5% of the computer's time is required. The relative priorities of the various interrupt tasks are given below. The arrows indicate tasks which may be software triggered by other tasks:

(Highest) Power On/Off
Memory Parity Error/Out-of-bounds Reference
Protect Violation Task
I/O Task
Motor Task
Beam Interrupt Task
Application Program
Keyboard Interrupt Task
Monitor Message Task
RBM Control Task
(Lowest) Background

The Non-Resident Foreground area may contain only one program at a time. RBM maintains a queue of requests for execution in this area. The next program in the queue is not brought into memory until the current program makes a request to be "unloaded." If a program is requested whose memory requirements exceed the size of the Non-Resident Foreground area, the entire background is suspended and written onto disk, allowing the loaded program to use the entire background area as well as the NRF area. The programs which are executed in this area are called application programs. Associated with each such program is an alphanumeric display. When a new display is requested by the operator, an Application Program is also loaded. The operator uses the display to communicate with the program. The program is triggered at every "beam-interrupt" time for parameter updating or other on-line activity. It is also triggered by a keyboard interrupt in response to the operator's finger. Of significant aid to the operator is the use of the cursor position in the display as a pointer. By this one can have the programs take a course of action based on which line the cursor is on when the keyboard interrupt is activated, for example. One common use is control of a magnet current or probe motor by merely setting the cursor to the line on which the parameter is described and turning the knob in the time-honored fashion, observing the changing value as well as a graphic display of a selected parameter plotted against the current reading of the parameter being controlled, on-line and in real time.

The background area is used for program preparation or more routine computational programs, including beam-transport calculations and wire list generation. The hardware-protect system prevents the background from modifying the foreground portion of memory and from executing certain privileged instructions.

Since all analog data is read every beam pulse, the most recent data is always available to any program. It requires less than 10% of the computer's time to read 600 channels of analog data 15 times per second.

The approach taken in programming this control system is a simple one. A structure is provided which makes it easy to add an application program to the system. The application program is usually coded in FORTRAN with the aid of about 80 library subroutines in addition to the standard FORTRAN library. Each program is executed as an interrupt task which receives four kinds of interrupt triggers. There is an initialization trigger upon loading the program so that flags and counters may be preset. Once this has taken place, the program resides in the Non-Resident Foreground area of memory and may be triggered at every beam-interrupt time as soon as the analog data has been read into the data pool. These data may be accessed by the program, parameter values may be read from or written onto the display, graphical displays may be generated, calculations on data performed, results output to the printer or magnetic tape, or whatever other action is desired. Also, the application program is triggered each time the keyboard interrupt is activated. Finally, a termination trigger is given when the operator requests the next display, allowing for files to be updated and closed. The Keyboard Interrupt Task then saves the current state of the display on the disk to be restored the next time that display is requested. Hence, the entire saved display may be thought of as a data storage for the application program. Program switching requires about 1 second.

The Display Index in Fig. 3a lists the available application programs. One of the early programs is the Cavity Field Measurement program[4] (Fig. 3b). A bead is pulled through a linac tank excited with low-level rf. The frequency perturbations are measured and used to give a display of the normalized fields in each gap. Another frequently used program is the Beam Emittance program[5] (Fig. 3c, 3d). Here, a measurement of the emittance of the beam is made by passing a slit across the beam backed up by a set of parallel collector strips. At each beam pulse, data from the strips are gathered and used to compute the beam emittance and present various graphic displays of the data (Fig. 4). A more recent application in measuring emittance is the use of wire scanners to collect beam-profile data simultaneously at three points along the beam path. These data are then used to calculate a beam emittance assuming that the beam is an ellipse in phase space. All three application programs may record their data on magnetic tape for replay at a later time.

