Vacuum Chamber of the Injector Synchrotron for the Advanced Photon Source*

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Abstract

The 40 chambers of the 368 m, 7-GeV injector synchrotron of the Advanced Photon Source are made from 1 mm-thick, 316LN stainless steel tubing. Tubes are cold-drawn to an elliptical shape with inside major and minor axes of 6 cm and 3.7 cm, respectively. This results in a thin metallic chamber without corrugations, which allows maximum beam space in the magnets and withstands atmospheric pressure. Sections of the chamber are bent to match the radius of curvature (33.3 m) of the beam over the entire effective length of the dipole magnets. A modified orbital welder is used to join sections of tubing. The chambers and the pumping system required to achieve a pressure of 10^{-9} Torr are described. A straight section of chamber tubing was tested under external pressure up to 60 psig. At 15 psig, the resulting deflection at the minor half axis was 0.2 mm and a maximum compressive stress of 13 500 psi was measured. Tube deformation remained in the elastic region up to ~ 38 psig.

I. INTRODUCTION

The Advanced Photon Source (APS), currently under construction at Argonne, is a synchrotron radiation research facility. It comprises a 200-MeV electron linac whose output is focused on a tungsten target, a 450-MeV positron linac which receives the target positrons, followed by a positron accumulator ring (PAR), a low energy transport line, a 7-GeV injector synchrotron (IS), a high energy transport line, and a storage ring which can circulate more than 100 mA of positrons for times greater than 10 h, allowing photon beam research at its many experimental beam lines.

The IS (Fig. 1) boosts the beam energy E from 450 MeV to 7 GeV. It has a circumference of 368 m and operates at a repetition rate of 2 Hz. Once each cycle, the positron bunch accumulated in the PAR containing up to 3.6×10^{10} positrons is transferred to the IS for acceleration to 7 GeV. The rf system has a frequency of 351.93 MHz with a harmonic number of 432 (revolution time is 1.228 μs). The magnetic field is essentially a triangle wave-shape with a dipole peak field of 0.7 T. At this field a 7-GeV beam has a radius of curvature $\rho = 33.3$ m. At 7 GeV, the beam bunch is extracted and transported to the storage ring for injection.

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II. VACUUM CHAMBER

A. Configuration

The IS has forty chambers, connected by circular bellows with Conflat type flanges. There are eight Viton sealed gate valves for isolating sections of the ring. Twenty-eight of the chambers are normal cells (NC). Figure 2 shows a mock-up of a NC and Fig. 1 (center) indicates the configuration of its components. A NC (9.2 m long) is enclosed within pairs of H-frame dipole magnets, quadrupoles, sextupoles, and correction magnets. Two beam position monitor (BPM) chambers and one bellows are part of the NC. The NC also includes one Conflat type flange at each end and three Conflat type pumping ports. The lower ports are intended for ion pumps (30ℓ/s each) whereas the top port is isolated with a Viton sealed valve for rough pumping. Sectors 11 and 31 with only one instead of two quadrupoles each, help form mirror symmetry between the top and lower chambers. Sectors 1-3, 19-23, 39, and 40 have one or two "missing dipoles". They house instead, rf cavities, kicker magnets, and septum magnets.

B. Construction

The NC combines straight and bent tubes. The tubes are made from 316 LN S.S. welded sheets. Blanks of 2.5" O.D. x 0.106" wall x 45" long are cold-drawn in three steps to the correct wall thickness (1.0 mm) and equivalent perimeter of the ellipse. The final elliptical shape with inside major and minor axes of 6 cm and 3.7 cm respectively (Fig. 1) (center) is formed in a turk's-head roll set. The final tube length is ~ 340 cm.

The tube wall is sufficiently thin to reduce eddy currents caused by the 2-Hz magnetic field to an acceptable value and thick enough not to require reinforcing ribs. Following a cleaning procedure, the elliptical tubing is annealed at ~ 1000°C in a vacuum furnace. This is a degassing and cleaning operation in addition to stress relief and restoration of low permeability to $\mu \leq 1.01$. Stress relief is desirable before proceeding with the bending operation.

Only tubes which are placed within the dipoles are bent. Bent tubes match the radius of curvature of the beam to the boundaries of the effective length of the dipole magnets. The remainder of the chambers are straight. Special care is taken to protect the annealed chambers from contamination especially during the bending operation. After forming and annealling, tubes are curved in a 3-roll bending machine.

