X-RAY RF SYSTEM UPGRADE AT THE NSLS*

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Abstract

A third RF system was commissioned and the existing two systems were modified. Included in the revisions were a new 100 kW, 50 MHz power amplifier, an infra-red heat sensor monitoring the accelerating cavity temperature to compensate for water film coefficient thermal loss, and the isolation of vacuum-RF seals on the accelerating cavity. The results of these changes will be detailed.

Introduction

With the addition of a second RF power amplifier, 120 milliampere stored beam at 2.5 GeV was achieved in 1985.[1] New lines and additional users were coming on line and the machine was fully operational. Reliability became the top priority. The rf power amplifier was operating near peak ratings as higher beam currents were achieved. Failure of either the PA tetrode or the plate power supply persisted. In addition, heating of the copper clad acceleration cavity caused nagging problems, but replacement of the cavities with a new design would take too long. The addition of a new RF power amplifier and improvements to the existing accelerating cavities have substantially improved system reliability.

Addition of Third RF Power Amp and Accelerating Cavity

For 2.5 GeV operation the stored beam loss per turn is 500 kilovolts. With an overvoltage factor of 1.2, the required total gradient is 600 kilovolts. Using a two cavity system would mean the total voltage/cavity is 300 kilovolts which would require 45 kilowatts of power for cavity copper losses. However, if a third system is used, because the copper losses are reduced by a factor of 2.25 (1.5^2), only 20 kilowatts per cavity is required. For 200 milliamps of stored beam, a two cavity system requires 95 kilowatts of rf power as opposed to 52 kilowatts for a three cavity system. In case one, the power amplifiers runs close to their maximum output capability as opposed to a conservative value of 50%.

In addition, it should be noted that the cooling requirements for the accelerating cavity would also be reduced by 55%.

As expected, the addition of the third system was a major factor in the substantial improvement of reliability.

RF Power Systems

A parallel effort was needed to supply reliable high power to the three x-ray rf cavities. Early problems using air-cooled RCA tubes, modified for the NSLS for higher power dissipation using a water-cooled anode jacket, caused warping of internal tube elements. RCA (now Burle Industries) put substantial effort to modify the design for reliable operation. These RCA type S93414E tetrodes have operationally supplied 100 kW into the x-ray rf cavity when a two cavity system was employed.

Concurrently, an Eimac high power amplifier cavity was installed into a third system using a 4 CW 100,000 tetrode. This system has been operational for 15000 hours with no tube change.

Cavity Temperature Control

A stable, heat/cool temperature control system has been installed to coursely maintain frequency of the x-ray RF cavities at high power levels. Previously, copper I^2R losses at the 50 kilowatt level caused the cavity center electrode surfaces to rise above the external RTD controlled cooling water tempertures by 25°C. This is due to the film coefficient of the copper at a 13 gpm flow rate. This electrode absorbs almost 80% of the total cavity power. Erratic flow through a nonlinear mixing valve with a poor response time further degraded the system. Thermal expansion and contraction of the center electrode stem changed the accelerating gap spacing and had a substantial effect on the tuning of the resonant frequency. The gap sensitivity is 2 KHz per mil in an 8 Khz bandwidth.

The solution was twofold. The flow was substantially increased to 40 gpm and an infra-red system was installed to monitor the internal temperature of the cavity resulting in a more stable system with a better response time.

The simplified block diagram in Fig. 1 shows the basic system. A small target size, infra-red detector senses the temperature of a highly emissive, graphite spot on the center electrode stem and drives a PID type controller. In this way, a loop is closed on the stem surface and forces the temperature to within ± 0.1°C. A mechanical, motor-driven, shorted loop does the fine frequency tuning.

