E.5 Vacuum

5.1 INTRODUCTION

This section considers the vacuum systems of the Storage Ring. By *vacuum systems* is meant primarily the means by which appropriate pressures are achieved (i.e. pumping) and measured (i.e. gauging) and how such pumps and gauges are controlled. This will, perforce, require some discussion on constructional materials for vacuum vessels and on processing of such vessels to achieve the necessary outgassing rates. Except for reasons of clarity, the mechanical construction of the vacuum vessels is not discussed here. Fuller details of this are to be found in Section E.7.

The Storage Ring operates in the ultra high vacuum (UHV) pressure region.

5.2 DESIGN OBJECTIVES

The following objectives were adopted in this design

- to obtain in a reasonable conditioning time (chosen to be 100 Ah) a dynamic pressure of 1 x 10^{-9} mbar at 300 mA stored current, thereby obtaining a beam lifetime of at least 10 hours
- to obtain this dynamic pressure without using an *in situ* bakeout of the storage ring
- to use insofar as possible only proven materials, design methods and techniques
- to use as much modularity as possible in the construction of the vacuum envelope of the storage ring
- to use insofar as possible only standard, commercially available items of vacuum equipment

These objectives have been met in the design presented here, although some details remain to be clarified during the next phase of this project.

These objectives lead to a design which is of all-metal, stainless steel construction, with all vacuum vessels rigorously pre-cleaned and vacuum baked prior to installation.

5.3 BASIC LAYOUT

The Storage Ring is divided into 24 cells. From a vacuum point of view, each cell is divided into a "straight" and an "arc" (in that order). Most straights will, in due course, accommodate an insertion device, although some will be devoted to machine requirements, *viz.*, rf, injection and diagnostics. Each straight will have an in-line vacuum isolation valve (so called sector valves) installed at either end, although some, notably the rf straight, will include further in line isolation valves. The arc contains the achromat, short pieces of straight adjacent to each end of the achromat and the spouts to beam port front ends. There are no in-line vacuum isolation valves in the arcs, although each beam port is so isolated.

For reasons discussed elsewhere, the storage ring will be constructed on a series of girders, with five to each arc. From arc to arc, vacuum vessels and equipment installed on each corresponding girder will be identical. It is intended that for all but minor maintenance work on the vacuum vessels during the operational life of the machine, complete girders will be removed from the ring tunnel to a maintenance area. A "stand-by" preconditioned girder assembly will be installed as a replacement.

Figure 5.3-1 shows the arc layout in schematic form.

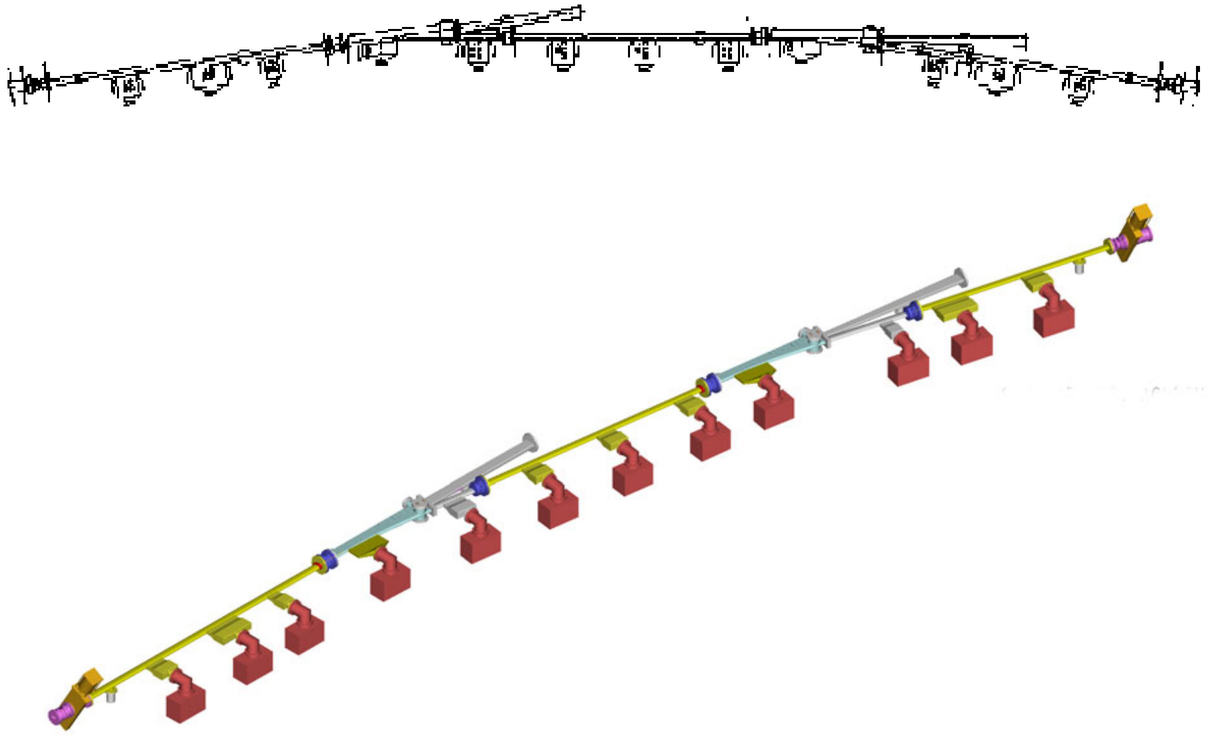

Figure 5.3-1 Schematic of arc layout

5.4 CONSTRUCTIONAL MATERIALS FOR THE VACUUM CHAMBERS

5.4.1 General

One of the major decisions concerning the vacuum system for a synchrotron light source is the material from which the vacuum chambers are to be fabricated. There are a number of points to be taken into consideration. Important ones are properties of the material (vacuum and mechanical) and economics.

Traditionally, synchrotron light source vessels are fabricated mainly from either stainless steel or aluminium. Other materials such as copper or GlidCop™† are used internally in photon stops or radiation absorbers where high heat loads have to be dissipated. Titanium is also a good candidate for special purpose vacuum vessels although it would probably prove too expensive for general use. Some machines - notably B-factories - have used copper as the vessel material.

It should be noted that although one talks about aluminium or titanium, in reality it is alloys of these materials which are used – and a range of alloys are suitable. Likewise, several grades of stainless steel are suitable. These include, *inter alia*, 304L, 304LN, 316L and 316LN.

5.4.2 Vacuum properties

In practice, the main vacuum property of concern is the photon desorption yield and its reduction with beam dose ("cleanup"), illustrated in Figure 5.4-1.

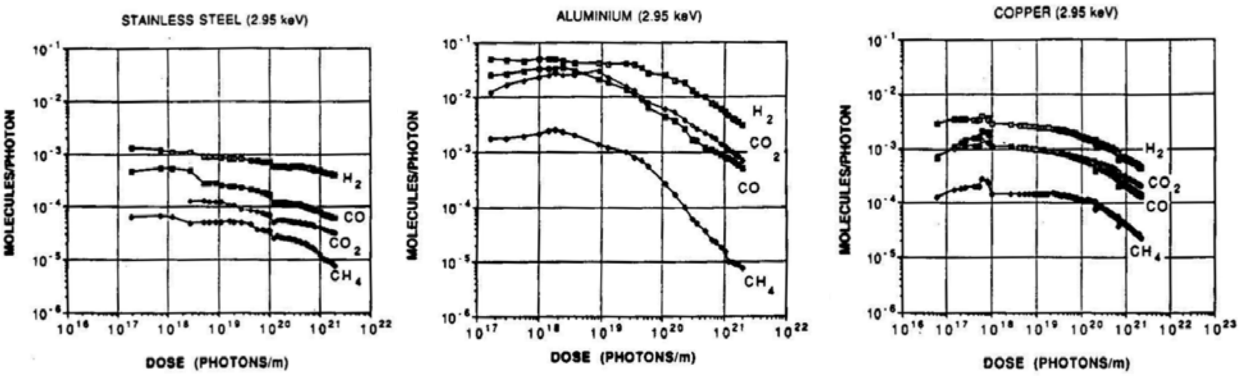

Figure 5.4-1 Photon stimulated desorption yields as a function of beam dose for stainless steel, aluminium and copper [1]

It will be noted that, apart from hydrogen which need not concern us, the three materials behave very similarly after relatively modest exposures to synchrotron light. Copper and aluminium start somewhat higher than stainless steel. All exhibit the so called memory effect in that after a period of beam exposure, subsequently exposing

† GlidCop: Registered trademark of OM Group, Inc., Cleveland, Ohio, USA

surfaces to atmosphere does not lead to desorption yields as high as those from a virgin surface. Aluminium is the poorest of these materials in this respect.

Provided therefore that the vacuum system of DIAMOND is designed to cope with the appropriate gas loads generated in the early stages of commissioning and after exposure of the vacuum system to atmosphere, the use of any of these materials for the vacuum chambers should provide an adequate vacuum level for good lifetime.

Finally, in this context, it should be noted that the dynamic pressure in the machine is limited ultimately not by the desorption from the photon stops or absorbers which the emitted synchrotron light strikes directly, but by desorption by scattered and reflected photons (and by photoelectrons) at other parts of the vacuum chamber. The high intensity in the direct beams leads to rapid cleanup of these relatively small areas, but the lower intensity elsewhere gives a much slower net effect.

This will be discussed in more detail later (Section 5.6 below).

5.4.3 Other considerations

The material choice therefore comes down to factors other than pure vacuum performance. Among these will be how easy the material is to fabricate and clean, things like strength, thermal conductivity, magnetic permeability, surface resistivity and so on. The mechanical complexity of the chamber construction, necessary strengths to minimise distortion and allowable wall thickness will all play their part.

If stainless steel is chosen, then some care needs to be taken in selection of alloys for low magnetic permeability, particularly in weld regions. A value of $\mu < 1.005$ has been used in the past [2]. Such considerations do not arise for the other materials mentioned here.

If stainless steel is the principal material, then there is some concern that the surface electrical resistivity might be too high. The acceptability, complexity and cost of techniques for coating the inner surfaces (e.g. by sputtering of copper) will be considered during the construction phase of the project if it should be deemed necessary. This is also the case for titanium alloys.

One important consideration is the thermal stability of the machine. Stainless steel with its poor thermal conductivity is difficult to stabilise whereas aluminium is much easier. Extruded aluminium vessels can easily incorporate water channels to maintain uniform temperatures, and the possibility of running the machine at a somewhat elevated temperature may be attractive from the control point of view. However, aluminium has a large temperature coefficient of expansion which makes mechanical design more difficult. It is also more difficult to weld than stainless steel, and UK industry has little experience of this for UHV applications. Aluminium vessels may need to be thicker for adequate strength and therefore magnet gaps may need to be larger to accommodate this.

One area where aluminium will almost certainly be used is in the construction of long, narrow gap insertion device vessels. Here the required tolerances are difficult to achieve in a fabricated vessel, whereas a drawn or extruded vessel can so do. Likewise, vessels requiring complex machining are more easily manufactured in aluminium than stainless steel. Where aluminium is used as the vessel material, stainless steel to aluminium transition flanges are commercially available [3].

Copper (or at least copper alloys with suitable strengths) will probably prove more expensive than the other options, and again joining techniques are more difficult.

The experience at the SRS, Daresbury Laboratory, and indeed in most of the UK vacuum industry, is almost entirely with stainless steel and so there is some prejudice in its favour. It appears most likely that most of the storage ring will be fabricated from stainless steel but that aluminium and maybe copper will be used for special vessels where their properties are superior, e.g. small gap insertion device vessels.

Satisfactory cleaning techniques are known for each material. Since new facilities will have to be provided at RAL whatever the choice, there is no major predetermined influence here. (See also Chapter D.3)

5.4.4 Choice of material

Based on the above, the machine will be constructed from stainless steel. Once detailed design of individual vacuum vessels is undertaken during the construction phase of the project, considerations such as economical construction or tolerance requirements might dictate otherwise in individual cases.

5.4.5 Demountable vacuum joints

(a) Flanges

The standard demountable flange for UHV use is of the type knife-edge-on-copper-gasket. There are good, robust design implementations, widely available commercially of which the Conflat™† configuration is the best known. For flanges above 250mm od., there is no standard however and care has to be taken to ensure compatibility. For general use, such a flange will be adopted throughout the machine, particularly for the attachment of standard components such as pumps and gauges. To ensure compatibility, the Daresbury Laboratory standard series of flange types will be adopted [4]. Such flanges are manufactured from cross-forged ESR grade stainless steel, type 316LN[5]. The welding of such flange material to other grades of stainless steel is well understood.

This type of flange normally has a circular configuration. Non circular types are available, but these are not in widespread use. Circular flanges have the disadvantage of being not well matched to the general pseudo-elliptical cross section of vessels

† Conflat is a registered trademark of Varian, Inc, Lexington, Mass, USA

required for the diamond storage ring, either thermally or dimensionally. In addition, there is an internal gap between the closed flange pairs which requires electrical bridging for impedance reasons where flange pairs are in line with the beam orbit.

An alternative type of flat flange using a trapped diamond cross section gasket can easily be made conformal to this vessel cross section and the gasket itself bridges this gap. A commercial implementation of this type of flange configuration (one of which is the so called VATSEAL™[†]) will be adopted for this use. Tests have been carried out at Daresbury Laboratory to confirm their general acceptability. A potential advantage with flange joint of this type is the possible use of a chain clamp rather than a set of fasteners. This has advantages in ease of assembly and requires less space along the beam orbit than that required for bolt insertion. However, tests on the use of such clamps have not been satisfactory and they will not be adopted.

Large joints will use flat flanges with wire seals or Helicoflex™[‡] seals as appropriate.

(b) Gaskets

Where a large machine is required to be bakeable, the use of high reliability gaskets is an imperative. Such gaskets are machined from OFS copper alloy (oxygen free high conductivity copper with 0.1% silver) to high tolerance and silver plated. Such gaskets have good elastic properties up to normal bake temperatures [6].

Diamond is not bakeable *in situ*, but all components require to be baked before installation. For such use, standard OFHC copper gaskets, silver plated, will be acceptable for all flange types.

5.5 VESSEL PROCESSING, TESTING AND QUALITY ASSURANCE

In common with the majority of Synchrotron Sources, diamond will employ rigorous cleaning processes to pre-condition the vacuum chambers and components before installation in the machine complex. This will include pre-installation bakeout for all vessels and components, with the possible exception of the gun/linac.

The cleaning process is described more fully in Part D.3 of this report.

Full details of cleaning, processing, test specifications and item tracking procedures are to be found in the Manual of Quality Assurance Procedures for Vacuum for the diamond Project [7].

[†] VATSEAL is a registered trademark of VAT Vakuumventile AG, Haag, Switzerland.

[‡] Helicoflex is a registered trademark of Cefilac, Saint-Etienne, France

5.6 TO BAKE OR NOT TO BAKE *IN SITU*?

As mentioned in 5.5 above, diamond will employ rigorous cleaning processes including pre-installation bakeout to pre-condition the vacuum chambers and components before installation in the electron storage ring machine complex. This is an essential step in achieving the low photon and thermal desorption rates from the vacuum chamber surfaces required for good beam lifetime. However, it is clear that there is some division of opinion as to whether or not an in-situ bakeout is also essential to reach such a state.

We recall that the main purpose of a bakeout is to desorb water from the surface. Water has a heat of adsorption on most metal surfaces which means that its thermal desorption is rather inefficient at room temperature, although sufficiently high to limit pressures in vacuum systems to around 10^{-8} mbar for very long periods of time [8]. A bakeout at temperatures above 150°C is sufficient to deplete the surface. The depletion is, of course, time dependent and it has been determined pragmatically that to reduce the time required at temperature to less than about 24 hours a temperature of 250°C is required. It is also known that synchrotron radiation desorption of water is a rather efficient process [9]. It is also useful that once the surface is depleted of water, provided that it is initially only exposed to dry gas (containing less than around 1ppm of water) resorption is a relatively slow process [10].

Taking these together, it seems that a good case can be made that bakeout is not essential for machines like diamond.

A survey of operating facilities has been undertaken to assess current practice. Little information on this is available in the published literature. Although not all sources have responded, sufficient have done so for a reasonable picture to emerge [11]. Table 5.6-1 summarises the results of the survey. It will be seen that the twelve facilities listed split evenly. There is no discernable pattern between different types of material or beam energy. Therefore the conclusion is drawn that since so many facilities are in fact capable of operating without bakeout, it is reasonable to assume that diamond can similarly.

It could be argued that some of the facilities were originally designed to be baked *in situ* and it is only later, following considerable conditioning by beam, that it became possible to operate without bakeout. The evidence does not support this since some of the facilities have never been baked.

Table 5.6-1 Summary of use of *in situ* bakeout at various facilities

SR Facility	Material	Beam energy (GeV)	In-situ bakeout used
APS, Argonne National Laboratories, USA	Aluminium	7.0	Yes
BESSY II, Germany	Stainless steel	1.9	No
CERN, Switzerland	Stainless steel and Al	300	Yes
CHESS, Cornell, USA	Aluminium	5	No
ELETTRA	Stainless steel	2	No
ESRF, Grenoble, France	Stainless steel	6	Yes
KEKB, Japan	Stainless steel and copper	8	No
LNLS, Brazil	Stainless steel	1.15	Yes
MAX-LAB, Sweden	Stainless steel	1.5	Yes
NSLS, Brookhaven, USA	Aluminium	2.5	Yes
SLS	Stainless steel	2.4	No
SRS, Daresbury Laboratory, UK	Stainless steel	2	No

5.6.1 Surface Treatments for diamond Vacuum Vessels

To clarify the requirements for surface treatments for the vacuum vessels for diamond, a consultant, Dr E. M. Williams was engaged to carry out a literature survey in this area, supplemented by visits to various European Accelerator Laboratories [12]. A full report is in the course of preparation [13], but the following is a summary of the findings.