A display useful for the the more usual on-line parameter presentations is the Custom Display. One example is the 66-MeV display in Fig. 5a. In this display, the operator has up to 20 lines containing an analog parameter description and value expressed in units appropriate for that parameter. At any time he may replace the parameter displayed on any line by merely typing the call number for the new parameter at the start of that line. Description and calibration information are contained on disk for each parameter. This information is catalogued by call numbers chosen to take advantage of the repetitive structure of the linac insofar as is practical in order to make it easier for the operator to remember them. (The reason we try to make things easy for the operator is that most often he turns out to be us.) The usual presentation consists of 13-pulse averages updated about once a second. The operator may, by pressing sense switches, alter the presentation to give data-channel numbers, D/A setpoint values, or monitored values or tolerances. The most common form of control is to move the cursor to the line on which is displayed the value of the parameter to be controlled, and turn the knob. Immediately, the storage display is prepared with a grid for generating a plot of one or two parameters as specified on the display (by call number) versus the reading for the parameter being controlled. As long as the operator is adjusting the knob, a point is added to the display 15 times a second. At the same time, of course, the parameter value is being updated on the alphanumeric display. (In setting D/A's by use of the knob, it was found early in our experience that the computer must always keep track of the last D/A voltage sent out, for use as a base value in computing a new setting from a knob change. Using the current A/D reading can cause the parameter setpoint to "walk" as one makes minute knob changes due to inevitable small differences in A/D and D/A calibrations.) This use of the knob allows one to vary parameters in a relative way. Parameters may be set absolutely by merely typing in the desired value in place of the updated value. (There is no conflict in doing this since the program is constantly watching the position of the cursor and knows enough not to overwrite the operator's value being typed.) Control of parameters may be either by stepping motors or by D/A's. (D/A's in the high-voltage "dome," which are operated via light links, appear to the operator no different from any other D/A.) The program knows the details through the calibration information so that to the operator, the mode of control makes little difference. Another simple but useful plot generated by this general parameter display shows one or two parameters plotted as a function of time, where again a new point is added to the display 15 times a second. One common use of this plot is investigating noise behavior. By setting a sense switch, the operator can cause an on-line display of four-jaw beam-scraper signals plotted as a cross, where the length of each arm of the cross is proportional to the log of the corresponding signal. This cross is displayed 15 times a second and is useful for tuning up quadrupoles or steering magnets in a beam-transport line.

From the previous discussion of the use of the knob, it would seem easy enough to control several magnet supplies; however, using the knob to set 170 pulsed quadrupole supplies, as exist for the 9 linac tanks, does not sound particularly appealing. Another application program deals with this problem (Fig. 5b, 5c). The nominal settings for these supplies are stored on disk. The supplies for a given tank may then simply be set at nominal or some percentage away from nominal.

Video signals are brought to the computer via a set of video matrix units. In the control room are 6 video outputs. Selection of a video signal is accomplished through another application program where one types the video matrix signal designation number on 1 of 6 lines on the display to connect a new video signal.

Diagnostic displays helpful in checkout of signals being sent to the computer include a display showing A/D voltage readings of all channels (Fig. 5d) and a display of all binary readings.

A linac log program produces a printout of every analog data point we care about. When the operator desires a log, he merely presses one button. This calls up the log program display which in about 10 seconds begins printing 13 pulse averages of the data, including standard deviations, maximum and minimum deviations, and D/A setpoint values. Currently about 300 parameter values are output in a total time of about 30 seconds. Figure 6 is part of such a log printout.

As mentioned above, application routines are coded in FORTRAN. Because this simplifies the programming effort by shortening writing and debugging time, it makes it possible to respond to rapidly changing needs of those who are trying to operate the linac. While it is true that machine language code is usually much more efficient in space, this efficiency advantage is not so significant when most of a given program consists of machine language library routines anyway.

In the early planning stages for the linac control system, it was clear that the logical starting point was a "points list" itemizing the parameters to be brought to the computer and the parameters to be controlled. The linac staff met several times and generated such a list, which has largely been followed as the linac is being built. It was decided also that it should be possible to run the linac without the computer in case of computer malfunction. It is probably still possible to do so since the computer does nothing vital to linac operation. The only place where information from the entire linac is available, however, is at the computer control console. Since the local consoles are scattered throughout the length of the linac, operation without the computer would probably require either a lot of people or a lot of luck.

ACKNOWLEDGMENTS

The author wishes to acknowledge the continual support and encouragement given by D. E. Young and P. V. Livdahl. Many valuable ideas resulted from discussions with M. F. Shea and other members of the Linac Section.

REFERENCES

[1]A. R. Donaldson, Telemetry of Control and Monitoring Signals Across a High-Voltage Interface Using Light links, Proc. of the 1970 Proton Linear Accelerator Conference, National Accelerator Laboratory, p. 591.

[2]Anthony R. Donaldson and Robert W. Goodwin, A Computer-Storage Scope Display Interface, Proc. of the 1970 Proton Linear Accelerator Conference, National Accelerator Laboratory, p. 443.

[3]Elton W. Anderson, Hong C. Lau, and Frank L. Mehring, The Computer Monitoring and Control System for the NAL 200-MeV Linac, Proc. of the 1970 Proton Linear Accelerator Conference, National Accelerator Laboratory, p. 451.

