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PUMP REQUIREMENTS FOR THE PETRA VACUUM SYSTEM

by

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Introduction

The operating pressure in the magnet sections of PETRA will be obtained with the use of linear sputter ion pumps integrated in the magnet chambers. However, there still remains a considerable fraction of the circumference which has to be pumped by conventional sputter ion pumps distributed at regular intervals along the chamber. In evaluating the size and the separation of these pumps it has been assumed that the average pressure in these sections should be at least as good as in the normal magnet structure.

The optimisation of the vacuum design can be simplified using the concept of an effective pumping speed per unit length which, together with the specific linear outgassing rate, determines the average pressure as seen by the beam.

We may define the effective pumping speed in a particular section of the vacuum system of length L

$$S_{eff} = \int_0^L Q(x)dx \Big/ \int_0^L P(x)dx$$

where Q(x) is the specific linear outgassing rate and P(x) the pressure along the beam pipe. In PETRA the wall outgassing will be partly determined by thermal degassing but predominantly by photoelectron induced desorption due to the intense synchrotron radiation. In evaluating the effective pumping speed, the simplifying assumption of a constant desorption rate along the particular vacuum section has been made. To account for the different synchrotron radiation levels in curved magnet chambers or straight sections, suitable corrections can be applied.

Effective pumping speed in the normal cell

In the bending magnet structure the vacuum system consists of a succession of 5.3 m long sections pumped by integrated linear ion pumps and 1.9 m long straight sections. For a uniform outgassing rate Q, the pressure profile is symmetric with respect to the centre of the integrated pump and the middle of the straight section. The pressure as function of the longitudinal coordinate x follows from the differential equation

$$cP''(x) - s.P(x) + Q = 0$$

where c is the specific conductance (mℓ/s) of the vacuum pipe and s the specific pumping speed of the integrated pumps (ℓ/sm). In the straight sections s = 0 and the pressure profile has the well known parabolic shape.

In PETRA the specific conductance of the beam pipe is about 67 mℓ/s, and the measured speed of the integrated pumps is 120 ℓ/sm at a pressure of 10^{-9} torr. The calculated profile P(x)/Q is shown in Figure 1. The pressure peak which occurs in the centre of the straight sections is about a factor of 3 higher than the minimum pressure in the magnets. By integrating the pressure over the period of length L, one arrives at an effective pumping speed S_{eff} = 69 ℓ/sm corresponding to only about half of the speed of the integrated pumps. This surprisingly low value of S_{eff} demonstrates the strong effect of the unpumped straight sections on the average pressure. The importance of this fact may be further illustrated by assuming a different outgassing rate (torr ℓ/sm) in the straight sections, Q_{ss}, and in the magnet chambers, Q_m. In this case, one finds that the average pressure in PETRA follows the relation $P_{av}(\text{torr}) = 6.12.10^{-3} \cdot Q_{ss} + 8.33.10^{-3} \cdot Q_m$. Any additional gas load Q_{ss}, as may be produced by heating and increased thermal desorption or alternatively by increased absorption of synchrotron radiation, will strongly affect the average pressure and therefore the beam lifetime.

Effective pumping speed in sections without integrated sputter ion pumps

The pressure along a vacuum pipe with the specific conductance c(mℓ/s) and with a uniform outgassing rate Q, follows the differential equation $c \cdot \frac{d^2P}{dx^2} + Q = 0$ and has the well known parabolic form

$$P(x) = Q\left[L(1/S + L/8c) - \frac{x^2}{2c}\right]$$

where L is the distance between pumps of pumping speed S. Integrating this pressure profile one obtains the effective pumping speed as function of c and S

$$S_{eff} = \frac{12c}{L^2 + 12cL/S}$$

Figure 2 illustrates in the case of the PETRA vacuum chamber with its specific conductance of 67 mℓ/s, the dependence of S_{eff} on the pump distance L. It should be noted that S is the net pumping speed available in the chamber and that reductions due to pump connections have to be accounted for when dimensioning the pumps. The horizontal lines corresponds to the previously determined value S_{eff} = 69 ℓ/sm and to 53 ℓ/sm as discussed in the following section.

