CONTROL SYSTEM FOR THE HOLIFIELD HEAVY ION RESEARCH FACILITY BEAM BUNCHER

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Summary

A beam buncher has been developed to produce very short pulses of beam from the 25 MV accelerator for injection into ORIC. The buncher is a two-harmonic double-drift klystron-type operating over a frequency range of 4.5 to 14.5 MHz and has produced 1.1-ns pulse widths of ^{16}O in tests on the ORNL EN tandem accelerator. Both rf voltage on, and relative phase between, the two buncher drift tubes must be accurately controlled to maintain the required narrow pulse width. A control system has been developed which accomplishes these tasks as well as automatic tuning of the buncher resonators, monitoring system parameters, and remote adjustment of various mechanical devices. Input commands and monitoring signals are CAMAC-compatible so that the system can eventually be included in the computer-based control system for the accelerator. In addition to the requirement for a very narrow beam pulse, the pulses must arrive at the ORIC dee gap with precise phasing. A closed-loop control for this task is being constructed using the beam pulse phase detector circuit developed at Argonne National Laboratory.

Introduction

The Holifield Heavy Ion Research Facility (HHIRF) will employ two accelerators to provide a wide range of energetic ions for the researcher. One of these accelerators is the existing Oak Ridge Isochronous Cyclotron (ORIC), and the other is a 25 MV electrostatic tandem accelerator now nearing completion. The two accelerators may be operated independently or in combination, in which case the ion beam from the 25 MV machine is injected into ORIC for further acceleration. Since the ORIC will only accelerate beam which is injected within a 6-degree window of the rf cycle, it is desirable to bunch the beam from the 25 MV accelerator when the machines are used in series. Otherwise, less than 2% of the DC beam from the electrostatic machine could be accelerated in ORIC.

A double-drift klystron-type buncher[1] has been developed and tested on the EN tandem accelerator at ORNL. In these tests the buncher compressed about 60% of the average beam into bunches which were about 1 ns wide. The buncher consists of two drift tubes, plus rf drivers, located in the injection beam line of the electrostatic accelerator. In the HHIRF the tubes will be separated by a distance of one meter. The first tube encountered by the beam will be driven at ORIC frequency while the second is operated at twice this frequency. ORIC's operating frequency spans the range of 7 MHz to about 18.5 MHz. However, the useful heavy ion rotational frequency is limited to a range of about 4.5 to 14.5 MHz. The low end of this band may be covered by operating the ORIC rf system on the third harmonic of the ion rotational frequency; however, the buncher should operate at the rotational frequency. To achieve the narrow bunch width and efficiency required, the voltages on the buncher tubes must be very stable in both amplitude and relative phase. Also, the time of arrival of the bunches in the ORIC dee gap must be very accurately controlled. Closed-loop controls have been constructed to stabilize both the amplitudes and relative phases in the buncher system.

Control Scheme

A block diagram of the control system is shown in Figure 1. There are basically two separate control systems. One, consisting of phase shifter #2, phase flipper and beam pulse phase detector, controls the relative phase between the beam pulse arriving in the ORIC gap and the ORIC rf dee voltage. The second system consists of the amplitude and phase controls for the buncher tubes and is adjusted for optimum bunching. The first system, which may be termed the beam pulse phase stabilizer, is almost identical to the system developed at Argonne National Laboratory.[2,3] It stabilizes the phase of the beam bunches against variations in beam velocity due to noise in both the ion source and the electrostatic accelerator. Briefly, the phase stabilizer operates as follows: A signal derived from the ORIC dee is coupled through phase shifter #1 to provide a reference for the system; this reference is phase-flipped (180°) at an audio rate and coupled to a resonant circuit connected to a drift tube in the high energy beam line; beam pulses passing through the tube induce currents in the resonant circuit at the fundamental bunching frequency and higher harmonics; the net voltage appearing across the resonant circuit is then the sum of the induced voltage and the phase-flipped reference; this net voltage, in general, is amplitude modulated at the phase-flip frequency; it is amplified and detected to produce an audio error signal (the signal is zero for 90° phase difference between the rf reference and beam pulses); the audio error signal is then synchronously detected to obtain a DC error signal which is applied to electronic phase shifter #2 to correct the phase of the rf applied to the buncher tubes. Aside from the necessity of tuning the resonant circuit, the phase stabilizing system is very similar to the Argonne circuit and will not be discussed further. Adjustment of the arrival time of beam bunches in the ORIC dee gap is provided by phase shifter #1.