[4]C. W. Owen and J. D. Wildenradt, Experiences with Post Coupler Stabilized Structures in the NAL Linac, Proc. of the 1970 Proton Linear Accelerator Conference, National Accelerator Laboratory, p. 315.

[5]Robert W. Goodwin, Edward R. Gray, Glenn M. Lee, and Michael F. Shea, Beam Diagnostics for the NAL 200-MeV Linac, Proc. of the 1970 Proton Linear Accelerator Conference, National Accelerator Laboratory, p. 107.

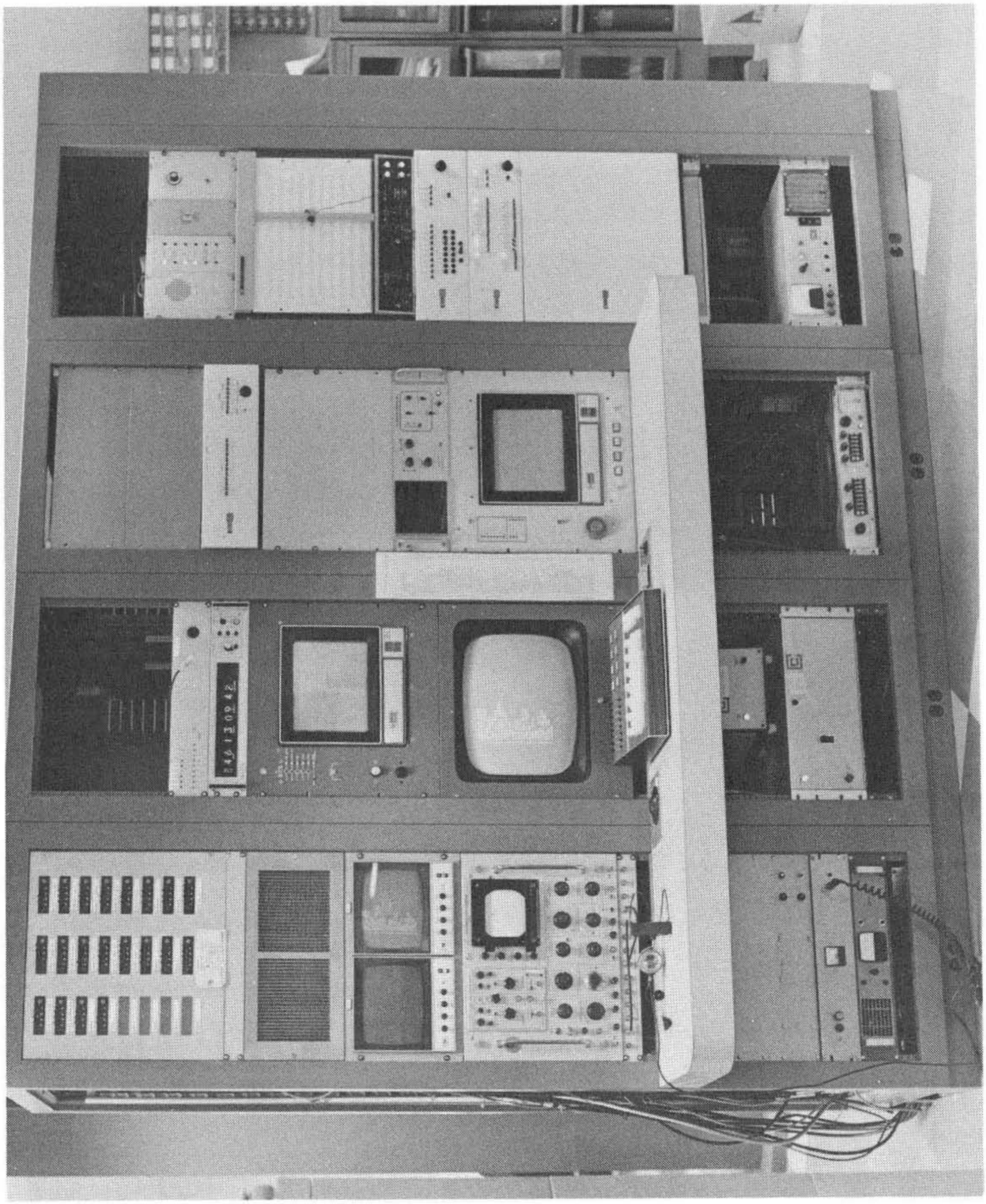

Fig. 1. NAL linac control console.