"There is by now a broad database on the response of gas desorption at technological materials arising from stimuli of electrons and photons available to the designer of vacuum systems for modern synchrotrons. Moreover, studies with photon stimulated desorption have progressed from observations on small samples of wall material, to the investigation of desorption yields directly at real sections of vacuum ducts, simulating the actual conditions within a storage ring. These have shown that the desorption yields are dependent upon material and surface pre-treatment mainly during the initial stage of irradiation. Furthermore, high initial desorption yields tend to reduce more speedily and the difference between material and surface-pre-treatments become smaller as beam conditioning proceeds. The cleaning process imparted by the stored beam serves to deplete both surface and sub-surface/bulk gas and involves the whole of the vacuum enclosure, not only the part directly illuminated by synchrotron light. Bakeout and glow discharge cleaning can accelerate the removal of the more immediate surface components of gas, but offer no substitute to the action of the synchrotron light in reducing the desorption response to the levels ~10^{-6} mol./photon required to attain working beam-lifetimes.

"In assessing the role of the synchrotron light in the conditioning of third generation light source, a distinction can be drawn between the achromat regions with relatively high photon intensity and the straight sections for insertion devices (I.D.), which are illuminated mainly by radiation incident at the up-beam end. This offers realistic conditions for beam cleaning at the achromats, however, the whole of the machine is involved in the progression towards the design lifetime. For the straight sections, considerations for vacuum are not only linked to lifetime, but as recent experience has shown the utilisation of synchrotron light by users can be impeded by the build up of significant bremsstrahlung radiation over the 10-15 m linear dimensions of these regions. The design of vacuum systems for external I.D.'s has been approached along two fronts - either with an antechamber design so as to offset the low conductance inherent with the narrow vertical spacing, or using NEG coatings as a distributed pump directly at the interior. Both approaches are likely to incorporate bakeout facilities, additionally for the NEG coating, heating forms part of the activation procedure. In this regard, the discovery of ternary alloy NEG materials with activation temperatures as low as 180°C is clearly viewed with some interest.

"In the case of in-vacuum undulators, designs can be based on more conventional vacuum approaches.

"The action of beam conditioning at the achromats proceeds through primary irradiation as well as through the action of reflected and fluorescence radiation, which pervade the whole of the interior surface. Tests with sample ducts predict that the desorption yield beyond an exposure around 10^{21} photons/m follows an inverse dependence on the accumulated beam exposure, taking a form independent of the initial surface preparation. To reduce yields towards the lower limits demanded by lifetime considerations requires doses in the region of 10^{24} photons/m. Under typical conditions of operation of a third generation light source, this accumulation occurs over a period ~100 Ah of beam operation. The initial phase of gas desorption imposes the greatest load and its reduction ahead of beam cleaning has traditionally been the role of an in-situ bakeout. At this stage of operation, water is likely to dominate the residual gas spectrum. Experience at ELETTRA in the mid 90's, demonstrated that the storage ring could be commissioned on a practicable time scale with total reliance on beam cleaning and without requiring an in-situ bakeout. More recently synchrotron sources both in Europe (SLS, ANKA) and Japan (KEKB, PF) have been designed to operate with this philosophy. The most rigorous approach for the reduction of the initial gas load has been the strategy followed at the SLS. This involved a pre-bakeout of assembled achromat sectors at 250 °C and their subsequent transfer under UHV to form the storage ring. A comparison of operational data between the SLS and the ANKA storage ring, where pre-bakeout of chambers was carried out as part of a vacuum integrity test, suggests a gain by a factor of between 2 and 3 in the time scale of vacuum performance. The current-lifetime figure and specific pressure rise found at the SLS with an accumulated dose of 100 Ah are respectively 4 Ah for and 3.10^{-8} mbar/A, which are quite comparable to findings quoted for ELETTRA and for the ESRF. Likewise at the electron storage ring at KEKB utilising copper duct material, the same figure of specific pressure rise is apparent at 100 Ah beam exposure. The procedure followed by the Japanese workers has been to bakeout individual chambers at 150 °C, followed by nitrogen purging and sealing prior to incorporation at the ring, with particular care to minimise air exposure.

"Thus, omitting in-situ bakeout is a feasible option for the achromat sections, although preparations such as pre-baking and the careful control of UHV integrity will contribute to a successful start up. The procedure to be followed is finally a matter of one's design philosophy. There are considerations of accidental damage and problems with leaks, and this is where the procedure with an in-situ bakeout would perhaps be likely to score, although reflecting upon practice at ELETTRA the turn around while attending to repairs or modifications is not seen as a particular limitation. In this regard, the memory effect which accompanies the beam clean-up serves to advantage. For the straight sections with external I.D.'s, then from a vacuum standpoint the choice of either an ante-chamber or a NEG approach is acceptable. The decision hinges on the philosophy which relates to the whole machine, in particular, the design and utilisation of local absorber sites at the achromats which can be set closer to pumps with a full ante-chamber design." [13]

5.7 VACUUM PUMPING

5.7.1 Rough Pumping

(a) Introduction

Rough pumping of the Diamond storage ring is an essential and important process. The need to generate pressures lower than 1×10^{-6} mbar in a reasonable time so that the UHV pumps can be started is crucial to the efficiency with which Diamond can reach base pressures and begin operation. It is also essential that the pumping systems employed are clean so that there is no possibility of contamination of the storage ring. Therefore it is most likely that clean turbomolecular pumps with magnetic suspension and backed by molecular drag pumps and either scroll or piston pumps will be used. Other combinations are possible and will be evaluated during the procurement phase of the project.

Calculations of rough pumping times have been performed using Vactran™ [14], a vacuum technology software package capable of simulating real vacuum systems in both viscous and molecular flow pressure regimes.

There are two considerations in calculating such pump down times for large vacuum systems like the storage ring. The first is the volume of the vacuum system to be pumped and the second is gas flow conductance along the beam tube, which limits the rate at which gas can reach the pumps. Conductance is the dominating factor in the diamond storage ring. When one cell of the storage ring is considered, it is clear that there are a number of different conductance elements, which will limit the pump down time. These include the pumping ports, bending magnet vacuum chambers, multipole magnet vacuum chambers and straight sections.

Although Vactran™ has limitations, for example it only permits circular pipes to be considered, these can be overcome and test calculations on the existing SRS machine configuration gave results comparable to pump down times achieved in practice.

(b) Pumping stations

A fundamental matter to be considered is whether to use fixed (i.e. built in) rough pumping stations or mobile pumping units. The arguments for and against each type are discussed thoroughly elsewhere [15]. On the basis of the evidence presented there and on many years of operational experience of the SRS, fixed pumping stations will be provided. There are major advantages in this approach, even though it is the more expensive option. A pumping system is always available when required and it can be kept clean and free from contamination. This results in major gains in operational efficiency, especially when an emergency intervention is required.

Pumping stations will be located adjacent to each insertion device straight and to the rf straight, injection straight and diagnostic straight. The stations can be manifolded to each adjacent arc and to the straight by means of manual valves, giving some flexibility in their use.

(c) Pump down times

Figure 5.7-1 shows the pump down time for an arc using a pump set comprising a nominal 300 l sec^{-1} turbomolecular pump and a combination drag and diaphragm pump. The curves to consider are those showing pump down with gas load (composed primarily of water vapour). The upper set of curves is essentially the pump down by the primary pump set and the lower that of the turbomolecular pump. A pressure of 10^{-5} mbar is a reasonable upper limit for starting and conditioning ion pumps (see 5.11.4(b) below), so it will be seen that about two days prepumping is required per cell. This is considered to be acceptable. It can be shortened by applying pumping at each end of the arc from the pump sets in adjacent insertion device straights. This will be useful during operations when quick pump downs are desirable. On the other hand, using a single pump set to pump two adjacent arcs (i.e. installing a roughing set only every other straight produces an unacceptable pump down time of about a week for an arc without the possibility of enhancement.

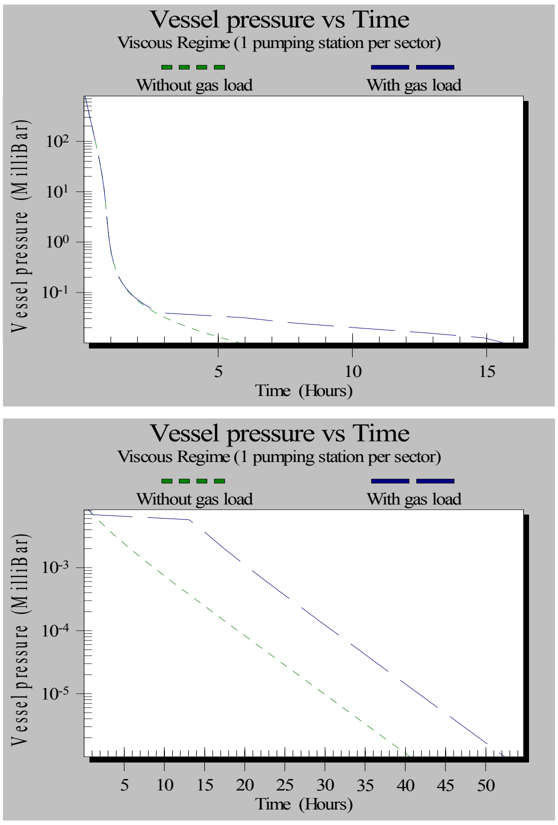

Figure 5.7-1 Pump down times for the Diamond storage ring with one pumping station per cell

5.7.2 UHV pumping philosophy

In this design, the aim is to achieve the necessary pumping by using only lumped pumps attached to the vacuum vessels by pumping spouts of some sort. This simplifies the mechanical design, since no special arrangements are required to accommodate integrated pumps within the vacuum envelope. It also improves serviceability, since, with careful attention to layout detail, individual pumps can be removed and replaced without necessarily removing vacuum vessels to strip out internal pumps. This feature is, of course, not so important if the removable girder philosophy is adopted, but is still convenient for increasing maintenance options. The types of pumps used are discussed below.

The available space in the storage ring for installing vacuum pumps is very restricted, so it appears that most of the pumps have to be attached to the electron beam tube through horizontal pumping spouts aligned along the beam tube and coming in through either the dipole magnet aperture or between the poles of the quadrupole magnets. Because the vertical aperture available is less than the dimensions of a typical pump throat, most of the lumped pumps are attached to the chambers by fin-shaped pumping spouts similar to those shown in Figure 5.7-2. The gas flow conductance of these spouts limit the pumping speed which can be deployed. Some of the pumps can be fitted beneath the vessel containing the crotch absorber or beam port absorber and in these cases, larger aperture tubes can be used and a greater pumping effect achieved.

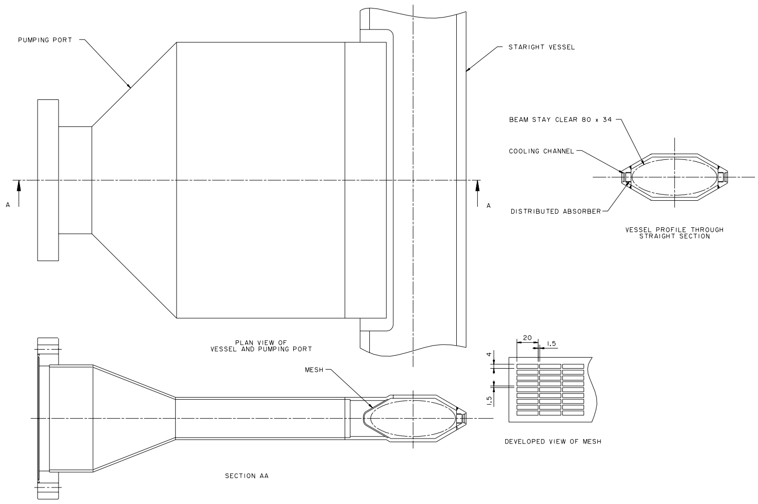

Figure 5.7-2 Schematic of a typical pumping spout

In a storage ring like diamond, apertures such as these pumping ports are usually screened with a mesh comprising a thin plate pierced by rectangular apertures with the long side of the aperture oriented along the beam direction. This is to provide radio-frequency electrical continuity along the pipe. Such meshes of course further reduce the available pumping speed at the beam orbit, although the effect can be made quite small with careful design.

5.7.3 UHV pumps

The generic types of UHV pumps to be considered for use in diamond are

(a) Sputter ion pumps: differential ion diode configurations will be used since these display the best compromise of properties – good starting at relatively high pressures; good low pressure performance and good pumping speed for inert gases. These will be the "workhorse" pumps.

(b) Titanium sublimation pumps: these give good pumping performance for active gases at low pressure and are relatively inexpensive. Long experience of their use in the SRS has demonstrated that with careful control and rigorous outgassing they provide useful pumping over long periods of time before requiring filament replacement. The pumping speed and capacity depends on the surface area available to be coated by the thin film of titanium (or usually titanium-molybdenum alloy)

(c) NEG (non evaporable getter) cartridge pumps: these also give good pumping for active gases at low pressures. They provide high pumping speeds in small pump volumes but have the disadvantage of requiring high temperature activation from time to time and are relatively expensive.

In addition to these pumps, the relatively new technology of using vessels internally coated with a sputtered film of NEG material will be adopted for special situations [16]. Although this technology provides good pumping speeds in conductance limited situations where other pumping is relatively ineffective, it is a new technology and long term efficacy is still not proven. It will therefore be adopted only for vessels which can readily be replaced without compromising the operation of the storage ring, e.g. in insertion device vessels.

5.7.4 Applied pumping speeds

As noted above, much of the pumping available in the beam tube is applied through the fin-shaped pumping spouts illustrated in Figure 5.7-2 above The actual pumping speed available is therefore restricted by the transmission probability of gas molecules through these spouts to fixed vacuum pumps (some combination of ion pumps, titanium sublimation pumps or non evaporable getter pumps). The physical size of these spouts in the vertical plane is severely limited by the need to bring them through the pole pieces of the quadrupole magnets in the present design. There is somewhat more flexibility in pumping in the region of the dipole magnets.

The transmission probabilities for several variants of the pumping spouts (details are shown in diamond drawings A0-302/10292 to A0-302/10296) have been calculated using Monte-Carlo simulations [17]. These are referred to in Table 5.7-1 as “narrow ports” and are as shown in Figure 5.7-2. There is, however, the possibility – at the cost of some minor engineering complexity - of opening out these spouts as soon as the magnet aperture restrictions are cleared. These are referred to here as “open ports”. The table shows the effective pumping speeds available at the beam for the different pump spouts with nominal pump speeds of 200 and 500 l sec^{-1}. As may be seen, there is no benefit in using larger pumps with the narrow spout, i.e. the effective pumping speed is limited by the conductance of the pumping spout. However, the effective pumping speed can be increased by a factor of about two for the open port using a pump of nominal speed 500 l sec^{-1}.

The implications of this on the sizes (speeds) of the actual pumps to be used will be considered later (5.9.2 below).

Table 5.7-1 Effective pumping speeds at the electron beam orbit

	Pumping port			Effective pumping speed S_{eff} (l sec^{-1}) for a pump with pumping speed S			
	Width (mm)	Transmission probability	Vacuum conductance (l sec^{-1})	S (l sec^{-1}) 200	300	400	500
Dipole vacuum chamber spout	260	0.198	202	100	120	134	143
Quadrupole vessels with narrow pumping ports							
Wide gap 23 mm	200	0.155	75	54	60	63	65
	300	0.145	106	69	78	84	87
	500	0.117	143	84	97	105	111
Narrow gap 16 mm	300	0.128	62	47	52	54	55
Quadrupole vessels with open pumping ports							
Wide gap 23 mm	200	0.38	183	96	114	125	134
	300	0.352	256	112	138	156	169
	500	0.292	357	128	163	189	208
Narrow gap 16 mm	300	0.38	185	96	114	126	134

5.8 AVERAGE DYNAMIC PRESSURE

5.8.1 General considerations

The gradual reduction of pressure in an electron storage ring as it is exposed to the photons generated by the circulating electron beam is by now well known [18]. The phenomenon of beam cleaning or “scrubbing” is reasonably well understood insofar as generalised predictions of clean up rates can be made on a phenomenological basis by drawing on the experience of operational storage rings around the world. The basic physics, chemistry and materials science underlying this phenomenological approach to this complex process is not well understood. In this report, it is assumed without further discussion or justification that this approach is valid.

5.8.2 A model of dynamic desorption processes in a beam vacuum chamber

The equations of gas dynamic balance inside a vacuum chamber can be written as:

$$V\frac{dn}{dt} = q - cn + u\frac{d^2n}{dz^2}; \qquad \textbf{(1)}$$

where n	[molecule m^{-3}]	is the gas volume density;
z	[m]	is the longitudinal axis of the vacuum chamber
V	[m^3]	is the vacuum chamber volume;
q	[molecule sec^{-1}]	is the gas desorption flux;
$c = \rho A_{mesh}\bar{v}/4$	[m^2 sec^{-1}]	is the distributed pumping speed,
ρ		is the capture factor for the pump including a pumping port and a mesh,
A_{mesh}	[m^2]	is the mesh area,
$\bar{v}$	[m sec^{-1}]	is the mean molecular speed.
$u = A_c D$	[m^4 sec^{-1}]	is the specific vacuum chamber molecular gas flow conductance per unit axial length,
A_c	[m^2]	is the vacuum chamber cross section;
D	[m^2 sec^{-1}]	is the Knudsen diffusion coefficient.