Buncher Voltage Control

Referring again to Figure 1, it will be seen that the buncher control system receives an rf signal from phase shifter #2. This signal is split with one part proceeding to the 1f buncher tube and the second going to the 2f tube. The relative phase between these two signals is controlled by an error signal from the phase detector. The 1f signal is amplified and applied to the 1f buncher resonator. After passing through a frequency doubler the 2f signal is treated likewise. Capacitive dividers provide small samples of both the 1f and 2f buncher voltages. The 1f sample passes through phase shifter #3, is doubled in frequency, and compared in phase with the 2f sample. A phase error signal is then derived from the phase detector to control the relative phase between the two signals out of the signal splitter. Phase shifter #3 is, effectively, in the feedback path of the phase stabilizing system and thus determines the relative phase between voltages on the 1f and 2f buncher tubes. This arrangement minimizes the phase dependence on rf amplifier tuning.

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A more detailed diagram of the signal-splitter with phase and amplitude controls is shown in Figure 2. The frequency doubler and current-controlled attenuators are basically double-balanced mixer circuits. These components, as well as the splitter-combiners, are small commercial units. The electronic phase shifter functions over a relatively small range by controlling the amplitude of two signals. A continuously variable control is achieved by differentially varying the control currents in the two attenuators. If either of these currents reach set limits the stepping switch on the 100 ns input delay line is actuated to change the delay in the 1f and 2f signal paths in a direction which will return the electronic phase shifter to its normal range. The circuitry represented by Figure 2 is mounted on a 5-in. x 7-in. printed circuit board which also contains pre-regulator circuits for the 1f and 2f signals.

Buncher RF Power

Figure 3 is a diagram of the RF control and drive sections. This diagram is applicable to either the 1f or 2f unit. The attenuator here is also indicated in Figure 2 (CCA's). The rf output of the attenuator drives a solid-state amplifier (A-300) having a band width of 30 MHz, a power gain of 55 db. and a maximum power output of 300 watts. This amplifier is loop-coupled to the buncher resonator. Both coupling and tuning of the resonator are remotely adjustable. In addition, an automatic tuning system has been provided. The coupling loop is positioned to maximize the ratio of incident power to reflected power as indicated on the power monitor in the loop drive line. An error signal for the automatic tuning system is derived from a double-balanced mixer which compares the phase of the drive-loop voltage with a sample from the buncher tube.

Each buncher resonator consists of a shielded coil and a variable vacuum capacitor. Both resonators are contained in aluminum boxes having dimensions of 8 in. x 8 in. x 18 in. long. Coils are wound of 1/4-in.-diam copper tubing. The 1f coil has a mean diameter of 4 1/8 in. and about 7 turns spaced on 7/8-in. centers. In the 4.5 to 14.5 MHz frequency range the 1f resonator exhibited Q-values ranging from 650 to about 880. Equivalent shunt impedances were calculated to range from 50 kilohms at 4.5 MHz to about 240 kilohms at 14.5 MHz. The 2f coil has a mean diameter of 3 in. and about 3 turns spaced on 1 5/16-in. centers. Q-values for the 2f resonator vary from about 600 to 900 in the 9 to 29 MHz band with calculated shunt impedances ranging from about 25 to 85 kilohms. Peak voltage required by the buncher will be about 2500 volts on 1f and 1200 volts on 2f resulting in estimated power requirements of about 30 watts and 15 watts respectively.

Adjustment and Monitoring

In Figures 1 and 3 some inputs and outputs of the various blocks are labeled AI, AO, DI, and DO. These are control and monitoring signals either originating or terminating in CAMAC modules as indicated in Figure 4. AO and DO are, respectively, analog and digital control signals, while AI and DI are signals monitored by CAMAC. Initially, adjustment and monitoring of the buncher system will be accomplished from a "stand-alone" CAMAC crate as shown in Figure 4; however, it will eventually be integrated into the serial highway system of the 25 MV accelerator.

Conclusion

The beam bunching system for the HHIRF will bunch about 60% of the beam from the tandem accelerator into pulses having a width of about one nanosecond. Several closed-loop regulators are employed to stabilize the system against normal disturbances. Adjustment and monitoring of the system will be achieved through a CAMAC-based control system.