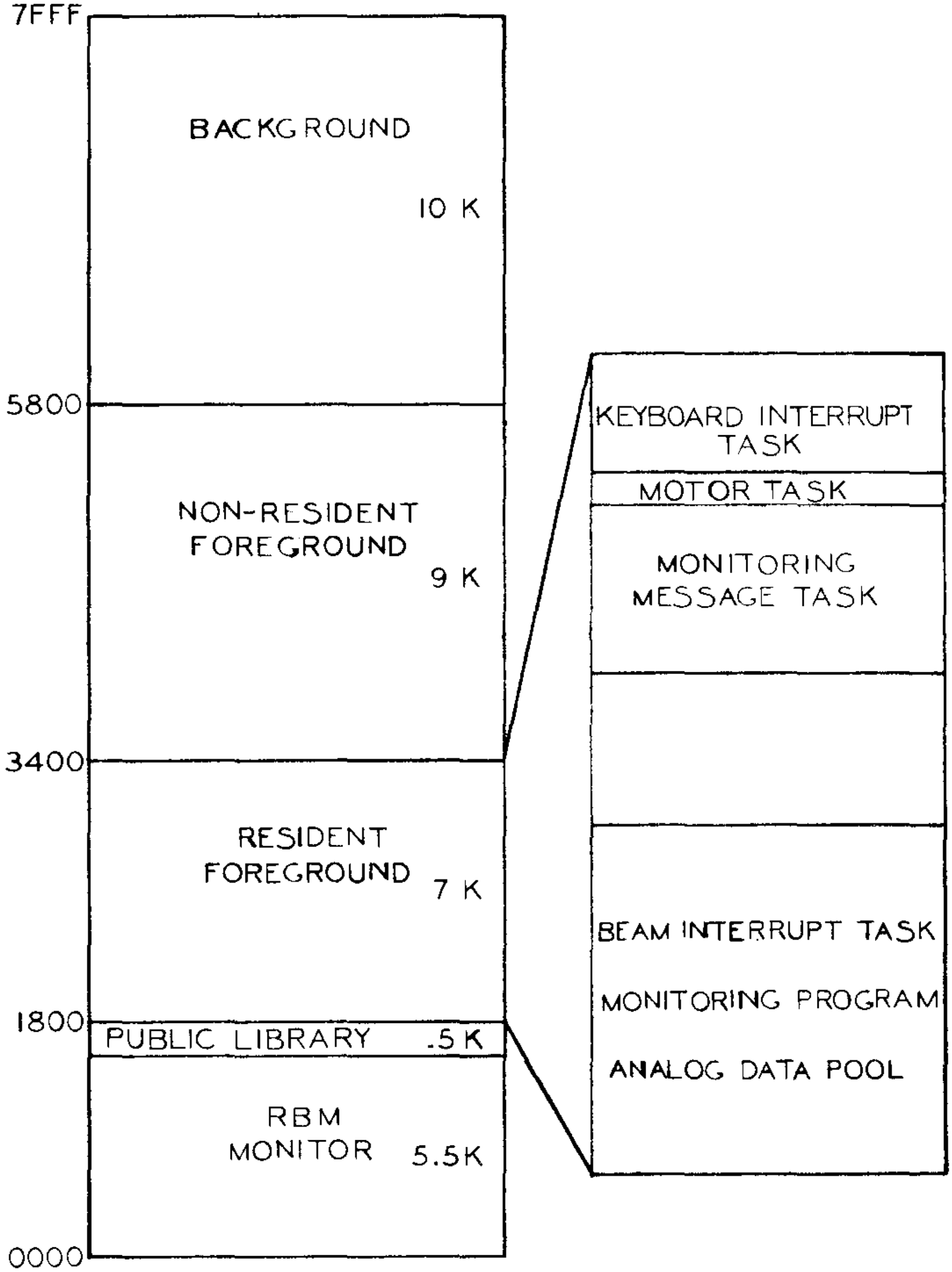

Fig. 2. Memory program allocation.

```
  DISPLAY INDEX
1 PREACCELERATOR
2 750 KEV TRANS
3 RF SYSTEMS
4 TANK QUADS
5 200 MEV TRANS
6 EMITTANCE MEASURE
7 EMITTANCE PLOT
8 VIDEO MATRIX
9 LINAC LOG
0 MISC
1 A/D DATA
2 DIO DATA
3 750 KEV SLITS
4 CAVITY FIELDS
5 CUSTOM
6 BEAM TRIAL
7 DEMO
8 MOTOR TEST
9 LINAC MONITOR
0 QUAD LADDER
1 DIODE CAL
2 CUSTOM
```