For the dimensioning of the vacuum system it may be more convenient to use the rearranged formula plotted in Figure 3, expressing S as function of L for particular values of S_{eff} and c

$$S = \frac{S_{eff} \cdot L}{1 - \frac{S_{eff}}{12c} \cdot L}$$

Within the linear part of the curves, increasing the pump size leads to a proportional increase of their separation.

However, when approaching the limiting distance $L_{max} = 12c/S_{eff}$, the required pumping speed increases very steeply and leads to technically unattractive solutions.

Gas desorption rate

To evaluate the required effective pumping speed for a given average pressure in PETRA it is necessary to estimate the gas desorption rate which is proportional to the local photoelectron current I and the desorption yield . Furthermore, one has to consider that the desorption yield depends strongly on the cleaning action of the beam and decreases with time according to the empirical expression $\eta = \eta_o \cdot (I \cdot t)^{-0.63}$, ref. 1. Parts of the vacuum chamber which are exposed to less synchrotron radiation will experience a correspondingly slower decrease of η. It follows from this argument that at a given time the linear outgassing rates of two chambers should follow the relation

$$Q_1/Q_2 = (I_1/I_2)^{0.37}$$

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1) J. Kouptsidis, M. Schwartz, DESY H3-75/01.

Numerically one finds for a chamber which receives only half of the normal synchrotron radiation dose a reduction of the gas desorption of only about 23%.

Due to this rather weak dependence of Q on the local synchrotron radiation level - and hence of the required effective pumping speed for a given average pressure - it is, in most cases, adequate to distinguish rather crudely between chambers receiving synchrotron radiation from both counter-rotating beams, chambers which are exposed to one of the two beams only or long straight sections at long distances from the bending magnets.

Pump requirements for specific sections in PETRA

(i) 16% Magnet

Due to the low magnetic field the chambers in these magnets cannot be pumped by the normal integrated pumps. Since the chamber absorbs synchrotron radiation from one beam only, an effective pumping speed of only about 53 ℓ/sm is required. Using Figure 3 the corresponding combinations between pump size and distance can be directly determined. It becomes immediately apparent that the required S_{eff} cannot be achieved by pumps mounted at the end of the magnets at 5.3 m distances. For this reason it will be necessary to fit the pump connections sideways to the chamber in a similar manner as done for the holding pumps. Due to the limited conductance resulting from this arrangement it is difficult to achieve higher net pumping speeds than about 20 ℓ/s which in turn determines an interpump distance of only about 40 cm. This results in typically 14 pumps to be mounted on these chambers.

A reduction of the number of pumps seems possible only by increasing the cross section of the pump-ports or else by installing vacuum chambers of larger conductance. These solutions imply more complicated and rather special mechanical arrangements.

(ii) Injection straight sections and corresponding straight sections in the other octants

These straight vacuum sections offer the opportunity of mounting the pumps directly on to the beam chambers through a short connecting tube. In this way it is possible to obtain with the individual pump a net speed of about 120 ℓ/s. The pump separation can be increased to 1.4 or 1.8 m depending on whether the radiation from both beams or a single beam only is absorbed by the chamber.

An alternative design would again use a large number of small pumps (about 60 ℓ/s) of the same kind as the holding pumps. Since the connections could be made very short in this case, a net speed of up to 40 ℓ/s may be achieved corresponding to pump distances of about 70 cm. A closer analysis taking into account the actual price for the pumps and their power supplies but also the price for the pump connections and their mechanical complexity, needs to be undertaken to show in which direction the most economical solution lies.

(iv) In the long straight sections of PETRA the vacuum chamber cross-section will be round with 120 mm diameter. Here the specific conductance is about 216 mℓ/s. The corresponding pump size as function of distance L is shown in curve C of Fig. 3. Due to the larger conductance the linear region is extended and it is therefore technically justified to use larger pumps at increased distances.

Summary

Starting from the working assumption that the average pressure in all parts of the PETRA vacuum system should be at least as good as in the normal bending magnet structure, one arrives at a design concept which can be applied to individual sections. The analysis shows that due to the conductance limitation of the vacuum chamber increasing the net pumping speed of individual pumps beyond about 140 ℓ/s brings, from a technical point of view, only little gain. To obtain the desired effective pumping speed in PETRA requires in fact pump distances well below 2 m over a considerable part of the magnet-free circumference with the exception of a few locations particularly well screened from synchrotron radiation.

