

PRELIMINARY DESIGN OF THE VACUUM SYSTEM FOR DIAMOND

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Abstract

The design of vacuum systems for modern third generation synchrotron light sources is by no means straight forward, especially to achieve the necessary low pressures throughout the small aperture magnet vessels. A number of computational methods, including Monte-Carlo simulations, have been developed recently to aid the designers of such systems. Experience has demonstrated that some degree of confidence can be placed upon the results obtained from them, providing they are used with care. We are embarking upon the detailed design study of a light source known as DIAMOND, that will meet user requirements well into the next century. To assist in the design of the vacuum system, we have used a Monte-Carlo simulation program[1] to calculate pressure profiles around the storage ring. Here we describe the use of the program as part of an iterative process leading to a satisfactory vacuum system design for DIAMOND.

1 INTRODUCTION

DIAMOND is an unfunded synchrotron light source currently being designed at Daresbury Laboratory. The new light source would be a replacement for the Synchrotron Radiation Source (SRS) at Daresbury. DIAMOND is characterised as a third generation machine having the following main parameters[2]:

- 3.0 GeV Energy.
- 345.6m Circumference.
- Racetrack Design with DBA Lattice.
- 16 Cells.
- 1.4T Magnetic bending field.
- 5m Insertion Device Straight Sections with two 20m Insertion Device Straights.

Third generation light sources are optimised for the use of insertion devices (e.g. wiggler and undulator magnets) installed in straight sections to provide the users with high brilliance or high flux synchrotron light at high electron (or positron) currents while maintaining low beam emittance.

2 BASIC VACUUM REQUIREMENTS

The design of vacuum systems for third generation light sources is complex and unique to each project. The following requirements need to be considered in detail:

- Small apertures of insertion devices leads to low conductance vacuum vessels.
- High beam currents produce very high desorption rates.

- Long lifetimes require low total pressures and low partial pressures of high mass gas species.
- Short conditioning times require high initial pumping speeds.

As well as accommodating these requirements, the vacuum scientist has to address some key issues that will influence the overall design of DIAMOND considerably:

- What material should be used in the construction-stainless steel, aluminium, copper, titanium, others?
- Is it necessary to design the vacuum system to incorporate in-situ bakeout? Recent experiences at third generation light sources (e.g. ESRF, Elettra[3]) indicate that this subject needs detailed investigation.
- Lumped and distributed pumping options need to be considered.
- Discrete and/or distributed absorbers can be used.
- What advantage can be gained (if any) by adopting an ante-chamber design for the vacuum vessels.

Perhaps the most difficult problem that the vacuum system designer faces is the way the design of DIAMOND evolves from concept to construction. As each design team (e.g. magnet, accelerator physics, RF, controls etc.) optimise their design, so the vacuum design has to change, sometimes in a radical way. This means that calculations need to be easily re-worked to address these changes. Complicated hand written solutions are often time consuming, tedious and indeed may not be tractable. In recent years the use of computer simulations has become practical and have been shown to be reliable[4]. The use of these methods to produce pressure profiles in light source vacuum systems has been a particular benefit and at Daresbury we have made use of one such computer simulation to assist in the design of the vacuum system for DIAMOND.

3 PRESSURE PROFILES USING MOLFLOW

MOLFLOW is a computer program written by Roberto Kersevan of the Wilson laboratory, Cornell university (previously of the Elettra Light Source, Trieste, Italy) and made available to Daresbury and other laboratories.

Molflow stands for MOLEcular FLOW, the vacuum pressure regime in which the calculations are valid. In molecular flow, gas molecules do not interact with each other but only with walls and surfaces within the vacuum system, and so can be treated independently.

The program, written in Turbo Pascal and compiled for the IBM PC platform, is based upon the well known Monte-Carlo method, a computational simulation method

for solving complex differential equations. The method relies upon random sampling as a means of iterating a set of equations with well defined boundaries. In this formulation, components of a vacuum system can be analysed individually or as a complete system. The ability of the simulation to cope with three dimensional objects is one of its great assets.

The software package consists of two linked programs, an editor program that is basically a data base into which various parameters defining the specific calculation are entered, and the Monte-Carlo simulation itself.

4 USING MOLFLOW FOR DIAMOND

The first step is to load the dimensions of the vacuum envelop of DIAMOND into the data base of the editor program. For the initial series of calculations, only the achromat portion of the unit cell was considered as this is the most complex. The achromat was divided into five parts, so that individual sections could be considered separately. Figure 1 shows a schematic diagram of the achromat.

Each of the five parts of the achromat are further split into sensibly sized component surfaces called 'facets'. The characteristics of each facet can be programmed to determine the way it will behave during the simulation, e.g.:

- Pumping surface (sticking coefficient > 0)
- Thermal desorbing surface
- Synchrotron Radiation induced desorbing surface
- Transmission piece between components
- Surface used to visualise the pressure profile

The position and size of an assumed set of vacuum pumps is also established in the editor program.

Simulations are run with increasing numbers of molecules, until a stable pressure profile - i.e. distribution of molecules impacting a given surface,- is obtained.

For the initial design of DIAMOND we choose the following design constraints :

- The material for the vacuum envelope is stainless steel
- Discrete photon stops will intercept the direct synchrotron radiation in well defined areas
- All pumping will be provided by lumped pumps
- There will be no true ante-chamber

4.1 Thermal Desorption

For thermal desorption, all the in-vacuum surfaces are defined as being desorbing surfaces, with the exception of pumps. The total system desorption is calculated as the total surface area of the desorbing surfaces multiplied by the thermal outgassing rate for stainless steel. This can vary widely dependent on surface treatment. However, we assume a value of 1×10^{-11} torr l s⁻¹ cm⁻², which is readily achievable by thorough pre-cleaning and conditioning of the vacuum vessels[5].

