EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-LEP-VA/86-31

CONTROLS FOR THE VACUUM SYSTEM OF LEP

P.M. Strubin

ABSTRACT

The very large size (27 km circumference) of LEP (CERN Large Electron Positron Storage Ring) makes it mandatory to provide extensive remote control for installation, commissioning and operation. The control facilities will be available both at fixed locations and in the form of mobile consoles which will follow the installation teams. All operations must be accessible to vacuum technicians, who may have little or no computing knowledge. Therefore, menu driven consoles, using a screen and light pen, will be made available to the operators. The large number of pumps, gauges and valves makes it necessary to find solutions to reduce the cabling costs. An original way of powering the sputter ion pumps uses a single power supply and cable for up to 8 pumps, yet allows individual current monitoring for each pump. An ionisation gauge power supply for 8 heads is economical and saves rack space by multiplexing the ion currents while powering and regulating continuously all filaments. All power supplies must be integrated in the general control system of the LEP machine. This is done by using so-called intelligent equipment controllers, which exchange messages with the main control room by a network of multidrop busses. A sophisticated data base management system is required in order to keep track of the numerous items connected to the vacuum system.

Geneva, November 1986

Paper presented at the 10th International Vacuum Congress in Baltimore, 27-31 October 1986

1. INTRODUCTION

CERN is constructing a Large Electron Positron storage ring (LEP) for colliding beam experiments near its present site. This will be installed in an underground ring tunnel of approximately 27 km circumference, straddling the border between the Swiss Canton of Geneva and the French Département de l'Ain. The first phase, which is now authorized, will involve the construction of the complete magnet and vacuum systems, and sufficient radiofrequency and auxiliary equipment to store beams of electrons and positrons up to an energy of between 50 and 60 GeV.

The major part of the LEP vacuum system will consist of extruded aluminium chambers. The pumping of the vacuum chamber will be achieved by a non-evaporable getter (NEG) strip for the reactive gas and by sputter ion pumps for the non-reactive gas. The LEP vacuum system will be able to provide a base pressure in the low 10^{-9} Pa range and a working pressure in presence of electron and positron beams in the 10^{-7} Pa range. Pressure estimates will be provided in normal operating conditions by reading the discharge current of the sputter ion pumps.

This paper will review the main aspects of the required power supplies and control units for the LEP vacuum system.

2. SPECIFIC PROBLEMS OF THE LEP MACHINE

The major difficulty resides in the unusual length of the LEP ring tunnel¹⁾. The immediate implications are the length of the vacuum sectors, which can extend over 474 metres and their location, which may be as far as 1.7 km from the access shafts. These distances mean that it will not be practical to use manual controls, even at the level of one sector.

In order to minimize the cost, and because organic materials (like oil or rubber seals) and electronics would be damaged by the synchrotron radiation^{2,3,4,5)} if left in the tunnel when the machine is operated, many standard vacuum items are made mobile. These include 60 turbo-molecular roughing pumping stations, 30 residual gas analysers, 30 non-evaporable getter (NEG) pump power supplies and 25 bake-out heating units. Some of the difficulties for the control system stem from the fact that these items are not permanently connected to it.

Related to the size of the LEP machine is the large number of individual components. More than 1800 sputter ion pumps, 22 km of NEG pumps, 127 all-metal sector valves, 200 Pirani gauges, 60 Penning gauges and more than 250 ionisation gauges will have to be permanently powered and monitored. The integration into the global LEP control system puts a number of constraints on the available interfaces on the power supplies.

This last aspect is emphasized in the use of many components salvaged from the Intersection Storage Rings (ISR), which are more than 10 years old and are not equipped with a suitable interface for a modern control system.

3. GENERALISED CONTROL PANELS

As most of the power supplies and control units are located in areas which are not normally manned, or are at large distances in the tunnel, the vacuum operators will be provided with generalised mobile control panels allowing them to take control of any equipment connected to the vacuum sector on which they are working. The prototypes of these control panels have been built using a 7 inch CRT screen and a light pen. The associated microprocessor allows the operator to select either command or display facilities, using a menu driven approach.

Various goals will be achieved with these control panels. The cost of the numerous power supplies can be significantly reduced by suppressing all knobs and meters on their front panels. Pressures (and other values) will be displayed with the correct units; extensive interlocks against wrong operations will be possible because of the availability of the information from a complete vacuum sector in a control panel. Graphic display facilities, such as histograms and bar graphs, are very effective for the supervision of a large number of items. It remains, however, to convince the vacuum operators that this is an adequate alternative to individual front panels.