Gas desorption consists of two main sources: thermal and photon stimulated desorption:

$$q = \eta_t F + \eta_\gamma \Gamma; \qquad \textbf{(2)}$$

where η_t	[molecule sec^{-1} m^{-2}]	is the thermal desorption yield,
F	[m^2]	is the vacuum chamber surface area,
η_γ	[molecule photon^{-1}]	is the photon stimulated desorption yield,
Γ	[photon sec^{-1}]	is the synchrotron radiation photon flux.

Here we are interested in the solutions of equation (1) in the quasi-equilibrium state when the condition $V\,dn/dt = 0$ is satisfied.. Therefore, equation (1) can be re-written as:

$$u\frac{d^2n}{dz^2} - cn + q = 0\,. \qquad \textbf{(3)}$$

The second order differential equation (3) for the function $n(z)$ has two solutions:

Case (a) $$n(z) = -\frac{q}{2u}z^2 + C_{1a}z + C_{2a} \quad \text{for } c = 0; \qquad \textbf{(4)}$$

Case (b) $$n(z) = \frac{q}{c} + C_{1b}e^{\sqrt{\frac{c}{u}}z} + C_{2b}e^{-\sqrt{\frac{c}{u}}z} \quad \text{for } c > 0. \qquad \textbf{(5)}$$

where the constants C_1 and C_2 depend on the boundary conditions.

As mentioned above, the longitudinal dimension of the pump aperture is much greater than the cross sectional dimensions of the beam tube, so the pump can be regarded as a pumping speed distributed along a length equal to the overall length of the mesh. Hence, the solutions for c = 0 corresponds to the vacuum chamber between pumps and the solutions for c > 0 corresponds to a vacuum chamber where there is a mesh and a pumping port.

The vacuum chamber along the beam can be considered as being divided into N longitudinal elements with c = 0 or c > 0. Every i^{th} element lying between longitudinal co-ordinates z_{i-1} and z_i will be described by equation (4) or (5) with two unknowns C_{1i} and C_{2i}. The boundary conditions are $n_i(z_i) = n_{i+1}(z_i)$ and $\partial n_i(z_i)/\partial z = \partial n_{i+1}(z_i)/\partial z$. For the first element we use the boundary conditions $n_1(z_0) = n_1(z_1)$ and $\partial n_1(z_0)/\partial z = \partial n_1(z_1)/\partial z$; and for the last one we use $n_N(z_{N-1}) = n_N(z_N)$ and $\partial n_N(z_{N-1})/\partial z = \partial n_N(z_N)/\partial z$. In this case C_{1i} = C_{2i} for i = 1 and i = N. Now for the N elements of the vacuum chamber we have a system of 2N–2 equations with 2N–2 unknowns, which can be easily solved with the numerical calculation package MathCad-2000 [19].

One numerical problem exists in such modelling. This lies in the numerical precision when two large values have a small difference. For example, if $a=10^{80}+10$ and $b=10^{80}$ then instead of the expected value of a–b=10 the computer may show a–b=0. This happens here for large z. The problem may be successfully overcome simply by a change of variables on every element: $Z_i = z - z_i + L_i/2$, where L_i is the length of i-th element, i.e. Z_i varies between $-L_i/2$ and $L_i/2$: $-L_i/2 \le Z_i \le L_i/2$.

The solutions to the equations (4) and (5) can be found for three distinct pumping configurations employed in the straight section of Diamond and are given below. Consider a vacuum chamber of length L, centred at z = 0, then the following solutions are used:

For a finite length vacuum chamber with distributed pumping between two pumps with a pumping speed S_p:

$$n(z) = \frac{q}{C}\left(1 - \frac{\cosh\left(\sqrt{\frac{C}{u}}z\right)}{\cosh\left(\sqrt{\frac{C}{u}}\frac{L}{2}\right)\left(1 + \frac{\sqrt{Cu}}{S_p}\tanh\left(\sqrt{\frac{C}{u}}\frac{L}{2}\right)\right)}\right). \tag{6}$$

The average value of the gas density is: **(7)**

$$\langle n(L)\rangle = \frac{q}{C}\left(1-\frac{\tanh\left(\sqrt{\frac{C}{u}}\frac{L}{2}\right)}{\sqrt{\frac{C}{u}}\frac{L}{2}\left(1+\frac{\sqrt{Cu}}{S_p}\tanh\left(\sqrt{\frac{C}{u}}\frac{L}{2}\right)\right)}\right).$$

For a finite length vacuum chamber without distributed pumping between two pumps with a pumping speed S_p:

$$n(z) = \frac{q}{2u}\left(\frac{L^2}{4}-z^2\right)+\frac{qL}{2S_p}. \qquad \textbf{(8)}$$

The average value of the gas density is:

$$\langle n(L)\rangle = q\left(\frac{L^2}{12u}+\frac{L}{2S_p}\right). \qquad \textbf{(9)}$$

This solution should be also used for inert gases, CH_4 and other hydrocarbons where there is distributed NEG pumping.

This analysis is basically a one-dimensional simulation. Therefore, the question of applicability and accuracy of such a simulation to a three-dimensional problem may arise. In fact, much of the storage ring is a close approximation to a thin pipe, which is almost one-dimensional.

The analytical method described here has been benchmarked against a Monte-Carlo simulation program [17] that is used quite extensively in particle accelerator laboratories for this type of work, with the same system parameters.

Calculations were carried out for the regular vacuum chamber of elliptic cross section and for the most complicated element of the diamond vacuum chamber: the dipole vacuum vessel. The result for the dipole vessel is shown in Figure 5.8-1. There are some minor differences in the pressure profiles, but the *average* value of pressure along this vessel is in fact similar in both cases. There is no significant difference in the pressure profile or average pressure in the regular vacuum chambers with elliptic cross section calculated using either method.

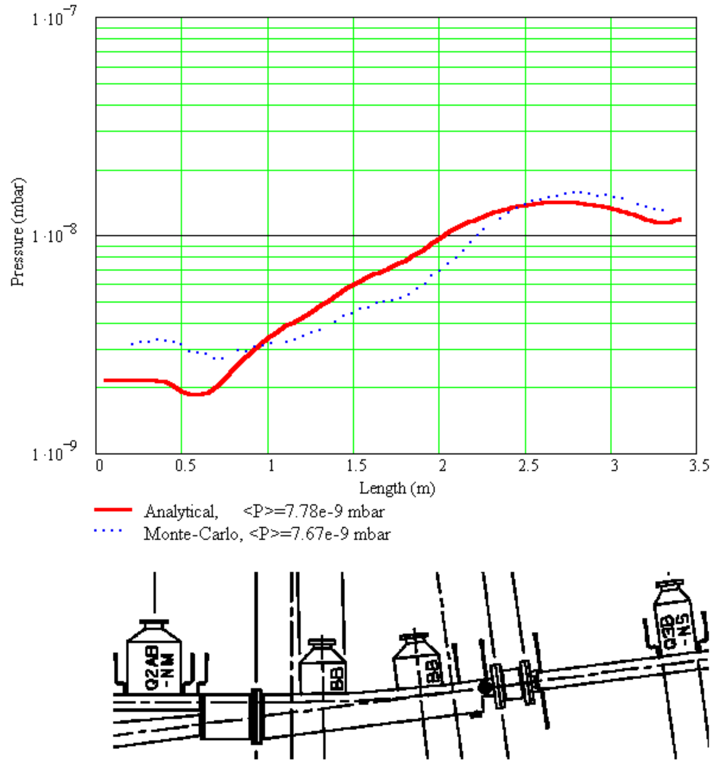

Figure 5.8-1 Comparison between the analytical methodology described here and a Monte-Carlo simulation for some elements of the diamond vacuum chamber

Therefore, it is concluded that overall estimates of pressure profiles along the diamond arc and of average pressures can be made to sufficient accuracy using the analytical method, which is much faster, more convenient and more flexible for calculations where many variations in input parameters are required.

5.8.3 Thermal desorption

All materials used to build accelerators, such as stainless steel or copper, desorb gas into the vacuum system. This thermal desorption is described by an outgassing rate q_{th} [mbar l sec^{-1} m^{-2}] or a thermal desorption yield η_t [molecule sec^{-1} m^{-2}]. These initially decrease exponentially with pumping time and a value of about 10^{-14} mbar l sec^{-1} m^{-2} (or $2.5{\cdot}10^{12}$ molecule sec^{-1} m^{2}) will be easily obtained for carefully chosen and well-prepared materials after a few hundred hours of pumping [20]. Thermal desorption determines the base pressure in the storage ring without beam.

5.8.4 Photon stimulated desorption

In the presence of beam, the main source of gas is photon stimulated desorption (psd). Photon stimulated desorption yields have been experimentally studied in many research centres. The most appropriate results for diamond are to be found in references [21], [22], [23], [24], [25], [26], [27], [28], [29]

In general, the psd yield, η, for a vacuum chamber decreases with photon dose proportionally to D^{-a}, where D is the integrated photon dose to which it has been exposed. At room temperature, the exponent a lies between $2/3 \leq a \leq 1$. Proper cleaning procedures, pre-baking and baking *in-situ* will lower the dose required to obtain a given value of the psd yield. The initial desorption yield of a pre-baked and/or *in-situ* baked vacuum chamber will be lower but the cleaning rate (the exponent a in D^{-a}) is also lower. Similarly the psd yield of an unbaked vacuum chamber reaches the same low value of η and of clean-up rate $\eta \propto D^{-a}$ with $2/3 \leq a \leq 1$, but at higher photon doses. At very high photon doses there is no significant difference between baked and unbaked vacuum chambers. A comparison between baked and unbaked vacuum chambers is shown in Figure 5.8-2.

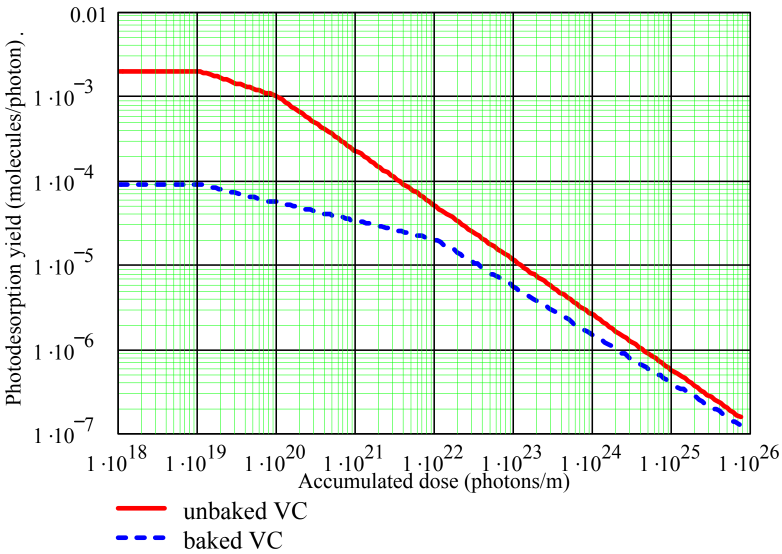

Figure 5.8-2 Photon stimulated desorption yield for CO for unbaked and baked vacuum chambers [22]. Yields for doses higher then 10^{23} photons/m are extrapolations.

Herbeaux *et al* [21] and Foerster *et al* [22] describe desorption from a stainless steel vacuum chamber pre-baked at 200°C for 24 hrs (but not baked *in-situ*) by synchrotron radiation with E_c=3.35 keV and 500 eV respectively. Additionally, the dependence of PSD yields on different pre-treatments has been studied by Foerster *et al* [22] and by Malyshev [23]. The results of both studies are in good agreement. Although the initial values of the psd yield at a dose of 10^{19} photon m^{-1} found by Herbeaux is about four times higher than that measured by Foerster, the difference at doses of 10^{22} to 10^{23} photon m^{-1} is already negligible and may be related to the different diameters of the sample tubes and/or the different photon critical energies. The complication for predicting the pressure in diamond is that the experimental measurements were obtained for doses of up to $2{\cdot}10^{23}$ photon m^{-1} (about 1.7 Ah in the most intensively irradiated part of the vacuum chamber). Therefore some extrapolation must be done to a dose of $1.2{\cdot}10^{25}$ photon m^{-1} (about 100 Ah). Herbeaux finds a=1 while a=2/3 in Foerster. Thus an extrapolation of Foerster's data gives higher psd at high doses. To avoid underestimating the pressure and therefore the necessary conditioning time in diamond we use the more pessimistic extrapolation in this estimation.

Photon stimulated desorption yields from an OFHC copper vacuum chamber are described in references [24] to [29]. The main conclusion from this work is that copper has about the same psd yield as stainless steel after a dose of about 10^{23} photon m^{-1}. This means that using elements made of copper inside the vacuum chambers should not affect the predicted pressure significantly.

Anashin *et al* [26] describe psd measurements at E_c=2.66 keV from a crotch absorber made of copper. The values in that paper are used for the psd estimates for the diamond crotch absorbers.

5.8.5 Desorption yields

It should also be noted that thermal and photon stimulated desorption yields are not constant or, indeed, well defined. They vary between materials and with preparation techniques and the previous history of irradiated samples. However, there is a sufficient body of information in the literature that their magnitude and behaviour can be determined pragmatically as noted above. However, even with a very good model and precise calculation, the real and predicted values may nevertheless differ by a factor two or even more because of these uncertainties.

5.8.6 Photon fluxes

There are two main sources of photons in the storage ring: synchrotron radiation from dipoles and synchrotron radiation from the insertion devices. About 30% of the synchrotron radiation from the dipoles irradiates the walls of the vacuum chamber; about 45% strikes the crotch absorber and the remainder (~25%) is transmitted down the beamlines . The synchrotron radiation from the insertion devices should all pass along the beamline. However, a vertical undulator will partially irradiate the dipole vacuum chamber upstream of its beamline. Hence it may be seen that the pressure in the beam pipe is mainly affected by synchrotron radiation from the dipoles.

(a) Photon flux from dipoles

The total photon flux from the dipoles along the main ring can be estimated from:

$$\Gamma_{tot}\left[\frac{photons}{\mathrm{sec}}\right] = 8\cdot 10^{20}\cdot E[GeV]\cdot I[A], \qquad \textbf{(10)}$$

where E is the beam energy and I is the beam current.

For diamond at E = 3.0 GeV and I = 300 mA the total photon flux from the dipoles is Γ_{tot} = $7.24\cdot 10^{20}$ photon sec^{-1}. In other words each of the 48 dipoles radiates a photon flux of Γ_{dip} = $1.5\cdot 10^{19}$ photon sec^{-1} into an angle of 131 mrad (7.5°). Synchrotron radiation from about 30 mrad is passed to users through the beamlines, the rest of the synchrotron radiation from the dipoles is intercepted by the walls of the vacuum chamber and the crotch absorber (about 50 mrad each). It is important to know how the photon flux is distributed along the diamond vacuum chamber.

The photon flux distributed per meter of vacuum chamber length depends on the total photon flux and the distance from the source point to the point of impact. For practical use it is more convenient to write a formula for the photon flux per meter, Γ_m, as a function of distance, z, from the end of dipole, which has a bending radius R_d, and horizontal half-aperture of vacuum chamber, a:

$$\Gamma_m(z) = \frac{\Gamma_{tot}}{2\pi}\left[\frac{(R_d + a)}{(R_d + a)^2 + z^2} - \frac{R_d z}{\left((R_d + a)^2 + z^2\right)\sqrt{z^2 + 2R_d a + a^2}}\right] \qquad \textbf{(11)}$$

The estimate for a vacuum chamber with a=4.0 cm is shown in Figure 5.8-3. The photon flux varies from $1.5{\cdot}10^{19}$ photon sec^{-1} m^{-1} just after the dipole down to $1.5{\cdot}10^{17}$ photon sec^{-1} m^{-1} at about 5 m away from there (the distance between the two dipoles in the achromat is 5.2 m and the straight from the dipole to the first insertion device vacuum isolation valve is 5.1 m). The photon flux along the insertion device straights will be even lower: between $2{\cdot}10^{16}$ and $1{\cdot}10^{17}$ photon sec^{-1} m^{-1}. The minimum photon flux will be incident on the walls of the vacuum chamber from the valve after the insertion device to the following downstream dipole.

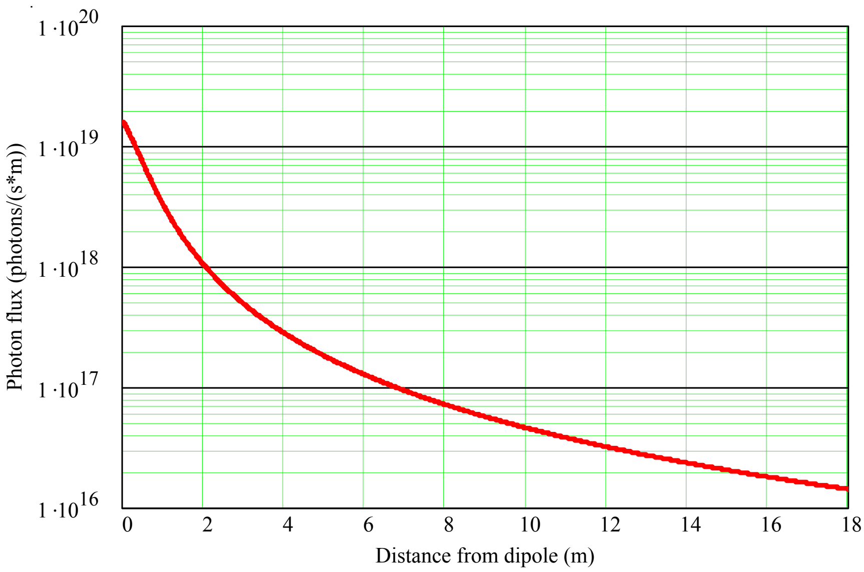

Figure 5.8-3 Photon flux incident on the vacuum chamber walls along the straight sections as a function of distance from a dipole

It should also be noted that some of the photons can be reflected and therefore the real photon distribution along the beam vacuum chamber will be more uniform than indicated. However, this will affect only the parts which receive a very low direct photon flux, i.e. mainly the vacuum chamber of the insertion devices and the region from the valve between the insertion device and the downstream dipole. There are two independent studies of photon reflectivity in synchrotron radiation beam lines:

one on EPA at CERN [30] and a second on VEPP-2M at BINP [31]. Both demonstrate that, for an average grazing incidence angle of 11 and 20 mrad respectively, the forward scattered photon reflectivity may range from 2% up to 20% for a stainless steel vacuum chamber. Hence, for a forward scattered reflectivity of 20% the uniformly reflected photon flux along the insertion device straights cannot be higher than $1{\cdot}10^{17}$ photon sec^{-1} m^{-1}.

