Vacuum System of the ESRF

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Abstract

The general principles of the ESRF storage ring vacuum system are based on the high power density of the photon beams delivered to the fixed absorbers inside the vacuum vessels. Investigations have been made into the behaviour of classical and exotic absorber materials. The construction of the stainless steel vacuum vessels has raised several challenges for the ESRF and for European Industry charged with vessel manufacture. The pumping and vacuum monitoring equipment, as well as the computer control system for it, is described in this paper which also reports on the results of Booster commissioning.

1. INTRODUCTION

The basic design of the ESRF vacuum system and its evolution have been reported previously [1] [2]. This report concentrates on the design which has been implemented together with first results in commissioning the various systems.

For a stored beam lifetime of 10h or more an operating pressure of around E-9 mbar is required. To obtain such a vacuum under stored beam conditions, the ESRF has developed a system based on a stainless steel structure which has distributed absorbers in the straight vessels and lumped absorbers at the outlets of the dipole vessels. Lumped ion and lumped nonevaporable getter pumps (NEG's) provide the high pumping speed and gas capacity necessary for the gas load desorbed by the stored beam. Pressure measurement is made with Pirani gauges and Inverted Magnetron Gauges (IMG's) which also provide vacuum interlocks for pumps, valves, etc. Quadrupole type analyzers [3] enable residual gas analysis over the mass range from 1-100amu. They are operated via serial links either locally with a PC or from the Main Control Room.

2. DESIGN FEATURES

2.1. *Straight Vessels*

These vessels have a copper absorber brazed on the stainless steel side-wall over the full vessel length. Some of the synchrotron radiation power striking this absorber is "reflected" from it by several processes the dominant one being fluorescence [2]. Since the vessel is made from stainless steel which has a poor thermal conductivity, this design could result in the heating of vessel surfaces causing severe mechanical stresses and distortions besides increased thermal outgassing. Therefore a key point in the design is the inclusion of two water cooling pipes opposite the absorber on the outside of the vessel over the full vessel length, which then eliminates significant thermal stresses.

2.2. *Crotches*

The high power absorber at the exit of each dipole vessel, the so called crotch, together with the absorber on each beam port, i.e. where there is no beam line, are of a similar design with a flattened "C" type section to act as a photon trap [2] [4]. In this first period of commissioning of the storage ring these absorbers are made from OFHC copper. At a later stage, the material will be changed for GLIDCOP AL-15 [5] to give a safety factor with the high thermal stresses when operating with the design stored current.

2.3. *Pumps*

Starcell [6] triode type ion pumps are used throughout the facility and already the ease of starting these pumps is apparent and of great benefit during the commissioning phase when there are many pumpdowns from Atmosphere.

Our tests on NEG showed very little difference in the pumping speeds of St101 and St707 [7] so that we have opted to use only the lower temperature activated St707 in standard cartridge form. On the vessels, GP200 cartridges are mounted in uncooled stainless steel housings, since during activation at 450°C for 1h the maximum temperature on the outside surface of the housing only reaches 120°C. On each crotch a GP500 cartridge is inserted into the double ended 400l/s ion pump. Tests showed that it was not necessary to shield the cartridge from sputtered deposits from the ion pump, so that maximum pumping speed is obtained, i.e. below E-8mbar the pumping speed for hydrogen is 2000l/s and for carbon monoxide 800l/s.

First tests with NEG on a baked cell of the storage ring showed that all eleven NEG pumps in the cell can be activated at 450°C for 1h, pumping just with the cell ion pumps. During this process the total pressure exceeds E-6mbar with hydrogen the dominant gas and all other gases, mainly carbon monoxide, methane and carbon dioxide, at <1% of the hydrogen pressure. Within 15 minutes of switching off NEG power the partial pressures of all gases except hydrogen are <1.E-10mbar. The resulting ultimate pressure is then limited by the thermal desorption of hydrogen from vessel surfaces exposed to the relatively high partial pressure of hydrogen during the activation process. Recovery to around 1.E-10mbar, which is typically the ultimate vacuum achieved after bakeout at 200°C for 24h, takes about one week, but it is anticipated that during Machine operation photons will rapidly desorb this hydrogen from vessel surfaces. In any case beam lifetime is not significantly affected by hydrogen desorption.

