TOTAL PRESSURE MEASUREMENTS IN THE ELETTRA STORAGE RING ACCORDING TO THE PERFORMANCE OF THE SPUTTER-ION PUMPS

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Abstract

In the storage ring and the transfer line of the Elettra synchrotron radiation facility the total pressure measurements are not only performed by cold cathode gauges which, however, suffer from known start up problems, but also by utilising the electrical discharges of sputter ion pumps (SIPs). The throughput Q of a SIP is proportional to the ion current I and the real current is considered constant at each applied voltage. In this case the current I [A] absorbed in the pump is proportional to the pressure P [mbar] , $I = K P^n$, where K and n are constants depending on the nominal pumping speed and have to be specified for each applied voltage. The system developed in our laboratory allows to supply up to 8 SIPs using one power supply. The absorbed current for each pump can be measured and an automatic current to pressure conversion made. This system was calibrated in the UHV pressure range for 45, 120, 400 and 900 l/s SIP's, and was succesfully tested during the commissioning of Elettra.

1. SPUTTER-ION PUMP DESIGN

The sputter ion pumps are designed such that an electrical discharge occurs between the anode and the cathode at a potential of several thousands of volts in a magnetic field of a few thousand gauss. According to the standard theory of ion pumps the throughput Q is proportional to the ion current I

$$Q = k\, I \qquad (1)$$

The current measured in the pump is due to the positive ion collected at the cathode. Collected ions - besides other secondary effects - could cause two main phenomena: sputtering of cathode material and induced emission of electrons. It means:

$$I_{(measured)} = I_+ + I_- \qquad (2)$$

where I_+ is the positive ion current and I_- is the electron current.The amount I_- is a function of the number of incoming ions I_+ and their energy. The higher the applied voltage, the higher the ions energy, and the higher the number of emitted electron per incident. The real ion current can be considered as a constant at each applied voltage. In this case the current I [A] absorbed in the pump is proportional to the pressure P [mbar]:

$$I = K\, P^n \qquad (3)$$

where K and n are constants depending on the nominal pumping speed of the pump and have to be specified for each voltage.

3. ELECTRONIC CIRCUITS

3.1 The block diagram.

The SIPs are connected to the Power Supply (PS) as it is shown in fig.1. The PS has two modes of operation: Start and Protect. In Start mode the PS supplies a fix output voltage of -7 kV. In Protect mode, that is the recommended operation mode, the PS decreases its output voltage in two steps, at first to -5 kV and later to -3 kV, according to the current absorbed by SIPs; as lower is the absorbed current as lower is the output voltage. This mode of operation improves the pumping speed at low pressures and, minimising the leakage current inside the pumps, assures more accurate current measurements. The High Voltage (H.V.) output power of the PS is split to the SIPs by means of shunt resistors which convert the current absorbed by SIPs into voltage.

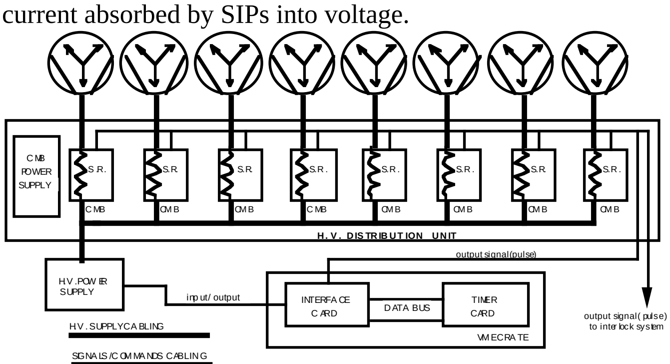

fig. 1. - The complete block diagram.

