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United Kingdom Atomic Energy Authority

RESEARCH GROUP

Report

AN ON-LINE DATA ACQUISITION SYSTEM USING A LINC-8 COMPUTER

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1970

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AN ON-LINE DATA ACQUISITION SYSTEM USING A LINC-8 COMPUTER

by

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C.A. STEED

ABSTRACT

This report describes the hardware and software of an on-line data acquisition system used on a plasma physics experiment. The purpose of the system is to sample analogue signals under program control, file the data on magnetic tape, perform routine computations on that data, print out the results, and display the raw data in an easily assimilable form on an oscilloscope. The programs have been designed to provide a flexible system and, by making programs fully interactive where necessary, to be used by people with no knowledge of computers.

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May, 1970.

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1. INTRODUCTION

In order to perform an experiment efficiently, it is necessary to assess the information coming from the experiment in time to determine the next step. Where the experiment involves the measurement of many parameters this is difficult enough but if, in addition, the experiment is pulsed and the control of some of the variables is imprecise, a great deal of computation and graph plotting may be necessary before a sufficient assessment of the data from a pulse can be made. The PHOENIX II experiment[(1)] has these features and it was found necessary to install a small on-line computer to help with the data acquisition and analysis.

PHOENIX II is a magnetic bottle which is filled with plasma by injecting a beam of energetic neutral hydrogen atoms across the magnetic field where a small proportion of the incident beam is ionised by the Lorentz $\underline{v} \times \underline{B}$ force and the resulting ions and electrons are trapped in the magnetic field. The magnetic field is switched on for up to 10 seconds during which time plasma experiments are performed.

The choice of peripheral equipment was dictated mainly by the usual principle that pattern recognition is best done by the experimenter and 'number shuffling' by the computer. A visual display was therefore indispensable and furthermore, because it is necessary to compare data from one pulse with that from another, immediate access to all the raw data from a series of pulses was needed. A local backing store in the form of two magnetic tapes was used. Programs were stored on one of these tapes leaving the other for data. Facilities for sufficient analogue channels and for analogue to digital conversion under program control were also obviously necessary.

In designing the software attempts to make the system easy to use employed the 'question and answer' technique to make the computer fully interactive with the operator. For speed the computer prompts appeared on the visual display screen as did the responses. Experience has shown that a 'novice' can get useful results from the system after an hour or so of familiarisation.

The general time sequence of operations starts with the causing of an interrupt about 10 seconds before the data needs to be sampled. This allows the sampling program to be read into memory from the program tape. A second pulse from the experiment initiates the taking and storing of the zero error on each of the channels subsequently to be sampled. A series of timing pulses from the experiment then initiate the sampling from any of the 24 analogue channels at a time and frequency dictated by a control block compiled during the INITIALISE phase (this can be done at any time except of course during sampling). When the total time allowed for sampling has been exceeded, the data, with zero error subtracted, is filed together with its control block on the data tape and an entry is made in the index for subsequent retrieval of that data by its pulse or experiment number. The computer then enters a series of specialised routines to compute required parameters. In our case plasma density, decay time and associated statistics, magnetic field strength and depth of magnetic well are computed - other routine computations can be added when required. After outputting the computed results on the teletype, the raw data is displayed in an easily assimilated form on the display oscilloscope. Up to this point everything is completely automatic and will continue to be so when the next pulse is initiated; this includes incrementing the pulse or experiment number by one each time.

During the DISPLAY phase one can manipulate the data and read off values using a cursor as described in Section 4.7. It is not possible to do computation at this stage except to recompute the previously mentioned parameters. However, one can exit from this programme in two useful ways from the point of view of data manipulation. One can enter the PLOT routine which will display any channel plotted against any other and also enable entry into a graph assembly routine supplied by the manufacturers; this allows a graph to be labelled. Superposition of displays from these programs yields polaroid photographs, an example of which is shown in Fig.1. The other useful exit is to any named user program; this allows manipulative tools to be added as required.

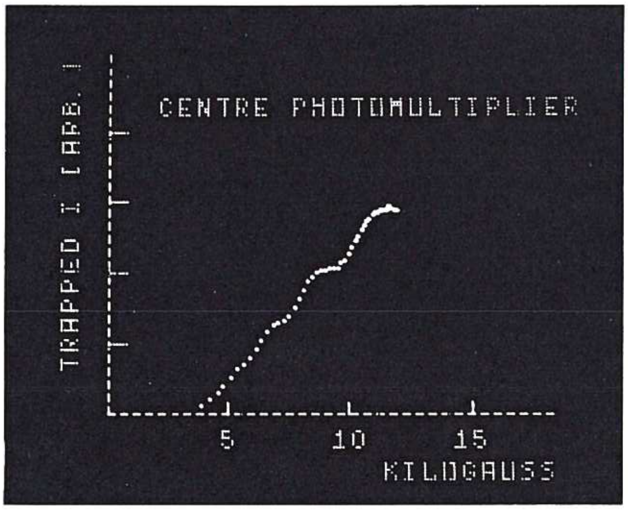

Fig.1 Plot of trapped current due to Lorentz $\mathbf{v} \times \mathbf{B}$ ionization as a function of magnetic field obtained by superposition of the visual display from PLOT and GRAPHA. The bumps are due to the way the various principal quantum states of the excited hydrogen atom contribute to the total ionization at different magnetic fields.

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This report describes the hardware and software[2] comprising the system. While the application described here centres around a specific experiment, the system itself could with very minor modifications be used anywhere subject to the limitation that the maximum sampling rate possible is 5 kHz on any one channel.