References

1. W. T. Milner, "Double-Drift Beam Bunching Systems," Proceedings Fifth Conf. on Application of Small Accelerators, IEEE Trans. Nucl. Sci. NS-26, No. 1, Part II (Feb. 1979).

2. R. N. Lewis, "Phase Measurement and Control of Bunched Beams," to be published in Proceedings of 1978 Symposium of Northeastern Accelerator Personnel (SNEAP).

3. F. J. Lynch, et al., "Beam Buncher for Heavy Ions," to be published in Nucl. Instrum. and Methods.

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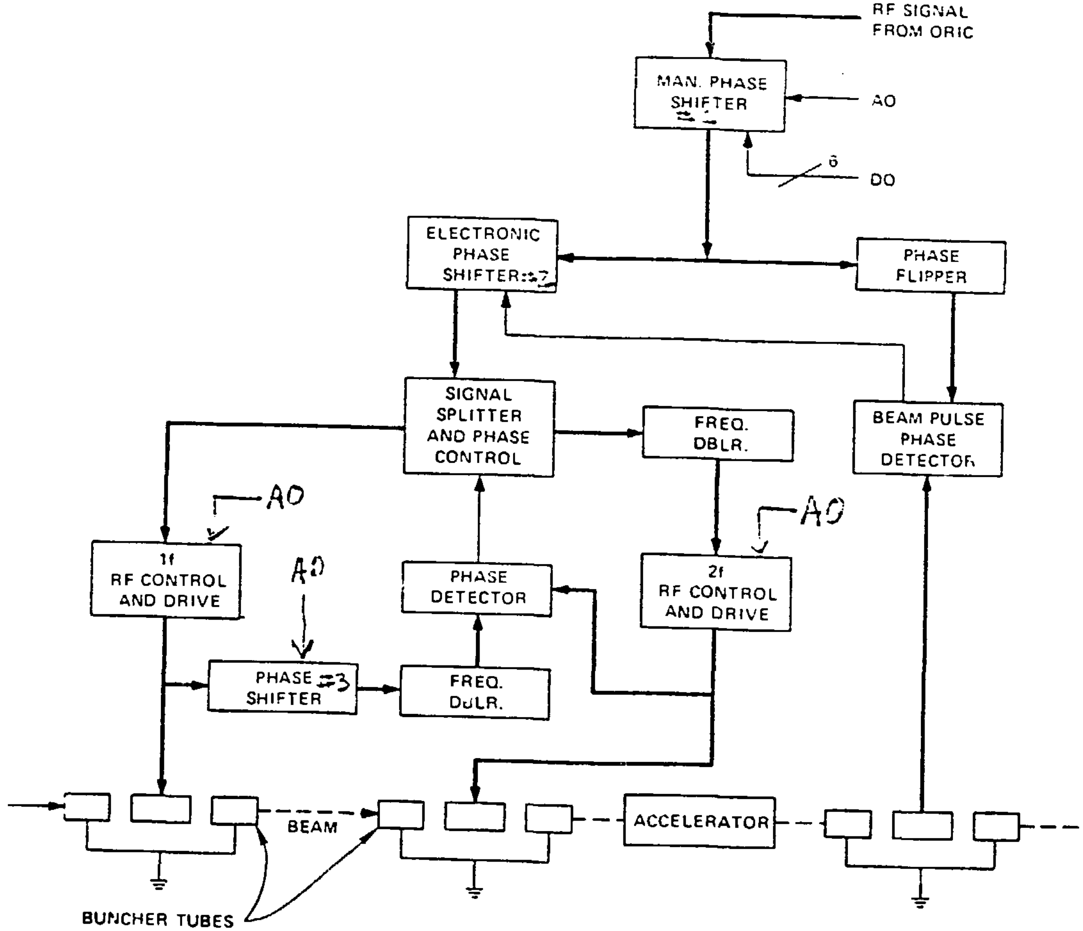

