DAΦNE TECHNICAL NOTE
INFN - LNF, Accelerator Division

Frascati, Sept. 10, 1991
Note: **V-6**

VACUUM SYSTEM FOR DAΦNE ACCUMULATOR

A. Clozza

1. INTRODUCTION

The preliminary design for an all metal ultra high vacuum (UHV) system for DAΦNE accumulator is described.

Since the design pressure is 10^{-8} Torr it is possible to reach UHV in the accumulator vacuum chamber using standard technologies and without special devices, like distributed ion pumps, light absorbers and so on. The vacuum chamber is made of 304 L stainless steel while the UHV pumping system is made with lumped sputter ion pumps (SIP). We do not intend to use an in situ baking system for the vacuum chamber, and if possible, no cooling for the thermal load due to the synchrotron radiation. Cleaning, prebaking and mounting procedures are of extreme importance in order to achieve the desired operating pressure.

2. MACHINE VACUUM RELATED PARAMETERS

The vacuum system for an electron storage ring is closely related to some machine parameters like: aperture, synchrotron light intensity, required working pressure etc.

In the case of the e^+/e^- DAΦNE accumulator the design[1] parameters relevant for the vacuum system are:

Beam energy	510 MeV
Beam current	130 mA
Dipole bending radius	1.1 m
Maximum working pressure	~10^{-8} Torr
Synchrotron light critical energy	270 eV

The shape of the vacuum chamber is, in the straight sections, a cylindrical pipe 291 cm long and 85 mm inside diameter, while in the curved sections it is an almost rectangular pipe 86.5 cm long and 30 by 100 mm inside aperture.

3. VACUUM CALCULATIONS

It is well known that the most important problem for a storage ring vacuum system is to maintain the internal pressure below a given value, in order to minimize the beam degradations due to interactions of the stored particles with the residual gas[2]. So a continuously operating pumping system is needed to pump away the gas load coming from the thermal desorption of the inner vacuum chamber wall and from the photodesorption due to the synchrotron radiation emitted by the circulating particle beam.

As we said before, a first contribution to the total gas load Q_T arises from the thermal outgassing of the vacuum chamber walls, and it is possible to evaluate its amount using a simple relation:

$$Q_W = Q_0 A$$

where Q_W is the thermal gas load (Torr l s^{-1}), Q_0 is the specific gas load (Torr l s^{-1} cm^{-2}) and A is the total inner surface (cm^2).

To evaluate Q_W we must compute first the inner surface A. To do this, we can schematize the accumulator vacuum chamber by 8 curved sections, each about 86.5 cm long and 3 by 10 cm of inner cross section, and by 8 straight sections each about 291 cm long and 8.5 cm of inner diameter. These dimensions give the following surface values: $A_c = 2250$ cm^2 for each curved section and $A_s = 7780$ cm^2 for each straight section. So the total inner surface will be about $A = 81000$ cm^2.

The second term of the previous formula Q_0 depends strongly on the history (cleaning treatments, baking, air exposures etc.)[3] of the vacuum chamber and also, but to a lesser extent, on the temperature. For a well cleaned and prebaked chamber it is possible to have for Q_0, at room temperature, the value:

$$Q_0 = 5 \cdot 10^{-12} \text{ Torr l s}^{-1} \text{ cm}^{-2}$$

so the thermal gas load is

$$Q_W = Q_0 A = 4 \cdot 10^{-7} \text{ Torr l s}^{-1}$$

The second contribution to the total gas load Q_T arises from the photodesorption due to the synchrotron light emitted by the circulating particles. The evaluation of this contribution is more difficult than the previous one.

It is well known that charged particles moving in a circular arc in a magnetic field undergo radial acceleration, and radiate electromagnetic energy. In the case of particles having total energy much greater than rest energy, like in DAΦNE accumulator, the "synchrotron" emitted radiation has a broad spectral distribution, ranging from infrared to X-ray, and the emission is restricted in a narrow cone tangent to the curved orbit path. It is possible to demonstrate[4,5,6] that the total spectral power radiated by an electron is given by:

$$P(\lambda, t) = \frac{3^{5/2} e^2 c \gamma^7}{16\pi^2 \rho^3} \left(\frac{\lambda_c}{\lambda}\right)^3 \int_{\lambda/\lambda_c}^{\infty} K_{5/3}(\eta) d\eta$$

