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Publication Date
1981-03-01

Peer reviewed

LBL-11709
CONF-810314--158

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Accelerator & Fusion Research Division

Presented at the IEEE 1981 Particle Accelerator Conference, Washington, D.C., March 11-13, 1981

MASTER

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March 1981

Prepared for the U.S. Department of Energy under Contract W-[illegible]

USE OF A SMALL OFF-LINE COMPUTER IN THE OPERATION OF A VERSATILE HEAVY-ION CYCLOTRON*

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Abstract

In a modern heavy ion cyclotron with variable energy and particle species, it is essential to provide the operations staff with fast and easy access to parameter information. At the Berkeley 88-Inch Cyclotron, which operates under manual control, an interactive computer program has been developed to meet this requirement. The program is written in BASIC on a small off-line computer to perform a variety of calculations for any ion species and energy. The program can provide the operator with cyclotron and beam line settings for any beam, regardless of whether or not the beam has been previously run, by utilizing the broad data base acquired over a decade of heavy ion operation. A number of additional calculations now being performed conveniently and routinely by the operations staff will be discussed. The use of this program has greatly streamlined the operation of the cyclotron because needed information can be obtained quickly and reliably.

Introduction

The acceleration of beams at the 88-Inch Cyclotron in the mass range 1 A 40 provides a continuously variable range of energies for well over 300 different stable ions. For any one of these ions, and for any given final energy, approximately 50 cyclotron parameters must be specified to tune out an external beam[1] and another 11 beam line parameters must be specified in order to deliver the beam to the target. In calendar year 1979, 435 beam tune-outs were required to meet the needs of the experimental program. In calendar year 1980, this number was 409. In order to provide an efficient data management system a series of computer programs has been written for the PET computer in the cyclotron control room. It serves as an off-line resource of information for both operations staff and users. This combination of programs has been consolidated into one program called MASTER, which makes possible many of the routine calculations required in the day-to-day operation of the cyclotron.

Computer Hardware

The PET system at the 88-Inch Cyclotron is shown in Fig 1. The PET model 2001 was purchased with 8K bytes of 8 bit RAM and 14K of ROM in which resides the BASIC operating system. An additional 24K of external memory is interfaced through an S100 bus (BETS1 board) to the external memory port of the PET. An IEEE/488-RS232 link permits access to the TI Silent 700 ASR printer. The CBM 2040 dual floppy disk drive was added to the system later and has now become indispensible. The audio cassette drive can still be used to load programs from cassettes, but it is very slow. An auxilliary keyboard was added and operates in parallel with the main keyboard.

General Description of Program MASTER

There are currently six basic options from which users of the program may choose. They are displayed

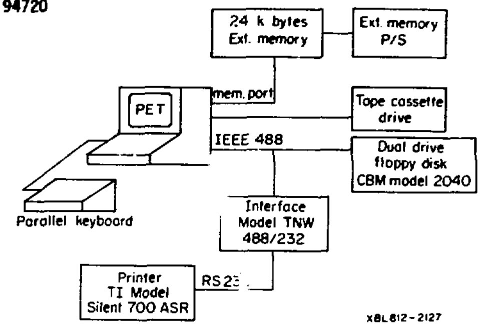

Fig. 1 - Schematic representation of computer hardware

on the PET screen as follows:

TYPE NUMBER OF DESIRED PROGRAM

1. BRHO	2. FREQUENCY
3. PRE RUN	4. ENERGY
5. RESONANCE TABLE	6. CYCLOTRON SETTINGS

The calculations which are performed in each of these six parts of the program are all based upon a mass table which includes the atomic masses of all stable isotopes from atomic number Z = 1 to 18. Certain long-lived isotopes (e.g. ^{14}C, ^{10}Be, and ^{36}Cl) are also included since they have been used to produce beams of interest in radioisotope dating[2]. The mass of ^{40}Ca is also included in the table as are several molecular ions and the stable isotopes of krypton.

The magnetic rigidity (BRHO), the frequency of the cyclotron RF system, and the beam energy are calculated when the user selects options 1, 2, and 4 respectively. The magnetic rigidity is calculated from the mass (mc^2), kinetic energy (E), and charge state (Q) from the expression

$$BRHO = \frac{1.3132653 \times (E^2 + 2mc^2E)^{1/2}}{Q} \text{ kG-inch} \quad (1)$$

where mc^2, the ionic rest mass, is given by

$$mc^2 = 931.478 \times A - 0.51106 \times Q \text{ MeV}$$

In this expression, A is the atomic rest mass in amu, and E is given in MeV. The frequency of the cyclotron RF system is given by

$$F = 48.6160 \times H [1 - (1 + E/mc^2)^{-2}]^{1/2} \text{ MHz} \quad (2)$$

where H is the harmonic number.