Some photons will be scattered diffusely and there will also be the emission of some fluorescent photons. However, the amounts will be less than for specular reflection – although dependent on the optical properties of the surfaces. It is safe to assume, based on experience at many synchrotron sources, that any effects induced by such photons will be at the 10% level or less – well within the other uncertainties in analyses of this type.

It should also be noted that some of the emitted synchrotron radiation photons have energies below the threshold energy for desorption, the cut-off conventionally being taken to be 10 eV. Since equation (10) yields total photon fluxes, there is an element of conservatism in these calculations

(b) Photon flux from insertion devices

All of the synchrotron radiation from the ID's should pass along the beamlines. The front of the beamports are, however, in the same vacuum system as the storage ring. There is a movable synchrotron radiation absorber in front of the first vacuum valve, and we need to ensure that the vacuum system is capable of handling the desorption from this absorber when closed. Table 5.8-1 shows the estimated parameters for the first tranche of beam lines.

Table 5.8-1 Parameters for the first tranche of beamlines

Beam-line	ID	E_γ (keV)	ID length (m)	Straight length (m)	Gap (mm)	Γ (photon sec^{-1})
1	3.5 T MPW	2-200	1.5	5	10	$\sim 3.6{\cdot}10^{19}$
6, 8-11,13	Undulators	3-20	2	5	7	$\sim 3.4{\cdot}10^{18}$
14	Helical undulator	0.1-1.5	5	5	12	$\sim 2{\cdot}10^{19}$

5.8.7 Photodesorption

(a) Photodesorption along the straights

As was discussed above, the psd yields for CO from a stainless steel vacuum chamber as measured by Foerster [22] were used in these simulations. The psd yield, the desorption yield and the flux dependence on the distance from a dipole magnet are shown in Figure 5.8-5.

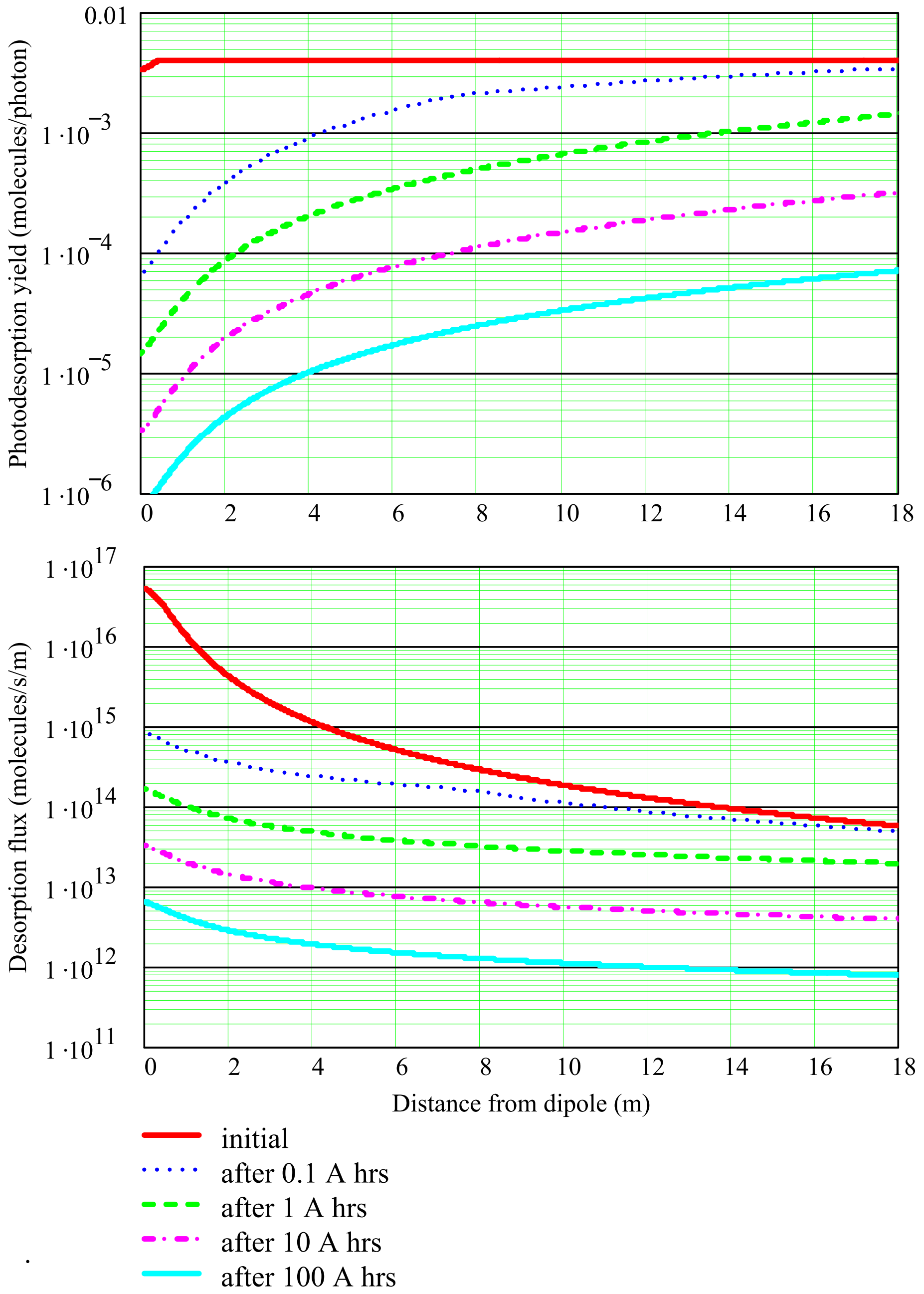

Figure 5.8-4 Photodesorption yield, the desorption yield and the flux dependence on the distance from a dipole magnet.

(b) Photodesorption flux from a crotch-absorber

Desorption from a typical design of crotch-absorber was estimated using the psd yield data from Anashin [26] and is shown in Figure 5.8-5. The experimental data are for doses up to $8{\cdot}10^{23}$ photons and are extrapolated to higher doses

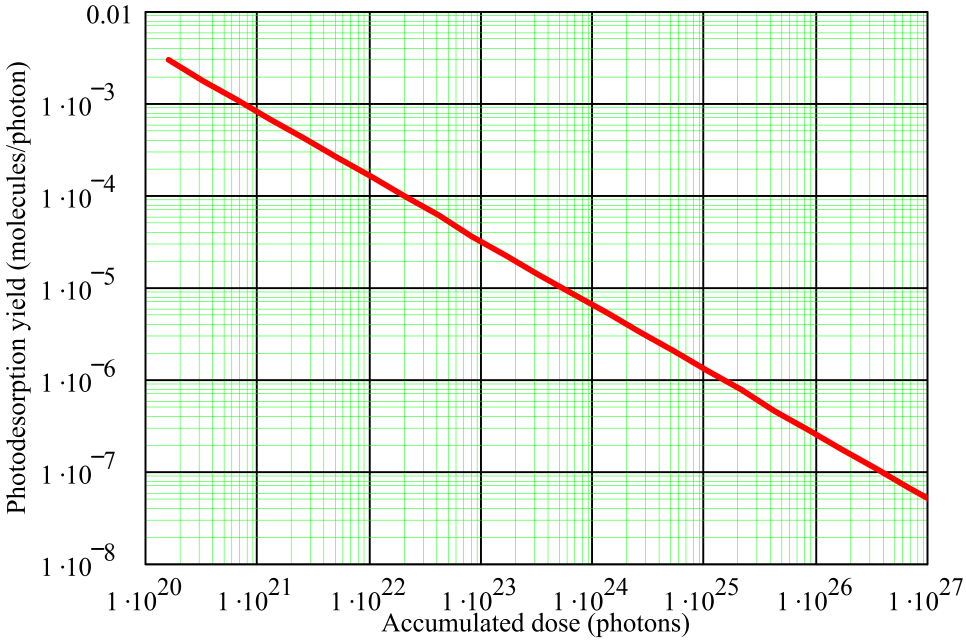

Figure 5.8-5 Photodesorption yield from a 35-mm wide strip of an OFHC copper crotch-absorber as a function of photon dose

After 10 Ah the desorption yield is estimated to be $\eta\approx10^{-6}$ molecule photon^{-1}, and the corresponding photodesorption flux is $\sim4{\cdot}10^{12}$ molecule sec^{-1} = $9{\cdot}10^{-8}$ mbar l sec^{-1}.

5.8.8 Pressure profile along the arc during and after 100 Ah beam conditioning

Separate pressure profiles along the arc were calculated for thermal desorption and photon stimulated desorption. The former gives the base pressure in the arc without beam while summing the two profiles gives the dynamic (operational) pressure profile at a given beam current.

Table 5.8-2 Average dynamic pressure along the diamond arc during machine conditioning

Beam Dose (Ah)	Specific dynamic pressure (mbar mA^{-1})	
	Narrow ports	Open ports
First injection	$8 \cdot 10^{-9}$	$3 \cdot 10^{-9}$
0.1	$3 \cdot 10^{-10}$	$2 \cdot 10^{-10}$
1	$8 \cdot 10^{-11}$	$3 \cdot 10^{-11}$
10	$1.5 \cdot 10^{-11}$	$1 \cdot 10^{-11}$
100	$4 \cdot 10^{-12}$	$3 \cdot 10^{-12}$

Table 5.8-3 shows the pressure along the arc after a beam dose of 100 Ah. There are two cases shown: static pressure, (i.e. without a beam: only thermal desorption) and dynamic (i.e. with the 300-mA beam: thermal desorption + photodesorption). These estimates are made using pumps with a nominal pumping speed of 500 l sec^{-1}. In the case of both narrow and open ports (see 5.7.4 above), there are significant pressure bumps at the ends of the arc. This is because of the distance between pumps in the initial layout of the arc. These bumps may be reduced by the addition of a small pump with an effective pumping speed of about 150 l sec^{-1} situated between the two fast corrector magnets at each end of the arc. It can also be demonstrated that one of the two pumps on the dipole spouts can be removed with little change to the average pressure.

Table 5.8-3 Average pressures along the diamond arc after 100 Ah of beam conditioning. $\langle P_{th} \rangle$ is the average pressure due to thermal desorption only; $\langle P_{ph} \rangle$ that due to photon desorption with a 300 mA beam only and $\langle P_{dyn} \rangle$ the summation of these two

	Pressure (mbar)		
	Narrow ports	Open ports	Open ports and an additional pump between the Fast Corrector magnets
$\langle P_{th} \rangle$	$4.1 \cdot 10^{-10}$	$2.7 \cdot 10^{-10}$	$2.2 \cdot 10^{-10}$
$\langle P_{ph} \rangle$	$9.5 \cdot 10^{-10}$	$6.4 \cdot 10^{-10}$	$5.2 \cdot 10^{-10}$
$\langle P_{dyn} \rangle = \langle P_{th} \rangle + \langle P_{Ph} \rangle$	$1.4 \cdot 10^{-9}$	$9.1 \cdot 10^{-10}$	$7.4 \cdot 10^{-10}$

The pressure profiles for each case considered in Table 5.8-3 are shown in Figure 5.8-6, Figure 5.8-7 and Figure 5.8-8 respectively.

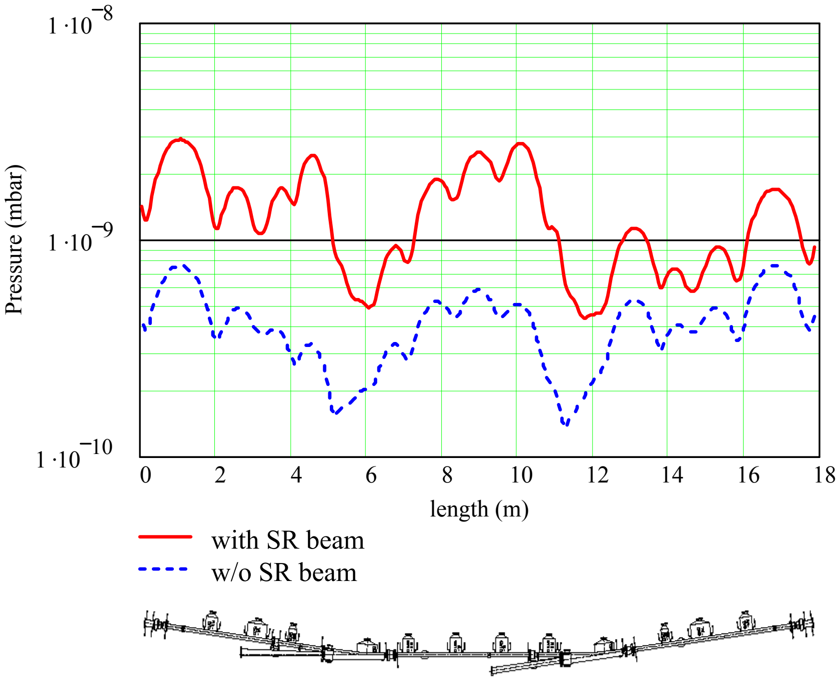

Figure 5.8-6 Pressure profile along the arc with 'narrow' ports with a 300 mA beam after 100 Amp·hrs of beam conditioning.

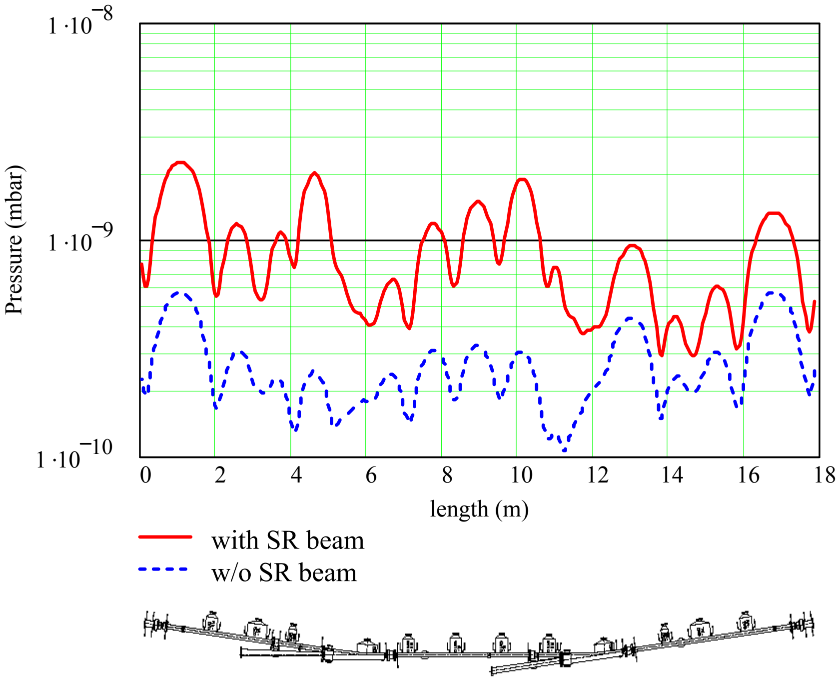

Figure 5.8-7 Pressure profile along the arc with 'open' ports with a 300 mA beam after 100 Amp·hrs of beam conditioning.

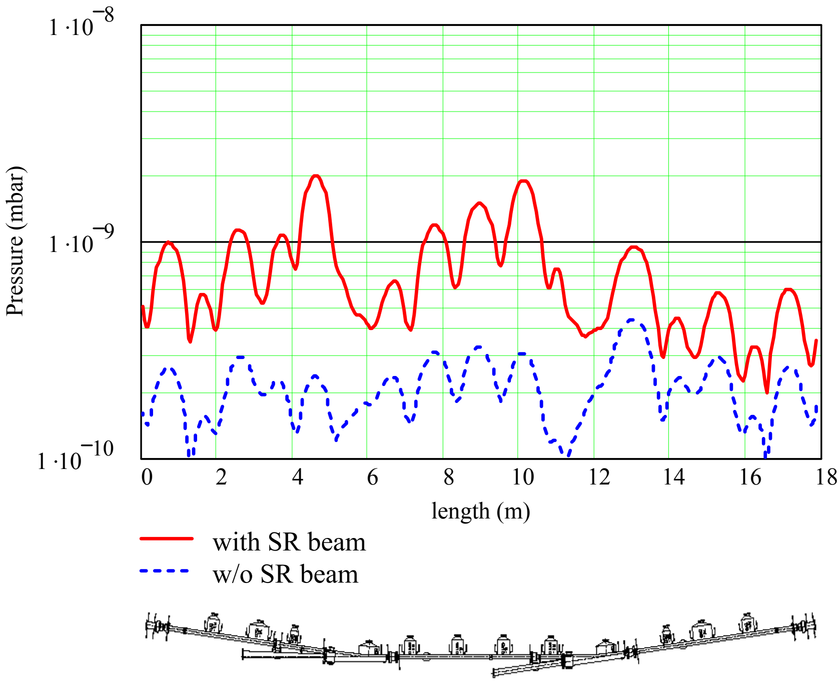

Figure 5.8-8 Pressure profile along the arc with ‘open’ ports with two additional pumps between FC’s with a 300 mA beam after 100 Amp·hrs of beam conditioning

5.8.9 Pressure profile along insertion device straights after 100 Ah beam conditioning with synchrotron radiation from the dipoles

Several different cross sections of the insertion device straight vacuum chambers, which have lengths of either 5.5 or 8.5 m, have been considered at this stage -

(a) a simple make-up pipe with a diameter of 100 mm;

(b) an elliptical pipe with a height of 7 to 12 mm and a width of 80 mm (the same as in the arc);

(c) the same pipe as in (b) but with an ante-chamber added (assumed to be a simple tube with a diameter of 60 mm)

(d) the same vessel as in (b) but with the inside surface coated with a film of non evaporable getter material.