The next question arises of how to obtain in practice a given net pumping of, for example, 140 ℓ/s in the chamber. Here the important element is the pump connection to the vacuum chamber and how it can be designed to give a maximum conductance. For reasons of avoiding the higher order mode losses the pump ports have to be connected to a perforated section of the vacuum chamber. Without excessively complicating the mechanical design one may estimate a realistic upper limit for the achievable conductance of about 200 ℓ/s. Nevertheless, since the working pressure in PETRA should be in the 10^{-9} or perhaps the low 10^{-8} torr region, these pumping speeds should be valid in this pressure range. Since with a typical sputter ion pump the actual pumping speed falls off towards lower pressures - at 10^{-8} torr it will typically be around 70% of the nominal speed - this reduction should be taken into account when dimensioning the pumps. A numerical example may illustrate the various effects : choosing a pump with a nominal speed of 240 ℓ/s at 10^{-6} torr provides typically 170 ℓ/s at 10^{-8} torr but, including the conductance of the pump connection of 200 ℓ/s, results in a net pumping speed of only about 92 ℓ/s. From Figure 3 one deduces typical pump distances between 1.2 and 1.5 m only. It becomes apparent that a design and cost optimisation of the pumping system must - besides the ion pumps and power supplies - necessarily also include the pump connections to the vacuum chamber.

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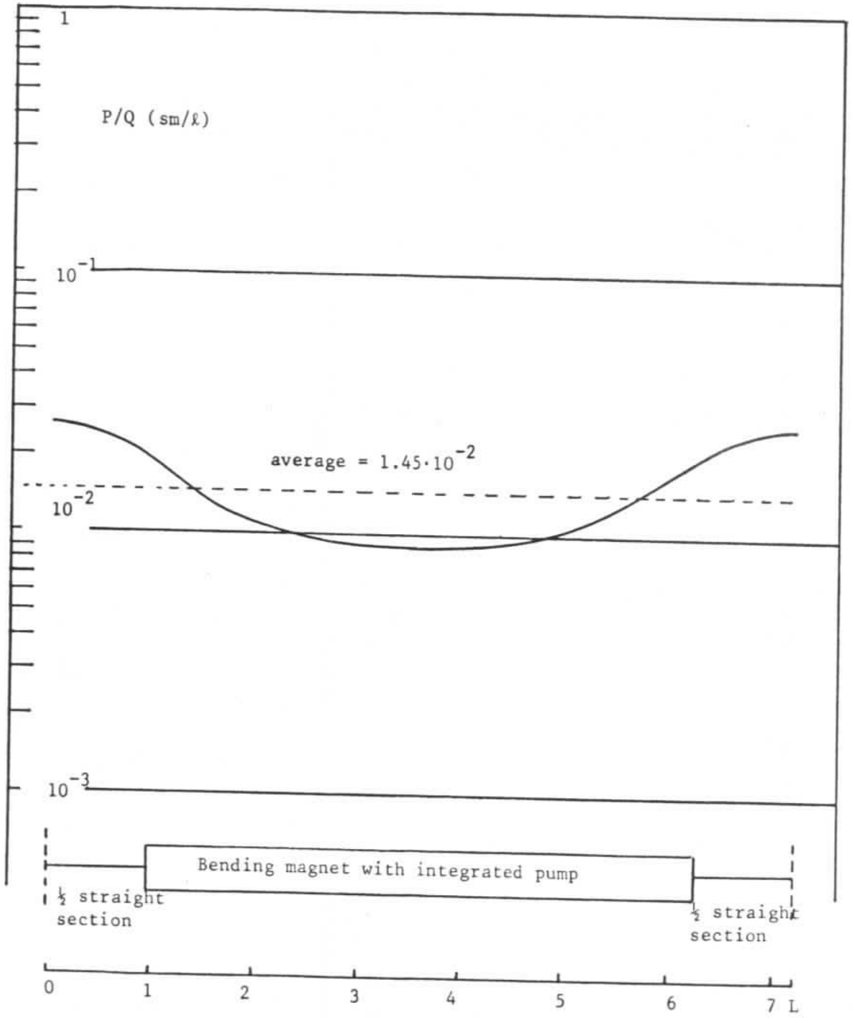


Figure 1 : Pressure distribution in the normal magnet structure of PETRA for a constant linear outgassing rate Q.