4.2 Photon Stimulated Desorption

When considering photon stimulated desorption, all the surfaces of the vacuum vessels are defined as being non-desorbing surfaces. New facets are created inside the vacuum vessels to represent the photon stops which are struck by synchrotron radiation. The area chosen for each of these facets is proportional to the horizontal angular acceptance of the stop. Knowing the number of photons of energy greater than 10eV intercepted by the stop and using an achievable, but not conservative, value of 10^6 gas molecules desorbed per incident photon[6], allows the emitted gas load to be easily calculated. Note that at this stage of the design we are not considering desorption arising from reflected and scattered photons, etc. This will be added at a later stage.

Molflow is used to calculate pressure profiles independently for thermal desorption and photon desorption. These can be added to generate an overall pressure profile.

5 PRESSURE PROFILES FOR DIAMOND

Space only permits us to present a limited selection of the results of many simulations carried out for DIAMOND. We illustrate these in Table 1, presenting the changes in predicted total pressure for a given pumping arrangement in the achromat. In run 2 a set of pumps was assumed, their positions largely dependent upon the physical space available in the initial mechanical layout of the design. Table 1 shows that run 2 did not produce a pressure profile which meets the design criteria (i.e. average base pressure of 1×10^{-9} torr at 300mA[7]). In

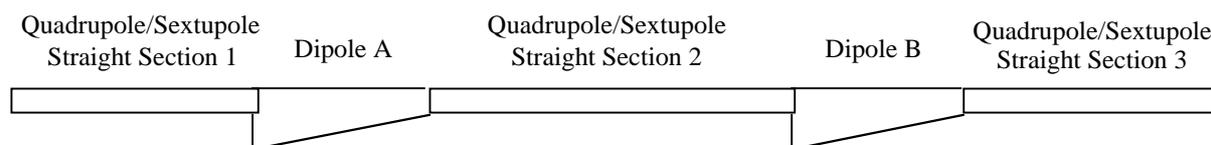


Figure 1: Schematic of Achromat Layout for DIAMOND in Molflow.

run 3, more pumps were added and the position and size of the pumps was tailored to the profile produced in run 2. This produced a profile much closer to the design specification and run 5 shows how a similar profile was obtained by reducing the number of pumps used, but carefully positioning them.

Figure 2 shows a typical example of the pressure profile in the achromat as calculated by Molflow. The two profiles are for thermal desorption and SR induced

critical high pressure areas in the DIAMOND achromat are at the exit of each dipole magnet which coincides with the highest beta functions. This complicates the design even more.

We still need to consider how we can physically obtain sufficient pumping speed at the desired pump locations. This is limited by the mechanical layout of the cell and the physical space available.

Table 1: Summary of Pressure Profiles for DIAMOND Achromat, with a stored current of 300mA.

Monte-Carlo Run	Total Number of Pumps	Total Pumping Speed / ls ⁻¹	Average Pressure / Torr	Maximum Pressure / Torr
2	11	11,400	7.5 x 10 ⁻⁹	1.9 x 10 ⁻⁸
3	15	20,400	2.3 x 10 ⁻⁹	1.0 x 10 ⁻⁸
5	13	18,000	2.6 x 10 ⁻⁹	1.0 x 10 ⁻⁸

desorption respectively. The total desorption will simply be the addition of these two profiles. The two peaks coincide with the exit of each of the two dipole magnets which is the position of the main photon stops.

6 SUMMARY

Table 1 shows that we have not yet reached the design criterion of 1 x 10⁻⁹ torr. There is clearly much work to be done before a working design is produced for the vacuum system of DIAMOND. However, the design has reached a stage where estimates of cost and mechanical layout can be made with some confidence.

The vacuum design may be further optimised taking into account accelerator physics considerations by permitting higher local pressures in areas where the vertical beta function is low and only requiring the lowest pressures where the vertical beta function is large. The

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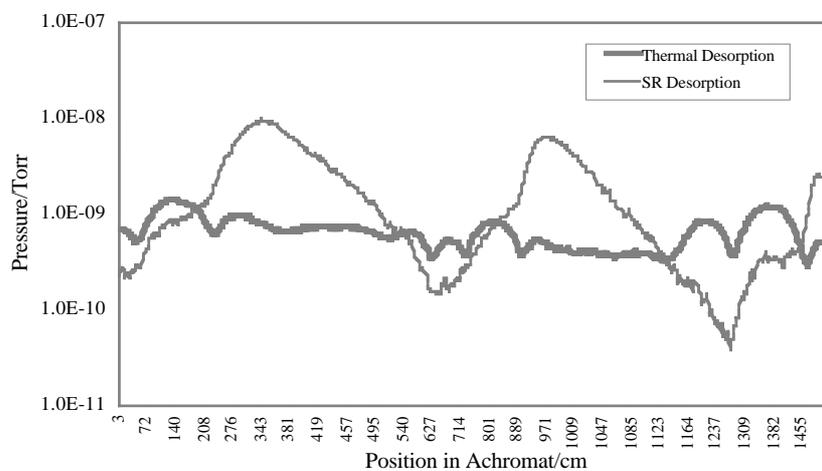


Figure 2 : Pressure Profile for DIAMOND, with a stored current of 300mA.