where $\lambda_c = 4\pi\rho / 3\gamma^3 = hc/\varepsilon_c$ is the critical wavelength and $K_{5/3}$ is a modified Bessel function of order 5/3. The critical energy is related to the critical wavelength by: $\varepsilon_c = hc/\lambda_c$. This is the exact formula, but it is not so easily to compute, so with some mathematical manipulations we can write a simpler formula, using practical units:

$$P_{Tot}[\mathrm{kW}] = 88.5 \frac{E^4[\mathrm{GeV}]\, I[\mathrm{A}]}{\rho[\mathrm{m}]}$$

which, for DAΦNE accumulator (E = 510 MeV, I = 130 mA, ρ = 1.1 m), gives a total power of:

$$P_{Tot} = 710 \text{ W}$$

This value does not present thermal load related problems.

A different scenario appears when we look at the photodesorption due to the photons impinging upon the vacuum chamber walls.

The following formula gives the spectral distribution of the photons[6]:

$$N(\lambda, t) = \frac{3^{3/2} e^2 \gamma^4}{4\pi h \rho^2} \left(\frac{\lambda_c}{\lambda}\right)^2 \int_{\lambda/\lambda_c}^{\infty} K_{5/3}(\eta) d\eta$$

To compute the total number of photons radiated by the particle beam it is possible to use the approximated formula:

$$N_\gamma = 8.08 \cdot 10^{17} E[\mathrm{GeV}]\, I[\mathrm{mA}]$$

which for DAΦNE accumulator (E = 510 MeV, I = 130 mA) yields

$$N_\gamma = 5.4 \cdot 10^{19} \text{ phot/s}$$

Introducing the photodesorption coefficient η [molecules/phot.], it is possible to obtain the number of desorbed molecules per unit time:

$$N_m = \eta\, N_\gamma$$

By assuming for η a conservative value of ~ 10^{-5} molec/phot, we get

$$N_m = 5.4 \cdot 10^{14} \text{ molec/s}$$

From the law of ideal gases the gas load Q_L, due to the synchrotron radiation, is given by

$$Q_L = \frac{RT}{N_A} \eta\, N_\gamma [\text{torr l / s}]$$

where R is the gas constant, T the absolute temperature and N_A the Avogadro number. In the case of DAΦNE accumulator Q_L takes the value:

$$Q_L = 4 \cdot 10^{-20}\, \eta\, N_\gamma = 2 \cdot 10^{-5} \text{ Torr l / s.}$$

Finally, to obtain the total gas load Q_T we have just to add the two contributions Q_W and Q_L (since the value of Q_W is 2% of Q_L, we neglect the thermal gas load with respect to the photodesorption one:

$$Q_T = 2 \cdot 10^{-5} \text{ Torr l / s.}$$

To reach a pressure P = $1 \cdot 10^{-8}$ Torr, with the above gas load, it is necessary a total effective pumping speed S given by:

$$S = Q_T / P = 2000 \text{ l / s,}$$

a value easily obtained with traditional lumped sputter ion pumps.

4. CLEANING PROCEDURES

The cleaning treatments have a very strong influence on the thermal outgassing coefficient: indeed it is possible to have differences of about a factor of ten, or even more, for different cleaning procedures. For DAΦNE accumulator, to reach the value of $Q_0 = 5{\cdot}10^{-12}$ Torr l s^{-1} cm^{-2}, the vacuum chamber must undergo a specific cleaning treatment: after machining, each part of the vacuum chamber must be degreased, and cleaned, in order to remove any trace of lubricating oil and other surface contaminants before welding. Cleaning procedure will depend on the condition of the metal and will end with either distilled water or alcohol rinse followed by hot air or oven drying. Completed vacuum chamber will be vacuum baked to 250 °C[7], glow discharge cleaned (GDC) with a mixture of argon and oxygen at 200 °C, filled with very dry nitrogen[8] and then carefully mounted in place. It is of extreme importance that all the cleaning treatments, vacuum bakings and mechanical mountings will be done in a very clean and dust free environment. If all the previously described operations are done with care, the specific thermal outgassing coefficient Q_0 will be equal to $5{\cdot}10^{-12}$ Torr l s^{-1} cm^{-2} and the photodesorption coefficient should reach a value lower than $1{\cdot}10^{-5}$ molec/phot after about 20 Ah of beam dose.

