A New Data Acquisition and Control System for the Power Amplifier Test Station

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Abstract

The RF Group at Fermilab maintains approximately 50 power amplifiers that provide RF power for particle acceleration in the Booster and Main Ring accelerators. These amplifiers must be highly reliable since a failure necessitates shutting down the accelerator to allow for technician access to the beam tunnel. To ensure reliability after repairs, each amplifier is tested on an automated test station prior to being placed back in service. By using automated testing we ensure that all amplifiers are tested under the same conditions. Hence comparisons may be made and trends observed. Until recently the test station was controlled and monitored via a Z80 based microcomputer. The system was inflexible, user unfriendly, and increasingly unreliable. An IBM PC/AT with A/D and D/A cards has been installed and programmed using C language. The new system is easily modified and continues to evolve as needed. This paper describes the test station hardware and software.

I. INTRODUCTION

This paper describes the recent upgrade of the data acquisition and control system of the power amplifier (PA) test station. The PA's will be described in section II followed by a description of the test station in section III. The upgrade will be described in section IV, including discussions of the hardware, software, and tests performed. A conclusion is given in section V.

II. POWER AMPLIFIER DESCRIPTION

The RF power for a single accelerating station in the Booster and Main Ring accelerators is provided by a three-stage 100 kW power amplifier [1]. The first stage is the distributed amplifier which makes use of six 4CW800F tetrodes to raise the RF power level from 1 W to 100 W. The second stage is the lower half of a cascode arrangement based on fourteen paralleled 4CW800F tetrodes. This stage raises the RF power level to 2500 W. The final stage and upper half of the cascode depends on a Y567B tetrode to provide 100 kW of RF power to the accelerating cavity. The output power may be varied through programming of the cascode grid bias voltage and of the power tube anode voltage. Maximum output power is approximately 140 kW at an anode voltage of 25 kV. The input level to the distributed amplifier is held constant regardless of the desired output power. The range of frequencies required for the Booster and Main Ring systems is 30-53 and 52.8-53.1 MHz, respectively. Cavity tuning is achieved via horizontal ferrite tuners mounted adjacent to the cavity structure. A wide dynamic power range is required due to varying ferrite losses and gap voltage requirements.

III. TEST STATION DESCRIPTION

The PA test station may be described as consisting of three major subsystems: (1) the physical PA test stand including the PA, the anode resonator, and RF load, (2) the power supplies providing AC and DC voltages and RF drive, and (3) the control and data acquisition system. A functional diagram of the test station is shown in Figure 1.

Instead of mounting the PA directly onto an accelerating cavity, a water-cooled 50 Ω load is used to dissipate the output power. The power amplifier is mounted on a coaxial cavity resonator that is resonant at about 51 MHz with a Q of 60. Power is coupled out of the resonator via a tap on the center conductor and feeds into a 6 inch coaxial line which is terminated with the 50 Ω RF load.

The 30 kV anode supply feeds into the anode modulator which is used for programming the anode voltage on the power tube. The modulator cabinet also houses filament, screen, bias and other supplies necessary for operating the PA. The RF drive is obtained from a programmable frequency synthesizer and 3 W amplifier.

The data acquisition and control is handled by a computer system with digital-to-analog (D/A) and analog-to-digital (A/D) converter cards. The D/A card is used to program the power tube anode voltage, the cascode grid bias, and the RF drive level. (Although the RF drive level is constant in the Booster and Main Ring accelerating stations, the test station RF drive level is adjustable.) The A/D card is used for monitoring the operating parameters of the test station. Most of the inputs to the A/D card come from a monitor box mounted above the PA. This box contains voltage dividers, Hall Effect current sensors, and RF diode detectors. Isolation amplifiers are used to adjust the signal levels to ±10 V referenced to system ground.

Monitoring of the PA output power is accomplished via calorimetry. The water flow through the RF load and the temperature differential between the inlet and outlet are used to calculate the power dissipation. In addition, several RF monitors are built into the PA so that the RF waveforms may be observed.

Until recently the computer system in use was a Z80 based microcomputer equipped with an 8-channel D/A converter and

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a 32-channel A/D converter. There was no disk storage of any type, and the program resided entirely in read only memory. There were a number of code patches that had to be typed in each time the computer was restarted. The system was completely inflexible and was becoming increasingly unreliable, hence it was decided to install a new computer system, which is described in the next section.

