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PRESSURE MEASUREMENTS FOR THE ISR AT CERN

by

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PRESSURE MEASUREMENTS FOR THE ISR AT CERN

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Abstract: A total pressure gauge of the Bayard-Alpert type has been developed for the 2 km ISR vacuum system which now operates at an average pressure lower than 10^{-9} Pa (N_2 equivalent). Approximately 350 such gauges will finally be installed. Prior to installation, all gauges undergo calibration on a specially designed vacuum system which can handle 20 gauges in simultaneous operation and routinely yields ultimate pressures ranging between 1 and 3×10^{-10} Pa. Calibration for sensitivity is carried out at higher pressures by means of the dynamic expansion method. So far about 300 gauges have been tested and 137 installed on the ISR. Their average characteristics are : sensitivity for N_2 0.32 Pa^{-1} (42 $torr^{-1}$), pressure equivalent to the residual current 2.4×10^{-10} Pa, modulation factor 0.86. These values are obtained with + 150 V and + 50 V bias voltages on grid and filament respectively, and modulation from grid voltage to ground.

INTRODUCTION

About 700 titanium sublimation pumps were added over the last years to the ISR vacuum system in order to reduce pressure and beam instabilities in presence of intense proton beams /1/. As a consequence the average pressure decreased from about 10^{-8} Pa (N_2 equivalent) to below 10^{-9} Pa, i.e. below the measuring possibilities of the pressure gauges which had been initially installed /2/. A laboratory investigation as well as clearing current measurements in the ISR showed that pressures in the low 10^{-10} Pa range would have to be measured /3/. Specifications were subsequently written /4/ for new gauges which, in addition to fulfilling the more common requirements of reliability, leak tightness, etc., had to provide reasonably accurate measurements at these extremely low pressures. More precisely the required low pressure measuring uncertainty was better than 7×10^{-11} Pa and the sensitivity high enough to yield, at the operating electron emission current, an ion collector current not lower than 7.5×10^{-4} A Pa^{-1} (or 10^{-1} A $torr^{-1}$). The ≃ 400 gauges initially installed on the ISR were of the Bayard-Alpert type (BAG) with modulator and the choice of a gauge of different type would have required expensive modification of the power supplies. An investigation of the low pressure behaviour of the BAG gave the somewhat surprising result that its sensitivity remains practically constant when reducing the collector diameter down to 25 μ provided that the grid structure is properly closed /5/. Since the reduction of the collector diameter is accompanied by a proportional decrease of the residual current (I_R) of the gauge, the pressure equivalent to this current (P_r) can be reduced such as to fulfil the ISR measuring requirements. Extra benefits are provided by enlarging the grid diameter, as is made possible because of the size (60 mm diameter) of the tubular connections in which the ISR gauges are inserted. Larger grids present a two-fold advantage. The decreased solid angle subtended from the grid to the collector results in a smaller value of I_R /6/. Furthermore, the gauge sensitivity increases because the path of the ionising electrons inside the grid is lengthened.

For all these reasons, a BAG was finally selected for the ISR with a grid diameter of 35 mm and a collector diameter of 50 μ. The grid, 45 mm long and closed at both extremities, is made with Pt-Ir wires of 130 μ diameter and 2 mm pitch. The 2 tungsten filaments have a hair-pin structure to reduce the measuring limitations produced by space charge /5/ and their distance from the grid is 3 mm. Two modulators (which are of tungsten, as is the collector) of 0.7 mm diameter, are symmetrically placed at 30^{o} with respect to the straight line which joins the two filaments and the collector.

TESTING APPARATUS AND PROCEDURES

Prior to installation in the ISR all the 500 purchased gauges undergo a series of acceptance tests, namely leak detection, thermal cycling to 350°C (at least twice), calibration for N_2 and H_2, measurements of the modulation factor k (Redhead's definition /6/), of the rate of degassing during normal operation and of P_R.

To reduce the number of manipulations and therefore the risk of pollution and accidents, all these tests are carried out on a unique vacuum system. The main requirements for this system are a very low ultimate pressure (10^{-10} Pa) and a reasonably high testing rate (of the order of a gauge per day). The calibration system is shown schematically in Fig. 1. It consists of a condensation cryopump /7/ to which two vessels of spherical geometry, each furnished with 10 gauge ports, are symmetrically connected. The pumping speed of the cryopump is about 27'000 ℓs^{-1} for H_2 and about three times lower for N_2. Its ultimate pressure is about 1.5×10^{-11} Pa. A condensation cryopump is ideally suited for this application because it provides large pumping speeds which are independent both of pressure and amount and nature of the pumped gases in the range from 10^{-10} to 10^{-3} Pa /7/. Rough pumping is provided by a 120 ℓs^{-1} turbomolecular pumping station and by a 350 ℓs^{-1} sputter ion pump, which can both be valved off. The spheres have a diameter of 600 mm and a surface area of approximately 1 m^2 each. This large diameter is required for spacing the gauges, thus avoiding mutual influence.

