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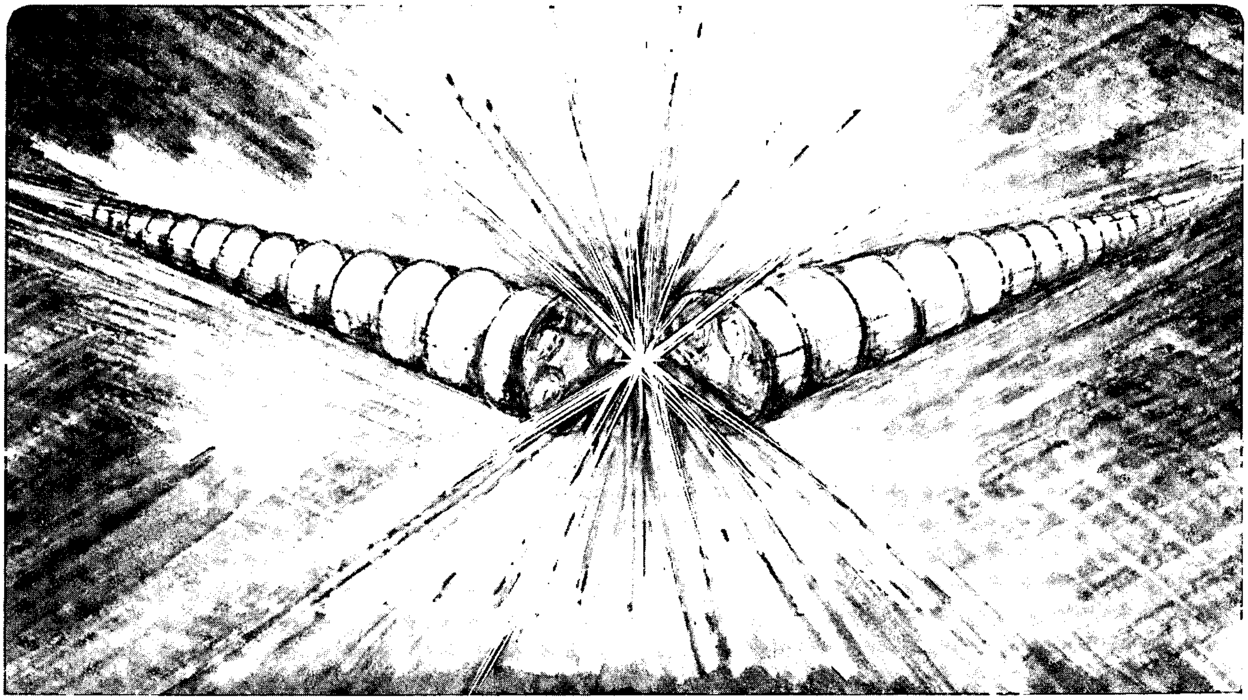

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INSERTION DEVICE VACUUM SYSTEM DESIGNS

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ABSTRACT

Synchrotron light source insertion device vacuum systems now in operation and systems proposed for the future are reviewed. An overview of insertion devices is given and four generic vacuum chamber designs, transition section design and pumping considerations are discussed. Examples of vacuum chamber systems are presented.

INTRODUCTION

During the past 10 years increased flux and brightness of synchrotron radiation has been achieved from electron storage rings with the development and installation of insertion devices (wigglers, undulators and wave-length shifters) at these facilities[1]. Successful vacuum system design of these devices has contributed to this development. With the advent, in the near future, of the 3rd generation synchrotron light facilities, those designed as low emittance electron storage rings expressly for wiggler/undulator sources, vacuum system design for these insertion devices will be challenging.

The importance of vacuum system design for insertion devices can be appreciated when reviewing the development of insertion devices. Most insertion devices built to date can be grouped according to the technology used in the magnetic field structure construction. These include conventional electromagnet, superconducting magnet and permanent magnet technologies.

Figure 1 summarizes peak field performance for period length of various devices built and operated to date[2,3,4,5,6,7,8,9,10,11]. Dashed curves show approximately the present range of performance of insertion devices for the various construction technologies. Insertion devices built with conventional electromagnet technology are generally longer period length devices. At long period lengths these devices have peak fields near the saturation induction of iron and at shorter period lengths the peak field decreased due to limitations in coil cooling. Superconducting magnet technology construction generally is limited in peak field by critical current density in the superconductor. Systems of this type generally tend to be complex and expensive. Wave length shifters use this technology because very high fields are possible. Peak fields obtained in insertion devices built with permanent magnet technology are dependent on the permanent magnet materials used and geometry. Devices using rare-earth-Cobalt and Neodymium-Iron magnetic materials have demonstrated high peak fields with short period length. Generally, peak field performance of conventional and superconducting magnets is inverse to the magnet gap if iron saturation, coil cooling or critical current density are not limiting whereas with permanent magnet insertion devices the field is approximately proportional to the inverse exponential of the

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magnetic gap with highest fields obtained with smallest gaps. Despite the small gap limitation, most insertion devices to date have been built with this technology, primarily because high peak field can be achieved with short period length with simplicity and economy in design. This paper will primarily address vacuum chamber design for electromagnet and permanent magnet insertion devices.