2.4. *Gauges*

In each of the 32 cells of the storage ring a Pirani gauge covers the pressure range from Atmosphere to E-3mbar and six IMG's [8] then continue the range down to <E-10mbar. Up to 4 IMG's and 2 Pirani's are controlled independently from one gauge contoller [9]. To prevent impairing uhv measurements, software in the gauge contollers limits IMG operation above 1.E-5mbar to 5 seconds, which is just sufficient to obtain a reading before the gauge's high voltage is switched off and "HI P" is displayed. Also, the interpretation of gauge current below around 1pA as pressure, i.e.≤1.E-11mbar, is not meaningful and instead "LOW P" is displayed. We have found that the IMG current I (A) versus absolute pressure P (mbar) for carbon monoxide is well defined from E-5 to E-10mbar by relationship (1), which is used for the calibration curve embedded in the gauge controllers.

$$I = 33.2P^{1.23} \qquad (1)$$

2.5. *Vacuum Controls*

2.5.1. *General structure*

The Vacuum control system as for all other parts of the Machine complex is based on multi-level architecture of distributed hard and software processing units [10]. Fast and simultaneous control of equipment requires a distributed software structure with a reliable and completely transparent infrastructure between the various distributed systems. Physically the control system is split into 2 levels. All nodes of the presentation and process level consist of UNIX based workstations linked by Ethernet. VME bus crates equipped with 68030 CPU boards form the interface to vacuum devices. These systems run on the OS9 multitask real time operating system [11].

2.5.2. *Vacuum hardware*

At the lowest control level equipment is interfaced by intelligent controllers. Whenever possible specially developed modular controllers are used. Control and monitoring is available for up to 4 pumps of different sizes with each ion pump power supply [12], and up to 2 Pirani's and 4 IMG's with each gauge controller. For gate valves [13] the control and monitoring as well as the internal and external vacuum interlock system is via Programmable Logic Controllers (PLC's) [14], in each of which the embedded program is safely stored on EPROM.

The above controllers as well as those for the RGA's are linked to the VME crates via RS422 serial lines. The use of asynchronous serial lines keeps to an ESRF goal to use whenever possible commercially available equipment. The RS422 interface was selected because of the requirement for cable lengths up to 100m, the possibility for higher transmission rates and insensitivity to noise. Although these interfaces are in principle standard, experience has shown that with the large number of serial lines from different devices, it was still necessary to carefully define the hard and software specifications to achieve the required compatibility for the whole system.

For NEG pump supplies control is via analog signals of 0-20mA. Thermocouple monitoring is based on a G64 system. The requirement for fast data acquisition, from up to 64 thermocouples of both T and K-type in each of the 32 cells, was solved by using a high speed multidrop bus developed at the ESRF [11].

2.5.3 *Software*

Low level software for the distributed control system is based on a "client/server" architecture, which is the intermediary between application programs and vacuum equipment [15]. It contains specific codes for devices, and isolates the applications from hardware differences. The use of "Remote Procedure Call" enables complete transparency between the different communication features [16].

Each device is addressable independently of its hardware connection and from different nodes. A command system is available in the form of application programs for the Booster, Transfer Line 2 and Storage Ring, to monitor and control the main vacuum equipment, i.e. pumps, gauges, valves and thermocouples. It allows individual device control, display of status, and display of pressure and temperature profiles together with zoom facilities for more detailed information. The use of a static data base to define important device parameters, such as set points, guarantees the required configuration for each instrument.

In order to achieve a fast response time of the whole vacuum system, e.g. Storage Ring pressure profile in a few seconds, the use of a dynamic data base with data acquisition continuously updated is envisaged.

