COMPUTER CONTROL OF THE M.S.U. 50 MeV CYCLOTRON*

J.F.P. Marchand
Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824

Abstract

The MSU cyclotron control system employs a novel concept of operator-machine interface. An Intel 8080 front end microprocessor to a DEC PDP 11/20 minicomputer is dedicated to the control of the trim coils and centering coils and the beamline quadrupole magnets. The operator has control of these elements through dedicated control modules. Each module has a digital readout, a thumbwheel switch and a rotary knob for control of the setpoint. Standard CAMAC hardware is used in the interface.

The R.F. system tuning elements can also be set with the computer. Radial beam current traces can be taken and displayed on a graphics terminal. A link to the laboratory Σ-7 computer allows access to its mass storage devices and peripherals.

Introduction

The computer control system for the 50 MeV cyclotron performs a dual role of in-line control of cyclotron parameters and of beam diagnostic functions. Central to the computer system is a Digital Equipment PDP 11/20 minicomputer (see Fig. 1) with a Tektronix graphic terminal and a dual floppy disc mass storage device with a capacity of 512 k bytes. An RT 11 real time operating system[1] provides the facilities for program development and retrieval. A data link to the laboratory Scientific Data Systems Sigma 7 computer gives the minicomputer access to its peripheral devices. This link is mostly used for access to the line printer, during program development, and to store files on the mass storage devices of the Sigma 7. The PDP 11/20 is interfaced to the cyclotron through a custom built general purpose interface[2] and a standard CAMAC system[3]. These interfaces have access to a Tektronix sampling oscilloscope, a 120 Hz line frequency clock, the cyclotron main control panel, 28 power supplies through a dedicated microcomputer, a 32 channel analog to digital converter, the radial beam probe and the Radio-Frequency system.

The Microcomputer System

The power supplies for the cyclotron trim coils and centering coils, electrostatic deflector, beamline quadrupole magnets and a few correction magnets are controlled by a small dedicated microcomputer subsystem. The central processing unit is an Intel 8080 one-chip microprocessor with 6 k-bytes of random access memory. A data link to the PDP 11/20 computer allows for control of the power supply settings. Programs for the microcomputer are developed with the PDP 11/20 and loaded through a direct memory access channel. The power supplies are controlled with a set of 28 digital to analog converters. These converters have a resolution of 12 bits and an output voltage range of 0-10 V. The analog output voltage of each converter is electrically isolated ('floating') from its environment, so as to avoid any ground loop problems.

The operator has control over the power supply settings through a set of modular control heads (Fig. 2). Special crates, mounted in the control console (Fig. 3) hold eight heads each. Each control head has a four digit readout of the power supply set-point, a four digit thumbwheel switch and an optical rotary encoder. The operator can control the setpoint by entering the desired value on the thumbwheel switch and pushing the knob of the rotary encoder.