Each shunt resistor is mounted in a current measuring board (CMB), this card converts the input signal which will be collected to the control system. The shunt resistor signal, in fact, is referred to the H.V. potential (up to -7 kV). At first the input voltage is converted into a frequency by means of a voltage to frequency converter integrated circuit (V/F), and later the signal is transformed in a TTL ground referred form by means of a 15 kV of electrical insulation optocoupler. The CMB cards are mounted in the H.V. distribution box and are supplied by the CMB power supply. This one is a double power supply which has one normal output of +5 V to supply the ground referred side of the card, and one +/- 15 V output to supply the H.V. side of the card. This side is floating on the -7 kV, so a high voltage insulation transformer is used. The output signal of the CMB goes into the home made interface boards (IB), it accepts up to eight channels from the same amount of CMB. The IB is installed on a VME crate and it is totally optoisolated from the VME. The IB also drives the input/output of the PS and is connected to a TSVME405 THEMIS board (TB), which is really the board which transfers the data to the VME. More details about the VME hardware and software, and about data transmission from it to the control room, are explained in the ref.1. In the control room the pressure values for each vacuum sector are displayed on monitors, in fig. 2.

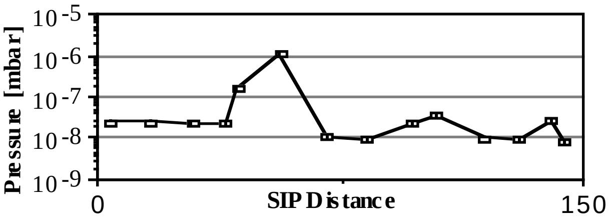

fig 2 - Pressure profile of the transfer line

Each dot represents one SIP, clicking on it the identification name of the pump and its actual value of the pressure, are displayed in the window. The diagram shows the transfer line vacuum profile when a leak occurred in the beam stopper. The interlock system automatically closed the valves in about four-to five seconds, to prohibit the pressure increase to propagate down the vacuum tube. From the pressure profile it is possible to discover immediately the vacuum problem. The updating of all diagrams is done every twenty seconds. It is also possible to open a panel which shows for each SIP the pressure, the applied voltage and the timing signal, corresponding to the absorbed current.

3.2 The Current Measurements Board.

We designed all the pressure measuring system.considering that the operating pressure is from 10^{-9} to 10^{-8} mbar. The chosen V/F, works in six decades of conversion. The upper value is limited by the 15 V of supply voltage of the V/F, such the theoretical lowest limit is 150 μV. A 120 l/s SIP, absorbs about 10 μA at the pressure of $2x10^{-8}$ mbar, choosing a 10 kΩ shunt resistor the input voltage at this pressure is 100 mV. It means that the upper limit of the measurement is about $2x10^{-6}$ mbar (about 1,4 mA of absorbed current corresponding to 14 V of input voltage). The lowest value is limited by the noise, we can measure up to 100 μV, equal to 10 nA of absorbed current. The theoretical corresponding pressure is in the range of 10^{-11} mbar, but in this range the expression which correlates absorbed current versus pressure is not very reliable. However, all SIPs were calibrated up to about $5x10^{-11}$ mbar, according to the lowest limit of the Penning gauge IKR 20 connected with a triaxial cable. This pressure range from 10^{-6} mbar to 10^{-11} mbar is more than sufficient for our purposes. In the transfer line the pressure is about one decade higher than in the storage ring, so the shunt resistor is 1 kΩ, to shift also the range of measurements. The output of the V/F is a pulse series of about eight μs of duration. This frequency, depending linearly by input voltage is calibrated to 100 kHz full scale, corresponds to the 10V of input. This signal drives the LED of the optocoupler, the output is referred to the ground and finally goes out of the CMB via a quad TTL driver. The signal is split in four channels; three of these are used as auxiliary outputs and one for the measurements. The schematic block of the CMB is shown in fig.3.

