THE RF SYSTEM OF THE SYNCHROTRON X-RAY SOURCE AT ARGONNE*

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A Positron Storage Ring for the Synchrotron X-ray Source at Argonne is under design. The rf system is described. The rf system is divided into four stations, each using a one-megawatt klystron to excite four single-cell spherical cavities to a gap voltage of 761 kV at the operating frequency of 350.8 MHz. The same klystron also provides the beam power for synchrotron radiation losses of the positron beam of up to 300 mA, the higher-order-mode power losses, the power losses in the beam due to the insertion devices, and the rf power transmission losses. The transmission waveguide system includes magic tees for splitting the power of each klystron to four cavities, isolators to protect the klystrons, harmonic and higher-order-mode absorbers, and mechanical phase shifters for fine phase tuning.

Introduction

The energy of the positron storage ring for the Advanced Photon Source (APS) at Argonne is 7.0 GeV for nominal operation.[1] The hardware design can achieve 7.7 GeV operation. The maximum circulating current is 300 mA at 7.0 GeV and lower at higher energies, subject to rf power availability and vacuum chamber heating limits. The relevant parameters for the design of the rf system are listed in Table 1.

Table 1
Design Requirements for the RF System

	7.0 GeV	7.7 GeV
Voltage for bending magnet radiation, MV	5.45	7.98
Voltage for insertion devices, MV	1.25	1.51
Voltage for Parasitic Modes (per 100 mA), MV	0.25	0.25
Peak RF Voltage, MV	8.43	11.74
Harmonic Number	1248	1248
Energy Spread of Beam, σ_E/E_o, %	0.096	0.106
Energy Spread of Bucket, $\pm \Delta E/E$, %	1.35	1.48
Bunch Length, σ_ℓ, cm	1.36	1.34
Synchrotron Frequency, ν_s	5.6×10^{-3}	6.33×10^{-3}

The frequency of operation was chosen to be 350.8-MHz based on machine physics considerations and the availability of existing 1-MW klystrons.[2,3] Individual single cell spherical cavities of the KEK[4] and SRS[5] design were chosen over a multicell cavity in order to keep the input power per window under 250 kW. Ceramic windows in post-coupled waveguides operate with reasonable reliability in light sources at this power level.[4] A multicell cavity, such as the LEP type,[2] would require input of nearly a megawatt of power if the full voltage capability of the 5-cell cavity was used. Too many operating problems were envisioned with trying to handle that much required power per cavity.

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Cavity

A cross section of the cavity looking in the direction of the beam is shown in Fig. 1. The cavity is directly scaled from the 500-MHz cavity that is being successfully used on the Photon Factory.[4] This allows confident use of scaled values of the well-documented higher-order modes.[5] Direct scaling results in a 14-cm inside bore diameter which, compared to a design optimized for higher-shunt impedance, reduces the peak electric field on the reentrant nose and provides larger clearance to avoid synchrotron radiation striking the cavity surface.

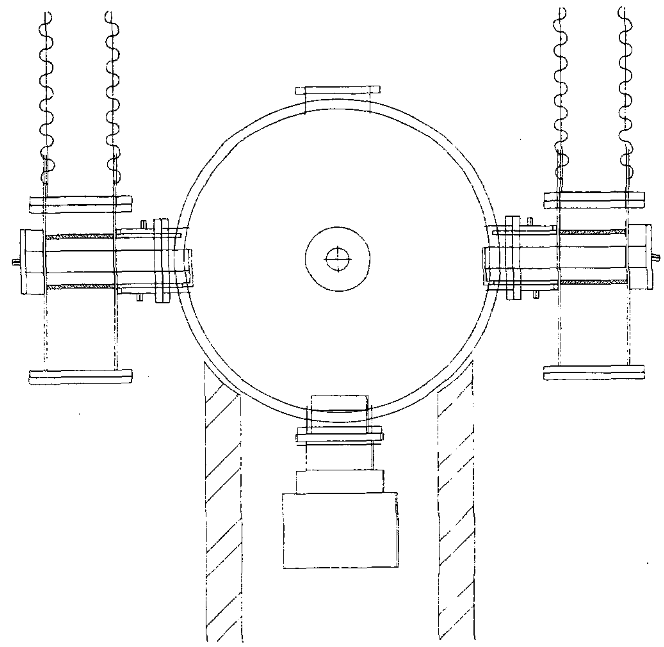

Fig. 1. Cross section of single cell cavity looking in direction of beam.