IV. Upgrade Description

A. Hardware

The main component of the upgrade is an IBM PC/AT personal computer. Accessories include a 20 M-byte hard disk, 3.5-inch and 5.25-inch floppy drives, 640 k-byte base memory and 2944 k-byte extended memory, an enhanced color display, and a dot-matrix printer. The Burr-Brown PCI-20000 instrumentation system was chosen for handling data acquisition and control. This system offers modularity via a carrier card and up to three instrument modules. The carrier card provides interfacing to the PC bus, provides power and mounting for the instrumentation modules, and provides for inter-module communication. We are using the PCI-20041C-3A carrier which supports direct memory access data transfer and supplies 32 bits of digital input/output (I/O). The three instrumentation modules include the PCI-20021M-A 12-bit, 8-channel D/A converter, the PCI-20019M-1A 12-bit, 8-channel A/D converter with sample-and-hold, and the PCI-20031M-1 32-channel analog expander. The expander module works in conjunction with the A/D module to provide 32 channels for monitoring analog signals in the range of ±10 V. The D/A converter is configured to produce analog signal in the range of ±10 V.

B. Software

The software is written entirely in C language and is compiled using Microsoft C version 6.0. The test program begins execution by initializing the instrumentation system and setting up the data structures used throughout the program. It also prompts for the name of the operator and the serial numbers of the PA being tested. After initialization, the main control loop is entered. This loop awaits keyboard input and passes control to the appropriate routines when activity is detected. Control is accomplished via the function keys and the numeric keypad. The function keys initiate major tests such as the Q test and the phase test, provide a help screen, allow for system reset, and provide for exiting the program. The numeric keypad provides cursor movement in the control section of the display (lower left corner of Figure 2). The RF drive frequency and level, the power tube anode program, and the cascode grid bias program can all be adjusted in this section.

Data acquisition occurs in one of two ways depending on the RF duty factor. If the duty factor is less than 100%, the duty cycle generator interrupts the computer when the RF turns on to initiate data acquisition. If the duty factor is 100%, no interrupts are generated and the program acquires data periodically as determined by an internal timer.

C. Tests Performed

The first test performed after a PA has been mounted and the filaments have warmed up is to check the system Q. A single keystroke initiates this test, which is performed at an anode voltage of 20 kV, a cascode cathode current of 1.75 A, and a cascode grid RF level of 35 $V_{p\text{-}p}$. The input RF is swept from 49-53 MHz while monitoring the power tube anode RF. A least squares fit is performed on the measured Q curve, and the resulting fit and the measured data are plotted on the computer display. The system Q and resonant frequency are also displayed. Subsequently, the RF input frequency is automatically set to the resonant frequency.

A phase test is performed to check that the "time-of-flight" through the PA stages is correct. Setup of this test requires disabling the DA grid bias so that the RF power levels are kept low. Two test sequences are performed: (1) the phase difference is measured between the RF drive and the cascode grid RF, and (2) the phase difference is measured between the RF drive and the power tube cathode RF. During each sequence the phase difference is measured at 30, 40, and 50 MHz at power tube anode currents of 2, 4, and 6 A. Performing the phase test requires only that the operator swap coaxial cable connections at the PA as prompted by the computer.

Assuming success with the first two tests, the PA is subjected to power testing. It is operated at anode voltages of 20, 22.5, and 25 kV. Output power levels range from roughly 85 to 140 kW. Power testing is performed either with a 50% duty factor with a period of 100 ms, or with a 67% duty factor with a period of 16 seconds. It is desirable to run the power amplifier at power levels of 90-100 kW for several days to ensure reliability. Operating parameters are compared with nominal parameters so that abnormal conditions may be easily noted. High or low readings are displayed in different colors on the computer display. An example of the computer display during a power test is shown in Figure 2.

V. Conclusion

As a result of this upgrade, the PA test station now has a flexible data acquisition and control system. The software is slowly evolving as we gain experience with the system. A goal for the future is to develop an on-line database of test results so that it is easier to monitor trends, make comparisons, and generate reports.

VI. Acknowledgement

Thanks to Jim Crisp for his contributions to this project.

VI. References

[1] Q.A. Kerns and H. W. Miller, "100 kW RF POWER AMPLIFIER," IEEE Transactions on Nuclear Science, vol. 18, pp. 246-248, 1971.

