IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

Performance of the SPS Ring Vacuum System for Colliding Beam Operation

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SUMMARY

The SPS ring vacuum system was recently upgraded to the vacuum requirements for proton-antiproton collider operation. The new specification stipulated an average operating pressure in the ring of 3.10^{-9} mbar, to be reached within 10 days of pumping after a venting to air. The pressure is expressed in nitrogen equivalent gauge reading.

Bakeout to rapidly reduce the gas desorption from the system cannot be used in the SPS, except at a few special positions which cover less than 5% of the ring circumference.

The specified pumping time is much shorter than the time it usually takes for an unbaked vacuum system to reach its limit pressure. The pressure thus continues to fall for roughly 3 months from the beginning of a pumpdown and finally settles at about 7.10^{-10} mbar.

INTRODUCTION

The SPS vacuum system was originally built to provide a pressure in the ring of better than 3.10^{-7} mbar after one day of pumping. This performance was adequate as long as the SPS only operated as an accelerator for fixed target physics. After a couple of months of relatively undisturbed pumping a limit pressure of the order of 10^{-8} mbar was reached in the vacuum system.

A natural way to both reduce the pressure and to obtain a short pumping time would have been to bake the vacuum system. This unfortunately is not possible mainly because the vacuum chambers in the main bending magnets are pressed against the polefaces and the coils of the magnets. Thus there is hardly any room for heating elements and the magnet cores would also act as efficient heat sinks. Bakeout is therefore exclusively used for certain equipment in the SPS long straight sections which form but a small part of the ring circumference.

In most of the ring the performance of the vacuum system could only be improved by the addition of further pumps. The vacuum pump layout in the normal machine periods was mainly determined by the magnet lattice as the pumps had to be fitted in the inter-magnet gaps. For normal accelerator operation it was satisfactory to place a high vacuum pump (sputter ion pump) in every second gap.

The vacuum improvement programme mainly consisted in fitting sputter-ion pumps in every inter-magnet gap in the normal periods and in adding a getter pump (sublimation pump) to every sputter-ion pump all around the ring.

DESCRIPTION OF THE SYSTEM

Eighty percent of the 7 km circumference of the SPS ring consists of normal machine periods. The vacuum system in these periods is relatively simple and is mostly made up of stainless steel tubes. Sputter-ion pumps of 30 ℓ/s pumping speed are placed about every 6.5 m along the beam channel. A titanium sublimation pump is inserted in the short pipe which connects the sputter-ion pump to the system. Details of the standard pump layout in the gap between two main magnets are given in Fig 1. The available pumping speed in the manifold above the pumps is of the order of 100 ℓ/s for nitrogen.

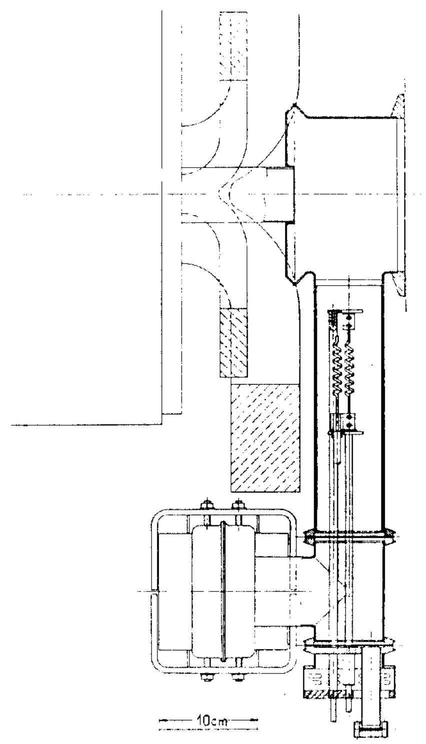

Figure 1

There are six long straight sections in the ring. Four of these contain the equipment for beam injection, acceleration, extraction and dumping and the remaining two are occupied by the collider experiments. The latter contribute very little to the average pressure in the ring but the other four long straight sections constitute major gas loads which are pumped by a large number of sputter-ion pumps of about 400 ℓ/s pumping speed. Some cores of extraction magnets etc. which are mounted in the vacuum system are bakeable and use internal heaters to speed up the pumpdowns.

The 400 ℓ/s sputter-ion pumps were also combined with sublimation pumps in the connecting ducts to the system. A total of about 1300 sublimation pumps were fitted in the SPS.

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Metal sealed joints were used throughout for the assembly of the ring system. Elastomers were excluded from the vaccum chamber because of the radiation levels encountered during accelerator operation for fixed target physics. Rough pumping is achieved by turbomolecular pumping stations. These furnish a pumping speed of at least 1 ℓ/s at any point in the system.