As was discussed in 5.8.6(a) above, the photon flux from the dipole along the insertion device straights is less than $1{\cdot}10^{17}$ photon sec^{-1} m^{-1} and the estimated photon stimulated desorption flux is about 10^{12} molecule sec^{-1} m^{-1}. The estimated thermal desorption flux is $5{\cdot}10^{11}$ molecule sec^{-1} m^{-1} for the elliptical cross section pipe and about 10^{12} molecule sec^{-1} m^{-1} for both the make-up pipe and for that with an antechamber.

Table 5.8-4 shows the average dynamic pressure (i.e. with beam) within an insertion device straight for the first tranche of beam lines insofar as these are known at present. The estimates were made for two straight lengths: 5.5 m and 8.5 m, and for two or three pumps per insertion device, i.e. 2 pumps located at the ends of the insertion device straight section or two pumps at the ends with one in the middle of the insertion device straight section. The effective pumping speed is assumed to be 400 l sec^{-1} in each case. The pressures are calculated in a manner similar to that in the arcs (except for the NEG coated chamber). The pressures without beam are lower by a factor of about 2.

Table 5.8-4 Pressures in mbar along various assumed insertion devices in the presence of a 300 mA beam.

Beam-line	Cross section (mm)	Straight length (m)	Average pressure (mbar)				
			2 pumps	3 pumps	Ante-chamber with 2 pumps	Ante-chamber with 3 pumps	NEG coated vessel with 2 pumps
Make-up pipe	100	5.5	$1.3{\cdot}10^{-9}$	$4.8{\cdot}10^{-10}$	–	–	–
6, 8–11, 13	7 × 80	5.5	$9.5{\cdot}10^{-8}$	$2.4{\cdot}10^{-8}$	$8.8{\cdot}10^{-9}$	$2.2{\cdot}10^{-9}$	$1.9{\cdot}10^{-10}$
1	10 × 80	5.5	$4.8{\cdot}10^{-8}$	$1.2{\cdot}10^{-8}$	$8.8{\cdot}10^{-9}$	$2.2{\cdot}10^{-9}$	$1.9{\cdot}10^{-10}$
14	12 × 80	5.5	$3.3{\cdot}10^{-8}$	$8.5{\cdot}10^{-9}$	$8.8{\cdot}10^{-9}$	$2.2{\cdot}10^{-9}$	$1.9{\cdot}10^{-10}$
Make-up pipe	100	8.5	$2.9{\cdot}10^{-9}$	$9.5{\cdot}10^{-10}$	–	–	–
6, 8–11, 13	7 × 80	8.5	$2.4{\cdot}10^{-7}$	$6.1{\cdot}10^{-8}$	$2.4{\cdot}10^{-8}$	$5.8{\cdot}10^{-9}$	$4.6{\cdot}10^{-10}$
1	10 × 80	8.5	$1.2{\cdot}10^{-7}$	$3.1{\cdot}10^{-8}$	$2.4{\cdot}10^{-8}$	$5.8{\cdot}10^{-9}$	$4.6{\cdot}10^{-10}$
14	12 × 80	8.5	$8.5{\cdot}10^{-8}$	$2.1{\cdot}10^{-8}$	$2.4{\cdot}10^{-8}$	$5.8{\cdot}10^{-9}$	$4.6{\cdot}10^{-10}$

It is important to know the sensitivity of these values to the effective pumping speed, i.e. to the choice of the pump and its connection to the insertion device vessel. The average dynamic pressure as a function of effective pumping speed for a 5 m long insertion device vacuum chamber with three pumps is shown in Figure 5.8-9. Only the make-up pipe exhibits a significant variation in pressure for effective pumping speeds between 50 and 800 l sec^{-1}; the pipe with an antechamber is rather insensitive to pumping speeds above 400 l sec^{-1} and the elliptical vacuum chambers are seen to be completely conductance limited and insensitive to effective pumping speeds above about 100 l sec^{-1}.

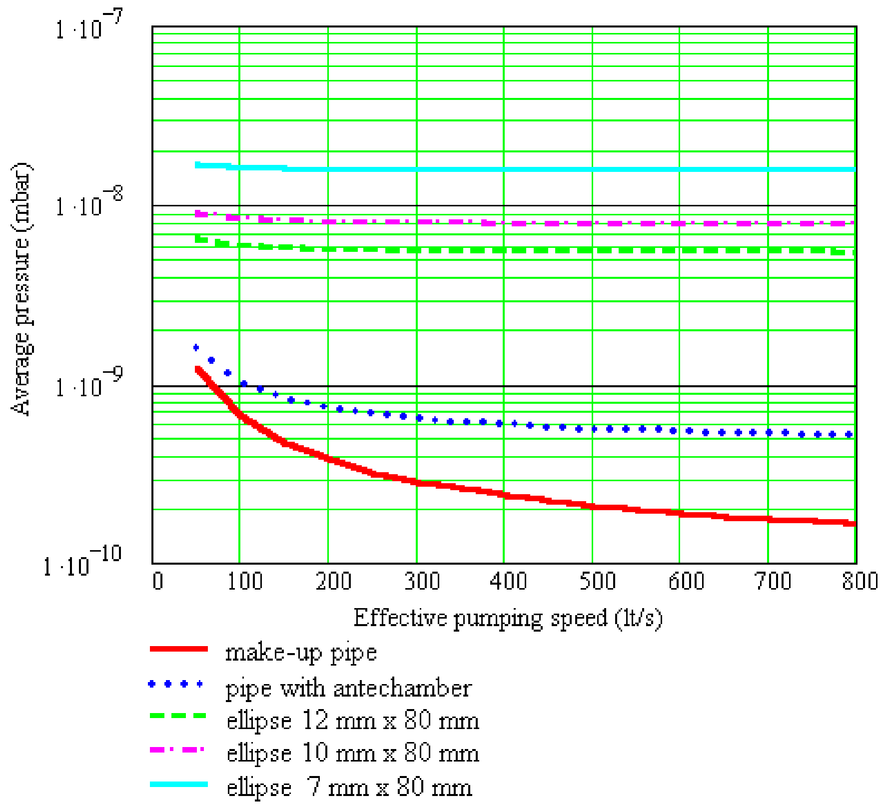

Figure 5.8-9 Average pressure as a function of effective pumping speed for various 5 m long insertion device vacuum chambers with 3 pumps with a 300 mA beam

The use of NEG (non evaporable getter) coating as an effective pumping solution for conductance limited vacuum chambers has been developed at CERN over the last few years [16], [32], [33], and is available commercially. Independent confirmation of its efficacy has been obtained in studies performed at BINP in collaboration with CERN [34].

The estimates for the NEG coated insertion device vacuum chamber shown in Figure 5.8-10 were made using the recent experimental data from BINP [34]. In the NEG coated vacuum chamber, CH_4 and H_2 dominate the residual gas spectrum, in contrast to that in a conventional, well conditioned ultra high vacuum chamber where the main gas species are H_2, CO and CO_2. The pressure inside the NEG coated vacuum chamber without a beam is below the gauge sensitivity limit of 10^{-12} mbar.

Using the above values we can conclude that in the insertion device straights, a make-up pipe can be efficiently pumped by 2 or 3 pumps each of effective pumping speed 400 l sec^{-1}. An insertion device vacuum chamber with an elliptic cross section but which has neither an antechamber nor NEG coating or some other form of distributed pumping is unacceptable because of the high average pressure.

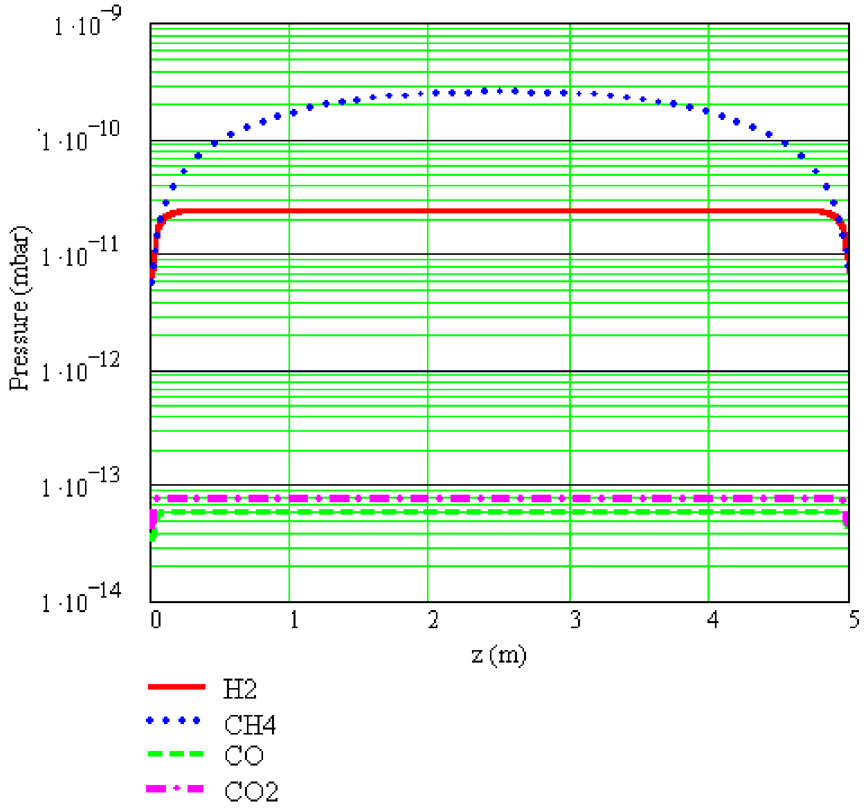

Figure 5.8-10 Pressure profile along a 5 m long NEG coated insertion device vacuum chamber with a 300 mA beam

This analysis has concentrated on average pressures that do not give rise to excessive gas scattering which is detrimental to beam lifetime. It is assumed that such pressures will also give rise to sufficiently low bremsstrahlung along the beamlines for safe operation.

ESRF has had about two years experience of operating some insertion device vessels with NEG coatings [35], [36] and Elettra has also recently installed such a vessel [37]. In both cases, the conditioning time of a new vessel has been dramatically reduced. The main problem with their using narrow gap insertion device vessels was bremsstrahlung passing along the beam lines to the experimental areas. With the NEG coated vessels, the radiation levels dropped by over an order of magnitude, enabling beam lines to be opened very quickly.

5.9 ARC PUMPING SCHEME

5.9.1 Generic vacuum pumps

In line with the comments in 5.7.4 above regarding the applied pumping speeds through the pumping spouts, the generic pumps listed in Table 5.9-1 have been selected for use in this design.

Table 5.9-1 Generic vacuum pumps

Pump Type	Nominal Pumping Speed (l sec^{-1})
Ion Pump	240
Ion Pump	500
NEG Cartridge	180
TSP	1000

Although these are all specified generically, the values are chosen to correspond to real, commercially available pumps at the time this report was prepared. It should be noted that at 10^{-9} mbar, ion pumps will exhibit a reduction in pumping speed of about 30% from their nominal value. This has been taken into account in the calculations.

A TSP (Titanium Sublimation Pump) is different from other pumps in that it works by intermittently evaporating a film of titanium onto a surface, and the pumping speed generated for nitrogen may be taken to be about 1 l sec^{-1} cm^{-2} [38]. Therefore in this case, it is necessary to have a surface area of about 1000 cm^2. A pump configuration similar to that used in the SRS could be adopted, although consideration will be given to utilising an integrated ion pump/TSP assembly.

5.9.2 Pumping spouts

As noted, every pump is connected to the beam pipe by means of a spout of some sort. These spouts are listed in Table 5.9-2 and the molecular flow conductance of each type is shown. Types 1 to 4 are the relevant ones selected from those discussed in 5.7.4 above. The table shows two additional spouts -

- Type 5 is used to connect a pump between the two fast corrector magnets and is assumed to be a pipe of minimum diameter 10 cm and maximum length 3 cm.

- Type 6 is mounted underneath the crotch absorbers at the downstream ends of the dipole vessels and is assumed to be a pipe of minimum diameter 20 cm and maximum length 10 cm.

Table 5.9-2 Pumping spouts

Spout Type	Location	Molecular Flow Conductance ($l\ sec^{-1}$)
1	Quadrupole Q1B	256
2	Quadrupole Q2B	357
3	Quadrupole Q3B	183
4	Dipole Chamber	202
5	Between Fast Correctors	720
6	Crotch Absorber	2500

Note that the quadrupole magnet type designations in Table 5.9-2 and Table 5.9-3 are as shown in the drawing A0-302/10297.

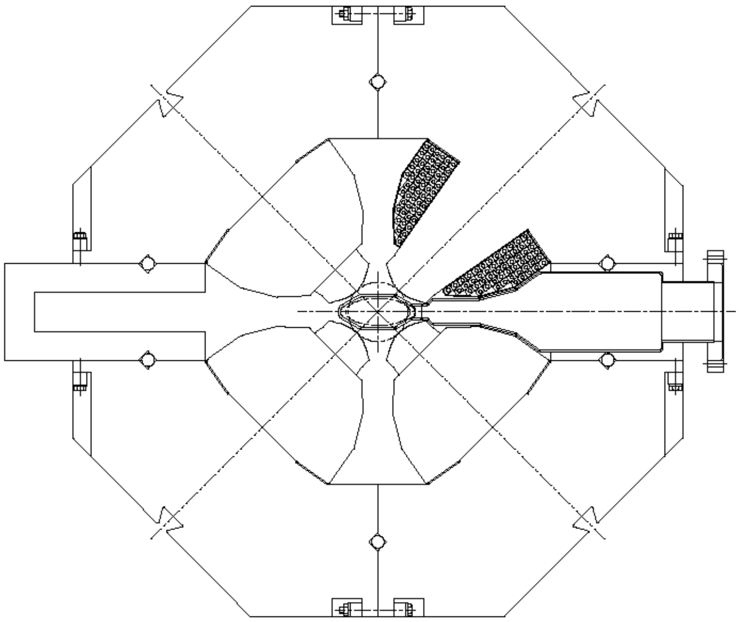

Figure 5.9-1 Schematic of an 'open' pumping port in a quadrupole.

5.9.3 Pump locations

Table 5.9-3 shows the pumping speed required (at 10^{-9} mbar) at each of the pumping positions along the arc. These are *nominal* speeds applied at the end of the spout, not on the beam orbit. It also shows how these speeds can be achieved with a suitable combination of the generic pumps listed in Table 5.9-1. With this suite of pumps the expected average pressure along the arcs after about 100 Ah of beam conditioning is 9.6 x 10^{-10} mbar. The pressure distribution along the arc is shown in Figure 5.9-2.

Table 5.9-3 Actual pumps with their locations along the arc

Position	Pump location	Required speed (l sec^{-1})	Pump complement to achieve speed			
			Ion Pump (240 l sec^{-1})	Ion Pump (500 l sec^{-1})	NEG pump (180 l sec^{-1})	TSP (1000 l sec^{-1})
1	Between FC	180			✔	
2	Q1B-NM	170	✔			
3	Q2B-NL	170	✔			
4	Q3B-NS	170	✔			
5	Dipole	350	✔		✔	
6	Crotch	1300		✔		✔
7	Q2AB-NM	170	✔			
8	Q1AB-W	170	✔			
9	Q1AB-W	170	✔			
10	Q2AB-NM	170	✔			
11	Dipole	350	✔		✔	
12	Crotch	1300		✔		✔
13	Q3B-NS	170	✔			
14	Q2B-NL	170	✔			
15	Q1B-NM	170	✔			
16	Between FC	180			✔	

Figure 5.9-3 gives a schematic view of the location of the pumps along one of the arcs. This so-called vacuum flow diagram also shows the position of vacuum gauges and vacuum valves along the arc. These will be discussed later in this chapter. Not shown are the locations of beam port front end valves.

