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The Use of Digital Techniques for Automatic RF Control of the CS-15 Compact Cyclotron

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Introduction

The Sloan-Kettering Institute CS-15 compact cyclotron was the first prototype built by the Cyclotron Corporation. The description of the RF system for this machine has been reported by Hendry(1). The original automatic frequency control used a stable tuned frequency discriminator. However, for various reasons, this unit had never been put into service. In addition, unlike the newer model machines which employed a series pass tube for anode voltage control and regulation(2), our anode supply did not have such a device. Therefore the long term drift down of dee voltage had been quite appreciable. As a result, the external beam current was very unstable and a full time operator had to sit before the console constantly making necessary adjustments.

It became clear that a new stabilization system to hold firm both RF frequency and RF dee voltage was needed. Use of digital techniques was decided in the development of the control modules. Various control schemes to obtain optimum performance for this system were also developed.

Description of DAFC System

A block diagram of the Digital Automatic Frequency Control (DAFC) system is given in Fig. 1. The resonator frequency is monitored by a 0-50 MHz digital counter with a six digit display. The middle 4 digits of the frequency counter are brought out, in binary coded decimal (BCD) form and compared against the output of four BCD encoded thumbwheel switches. The digital comparator uses five National Electronic 8200 four bit magnitude comparators. The circuit theory is illustrated in Fig. 2. On each comparator, if we call the counter side 'A', the thumbwheel (or reference) side 'B', and the output Y and X respectively. The following truth table holds:

	X	Y
A > B	1	0
A < B	0	1
A = B	1	1

The X and Y outputs of each of the four digital comparators are fed into a fifth comparator. This last comparator then establishes that the four digits from the A side are either less than, equal to, or greater than the four digits from the B side. The X and Y outputs of this comparator then energize the appropriate relay driver which in turn energizes the motor drive to change the cyclotron oscillator frequency as required.

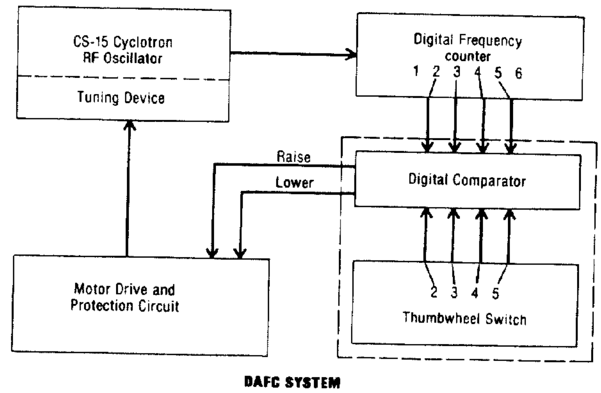

Fig. 1. Block diagram of the digital automatic frequency control system.

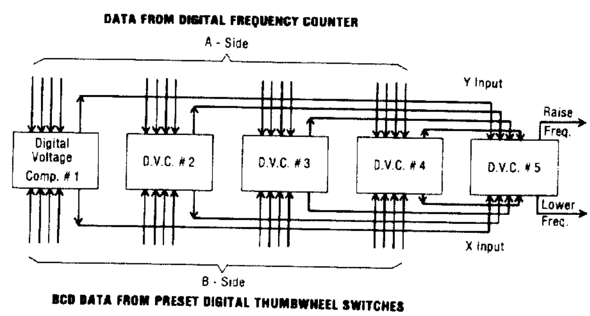

Fig. 2. Logic circuit of the digital comparator.

The operating frequency of our cyclotron is about 12.8 MHz for deuterons and $^{4}He^{++}$ ions, 16.8 MHz for $^{3}He^{++}$ and 24.0 MHz for protons. The counter is set such that the fifth digit corresponds to KHz. We found that this digit can easily be maintained over an extended period of time. Therefore our system can achieve better than 1 part in 10^5 stability.

The motor drive and protection circuit, as shown in Fig. 3., handles the various situations during the operation of the cyclotron. Specifically speaking, the system loop would not be closed if proper RF oscillation is not established. The motor power is always interlocked with crowbar relay. Then it goes through either the manual control or the automatic mode activator which is in turn interlock with anode power and dee bias control. The automatic mode is turned off when anode power is turned off and remains off even if anode power is turned on again. This scheme forces the cyclotron user to examine the resonator frequency before he activates the automatic control. The motor power is finally sent via a selection switch to one of three options of tuning.

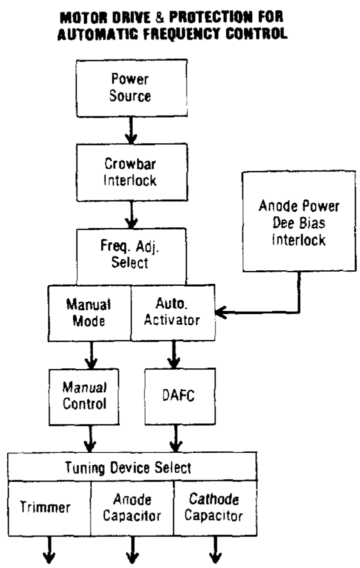

Fig. 3. Block diagram of the motor drive circuit.