The complexity of these control panels is greatly reduced by the fact that all power supplies do include one or more microprocessors, so that high level commands can be sent from one device to another. For example, only 5 messages, each less than 80 characters long, have to be sent from a gauge power supply to report fully on all 8 gauges connected to it. The main complexity of the control panels is therefore in the various display facilities.

4. INTERCONNECTIONS AND GLOBAL SUPERVISION (see Figure)

In order to reduce the cabling costs to a minimum, all the power supplies and controls equipment will be inter-connected using a multidrop bus over which messages can be sent. One cable, grouping the sector valve command and status information, the global vacuum status of the sector and a few wires for the data transmission will, be installed for each of the 127 vacuum sectors with derivations made available at the locations where mobile equipment is to be connected.

There will be one generalised control panel for each sector, located in the service areas where all fixed equipment will be installed. Up to six mobile control panels per vacuum sector will be available on the mobile pumping stations. They will all be identical, with some incorporated software protection to avoid inadvertant mis-use¹⁰⁾. The fixed control panels will also be the interface point to the next higher level of the control system.

This next level will be built using minicomputers¹²⁾ available at all 8 access pits of the LEP tunnel and will serve as local data concentrators. The lowest layer of the control system should allow for an autonomous operation of each vacuum sector, essentially for commissioning and diagnostic purposes. The next higher level will be used to run more generalised programs, like supervision of complete sectors or machine octants, and the recording of histograms or alarms.

All the local minicomputers will be connected together and to the main control room by a high speed message transfer system based on a token passing ring bus. It is the aim of the LEP controls group to provide users such as vacuum operators with a homogenous control system allowing the same programs to be run from anywhere on the LEP site. Therefore, local supervision programs will also be used in the main control room and only very few additional programs will be required for general vacuum supervision.

5. KEEPING TRACK OF THE MOBILE EQUIPMENT

One of the most challenging problems is to keep track of the mobile equipment in such a way that a vacuum operator does not have to know anything about the structure of the control system (e.g. addresses of devices). Our aim is that the operator dials in the position in the tunnel where he is connecting the mobile equipment to the multidrop bus and that a program in the higher levels of the control system recognises that a new item is to be controlled.

To assist us in this work, a versatile data base management system has been installed for the LEP project. Called ORACLE¹¹⁾, it is used for planning, installation and follow up of orders. It will eventually contain an extensive description of the LEP machine, which can be used for control purposes. The minicomputers available at all 8 access pits of the LEP tunnel will also hold a subset of the global data base, including the mobile equipment.

The fixed control panels will detect when mobile equipment is added or removed. They will pass this information to the closest minicomputer which will update its local data base, so that new equipment can be controlled from anywhere via the control system. To allow for the mobile equipment to be used everywhere around the LEP machine, they have to be identified by their type, which is a constant, and the physical position in the machine tunnel, which will vary.

6. SPUTTER ION PUMPS

In order to minimise the costs of cables and control units, the decision was taken very early in the project that up to 8 sputter ion pumps would be connected in parallel on one power supply, leading to the following two problems:

- How can a fault or a leak using the pump currents be localised?
- What happens if there is an electrical short circuit on one pump?

The first problem is particularly difficult, because of the large distances between pumps. Assuming that successive pumps are connected to the same power supply, the resolution is not better than 120 metres if the sum of the pump currents is used. To improve this situation and make leak detection possible with a resolution of 20 metres, we designed a current measuring device which converts the current fed to each pump into a frequency signal which is convenient for transmission over long distances of cable. The current to frequency conversion is done at the high voltage level and a high insulation transformer is used to decouple the output signal from the high voltage. The measuring devices are inserted into the cable which connects individual pumps to the main high voltage distribution. The readout and selection of a particular pump is done via auxiliary wires incorporated in the high voltage cable. The useful measuring range extends from 1 μ A to 10 mA, covering the pressure range from 10^{-7} to 10^{-3} Pa. As these items must be in the machine tunnel and, therefore, may be damaged by radiation, great care has been taken in the selection of the components to minimize their number and simplify their replacement.

In order to avoid having all pumps on one distribution cable out of service in case of the electrical failure of a single connector or pump feedthrough, a resistive cable will be used to connect each pump to the main distribution cables. 10 metres of cable add enough resistance to insure that about half of the nominal voltage remains on the other pumps, whilst limiting the dissipated power to less than 25 Watts per metre of cable.