(a)

```
   CAVITY FIELD MEASUREMENT
 TANK NUMBER........*PRINT.. 4
 LEAD-IN DISTANCE........... 50     MM
 EXIT DISTANCE.............. 25     MM
 DISPLAY MAX FREQ........... 2000   HZ
 LOWER DISPLAY START........ 15000  MM
                RANGE....... 2000   MM
 FREQ LIMIT -UPPER.......... 2000   HZ
            -LOWER.......... 1000   HZ
 INTEGRATION TRIM DISTANCE.. 0      MM
 STEP SIZE.................. 2      MM
 BASE POINT WINDOW.......... 2      STDEV
 INCLUDE T FACTOR   1=YES... 0
 NORM FIELD DISP HALF WIDTH  5      %
 CELL GROUP SIZE             4

*WRITE RUN  N= 550   *READ N= 546

*START RUN..........*DISPLAY
*CALCULATE AND PRINT FIELDS.
*DISPLAY FIELDS............. 6
*AVERAGE THIS RUN........... 3
*PRINT AVERAGES.............
*MOVE RUN X TO RUN Y     XY= 15
```

(b)

```
     EMITTANCE  MEASUREMENT
* IN< 2              >PR*BE PARA 2
* SLIT INITIAL POSITION......-  2.0 CM
       PRESENT POSITION......- 1.72 CM
*        STEP SIZE............ 0.05 CM
  BEAM CURRENT PRESENT......    162 MA
               ACCEPTABLE...    160 MA
               TOLERANCE....      5 %
  BEAM PULSES TOTAL NO......     10
              ACCEPTED......      8
* THRESHOLD LEVEL RECAL.....    .10
* RUN PROBES................   1234
* RETRACT PROBES............
* PRINT.....................
  INTERPOLATION ON LASL.....
  WRITE ON MAG TAPE.........


*READ RUN=           *REW      0
*SRB  *SRF  *LIST    *SFF        1
*WRITE RUN           *EOF      1
```

(c)

```
     EMITTANCE PLOT     PROBE 1
* PLOT..................... 15
  Z AXIS GAIN.............. 1
  NUMBER OF SLIT POSITIONS.. 101
  THRESHOLD FRACTION........ .06
  INTERPOLATION............. 5
  DATA MINIMUM..............-.214  V
  DATA MAXIMUM.............. 3.982 V
  SLIT POSITION OF MAXIMUM.. .78   CM
  ANGLE OF MAXIMUM.......... 3     MR
  PERCENT ABOVE THRESHOLD... 73.82
  INITIAL SLIT POSITION.....-3.048 CM
  STEP SIZE................. .06   CM
  % VS AREA THRESHOLD CUTS.. 30
  AREA FULL SCALE...........     50 MRCM
* BEAM GROWTH: PROBE A...... 3
*              PROBE B...... 5
*SCATTER PLOT     DOTS F.S.= 200
*DRIFT    WIRE=0    DELTA Z=-240 . CM -8
*READ RUN=  30      *REW     30
*SRB  *SRF  *LIST   *SFF     8
*WRITE RUN          *EOF     1
08/22/70  0009
```

(d)

Figure 3. (a) List of display programs available to the operator. (b) Display used for cavity field perturbation studies. (c) Display used for collecting beam emittance data with destructive probe. (d) Display used for generating graphical displays of beam-emittance data.