The peak field performance of a typical permanent magnet insertion devices, in this case the BL X Wiggler at SSRL, is shown in Figure 2[9]. Peak field is plotted both as a function of gap and gap to period ratio which allows scaling of magnetic performance to any period length. The figure shows that peak field of permanent magnet insertion devices is a strong function of gap to period ratio; for a given insertion device period length, the maximum field is achieved with a minimum magnetic gap.

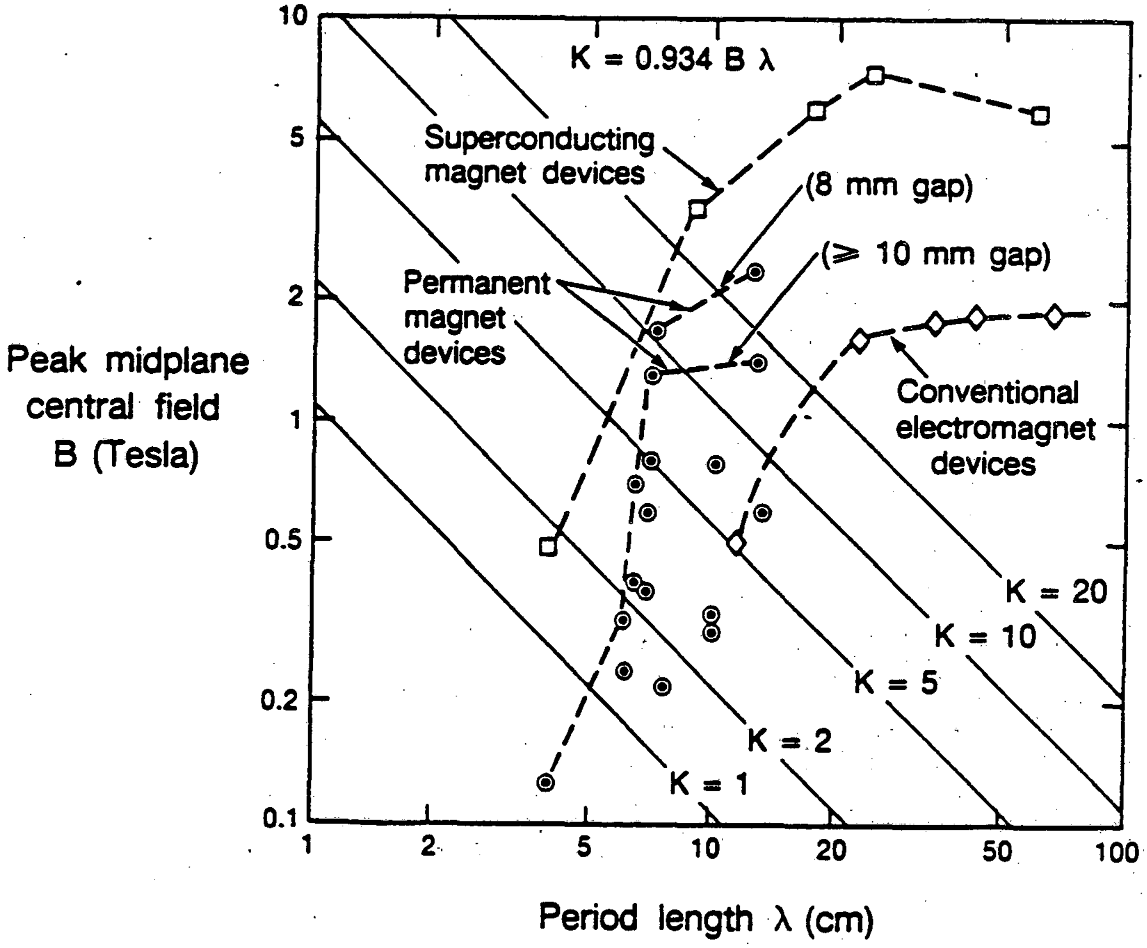

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Fig. 1. Peak Midplane Central Field as a Function of Period Length for Operational Planar Insertion Devices.