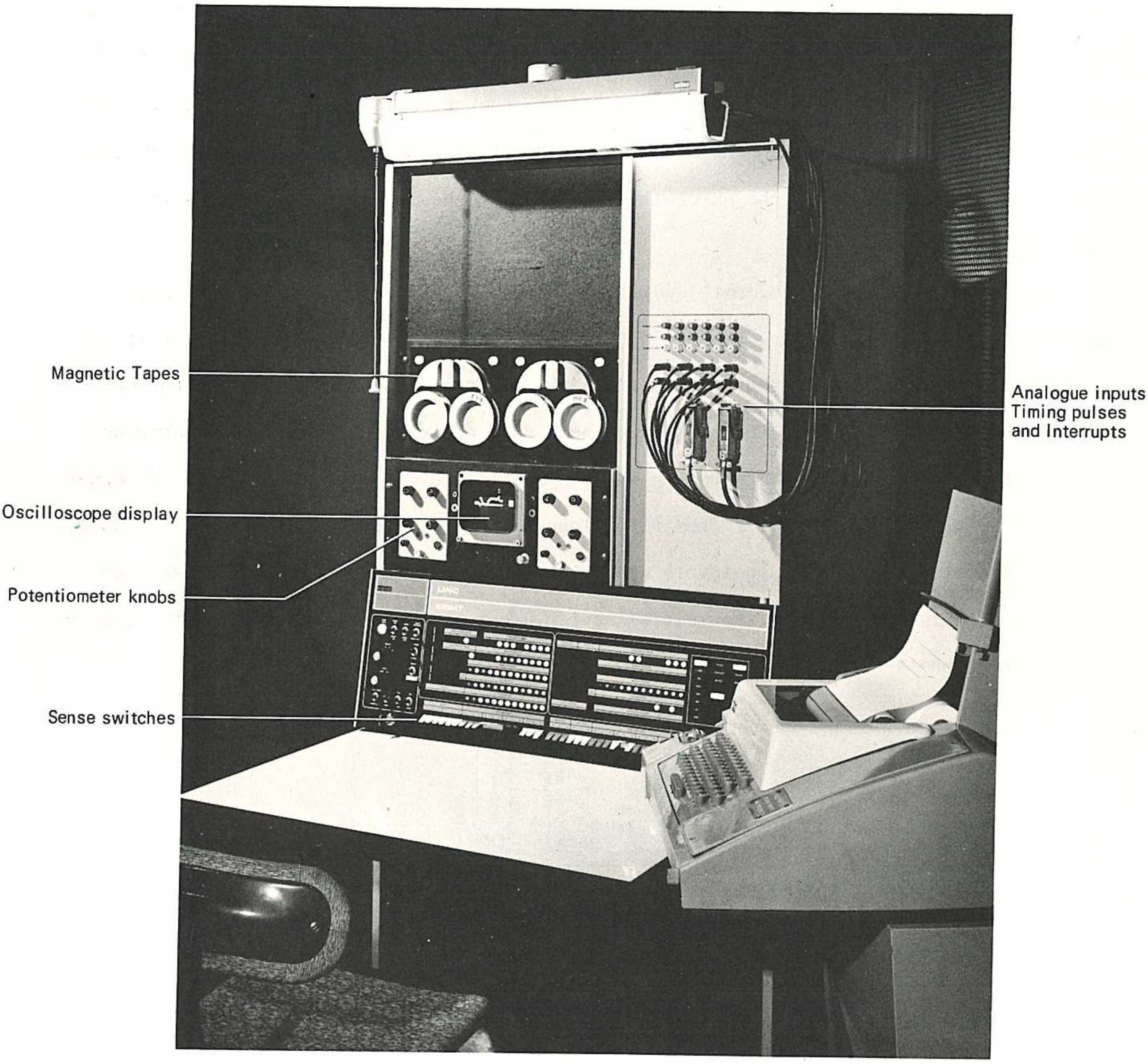

Fig.2 The LINC-8 computer.
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2. HARDWARE

2.1 COMPUTER

The computer used is a LINC-8 computer manufactured by Digital Equipment Corporation (DEC). A photograph is shown in Fig.2.

The LINC-8 is a dual computer system combining the Laboratory INstrument Computer (LINC) and the Programmed Data Processor - 8 (PDP-8). Both the LINC and the PDP-8 are one address, fixed word length parallel computers using 12 bit binary arithmetic. Cycle time of the 4096 word radom access magnetic core memory which is shared by both computers, is 1.5 μs. Some hardware additions have been made to the standard LINC-8 and these include 16 extra analogue channels, an interrupt device controlled by the PHOENIX II experiment, and extra hardware to allow the external sense lines to be grounded electronically.

2.2 HARDWARE ORGANIZATION

A block diagram of the overall system is shown in Fig.3. Analogue signals from various diagnostic devices are fed via buffer amplifiers into an analogue-to-digital converter. The sampling of the various inputs is performed under software control on receipt of timer pulses from the main experiment sequence timer via one of the external sense lines. This enables the sampling to be synchronised with the experiment. External hardware provides voltage levels from flip-flops which are triggered by changes in experimental parameters. The voltage levels are then used to ground the external sense lines, and an option is provided in the initialisation program which allows sampling to begin on specified channels when this occurs.

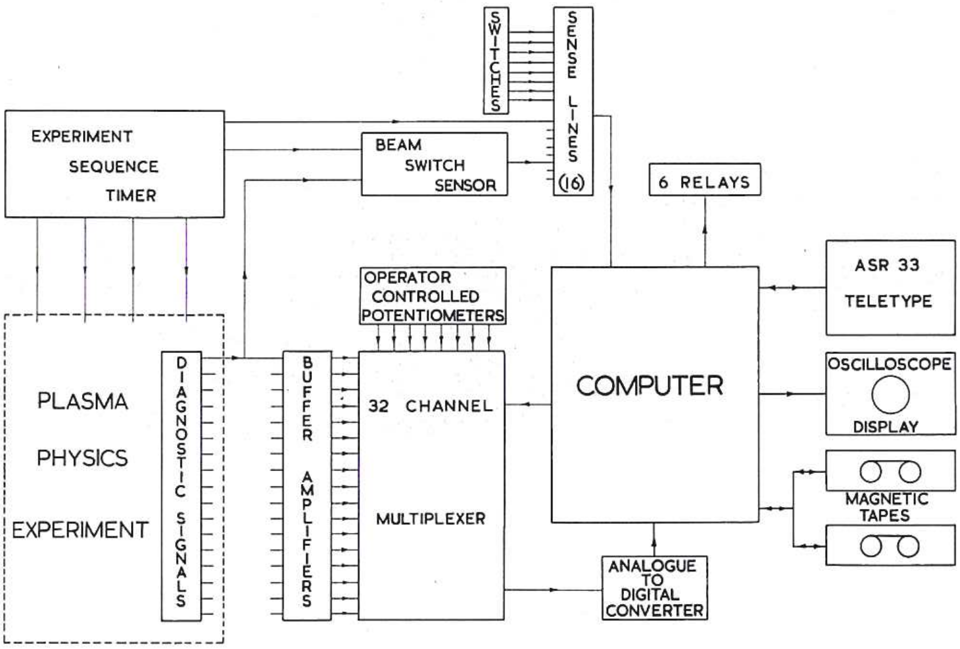

Fig.3 Block diagram of the system hardware showing, as well as the LINC-8, the experiment, the sequence timer and the beam switch sensor.

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2.3 INPUT/OUTPUT

A wide variety of input/output equipment is incorporated in the system. Communications between operator and computer is effected mainly by use of an ASR 33 teletype and a 5 inch Tektronix 561A oscilloscope. Information from the computer is output to the oscilloscope as alphanumeric text or in graphical form. Any response requested from the operator is entered via the teletype. Another means of communication exists in the form of 6 switches connected to sense lines which can be sensed under programme control. There is also a useful facility which enables the operator to input analogue voltages from eight potentiometers (KNOBS) and the software can use this as a source of data, for instance, to move a cursor over the face of the oscilloscope.

Communication between experiment and computer takes one of four different forms. The first of these is an interrupt flag which is set by the experiment to indicate to the computer that a pulse is about to begin. This interrupt makes the experiment a peripheral of the computer with its own device number and proceeds to load the sampling system into memory from magnetic tape and enter the sampling mode. When in this mode communication exists in 2 ways. Timer pulses are fed from the main experiment sequence timer via one of the external sense lines and used by the computer to synchronise the sampling of experimental data. Other signals can be fed from various external devices, depending upon specific requirements, via the external sense lines and used to control the sampling of specific channels as described in INITIAL. Secondly, diagnostic signals from the experiment are fed via buffer amplifiers to 24 analogue input channels where they are sampled under program control according to the information set up by the user by means of the INITIAL programme.

On completion of an experiment the diagnostic data with its associated data control block is written on to magnetic tape. The magnetic tapes each hold 512 directly addressable blocks of 256 12-bit words each. For details of the layout of the 2 tapes (program and data) see Appendix 1.

3. SOFTWARE

3.1 INTRODUCTION

The data acquisition system described in this and subsequent sections is completely self contained in that all programs required by the system are incorporated in it and linkage between programs is established within the system. Facilities are provided for the user to enable loading of programs previously written and filed under the LAP6 programming system.

One of the main objectives during development of the software, was to ensure ease of operation by users with little or no experience of operating a computer, while retaining the maximum flexibility possible. This has been accomplished by use of a question and answer procedure whereby communication with the user takes the form of text displayed on an oscilloscope and any response required is indicated by question marks displayed in this text. The user then enters his reply via the teletype and the question marks are replaced as each character is entered. Upon receipt of a carriage return this data is then acted upon. Often, to decrease the amount of typing to be done by the user, numbered options are presented and only the number of the option need be typed in. Unfortunately it is not possible to proceed in this way when data is being displayed and therefore it is necessary for the experimenter to know the facilities available in DISPLAY and how to use them.

