RESULTS OF THE ALS BOOSTER RING RF SYSTEM UPGRADE FOR TOP-OFF MODE OF OPERATION*

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Abstract

ALS, one of the first third generation synchrotron light sources which has been operating since 1993 at Berkeley Lab has been upgraded from its present operation scenario of injecting the 1.5GeV electron beam from the Booster ring into the Storage ring every 8 hours, where it is accelerated to the final energy of 1.9GeV, to full energy (1.9GeV) injection from the Booster ring into the Storage ring every 3 seconds for filling and every 30-35 seconds for “Top-Off” mode. Additionally the beam current will be increased from the time averaged value of 250mA to 500mA to increase the brightness. In this paper we will present the final design of the Booster RF power source and control system upgrades and the performance results of the new ALS injector RF system set-up for Top-Off mode of operation and.

INTRODUCTION

The up-grade to the Booster Ring RF system consists of replacing the modified 15kW (klystron based) commercial UHF transmitter with an 80kW Induction Output Tube (IOT) based commercial UHF transmitter, the transmission line and cavity RF window. The transmission line size was increased from nominally 3-1/8” to 6-1/8” coax line and the disc style aperture coupling RF window was replaced with a cylindrical style window, already in use in the ALS storage Ring cavities. The operating cycle has been changed from a 350ms accelerating ramp and a 650ms recovery period to a 1200ms accelerating ramp with an 1800mS recovery period that is dictated by the Booster dipole magnet power supply. The power profile for the RF cavity has changed from a range of 80W - 7kW, to a range of 40W - 60kW, injection to extraction. The total beam current in the Booster has remained the same, 4mA (1nC total beam charge). The control system interface to the Booster RF High Power Amplifier (HPA) has been upgraded from an Intelligent Local Controller (ILC) [1], based control system to a Mini-IOC [2] running Experimental Physics and Industrial Control System, EPICS [3], interfaced via ModBus/TCP to a bridge PLC.

BOOSTER RING RF SYSTEM

Injection Optimization

The beam loading effect in the LINAC dominates the bunch-to-bunch energy spread of the injected beam into the Booster Ring. Currently, the electron gun is operated with three 2.5-4ns pulses centered at 8ns intervals with a total charge in the range of 1-2nC. There are sub-harmonic pre-bunchers which shorten these pulses prior to entry in the LINAC. Since the pulse train length is significantly shorter than the fill time of the LINAC structure, for beam loading calculation purposes, the pulse train was treated as a macro pulse. For Top-Off operation we plan to operate with a ten pulse train keeping the total charge constant at ~1nC. This change is expected to result in a 10% reduction in the $\sigma E/E$.

Beam Physics

The dominant factor for determining the power requirements for the Booster Ring RF system is the quantum lifetime, the quantum emission of energetic photons by the electron beam. Calculations [4], show the quantum lifetime is expected to range from 17ms for 19kW to >61000s for 66kW. Measurements will follow once Top-Off operation begins after the limitations of the dipole magnet power supply and RF window are resolved.

To further promote Booster Ring efficiency we will program the RF cavity drive signal to hold the synchrotron tune constant throughout the majority of the energy ramp cycle. This will be done by increasing the cavity cell voltage proportionally with the energy ramp. Only near the end of the energy ramp will the synchrotron tune begin to vary since the installed RF cavity is limited to 70kW.

HIGH POWER AMPLIFIER

The existing UHF klystron based transmitter (15kW CW) was replaced with a UHF IOT based transmitter (80kW CW). The IOT based amplifier was chosen over the klystron due to its larger commercial availability, active development, and price-performance. Acrodyne Industries Inc. [5] supplied the complete turn-key system (80QCW), which included an IOT final amplifier (CPI, K2H80W), commercial broadcast high voltage power supply (NWL, Model 122245, 163kVA), WR-1500 waveguide switch, RF load, coax line, and bridge PLC with a ModBus-TCP interface for connection to our control system. A block diagram of the HPA system is in Figure 1 and the installed HPA at ALS is shown in Figure 2.

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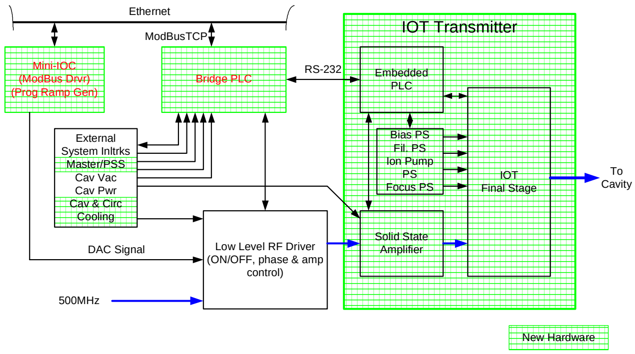

Figure 1: Block diagram of HPA system.

Figure 2: HPA installed at ALS.

The HPA was largely a standard "commercial off-the-shelf" UHF transmitter with the following modifications or additions: HVDC voltage regulator for the HVPS, permanently installed crowbar test fixture, infra-red temperature monitor for IOT output ceramic, various cabinet temperature monitors, self-oscillation interlock, redundant low level RF switch, and a bridge PLC that interfaced to the embedded PLC in the HPA and all existing Booster Ring RF sub-systems I/O channels. The HVPS supplied by NWL [6], is an oil cooled unit located some 400 feet from the HPA, external to the ALS building. The HPA was fully tested to 80kW CW, see Table 1 for results, at the factory and again at LBNL for acceptance.