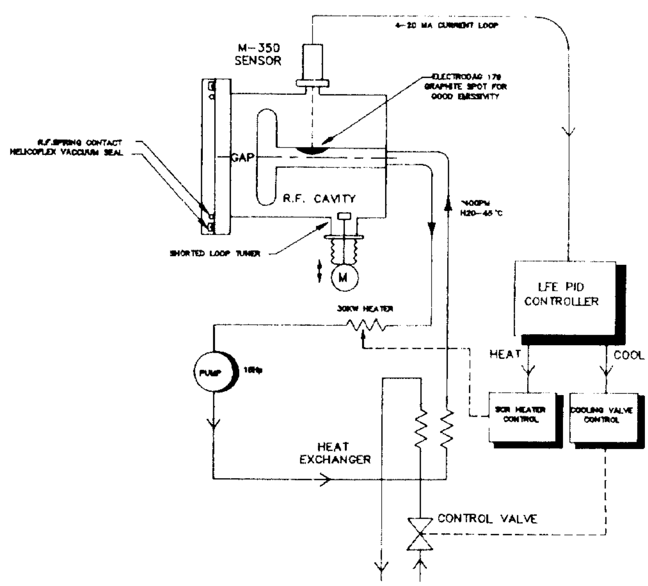

Fig. 1
Xray R.F. Cavity Cooling System

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A 38 mm diameter, AR coated, zinc selinide crystal window sealed in a modified 2 3/4" conflat vacuum flange is installed onto one of the ports of the cavity to house the infra-red sensor. Vacuum seals used in the flange are spring-loaded, soft aluminum, Helicoflex rings with measured leak rates of less than 10^{-10} Torr liter/sec. The 3 mm thick crystal is mounted between two seals and has a flat response over a temperature range of 25°C to 60°C with a >90% transmission, insuring good control stability.

Cavity End-Cover Vacuum Seal

Originally, end cover seals were made up of a ring of annealed copper wire, the ends of which were welded together, and was crushed between two steel surfaces using high torque strength bolts.

The seal served two functions; to seal the cavity, and to finely adjust the resonant frequency. Since the ring had to be crushed an unpredictable amount until a seal was made, the frequency requirement was not always achieved (the cavity bandwidth ≈ 8 KHz and the end cover sensitivity = 8 KHz/0.1 mm).

Now, a one meter diameter Helicoflex seal is mounted on the end cover flange, via eight small screws, between the two polished steel surfaces of the end cover and the cavity proper. The configuration is designed in such a way so that the seal is crushed an amount (~ 1 mm) to insure a good vacuum and also to get the cavity to the proper frequency (see Fig. 2).

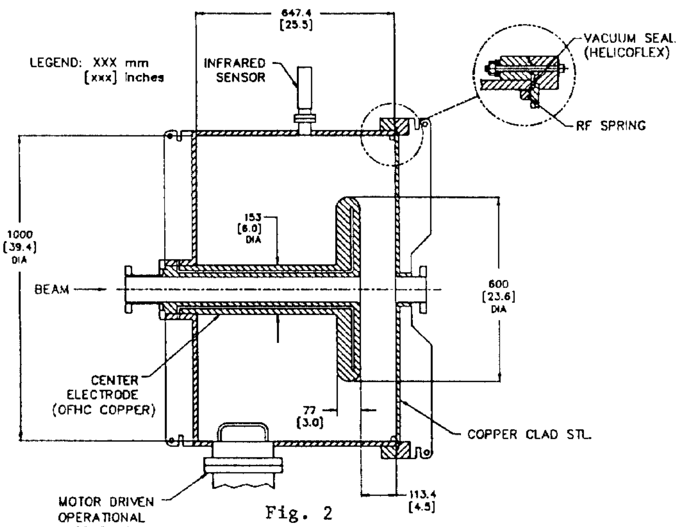

Fig. 2

52.88 Mhz RF CAVITY ASSEMBLY

Performance: Upon changing the seal three times, the resonant frequency of the cavity changed less than 5 KHz, measured after evacuation. These small changes could be adjusted out by changing the bolt torque.

Shorting Loop vs. Slug Tuner

To compensate for beam cavity detuning and water cooling temperature variation, a motor driven cavity tuner is required. Initially a slug tuner was used but spring fingers continuously burned out because of the high cavity wall currents passing through a moving joint. By inserting a shorted loop in the cavity, the center frequency will be increased. The amount of frequency shift will depend on the mutual inductance and self inductance of the loop (see Fig. 3). It can be shown that:

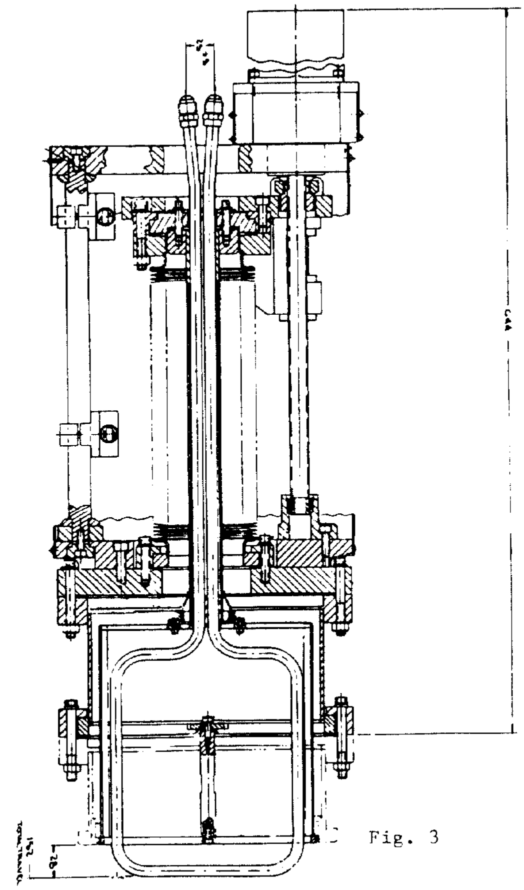
Fig. 3

$$\Delta f = \frac{k(w^2 d^2)}{(L_{loop})(r)}$$

where w = width of loop
d = distance inserted into cavity field
L_{loop} = self inductance of loop
r = distance of loop from cavity center

This assumes that only magnetic field is coupled into the loop. As "d" is increased electric field is coupled which will decrease the frequency change.

With a shorted loop, cavity current no longer passes over a sliding contact. Magnetically induced currents are confined to the water cooled loop. This current is in the range of 100 amperes with a gap voltage of 200 kilovolts. There is some displacement current due to the interception of electric field that travels down the loop shaft and returns to ground through a sliding contact located in the loop assembly. This current is very low however (≈ 15 amperes). It should be noted that in the slug design, 2000 amps passed over a sliding joint. The current density on the spring fingers was in the range of 200 amps/inch.

All cavities are presently equipped with loop tuners. There were some initial operating problems. The loop passes through a grate connected to the cavity by a spring ring, which tended to burn out. This problem was eliminated by welding the grate to the cavity body. In addition the bellows which provide a return path for any currents on the loop shaft, would get hot. This was eliminated by returning the shaft currents to the loop (steel) housing before it could get to the bellows. There is heating of the steel cylinder but it is small. A parasitic resonance was found at 120 MHz in the tuner assembly which coupled to the beam and caused multipactoring. This was also eliminated by the relocation of the shaft return.

Ramping Using Phase

The injection energy into the x-ray ring is 750 MeV. The stored beam is then accelerated to 2.5 GeV. To achieve the total effective voltage at injection the RF systems are counter phased to achieve the net effective voltage and then phased forward as the energy is ramped.[1] This has been effective, but it would still be preferable to ramp power instead of phase because of the complex nature of the impedance which is seen by each amplifier. The load impedance seen by each amplifier may be quite different depending on the method of phasing. At times, the phasing relationship is quite sensitive, with the possibility of beam drop out due to instabilities during the ramp.

The improvement of the cooling system does permit ramping power, but multipactoring still occurs. Recent experiments with titanium coating of cavity and windows have been successful on a new cavity in the NSLS booster cavity. It is intended to coat our test cavity and all three operating cavities.

Summary

The addition of a third RF system, increased cooling, infra-red detection with an improved temperature control processor, and loop tuner implementation have substantially improved the RF system reliability. The addition of a helicoflex vacuum seal and spring ring contact to the end cover has removed the fear of opening the accelerating cavity and aided in system maintenance.

The present system is capable of providing energy to a 2.8 GeV 100 mA beam with each system running at a conservative power of 70 kilowatts. If driven, the system could provide the power necessary for 250 milliamperes.

It is the intent to add a fourth system using a CERN type cavity (211 MHz) sometime in the future. The RF power amplifier system will use a pair of 35 kW Burle Industry amplifier cavities. One unit has been tested successfully and drives the accelerated cavity to a gap field of over 500 kilovolts.

References

1. NSLS RF System Improvements, J. Keane, M. Thomas, R. McKenzie-Wilson, R. D'Alsace, H. Ackerman, R. Biscardi, H. Langenbach, G. Ramirez, IEEE Trans. on Nuclear Science, Vol. NS-32, No. 5, Oct. 1985, pg. 2784-2885.