The value for the proportionality constant in Eq. (2) was determined at the 88-Inch Cyclotron by experimental measurement[3].

The beam energy can be calculated in any of three ways: from BRHO, from the frequency of the cyclotron RF system, or from the NMR frequency of the magnetic energy analysis system provided in magnet M41.[4]

Cyclotron Settings

For any requested beam within the operating

*This work was supported by the Director, Office of Energy Research, Division of Nucl. Physics of the Office of High Energy and Nucl. Physics, and Nucl. Sciences of the Basic Energy Sciences Program of the U.S. D.O.E. under Contract No. W-7405-ENG-48.

<u>Table 1</u>

Cyclotron settings for 140 MeV oxygen-16 4 +

Frequency = 6.6186 MHz (Res panels - D.V.M. = 24.04*)
Dee volts = 70 kV*
Main magnet current = 2419 Amps* (2390 - 2448)

Recommended trim coil solution

Trim Coil Settings

Coil	Amps	Index#	Soln#	FR	FS
		160.11	286	0	0
1	32				
2	-345				
3	0				
4	0				
5	0				
6	0				
7	0				
8	-142				
9	-147				
10	-393				
11	-578				
12	-478				
13	-907				
14	-1754				
15	-1599				
16	-2261				
17	2400				

<u>Valley Coils*</u>

Coil	1	2	3	4	5
Angle (DEG)	90	310	--	--	120
Amps	200	100	---	--	50

<u>Center Region</u>

RAD = 385
AZI = 20
ROT = 15
P N/S = 30*
P E/W = *

Deflector Positions	Deflector Volts*
1) 39.4	
2) .21	Entrance = 52.7 kV
3) 40.364	
4) .254	
5) 40.476	
6) .261	Middle = 62.4 kV
7) 42.921	
8) .496	
9) 43.57	
10) 1.25	Exit = 0 kV
11) 48.49	
12) 1.93	

*Optimize as required

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domain of the cyclotron, the program will generate a printout of cyclotron settings. A sample printout for a 140 MeV $^{16}O^{4+}$ beam is shown in Table 1. In the remainder of this section a brief description of the calculation for each parameter is presented.

In order to minimize charge-exchange losses during acceleration, the recommended <u>dee voltage</u> for most beams is 70 kV, close to the upper operational limit of the RF system. For beams of very low E/Q 7 MeV/Q, it is necessary to operate at reduced dee voltage to prevent orbit centering difficulties. In this case the program will scale down the recommended dee voltage to operate in a constant turn number mode.

The program estimates the required <u>main magnet</u> setting by an empircally determined relationship between coil current and BRHO, making a small correction for trim coil contributions. Using this approach the calculated main magnet current is generally within 1% of the experimentally determined value. A range of currents appears on the printout sheet as a guide to the operator.

The set of 17 <u>trim coil</u> currents to be used is determined by table look-up using an indexing system based on E/A and Q/A. Trim coil solutions for a total of 377 beams are stored on disk in a data file. For each of these beams the values for E/A and Q/A are stored in memory. In the example shown in Table 1, a trim coil solution for the requested beam was available directly from the disk. Beams for which trim coil solutions are (or will be) stored on disk are indicated in the resonance chart shown in Fig 2. If the requested beam has values of E/A and Q/A which do not coincide with one of the stored trim coil solutions, the program selects the nearest solution which can best provide the required field shape. The selection of the best trim coil solution is based on semi - empirical phase slip considerations discussed in ref 1. Figures of merit, FR and FS, are calculated by the program to provide a quantitative basis for selecting a trim coil solution. In Table 1, these quantities are both zero indicating the maximum level of confidence that the required field shape will be provided by the trim coil currents listed. A minimum level of confidence would be represented by FS = $\pm$ 1. The spacing of the 377 points on Fig 2, however, is adequate to ensure that <u>any</u> requested beam can be run from one of the corresponding trim coil solutions stored on disk. Experience to date has indicated that any solution recommended by the program with ABS(FS) 1 has a very high probability of providing an appropriate field shape.

The <u>valley (harmonic) coils</u>, the <u>center region</u> and the <u>deflector settings</u> are all determined by table look-up using previously developed settings appropriate to the requested beam. The value of E/Q for the requested beam is used to determine center region parameters and deflector positions, and to scale deflector voltages.

While in general a certain amount of fine tuning of the cyclotron parameters is required to optimize any given beam, the final tuned values are in very close agreement with the settings produced by the program.