5 VACUUM SYSTEM

The vacuum chamber of DAΦNE accumulator will be made of 304 L stainless steel. The ring (Fig. 1) is divided into four arcs by five sector valves: two valves will isolate the RF cavity, and the other three will be placed one in each remaining long straight sections.

5.1 High Vacuum

As seen before, the pumping speed needed to maintain the required working pressure, with 130 mA of beam, in the range of 10^{-8} Torr is less than 2000 l/s, and is easily obtained by using conventional sputter ion pumps (SIP).

In order to reach uniform pressure around the entire ring a distributed pumping system will be designed by placing a pair of about 200 l/s pumps at each end of bending magnet, connected, as close as possible, to the vacuum chamber via a short pipe (Fig. 2) that, at a pressure of 10^{-8} Torr, reduces the pumping speed of each pump to about S =130 l/s (Fig. 3). For a total of 16 pumps we have about 2000 l/s. This pumping speed will be reached only if the pumps are baked at 250 °C. However, 2000 l/s requirement is conservative and provides a good safety margin.

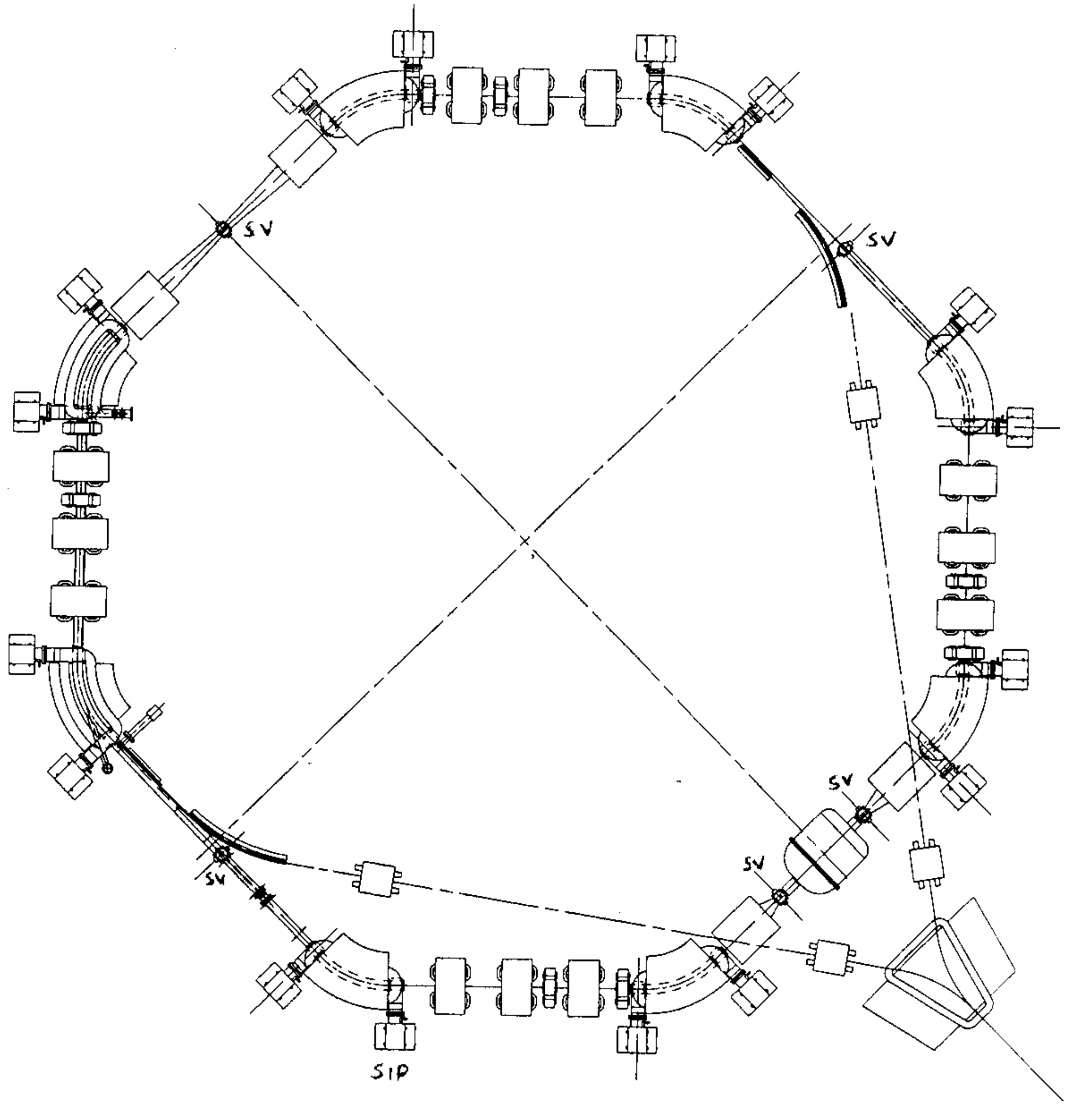

Fig. 1 - Plan view of DAΦNE accumulator. SV are the sector valves and SIP are the sputter ion pumps.

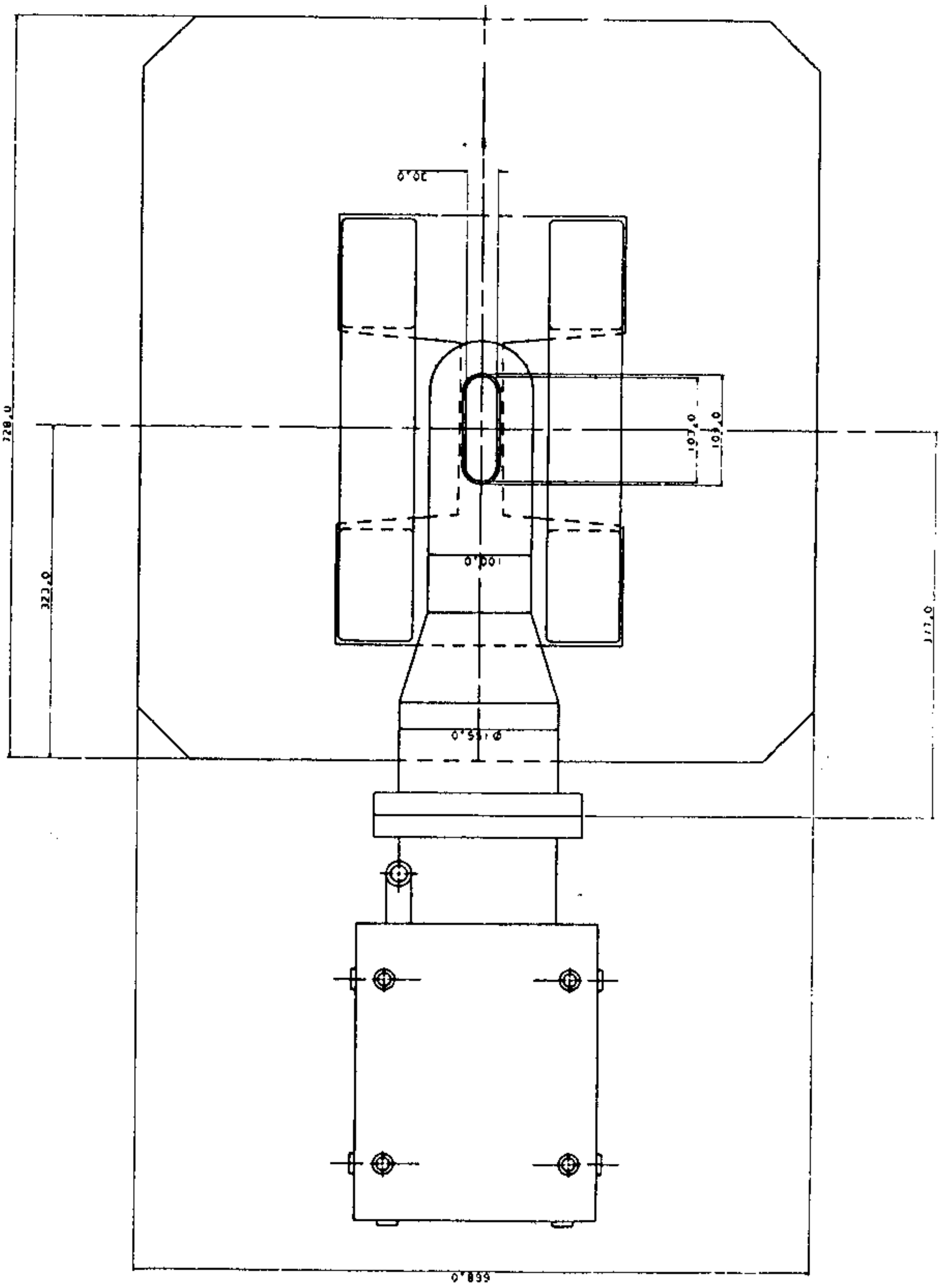

Fig. 2 - Cross section of the vacuum chamber showing the connection pipe for the SIP.