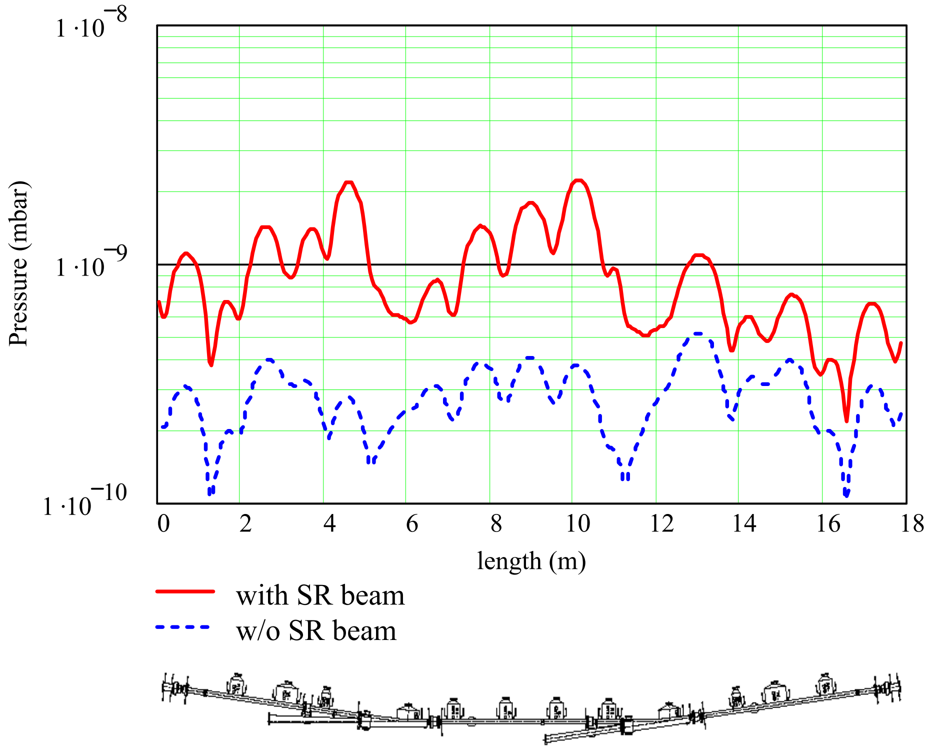

Figure 5.9-2 Pressure distribution along the arc with the suite of pumps listed in Table 5.9-3

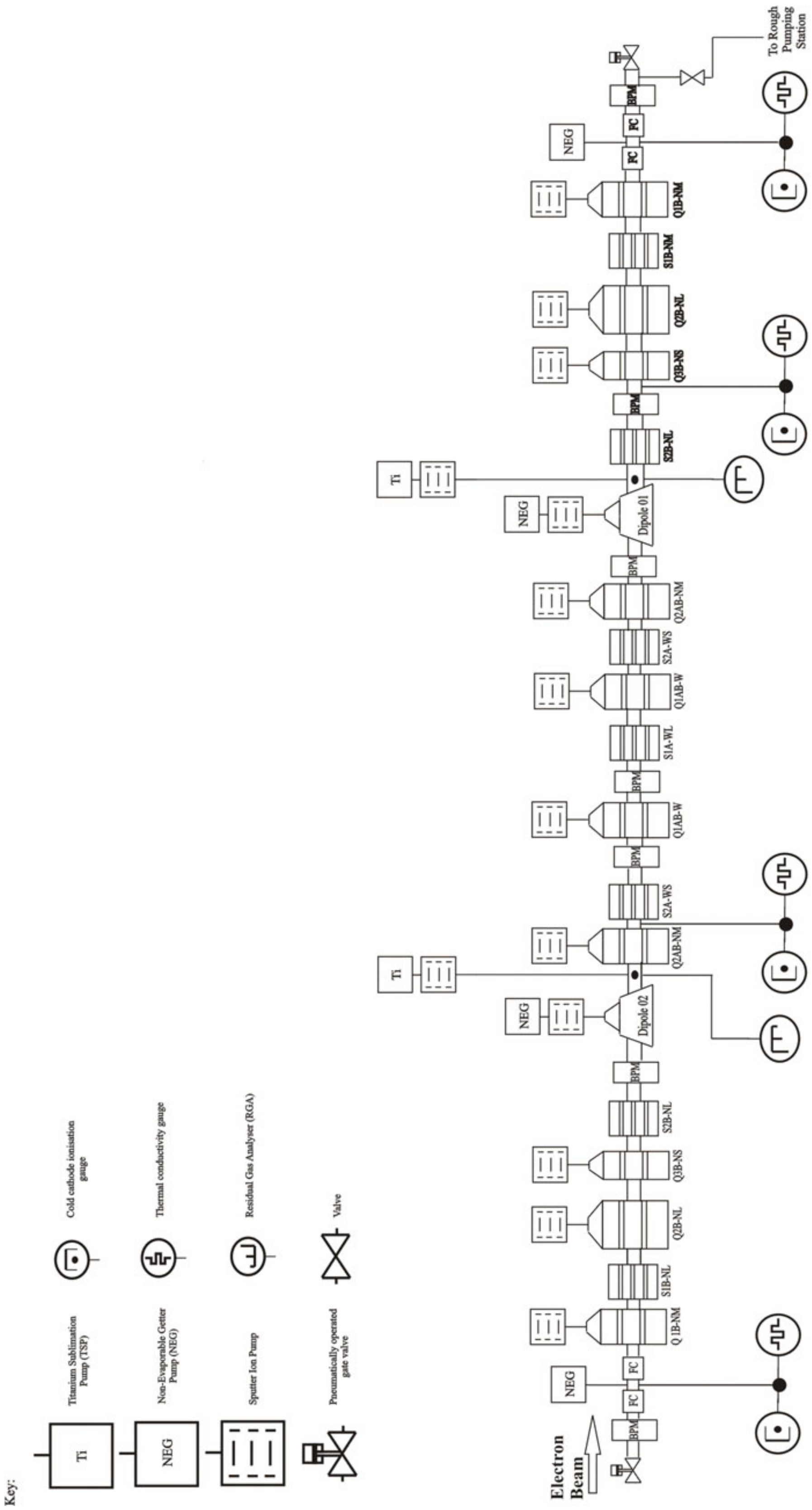

Figure 5.9-3 Vacuum flow diagram of an arc

5.9.4 Caveats

In order to derive the pumping scheme of Subsection 5.9.3, some assumptions have been made. If these assumptions turn out not to be substantiated in practice, this pumping scheme will need to be revisited.

The assumptions made include -

- little or no synchrotron radiation from the insertion devices impinges on the surface of the main ring vacuum vessels: it all passes along the beam ports to the beam lines. Any collimation, aperture restriction, etc., takes place in the beam port/line and the consequent desorption is handled locally by pumps installed for that purpose.
- the beam port front end absorber (in front of the first vacuum valve isolating the beam port from the storage ring vacuum) is situated close to the storage ring crotch absorber vessel so that desorption from the absorber when closed can be handled by the pump stack there.
- in normal operations, the front end absorber will not be closed when the full synchrotron radiation output of the insertion device is being generated.
- all arcs are identical.

If any of these should be untrue, then additional pumps may have to be installed at the appropriate positions.

5.9.5 Some specific points regarding the positions and mounting of the UHV pumps

(a) Dipole chamber pumps

Only one pump stack is required. This is in the position of the original upstream pump shown in the figures in Subsection 5.8.8 above. The spout should be lengthened along the vessel – a length of 400 mm was used in this calculation. The NEG pump will be installed integral with the ion pump body.

(b) Crotch absorber pumps

The pump stack on the crotch absorber is mounted below that absorber and connected to the vessel by as short and wide a spout as practicable, using a knife-edge flange of 250 mm nominal diameter (Type DL19 or 20).

(c) Pumps between the fast corrector magnets

The additional pump provided between the fast correctors is physically quite a small pump - a NEG cartridge. It will probably take the form of a SAES CapaciTorr D 400 [39] or similar. The pump housing will be a tube of length 150 mm and diameter 100 mm connected to a knife-edge flange of 150 mm nominal diameter (Type DL13 or 14) on the beam tube (with as short a connecting tube as possible). The pump cartridge requires a type DL4 or 5 knife-edge flange. The connecting flange should be underneath the beam tube and the pump housing should be vertically down.

(d) Ion pumps; titanium sublimation pumps and NEG pumps

All of these types of pumps generate particulates to a greater or lesser degree at some times during their operation. It is important that the possibility of these particulates finding their way into the beam tube is minimised. Such a circumstance can result in two effects. If a particle gets into the electron or photon beam, it can ablate and generate a local pressure pulse, possibly resulting in either partial or complete beam loss. Secondly, if a hard particle gets onto the seal mechanism of a vacuum valve, it can generate a leak across the seat when the valve is closed.

It is therefore recommended that all such pumps be mounted vertically with the pump throat on top and below the beam orbit. Side pumps should be connected to the pumping spouts through a large diameter short right angle elbow.

5.10 STRAIGHT PUMPING SCHEMES

5.10.1 Injection Straight

Little is yet known in detail about the exact nature of the components which will be in the injection straight. They will include the injection septum magnet, four kickers and some diagnostics.

From a vacuum point of view, the only real problem will be if the injection septum is a laminated *in vacuo* magnet similar to that installed on the Daresbury SRS. Because of the massive surface area, such magnets can generate a high degree of outgassing, particularly water, after atmospheric excursions. This gas load can be handled by the adoption of two stratagems. Clearly adequate pumping speed has to be installed. Secondly, the septum magnet will be one of the few vacuum items on diamond which will require routine baking. It will be warmed before the straight is vented to minimise water sorption and will be kept hot while the system is pumped out. Integral heaters will be provided for this.

Although this will be subject to detailed review once the septum magnet design is undertaken, we will assume that two 500 l sec^{-1} ion pumps each with 1000 l sec^{-1} of TSP will be adequate. The possibility of using NEG wafer modules close coupled to the magnet will also be investigated.

The kickers, if again modelled on those in the SRS, should not present any problems. Each will require one 240 l sec^{-1} ion pump. Any necessity for additional speed from TSP's or NEG's will be assessed once the design is finalised.

5.10.2 Radio Frequency Cavity Straight

The superconducting rf cavities are expected to be supplied as a complete assembly from a manufacturer. Therefore the detail of the vacuum system will be a matter of discussion with that manufacturer. However, the approach of the diamond Project should be similar to that adopted for the injector train, *viz.*, that the diamond Project will type approve particular pumps, gauges, valves, etc., which will most likely be supplied on free issue to the cavity manufacturer.

There will be three cavities in a single 8.5 m straight, and each will form an independent vacuum system. There will be an in-line vacuum valve at each end of the straight as usual, and there will be a pair of valves with a short interspace between each pair of cavities. Each cavity and each interspace will be linked to the roughing pump set in the straight via manual valves leading to a pumping manifold.

Each cavity will be fitted with a 500 l sec^{-1} ion pump on the beam tube close to the cavity and will have a 240 l sec^{-1} ion pump fitted to the waveguide (which is part of the cavity vacuum). It is anticipated that the interspaces will have no permanent pumping, although consideration may be given to fitting a small cartridge NEG pump once details of the design become available.

5.10.3 Diagnostic Straight

Little is yet known about the diagnostic straight and its contents. It will probably contain a short insertion device. Pumping appropriate to an insertion device straight will therefore be required.

5.10.4 Insertion Device Straights

For the initial assessment of the vacuum performance of the insertion device straights, we consider two simple vessel designs. From the generic pumps listed in Table 5.6-1, the 240 l sec^{-1} ion pumps have been selected as standard for use here. Four location options for these pumps have been considered.

- A two pump option with a single pump at each end of the vessel
- A three pump option with an additional pump in the middle of the straight
- A four pump option with one pump located at each end of the vessel and two more spaced equidistant along the vessel.

(a) A simple cylindrical make-up pipe with a diameter of 100 mm.

On day one of machine operations, it is expected that of the 24 insertion device straights, 15 will have a simple make-up pipe installed. Currently, it is expected that two of these will be 8.5 m straights and thirteen will be 5.5 m straights.

The 5.5 m long straights will require the three pump option to give an average pressure of $8.6.10^{-10}$ mbar and the 8.5 m long straights need the four pump option to give an average pressure of $9.5.10^{-10}$ mbar. Both these pressure will be obtained after 100 Ah of beam conditioning.

No *in-situ* baking is foreseen for these makeup pipes.

(b) An elliptical pipe with a height between 7 and 12 mm and a width of 80 mm with the inside surface NEG coated.

On day one of machine operations, it is expected that six straights will have a narrow gap insertion device installed with the internal height of the vacuum chamber between 7 and 12 mm. This will limit the longitudinal vacuum molecular flow conductance significantly. It is anticipated that the chambers will therefore be coated internally with NEG material. This new advanced vacuum technology needs quite careful maintenance but means that the required pressure can be reached in a very simple vacuum pipe with no ante-chamber or other distributed pumps).

Both 5.5 m and 8.5 m long straights will only require a single 240 l sec^{-1} ion pump installed at each end. The average pressure along the chamber will then be $2.0 \cdot 10^{-10}$ mbar and $4.7 \cdot 10^{-10}$ mbar respectively with the NEG activated.

Activation of the NEG coating by *in-situ* baking for 20 hours at the *activation temperature* which varies between 180°C and 350°C depending of choice of the NEG material, structure and others parameters is essential. This bakeout can be performed using very simple removable heater jackets and a portable control system.

5.10.5 Pumping spouts

Every discrete pump is connected to the beam pipe by means of a pumping spout of some sort. The spouts attached to the insertion device vacuum chambers should be made as short and wide as possible to avoid molecular flow conductance limitation of the available pumping speed.

All spouts are mounted underneath the vacuum vessels and are assumed to be cylindrical pipes of diameter 80 or 100 mm and of maximum length 100 mm. In this case the effective pumping speed is about the same as actual one, i.e. ~170 l sec^{-1} (The nominal pumping speed of 240 l sec^{-1} is reduced by ~30% at a pressure of ~10^{-9} mbar).

Table 5.10-1 Pumping spouts for insertion device vessels

Spout Type	Location	ID (mm)	L (mm)	Molecular Flow Conductance (l sec^{-1})
1	Make-up chamber	100	100	1230
2	Elliptical chamber	80	100	630
3	Elliptical chamber	80	80	790

5.11 VACUUM PUMP CONTROL

5.11.1 Control system

In common with all other instrumentation on the diamond machine complex, the vacuum pumps will be controlled and monitored through the main machine control system (Part D.2). This will be accomplished by each control unit being equipped with a standard communications interface such as RS-232. Protocols will be defined by the equipment manufacturer and the necessary interface layer to the EPICS control system software will be written by the Machine Controls Group.

5.11.2 Interlocks

The majority of interlocks to vacuum pumps will be implemented either by firmware in the pump control units or in software in the control system. However, where there is a possibility of a dangerous situation arising from the operation of a vacuum pump, then an additional, parallel, hardwired interlock chain will be implemented. “Dangerous” is defined here as being a situation which can lead to a possible compromise of the integrity of the vacuum envelope of the machine complex or to damage to an item important to the operation of the machine whose replacement requires part of the machine to be vented to atmosphere. An example of such a possible failure is switching an ion pump on at too high a pressure so that an internal arc discharge occurs in the ht feedthrough, leading to cracking of the insulator.

Interlock chains will be identified during the procurement phase of the diamond Project.

5.11.3 Location of power supplies and control units

It is considered desirable to locate all electronics outside the ring tunnels. This makes for ease of servicing – tunnel searches do not have to be interrupted to replace a faulty unit for instance. Radiation levels in the tunnel are high during operations and this adversely affects the life of electronics. However, this has to be balanced by the economics of installing long cable runs, especially where relatively high currents are involved. Cables also have to enter the tunnel through labyrinths which, inevitably, have limited capacity. Cables need to be compatible with the radiation environment.

Control units will therefore normally be installed in control racks situated outside the machine shield walls. Cable runs should be kept to a minimum and there should be no joints, except in proper junction boxes. Cables in the racks should be terminated in connectors interfaced directly to the control units. In the machine tunnels, cables will be terminated in marshalling boxes attached to the machine mounting girders. Cables to the equipment from these marshalling boxes will have no joints and will be as short as practicable.

5.11.4 Vacuum pump power supplies and control units

(a) Rough pump stations

The operation of rough pump stations will be essentially a manual one carried out by skilled operatives. However a certain amount of monitoring and datalogging information will be available – e.g. running hours for turbomolecular pumps. This will be collected by the Control System and stored in a history system of some sort.

(b) UHV pumps

<u>Ion pumps</u>

Each ion pump will have its own dedicated ion pump power supply that will operate the pump throughout the pressure range $5x10^{-3}$ to $1x10^{-10}$ mbar. The ion pumps will not normally be operated above $1x10^{-5}$ mbar. This gives a good lifetime for the ion pumps (in excess of 10 years) and reduces "regurgitation" which limits the ultimate pressure achievable in the pump. Power supplies which are available commercially have two high voltage channels in each power supply. Where a vacuum section has an odd number of ion pumps, a spare channel will be available for back up to any pumps in the section. The ion pump power supplies will be required to provide the following:

- a high voltage supply to a range of ion pump sizes and types that may be up to 100m away.
- a front panel reading that can display pump set up information and operational status e.g. voltage, current, pressure.

Criteria influencing the choice of ion pump power supplies will include -

- each power supply should provide at least one external interlock.
- size: there is only a limited amount of space available in the facility for control racks.
- minimising heat dissipation in the control racks is advantageous.

- manufacturer(s) should have considerable experience (over many years) in producing reliable electronic systems for ion pumps. Experience in providing solutions for synchrotron light sources will be advantageous.
- life time cost will be a major factor. Cost of ownership will be considered as well as installation costs.
- control units should be easy to use by vacuum and controls technicians.

A generic specification for ion pump control units is shown in Table 5.11-1

Table 5.11-1 Generic specification for ion pump control units

Ion Pump Control
Fully selectable range of ion pump sizes from 50 l $sec^{-1}$to 500 l sec^{-1}
Fully selectable high voltage from 5 kV-7.5 kV.
Provision to change the polarity of the high voltage without return to manufacturer.
Overload protection in the event of pump sparking, short circuit and high pressure.
Provide failsafe interlock protection in the event of disconnected high voltage connector.
Provide at least one interlock relay set point for each ion pump high voltage channel.
Interlock set point to be adjustable in the range $5x10^{-3}$-$1x10^{-9}$ mbar.
Provide a control interface that will be suitable for EPICS (EPICS, RS-232, RS 485 or other). Interface to provide full status information.
19 inch rack mountable in a minimum of space.
Provide front panel information regarding the set up of the power supply and the current status including high voltage, current and pressure.