The taking and displaying of data is governed by the data control block which is set up by the experimenter when he enters his sampling requirements using the INITIAL program. The data control block exists in two forms: one is on the systems tape (SMPLDATA) to be used for the next pulse and the other is filed with the data just taken on the data tape. The version on the data tape includes the values of the various quantities characterising the pulse calculated after the sampling has been completed, and also the pulse number and location of the data on the data tape. This leaves the way open for writing future programs which can search for pulses with specified characteristics.

3.2 SYSTEM ORGANIZATION

Although the LINC-8 is basically a 4K computer, 1024 memory locations are set aside for an operating system known as the PROGram OF OPerations (PROGOFOP). The function of this system is to handle interrupt requests, and to interpret and execute magnetic tape and other input/output operations. Thus the available memory for programs and data is actually 3K. Since with the LINC processor certain instructions are able to address up to 1024 locations directly it was decided that this would be a sensible maximum for system programs, leaving 2K of core store available for data. The layout of the core store is shown in Fig.4.

Because of the above limitations of core store the system software has been written in modular form with none of the programs used for data manipulation occupying more than 1K of memory at any given time. Calling a new program from magnetic tape is accomplished by overwriting the old program and determining subsequent routing by means of software clues.

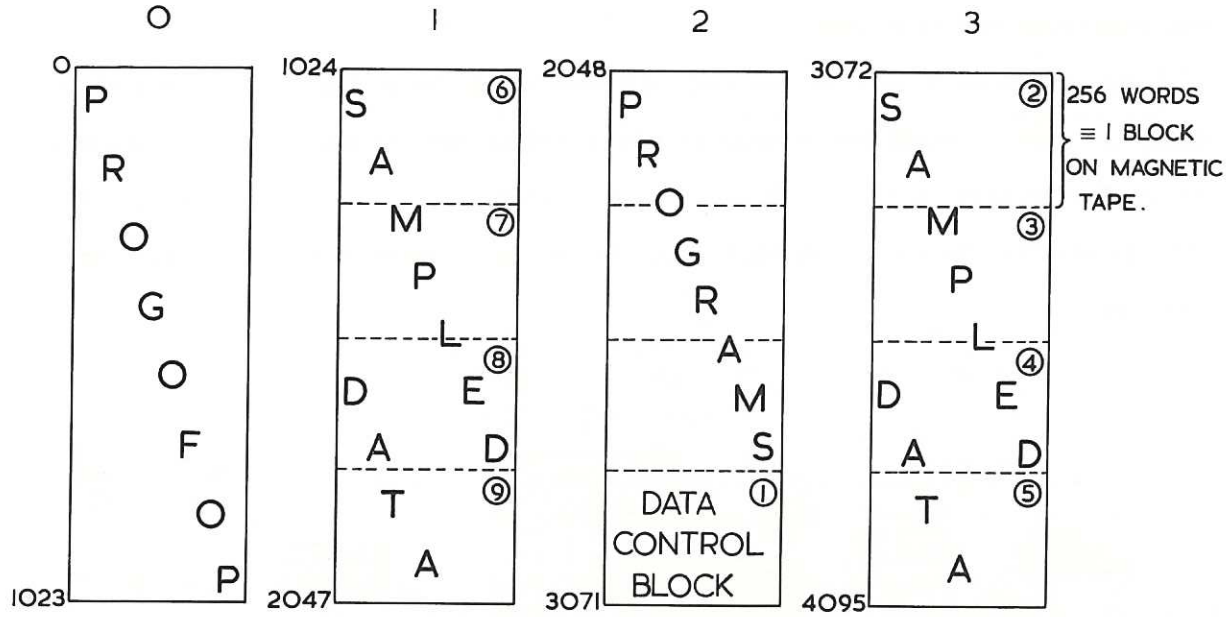

Fig.4 Layout of core store in the LINC-8. The 4K of store is divided into 4 memory banks numbered 0-3 the range of addresses for each bank being shown on the left. The circled numbers show the order in which the data is filed on magnetic tape (see also Fig.A.1). CLM-R 104

The layout of the systems and data tapes is described fully in Appendix 1. The systems tape is always mounted on tape unit 0, and the other tape unit, unit 1, is reserved for data storage.

The data sampling is governed by the data control block (SMPLDATA). This is one block of information 256 words in length which is compiled by INITIAL during the initialise phase and is loaded into the last 256 locations of the program section of memory when sampling is required. This block contains all the information relating to the sampling requirements of the user including the experiment or pulse identification, which input channels are to be sampled, in what order and, for each channel, the time at which sampling is to begin, number of samples required, and the time interval between samples. Also entered in this control block is the memory allocation for each set of samples as determined by INITIAL on completion of initialisation. This data control block is the first of the 9 data blocks saved on the tape and, in our application, the results of analyses performed immediately after a sample run are also saved in this control block on the data tape. The remaining 8 blocks contain the 2K words of experimental data.

It has been necessary to make modifications to the CAST (Create A System Tape) program provided by DEC so that, if a new systems tape is generated, both the LAP6 programming system and the data acquisition system software will be copied. Their system loaders have also been modified slightly so that as well as loading the operating system (PROGOFOP), the control and routing program (CONTROL) is loaded and started automatically. Finally a modification to PROGOFOP to load the sampling program on receipt of an interrupt from the experiment was necessary.

The operation of each of the programs comprising the system is described separately under the name by which the program is identified in the system. Where reference is made to another program, the system name of that program will be given in brackets. An overall flow diagram of the system software is given in Fig.5, which shows the linking between programs.