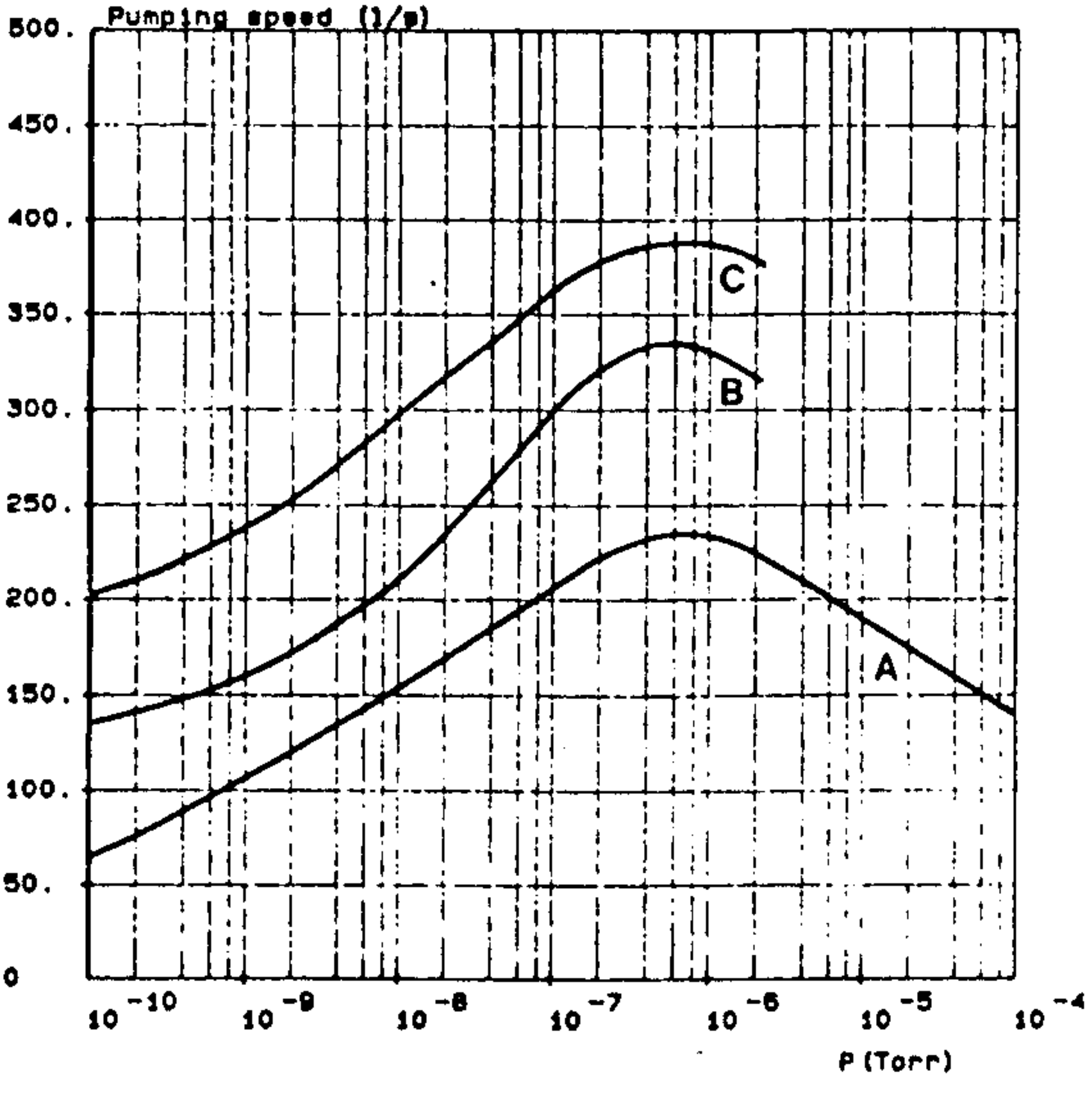

Fig. 3 - Pumping speed (for N_2) versus pressure for a 230 l/s Varian Star Cell sputter ion pump: A = unbaked, B = baked, C = with getter module.