During the initial part of the procurement phase of the diamond project, detailed evaluation will be undertaken regarding the possible use of so called “holding” ion pump power supplies. The current drawn by an ion pump (and hence supplied by the control unit) is a function of pressure as well as the size (pumping speed) of the pump. If all the ion pumps are only operated at low pressure (below about 10^{-5} mbar) a relatively small (and therefore cheaper) power supply can be used. This saves on rack space and heat dissipation. However, it will not be sufficient simply to install only such power supplies on diamond even though pumps will normally operate far below 10^{-5} mbar. During pump down of any part of the machine, ion pumps undergo a manually controlled conditioning process at higher pressures (referred to as “flashing”). This results in lower outgassing of the pump and therefore better ultimate pressures. It also removes embedded contaminants which can be pumped away. Larger power supplies capable of delivering higher currents will be required for this process.

The evaluation will therefore be to determine the cost advantage of installing mainly holding supplies plus a few larger power supplies which can be switched to each ion pump as required against the decrease in operational flexibility during conditioning.

Titanium sublimation pumps

Each Titanium Sublimation Pump (TSP) will have its own dedicated power supply. The power supply will consist of two separate units, a high current power supply located close to the TSP in the storage ring tunnel and a control unit that will provide remote operation of the power supply. Each control unit/power supply combination will be capable of selecting and powering one filament at a time in a multifilament TSP cartridge. The TSP power supplies will be required to provide the following:

- low voltage/high current power output capable of driving a TSP up to 3m away.
- control of power output by operating the TSP power source up to 100m away.
- front panel indication of filament status and operational status.
- quick and simple provision to select the TSP filament required.

Criteria influencing the choice of TSP power supplies will include -

- each power supply should have the provision to accept at least one external interlock to prevent operation at high pressure.
- size: there is only a limited amount of space available in the facility for control racks and equipment in the storage ring tunnel.
- minimising heat dissipation in both the control racks and ring tunnel is advantageous.
- manufacturer(s) should have considerable experience (over many years) in producing reliable electronic systems for TSP's. Experience in providing solutions for synchrotron light sources will be advantageous.
- life time cost will be a major factor. Cost of ownership will be considered as well as installation costs.
- control units should be easy to use by vacuum and controls technicians.
- selection of the TSP filament should be a simple procedure

A generic specification for the TSP control units is shown in Table 5.11-2

During the initial part of the procurement phase of the diamond project, detailed evaluation will be undertaken regarding the possible integration of ion pump power supplies and TSP control units. A separate power unit would still be required to provide the high current to the filaments. The aim will be to save on rack space, reduce heat dissipation and provide an economic solution.

Table 5.11-2 Generic specification for TSP control units

TSP Control
Output POWER to the TSP filament should be fully controlled and adjustable.
Provision for fully programmable ‘fire’ sequence including power ramp rate, dwell time and off periods.
Capacity to provide control of TSP cartridges from different manufacturers (details to be negotiated)
Provide overload protection in the event of filament short circuit.
Provide interlock protection in the event of a filament open circuit.
Accept over pressure interlock from total pressure gauge controller.
Provide a control interface that will be suitable for EPICS (EPICS, RS-232, RS 485 or other). Interface to provide full status information.
Ring tunnel power supply to be stand-alone and to be radiation hard, robust and able to withstand water ingress.
Remote control unit to be 19 inch rack mountable in a minimum of space.
Provide front panel information regarding the set up, current operational status, power output, interlock and filament status.

TSP’s need to be fired intermittently – at pressures below 10^{-9} mbar only once every few days – and this sequence will be carried out automatically by a scheduled control system task. This will generate a slow power ramp up to the preselected sublimation level, a short dwell and a ramp down of power. This will be repeated a predetermined number of times per fire cycle. However, before using a TSP filament, it has to be carefully degassed and conditioned over a period of some hours. This is essentially a manual operation so the control unit and control system will need to cater for this.

NEG pumps

Non Evaporable Getter (NEG) Pumps require a power supply to condition or activate the pump. Once activated the pump will remain operational for a period of time that is directly proportional to the gas load being pumped (limited by the capacity of the pump). For diamond it is anticipated that the NEG pumps will not require many re-activations in a year, perhaps only one. To reactivate the pump it will be necessary to bake the pump cartridges which have integral heaters. The power supply required to do this is relatively simple.

Since activation of these pumps is infrequent, it will not be necessary to have a dedicated power supply for each pump. For diamond it is intended to provide a number of portable power supplies that can be connected to the NEG pump in the ring tunnel. These power supplies will only be used during maintenance periods when the machine is not operating. The exact number of power supplies required has not been determined and will be part of a pump/power supply package through the same manufacturer. The NEG power supplies should meet the following criteria –

- provision to accept at least one external interlock to prevent operation at high pressure.
- adequate protection to prevent overheating of the NEG cartridge.
- ability to operate the NEG heaters through a connection lead up to 3m long.
- size will be important as there is only a limited amount of space available in the facility for storage of infrequently used equipment and working space will be limited in the storage ring tunnel.
- easy to use by vacuum technicians.

During the initial part of the procurement phase of the diamond project, detailed discussions will take place with the manufacturers of NEG power supplies to ensure that the power supplies are easy to transport around the ring tunnel.

The NEG coating on insertion device vacuum vessels is activated by baking the vessel, probably to about 180°C for a few hours. Control of this bakeout will be achieved by using a portable bakeout control system with datalogging facilities.

5.12 VACUUM VALVES

5.12.1 In-line valves (gate valves)

For operational convenience, in-line gate valves are used to separate the storage ring into small sections. This allows for relatively quick pump downs and limits the amount of storage ring exposed to atmosphere for maintenance, upgrading, etc., during operations. It is anticipated that after the initial installation and commissioning phase, the only parts of the ring to be let up with any frequency will be the insertion device straights. Therefore a gate valve of all metal construction will be installed at each end of the straight. In the open position, these valves will have an aperture conforming in shape to the elliptical vessels on each side. The aperture will be screened by a cage of spring fingers to provide rf electrical continuity along the beam orbit. The valves will be of the so-called fast closing type (operating in about 1 second).

In the case of the rf straight, there will be a pair of such valves installed between each cavity.

Similar valves, but with circular apertures and no rf screens will be used to isolate each beam port front end and the transport line from the Booster synchrotron. The beam port front end valves will, in the closed position, be protected by cooled synchrotron radiation absorbers.

All these valves will be pneumatically operated and fully interlocked to pressure gauges in each adjacent vacuum system. The valves in the electron beam path will be interlocked so that beaming is inhibited if any one is not open.

5.12.2 Roughing valves

Manual right angle, all metal valves of 63 mm aperture will be used to isolate the roughing stations from the storage ring. They will require position indicators to provide safety interlocks to the control system. Other valves in the roughing stations may be elastomer sealed (probably Viton™[†]).

5.12.3 Other valves

Many small, manual all-metal right angle valves will be required at convenient locations. Dry nitrogen let up valves will be of small-bore all metal manual construction and will be required on each roughing station. For reliability, the storage ring will be let up through the roughing station and not by valves directly on the ring.

5.13 PRESSURE MEASUREMENT

5.13.1 Total pressure gauges

It will be necessary to measure total pressures to $< 10^{-9}$ mbar throughout the vacuum system for the diamond facility. The gauge system will need to provide such capability. The storage ring and beam port front ends will require reliable readings of total pressure at 1×10^{-10} mbar.

There is no one gauge technology available that can measure over the full required range. Therefore gauges measuring the rough vacuum range (1000 to 10^{-3} mbar) and medium vacuum to UHV (10^{-3} to 10^{-10} mbar) will be required

(a) General criteria influencing the choice of total pressure gauges

Wherever possible, commercially available equipment will be purchased with no 'specials' or purpose built equipment. This will reduce operational costs and down time whilst increasing flexibility.

Gauge heads (measuring tubes) should be robust enough to remain unaffected by normal handling and processing associated with the building and operation of a synchrotron light source and present a minimal risk of vacuum failure during normal

[†] Viton is a registered trademark of DuPont Dow Elastomers, Wilmington, Delaware, USA

machine operation. This latter requires that any electrical feedthrough/connector combinations be intrinsically robust or be suitably protected.

Life time cost will be a major factor in selecting the gauge where technical differences between different technological solutions are small.

The gauge manufacturer(s) should have considerable experience (over many years) in producing reliable UHV gauge systems (experience in accelerator systems will be of benefit).

The gauge heads must be vacuum bakeable to 250^0C, and it will be advantageous if the gauges are able to be operated during such a bake.

The electronics required to operate the gauges should be located outside any radiation areas or be radiation hard.

Other components of the accelerator system should have a minimum influence on the pressure measurement system. Magnetic, electrical and mechanical noise may be significant and although careful positioning of the gauges can reduce these effects it will be necessary to consider such influences when selecting the gauge supplier.

The gauge heads should contain no materials that will have a deleterious effect on the ultimate vacuum.

(b) Rough vacuum gauges

The purpose of rough vacuum gauges will be mainly to provide an indication of the total pressure in the system when monitoring the progress of a pump down or when there is a degree of vacuum failure. The selection criteria noted in (a) above apply equally to these gauges, but because the gauge need not be very accurate, an economical solution is important. The Pirani gauge offers a good solution for measuring pressure in the range 1000-1x10^{-3} mbar (in the so-called convection Pirani configuration). Although there are other gauges available (such as the thermocouple gauge) these offer no real advantages over the Pirani.

(c) UHV gauges

Among the many types of UHV gauge available, there are three in particular that could be suitable for diamond. There are two acceptable variants of cold cathode gauges (Penning and Inverted Magnetron gauges) and a hot cathode gauge (Bayard-Alpert gauge) which need to be considered. All are commercially available from more than one manufacturer and are in common use on other accelerators around the world.

Table 5.13-1 Typical pressure ranges for hot and cold cathode gauges

Gauge Type	Typical Pressure Range (mbar)
Hot Cathode (Bayard-Alpert with Tungsten filaments)	$5x10^{-4}$ - $3x10^{-11}$
Cold Cathode (Based upon Penning discharge)	$5x10^{-3}$ - $1x10^{-9}$
Cold Cathode (Inverted Magnetron discharge)	$5x10^{-3}$ - $1x10^{-11}$

Table 5.13-1 shows typical pressure ranges for commercially available gauges. Economical rough vacuum gauges do not measure below 1 x 10^{-3} mbar, so it is not possible to cover the full pressure range with a hot cathode gauge and one such gauge. The ion pump power supplies could be used as pressure indicators but the best solution for ion pumps could be compromised. An intermediate pressure gauge could be used but the costs would be significantly higher. There are hot cathode gauges which work to higher pressures, but the UHV performance is compromised. Therefore the hot cathode gauge solution will not be pursued.

The Penning gauge does not measure reliably to sufficiently low pressures for the diamond Storage Ring so the inverted magnetron cold cathode gauge (IMG) will be adopted. Although the Penning gauge is slightly less expensive than the inverted magnetron gauge and could in principle be used in the injector, in the interests of standardisation only inverted magnetron gauges will be used in the machine complex.

(d) Generic specification of total pressure gauge heads

This is shown in Table 5.13-2.
Table 5.13-2 Generic specifications of total pressure gauge heads

Pirani Gauge	**Cold Cathode Gauge (Inverted Magnetron Type)**
Pirani or Convection Pirani configuration	Inverted Magnetron configuration cold cathode gauge.
Bakeable to 250^{0}C (preferably while operating)	Bakeable to 250^{0}C (preferably while operating)
Inlet flange to be decided at a later date (probably 70 mm od knife edge)	Inlet flange to be decided at a later date (probably 70 mm od knife edge)
Pressure range 1000 -1x10^{-3} mbar	Pressure range 5x10^{-3} mbar - 5x10^{-11} mbar
Interlock provision set anywhere in pressure range (single channel)	Interlock provision set anywhere in pressure range (three channels)
"On-board" electronics (if necessary) to be radiation hard.	On-board electronics (if necessary) to be radiation hard.
	Gauge starting times to be of the order of a few seconds at 1x10^{-9} mbar.

(e) Guidelines for positioning of gauge heads

The following general guidelines for gauge head positioning should be observed -

- gauge heads should be positioned in a convenient location that will allow reasonable access to the gauge for maintenance.
- gauge heads can be mounted horizontally or vertically. If mounted vertically, the inlet flange must be below the gauge tube.
- gauge heads should be kept out of the plane of synchrotron radiation.
- gauge heads should be mounted inside the electron orbit and as close as possible to the vacuum chamber and should be screened from direct exposure to synchrotron radiation or secondary electrons
- magnetic, electrical and mechanical noise sources should be avoided as far as is practical. Gauge heads should be at least 1m away from magnets that produce strong fringe fields (e.g. dipoles) or adequate magnetic screening should be installed
- stray magnetic fields caused by the gauge head should be small or screened.
- the beam pipe has a small gas flow conductance so it is necessary for a control gauge to be close to the vacuum component it controls. For reliability, gauges controlling items critical to operation of the machine (e.g. in line valves) should have a spare gauge head installed.
- each vacuum section (area between two gate valves) may contain more than one UHV gauge but may require only one Pirani.

(f) Location of gauge heads

<u>Arcs</u>

The gauges should be positioned such that they are located in the areas where the pressure profile calculations indicate that the highest pressures will be found. The pressure profile calculations indicate that four gauge pairs will provide sufficient information and control. Preliminary locations are shown in Figure 5.9-3.

Pirani gauges will interlock the ion pumps, which are spaced throughout the achromat, and so ideally the gauges should be equally spaced as well. The Pirani gauge also interlocks the cold cathode gauges that will be located close to the Pirani. Some cold cathode gauges will interlock the partial pressure gauges which will need to be close by (see 5.13.2 below). Some cold cathode gauges will also need to be close to the sector valves and the beam port front-end valves which they will interlock.

RF cavity straight

There will be three pairs of gauges, one dedicated to each rf cavity and a pair of gauges on each interspace.

Injection straight

There will be two pairs of gauges, exact position to be decided.

Diagnostic straight

There will be two pairs of gauges, exact position to be decided.

Insertion device straights

There will be one gauge pair located at the down stream end of each straight. A second cold cathode gauge head will be installed close by the first head to provide safety back-up in the event of failure. In some cases (very small gap insertion device vacuum chambers for example) more than one UHV gauge may be required. This will be assessed for each individual insertion device design.

Rough pump sets

In addition to Pirani gauges and inverted magnetron gauges as detailed above, the roughing pump sets installed in the machine complex (Section 5.7.1 above) will require simple local indication of pressure between 1200 mbar and 1 mbar. This will be provided using a mechanical gauge such as a Bourdon tube gauge or diaphragm gauge. These will not be monitored by the Control System.

The dry nitrogen gas line to the let up valves located near each rough pump set will require permanently installed dew point meters. In-line digital instruments are commercially available for this purpose. If possible, these will be monitored by the control system.

5.13.2 Partial pressure measurement

(a) Introduction

A vital diagnostic tool used on all synchrotron light source vacuum systems is the partial pressure gauge, typically a quadrupole radio frequency mass spectrometer used as a residual gas analyser (rga). It is important that the vacuum system for diamond incorporates a sufficient number of rga's and that they are located so as to take full advantage of their diagnostic capabilities.

The provision of such a full complement of instruments greatly enhances the operational flexibility of a source, enabling accurate diagnosis of problems associated with the "health" of the vacuum system. This can reduce machine down time to a minimum.

(b) Criteria influencing choice of residual gas analysers

Wherever possible, commercially available equipment will be purchased for diamond with no 'specials' or purpose built equipment. This will reduce operational costs and down time while increasing flexibility.

The gauge heads should be robust enough to remain unaffected by normal handling and processing associated with the building and operation of a synchrotron light source and present a minimal risk of vacuum failure during normal machine operation. This latter issue requires that any electrical feedthrough/connector combinations be intrinsically robust or be suitably protected.

Life time cost will be a major factor in selecting the residual gas analyser system to be used, although the technical specification must be met.

The residual gas analyser manufacturer(s) should have considerable experience (over many years) in producing reliable residual gas analyser systems. Experience in providing solutions for synchrotron light sources will be particularly important and will need to be demonstrated.

The residual gas analyser gauge heads must be able to withstand a vacuum bake to 250^0C, and it will be an advantage if the residual gas analyser will be able to be operated during bakeout, using a thermal extender if necessary.

The electronics required to drive the residual gas analyser system should be located outside any radiation areas or be radiation hard.

The effects from other components of the accelerator system on the operation of the residual gas analyser system should be minimal. Magnetic, electrical and mechanical noise may be significant and although careful positioning or shielding of the residual gas analyser head and electronics can reduce these effects it will be necessary to consider such influences when selecting the gauges and their position.

The residual gas analyser software should be commercially written, capable of networking, able to record data for each head continuously and be easy to use by a vacuum technician.

(c) Generic specification of the residual gas analyser system

This is shown in Table 5.13-3.

Table 5.13-3 Generic specification of the rga system

Residual Gas Analyser System
Quadrupole radio frequency mass spectrometer type.
Range of all instruments to be 1-200 atomic mass units (amu).
All instruments to have two detection systems (dual detector) consisting of a Faraday cup and a secondary electron multiplier (SEM – either channeltron or channelplate (lifetime/cost issueswill determine which)).
The ion source to be designed for UHV operation (open source).
Two independent tungsten filaments to be available and independently switched through software.
Analyser head to be bakeable to 250^{0}C (some degree of operation during bakeout will be desirable).
Inlet flange to be decided at a later date (probably 70 mm od knife edge).
The analyser to be supplied complete with a housing that includes one 90^0 bend between ion source and inlet flange.
Minimum detectable partial pressure to be less than $1x10^{-13}$ mbar.
The electronics to be capable of accepting an external interlock (typically pressure) to inhibit filament operation.
The electronics to be networked using the EPICS platform or one that EPICS can support.
The software to be networked and be optimised for remote operation through a PC. It should also be user friendly for operation by scientists and technicians.