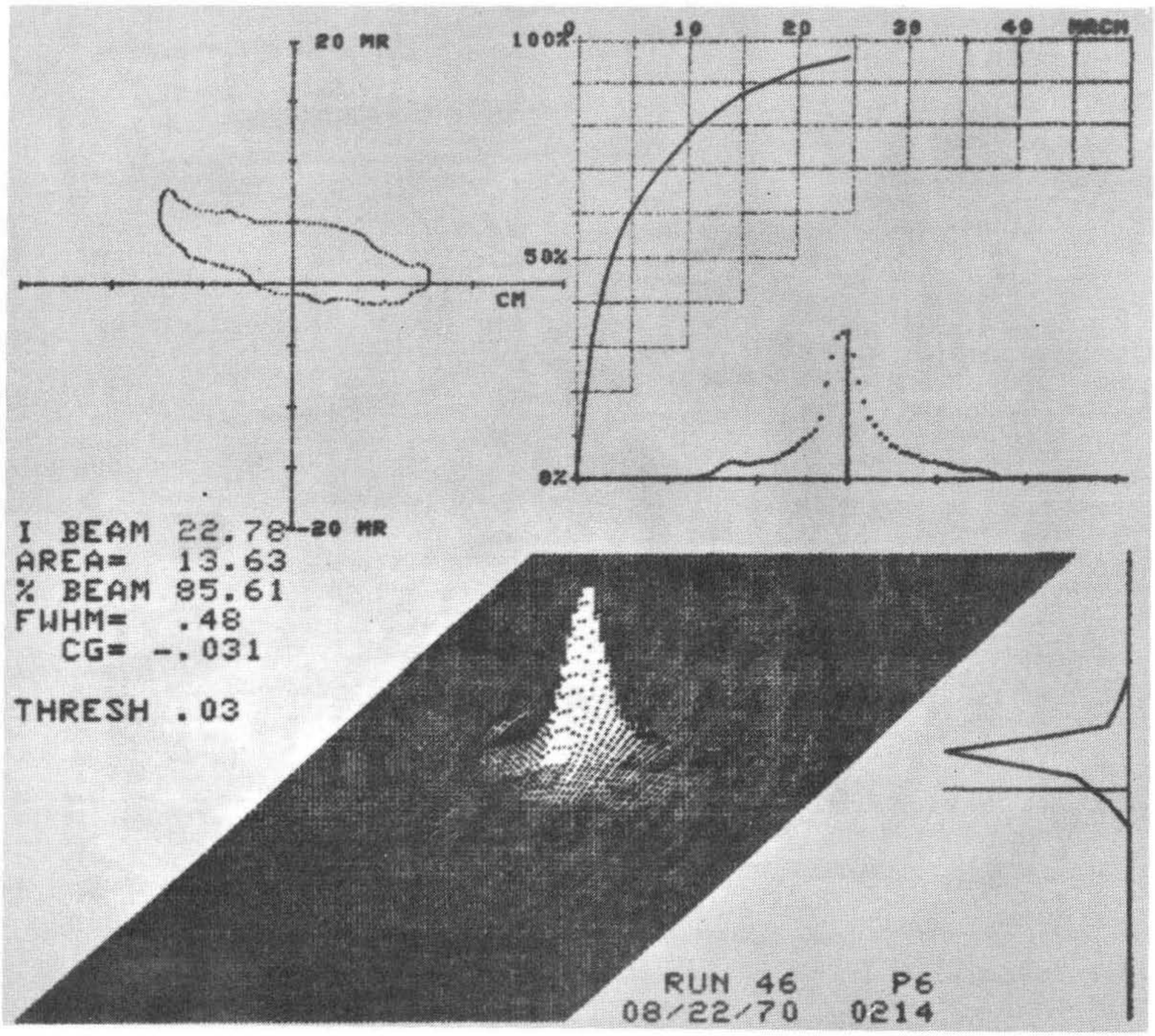

Fig. 4. Example of phase space plot of beam-emittance data.

```
   66 MEV XPORT      *PPINT
YCHAN=470  Y2=471   *TIME N= 10     SEC
YG=1    YNORM=        YZERO= 0      V
(1)CH (2)DA (3)NOM (4)TOL
T1 TOROID IN                 96.18 MA
T3 TOROID IN                 29.09 MA
T3 TOROID OUT                27.62 MA
T3 TRANSMISSION              95.62 %
T4 TOROID IN                 27.68 MA
T4 TOROID OUT                26.34 MA
T4 TRANSMISSION              95.87 %
BEAM DUMP CURRENT (66 MEV)   20.81 MA
T3 QPS #19 QUAD #35          92.83 AMPS
T3 QPS #20 QUAD #36          108.3 AMPS
*STEERING MAGNET  HORIZ     -2.613 AMPS
*STEERING MAGNET  VERT       .013  AMPS
*DOUBLET  QUAD 1             125.6 AMPS
*DOUBLET  QUAD 2             122.9 AMPS
*WIRE SCANNER 1 POSITION     3.136 CM
*WIRE SCANNER 2 POSITION     4.658 CM
*WIRE SCANNER 3 POSITION     2.614 CM
*ENERGY MONITOR POS (66 MEV) 63.51 MEV
```