PREPARATION OF THE VACUUM CHAMBERS

Already during the construction of the basic vacuum system all vacuum chambers went through a final degreasing and detergent cleaning procedure at CERN. For all the chambers in the normal periods this treatment was followed by a bakeout in atmospheric air at 150°C and a global helium leak test. After final assembly, all joints were leak tested and any leaky joints were remade. The leak detectors had a detection limit of 3.10^{-10} mbar ℓ/s of helium.

PUMPING CHARACTERISTIC

The ring vacuum system is divided into about 60 sectors which vary in length from a few metres to over 400 m. Each sector is fully independent from the point of view of vacuum production. The pump layout was initially chosen to make the pumping characteristics almost identical in all sectors.

A pumpdown starts with rough pumping to 4.10^{-5} mbar at which pressure the sputter-ion pumps take over. A series of pre-programmed sublimations is launched at about 4.10^{-7} mbar. The sublimations take place at intervals which are gradually lengthened from a few minutes to a few hours, in accordance with the fall in pressure which was observed in early pumping tests in the ring and which is assumed to be valid for any pumpdown. The programme includes 60 firings of the pumps over a 10 day period.

After this initial pumping period the sublimation pumps need only be fired about once per day. As the system approaches its limit pressure, a sublimation once per week will be adequate to keep the pressure fluctuations, caused by saturation of the titanium films, small.

Figure 2 shows a typical pumping characteristic obtained after the exchange of a machine element in the normal periods. The sector had been vented to dry nitrogen as is normal practice in the SPS. The work area was situated more than 30 m away from the gauge. A detailed plot of pressure versus time was made for the first month of pumping. Because the system had been vented with dry nitrogen prior to the intervention, this pumping time was sufficient to reach the limit pressure.

PRESSURE MEASUREMENTS

The normal periods contain just one total pressure gauge per vacuum sector but many sectors in the long straight sections have several gauges, while every special machine element tends to have its own gauge.

After the initial 10 day pumping period there are, in the absence of leaks, seldom any great local pressure variations. With a single gauge it is therefore normally possible to monitor the pressure even in very long sectors. The contribution of each sector to the average pressure in the ring is given a weight according to the length of the sector.

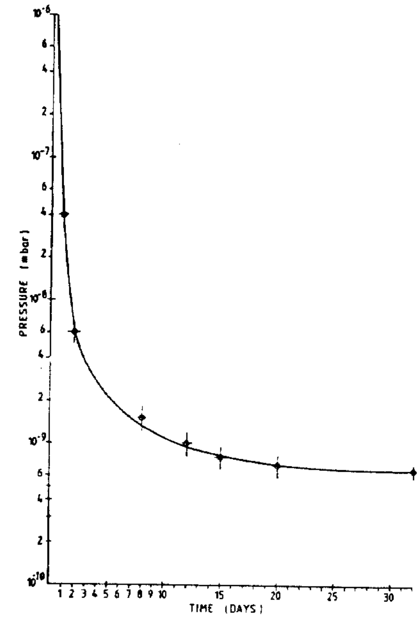

Figure 2

Very high pressures, due notably to leaks, can exist locally in a long sector and remain undetected by a gauge which is situated some distance away from the pressure bump. The sputter-ion pumps are therefore very important complements to the gauges as they permit a rough check of the pressure all around the ring, at points which are never located more than 6.5 m from one another. The present remote reading facility for the sputter-ion pump currents operating through the SPS control computers, has a detection limit corresponding to about 10^{-8} mbar. Readings which are taken manually on the pump power units usually allow estimates down to about 10^{-9} mbar. This virtually excludes the non-detection of any important leak.

Pressures near the system limit pressure are difficult to measure because the gauges have a fixed low pressure measuring limit, set at 2.10^{-10} mbar. The gauges are of the cold cathode type. They need to be studied further, under the operating conditions prevailing in the SPS, before any attempt can be made to use them for measurements below the present limit. In the normal periods a further difficulty is caused by the necessity to mount the gauges near the pumps as there is no space for gauge ports in the normal vacuum chamber.

The latter problem is largely overcome by multiplying the gauge readings by a correction factor which converts the pump pressure to average pressure in the beam channel. In the early pumping tests this factor was found to have a value of about 3.

Table 1 summarizes the gauge readings in the SPS late in 1982. The pressures are presented separately for each of the SPS sextants. A sextant consists of series of normal periods situated on either side of each long straight section (upstream and downstream side for circulating protons). The length of the sector or the group of sectors to which a given pressure reading refers is also given in the Table.