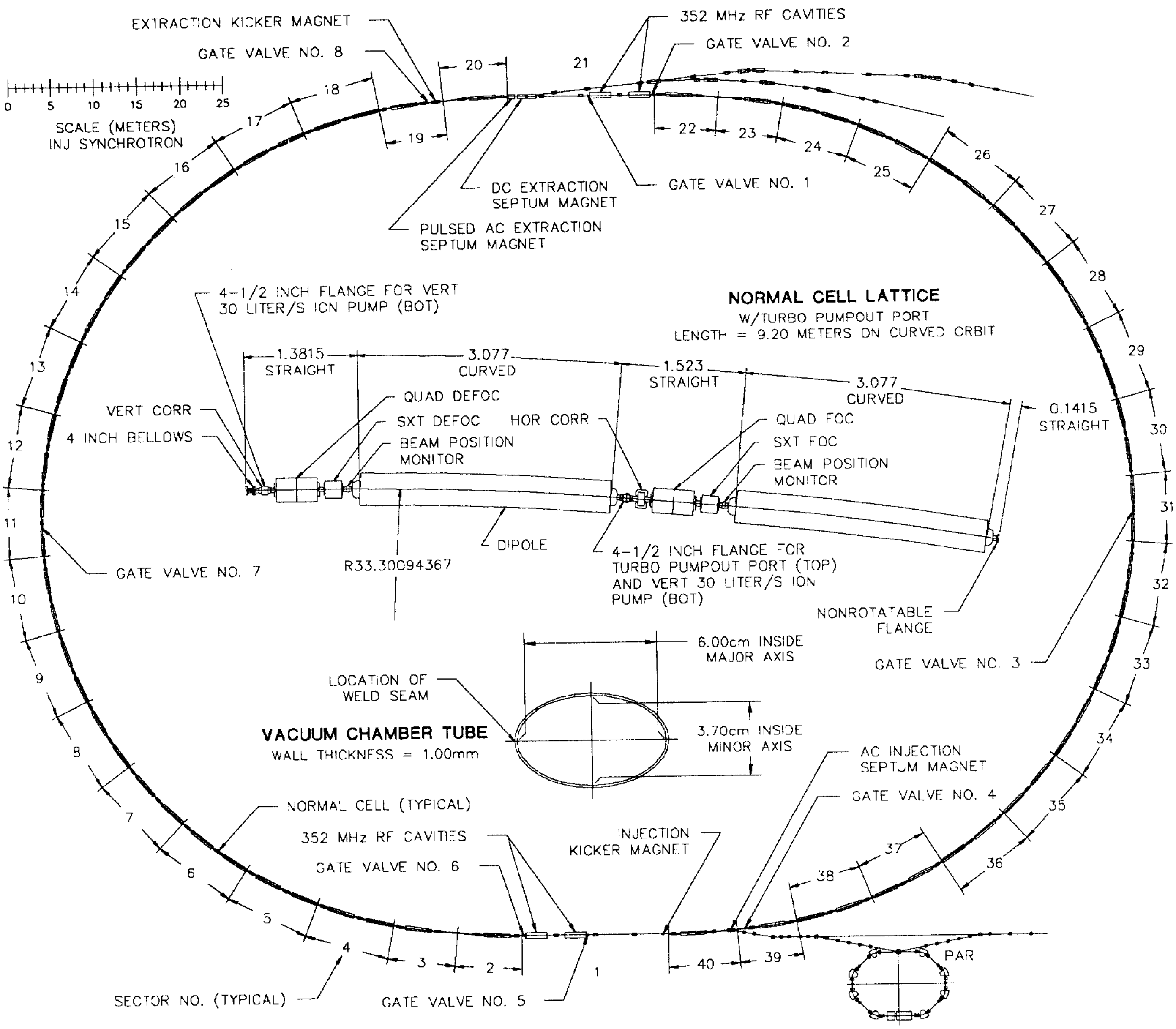

Fig. 1 Injector Synchrotron ring, normal cell lattice and vacuum chamber tube cross-section.

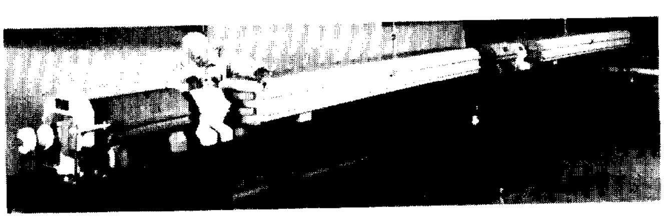

Fig. 2 Mock-up of normal cell lattice.

Roll tooling is specially made to maintain the elliptical tube cross-section. The bend radius of the tube is inspected by comparison against a precision ground template whose length equals that of the tubes themselves.

After conventional end-facing, sections of tubing are butt welded by means of a closed cassette type orbital welding system. The square grooved welds are full penetration, autogenous and made by the gas tungsten arc-welding (GTAW) process. The orbital welding head is provided with elliptically shaped collets to align and clamp the tube. The orbital welding head includes a cam follower designed so that the correct gap is maintained between the elliptical tube and the tungsten electrode.

No butt welds are included within the effective field of a magnet, to avoid magnetic coupling, should some ferrite be present in the welds. Conflat type flanges and other attachments are welded manually by the GTAW process.

C. Vacuum Performance

The assembled chambers are to be baked at 150 °C, mostly to remove water, checked out and stored with a positive nitrogen pressure until ready to install in the ring. Each quadrant of the ring will be rough pumped with three equally spaced turbomolecular pump stations (tmps). The tmps will be valved off when the two 30ℓ/s ion pumps per NC are operated.