Table 1: HPA Performance Test Results

Parameter	Idle	10kW	20kW	40kW	60kW	80kW
V_k (kV)	33.1	32.4	32.3	32.1	31.9	36.5
I_B (A)	0.2	1.1	1.56	2.28	2.95	3.21
V_g (V)	67	67	67	67	67	68
I_g (mA)	0.0	0.0	5.0	68.0	184.0	155
Drive (W)	0.0	53	104	208	335	422
Gain (dB)	-	22.8	22.8	22.8	22.5	22.8
η (%)	-	28.1	39.7	54.7	63.8	68

The HPA was installed temporarily, for 4 months prior to its final installation, for testing and control system integration. It has been in operation since December 2006 with greater than 3000 operational hours with only one IOT ion pump current-triggered crowbar, which occurred during the first 50 hours of operation.

Inductive Output Tube (IOT)

The CPI K2H80W IOT [7] (shown in Figure 3.) was chosen over others due to its superior anode cooling, greater gain and efficiency, 4 1/16" output line, easy replacement procedure, and price-performance. Information gathered from visits to CPI, from discussions with engineers at research facilities and in the broadcast industry was used to make this determination. Current development work on integrated-cavity IOT's at CPI promises to deliver up to 25% higher output power in roughly the same form factor.

Figure 3: CPI K2H80W IOT (80kW).

RF Window

To deliver the higher power to the RF cavity for Top-Off mode the disc style window was replaced with a cylindrical style, two-lobe lower iris flange that increases the coupling factor to ~3. The window design and titanium-nitride coating parameters are identical to windows installed in the Storage Ring cavities [8]. Fabrication, titanium-nitride coating and power testing/conditioning on the first of two windows purchased for this up-grade all proceeded without an issue, with only 3 vacuum trips, and no arc-downs up to a power level of 67kW CW on our test facility. However after installing this window in an identical cavity in the Booster Ring and during power testing/conditioning the window arced down at the 20-30kW level. The final arc caused a vacuum leak to develop in the wall of the alumina cylinder. The window was removed and will be inspected, repaired and tested. See Figure 4 for a plot of the window power conditioning data from the test facility.

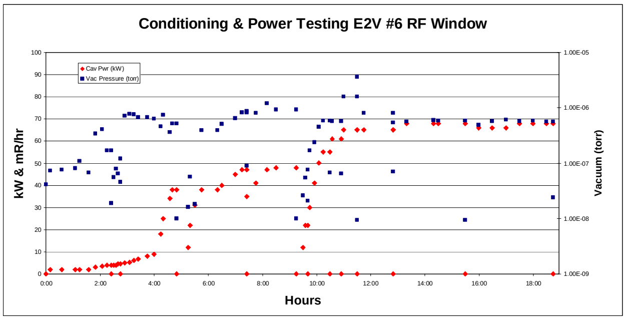

Figure 4: RF window E2V-6 power conditioning.

Transmission Line

All 3-1/8" coax line was replaced with 6-1/8" line with the exception of a 4-port WR-1500 switch installed between the HPA and circulator to allow HPA testing into a dummy load on one port while simultaneously low power network analysis of the cavity can happen on the other port. Both the HPA test load and the circulator reject load were provided by Mega Industries [9] and are of the type, Water Loads. The resistive element is the low conductivity water itself in a low-Q tank matched to WR-1500 transition. This type of load was chosen for its simple maintenance-free operation and relative compactness. However, an instability was found in the load's match at all power levels. The load's match is not only changing as a function of temperature but it also is changing sporadically and randomly. The most likely reason is that the reactance of the water is changing near the membrane between the waveguide and water tank. Mega continues to investigate this problem.

CONTROL SYSTEM INTERFACE

The HPA has two Horner Electric PLCs, one embedded in the HPA that performs IOT system control and protection functions running proprietary code supplied by Acrodyne and a second which is the bridge between the embedded PLC and the EPICS-based ALS control system. The two PLCs communicate with each other via ModBus serial while the bridge PLC, a Horner model NX-251, communicates with a mini-IOC via ModBus/TCP, an industry standard protocol for PLC communication. The IOC performs the role of *modbus master* requesting data from the bridge PLC acting as a *modbus slave*. The EPICS Modbus/TCP driver is provided by an IOC support module provided by TRIUMF [10].

ModBus/TCP Support Module

The Modbus module supports Modbus function 3 (read output registers) and function 6 (preset single register) and has record support for the standard EPICS record types. Read and Write groups can be defined that allow multiple Modbus registers to be transferred as a group between the IOC and PLC. In addition a *watchdog* register can be defined that is incremented by the PLC and checked by the IOC to assure that the link to the PLC is OK. Debug and testing of the interface and register mapping was done with a tool called *modpoll*, which is freely available for many host platforms.

Converting from ILC to PLC I/O Channels

The Booster RF sub-systems, excluding the HPA related channels, had 77 boolean inputs, 18 boolean outputs, 13 analog inputs and 4 analog out channels installed across 4 ILCs. All of this has been replaced by a single PLC (the bridge PLC) with the appropriate I/O cards and modules and one mini-IOC. To avoid changes to control room software, the process variable names were kept the same (except for some boolean output channels). A new Motif EPICS Display Manager (MEDM) screen was created for all Booster RF controls and locally at the bridge PLC control pages were created to access all channels.

CONCLUSION

The HPA system has met all specification parameters and has been running without a single trip for greater than 6 months. However, due to the RF window vacuum leak, we have limited the cavity power to 35kW max on the disc style window and therefore have been unable to complete the power testing with the cavity. Additionally, since the Booster Ring Dipole magnet power supply hasn't met its operational goals, the beam physics measurements will be delayed. The controls system upgrade has been completed smoothly and it has performed as expected, however operator control screens need further input and development. Even with the window and power supply delays we expect full Top-Off mode operation later this year

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