Between each sphere and the cryopump a two position moveable diaphragm provides effective pumping speeds on the spheres of about 28 and 2500 ℓs^{-1} for H_2 in the closed and open position respectively. If open, the diaphragm offers the large conductance which is required to achieve a pressure of about 10^{-10} Pa at the level of the gauges. This pressure is monitored by two reference gauges of the Helmer type to within 2×10^{-11} Pa /8/. Additional information on the gas composition at the ultimate pressure as well as on the evolution of the partial pressures at the various stages of the tests are provided by two residual gas analysers of the quadupole type. In the closed position the diaphragm provides the small and known conductance [(28.4 ± 2) ℓs^{-1} for H_2] which is required for calibrating the gauges by means of the dynamic expansion method. This consists in injecting gas in either sphere at known rate in presence of known pumping speed, so defining a pressure to which the readings of the gauges are compared. The controlled injection rate is provided by a plug, made of sintered silicon carbide, in which the small size of the pores maintains a molecular gas flow even when a pressure drop in the range of one atmosphere is established across the plug. The conductance of the plug is therefore constant for variations of pressures in a range where absolute and precise measurements are possible by means of a differential oil manometer.

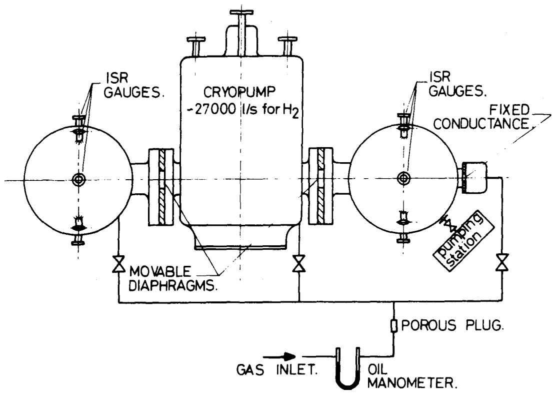

Fig. 1. The calibration system

Calibration of the new gauges is carried out in two steps. First, the reference gauges are calibrated by the dynamic expansion method in the range 10^{-5} to 10^{-6} Pa with the new gauges switched off. The uncertainty of this measurement, about 7%, is mainly due to the uncertainties in the values of the conductances of the porous plug and the diaphragm. Then the new gauges are switched on and their sensitivity is obtained, in the same pressure range, by comparison with the reference gauges. The reason for this double step is that each gauge can provide pumping speeds of a few ℓs^{-1} for H_2 because of dissociation of H_2 molecules which impinge on the tungsten filaments. These speeds are not negligible with respect to the conductance of the diaphragm with the result that the effective pumping speed on the spheres is no longer known when the gauges are in operation. The reference gauges are trouble-free in this respect because dissociation does not occur on their thoriated filaments. The estimated uncertainty for the sensitivity of the new gauges obtained in this manner is about 15%. However, the calibration uncertainty does not affect the sensitivity spread, which is directly obtained by simultaneously exposing the 20 gauges of each batch to the same pressure. This can be done for instance by varying the temperature of the pumping surface of the cryopump which had been initially saturated with H_2. By this method any pressure in the range from 10^{-10} to 10^{-4} Pa can be achieved and carefully stabilised for indefinite times. The corresponding temperature variation of the He bath is from 2.3 to 4.2 K. The possible use of the saturated vapour pressure of H_2 as a pressure reference is also being investigated.

TESTING CYCLE

After reception the gauges are ultrasonically cleaned in an alcohol bath to remove dust particles which could stick to the electrodes and carbonise during degassing. After installation of the gauges on the spheres the system is pumped to 10^{-2} Pa and leak detection is carried out. Bakeout at 350°C follows and a pressure of about 10^{-8} Pa is achieved in two days (see Fig. 2). The cryopump is precooled with liquid N_2, and then the liquid He is transferred and cooled to 2.3 K by reducing the pressure on the He bath to 50 torr. At this stage, with all gauges in operation (≃4 mA emission current) a pressure of about 2×10^{-10} Pa is normally obtained, which usually drops to slightly below 10^{-10} Pa when switching all gauges off (see Fig. 2). From this pressure variation the rate of degassing of the gauges in normal operation is obtained. At the ultimate pressure of the system the collector currents with modulator at grid and ground potentials are measured and I_R is derived. The pressure P_R equivalent to this current is then obtained after measuring the sensitivities of each gauge as described above. During the injection required for calibration the modulation factors k are also individually measured. After calibration a second bakeout is carried out while pumping with the cryopump. For the same temperature cycle as shown in Fig. 2 this second bakeout provides much lower pressures due to the larger pumping speed now available. Typically, a pressure of about 10^{-7} Pa is measured at 350°C on the spheres and the degassing of the gauges is started at ≃ 10^{-8} Pa. This second bakeout has many functions. It provides a second thermal cycle to check possible appearance of leaks subsequent to mechanical failure. It permits gauges to be degassed at lower pressures thus resulting, hopefully, in lower residual currents. Finally, it gives an indication of the evolution of sensitivity after each degassing of the gauges. In fact, the gauges are calibrated again after the second bakeout. In addition to this normal cycle about 10% of the gauges have been cycled 20 times between 20 and 350°C to check the dependence (if any) of the appearance of leaks on ageing.