The fine tuning of the resonator frequency is accomplished by adjusting either the trimmer in the resonator box, the variable vacuum capacitor in the cathode loop, or the variable vacuum capacitor in the anode loop. Each of them is driven by a stepping motor and controllable from the console. The method selected depends on the type of particle being accelerated. Usually the trimmer is preferred because there is little effect on the RF dee voltage and RF power. The AFC works extremely well using trimmer adjustment when the RF system is set up for ^{3}He operation.

However, in the case of accelerating protons, coupling between the low-impedence strap and the trimmer is very strong. A small movement of the trimmer of 0.1 mm could cause several KHz adjustment resulting in continuous hunting by the AFC. We found that fine tuning the anode or cathode capacitor provided a smooth and accurate frequency correction with a sensitivity of 4×10^{-6}. In this case the RF dee voltage or the RF power would change but is then compensated accordingly by an automatic RF dee voltage stabilizer which will be discussed later. The same technique is applied to the case of accelerating deuterons and alpha ions. For the trimmer is removed as a temporary solution to improve the ratio of RF dee voltage to anode voltage (from 1.5:1 to 2.5:1), so that maximum dee voltage under load can reach 25 KV.

Description of ADVC System

The RF dee voltage of the CS-15 cyclotron is a function of the anode voltage on the oscillator tube and the loading in the resonator tank circuit. The anode voltage is adjusted by a motor-driven three-phase variac, and is thus available for automatic control. A block diagram of the Automatic Dee Voltage Control (ADVC) system is given in Fig. 4. Similar to the DAFC system, the dee voltage is first digitized by a Datel 1000A digital voltmeter. The resulting digits in BCD format are compared to the preset number on thumbwheel switches in a commercially available digital comparator. An ERC 2544 4 digit BCD tracking comparator with dual limit is employed. The low and high limits set a window for the excursion of the dee voltage. If it falls outside of the window, the motor drive of the variac of the anode power supply is energized to make the required correction.

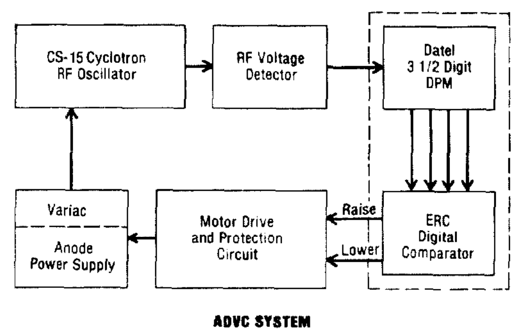

Fig. 4. Block diagram of the automatic dee voltage control system.

The resolution of the stability range depends on the width of the window in which the dee voltage can remain a reasonable length of time. In order to obtain a minimum window width along with an optimum response speed of the control loop, a sampling rate control for the voltmeter-comparator module and a speed control for the motor drive were also built. These two units enable us to set a window smaller than 0.1 KV at 20 KV indicating that a stability of ±2 part in 10^3 can be obtained.

The motor drive and protection for the ADVC system is very similar to that for DAFC system and is shown in Fig. 5. Here the dee voltage will be lowered automatically if crowbarring occurs, and then brought back to the preset level again by the ADVC system after crowbarring stops. This feature offers additional protection for the RF system and requires less attention from our cyclotron users.

Discussion

Our experience with the RF frequency and dee voltage stabilization systems reported here has shown that digital techniques can easily be applied to control many essential parameters of our cyclotron to a high degree of precision. These two units have now become indispensible for the routine operation of the machine. Since the resonator frequency and dee voltage can be held so tightly, preliminary setting up and tuning of the cyclotron becomes simple and is expedited. External beam current is always stabilized to within ±5%; the continuous attention of a full-time operator is no longer needed. The stabilized beam also revealed many other problems related to the performance of the cyclotron hence offered us a tool for further improvement and development.

References

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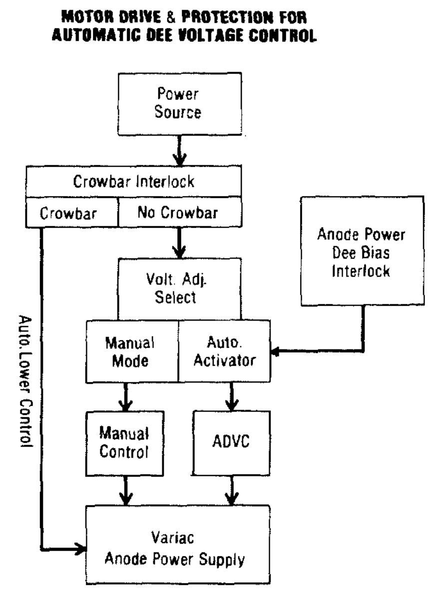

Fig. 5. Block diagram of the motor drive and protection circuit for ADVC system.