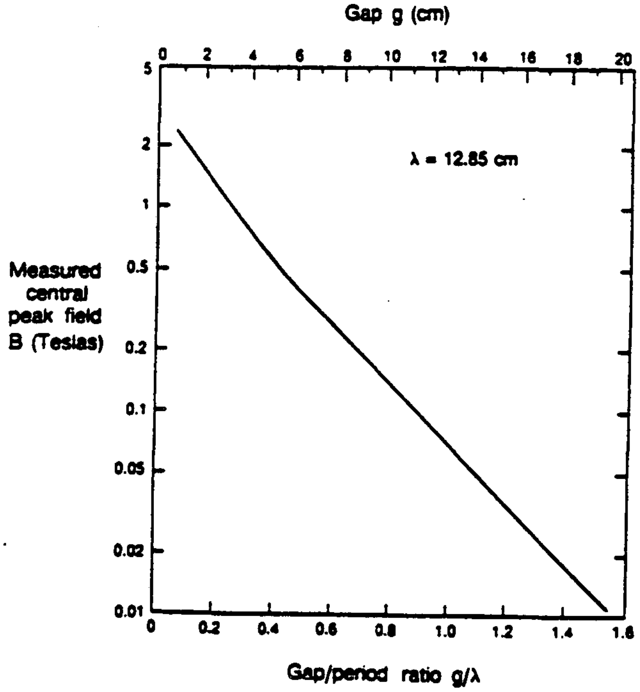

Fig. 2. Magnetic Performance of the BL X Wiggler

VACUUM SYSTEM DESIGN CONSIDERATIONS
VACUUM CHAMBER DESIGN

From the above, generally the main design objective for permanent magnet insertion device design is to achieve the highest possible field which implies the smallest possible magnetic gap. In this case, what is desired is the minimum material thickness between the magnetic structure gap and the beam aperture. This implies a minimum vacuum chamber or image current sheet/outgassing barrier thickness.

A variety of generic vacuum chamber design possibilities can be considered for insertion device vacuum chambers which meet the requirement of minimum thickness for permanent magnet insertion devices and are shown in Table I. The design approaches consider the magnetic structure either in or out of the vacuum chamber, the magnetic structure either bare or canned and the vacuum chamber of either a rigid or a flexible configuration.

Table I. Insertion Device Vacuum Chamber Design Possibilities

Design Type	Magnetic Structure - in or out of the vacuum	Magnetic Structure- outer construction	Vacuum Chamber Construction
A	Out	Bare	Rigid
B	Out	Bare	Flexible
C	In	Bare	Rigid
D	In	Canned	Rigid

Examples of the various vacuum chamber design possibilities suggested in Table I are described in more detail below.

Design Type A:

This fixed vacuum chamber design is the simplest of the approaches shown and has been used most frequently. Table 2 lists a number of chambers that have both been built and/or will be put into operation[9,11,12,13,14,15].

Figure 3 shows the SRC chamber for the LBL-SSRL Undulator[11]. Vacuum chamber thicknesses, fabrication tolerances and clearances add up to 5mm. Figure 4 shows the SSRL BL X Wiggler vacuum chamber. This design achieved 2.9 mm total of the vacuum chamber thicknesses [2 x 0.75mm], fabrication tolerances [2 x 0.53mm], and clearances [0.3mm][9]. Figure 5 shows the NSLS TOK vacuum chamber which totals to 3.2mm for chamber thicknesses, fabrication tolerances and clearances[13]. Figure 6 shows the approach taken at DESY where they have used the technology developed for the thin booster vacuum chamber and applied it to a wiggler chamber[14].

Based on Table 2, welded stainless steel vacuum chambers 2 to 3 meter long, can achieve flatnesses of 0.4 to 0.8mm. Typical loss of aperture due to chamber thickness, fabrication tolerance and clearance is 3 to 5mm. To date, welded aluminum construction for this application has not approached this performance.

Table 3 lists fixed aperture vacuum chambers for facilities now under construction or proposed[15,16,17]. These designs are for the most part conceptual and achieving the required tolerances will be challenging.