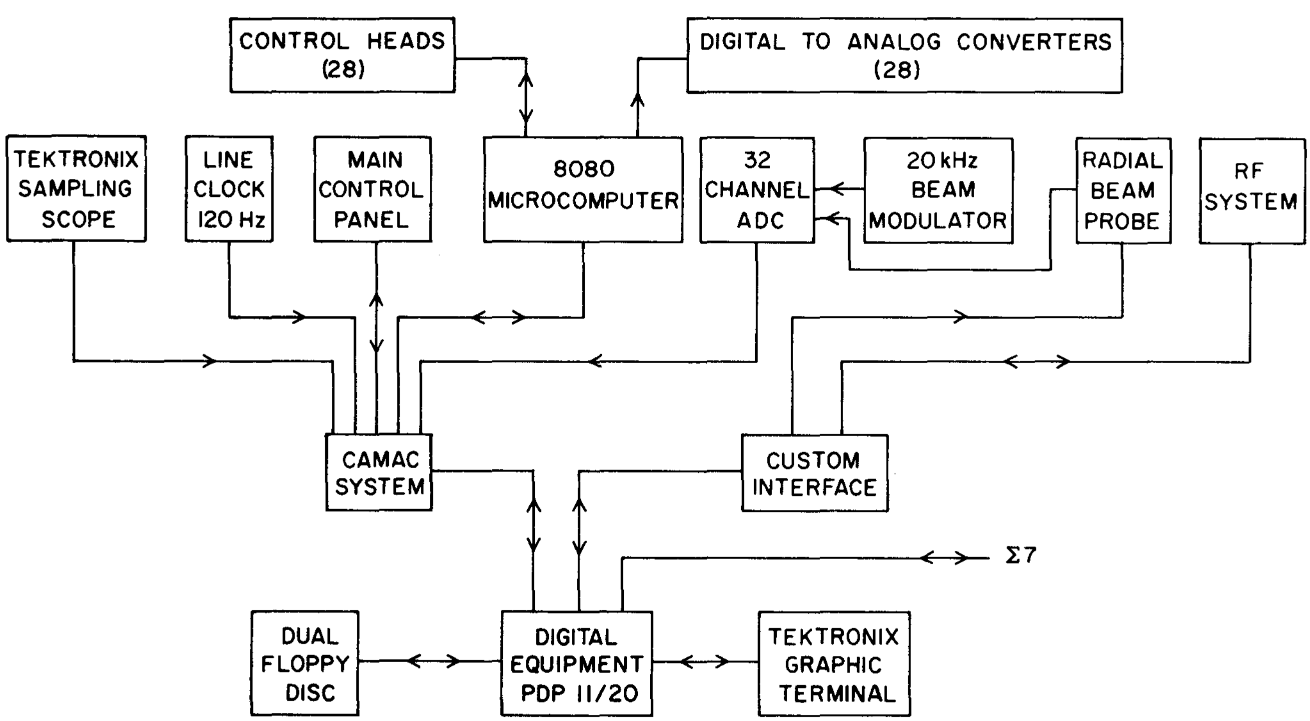

Fig. 1. Block diagram of the cyclotron control system.

*This material is based upon work supported by the National Science Foundation under Grant No. Phy 78-01684.

0018-9499/79/0400-2348$00.75

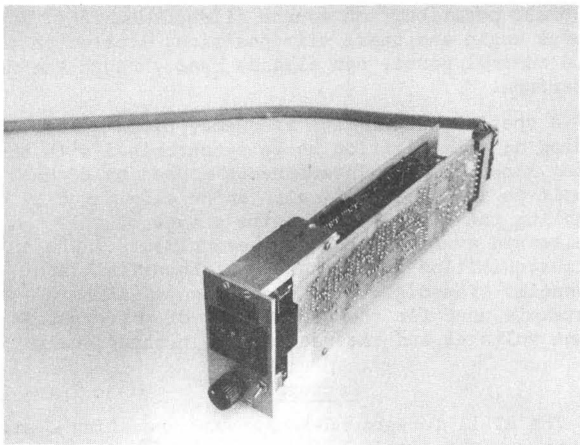

Fig. 2. One of the modular control heads with digital readout, thumbwheel switch and optical rotary encoder.

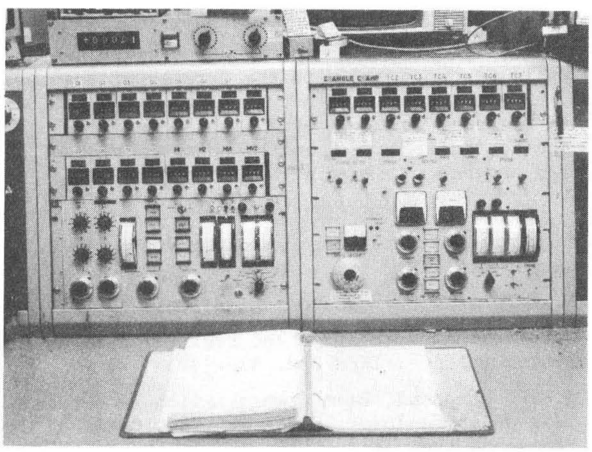

Fig. 3. Part of the main control panel with control heads installed.