RESULTS

About 300 gauges have been tested so far and 175 installed in the ISR. Statistical information given herein is relative to these numbers. Only two leaks have been found, both on the first batch of 20 gauges. The average degassing rate for a gauge operating at 4 mA is 7×10^{-11} Pa m^3 s^{-1} (5×10^{-10} torr ℓs^{-1}). This degassing is mainly H_2 (95%) desorbed by the tube in which the gauges are inserted.

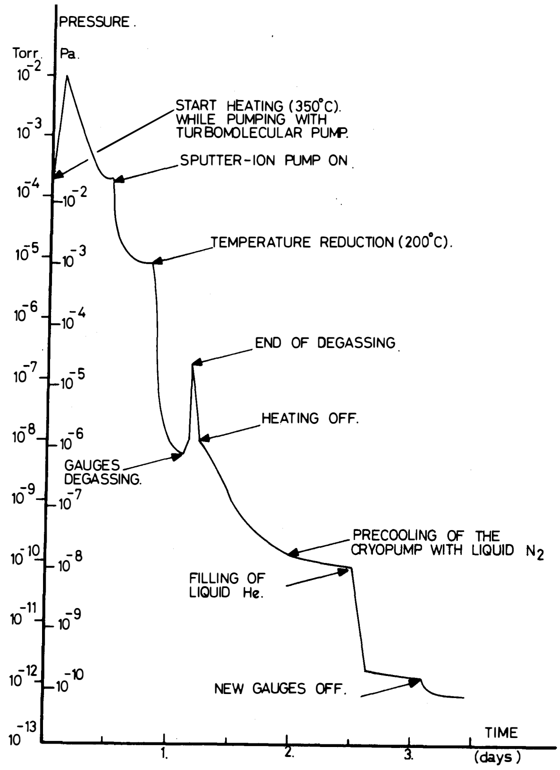

Fig. 2. The bakeout cycle

These tubes heat up due to the power dissipated by the gauge (about 10 W) and to the presence of heating elements around the tube which prevent cooling by air convection. The residual 5% of the degassing is CO which comes from the electrode of the gauge. The average modulation factor k is 0.86 with a standard deviation for individual gauges $\sigma = 0.02$. The average sensitivity S for N_2 is 0.32 Pa^{-1} (42 $torr^{-1}$) with $\sigma = 0.033$. For H_2, $S = 0.15\ Pa^{-1}$ (20 $torr^{-1}$) with $\sigma = 0.017$. These values are relative to the standard operating conditions, i.e. gauge inserted in a tubular stainless steel connection of 60 mm diameter and bias voltages of + 150 V applied to grid and of + 50 V to filament relative to ground. However, values as high as 0.45 Pa^{-1} (60 $torr^{-1}$) were measured when adjusting the voltages for maximum sensitivity. This situation is achieved when the orbits of the ionising electrons cross the grid cage at right angles /9, 10/.

The average value of the pressure P_R equivalent to the residual current is 2.4×10^{-10} Pa with $\sigma = 1.2 \times 10^{-10}$ Pa. This average value is about three times higher than the lowest values consistently measured on a few of these gauges and which are attributed to the x-ray effect. It follows that P_R is mainly the result of the collection of ions desorbed from the grid under electron bombardment. Particular attention was devoted to determining the origin of this grid pollution which was even more important for the first gauges delivered. It was finally attributed to O_2 released by a small glass tube which protects the collector feedthrough. This tube was overheated during degassing of the gauge because it approached too closely to the grid. Degassing was therefore tending to pollute, rather than clean, the grid. Drastic improvement was obtained upon shortening this glass tube, and the values of P_R which are now measured are about a factor of 2 smaller than specified. In fact, if one assumes that the value of P_R as obtained by modulation is affected by 10% uncertainty /11/, the low pressure measuring uncertainty of these gauges is now in the low 10^{-11} Pa range.

USE IN THE ISR

The 175 new gauges which have so far been installed in the ISR indicate an average pressure, in the absence of circulating proton beams, of about 8×10^{-10} Pa. In the presence of beams they can detect pressure variations smaller than 10^{-10} Pa, and are extremely useful to locate the weak points of the machine, even when the currents of the proton beams are not yet critical. Also, their use has clearly revealed a "fine structure" of the ultimate pressures as a function of the various pieces of equipment which are regularly distributed along the 2 km long ISR vacuum system. Furthermore, the pressure profiles in the sectors which have been baked a few times, after the replacement of the gauges, are very reproducible and therefore even small pressure changes from one bakeout to the next can be used as an indication to trigger specific action, as, for instance, leak detection.

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