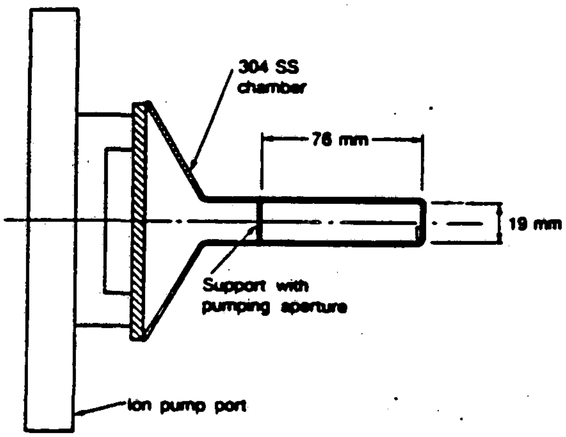

Fig.3. SRC Vacuum Chamber Section for the Undulator

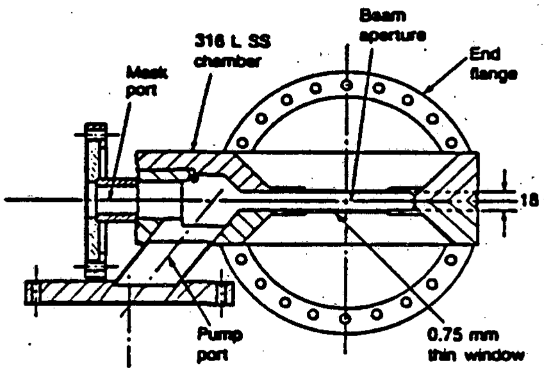

Fig. 4. SSRL BL X Wiggler Vacuum Chamber Section

TABLE 2. EXISTING FIXED APERTURE INSERTION DEVICE VACUUM CHAMBERS

FACILITY	DEVICE	CHAMBER MATERIAL/ CONSTRUCTION	CHAMBER INTERNAL DIMENSIONS (mmxmm)	MINIMUM MAGNET GAP (mm)	CHAMBER LENGTH (m)	ACHIEVED STRAIGHTNESS (mm)	PUMPING IN CHAMBER	VACUUM ACHIEVED (ntorr)	FEATURES/ COMMENTS
SRC 0.75 GeV	LBL-SSRL Undulator	304 SS/welded	19 x 76	24	2.23 m includes transitions	0.38 mm	Yes - 4 60 l/sec Ion Pumps	0.5 - no beam 1.0 with 185mA	perforated wall radial clearing electrodes
SSRL 3.0 GeV	Electromagnetic Wiggler BL IV/VII	6061 Aluminum/ Welded	18 x 127	30	2.04 m	>1.0 mm	No	?	Outer radius water cooled
SSRL 8 GeV	PEP Undulator	6061 Aluminum/ Welded	31 x 92	44	2.22 m	0.5 mm	Yes - 3 100 l/sec Ion Pumps	?	Outer radius water cooled
SSRL 3.0 GeV	BL V Undulator	6061 Aluminum/ Welded	18 x 127	30	2.04 m	>1.0 mm	No	?	Outer radius water cooled
SSRL 3.0 GeV	LBL-SSRL-LLNL BL X Wiggler	316L SS/Welded	18 x 222	21 at Poles	2.25 m	0.53 mm	Yes - 2-220 l/sec Ion pumps 2 more can be added	?	good long.conductance Photon masks at each end of chamber
NSLS 0.75 GeV	TOK Wiggler	304 SS/Welded	27.6 x 80	30.8 at Poles	2.32 m	0.37 mm	Yes - NEG strips 3 sublimation pumps, 120 l/sec Ion pump	0.5 - no beam 2.0 with 800 mA	
NSLS 2.2 GeV	X-1 Undulator	316 L SS/Welded	27 x 60	30	3.24 m	0.84 mm	Yes - 3 sublimation pumps & 120 l/sec Ion Pump	?	
HASY LAB 5.3 GeV	HARWI Wiggler	SS/Welded	?	?	2.5 m	?	No	?	Ribbed construction after the DESY Synchrotron const.
CHESS 5.0 GeV	3.3 cm APS Undulator	304 SS/Welded	12 x 51	?	2.4 m	<1.65 mm	No	?	Completed but not installed
CHESS 5.0 GeV	3.3 cm APS Undulator	304 SS/Welded	12 x 48	?	2.4 m	0.51 mm	No	?	In Fab

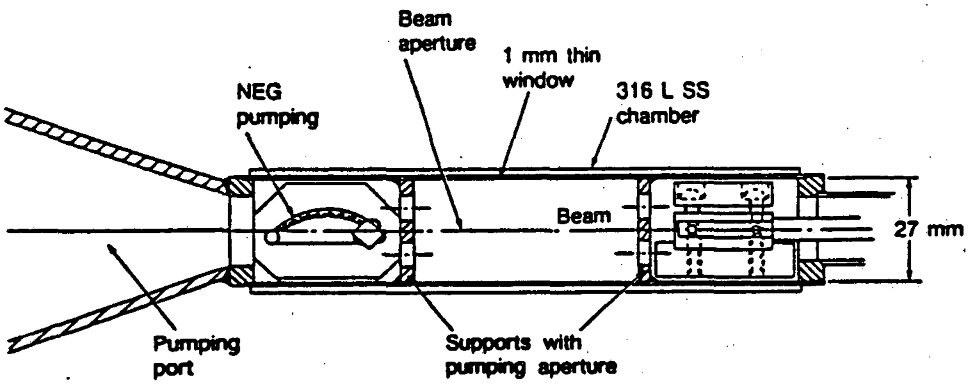

Fig.5. NSLS TOK Vacuum Chamber

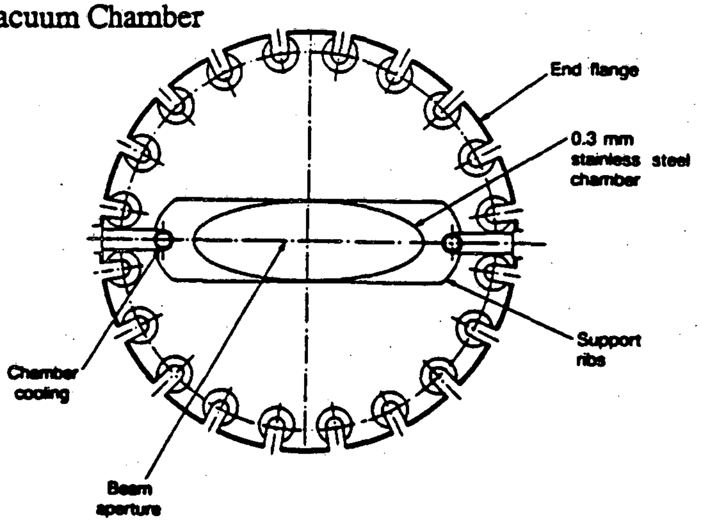

Fig.6. DESY HAWRI Vacuum Chamber

Figure 7 shows a small experimental extruded vacuum chamber built by the APS group that was clamped rigidly to a continuous support structure and found to be straight within 0.23mm over a 5.2m length[15]. Figure 8 shows a conceptual cross-section of the insertion device vacuum chambers for the Advanced Light Source.[16]

Design Type B:

The flexible vacuum chamber has some advantages when compared to the fixed aperture vacuum chamber. In typical electron storage ring operation, the largest beam aperture is needed at injection in the storage ring; thereafter, the beam is damped and then a smaller beam aperture will suffice for stable long lifetime operation. With the flexible vacuum chamber, the vacuum gap is opened for injection and then closed after the storage ring is filled allowing for a smaller magnetic gap, higher magnetic field, than with a large fixed aperture vacuum chamber. Other advantages include excellent pumping when both sides of the horizontal aperture are open and the option, when storage ring operation has difficulties, to open the chamber and operate at a larger gap. With a flexible chamber design, from start-up through dedicated operation, only one chamber is required. This is an alternative to using larger gap chambers at start-up and then retrofiting with smaller gap chamber for production operation that some of the new facilities are presently proposing. To date, the flexible vacuum chamber has been much expensive than a single rigid chamber.

TABLE 3. PROPOSED FIXED APERTURE INSERTION DEVICE VACUUM CHAMBERS

FACILITY	DEVICE	CHAMBER MATERIAL/ CONSTRUCTION	CHAMBER INTERNAL DIMENSIONS (mmxmm)	DESIGN MINIMUM MAGNET GAP (mm)	CHAMBER LENGTH (m)	DESIGN STRAIGHTNESS (mm)	PUMPING IN CHAMBER	DESIRED VACUUM (ntorr)	FEATURES/ COMMENTS
ALS 1.5 GeV	Undulators	Aluminum or Stainless Steel	10 x 235 (max)	14	5.0 m	1.1 mm	Lumped Pumping with good longitudinal conductance	1.0 @ 400 mA	
APS 7.0 GEV	Test Chamber	6063 Aluminum/ Extrusion	8 x 50	?	5.2 m	0.23 mm with support structure	Yes - NEG	?	10 mm extrusion thickness
APS 7.0 GEV	Insertion Devices	Aluminum Extrusion	8 x 50	?	5.2 m	0.34 mm	Yes - NEG	?	Cooling in Antichamber
ESRF 5.0 GEV	Insertion Devices	Aluminum or Stainless Steel	15 x 70 (Phase I)	20	?	?	Lumped or Distributed Pumping	?	

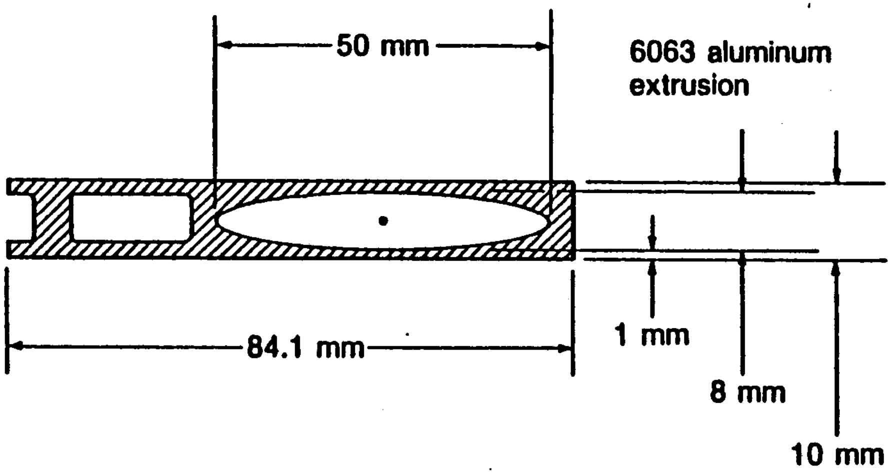

Fig. 7. APS Test Chamber

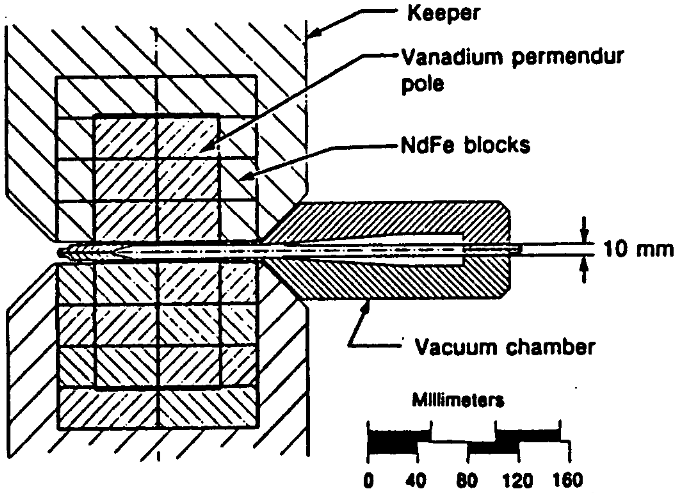

Fig. 8. ALS Conceptual I.D. Chamber

The vacuum chamber of the Beam Line VI Wiggler at SSRL is an example of this type and is shown in Figure 9[8]. Chamber thickness at the aperture is 4mm which has been scalloped out to 1mm thickness at the pole locations. Fabrication of the aperture chamber sections resulted in the surfaces flatness to within 0.5 and 1.0mm. Loss of aperture due to thicknesses, fabrication tolerances and clearances was 4mm. Figure 9 shows the two omega joints which give the chamber its flexibility. These joints, 316SS, 7.5cm nominal diameter and race track plan, 76cm by 254cm, allow the chamber to open to 1.8cm for injection and to close to a minimum of 0.5cm. The vacuum chamber is driven with a separate drive system.