By turning the rotary encoder knob the operator can change the setpoint independently of the thumbwheel setting. This dual control mode has proven to be very convenient for the operator. The setpoints can also be controlled by a command from the PDP 11/20 minicomputer. Most controls are a one to one function between readout and power supply. The three centering coils are located symmetrically around the central region of the cyclotron. The current in the three coils can be described with an amplitude and an angle rather than with the current in each coil. This transformation is performed in the 8080 microcomputer and the operator controls the setpoints for angle and amplitude. The control heads and digital to analog converters are mounted in custom crates, each equipped with a crate controller. These crates, in turn, are hooked to a common data bus from the microcomputer. The bus has 12 address lines, 4 data lines and control lines. Logic levels of +15 V and -15 V (true and false) with low impedance terminations (220Ω) and a long cycle time of ≈10 μsec insure a high level of noise immunity in this bus. Through the address lines any register in the control heads and digital to analog convertors are mapped into the memory space of the microcomputer.

The Radial Beam Probe and Beam Modulator

The most commonly used beam diagnostic instrument is the radial beam probe. It allows the measurement of the integral and differential beam current as a function of orbit radius. The probe can be controlled by the operator and by the computer. The resulting 'probe-trace' is displayed on a chart recorder at the console.

During computer operation the currents and probe-radius are measured periodically at a rate of 120 Hz while the probe is moved inwards or outwards through the beam orbits at a constant speed. The data points are taken synchronously with the power-line frequency, twice each period. The data taken in this fashion can be filtered digitally to remove the power line noise present. The probe traces can be displayed on the graphic terminal (Fig. 4 and 5, upper traces). During the cyclotron setup procedure it is of importance to know the separation of orbits as a function of radius. In cases where the beam orbits are not well separated it is very difficult to do so, in particular with automatic algorithms. The beam modulator provides a means to measure the orbit number directly without counting. The beam current is amplitude modulated by modulating the ion source arc-current (20 kHz, 100% modulation). This causes the accelerated beam current to be amplitude modulated by about 20%. This beam current modulation, as measured during the probe trace, is detected with a synchronous demodulator. The two quadrature signals are measured by the PDP 11/20, together with the integral and differential probe currents. The phase of the modulation has the following relationship to the orbit turn number:

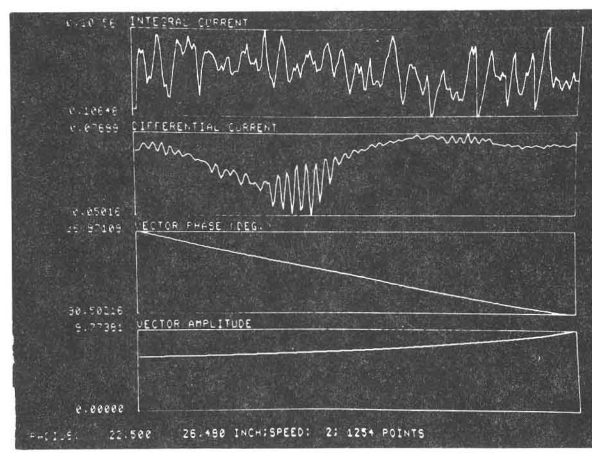

Fig. 4. Radial probe trace shows the integral beam current, the differential beam current and the phase and amplitude of the 20 kHz beam modulation (42 MeV α-particle, 11 μA beam intensity).