Table 1

Pressures in beam channel (mbar x 10^{10})

Sextant No.	NPU		LSS	NPD	
	384m	~104 m	~114m	~102m	448m
1	<6	9	20	6	6
2	<6	<6	7	6	<6
3	<6	<6	20	20	<6
4	9	<6	2	<6	<6
5	<6	<6	1	<6	<6
6	<6	<6	7	<6	<6

NPU : Normal period sectors, upstream of LSS

LSS : Long straight section group of sectors

NPD : Normal period sectors, downstream of LSS

For the normal periods the pressures are corrected for the gauge position. Each long straight section contains several short sectors. The pressures given are the average pressures in these sectors. The gauges are here mounted directly in the beam channel. From the given pressures and sector lengths an average pressure in the ring of 6.8×10^{-10} mbar can be calculated. The pressure quoted for 18 of the 24 sectors in the normal periods represent an upper limit as the gauges in these sectors had reached their low pressure limit of 2.10^{-10} mbar.

The gauge readings on which Table 1 is based, were accompanied by a survey of all sputter-ion pumps which showed that at the time there were only two high pressure areas in the ring. One was due to a leak and the other to the outgassing of a recently installed element. Both produced a pressure of about 3.10^{-8} mbar over a few metres of the beam channel. The total contribution of these areas to the average ring pressure was of the order of 10% which should be added to the figure deduced from Table 1.

Residual gas analysers are not permanently installed in the unbaked parts of the vacuum system. Typical spectra for these regions were determined during the first pumping tests in the ring. The composition recorded after two months of pumping is shown in Figure 3. It is likely that the water content shown in the spectrum represents an upper limit for the recent collider run. Most of the system had then actually been pumped continuously for 3 - 6 months. The very slow saturation rate of the sublimation pumps also suggests that residual gas components which, unlike hydrogen, do not diffuse into the bulk of the titanium film, have indeed very low partial pressures.

Using the gas composition in Figure 3 the true total pressure under limit pressure conditions, could be estimated to be 1.10^{-9}mbar and the nitrogen equivalent pressure for multiple scattering 4.10^{-10} mbar.This is in good agreement with the pressure which could be deduced from beam lifetime studies[1].

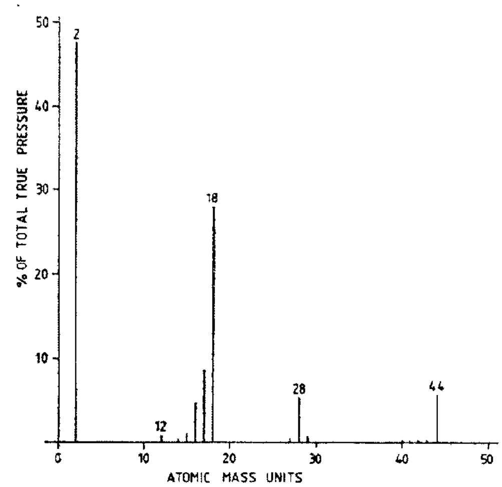

Figure 3

THE EXPERIMENTAL ZONES

The pressure in the vacuum chambers in the colliding beam experiments and in their immediate vicinity was reduced to about 10^{-10} mbar in order to bring the background from beam-gas interaction to an acceptable level. This was achieved by baking the vacuum system in these regions to 150°C.

Both experimental zones have the same basic vacuum layout. The central detectors, mounted on movable platforms, have a vacuum chamber that can be sealed at both ends by sector valves. The chamber is pumped and baked during the preparation of the detector outside the ring. Once the detector is in the final position its vacuum chamber is linked to the SPS via short transition chambers which are pumped in parallel with the setting up of the detectors.

The vacuum chambers on the platforms have a total length of about 12 m and have nearly the same apertures as in the typical chambers in the normal periods of the SPS. Most of these chambers were assembled from thin walled corrugated stainless steel elements similar to those made earlier at CERN for experiments at the ISR. In a couple of cases, 2 mm thick, smooth walled, beryllium elements of non-circular cross section were used. One of the beryllium chambers has a total length of about 6m. In one of the stainless steel chambers there was an insert of about 2.5 m^2 of Kapton foil which formed part of a detector arrangement.

CONCLUSION

The SPS ring vacuum system produces pressures which are much lower than specified when left under vacuum for a few months. This contributes to long beam lifetimes and to low backgrounds in the collider experiments. It also permits to restore the specified average pressure very rapidly after any repair or modification work during which it was necessary to temporarily vent part of the system.

References

1) L.R.Evans,J.Gareyte,CERN SPS/83-10 (DI-MST),1983