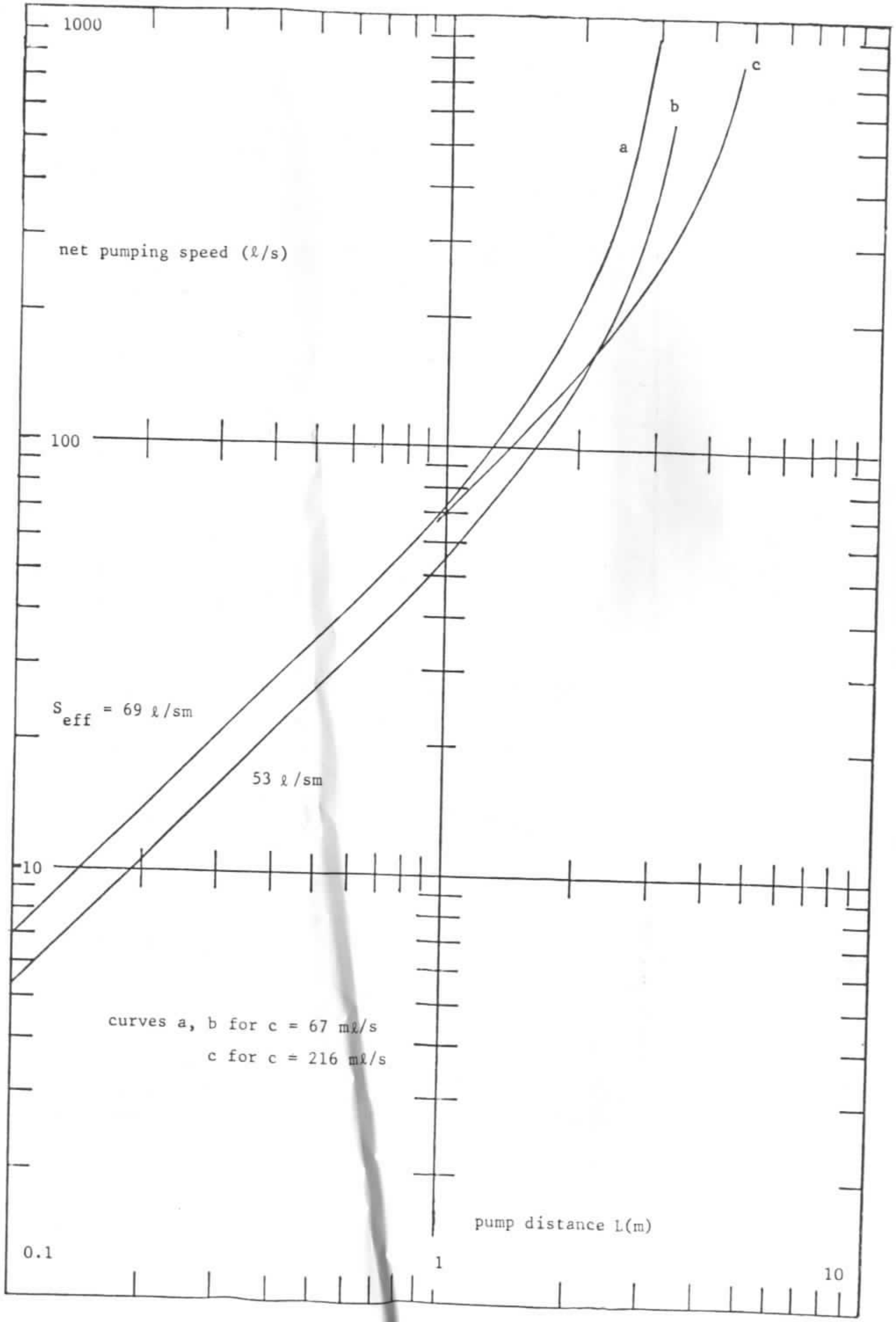
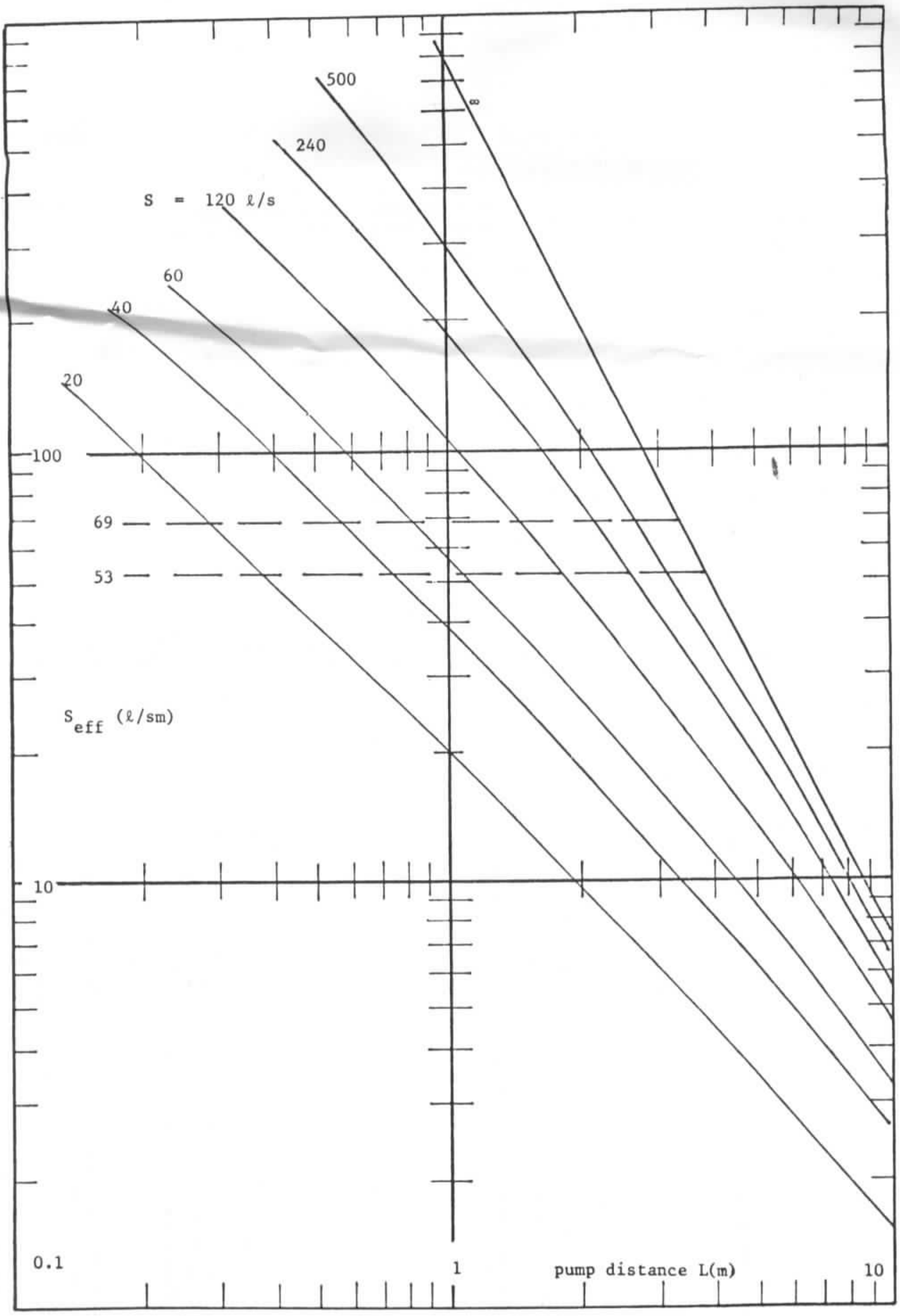


Figure 3 : net pumping speed as function of pump distance for a given S_{eff}



<u>Figure 2</u> : S_{eff} as function of pump distance for various net pumping speeds