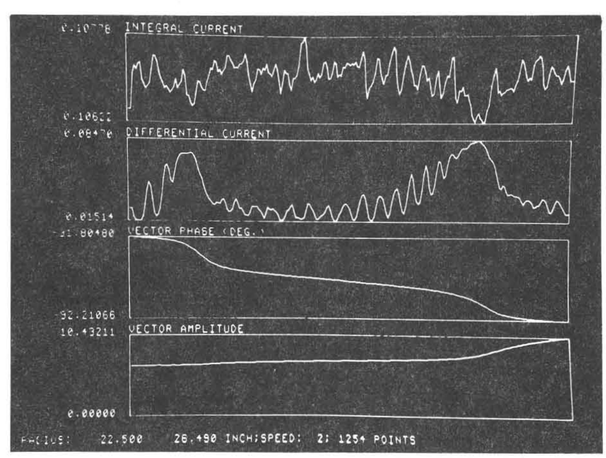

Fig. 5. Same as Fig. 4, but with maladjusted centering controls. Note the effect of radial beam oscillations in the vector phase plot.

$$\phi = \phi_o + N\frac{W_m}{W_c} * 360$$

ϕ = modulation phase (degrees)
ϕ_o = phase offset
N = orbit turn number
W_m = modulation frequency
W_c = cyclotron orbit frequency

Fig. 4 and Fig. 5 show, as functions of radius, the integral and differential beam current and the modulation phase and amplitude for two different settings of the centering controls. The phase curve of Fig. 5 shows very clearly a bunching of orbits at radii of 23 and 26 inches. The beam is 11 μA α-particle with energy of 42 MeV (orbital frequency is 9.7 MHz).

Sampling Oscilloscope

A Tektronix dual trace sampling oscilloscope is interfaced through the CAMAC system. Upon request from the PDP 11/20 the interface will digitize and store two complete traces of 1000 points each with an accuracy of 10 bits. The computer thus has access to the same image as is displayed on the oscilloscope screen. The sensitivity of the channels and the time-scale of the trace can also be read by the computer, but they have to be set by the operator. The sampling oscilloscope is useful for study of the fine structure of the beam and other real time problems. For example, measurement of the phase of the external beam with respect to the R.F. accelerating field has been done. The external beam signal is detected with a capacitive probe[4] in the beam line and displayed on a channel of the oscilloscope. The other channel is connected to an R.F. signal derived from the dee-voltage. From these two waveforms the relative phase of the beam can be determined. This phase information has been used to perform automatic phase stabilisation by controlling the cyclotron magnetic field.

Other Devices

The tuning elements of the radio-frequency system can be set with the computer. The digital readouts of probe position, ion source filament current, ion source angle and phase slit position, located on the main control panel, can also be read through the CAMAC interface.

A special 120 Hz line frequency clock allows analog data acquisition to be synchronised with the power line period. Interference caused by 60 Hz ripple on the analog signals can be eliminated by sampling the signal on opposite phases of the cycles and averaging the two measurements. The analog data acquisition system has 32 differential input channels. The digitizing resolution is 15 bits. The system is used for the measurement of power supply shunt voltages and the radial beam probe signals.

Software

The RT 11 foreground-background operating system allows for the simultaneous execution of two programs. The foreground program is given the highest priority. This program, written in machine language, can be considered as an extension of the operating system. It contains all the software required to control the interfaces to the cyclotron. A user program, running in the background, can invoke actions of the interface with standard Fortran subroutine calls, without having to be concerned with the details of the hardware. The communication between foreground and background programs is taken care of by the operating system and is transparent from the point of view of a Fortran program running in the background.

References

1. Digital Equipment Corporation, Maynard, Massachusetts 01754
2. R. DeForest, private communications
3. Modular Instrumentation and Digital Interface System (CAMAC), IEEE Std. 583-1975
4. J.F.P. Marchand, Beam stabilization by external beam-phase feedback, Proc. 7th Int. Conf. on Cyclotrons and their Applications, p. 349-352

0018-9499/79/0400-2350$00.75 ©1979 IEEE