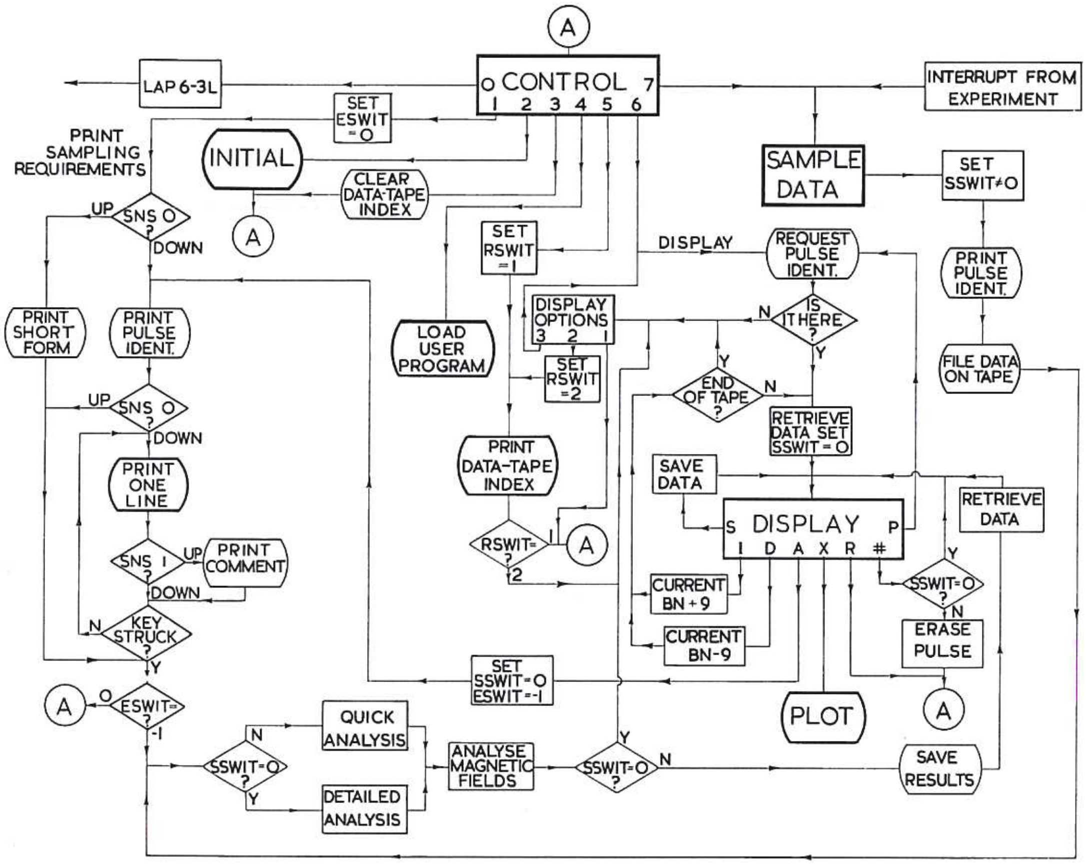

Fig.5 Flow diagram of the system software. Software switches ESWIT, RSWIT and SSWIT are set by programs as clues and are used by other programs to determine subsequent routing. Using similar clues some of these programs can be entered from LAP6 and will return control to LAP6 but generally it is inadvisable to do this. (BN = Block Number). CLM-R104

A basic limitation of this system is the maximum sampling rate of 5 kHz on any one channel; this arises because of the general nature of the software which allows users complete flexibility and is not a basic hardware limitation of the LINC-8 itself. Also, for samples requested at identical times on channels adjacent in the sampling sequence, a delay of 85 μsecs exists and this time is not dependent on whether the next channel in the sequence is to be sampled or not. Therefore the time delay between channels which are separated by n channels in the sampling order is a constant n x 85 μs.

4. SYSTEM PROGRAMS

This section describes the operation of each of the programs included in the system. As can be seen from Fig.5, entry to any program in the suite is possible from CONTROL.

4.1 CONTROL

This program maintains overall control of the system in general and allows the user to select any of the facilities provided. Some of the facilities are incorporated into this program and because of this there is no reference to other system programs under certain options. All options are selected by typing the appropriate number followed by carriage return.

8 options are provided, and these are as follows:-

0. RETURN TO LAP6.

This option allows a user to exit from the sampling system into the LAP6 programming system provided by the manufacturer and use those facilities for writing, assembling, and running programs on the LINC-8. Its use is fully described in the manuals provided by the manufacturer and therefore no further description will be included here.

1. PRINT SAMPLING DATA

It is possible, using this option (SAMPRINT), to print out on the teletype the contents of the current version of the data control block which exists on the systems tapes. This consists of the user's sampling requirements last set up under option 2.

2. INITIALISE

This option (INITIAL) enables a user to set up or amend the data control block on the systems tape. The user's sampling requirements are entered and saved on the systems tape for use during the next execution of the sampling program (SAMPLE).

3 CLEAR DATA TAPE INDEX BLOCK

It is necessary before using a new data-tape to first 'CLEAR' the index on that tape, i.e. the format of the index must be correctly laid-out in order for subsequent filing to be successful. This option also enables a tape identifier of up to 8 alphanumeric characters to be entered in the index for output when printing an index (TPNDXPNT). In order to provide some protection against accidental overwriting of the index on a partly full tape, and the subsequent loss of experimental data previously filed on that tape this option is executed in two stages. When first chosen the system responds with the query 'ARE YOU SURE?' and only on receiving confirmation is the index cleared; any other response results in a return to CONTROL. In the event of a complete breakdown in communications between user and machine resulting in the overwriting of an index another program (HELP) which may be loaded under option 4 is provided. This program will search the tape for data control blocks and regenerate the index on the tape.

4. LOAD USER PROGRAM

In order to improve the overall flexibility of the system this option (USERPROG) has been included to allow users to load programs external to the sampling system by name. These may be programs written and filed by users in the LAP6 programming system for the purpose of data manipulation etc. or they may be existing programs provided by the manufacturer. For example (GRAPHA) a graph assembling program provided by DEC which enables a user to assemble a graph with axes, scales, labels and titles.

5. PRINT DATA TAPE INDEX

This option (TPNDXPNT) enables the user to print out the contents of the data-tape index on the on-line teletype.

6. DISPLAY

This option enters the display mode (DISPLAY) which is one of the two stable states of the system the other being CONTROL. All other programs in the system are purely transitional, program control being ultimately returned to DISPLAY or CONTROL after execution. The purpose of this option is to enable the user to request retrieval and display of data filed on the data-tape. Retrieval is be means of the pulse identifier which is specified by the user.

7. SAMPLE

This option allows the user to load the sampling program (SAMPLE) and subsequently to take a set of samples defined by the data control block. In the application described here interrupt hadrware is used to load the sampling program automatically when the experiment requires servicing; thus there is no need for this option under normal conditions. It is, however, included to keep the system as complete as possible and also as a back-up should the interrupt hardware fail.

4.2 SAMPRNT

This program is used to print out the data set up by the initialisation program (INITIAL) on the on-line teletype.

Printing takes place in one of two modes.

(a) All the data is printed in tabular form with pulse number and headings.

(b) Only data requested by the user is printed in a compressed form. In this mode it is possible to check amended data quickly.

The mode used is determined on entry to the program by the position of Sense Switch 0, down for mode (a) up for mode (b). Examples of the output are given in Figures 6(a) and (b) where responses by the user are underlined.

```
   PULSE NUMBER  PH8028

TIMER PULSES EVERY     5 MS

SAMPLING      ST. TIME     NO. OF       SAMPLE
ORDER         X 10MS       SAMPLES      INTERVAL
   22          L  3          103            5  /THIS COMMENT WAS TYPED BY
    6          L  3          103            5  /LIFTING SENSE SWITCH 1.
   21           150          100           20  /
    6           150          100           20  /IN THIS MODE EVERYTHING
    7           150          100           20  /TYPED ON THE KEYBOARD
   22           150          100           20  /AT THE END OF THE CURRENT
    9           150          100           20  /LINE, AND TERMINATED WITH
   10           150          100           20  /A CARRIAGE RETURN IS
   11           150          100           20  /PRINTED.
   12           150          100           20
   13           150          100           20
   14           150          100           20
   15           150          100           20
   16           150          100           20
   17           150          100           20
   18           150          100           20
   19           150          100           20
    8           250          100            5
   23             0           79          100
   24             0           79          100
```

```
PRINT DATA
FROM?6
TO? 22
    6  L  3     103      5
   21   150     100     20
    6   150     100     20
    7   150     100     20
   22   150     100     20
```

Fig.6 Print out of the sampling data. Responses by the user are underlined. (a) full print out. (b) selected and compressed print out obtained with Sense Switch 0 up. CLM-R104

In mode (a) a facility to enable comments to be typed on the print-out is made available by lifting Sense Switch 1. Printing halts at the end of the current line to allow any comment to be typed. Upon receipt of a 'Return' printing continues and, if Sense Switch 1 is left up, will halt at the end of the next line. This has no effect in mode (b). Print-out in mode (a) may be abandoned by typing 'Return' at any time and the program will return to CONTROL as it would have done on completion of the print-out.

4.3 INITIAL

This program allows the user to record and amend his sampling requirements and is described in detail in Appendix 2. Extensive use of the 'question and answer' technique is made to request pulse or experiment identifier, frequency of timer pulses, duration of experiment, the order in which the analogue channels are to be sampled and, for each channel, the start time, number of samples and interval between samples. An amendment facility is provided in the sense that if no entry is made to a prompt the program assigns previously held values to the requested parameter. Also if the sampling order is changed then the old parameters pertaining to each channel remain associated with that channel unless the channel has been specified more than once (which is quite permissible). Facilities for stepping forwards or backwards through the prompt sequence are provided and it is possible to exit from the program at any stage with unamended data unchanged.