<u>Resonance Table</u>

Another useful feature of the program MASTER is the production of a table of all beams with nearly identical resonant conditions to those of the requested beam. That is, a list of beams with similar values of HQ/A. The operator, when presented with such a list, can quickly utilize his judgement to decide which of these beams may be of concern.

<u>Beam Line Settings</u>

A table of 19 beam line settings for up to 11 parameters is stored in memory. This table contains all the required settings for a 104 MeV $^{16}O^{4+}$ beam. If option 3 is selected the program will printout the settings for any requested beam and beam line by scaling these settings appropriately.

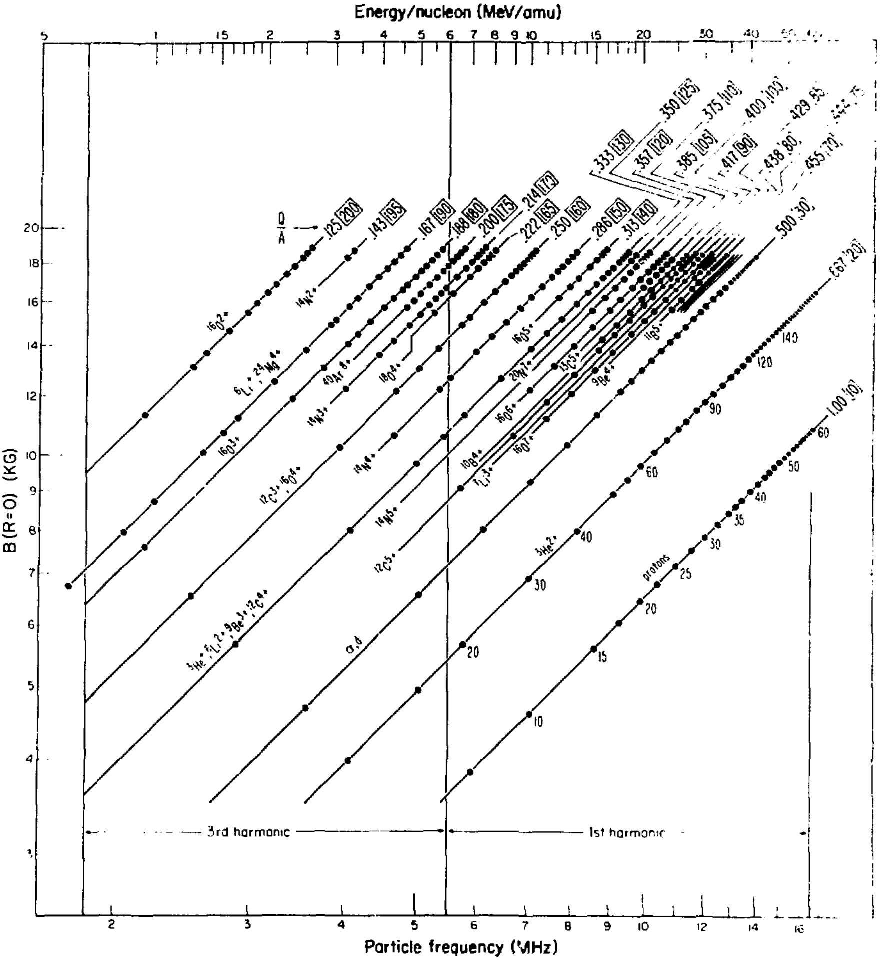

Fig. 2 - Resonance chart showing first and third harmonic beams for which trim coil solutions are required.

Conclusions

The program MASTER has been very effective in streamlining the operation of the cyclotron. It enables the operators to carry out their responsibilities with greater confidence and independence and has reduced the amount of time required for scheduled development of new beams. The ready availability of the computer to the operators and users of the cyclotron has been essential to the success of this effort.

Acknowledgements

The support, encouragement and suggestions of Dr. D. J. Clark and assistance with certain aspects of the programming from L. Chiesta and J. Catton are gratefully acknowledged.

References

1. "Systematics in the Control Settings of the Berkeley 88-Inch Cyclotron", D. J. Clark, R. A. Gough, W. R. Holley and A. Jain, Nucl. Instr. and Methods 154 (1978) 1.
2. "Radioisotope Detection and Dating with Accelerators", T. S. Mast and R. A. Muller, Nuclear Science Applications 1 (1980) 7.
3. B. G. Harvey, unpublished results.
4. "Beam Analyzing System for a Variable Energy Cyclotron", R. E. Hintz, F. B. Selph, W. S. Flood, B. G. Harvey, F. G. Resmini, and E. A. McClatchie, Nucl. Instr. and Methods 72 (1969) 61.