Fig. 1. Block Diagram of Buncher Control System

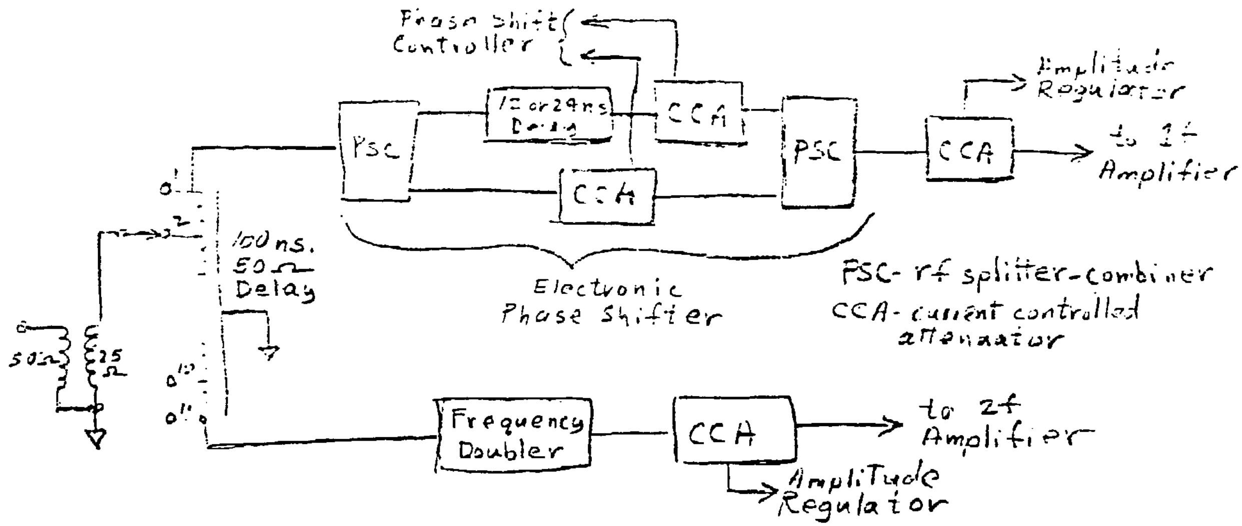

Fig. 2 - Signal Splitter & Phase Control

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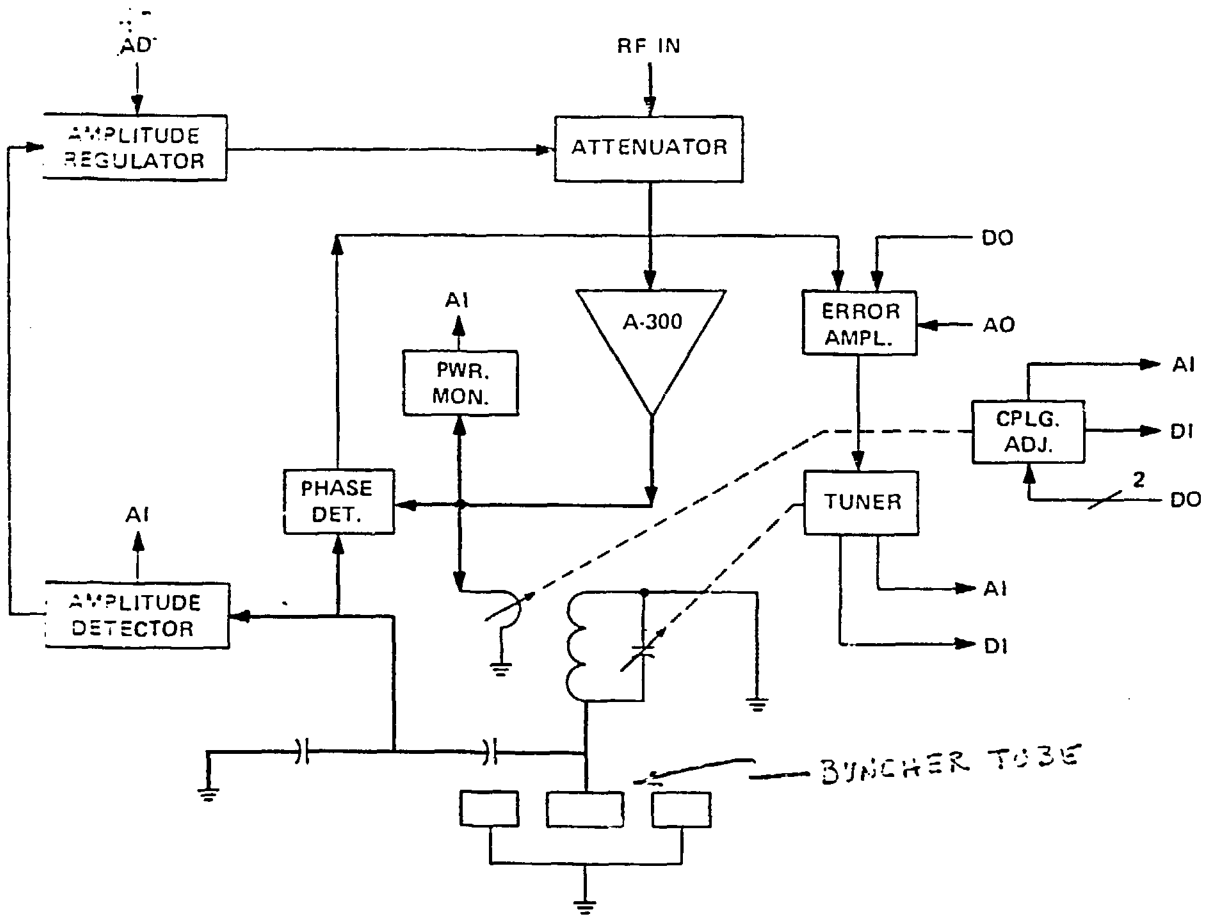