The program checks the entries as they are made for obvious errors and also checks that the total number of samples requested does not exceed the storage available (2K). On successful completion of inialisation the program allocates storage addresses, compiles the data control block and stores it on the systems tape before returning to CONTROL.

4.4 USERPROG

This program provides the user with a means of specifying, by name, a programme filed in the LAP6 system. It uses the LAP6 index on the systems tape to locate the named program, determine its length and, providing the required program is itself short enough to be loaded into core without disturbing the data residing there, USERPROG loads it and starts it in a manner identical to the LAP6 system, with the data in store completely intact. This allows the user to add manipulative tools with which he can operate on data already stored in memory and has been found very useful.

4.5 TPNDXPNT

This program enables the user to print out the data-tape index. When the program is entered sufficient paper is ejected from the teletype to enable any previous output to be removed; the program then waits for a key to be struck before continuing. The index is printed in 4 columns across the teletype, only columns containing information are printed, Sense switches 1-4 control the printing of the columns and lifting the appropriate switch suppresses printing in that column; all other columns are left adjusted. In this way a user may quickly search an index for a given identifier.

The information typed out is in the form of an experiment or pulse identifier and a block number indicating the location of the first block of that set on the tape. The listing may be terminated at any time by typing 'Return'. An example of the printout of a tape index showing the use of the sense switches is given in Fig.7.

```
TAPE INDEX        TAPE  PII ED7A
IDENT.   BN       IDENT.   BN
PH7972   006      PH8004   446
PH7973   017      PH8005   457
PH7974   030      PH8006   470
PH7975   041      PH8007   501
PH7976   052      PH8008   512
PH7977   063                         <---SENSE SWITCH 2 LIFTED
PH7978   074
PH7979   105
PH7980   116
PH7981   127      PH8013   567       <---SENSE SWITCH 2 LOWERED
PH7982   140      PH8014   600
PH7983   151      PH8015   611
PH7984   162      PH8016   622
PH7985   173      PH8017   633
PH8018   644                         <---SENSE SWITCH 1 LIFTED
PH8019   655
PH8020   666
PH8021   677
PH7990   250      PH8022   710       <---SENSE SWITCH 1 LOWERED
PH7991   261      PH8023   721
PH7992   272      PH8024   732
PH7993   303      PH8025   743
PH7994   314      PH8026   754
PH7995   325      PH8027   765
PH7996   336
PH7997   347
PH7998   360
PH7999   371
PH8000   402
PH8001   413
PH8002   424
PH8003   435
```

Fig.7 Print out of a full data tape index showing the effect of Sense Switches in suppressing the printing in the appropriate column. The block numbers are in octal.

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4.6 <u>SAMPLE</u>

This program performs the sampling function of the system. Controlled by the contents of the data control block this program accepts timer pulses via external sense line 0. These pulses are generated by the main sequence timer of the experimental configuration (see Fig.3). Using this method of timing ensures synchronisation with the timing of experimental apparatus. One second prior to the initiation of these pulses, another pulse is fed to the computer to initiate the measurement of amplifier zeros. This measurement is made by summing 64 samples on each of the input channels, the samples being taken over a multiple of 20 ms to eliminate 50 Hz ripple. The average value of the level on each channel is then determined, and automatically subtracted from the data taken during the main sampling sequence. The complement of this zero error is stored as the first piece of data on each channel.

On completion of the main sampling sequence, as determined by the total time entered in the data control block, the program examines the index on the data-tape to determine the next available block to store the data just sampled. At this point a check is made and if it is found that the present set of data will fill the tape the users attention is drawn to this fact by a continuous ringing of the teletype bell. The precise sequence of events when this happens is described in Appendix 3.

Having saved the data on tape, the program temporarily stores sets of data on the systems tape (DATASAVE) for immediate analysis (CALCBLCK, FLDCAL). This analysis is a standard analysis which is always performed following a sampling run and, in our application consists of calculating plasma density, plasma decay time constants, peak values of magnetic fields, and a magnetic field shape parameter. These results are entered in the data control block and stored with the relevant data on the data tape. The analysis routines in other applications would be written by users to perform analysis appropriate to their requirements.

Following the analysis the data just sampled is reloaded into core and entry is made into the DISPLAY program.

4.7 <u>DISPLAY</u>

This program enables the user to examine the data collected either during the last pulse or, if required, from some previous pulse, by specifying the appropriate pulse identifier.

The data is displayed as a plot of amplitude against time in either of two modes with the number of the analogue channel to which the trace corresponds on the left of the screen. In the normal display mode the information collected during the pulse on each channel is displayed in the form of an oscilloscope trace, (see Fig.8), information from each channel forming one trace. A limited autoscaling facility exists enabling 64, 128, or 256 samples to fullscale in the horizontal direction. Larger numbers of samples cannot be displayed conveniently. The channels are displayed in the order in which they are entered in the sampling sequence in the data control block and 1, 2 or 4 channels may be displayed per frame. If more than one channel is being displayed per frame the vertical deflection is scaled down appropriately. The user can leaf forwards or backwards through the channels and in this way all the data may be examined quickly. It may sometimes be necessary to compare data on two or more channels which do not appear on the same frame. To do this the second operating mode called 'List' mode is provided. In this mode the user enters the channels in which he is interested and these are displayed together on the same frame, again with autoscaling. The commands to achieve this are given in Appendix 4.

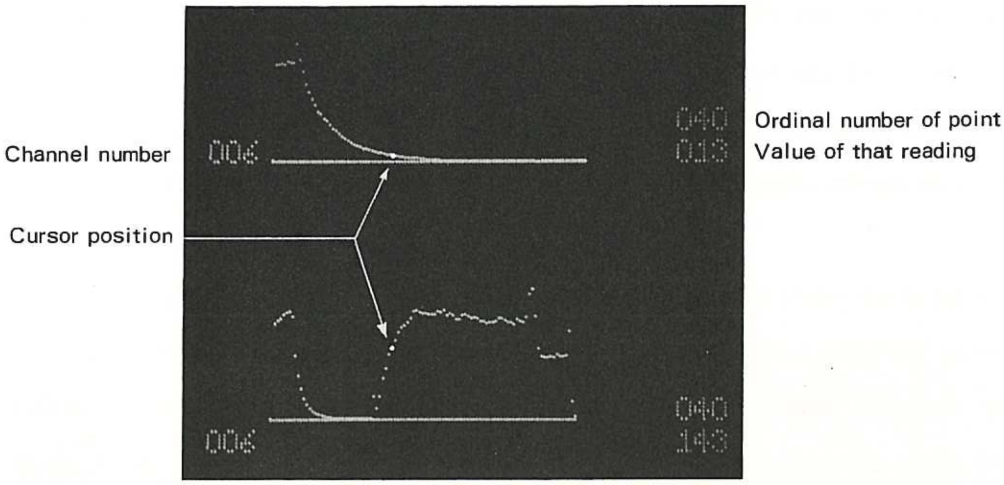

Fig.8 Typical output from the DISPLAY program showing readings from the same channel taken at different sampling frequencies. The figure illustrates the use of the cursor in obtaining values of readings pointed to by the cursor.
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In either mode a cursor is provided. This takes the form of a bright spot which may be moved to and fro along the displayed traces and is controlled by potentiometer KNOB 0. Two numbers which correspond to the x and y values of the cursor, are displayed on the right hand side of each trace. The cursor is displayed simultaneously on all traces and it is thus possible to make rapid measurements of data and also to correlate these measurements on different data channels very quickly and with an accuracy of better than 1%.