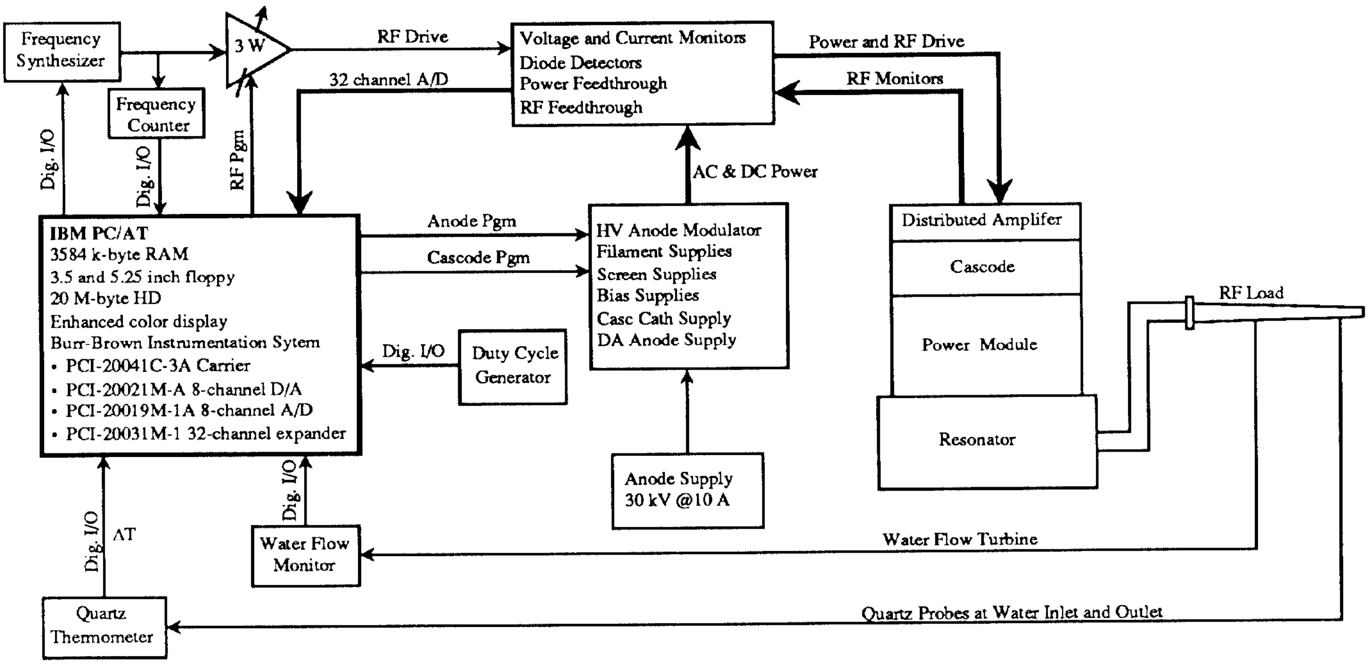

Figure 1. Functional diagram of power amplifier test station.

0	PA anode V	20.581	kV	1	PA Anode I	7.520	Amps
4	CASC cathode V	-704.102	V	5	CASC cathode I	-9.985	Amps
26	DA anode V	559.082	V	27	DA anode I	2.795	Amps
30	DA bias V	33.740	V	1	DA bias I	0.004	Amps
6	PA screen V	474.121	V	5	PA screen I	0.088	Amps
2	CASC screen V	295.898	V	27	CASC screen I	0.428	Amps
28	DA screen V	251.953	V	1	DA screen I	0.081	Amps
22	PA filament V	405.273	V	5	PA filament I	7.920	Amps
24	DA/CASC filament V	466.309	V	27	DA/CASC filament I	1.453	Amps
8	CASC bias	-11.621	V	1	CASC error	3.125	V
33	Frequency	51.464	MHz	16	Phase Detector	6.504	deg
33	Water flow	17.300	GPM	99	MOD HV on	YES	
33	Delta Temp	9.480	degC	99	MOD ready	YES	
33	Power	86.591	kW	99	Spark	NO	
33	Efficiency	56.053	%	99	Duty Factor	50	%
13	PA anode RF	4.137	Vpp	10	DA grid RF	1.233	Vpp
12	PA cathode RF	2.328	Vpp	11	RF Drive	16.081	Vpp
9	CASC grid RF	3.342	Vpp				
					Program Mode	MANUAL	
88	Frequency| |	51.465	Mhz		DA, Casc, PA #	15,15,15	
87	Anod Prog| |	20.000	kV		Tested by	M. Champion	
86	Casc Prog|6.000 |	6.000	V		Date	4/09/91	
85	RF Prog | |	4.4	V		Time	11:54:18	

Figure 2. Example of operating parameters display during power testing of PA.