Fig. 3 - RF Control & Drive Unit

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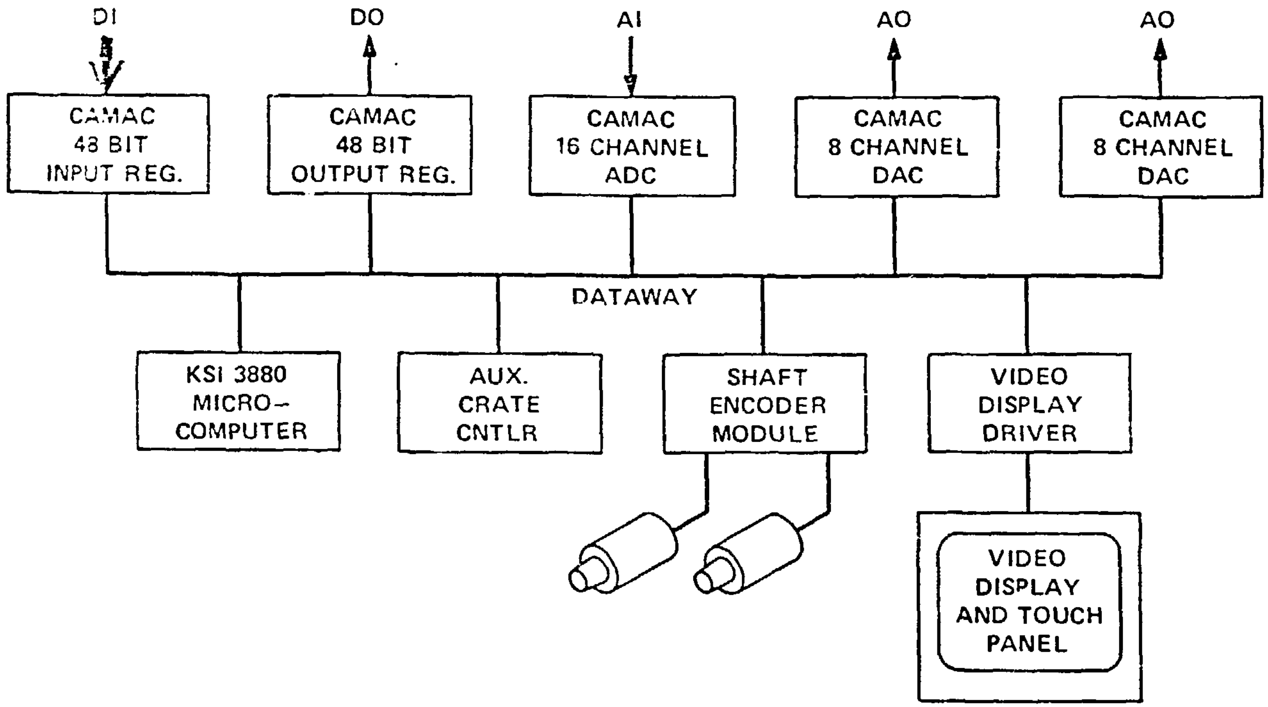

Fig. 4 Stand-alone CAMAC Control Crate