A variation of the Beam line VI vacuum chamber is being explored by the BESSY group for their proposed BESSY II facility[18]. The proposed conceptual design is shown in Figure 10. This design proposes only 1 omega joint, 10mm of motion and a preloaded vacuum chamber which is normally open to the largest gap and is closed to smaller gaps with the magnetic structure drive system.

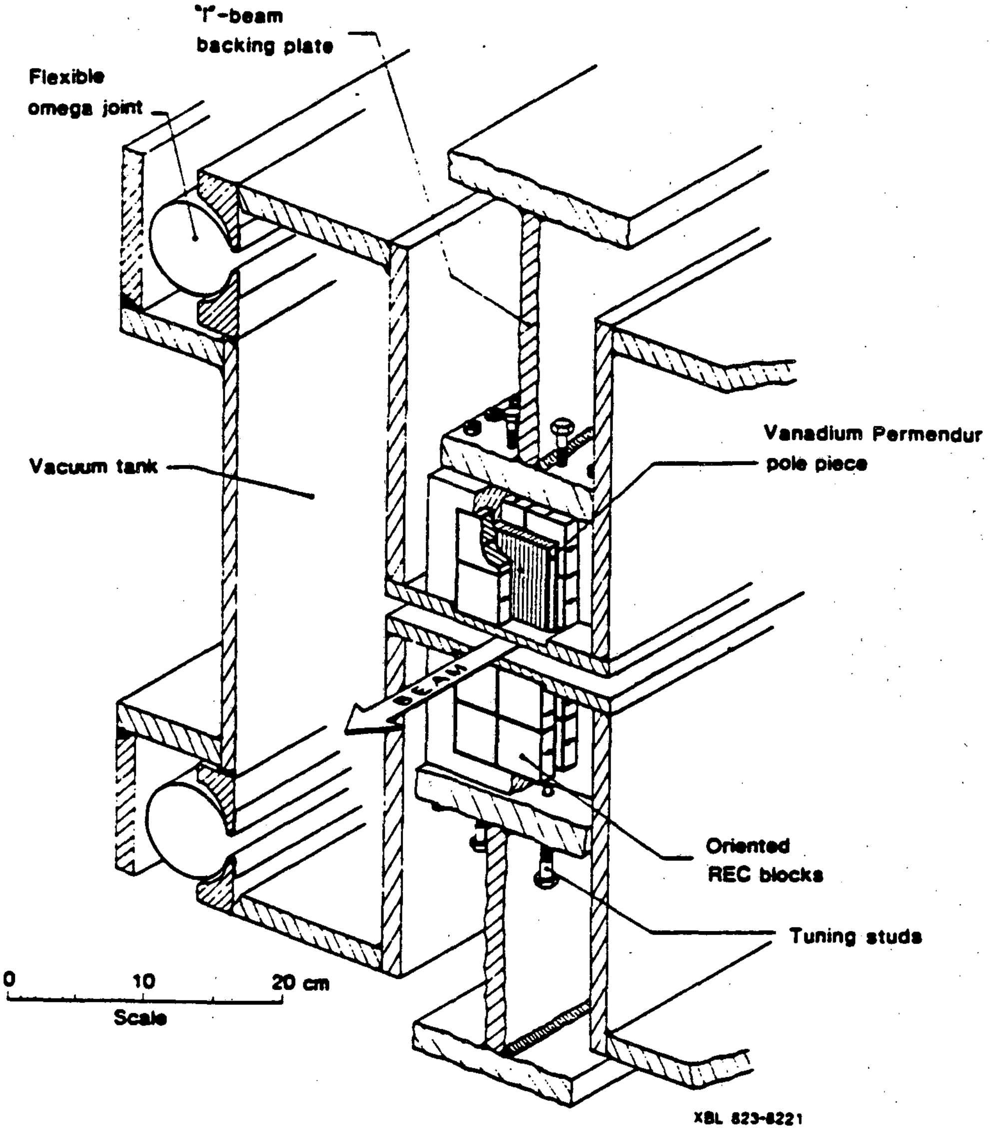

Fig.9. Beam Line VI Wiggler Flexible Vacuum Chamber

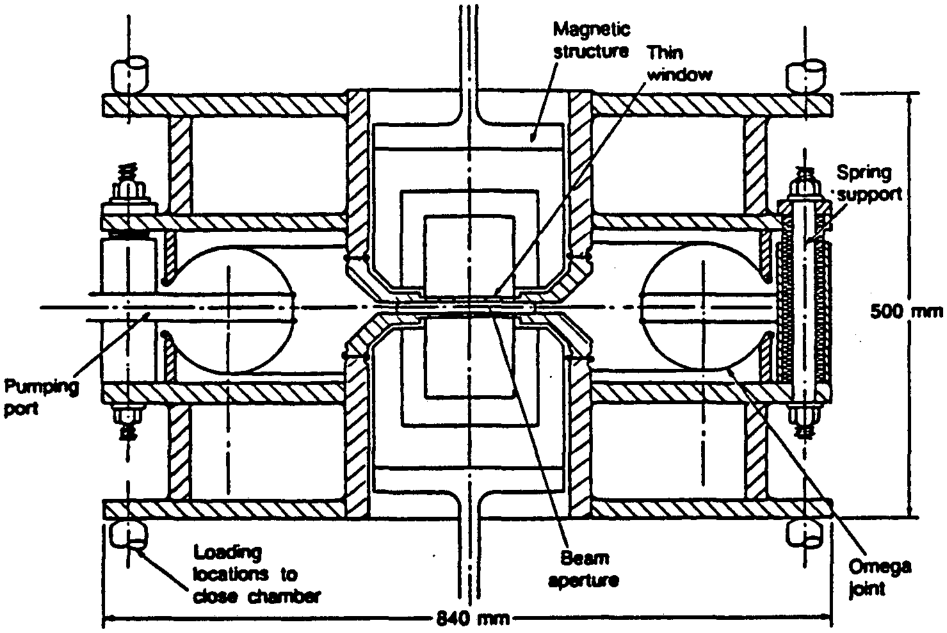

Fig. 10. Proposed BESSY II Insertion Device Vacuum Chamber

Design Type C:

This type of configuration has the insertion device magnetic structure inside the vacuum chamber with thin metallic sheets placed between the beam aperture and magnetic structure to allow for the flow of beam image currents and to reduce the amount of gas in the beam aperture. This type of configuration gives the minimum operational magnetic gap configuration which might be very important for very short period length devices. Disadvantages of this system are that a high pumping speed is required, there is probably limited access to the magnetic structure after it is installed in the vacuum chamber - local adjustments would be virtually impossible to make, and vacuum bakeout must be very carefully monitored and probably done at reduced temperature so as to not induce irreversible loss of magnetization in the permanent magnet structure. An SSRL proposal for a 1.5cm period device would use this type of construction[2].