The theoretical copper loss in the cavity is calculated to be 56 kW with 761 kV across the gap. The power loss in watts per cm^2 on the surface of the cavity varies from 3.5 at the outer radius, 5.6 at a radius of 25 cm from the beam, and 11.4 at 11 cm from the beam. On the tip of the reentrant cone, the power generation drops to 1.3 W/cm^2. The ability of placing cooling tubes close to the source of power generation makes cooling of the single-cell cavity relatively easy.

The voltage at the design limit for the cavity is 761 kV. This is somewhat higher than the 735 kV required for 7.7 GeV operation. The peak gradient on the reentrant cone is calculated by URMEL[6] to be 5.6 MV/m when operating at 761 kV. The voltage and peak gradient for 7.0 GeV operation is 527 kV and 3.9 MV/m, respectively. A tuning plunger is provided which can shift the frequency by 1 MHz to allow retuning of the cavity for beam loading and thermal changes. Power is fed to the cavity through a post coupler in a WR2300 waveguide and a cavity loop. The ceramic window is located around the post coupler. The cavity loop is mechanically adjustable for changing the coupling constant. Two 4" ports, located

90° apart, are provided for higher-order-mode damping using an antenna in one port and a coupling loop in the other, as was done for the Photon Factory cavities.[5]

RF System

A total of 16 individually-excited cavities generate the design value of 12.17 MV. Four straight sections of the storage ring, each with four cavities, will be used. The four rf straight sections will be located in two adjacent pairs that are diametrically opposite across the storage ring. They will be powered in groups of four from a single 1-MW klystron. The physical layout of one pair of rf stations in a storage ring utility building is shown in Fig. 2. A schematic of the waveguide system for a single klystron and four cavities is shown in Fig. 3. Half-height WR2300 waveguide is used throughout.

The 1-MW output from the klystron is equally divided to drive the four cavities. This is accomplished with a series T and two 3-db hybrids. The design of the rf system incorporates a number of elements to eliminate or minimize waveguide resonances and higher-order-mode problems that have been encountered in other heavily loaded synchrotron radiation storage rings.[7] The waveguide of each cavity has a harmonic absorber and a circulator between it and the 3-db hybrid power splitter. The object is to prevent resonating modes in the waveguide branches at the fundamental frequency or the first few higher-order-modes. In addition, each cavity has a coupling loop-antenna mode supressor of the type used

Fig. 3. Schematic diagram of rf system and controls.

at KEK.[5] This system prevents waveguide resonance problems and should help extend window lifetimes, the latter because there is some evidence to suggest that multipactoring due to the existence of higher-order-mode fields is partly responsible for window degradation.

The power requirements per cavity for various operating conditions are listed in Table 2. The highest power listed is 173.7 kW for operation at 7.7 GeV and 200 mA. This condition is for the highest energy of operation and maximum current that would be allowed due to heat limitations on the vacuum chamber components. An individual klystron would be delivering 694.8 kW to the cavities plus some rf transmission losses. Thus, the full klystron output of 1.0 MW would not likely be needed, so that the