Other facilities provided in the DISPLAY program enable the user to save data from specifiable channels in specifiable locations on magnetic tape, to perform standard analyses on the data, to change the data being displayed for data from another pulse, to erase newly gathered data or to exit from the program either to CONTROL or to one special user program. This last option is extremely useful for going directly to a frequently used user program and in our case this is PLOT which is described later.

5. AUXILIARY SYSTEMS PROGRAMS

This section describes two data manipulation programs which are of general use and a utility program which enables some editing of the data tape as well as the salvaging of data tape should it ever be corrupted. The two data manipulation programs PLOT and MEANRAT are dealt with first. PLOT enables user to display the data from a selected channel as a plot against that from another channel; MEANRAT prints out the average values of a specifiable number of consecutive readings in two regions of one channel and also the ratio of those averages.

5.1 PLOT

This is a program which either stands on its own or can be used in conjunction with DISPLAY and its purpose is to display one set of sampled data against another from the same experiment. In our case when the program is entered from DISPLAY by typing 'X' (Appendix 4) it detects that this has been done, types out the pulse number and requests the channels to be used as x and y coordinates. Entry in any other way will result in a request for a pulse or experiment identifier and the appropriate data is then retrieved via the index as usual.

The display is controlled not only from the teletype keyboard but also from the computer console switches which can only input a limited amount of information. However the use of the switches enable one to alter the scale factor for the data, to select which points are to be displayed, and to choose whether to incorporate the point (0,0) on the display. A detailed description of PLOT is given in Appendix 5. The display can be moved anywhere on the oscilloscope screen by means of two KNOBS designated to do the x and y shift functions.

Teletype commands allow the user to smooth the data according to the formula.

$$(V_{n-1} + 2V_n + V_{n+1})/4$$

and to restore the original data. The existing display can be replaced with one using data from a previous or succeeding experiment so that similar plots obtained from different experiments can be viewed in quick succession or, as has been done frequently, photographically superimposed on each other.

Four exits from this program are provided. Two of these - to CONTROL and to LAP6 - are ordinary exits but the other two take the user back to either DISPLAY or on to a DEC programme called GRAPHA which amongst other things allows labelling and formatting of graphs. Figure 1 was produced by superposition of such a format on a display obtained in PLOT. GRAPHA itself has been slightly modified so that the user can return from these directly to PLOT. The direct communication between DISPLAY, PLOT and GRAPHA has proved very useful.

Regrettably limitations in the amount of memory available make this program rather less elegant than desirable. It would have been preferable if the use of the console switches could have been avoided and replaced by a more flexible system of control whereby the scaling factors etc. could have been nominated in decimal numbers rather than in octal. Another useful addition would have been a cursor so that values could be read from the display.

5.2 MEANRAT

This program was written for a specific requirement but because it is basically general and capable of extension to operate in a much more sophisticated way it is included here and possible extensions are discussed in Section 7.

The basic program as it exists now, allows the user to nominate an experiment identifier and a channel number. The next request is for the first point and number of points to be used as 'Region A' and similarly for 'Region B'. The program then calculates the average reading in each region and the ratio of the two averages and prints these out.

5.3 HELP

This program was written to enable users to compile an index for the data tape. This is necessary if data has been transferred to a tape with no index or if the index on the data tape has been corrupted. Loss of the index could occur in a number of ways, by incorrect use of the 'clear data tape index' option (see CONTROL), by a malfunction of a user program, by mistakes on the part of the user when using the save option (see DISPLAY) or by a system hardware malfunction. Only the first of these possibilities has necessitated the use of HELP to date.

The program first of all asks the user if RELOCATION is required. If the index has been corrupted the answer to this question should be NO. The program will then read the whole of the data tape, recognising data control blocks, and generating the appropriate information in a new index. On completion the new index is written into blocks 0 and 1, and a tape identifier, which is to be inserted in the index, is requested.

The RELOCATION facility enables a user who has been compiling his own dapa tape containing only data of particular interest to him to have the new location of the data entered in the appropriate control blocks. This enables the user to have all the system facilities on his newly compiled tape because some of the facilities require the tape location of the data currently in memory to be accessible to the program. This is so for instance in the 'D' and 'I' commands in DISPLAY and PLOT and is necessary for storing the results of analyses in the appropriate control block.

6. ANALYSIS PROGRAMS

These are specialised programs which have been written to perform some standard calcalations required for each pulse on PHOENIX II and are called automatically by SAMPLE when all data has been filed. They can also be called from DISPLAY by the command 'A'.

The main results required include plasma density, decay time constant, magnetic field strength and maximum depth of the magnetic well.

The energetic protons are lost from the plasma by charge exchange with the background gas (neutral emission), as well as by any other loss processes that may be present and, consequently, when the injected neutral beam is switched off the plasma decays with a characteristic time constant depending on the pressure of the background gas. Decay times of interest are in the range 30 - 300 ms. The density of the plasma is the product of the neutral emission and the effective time constant multiplied by a calibration factor. The magnetic field is such that the field strength increases in all directions from the centre (magnetic well) and is characterised by the magnetic field strength at the centre and a ratio of currents which is a measure of the depth of the magnetic well. A typical print out for a pulse is given in Fig.9.

```
PULSE PH8024
   CHANNEL 22
        DENSITY =     7.182     FAST DROP =       .378
        TAU-EFF =    60.540      TAU-LONG =    159.918
   CHANNEL  6
        DENSITY =    49.092     FAST DROP =       .593
        TAU-EFF =    87.426      TAU-LONG =    147.195
    PK. MIRROR = 12.656KG       CR [PK.IOFFE]=    1.564
```

Fig.9 Typical print out of analysis after a pulse. The time constants TAU-EFF and TAU-LONG are in milliseconds and the calculated density is in volt-milliseconds and therefore the actual density depends on the detector used. The magnetic field is in kilogauss.

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6.1 CALCBLCK

In order to measure plasma density and plasma decay time constants the injected neutral beam is switched off for a period of about 0.5 sec. During this time the plasma decays and the neutral emission from it is measured using photomultiplier scintillator combinations and also an ion current along the magnetic field lines. Assuming an exponential decay with a time constant τ the density is $V_0 \tau$ where V_0 is the initial value. These signals are fed into the computer. Data samples are taken every 5 ms when -5 volts is applied to an external sense line specified in INITIAL. This voltage is generated by special hardware and is so arranged that a 40 ms long pulse is applied prior to beam switch off, allowing 8 samples to be taken on each channel specified. The hardware then monitors the beam until switch-off is sensed and at this time reapplies the -5 V level to the sense line. This enables the rest of the data samples to be taken during the plasma decay. It should be mentioned here that SAMPLE is performing all its other alloted tasks concurrently with that described here.

The following analysis which is performed by CALCBLCK on the data is described here for only one channel though it can be performed on the data sets for up to 5 different channels, these channels having at some time been specified to the system by entering the program TAU and responding to its requests for channel numbers. Immediately following an experimental pulse the data for each of the specified channels, whose start time was specified as an external level, is saved in a temporary area on the systems tape (TAUDATA) by a short utility routine (DATASAVE) and CALCBLCK subsequently uses these data sets for analysis.

CALCBLCK first of all calculates the mean of the first 8 samples prior to beam switch off (<PM>) and then integrates under the decay. This area is proportional to density provided the signal has fallen to zero; however, owing to the finite time for which the decay is measured, this is not always the case and it is necessary for a correction to be made.