Design Type D:

This configuration is similar to C in that the magnetic structure is placed in the vacuum chamber but the magnetic structure here is enclosed in a thin metallic envelope that is canned and can be at atmospheric pressure or at a reduced pressure. The advantages of the system are that very little aperture is lost to a vacuum barrier and when compared to the Type C design with less pumping required. Disadvantages are, as in the Type C design. that there is limited access to the magnetic structure and the bakeout must be very carefully monitored and probably done at reduced temperature.

Examples of this construction are the early NSLS UV Ring FEL magnetic structure and the BESSY Multipole Wiggler shown in Figure 11[2,5]. The BESSY device features an 80cm diameter by 2.5 meter long vacuum chamber which is pumped with a 2400 l/sec turbomolecular pump. The vacuum barriers are 0.5mm thick and the fabrication achieved flatnesses of 2mm on one side and less than 1mm on the other side.

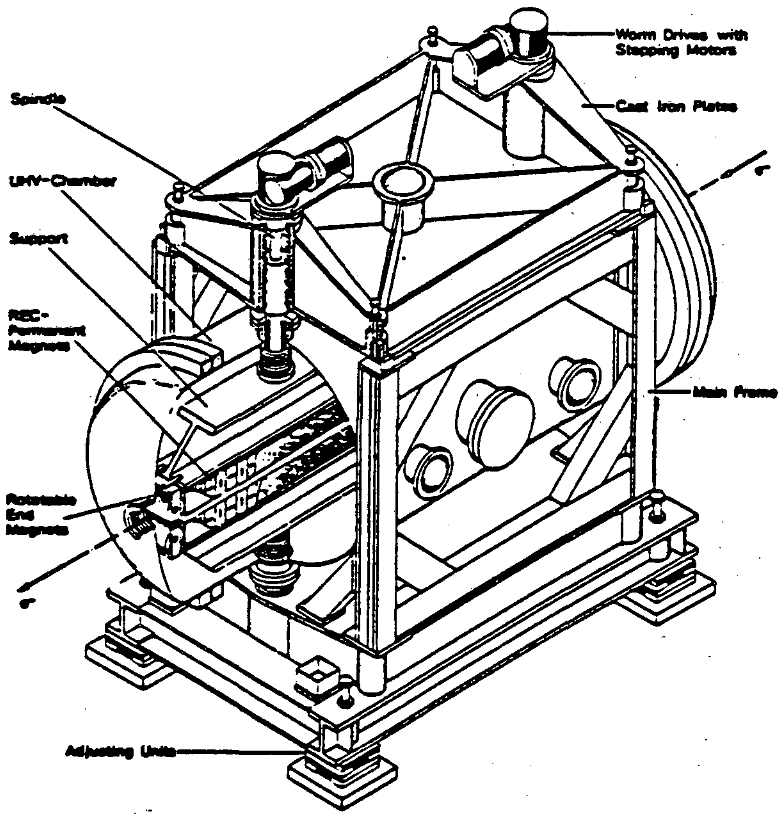

Fig. 11. BESSY Multipole Wiggler Vacuum System

TRANSITION SECTION DESIGN

The transition sections are the connections between the insertion device vacuum chamber and the storage ring vacuum chambers. Important design considerations here are that the transition section be compact and that they provide a conducting surface for the beam image currents from the storage ring vacuum chamber to the insertion device chamber in such a way as to minimize higher order mode losses.