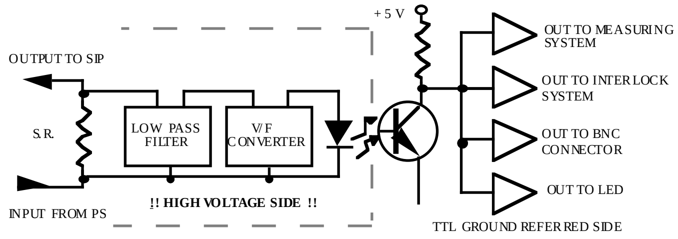

fig. 3 - Simplified schematic diagram of the CMB

3.2 The Interface Board and the THEMIS Board.

The TB has four timers and 88 configurable digital input/output. Each timer is separately controlled by others by means of its own I/O. The IB has a multiplexer to permit the interfacing of its eight channels to the only four channels of the TB. The IB consists principally of a FLIP/FLOP sequence which synchronises the following data: *i)* a pulse from the CMB (asynchronous), *ii)* a measure call from TB, *iii)* a VME clock that is divided into 16 by the same IB, before it is used . In practice the TB transfers a measuring call from VME bus to the IB, it waits for a synchronising process, and counts how many 1 MHz pulses can stay between two pulses from CMB; at the end of the second pulse IB gives back a stop count signal to the TB. To inhibit further measurement calls during all the time of this process, a busy signal is sent to TB. Other functions of the IB: *i)* a conversion of an analog signal from PS concerning its actual value of the output voltage into a digital one (this data is necessary for the current versus pressure calculations). *ii)* interfacing by means of optocouplers all the input /output of the PS.

3.3 Auxiliary function.

The other three auxiliary channels of the CMB, are used as follows: one for the interlock system, one for a local control by means of a BNC output and the third is for local control by means of a LED. The signal for the interlock system goes in an alarm boards. The alarm boards uses the same V/F integrated circuit of the CMB, to reconvert the input signals back into the voltage. In the same card a comparator with an adjustable threshold gives an output signal when the input signal (pressure) is too high. The interlock system collects all these outputs. Following some software instructions, if there is a dangerous pressure alarm, it sends back a closure command to the vacuum valves. In practice, according to the vacuum conditions, the action of the interlock consists of the closure of some valves to separate the part of the chamber where a leak is detected. The BNC output is useful for maintenance and for repairing operations. The last auxiliary output drives a LED; the LED is on the front panel of the CMB, and blinks at each pulse. During the shut down period, when no beam is accumulated, the pressure in the storage ring is so low that the CMB are in overflow. In that case all the LEDs are switched off or are blinking slowly. It is possible to make a fast but very useful test about vacuum conditions - simply by walking around the ring and looking at the vacuum racks - if one or more LEDs are blinking too fast or are completely switched on there is certainly something wrong in the vacuum chamber or in the pumping system.

4. CALIBRATION PROCEDURE

The transfer line of Elettra is pumped by twelve 45 l/s SIPs and the total pressure can be measured by fourteen cold cathode Penning gauges. The storage ring is pumped by 24 400 l/s SIPs and by 118 120 l/s SIPs and two 900 l/s SIPs pump the septum tank, which is a part of the storage ring. The pressure in the bending magnet vacuum chamber is measured by 24 cold cathode gauges installed close to the 400 l/s SIP. In total 22 Penning gauges are mounted in the rhomboidal electron vacuum chamber in different positions. This arrangement allows verification of the pressure profile in the ring at various stored beam currents and energies. During the first week of commissioning the pressure measurements according to the current absorbed by the pumps were not successful. The big discrepancy between the gauge values and the pressures calculated according to the equation (3) with constants recommended by Varian can be explained as follows:

i) All SIPs are modified with the NEG modules. The presence of the NEG, which was partially activated during the bake out of the pump at the temperaturte of about 220˚C, changes pumping conditions in the pump body and causes a decrease of the lowest limit of the absorbed current.

ii) Eleven of Penning gauges were installed directly over the vacuum chamber. The pressure readings were disturbed by photoelectrons and exceeded 100÷1000 times the real pressure value in the chamber.

iii) Some of electron chamber gauges were, due to assembling problems, mounted close to the edge of the bending magnet coils. The external magnetic field strongly affected those pressure measurements and firstly the appropriate shielding has to be found - see ref.[3].

Taking into account the above mentioned problems only 13 SIP+gauge combinations can be used to calibrate the 400 l/s SIPs, 18 SIP+gauge pairs were used for the 120 l/s SIP and only three gauges are installed in the septum tank which allows calibration of the two 900 l/s SIPs.