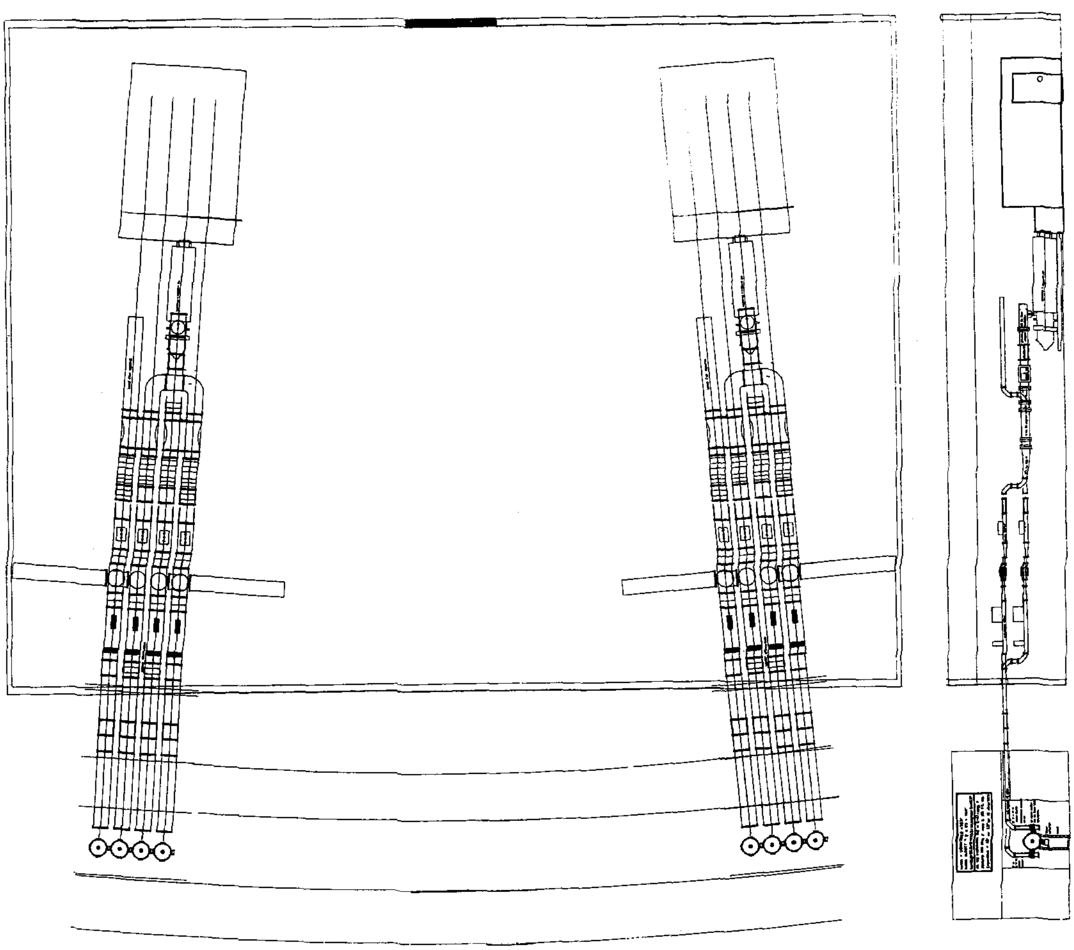

Fig. 2. Plan and elevation views of two adjacent rf systems in an rf utility building.

klystron would be optimized for maximum efficiency at about three-quarters of the maximum tube rating.

Table 2
Power Per Cavity Under Different Operating Conditions

	7.0 GeV 100 mA	7.0 GeV 300 mA	7.7 GeV 200 mA
Copper loss (kW)	26.8	30.1	52.0
Power for Bending Magnet Synch. Rad. (kW)	34.1	102.2	99.8
Power for Insertion Device Synch. Rad (full complement) (kW)	7.8	7.8	18.9
Power for Parasitic Mode Loss (kW)	1.5	4.5	3.0
Total Power Into Cavity (kW)	70.2	144.6	173.7

The controls for the rf system are indicated in Fig. 3. The voltage for the four cavities will be added and the sum fed into an AGC loop for voltage control. Phase shifters are provided for individual cavities. Each cavity has a motor driven plunger, the position of which is controlled by a cavity phase feedback loop.

A higher-harmonic-rf system is included in the design to provide Landau damping or bunch lengthening for added stability. A standing-wave-biperiodic structure of the on-axis-coupled geometry operating in the $\pi/2$ node is used to provide the required 1.8-MV-axial accelerating voltage. The minimum bore diameter of the cavity will be 6 cm. The frequency will be either the second or the third harmonic of the 350.8-MHz fundamental. Commerical klystrons are available for either harmonic.

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