Transition sections may include:

1. An expansion joint which allows for expansion and contraction of both the storage ring and insertion device vacuum chambers and for alignment for these components.
2. Beam position monitors for beam location.
3. Masks for intercepting unwanted radiation from the adjacent magnets.
4. Pumping at the masks for better vacuum.
5. Shutoff valve with "smooth" RF section when open.
6. Instrumentation for beam diagnostics.
7. Appropriate configurations between the storage ring chamber and insertion device chamber to minimize higher order mode losses.

An example transition section design is shown in Figure 12[9]. The bellows allows for 32mm of compression for bakeout and simultaneously a +/- 3mm transverse movement. The low loss RF transition includes a tapered section and capacitively coupled interleaved surfaces. Beam position is monitored with a four button arrangement mounted to the insertion device vacuum chamber. In this design, masking for radiation from the adjacent magnets is accomplished with a mask and pump located just inside the end of the insertion device vacuum chamber.

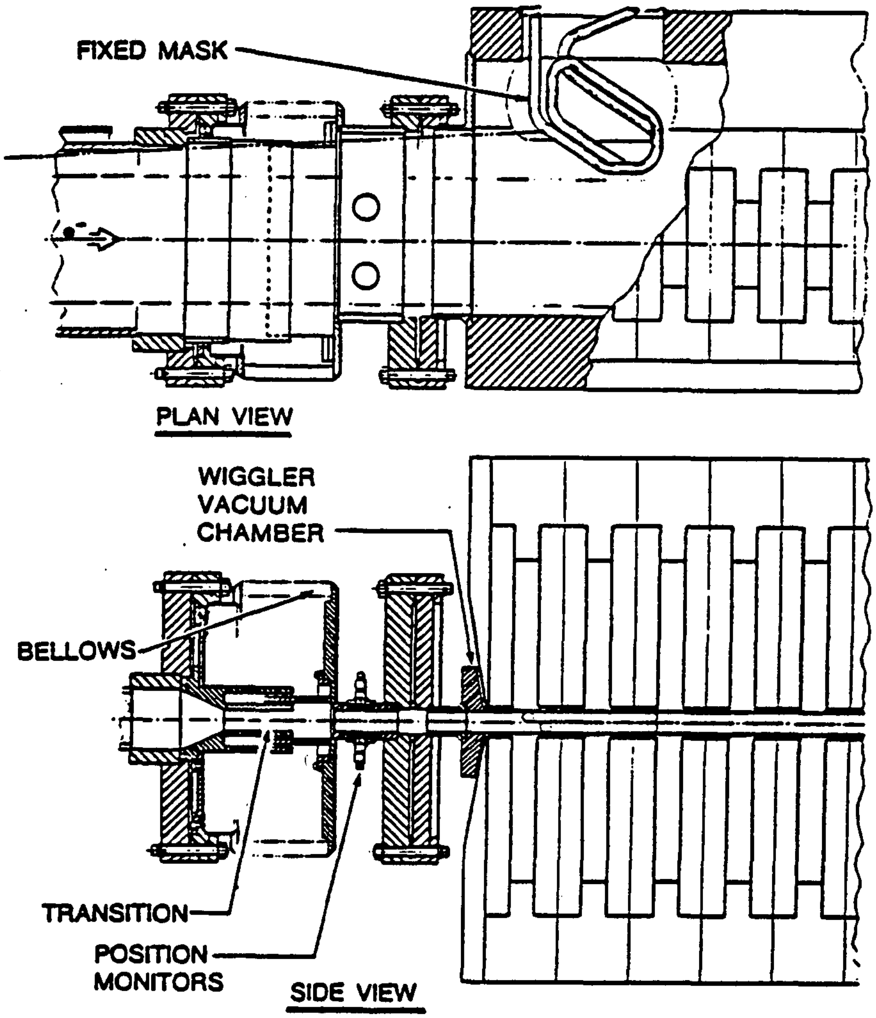

Figure 12: Beam Line X Wiggler Transition Design

PUMPING SYSTEM DESIGN

Base pressure and species of the residual gas in the insertion device vacuum chamber are important for proper operation of the synchrotron radiation source. Typically for an accelerator, the gas-scattering lifetime is inversely proportional both to the base pressure and to approximately the square of the atomic number of the residual gas species[19].

Gas loads in these systems are made up of thermal desorption of gas from the chamber and transition section surfaces but are dominated by photon induced desorption of surfaces due to radiation from the adjacent magnets striking surfaces in the insertion device region. Due to photon stimulated desorption suggests that configuration design and location of pumping should be such that high conductance is achieved from the dominant photon desorped surfaces to the pumped system so that the best possible low base pressure is achieved. High atomic number gases and contaminants need to be held to a minimum.

Pumping systems used for insertion device vacuum systems, now in operation include ion pumps, titanium sublimation pumps, non evaporable getter pumps, and turbomolecular pumps.

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