RF System for the Duke 1 GeV Storage Ring*

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Abstract

The RF frequency is 178.5 MHz. An amplifier built by the QEI corporation provides 50 KW power. All the power feeds to a single-cell RF cavity, built by BINP at Novosibirsk, Russia, giving a gap voltage of 720 KV. An ANT circulator is used in the feed line. There are four basic feed-back loops to stabilize the system operation : 1) Cavity frequency tuning loop. 2) Cavity voltage control loop. 3) RF phase stabilization loop. 4) Synchrotron oscillation damping loop. The whole system has been tested and operated since December 1993. It has provided secure and stable operation for the storage ring.

I. RF PARAMETERS

The main parameters of the RF system for the Duke storage ring are given in Table 1.

TABLE 1
RF system Parameters

Electron Beam Energy	1 GeV
Synchrotron radiation loss per turn	42KeV
Ring circumference	107.46 meter
Rf frequency	178.547 MHz
Harmonic Number	64
Available RF power	50 KW
Cavity shunt impedance	11 M Ohms
Cavity coupling coefficient	1.78
Maximum peak cavity voltage	720 KV
Cavity unloaded Q	40,000
Cavity frequency tuning rang	360 KHz

II. RF CAVITY

The RF cavity is made of copper-clad stainless steel. It is designed to have an operational capability of 200 KW CW power. The operating power is limited by its coupling loop which is not water cooled. The cavity itself has an adequate cooling water system. There are five cooling water channels around the cavity and a total water flow of 16 gallons per minute. Tests show a 20 KHz resonant frequency shift when the RF power to the cavity is raised from zero to 50 KW. The maximum temperature difference across the cavity wall is 18 degrees Centigrade at full power.

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* Work supported by U.S. Air Force Office of Scientific Research Grant F49620-93-1-0590 and U.S. Army Space & Strategic Defense Command Contract DASG60-89-C-0028.

There are four mechanical plunger tuners on the cavity. Two tuners are for fundamental mode and the other two are designed to shift the high-order mode frequencies but not affect the fundamental mode. The two high order mode tuners are tuned manually in the control room for better beam stability. The two fundamental mode tuners are automatically adjusted to compensate for reactive beam loading and thermal deformation. they provide a total frequency tuning range of 360 KHz.

The cavity is fed by an air-filled coax line through a ceramic window. The coax line connected to the cavity has an impedance of 75 ohms. The rest of the coax lines are 50-ohms impedance. An impedance adapter from 50 to 75 ohms is installed between them.

A more detailed description about this cavity can be found in the reference [1].

III. POWER AMPLIFIER AND CIRCULATOR

The 50 kW output stage uses a single Eimac 4CW100000E tetrode with a water cooled plate. The tube is operated in a grounded grid configuration. Air cooling is used for the output cavity and the control grid. At full output, the stage gain is approximately 12 dB and the plate efficiency is typically 50%. The plate power supply input is 480 Volt, three phase delta, with twelve pole output to the rectifiers. This unregulated supply can deliver over 100 kW continuously at 8.5 KV. The output stage and its associated power supplies occupy two 19X78 inch cabinets. Sixteen solid state modular amplifiers drive the output tetrode via combiners. Each amplifier is rated at 250 Watts. The nominal stage gain is 14 dB. Two more of these modules are used as low level drivers, also with a 14 dB stage gain. These amplifiers are powered by nine switch mode regulated power supply modules. A solid state pre-amplifier with a maximum nominal output of 10 Watts provides an additional 40 dB of gain, so that full output can be achieved with an RF input of less than 1 mW. The solid state amplifiers, their associated power supplies and the control circuits are contained in two more cabinets.

A three port circulator rated at 150 kW was installed between the 50 kW amplifier and the RF cavity. The ports are all 6.125-inch EIA coax. The circulator was supplied by ANT

Telecommunications Incorporated, and after sales service is being provided by Advanced Ferrite Technology. This circulator is fitted with arc detection and temperature compensation. The forward loss is under 0.15 dB and the isolation provided is greater than 20 dB. The circulator is connected to a regulated water circulating loop which maintains a temperature of 34 degrees centigrade at all times. Operation above ambient temperature ensures that water films are not formed on the ferrite surfaces in the circulator.

IV. CONTROL CIRCUITS

The control circuits deal with the control and stabilization of the amplitude and phase of the RF field in the cavity. Interlocks for the cooling water, cavity vacuum and personal safety are also provided. There are four feedback loops as follows:

1) Cavity frequency tuning loop:

This feedback loop compares the RF phase of the field in the cavity to the phase of the input signal to the cavity and uses the resulting difference to operate the tuners via a DC motor. The phase comparison is made by converting both RF signals to 2.79 MHz via a mixer; Then the phase is measured by the duty factor of the intermediate frequency output after the amplitude limiter. This phase detector circuit has a sensitivity of 50 mV / per degree. The same type of phase detectors are also used in the phase stabilization loop and synchrotron oscillation damping loop.

2) Cavity voltage control loop

This feedback loop compares the field amplitude detected from the cavity sampling loop to a fixed reference voltage. The resulting signal is applied to a gain-controlled amplifier in the drive line to the transmitter.

3) Phase stabilization loop

The main function of this loop is to lock the field vector in the RF cavity to the RF signal generator. The RF signal detected from the cavity sampling loop is compared with a reference signal which is derived from the RF generator. Its output signal is used to drive a phase shifter in the RF drive line. The phase shifter is made by two LC resonant circuits with two voltage variable capacitance (VVC) diodes as control elements. The phase range is over 360 degrees.

4) Synchrotron oscillation damping loop

This loop samples beam signal from one of the beam position monitors. After a frequency filter, the 178.5 MHz beam signal is compared with the reference signal in a phase detector. Its output signal is used to drive the same phase shifter in the phase stabilization loop. The loop has a frequency response of 4-20 KHz which covers all the synchrotron frequencies at different machine configurations.

The entire system can be operated locally or remotely by the EPICS (Experimental Physics and Industrial Control System, provided by Los Alamos National Laboratory) control system using Allen Bradley control hardware (see [2]). The operator can choose either of the following two operation modes in the control room. a) setting desired cavity voltage and cavity resonant phase, the system determines the RF power needed and stabilizes at that level. b) setting the coupling loop current which corresponds the RF power in the cavity, after the cavity voltage is chosen the system determines the resonant phase and vice versa.

This loop also keeps the phase of stored beam locked to the phase of RF generator which also is the source of timing system

V. OPERATION AND FUTURE PLANS

The RF system has been in operation with manual control since December of 1993. With on site support from QEI, ANT and BINP, the system was debugged and characterized. The control and read back circuits were integrated with the high level control system known as EPICS. In November 1994 the first stored beam was achieved and the optimum control settings were determined within a few weeks (see [3]).

Our long term objective is to increase the output power capability to 150 kW, at which point the circulator will become the limiting factor. In the near term there are some upgrades that are being considered.

The power supplies for the solid state amplifier stages generate noise at harmonics of the 20 KHz switching frequency. Harmonics derived from the line frequency are coming through the output tube plate supply. An inexpensive approach to reducing these noise sources is being studied.

To date we have not needed to run the amplifier above 15 kW for storage ring operations. Before full output can be used, power output stability must be improved. Water cooling the output cavity seems to be simple to implement and inexpensive, but other approaches are being considered.

VI. ACKNOWLEDGMENT

The authors wish to thank Carl Dickey and Owen Oakeley for their helpful efforts on the electrical controls and interlock circuits, Joe Faircloth and Pat Cable for the installation of cavity, coax line and transmitter; their contributions are much appreciated.

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