The calibration was performed mostly by increasing the pressure from 10^{-11} mbar to 10^{-8} mbar. In this pressure range the μ-8000 power supply works with -3 kV and -5 kV of the H.V. output. The abnormal pressure was generated at the beginning after a small accumulated dose only. In fig. 4 theoretical and experimental results for the pumps 120 l/s SIP are presented. The complete set of equations, which allows to calculate the total pressure in the storage ring according to the current absorbed in the pump is as follows:

I = 1850 P{exp 1.065}	SIP 45 l/s; H.V.: -3&-5 kV	(4)
I = 1590 P{exp 1.06}	SIP 120 l/s; H.V.: -3&-5 kV	(5)
I = 1200 P{exp 0.99}	SIP 400 l/s; H.V.: -3&-5 kV	(6)
I = 1050 P {exp 1.03}	SIP 900 l/s; H.V.: -3&-5 kV	(7)

To convert the timing to the current the expression I = 1/100xTiming has to be used due to the 10 kΩ resistence used in the PS of the storage ring SIPs.

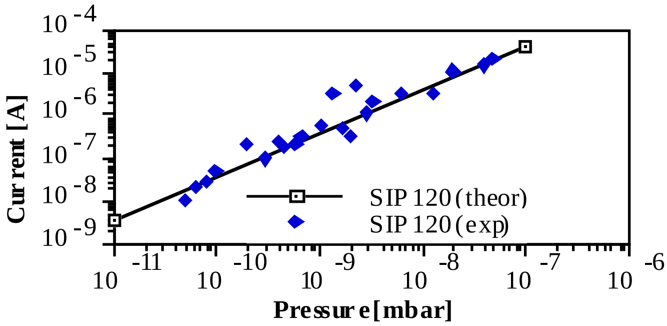

fig. 4 - Current x pressure dependence for the SIP 120 l/s

5. DISCUSSION AND CONCLUSIONS

The presented system seems to be suitable for the pressure measurements especially in big vacuum systems. In spite of above mentioned difficulties during calibration, the pressure profile in all vacuum sectors of the Elettra ring obtained by pump pressure readings is fairly uniform in the range $8x10^{-10}$ to $2.5x10^{-9}$ mbar. The pressure readings of each pump are very useful also in the lowest pressure range, where only the "UHV" value can be read on the power supply display, e.g. the measuring system overflows. At the same time, for example, from six 120 l/s SIP's supplied by the same one, the following timing is read: 142657, 283321, 346112, 186632, 425113, 203664. Then the sum of the pressures calculated by equation (5) is $6.5x10^{-10}$ mbar which is really lower than the lowest pressure of $8x10^{-10}$ mbar, which can be read on the power supply display. Penning gauges have some problems when switching on and during the start of pressure measurements in the UHV range (below 10^{-8} mbar). A similar problem can occur also in the case of SIP's, when the discharge current is too low and unstable at very low pressures. This inconvenience can be simply overcome by changing the working mode of the power supply from "Protect" to "Start". The high voltage then automatically increases to -7 kV, the discharge current is higher and can be maintained returning to the "Protect" mode, as well.

Our system was not calibrated at pressures higher than $1x10^{-7}$ mbar, because the SIPs are switched on only if the pressure in the vacuum chamber is lower than this value. The validity of expression (5) was checked comparing the pressure values in the RF cavities, where pressures were read by Penning gauges, with the pressures calculated from the timing of the RF cavity pumps. The gauge values are always slightly higher than the values obtained by the SIP's reading, which is consistent with the pressure distribution in the big RF cavity.

6. REFERENCES

[1] D.Bulfone: Status and prospects of the Elettra control system; N.I.M. A352 (1994), p. 63

[2] S.P. current measurement LEP 680-4221-050 D

[3] J.Miertusova, F.Daclon: Effect of Ext. MgF Rad. upon the Accuracy of total and Partial Pr. Meas., Proc. 4th EPAC'94, London, Vol. 3, p. 2512