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NSLS RF SYSTEM IMPROVEMENTS
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Abstract

It is required that the NSLS X-ray accelerator reach an energy of 2.5 GeV. An additional accelerating cavity and power amplifier system were installed to meet this goal. A new control system was designed to include phase and amplitude servos as well as computer interfacing. Commissioning and operating experience will be reported.

Introduction

During the spring and early summer of 1984, electrons were accelerated to 1.7 GeV in the X-ray ring. After a resonant coupling between the RF power amplifier and the ring cavity was diagnosed and eliminated, the operating energy was increased to 2 GeV in July. The RF power amplifier¹ delivered 40 kilowatts to establish a voltage of 282 KV in the accelerating gap. This corresponds to an overvoltage factor of 1.4 at 2 GeV. An additional 20 kilowatts of power was provided for 100 milliamp of beam load.

In order to achieve 2.5 GeV operation 500 kilowatt/turn is required to make up for electron beam radiation losses. This necessitated an upgrade of the RF system. In the latter part of 1984 an additional RF power amplifier system and accelerating cavity were installed. With two systems, each providing 280 kilovolt gap voltage, 2.5 GeV operation can be achieved. The installation difficulties and operational results are given.

X-Ray RF Control System

A new modular control system has been implemented to control the RF power in the two X-ray cavities. A Eurocard packaging system was chosen for its size versatility, reliable connectors and for the growth of OEM support. All dc control functions use standard +12V CMOS logic and interface to the RF microprocessor. Performance has been virtually trouble-free since the initial turn-on.

The simplified block diagram in Fig. 1 illustrates several analog control loops. A 53 MHz low pass filter is included in the cavity field monitor to eliminate errors from frequencies induced by higher order beam modes.

An auto-leveling control loop samples the cavity field and maintains cavity gap voltage as set by the computer reference signal. An isolated, low VSWR, full wave detector provides several volts of signal from a cavity field probe at maximum operating power. The field-reference error signal is amplified and serves an electronic attenuator in the low level drive system. Daily amplitude to reference repeatability is less than 1%.

A phase loop is required to lock the injection booster ring phase to the phase of both X-ray cavities. An additional phase shifter is added between cavities to optimize injection and high energy operation. Under present normal operating conditions, the range of actual field power is from 2 KW to 50 KW. A phase detector was developed to accept a change in input power level of 17 db with less than 1% phase

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Fig. 1. Simplified X-ray RF System Block Diagram

shift using front end limiters. Overall, less than 2° maximum phase change is typically measured throughout the system during beam injection and acceleration. A phase modulation input is provided to include a beam stability feedback system.

In order to maintain cavity tune during power changes and to compensate for reactive beam loading, a tuner control loop is employed. Both a plunger type and an end wall hydraulic "crusher" type tuner are incorporated. However, only the end wall tuner is used since higher order modes were found to be generated the farther the plunger tuner was driven into the cavity. RF forward power is sampled from a directional coupler in the 6" coaxial drive line to the cavity, and its phase is compared to the phase of a field monitor probe generating an error signal when off resonance. A stepper motor drives the end wall hydraulic tuner system at a frequency proportional to the error signal and maintains phase lock with an error of less than 2° during normal beam fills and ramping procedures. Cavity temperature is monitored and compared to the end wall pressure so that cavity tune can be preset manually or by computer to initialize cavity power excitation, after which the loop maintains resonance.

Two additional systems are being built for future installation.

Accelerating Cavity

The original X-ray cavity² has been split into two half cells by adding two end plates; each half cell is 60 cm in length and 1 meter in diameter. The machine

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presently operates with two half cells in the X-ray ring. Both cavities have small vacuum leaks and operate in the 2×10^{-9} Torr region at 2.4 GeV operation.

The cavities have operated for approximately 1500 hours at the 50 KW level and the basic design appears to be good. However, a number of problems have arisen related to vacuum sealing and center electrode cooling. The cover utilizes a 0.064 inch diameter OFHC copper wire formed into a ring as a seal member. This seal acts both for the vacuum and to make an RF contact. Some difficulties have been experienced in making a good vacuum seal while also obtaining the required tune in the cavity. Experiments are being carried out on a test stand with gold plated copper wire as a solution to this problem. RF heating in the vacuum seal area required additional cooling due to the removal of a small region of copper cladding. Additional experiments are being carried out with brush plating of copper to alleviate this problem.

Temperature control of the cavity center electrode forms part of the cavity tuning system. The water passages in the center electrode are restricted giving a high pressure drop. During a power ramp, measurements indicate that the mean temperature of the electrode stem rises by about 25°C. This temperature rise places a severe strain on the remaining cavity tuning systems, in particular the system for deflecting the end wall of the cavity. A design is being developed to replace the existing end cover with a cover containing a diaphragm tuner. This tuner will be servoed directly from the cavity frequency.

Initial Turn On

Initially, one of the RF amplifiers exhibited a tendency to oscillate. When this parasite appeared, all the forward power is seen in the output transmission line with no power delivered to the accelerating cavity. The frequency was 700 KHz below the operating frequency. When the coaxial transmission line length was increased to two wavelengths at the operating frequency of 52.88 MHz, the oscillating frequency moved to 53.88 MHz. In addition, its strength was diminished. It was eliminated by retuning the input to the amplifier. The mechanism for feedback is currently being studied.

Additional cooling on the end flange of the upstream accelerating cavity eliminated a serious vacuum leak that appeared when the RF power was above 30 kilowatts. The primary cause of this problem is again related to the poor vacuum seal.

Additional cooling was needed on a copper slug inserted into the cavity to adjust the operating frequency. A temperature of 90°C was read on the air side of the cavity, indicating the slug inside the vacuum chamber was much higher. By additional cooling the air side reading was reduced to 50°C.

The above fixes alleviated but did not eliminate the difficulties in accelerating from 750 KeV injection energy to 2.4 GeV. At injection, each cavity requires approximately 4 kilowatts of excitation power while at high energy 40 kilowatts must be maintained. During power ramping, gas discharges in the upstream cavity would cause beam drop out. The cavity gap voltage drops to zero for 200 microseconds when powered between 20 and 30 kilowatts. Above this power level these micro discharges are much less frequent.

To circumvent this problem it was decided to run both cavities continuously at 45 kilowatts but back phase one of the RF amplifiers at injection.

Fig. 2. Voltage Phaseback During Injection.

From Fig. 2 it can be seen that when the cavity voltages are backphased, one cavity delivers power to the beam while the other receives power from the beam. Since the cavity fields are fixed by the servo, this effect is seen by the appropriate increase/decrease in the forward power. When injection is completed the phase is then ramped during acceleration to 2.4 GeV. By adjusting phase, the temperature stabilization problem, associated with the increased power loss in the accelerating cavity during an amplitude ramp, is reduced.

Both cavities emit excessive X-rays above 20 kilowatts and shielding around the accelerating cavity had to be provided.

Results

A gap voltage of 400 kilovolts (80 kilowatts) was achieved in the downstream cavity indicating that an operating voltage of 300 KV is quite reasonable. Both cavities work quite satisfactory at the 40 to 50 kilowatt fixed power level. The RCA A3016 power tetrodes have been operating at the 60 kilowatt level. Both tubes have been operated in excess of 4000 hours without incident. To date we have achieved 120 milliamperes at 2.42 GeV. It is reasonable to expect routine operation over the summer at the 100 milliamperes level.

Further studies will be made to understand the cause of the microdischarges. Any conditioning process will be observed and recorded.

References

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