It is possible to evaluate the operating pressure with a simple schematization of the gas loads. For the curved sections it is possible to estimate the local total gas load q_{TC} as the sum of the local thermal outgassing q_W and the local photodesorption q_L with the respective values of $1 \cdot 10^{-8}$ Torr l/s and $1.5 \cdot 10^{-6}$ Torr l/s, yielding:

$$q_{TC} \approx 1.5 \cdot 10^{-6} \text{ Torr l/s.}$$

An analog procedure for the straight sections, with $q_W = 3.3 \cdot 10^{-8}$ Torr l/s and $q_L = 7.6 \cdot 10^{-7}$ Torr l/s, yields:

$$q_{TS} = 8 \cdot 10^{-7} \text{ Torr l/s}$$

To evaluate the pressure P_0 at the pump connection we can take for the gas load q the value:

$$q = q_{TC}/2 + q_{TS}/2 = 1.1 \cdot 10^{-7} \text{ Torr l/s}$$

so the base pressure is:

$$P_0 = q/S = 8.510^{-9} \text{ Torr}$$

and the maximum pressure rise in the curved and in the straight section is

$$\Delta P_C = q_{TC}/2C_C = 2.6 \cdot 10^{-8} \text{ Torr}$$

$$\Delta P_S = q_{TS}/2C_S = 1.7 \cdot 10^{-8} \text{ Torr}$$

where C_C, the conductance of the curved vacuum chamber, is 28 l/s and C_S, the conductance of the straight vacuum chamber, is 23 l/s.

5.2 Fore Vacuum

Each of the four accumulator sections will have an all metal right angle valve to allow connection to a fore vacuum pump, which will be a portable magnetic bearing turbo molecular pump backed by an oil free mechanical pump. Once the pressure of 10^{-5} Torr is reached the SIPs will be turned on. (It is very important not to turn on the pumps at high pressures for a long time).

5.3 Diagnostic

The vacuum instrumentation is placed on the fore vacuum extensions (Fig. 4) and will consist of a Bayard-Alpert UHV gauge BA, a residual gas analyzer RGA, a Penning HV gauge and a Pirani LV gauge. Pirani and Penning gauges are used for the first evacuation of the accumulator, the RGA for monitoring the gas species inside the vacuum chamber and for leak testing under good vacuum conditions, the BA gauges are used to monitor the total pressure in working condition and during stand by. An additional pressure read-out is obtained by monitoring the SIP current, which is quite accurate below 10^{-9} Torr range.