With a calculated specific molecular conductance of 13 ℓ · m/s, a specific inner surface area of 1480 cm^2/m and a thermal desorption rate $q_t = 2 \times 10^{-12}$ Torr ℓ/cm^2 · s, the calculated average chamber pressure, P_a, with no beam is 9×10^{-10} Torr. However, with beam, initial photo desorption, q_p, dominates the pressure.

We use Sands' expression[2] to determine the mean number of photons/e^+ · rad

$$\frac{5}{2\sqrt{3}} \frac{\gamma}{137} = 72 \text{ photons}/e^+ \cdot \text{rad} \quad (1)$$

where the total e^+ energy in units of rest energy $\gamma = 6850$ @ $E_{av} = 3.5$ GeV. Given 3.6×10^{10} e^+/bunch, 1.228 μs/rev and an acceleration time ratio of 0.5, we obtain 6.8×10^{18} photons/s. With the constant $K = 3.11 \times 10^{-20}$ Torr ℓ/mol and an assumed initial molecular yield $\eta = 2 \times 10^{-3}$ mol/photon where the contribution of each gas species is $H_2 = 1 \times 10^{-3}$, $CH_4 = 8 \times 10^{-5}$, $CO = 5 \times 10^{-4}$, and $CO_2 = 2 \times 10^{-4}$ mol/photon, a $q_p = 9 \times 10^{-10}$ Torr ℓ/s · cm^2 is obtained. This is a factor of 450 larger than q_t and yields a $P_{av} = 4 \times 10^{-7}$ Torr. Beam losses are dominated by scattering due to Bremsstrahlung and for $P_{av} = 3 \times 10^{-6}$ Torr, losses are acceptable (< 1%). The initial P_{av}, then, is not out of line. Even so, the pressure will improve with integrated stored beam D.

The rate of improvement depends partly on the critical energy of the photons ϵ_c and their angle of incidence Θ.

$$\epsilon_c = \frac{2.218 \times 10^3 (E^3)_{av}}{\rho} = 6.07 \text{ keV} \quad (2)$$

$$\text{where } (E^3)_{av} = \int_{0.45}^{7} \frac{E^3 dE}{7-0.45} = 91.6 \text{ GeV}^3$$

$$\text{and } \Theta = 42 \text{ mrad}$$

The Bessy[3] storage ring experience can be expressed empirically as $\eta = 5 \times 10^{-5} D^{-2/3}$, and is a conservative approach that could be used to estimate D in A-h when the pressure to attain is set at, say, 7×10^{-9} Torr. Since this is a factor of 57 improvement over the initial pressure $\eta \cong 3.5 \times 10^{-5}$ mol/photon then,

$$D = \left(\frac{5 \times 10^{-5}}{\eta}\right)^{3/2} = 1.7 \text{ A-h} \quad (3)$$

D. Structural Performance of Elliptical Tubing

A two-dimensional stress analysis[4] indicates that the structural performance of the elliptical tube is limited by the bending stress. When overloaded, bending stress exceeds the yield point of the material before the tube becomes unstable and buckles. With an external pressure of 15 psig, the maximum bending stress at the major axis is 14 400 psi for a 0.97 mm wall. The corresponding deflection across the minor axis is 0.51 mm. Since the anticipated maximum stress levels approach 1/2 the yield strength of the tube (minimum of 30 000 psi), a test was performed to verify the stress analysis. The test also serves to provide tube performance data under overload conditions allowing determination of tube safety factor for the vacuum condition.

A section of elliptical tube 3.35 m in length was prepared by compressing a 2-in. O.D. 304 S.S. tube of circular cross-section. The resulting oval tube approximates the true elliptical cross-section of the chamber tubing. The difference in radius between the compressed oval tube and the true elliptical shape is less than 0.4 mm over most of the tube. The elliptical tube was fitted with two vertical reference pins protruding internally on the minor axis near the midpoint of the 3.35 m length for sighting the deflection under load. The pins are visible from the ends of the tube and any movement was observable from a distance. Strain gauges were placed mid tube also, along the outside perimeter. The tube was enclosed within a slightly shorter 3.5-in. diameter pipe and welded shut against the tube at the ends of the pipe. The electrical connections to the strain gauge were accessed through a feedthrough. The pipe was filled with distilled water and pressure was varied with a hydraulic pump. The pressure was raised in steps of 5 psi and back to 0 psig until 60 psig was reached.

At 15 psig the measured deflection across the minor axis was 0.41 mm and the maximum measured bending stress was 13 500 psi. Permanent deformation occurred between 35 and 40 psig. Therefore, under vacuum, the tube is operating with a safety factor > 2.5. Thus, the experimental results are more favorable than the analysis, indicating that the elliptical chambers are structurally sound for vacuum operations.

III. ACKNOWLEDGEMENTS

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IV. REFERENCES

[1] "7-GeV Advanced Photon Source Conceptual Design Report", ANL-87-15, April 1987.

[2] M. Sands, SLAC-121, p. 117, Addendum, May 1979.

[3] L. Schulz, et al., *AIP Conf. Proc.* No. 171, pp. 116-123, 1988.

[4] J. Howell, "Analysis of the IS Chamber Tube Loading due to External Pressure," Advanced Photon Source note, Oct. 1990.