The Vacuum Behaviour of Screen Pumping Holes in the LHC Studied by Monte Carlo Simulation Techniques

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Abstract

A Monte Carlo simulation program has been developed to study the vacuum behaviour of the LHC screen pumping holes. The program is based on GEANT, a huge simulation library, developed at CERN.

Preliminary results of the simulation applied to the LHC geometry are reported here, further studies are continuing.

The relative pumping speed of LHC screen pumping holes has been calculated and found to be independent of the position of the holes.

1 INTRODUCTION

In the LHC (Large Hadron Collider) present design [1], a beam screen at about 10 K is foreseen to absorb the 18 kW of synchrotron radiation power emitted by the 7.7 TeV protons, which would otherwise be absorbed at 1.9 K, the temperature of the magnets. The synchrotron radiation desorbs gas from the surface of the beam screen. This gas immediately condenses on the 10 K surface and, with time, thick layers build up. In the case of hydrogen, which is one of the gases desorbed, when the layer exceeds one monolayer, there is a rapid increase in the thermal vapour pressure which, at 10 K exceeds 10^{-6} Torr. The provision of pumping holes to the 1.9 K surface, at which temperature the vapour pressure of hydrogen is negligible, behind the beam screen would limit this increase to an acceptable value depending on the size of the pumping holes in the screen.

A good estimation of the pumping performance of these holes is therefore necessary to decide on the best position and shape.

In order to simulate the whole process a Monte-Carlo simulation program in the frame of GEANT [2] has been developed. The program has been written in FORTRAN and it can be run under a VM/CMS operating system. Nevertheless it is also possible to use it in other platforms provided the CERN Program Library [3] and a FORTRAN compiler are installed.

GEANT is a huge library widely used on high energy simulations, but it is also possible to use it for other problems. The advantage of using such a frame, is that it is very easy to define the geometry, to use random generators, and to extend the program, adding more and more complications as we are progressing. As an example it is possible to include a magnetic field, thus describing the real LHC situation.

2 GENERAL CONSIDERATIONS ABOUT THE SIMULATION METHOD

The following assumptions have been made, in order to simulate the equilibrium state:

1. The trajectory of an individual molecule is independent of the trajectories of the other molecules. So it is possible to send particles one by one for the simulation.
2. The trajectory of one molecule depends only on its initial position and velocity.
3. A molecule can be either adsorbed on the walls or rejected following a cosine distribution law, i.e. assuming the wall is a perfectly diffuse emitter.
4. Once a molecule has been adsorbed on the walls, it will stay there during the whole process.
5. The kinetic energy and the modulus of the velocity are taken as unity for all the particles.
6. Only primary photodesorbed molecules have been considered, thus neglecting all secondary processes, such as photoelectrons, scattered photons, etc.
7. As a starting point, we have assumed that the walls of the pumping holes are perfectly sticky, i.e. the sticking factor is equal to unity.

Concerning this last point, in the near future it will be possible to reproduce the behaviour of the walls of the holes, assigning a sticking factor to them and following the trajectory of molecules to and from them.

3 GEOMETRY

In all the calculations performed, a tube of internal radius 18 mm and length of 3 m has been considered as the beam screen. The thickness of the walls is 1.1 mm. The tube has been divided into equally spaced sectors of 5 mm length along the axis of the tube (Z axis). For each of these sectors, the number of hits on the walls and number of adsorbed particles is stored. An outer tube at a distance of 1 mm from the inner screen is also defined and equally divided into sectors as explained above.

The generation takes place in a narrow strip of 1 mm height on the wall of the inner screen to simulate the molecules photodesorbed by the synchrotron radiation, which is concentrated in such a narrow strip along the tube.

The generation length in the screen tube is 0.5 m (100 sectors), which is shorter than the tube, to avoid particles escaping through the ends.

The holes are 1 mm square and there are 8 per sector symmetrically arranged, thus covering 1.4 % of the inner area. A view of one of these sectors with its corresponding holes can be seen in fig. 1.

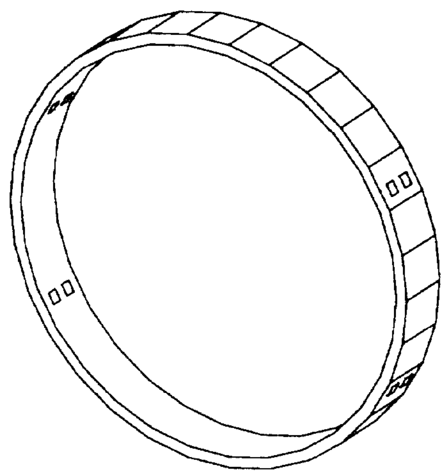

Figure 1: Perspective of one sector of the inner screen, where the position of the holes can be seen.

The angle θ, defined in fig. 2, is varied from 2° to 80°, in order to estimate the differences in pressure between the different orientations of the holes.

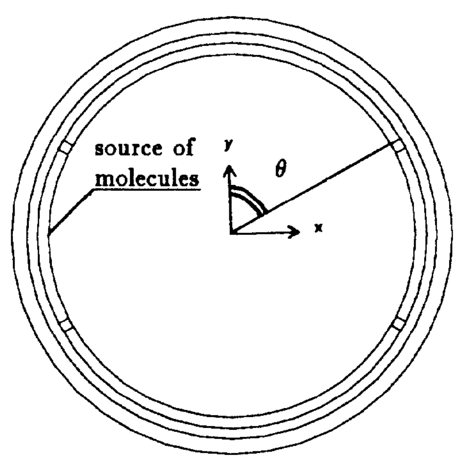

Figure 2: Z axis cut of beam screen with the holes and definition of θ (In this case, θ is 60°).