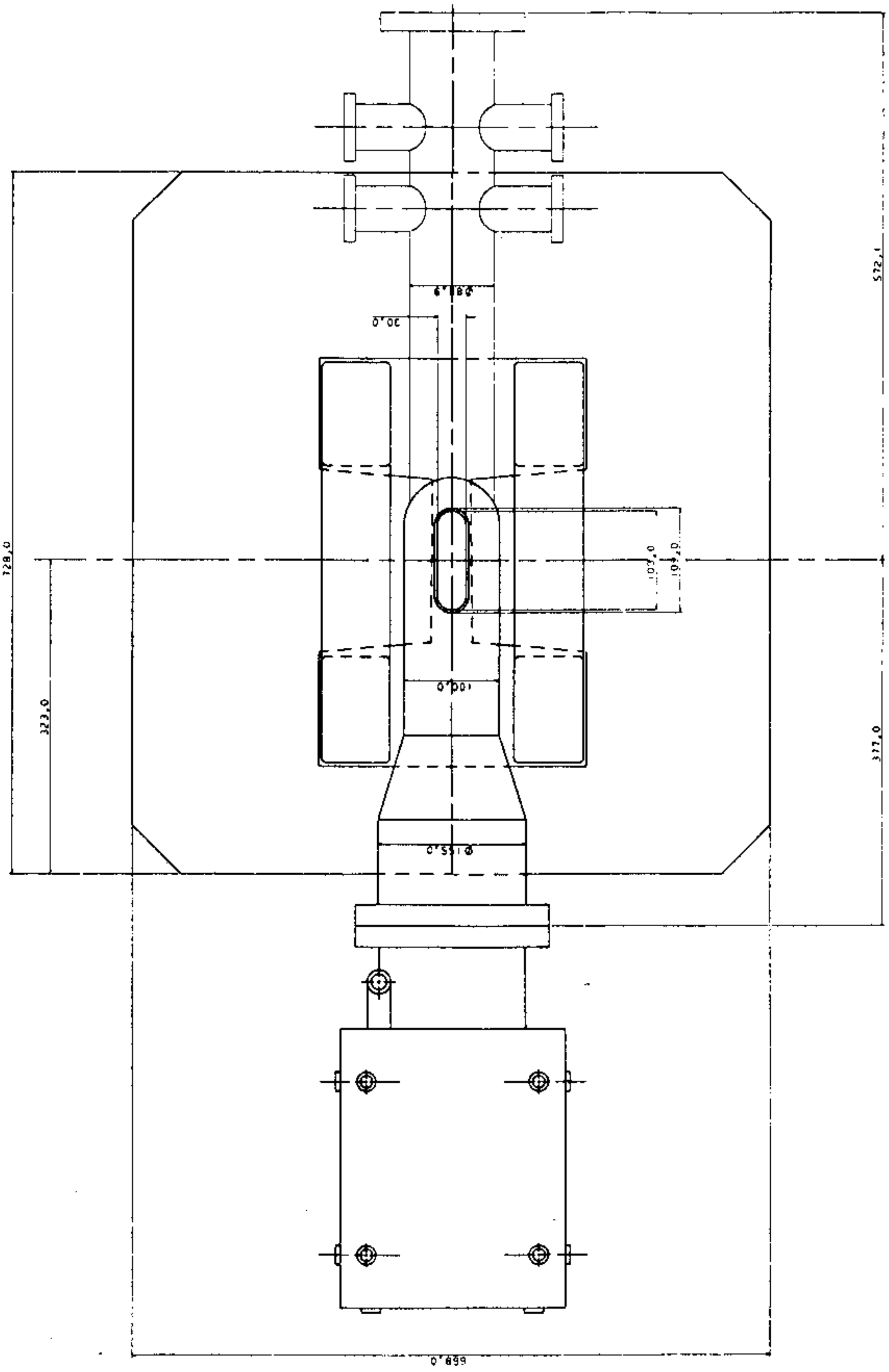

Fig. 4 - Cross section of the vacuum chamber showing the connection pipe for the SIP and the fore vacuum extension with the flanges for the diagnostics.

6. CONCLUSIONS

The vacuum system for DAΦNE accumulator is quite simple and does not present any big problem.

It is possible to reach the desired working pressure of about $1 \cdot 10^{-8}$ Torr using standard technology, i.e., stainless steel vacuum chamber and lumped sputter ion pumps for the high vacuum system. I propose to use 16 SIPs with nominal pumping speed in the range of about 180-230 l/s. We do not need any in situ baking, except for the ion pumps. The power load due to the synchrotron radiation is about 30 W/m and it should not need a cooling for the vacuum chamber.

The main requirement to reach these characteristics is a very good cleaning procedure, a prebaking and GDC in very clean working area. Under these conditions and with a very careful assembling work, the vacuum system of DAΦNE accumulator will satisfy the required specifications.

ACKNOWLEDGEMENTS

I would like to thank Dr. H. Halama for his helpful discussion and suggestions.

REFERENCES

[1] M. Preger "A positron and electron accumulator for DAΦNE", DAΦNE technical note I-1 (1990).
[2] C. Benvenuti, R. Calder and O. Gröbner, Vacuum 37, 699 (1987).
[3] K. Odaka, Y. Ishikawa and M. Furuse, J. Vac. Sci. Technol. A5, 2902 (1987).
[4] J. Schwinger, Phys. Rev. 75,1912 (1949).
[5] R. A. Mack, Internal Report CEAL 1027, Cambridge Electron Accelerator (1966).
[6] G. K. Green, Spectra and Optics of Synchrotron Radiation, BNL Report N° 50522 (1976).
[7] C. L. Foerster, H. Halama, and C.Lanni, J. Vac. Sci. Technol. A8, 2856 (1990).
[8] J. R. Chen, C. H. Lee, J. C. Chen, H. L. Hsieh and Y. C. Liu, J. Vac. Sci. Technol. A5, 3422 (1987).