To do this the computer calculates $\bar{R} = (\sum_{n=10}^{n=80} (V_n/V_{n+10})/70$ and then, assuming the decay to be of the form $V = V_0 e^{-t/\tau}$, τ is calculated from the relationship $\tau = 50/\ln \bar{R}$. The variance of the ratio is also calculated as a check on the possible errors involved. This value is denoted by TAU-LONG and the correction to the integral is made by multiplying the average of the last 20 readings by TAU-LONG and adding this to the area under the measured portion of the decay.

In certain circumstances when the input neutral beam is turned off the plasma is observed to decay very rapidly initially with a short time constant and subsequently to decay with a much longer time constant. Thus a useful parameter to know is an effective time constant TAU-EFF, and a ratio TAU-EFF/TAU-LONG. TAU-EFF is defined as Density/<PM>. The ratio TAU-EFF/TAU-LONG, designated as 'FAST DROP', is an indication of how far the decay deviates from a true one-component exponential form.

During the calculation certain problems arise such as dividing by zero and relatively unsophisticated methods of dealing with the situation are used by the program. If such an instance occurs the print-out contains a message that an error may have occurred. The detailed analysis resulting from the command 'A' in DISPLAY will give statistics of the occurrence of each of the possible errors catered for by the program.

6.2 FLDCAL

The magnetic field of PHOENIX II is generated by superimposing fields generated by two separate coil systems. The first of these takes the form of a magnetic mirror (MIRROR FIELD), while the second takes the form of a cusp shaped field generated essentially by currents flowing in four conductors placed parallel to the axis of the mirror system around the containment vessel (IOFFE FIELD). Signals indicating the magnitude of the currents flowing in these two coil systems are fed into channels 23 and 24 in the computer.

FLDCAL finds the maximum values of both the mirror field and Ioffe field and determines whether the mirror field at the time that the Ioffe field was maximum was within a few percent of the peak mirror field. If this was so then the mirror field and compensation ratio (CR) are calculated, using calibration factors previously stored in FLDCAL, and printed out. If the peak mirror field does not coincide closely enough with the peak Ioffe field then the peak mirror field as well as the mirror field and compensation ratio at peak Ioffe fields are printed out. Checks are made for the presence of a signal in both cases and if no signal has been recorded the appropriate diagnostic message is printed.

Calibrated factors are specified by entering FLDCAL either from USERPROG or LAP-6 and responding to prompts on the teletype. This leaves a printed record of the constants held by FLDCAL.

7. POSSIBLE DEVELOPMENTS

As far as the main systems programs are concerned the limit of what can be done with the 1K of memory set aside for programs is already being reached. However, there is still scope, even within the memory limitations, for improvements to some of the systems programs especially in INITIAL where a rewrite of that program could be undertaken with better editing facilities in mind. The biggest improvement in the main system is unfortunately not possible without extra memory. Given extra memory one could easily add data manipulation facilities to DISPLAY to enable the user to select groups of data points and to operate on them by adding, multiplying, differentiating, integrating, filtering out high or low frequency fluctuations or other more ambitious processes.

Within the auxiliary systems programs there is much more scope for development in that more tools could be added. The adaption of existing Fourier analysis, correlation and curve fitting programs to locate the required data before operating on them would be a fairly simple matter. However, there is a paucity of programs which enable one to operate on one set of data with another. The simplest of these operations, apart from the plotting of one set against another, is normalisation and frequently one needs to know how a more complicated arithmetic combination of continuously measured quantities varies with time. It is envisaged therefore that a program will be written which will enable the user to specify sets of data from different channels, and, by specifying an algebraic expression, be able to carry out arithmetic operations on those sets point-for-point.

Another field in which programs are required is in collation of data. The beginnings of such a system have been laid by writing calculated quantities for each experiment in the data control block of the data from that experiment. The next stage will be to have a program to which the user can specify the range of experimental parameters of interest to him so that the computer will be able to search the data tapes and compile a new data tape containing only the data of interest. At this time the data from more than 3,000 experimental pulses is stored on magnetic tape and it is estimated that the computer should be able to execute a complete search of the data in about 30 minutes. Manually this task would take so long that it is doubtful if it would be attempted.

8. CONCLUSIONS

The system described in this report has now been in use on the PHOENIX II experiment for nearly two years and during this time it has been found to be a very valuable aid to the experimenters. Though the amount of assistance that can be given to the experimenter depends to some extent on the nature of the experiment, it is estimated that the process of organising new data into a presentable form has been speeded up by a factor of 5 or more. In addition, because data can be organised quickly, the experimenter can be guided in the course of his experiment by a better appreciation of results obtained so far; this is particularly valuable in pulsed experiments.

Apart from the fact that the data exists in digital form and therefore lends itself to automatic manipulation, the biggest contribution to the effectiveness of this system has been made by the visual display which enabled rapid communication between the computer and experimenter by allowing the human being to use his unique talent for pattern recognition. The existence of magnetic tapes in the system has also contributed to rapid communication by enabling the presentation of fresh data to the experimenter within seconds. In any case for a small computer a fast access bulk storage system is necessary for storing programs (in our case the complete suite of programs runs to more than 10 K words and runs in a core store area of 1K words). It is essential therefore for any data acquisition and processing system to have both a visual display and access to a reasonably fast bulk store.

It has been found that the most valuable part of a small computer can play in a physics experiment is in the assembly and handling of data in a simple form. For short term problems it is not profitable to write and debug complicated analysis routines of restricted application. In this case, for speed, efficiency and flexibility numerical values of the raw data are read from the visual display and dealt with by slide rule and graph paper.

Although there is still some scope for developing the data taking and analysis software described here, the limit of what can be done with the restricted memory available for programs is being reached and further significant development could only be undertaken by restricting the amount of data handled per experiment or by increasing the total amount of core store.

Two programs not mentioned previously are TAUCALC and TAUCNTRL which are effectively duplicates of the CALCBLCK and CONTCALC programs. The results from TAUCALC are the rather more detailed ones generated by the 'A' option in the DISPLAY program.

The layout of the system programs is arranged to minimise the amount of tape movement necessary during normal operation.

A.1.2 DATA-TAPE

The general layout of the data tape is shown in Fig.A1(b). Blocks 0 and 1 are dedicated to the index and data is stored beginning at block 6. This leaves 4 blocks, 2 to 5 inclusive, which may be used as temporary workspace by anyone using the system. The index blocks are laid out as follows:-

word 0 → 2 6 character pulse identifier (2 chars/word).

3 Block no. at which 1st block resides.

Four words are required for each entry on the tape; all other locations must be set to 7777_8 for correct operation with the exception of the last 4 locations in block 1 which contain an 8 character identifier for the data tape. The purpose of option (CLEAR DATA TAPE INDEX) in the control program is to set up the index in this standard format and enter the tape identifier for the user.

The sampling system normally stores 9 blocks of data for each pulse and this means that 1 data tape of 512 blocks can contain a maximum of 56 data sets. Under these conditions one index block would have been adequate. A second index block has been provided because provision has been made in the programs for a user to reduce the number of blocks stored per pulse by changing certain constants while still allowing the system facilities to be used. The interested user is referred to the detailed listings(2) of SAMPLE and PSDSPLY where the constants to be changed are indicated.