3. BOOSTER VACUUM

3.1. *Vessel design*

The Booster vacuum system has a total circumference of 300m and is divided into 9 sectors by electropneumatic valves. Sectors consist of a number of magnet cells each of which comprises a dipole, quadrupole and sextupole magnet all mounted together on one girder. A 5m long thin walled stainless steel vacuum vessel, with elliptical section (35 x 70mm) and insulated at each end by enamelled flanges, passes through these various magnets. In order to reduce the thermal and magnetic effects generated by eddy currents in the vessel walls during operation, the wall thickness is only 0.3mm with externally brazed reinforcing ribs for support about every 40mm [17].

3.2. *Pumping system*

An analysis based on equation (2) showed that with one 30l/s ion pump per cell an average pressure of 1.E-8mbar would be reached after several weeks of pumping.

$$P_{av} = qbL\left(\frac{1}{nS} + \frac{L}{12n^2k}\right) \qquad (2)$$

where q = specific surface outgassing rate (=5.E-11 mbar.l/s/cm^2 for unbaked clean stainless steel after a few weeks pumping).
b = peripheral length of vacuum duct (=14.9cm).
L = total length of vacuum vessel (=489.3cm).
k = specific duct impedance (= 849 l.cm/s, mass 28, 298°K).
S = pumping speed of each pump symmetrically placed in the cell.
n = number of lumped pumps in the cell.

For the Booster 45l/s triode ion pumps were chosen and installed on pumping tees situated between the magnet girders in each cell. The two RF cavities are each pumped by two 400l/s triode pumps, which give a base pressure in the E-9mbar range.

In each sector, pressure measurement is made by one Pirani gauge and one IMG, which together with a PLC are also used for the interlock system. In addition, RGA's are fitted in special sectors, i.e. in the injection, extraction and RF cavity sectors.

3.3. Pressure evolution during commissioning

Fig. 1 shows the average pressure in 6 standard sectors, each 40m long, over about a 3 month period. The dashed curve is without beam, the + curve with around 1 mA beam at an Energy of 3 to 5 GeV and the * curve with around 1 mA beam at 6 GeV. The initial pressure rise on the * curve, due to the 700W or so of synchrotron radiation, corresponds to a molecular desorption yield of around 1.E-1 molecules per photon.

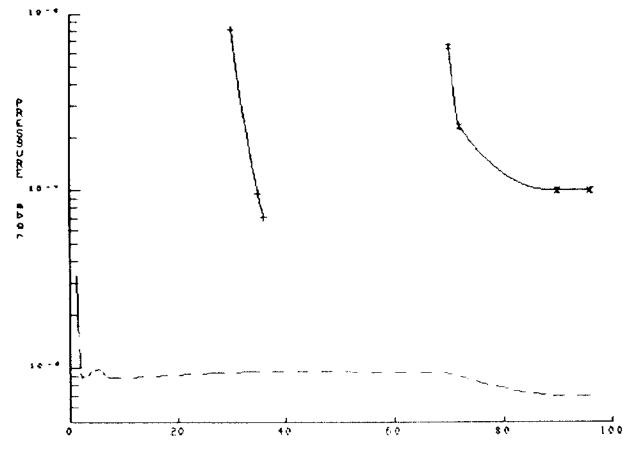

FIG. 1

The pressure in the extraction sector reached ≈E-5mbar when the septum magnets were first pulsed at maximum power. To reduce the outgassing, the second extraction septum magnet was baked by pumping hot pressurized water (120°C, 6 bar) through the cooling circuit.

3.4. Conclusions

3.4.1. The Booster base pressure has evolved in accordance with predictions made in the design phase, with a limit pressure of around 1.E-8mbar.

3.4.2. Failure rates have been very low; one problem encountered was due to electrical leakage followed by an air leak on the high voltage feedthrough of one of the ion pumps on the LINAC. This problem was solved by coating externally the insulators with silicon grease to inhibit "corona".

3.4.3. The vacuum design of Transfer Line 2 , which had been contracted out, proved to be too optimistic; two 60l/s ion pumps had to be added in order to reach an acceptable pressure along the 63m long line, where differential pumping is foreseen to cope with the two orders of magnitude lower pressure in the Storage Ring.

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