(d) Guidelines for positioning of residual gas analyser gauge heads

The following general guidelines for gauge head positioning should be observed -

- gauge heads should be positioned in a convenient location that will allow reasonable access to the gauge for maintenance.
- gauge heads should be mounted vertically in a housing with the inlet flange at the bottom.
- gauge heads should be mounted inside the electron orbit and as close as possible to the vacuum chamber.
- gauge head ion sources and detectors should be kept out of the plane of synchrotron radiation
- magnetic, electrical and mechanical noise sources should be avoided as far as is practical. Gauge heads should be at least 1m away from magnets that produce strong fringe fields (e.g. dipoles) or adequate magnetic screening should be installed.

(e) Location of residual gas analyser gauge heads

Arcs

There will be two residual gas analysers in each arc. In order to provide maximum coverage of the arc vacuum system and diagnostics of the dipole crotch absorbers, it will be necessary for the residual gas analysers to be located down stream of each of the two dipole magnet vacuum chambers and if possible close to a total pressure gauge for comparison. Preliminary locations are shown in Figure 5.9-3.

RF cavity straight

There will be three residual gas analysers, one dedicated to each rf cavity.

Injection straight

There will be one residual gas analyser, exact position to be decided.

Diagnostic straight

There will be one residual gas analyser, exact position to be decided.

Insertion device straights

There will be at least one residual gas analyser in each straight, dependent on the nature of the device. If there is only one, it will be located at the down stream end of the straight.

5.14 CONTROL OF VACUUM GAUGES

5.14.1 Control system

In common with all other instrumentation on the diamond machine complex, the vacuum gauges will be controlled and monitored through the main machine control system (Part D.2). This will be accomplished by each control unit being equipped with a standard communications interface such as RS-232. Protocols will be defined by the equipment manufacturer and the necessary interface layer to the EPICS control system software will be written by the Machine Controls Group.

5.14.2 Interlocks

The majority of interlocks to vacuum gauges will be implemented either by firmware in the gauge control units or in software in the control system. However, where there is a possibility of a dangerous situation arising during the operation of a vacuum gauges, then an additional, parallel, hardwired interlock chain will be implemented. “Dangerous” is defined here as being a situation which can lead to a possible compromise of the integrity of the vacuum envelope of the machine complex or to damage to an item important to the operation of the machine whose replacement requires part of the machine to be vented to atmosphere. An example of such a failure might be burning out the filament of a residual gas analyser by switching on at high pressure.

Interlock chains will be identified during the procurement phase of the project.

5.14.3 Location of vacuum gauge power supplies and control units

It is considered desirable to locate all electronics outside the ring tunnels. This makes for ease of servicing – tunnel searches do not have to be interrupted to replace a faulty unit for instance. Radiation levels in the tunnel are high during operations and this adversely affects the life of electronics. However, this has to be balanced by the economics of installing long cable runs, especially where relatively low currents are to be measured or where high currents have to be delivered. Cables also have to enter the tunnel through labyrinths which, inevitably, have limited capacity. Cables need to be compatible with the radiation environment.

Control units will therefore normally be installed in control racks situated outside the machine shield walls. Cable runs should be kept to a minimum and there should be no joints, except in proper junction boxes. Cables in the racks should be terminated in connectors interfaced directly to the control units. In the machine tunnels, cables will be terminated in marshalling boxes attached to the machine mounting girders. Cables to the equipment from these marshalling boxes will have no joints and will be as short as practicable.

During the initial part of the procurement phase of the diamond project, detailed evaluation will be undertaken regarding the possible use of so-called “smarthead” gauges. Here, the bulk of the gauge control electronics (if not all) is located in a pod attached directly to the gauge head. This pod typically simply requires a low voltage dc electrical supply (usually 24 V) and a standard data interface connection (e.g. RS232 or Ethernet). Potential advantages of using such gauges include reduced cabling cost, reduced requirement for rack space and reduced heat dissipation in the control racks. Potential disadvantages include the possible reduced lifetime of the electronics caused by radiation and possibly reduced functionality.

5.14.4 Total pressure gauge power supplies and control units

(a) General requirements

The total pressure gauge control units selected for diamond will be required to provide -

- the necessary power requirements and signals to drive gauge heads that may be up to 100m away.
- a front panel total pressure reading.

- control interlocks for other equipment.
- interfacing with the high level EPICS control system of the diamond facility.
- the capability of driving four gauges: two Pirani gauges and two inverted magnetron gauges. In some cases, there may not be a full complement of gauges installed in the control unit. This will be acceptable in the interests of standardisation.

A number of different manufacturers offer solutions that would be suitable with the main differences being the size and cost of the equipment. The 'ideal' package does not exist, but as already stated 'specials' will not be used unless absolutely necessary.

(b) Criteria influencing choice of total pressure gauge control units

These will include -

- the pressure measurement display shall be capable of being read from a distance of a few metres.
- the pressure readings on all gauges installed in a control unit shall be available simultaneously.
- at least two fully variable external interlocks shall be provided from each cold cathode gauge and one from each Pirani gauge. A further interlock will be required from the Pirani to control the start-up operation of the cold cathode. This may be either an external interlock or embedded in the firmware of in the control unit.
- size will be a factor that will need to be considered. There is only a limited amount of space available in the facility for control racks. Similarly, minimising heat dissipation in the control racks is advantageous.
- manufacturer(s) should have considerable experience (over many years) in producing reliable electronic systems for vacuum gauges. Experience in providing solutions for synchrotron light sources will be an advantage.
- life time cost will be a major factor. Cost of ownership will be considered as well as installation costs (some systems require heavy duty cables for example).
- control units should be easy to use by vacuum and controls technicians.

(c) Generic specification of total pressure gauge control units

This is shown in Table 5.14-1.

Table 5.14-1 Generic specification for total pressure gauge control units

Simultaneous control of gauge heads	Two cold cathode and two Pirani gauges.
Fully variable set point relay interlocks	Minimum of two for each cold cathode and one for each Pirani.
Cold cathode interlock range.	$1x10^{-3}$-$1x10^{-9}$ mbar.
Pirani gauge interlock	Atmosphere-$5x10^{-3}$ mbar.
Control interface	Suitable for EPICS (EPICS, RS-232, RS 485 or similar).
Display of pressure	Each of the four gauge heads simultaneously. (Display of Pirani gauges may be a simple indication when the cold cathode gauges are on.)
Size	19 inch rack mountable in a minimum of space and to fill a full rack width in multiples of control units (fixing kits and spacers can be used).
Cable length	The control units should be capable of driving gauges through cables up to 100m long.
Radiation resistance	If the gauge control requires electronics at the gauge head then it should be radiation hard with a lifetime of at least 1 year, preferably 10 years.

5.14.5 Partial pressure gauge power supplies and control units

(a) General requirements

The partial pressure gauge control units selected for diamond will be required to provide –

- the necessary power requirements and signals to drive the gauge heads that may be up to 100m away. Some of the electronics required to do this may need to be very close to the gauge head and will need to be radiation resistant.
- user friendly control software.
- capability of receiving control interlocks from a total pressure measurement device and the capability of generating interlocks from set points associated with at least four individual mass spectra peaks.
- interfacing with the high level EPICS control system of the diamond facility.
- the capability of networking the control software so that multiple gauge heads can be observed simultaneously and all gauges heads can be gathering/storing data simultaneously.

A number of different manufacturers offer solutions that would be suitable with the main differences being the software interface, networking capability and cost of the equipment. A detailed study of the market will be carried out before selecting the final package for diamond.

(b) Criteria influencing choice of partial pressure gauge control units

These will include -

- vulnerability of electrical feedthrough assembly to breakage/stress.
- suitability of electronics for radiation environment.
- software features.
- software user friendliness.
- mass spectrometer specifications, namely minimum detectable partial pressure, resolution, spectrometer scan speed and immunity to ion source contamination/memory effects.
- provision of set point interlocks to accept total pressure gauge interlock and provide at least four external interlocks from individual mass spectra peaks.
- size will be a factor that will need to be considered. There is only a limited amount of space available in the facility for control racks. Similarly, minimising heat dissipation in the control racks and ring tunnel is advantageous. The requirement for support structures for any electronics inside the ring tunnel will also be considered.
- manufacturer(s) should have considerable experience (over many years) in producing reliable electronic systems for mass spectrometers. Experience in providing solutions for synchrotron light sources will be an advantage.
- life time cost will be a major factor. Cost of ownership will be considered as well as installation costs (some systems require bulky multi-core cables for example).

(c) Generic specification of partial pressure gauge control units

This is shown in Table 5.14-2.

Table 5.14-2 Generic specification for partial pressure gauge control units

Software	Commercial software shall be used to control the rga's with demonstration of use on at least one other synchrotron facility. Software must include the following modes of operation as a minimum: Analogue, multi trend and leak detect.
Control interface	Suitable for EPICS (EPICS, RS-232, RS 485, Ethernet or other)
Data storage	Continuous data storage available for all modes of operation. Data to be stored in a user defined file structure and in a commonly used file format.
Data recall	The stored data should be easily recalled into spectral display software.
Size	19 inch rack mountable in a minimum of space and to fill a full rack width in multiples of control units (fixing kits and spacers can be used). If essential some parts of the equipment can be located in the ring tunnel. Such parts should be relatively small and if connected directly to the gauge head should not require any support structures.
Cable length	The control units should be capable of driving gauges through cables up to 100m long.
Radiation resistance	If the gauge control requires electronics at the gauge head then it should be radiation hard with a lifetime of at least 1 year, preferably 10 years. Radiation dose to be specified.

5.15 RING TUNNEL SERVICES FOR THE VACUUM SYSTEM

5.15.1 Electrical supplies

It is proposed that all the electrical equipment for vacuum components will be housed in racks in small enclosures around the outside of the machine (see Part D.2). The initial estimates for all controls and instrumentation equipment are that there will be 5 instrumentation rooms with 30 racks per room. it is likely that the vacuum equipment will be distributed around these rooms in order to maintain cable lengths to a reasonable value.

The total estimated power requirements are shown in Table 5.15-1. These are all single phase 230V ac supplies with the exception of Valves, where the supply is 24V dc.

Table 5.15-1 Estimated power supply requirements for vacuum equipment. Some diversity factor must be applied to these values.

Equipment Type	Number required	Power consumption (maximum) per Item	Total Maximum power requirements
Total Pressure Gauges	145 (of each gauge)	<1W	<145W
Total Pressure Gauge Control Units	95 (2 pairs of gauges)	35W	3325W
Partial Pressure Gauges	72	75W	5400W
Partial Pressure Gauge Control Units	72	No information	No information
Ion Pumps (500 l sec^{-1})	120	240W (400 l sec^{-1}) at maximum sustainable pressure	28800W
Ion Pumps (300 l sec^{-1})	288	160W (220 l sec^{-1}) at maximum sustainable pressure.	46080W
Ion Pump controllers	408	Medium 100mA HV section: Min - 5W, Max - 325W	2040W Min., 132600W Max.
Titanium Sublimation Pumps	48	400VA (max. when sublimating)	19200VA
NEG pumps	48	90W under activation	4320W
NEG pump controller	48	1500W maximum when activating the NEG	72000W
Forevacuum pumps	24	400W maximum	9600W
Turbomolecular pumps	24	No information	No information
Turbo pump controllers	24	500W	12000W
Valves	400	2.5W	1000W

5.15.2 Dry nitrogen

Dry nitrogen is required for venting the vacuum systems of diamond to atmospheric pressure. This enables quick pumping of a well outgassed system back down to UHV without baking. The requirement is for a supply of nitrogen of purity > 99.998%, with dew point < -70°C (i.e. ≈ 1 ppm of water) at a pressure ~ 0.5 psi.

Such a supply may conveniently provided from liquid nitrogen boil-off. Supply lines will be of stainless steel, cleaned and dried to a high standard. In-line dew point meters will be provided near the take-off points, which will be at the rough pumping stations.

5.15.3 Compressed air

A compressed air supply is required to operate the vacuum gate valves and other pneumatic actuators at various points around the machine. The upper pressure limit is determined by the safe operation of the gate valves. Cleanliness is an important issue for the compressed air supply. In the case of one of the actuators failing from bellows rupture, compressed air can enter the vacuum system and contaminate it. The requirement is for an "oil free" supply (i.e. < 1 ppm of oil) at 8 bar.

5.15.4 Helium

A piped helium supply at a few psi is required for leak chasing the vacuum system with take off points situated conveniently around the ring. The specification for the supply is not very critical. It should be oil free as for the compressed air, but the helium concentration need not be greater than 80%. The balance should be substantially nitrogen, although some oxygen is acceptable.

5.16 SAFETY

All items of vacuum equipment will be required to adhere to the general safety requirements of the diamond Project.

Specific points to note include –

- Ion pumps operate at high voltages (3 – 7 kV), so cables and connectors will have to be adequately protected. The power supplies can deliver modest currents (up to 500 mA). Safety interlocks switch this voltage off if connectors are disconnected.

- Inverted magnetron gauges operate at voltages of about 3kV so cables and connectors will have to be adequately protected. Currents are limited to very low values.

- RGA gauge heads contain hot filaments so housings can get hot to the touch.

5.17 REFINEMENT OF THE DESIGN

There are a number of areas in which further work needs to be done in order to optimise the vacuum design. These can be accomplished in the first few months of the procurement phase of the diamond Project without compromising the overall schedule.

The main work items are as follows –

5.17.1 Arc Pumping Scheme

The arc pumping scheme derived in 5.9 above is based on the emitted photon flux being distributed in some part along absorbers integral with the sides of the vacuum vessels. It may be possible to optimise the pumping rather better by "catching" most of it on discrete photon stops. Although there are significant engineering complexities in doing this, a full investigation needs to be undertaken.

5.17.2 Pumping Spouts

As noted 5.9.2 above, much of the pumping relies on fin shaped spouts penetrating the quadrupole magnets. It would be desirable to eliminate these. Partially this depends on the possibility of using discrete photon stops as discussed in 5.17.1 above, although the two are not inextricably linked. Some preliminary work has indicated that this is possible in the centre part of the arc, but further work needs to be done to assess if this is possible elsewhere and the overall benefits.

The advantage of doing this is that it simplifies the design of the magnets.

5.17.3 Beam Port Front Ends

The detailed layout of the first few components of the beam ports and their interaction with the vacuum system of the storage ring has not yet been assessed.

5.17.4 Injection and Diagnostic Straights

Detailed analysis remains to be done once design details are available.

References

[1] Data from the late A.G. Matthewson, CERN, private communication

[2] SRS Specifications, Daresbury Laboratory

[3] Atlas Technologies, Port Townsend, Wa, USA

[4] Drawing DL/A0-48/037, Daresbury Laboratory

[5] diamond Vacuum Quality Assurance specification, VAC-QA-spc-008, *to be issued*

[6] SRS Specification CG/02/90/A, Daresury Laboratory

[7] diamond Vacuum Quality Assurance Manual *to be issued*

[8] P.A. Redhead, J P Hobson and E V Kornelsen, *The Physical Basis of Ultra High Vacuum*, Chapter 10. AIP, New York, 1993. ISBN 1-56396-122-9

[9] C. Herbeaux *et al*, Vacuum **60** (2001) 113

[10] Liu *et al*, Vacuum **44** (1993) 435

[11] VAC-SR-rpt-007

[12] Agreement No 4121614, E.M. Williams and CLRC

[13] E.M. Williams, to be submitted

[14] Professional Engineering Computations, Livermore, California, USA

[15] VAC-SR-rpt-005

[16] C. Benvenuti *et al*, Vacuum **53** (1999) 219

[17] MOLFLOW, supplied by R Kersevan, ESRF, France

[18] R J Reid, Vacuum **44** (1993) 473

[19] Mathsoft, Inc., Cambridge, Ma, USA

[20] K Akaishi *et al*, Vacuum **47** (1996) 741

[21] C. Herbeaux, *et al*, J.Vac.Sci.Technol **A17** (1999) 635

[22] C.L. Foerster, *et al*, J.Vac.Sci.Technol A8(3) (1990) 2856

[23] O.B. Malyshev, Thesis, Novosibirsk,1995.

[24] O. Gröbner, *et al*, J.Vac.Sci.Technol **A12** (1994) 846

[25] Y. Hory, *et al*, J.Vac.Sci.Technol **A12** (1994) 1644

[26] V. Anashin, *et al*, Proc. EPAC-98, Stokholm, 1998, v. 3, 2163

[27] J. Gómez-Goñi, e*t al*, Vacuum Technical Note 92-06, CERN, 1992.

[28] J. Gómez-Goñi, e*t al*, Vacuum Technical Note 92-12, CERN, 1992.

[29] C.L. Foerster, e*t al*, J.Vac.Sci.Technol **A12** (1994) 1673

[30] V. Baglin, e*t al*, LHC Project Report 206, CERN.

[31] V.V. Anashin, e*t al*, Nucl. Instrum. Methods Phys. Res.; **A 448** (2000) 76

[32] C. Benvenuti. Proc. PAC ’01, 2001

[33] C. Benvenuti, e*t al*, Vacuum **60** (2001) 57

[34] V. Anashin, e*t al*, private communication.

[35] R. Kersevan, e*t al*, Proc. EPAC 2000, Vienna, Austria, 2289

[36] R. Kersevan, private communication.

[37] F Mazzolini, private communication.

[38] A K Gupta and J H Leck, Vacuum **25** (1975) 362

[39] SAES Getters, SpA, Milan.