4 RANDOM GENERATION

The vacuum behaviour of the LHC screen pumping holes will be simulated, assuming a given amount of photodesorbed molecules from the walls of the tube. As the size of the synchrotron radiation beam will be very small, we can generate the particles photodesorbed in a narrow band along the wall of the tube.

The velocity is generated according to a cosine law distribution, thus assuming a perfectly diffuse emitter. To do so, we have generated two random numbers, r_1, r_2, and the components of the velocity can be written as:

$$\begin{aligned} v_x &= p\cos\phi \\ v_y &= p\sin\phi \\ v_z &= q \end{aligned} \tag{1}$$

where, $p = \sqrt{r_1}$, $q = \sqrt{1-r_1}$ and $\phi = 2\pi r_2$. The derivation of these relations is shown in detail in ref. [4].

5 RESULTS

The errors were estimated taking the 60 central sectors, and calculating the mean value and the standard deviation. As the number of hits decreases the errors are bigger, but they did not exceed 9%.

In table 1 the average values of the number of hits per sector corresponding to the central section of the tube are presented, for different sticking values and positions of the pumping holes.

Table 1: Average number of hits per sector on the central section of the tube (60 central sectors).

	Sticking factor		
Angle (°)	0.1	0.5	0.8
2	832	195	125
20	827	194	124
45	831	195	124
60	842	196	124
80	836	195	124

As the sticking factor increases this number decreases, because it is proportional to the pressure inside. No big differences can be seen as we vary the position of the holes, thus indicating that no gain can be expected. This is shown in fig. 3.

In order to compare the performance of the holes for the different values of the sticking factor we have defined, s, given by the following expression:

$$s = \frac{N_{Holes}}{N_{Hits}} \tag{2}$$

where N_{Holes} is the number of particles passing through the holes and N_{Hits} is the total number of hits on the inner surface of the screen. This quantity is proportional to the pumping speed of the holes, because at equilibrium, the number of particles passing through holes is equal to the product of the pressure and the pumping speed. As the number of hits is proportional to the pressure, we can say that s is proportional to the pumping speed of the holes.

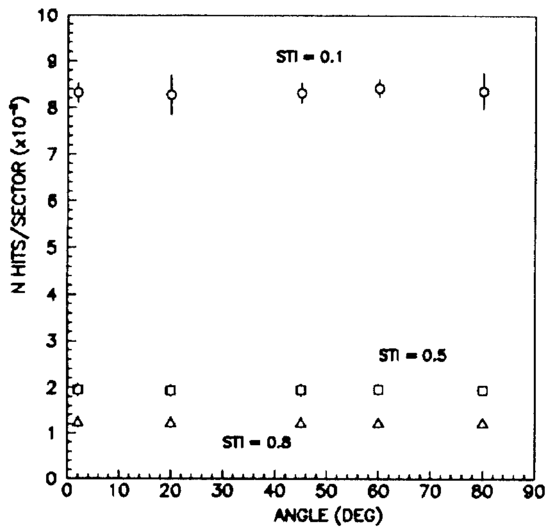

Figure 3: Number of hits per sector in the central section of the beam screen.

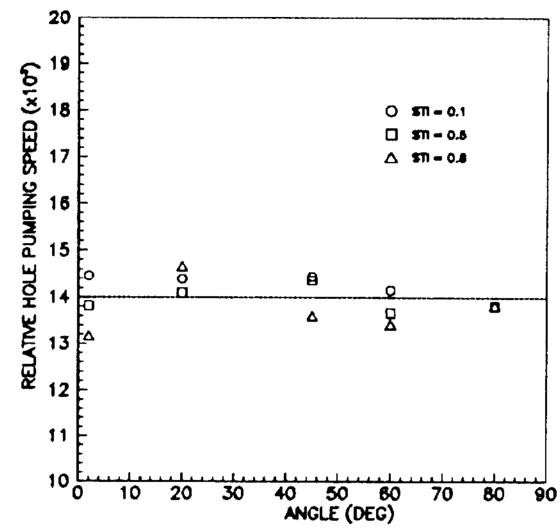

Figure 4: Relative pumping speed of holes, s, as function of the angle θ for different sticking factors.

In fact this number is the probability that a particle will pass through the holes and it is related to the percentage of the surface covered by holes. This is so, because if we had an homogeneus emitter in the centre of the tube and a sticking factor of unity, we would have a probability equal to the fraction of the surface covered by holes.

In figure 4 and in table 2 are shown the values of s for different angles and sticking factors.

No big differences can be seen in the relative pumping speed, with the variation of both the position of the holes and the sticking factor in the inner wall of the screen. Nevertheless, it must be pointed that the errors are larger than those of the average number of hits, because the statistics is not so good. The fraction of surface covered by holes is also shown in the picture as a discontinous line for comparison.

Table 2: Relative pumping speed, s ($\times 10^{-2}$).

	Sticking factor		
Ang (°)	0.1	0.5	0.8
2	1.44	1.38	1.32
20	1.44	1.41	1.47
45	1.44	1.44	1.36
60	1.42	1.37	1.34
80	1.38	1.38	1.38

6 CONCLUSIONS

Preliminary results on the simulation of the vacuum performance of screen holes have been obtained. No big differences arises from changing the position or the sticking factor on the wall of the screen. Further studies are continuing.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

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