(a)

```
   TANK 1 QUADRUPOLE MAGNETS

* D.T.QUADRUPOLE MAGNET DTQ-      10
                 PARTNER DTQ-     11
  MAGNET GROUP NUMBER.......       2
* POWER SUPPLY NO.  LME-DQS-       6
* NOMINAL FIELD GRADIENT.... 6.5    KG/CM
  REQUESTED FIELD GRADIENT.. 6.5    KG/CM
  WORKING FIELD GRADIENT.... .723   KG/CM
  REQUESTED SUPPLY CURRENT.. 150    A
  WORKING SUPPLY CURRENT.... 16.69  A
* A INDIVIDUAL SUPPLY ADJ... 0      %
* A MAGNET GROUP ADJ........ 0      %
* A FULL TANK ADJ........... 0      %
* A FULL TANK SLOPE......... 0      %
* B INDIVIDUAL SUPPLY ADJ... 0      %
* B MAGNET GROUP ADJ........ 0      %
* B FULL TANK ADJ........... 0      %
* B FULL TANK SLOPE......... 0      %
* SELECT:   1-NOM., 2-A, 3-B      1
* READ CARDS FOR NEW FIELDS
* PLOT: 1-NOM, 2-REQ, 3-WORK      2
* PRINT
  MONITOR TOLERANCE          0      AMPS
```

(b)

```
    LADDER QUAD CONTROL TANK 2
* FIELD LEVEL CHANGE           1      %
* FIELD SLOPE CHANGE           0      %
* MONITOR  OFF      TOLERANCE  0      %
* PLOT FIELDS
  POWER SUPPLY NUMBER.......   1
        CALIBRATION ERROR...   6.333  %
        CURRENT VALUE.......   155.7  AMP
* NEW SHUNT CONSTANT........   1.032
  END QUAD SUPPLY 1.........   1685   G/CM
  END QUAD SUPPLY 2.........   1685   G/CM
  END QUAD SUPPLY N-1.......   1544   G/CM
  END QUAD SUPPLY N.........   1431   G/CM
* PRINT NOMINAL VALUES
* NEW NOMINAL VALUES CARDS
* PRINT
```

(c)

A/D DATA *PRINT
INITIAL CHANNEL.............. 100

100	-.232	.009	.012	.017	0
105	.015	.019	-.117	.426	.312
110	.015	0	.754	.634	.503
115	.688	.461	.481	.51	.351
120	.514	.507	.515	.022	1.017
125	1.024	1.02	1.003	1.023	.935
130	1.027	.398	.081	.005	10
135	.008	.006	-1.475	.005	-.037
140	.074	.081	.012	.004	.097
145	.086	.089	.139	-.132	.083
150	.195	.2	.266	.106	.197
155	.187	-.532	-.193	-.425	-.45
160	-.367	-6.473	-6.09	-5.864	-5.739
165	-5.652	-4.826	-4.765	-4.699	-4.69
170	-4.571	-4.503	-6.587	-6.564	-1.32
175	-6.449	-6.276	-6.178	-6.017	-5.957
180	-5.918	-4.273	-4.336	-4.295	-4.119
185	-4.292	-4.174	-4.172	-4.201	-4.067
190	-4.09	-4.054	-1.31	-3.765	1.603
195	.26	0	.041	.395	1.041

(d)

Fig. 5. (a) Example of a custom display used during 66-MeV beam studies.
(b) Display used for setting quadrupole supplies in the first linac tank.
(c) Display used for setting quadrupole supplies in the later tanks.
(d) Display used for reading raw analog-to-digital voltages.