APPENDIX 2

INITIAL

This program is used to record and amend sampling requirements in accordance with the user's needs. The sequence of prompts which appear on the oscilloscope are as follows:-

(a) INITIALISATION	'Return' for next prompt.
(b) PULSE NUMBER XXXXXX	The current pulse number (XXXXXX) may be changed by typing in a new number followed by 'Return'. The next set of data will be filed under this number plus one, unless Sense Switch 5 is up. (See SAMPLE).
(c) TIMER PULSES EVERY ?? mS	Enter the interval between timer pulses being fed into the computer for sampling purposes. These are external to the computer and come from the timer through hardware which in our case gives timing signals every 1, 2 or 5 ms.
(d) TOTAL TIME ???? x 10 mS	Enter the total time in tens of milliseconds over which sampling is expected to take place during a pulse. After this time sampling ceases even if all samples have not been taken.
(e) SAMPLING ORDER ??	Enter the channel numbers in the order in which they are to be sampled, each one terminated by a 'Return'. When the sampling order is complete, type 'Return' with nothing entered to proceed to the next prompt.
(f) CHANNEL NO. XX	This indicates the channel number (XX) for which the following data will be accepted. Type 'Return' for next prompt.
(g) START TIME ???? X 10 mS	Enter the time in tens of milliseconds at which sampling is to begin on the above channel. It is possible to begin sampling on application of a -5 V level to one of the external sense lines. In this case enter Ln

where n is the number of the external line used. Sampling only takes place while the -5 V level is applied.

(h) NO. OF SAMPLES ????

Enter the number of samples required on the above channel. Any number of samples may be entered, providing the amount of available core is not exceeded (2047). However DISPLAY which contains auto scaling facilities cannot scale more than 256 samples, thus if more this are requested the corresponding display will tend to wrap itself around the oscilloscope screen. If more than 256 samples are required a convenient way of achieving this would be to enter the channel number (say) twice in the sampling sequence and request 256 samples on each with the same interval between samples but arrange to start sampling on the second entry when 256 samples have been taken on the first. This method gives 512 successive samples on the same channel, but they will be displayed in a convenient form by DISPLAY. This can be done for up to 9 entries of the same channel number in the sequence.

(i) SAMPLE INTERVAL ???? mS

Enter the time interval between samples on the above channel.

The prompt sequence now returns to (f) with the next channel number in the sampling order displayed. Normal exit from the sequence occurs when all channels entered have been initialised. Exit from the sequence may be forced, by typing /(slash) in response to any prompt but data entered since the last 'Return' will not be accepted.

The maximum rate at which samples may be taken is determined by the number of entries in the sampling order. The limitations are as follows:-

At 1 ms intervals no more than 5 entries allowed.

At 2 ms intervals no more than 10 entries allowed.

At 5 ms intervals no more than 25 entries allowed.

The program checks the entries to each prompt on input, and if any errors are found the following messages are displayed:-

NO. > 2047	The maximum number which can be accepted is 2047. Type 'Return' to re-enter the sequence at the prompt which was in error.
NOT BETWEEN 1 AND 24 INC.	This error occurs if the channel number entered in response to prompt (e) did not lie between 1 and 24 inclusive. Type 'Return' to re-enter the sequence as above.

At the completion of initialisation the program allocates storage and if the number of samples requested exceeds the core allocation the following is displayed.

NOT ENOUGH ROOM	The amount of room available for data storage is 2047 samples. If the TOTAL number of samples requested exceeds this then storage cannot be allocated. Typing 'Return' re-enters the prompt sequence at (e) allowing the sampling order to be shortened or the number of samples on the various inputs to be amended.

On successful completion the INITIAL program compiles the data control block, stores it on the systems tape (SMPLDATA) for use in the next sampling sequence and returns to CONTROL.

Limited facilities exist for editing the SMPLDATA block. When the initialisation program is called, it puts the existing version of the SMPLDATA block into memory and overwrites this as the user enters his requirements. However:-

(a) Typing 'Return' to any prompt with nothing entered proceeds to the next prompt in sequence leaving the existing data UNALTERED.

(b) Typing 'Rubout' with nothing entered steps back to the previous prompt again leaving the data UNALTERED.

(c) Typing /(slash) causes unconditional exit from the prompt sequence with all remaining data UNALTERED. Any amendment must be accepted by typing 'Return' first.

(d) If the sampling order is changed then the old parameters pertaining to each channel remain associated with that channel except if one channel has been specified more than once. In that case the data for all except the first entry of that channel number in the sampling order must be re-initialised.

e.g.

Previous Sampling Order	New Sampling Order
22	22
15	17
17	22 REINITIALISE
21	15
22	21
6	15 REINITIALISE
22	6
15	22 REINITIALISE

In this way amendments to the data are fairly easily made though the arrangements are not ideal.

APPENDIX 3

WHEN THE TELETYPE BELL RINGS

If the sample program finds that the set of data it is about to file on the data tape will fill the tape, or that the tape is already full, it causes the teletype bell to ring continuously. In the former case the warning that a new data tape will be needed having been given, the storage of data and all subsequent action will continue normally when any key on the teletype is struck. In the latter case there is no room to file data on the data tape and this time on striking any key the user is presented with the following list of options printed on this teletype:-

```
DATA-TAPE FULL
TYPE:-
  C - CLEAR DATA TAPE INDEX
  S - SAVE DATA
  A - JUST ANALYSE
```

At this point the user may clear the index of an old data tape and proceed to save the data etc., or if a clear data tape is mounted option S alows him to save the data on this tape and proceed normally. Failing everything, the user may accept the loss of the data but he can still obtain analysis and display of the data with option A.

APPENDIX 5

PLOT

On entry to PLOT the program requests an experiment identifier and then fetches the corresponding data. The program then requests the channel to be used for the x co-ordinate followed by that for the y co-ordinate and then displays the appropriate plot. If the program is entered from DISPLAY it is assumed that the data is already im memory and the program starts by requesting channel numbers. If either the channel number or identifier cannot be found then 'NO' is displayed and a carriage return will resume the program at the previous prompt. The number of samples in the chosen channels is compared and if they are not equal the computer halts as an indication that something may be amiss. Lifting the 'Resume' switch will allow the program to continue with the given data.

The display can be controlled by the use of the console switches and KNOBS as follows:

LEFT SWITCHES Bits 0-8 are used to define the octal number of points to be displayed.
Bits 9-11 are used for scaling the x co-ordinate by powers of 2.

RIGHT SWITCHES Bits 3-11 are used to define the ordinal number (in octal) of the first point to be displayed out of the whole sequence in the channel.
Bits 0-2 are used for scaling the y co-ordinate by powers of 2.

SENSE SWITCH 1 if this is up the KNOBS (see below) become inoperative.

SENSE SWITCH 0 if this is up to the (artificial) point (0,0) is not displayed otherwise the point (0,0) is normally the brightest point in the display.

KNOB 0 acts as an x shift.

KNOB 2 acts as a y shift.

By striking the appropriate key the display can be controlled from the keyboard in the following manner.

S enters the routine for smoothing the data according to $(V_{n-1} + 2V_n + V_{n+1})/4$. The display will disappear until either 'X' or 'Y' is typed when the display reappears with the smoothing applied to the appropriate data.

R restores the original data by reading it afresh from the magnetic tape.

I gets the data from the next pulse and operates in the same way as it does in DISPLAY (see Appendix 4).

D gets the data from the previous pulse (again see Appendix 4).

P returns control to DISPLAY with the data intact. Consequently if the data has been smoothed as above then the effect of this smoothing on the raw data can be seen.

G enters the DEC program GRAPHA. At this stage the data is generally corrupted. GRAPHA has been slightly modified to enable return to PLOT.

C returns to CONTROL.

L returns to LAP6.

Note. For convenience GRAPHA and PLOT are placed in contigous blocks on the systems tape (blocks $150\text{-}160_8$ and $161\text{-}163_8$ respectively). In this position, however, they are too far away from DISPLAY (see Appendix 1) but to place them closer would necessitate a fairly big re-organisation of the systems tape.

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2. Listings of programs in the Phoenix On Line Data Acquisition System may be obtained from the authors.

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