LINAC LOG 08/13/70 0010

*HIGH VOLTAGE	62.54	KV	(5.50)	3.652	-15.63	
*ION SOURCE MODULATOR DC	0	V	(0)	0	0	175.6
*ION SOURCE MAGNET CURRENT	0	AMPS	(0)	0	0	5.458
ION SOURCE FILAMENT VOLTAGE	0	V	(0)	0	0	
*ION SOURCE FILAMENT CURRENT	0	AMPS	(0)	0	0	23.94
*ION SOURCE LEAK SETTING	0	AMPS	(0)	0	0	4.575
ION SOURCE PRESSURE	0	MIC	(0)	0	0	
*ION SOURCE EXTRACTOR VOLTAG	0	KV	(0)	0	0	3.241
ION SOURCE ALTERNATOR	0	V	(0)	0	0	
ION SOURCE ALTERNATOR PH-B	0	AMPS	(0)	0	0	
TOROID #1 CTM1 OUT	134.5	MA	(2.89)	4.798	-4.601	
TOROID #2 BUNCHER IN	119.8	MA	(2.55)	3.481	-4.362	
TOROID #3 BUNCHER OUT	117.2	MA	(2.93)	4.486	-4.089	
T1 TOROID IN	95.64	MA	(3.00)	5.376	-5.611	
T2 TOROID IN	34.37	MA	(.923)	1.041	-1.473	
T2 TOROID OUT	.402	MA	(.027)	.05	-.048	
T3 TOROID IN	31.28	MA	(.927)	1.085	-1.697	
T3 TOROID OUT	-28.67	MA	(.642)	1.02	-1.225	
T4 TOROID IN	-.017	MA	(.059)	.09	-.105	
T4 TOROID OUT	12.56	MA	(1.93)	2.864	-3.447	
T1 TRANSMISSION	35.95	%	(.876)	1.763	-1.332	
T2 TRANSMISSION	1.166	%	(.07)	.109	-.099	
T3 TRANSMISSION	-91.69	%	(2.56)	3.828	-4.326	
T4 TRANSMISSION	-123	%	(97.3)	-76.93	123	
XMSN TRIPLET#1 TO BUNCHER	89.07	%	(.61)	.869	-.974	
XMSN THRU BUNCHER	97.78	%	(.928)	1.01	-2.658	
XMSN THRU TRIPLET#3	81.58	%	(1.51)	2.899	-2.289	
XMSN THRU 750 KEV XPORT	71.05	%	(1.22)	1.596	-1.895	
LINAC TRANSMISSION	-29.99	%	(.88)	1.187	-1.659	
T1 TOROID IN ZERO	3.519	MA	(.884)	1.333	-1.779	
T2 TOROID IN ZERO	2.501	MA	(.275)	.435	-.566	
T2 TOROID OUT ZERO	25.5	MA	(.887)	1.734	-1.049	
T3 TOROID IN ZERO	2.558	MA	(.457)	.963	-.709	
T3 TOROID OUT ZERO	1.857	MA	(.462)	.65	-1.131	
T4 TOROID IN ZERO	-10.99	MA	(.061)	.114	-.106	
T4 TOROID OUT ZERO	-.542	MA	(1.24)	1.793	-2.149	
*750 KEV SLIT X POS	5.1	CM	(0)	.001	-.001	
*750 KEV SLIT X WIDTH	.153	CM	(0)	0	-0	
*750 KEV SLIT Y POS	5.497	CM	(.001)	.001	-.002	
*750 KEV SLIT Y WIDTH	.128	CM	(.003)	.005	-.006	
RF1 PICKUP LOOP #1	.028	V	(.002)	.005	-.004	
*RF1 GRADIENT (LOOP #2)	-1.203	V	(.002)	.003	-.005	
RF1 PICKUP LOOP #3	.03	V	(.003)	.005	-.005	
RF1 PA FWD PWR	-.53	V	(.006)	.011	-.01	
RF1 PA REV PWR	-.017	V	(.003)	.005	-.006	
RF1 DRIV FWD PWR	-.702	V	(.002)	.004	-.006	
RF2 PICKUP LOOP #1	.014	V	(.004)	.006	-.012	
*RF2 GRADIENT (LOOP #2)	10	V	(0)	0	0	
RP2 PICKUP LOOP #3	-.885	V	(.004)	.006	-.006	
RF2 PA FWD PWR	-.617	V	(.008)	.014	-.015	
RF2 PA REV PWR	-1.489	V	(.016)	.041	-.027	
RF2 DRIV FWD PWR	.001	V	(.005)	.015	-.004	
RF3 PICKUP LOOP #1	-9.086	V	(.07)	.069	-.155	
*RF3 GRADIENT (LOOP #2)	-3.392	V	(.021)	.036	-.036	
RF3 PICKUP LOOP #3	8.426	V	(.014)	.014	-.022	
RF3 PA FWD PWR	-3.532	V	(.023)	.039	-.039	
RF3 PA REV PWR	.078	V	(.008)	.015	-.018	

Fig. 6. Part of linac log printout.

DISCUSSION

D. Young (NAL): I would just like to make one comment. When we were first thinking about this system, we were concerned about where we would find all the programmers to do all the programming. We have found that this is only a one-man job with our system, and I think some people might be misled in their thinking about computers when they consider how much programming effort might be involved.

T. M. Putnam (LASL): How big is the program you got from XDS, the basic-systems program?

R. W. Goodwin (NAL): The operating system Real Time Batch Monitor takes about 5-1/2 K in our system.

R. P. Featherstone (Central Engineering): Have you enough accumulated experience now so that you have a feeling as to the reliability of the system? How many hours in the month or year do you feel like going home?

R. W. Goodwin: The computer is usually working. We probably have more time spent in trying to get the interface equipment operating to the expectations that we would like; the computer itself is probably pretty good.