Four hundred and fifty power supplies, with the capability of driving the above mentioned current measurement devices will be built and be used to supply one thousand five hundred pumps of 40 l/s. They will have no front panel controls, therefore all readings and settings will be done via the control system. The microprocessor in the power supply will be able to deliver the output voltage and current values to the control system at least once per second. Individual pump currents will be available at intervals of less than 4 seconds, depending on the actual value of the current.

Some further 300 power supplies from the ISR machine have been modified and will be used for the three hundred pumps of 400 l/s. A dedicated interface will be added to these power supplies so that they appear identical to the new 40 l/s pump supplies for the control system.

7. IONISATION GAUGES

In earlier accelerators, the ionisation gauges were traditionally powered using analog techniques. This led to readings which had to be manipulated by the controls computer to give meaningful values (e.g. taking care of the X-ray limit in a modulated Bayart-Alpert gauge). As it was known early in the project that the LEP control system would require so called intelligent equipment^{6,7)}, an attempt was undertaken to make the most efficient use of the microprocessor already needed to satisfy the controls requirements.

The first use of ionisation gauges was defined for the monitoring of the 128 RF cavities, which will be positioned by groups of 8 into individual vacuum sectors. A power supply which can permanently heat and regulate the filaments of 8 gauges was therefore designed. The regulation is done by the program in the microprocessor, so as to minimize the required hardware. The electrometer, which is the most expensive part of any ionisation gauge power supply, is shared between all 8 gauges. The overpressure protection is however individual, to keep its action fast and to allow the gauges to be located in physically different vacuum sectors. The penalty introduced by the shared electrometer resides in an

access time of up to 5 seconds to the readings of a specific gauge, due to the electrometer stabilisation time needed when the latter is switched from one gauge to another. To keep the response time acceptable for the control system, the microprocessor updates a table in its memory with the latest measurements. It is this table which is read remotely.

The software included in the power supply allows remote computers or control panels to receive pressure readings which take into account the electrometer offset, the actual emission current and the X-ray limit when used with modulated gauge heads. Different types of gauges can be connected to the same power supply with the microprocessor keeping tables of their individual characteristics. The modulation and the degassing of the gauges are completely remote controlled. The electrometer allows for a useful measuring range covering $5 \cdot 10^{-10}$ to 10^{-4} Pa, when used with a modulated Bayart-Alpert gauge.

8. PIRANI AND PENNING GAUGES

Pirani gauges will be used to provide a high pressure indication in the 127 vacuum sectors of LEP. They will also be used on the 60 mobile turbomolecular pumping stations. In both cases, they will be operated during bake-out at temperatures up to 150°C . To obtain meaningful results over this temperature range, a new compensation scheme using an analog multiplier to modulate the power delivered to the gauge head has been designed⁸⁾. The gauge heads for the mobile pumping stations are units recovered from the ISR machine with a Pt temperature sensor fitted on the outside of the vacuum tube. For the gauges required in the vacuum sectors, new heads with the sensor mounted inside the vacuum will be used. With this new gauge it is possible to measure from atmospheric pressure down to 10^{-1} Pa and over a temperature range of 30 to 150°C , with a maximum error at the lowest pressures of less than a factor of two.

Penning gauges are only used on the mobile pumping stations. They will be controlled by a dedicated power supply, which is combined with the Pirani power supply and is compatible with the bus system which is used throughout the vacuum control system.

9. POWERING OF THE NON EVAPORABLE GETTER PUMPS

The non evaporable getter (NEG) pumps require two distinct modes of operation⁹⁾. The first is the activation at 700°C which is required after pump down from atmospheric pressure and is achieved by passing a current of 105 A

through the NEG ribbon. The second mode is for conditioning, which will have to be repeated at regular intervals using 50 to 60 A to heat the ribbon to some 400°C. The latter operation is done by cabling enough vacuum chambers in series (typically 6 standard 12 metres dipole chambers) and connecting them directly to the mains at 380 V, via remotely controlled circuit breakers. The activation, however, requires the current to be adjusted to within a few amperes. This will be done by inserting portable thyristor regulators. These regulators will be remotely adjustable to allow a smooth ramp up of the current, which helps to preserve the NEG lifetime. A limited number of thyristor regulators will be permanently installed for those sectors where it was not possible to have enough chambers in series for a direct connection to the mains for conditioning.

10. MOBILE TURBOMOLECULAR ROUGHING STATIONS

The mobile pumping stations are controlled by a dedicated micro-processor, which also drives the Penning and Pirani power supplies. All valves (including the high vacuum roughing valve), the rotary backing pump and the turbomolecular pump are controlled by this unit. Even though they can be completely remote controlled, these units will be provided with a front panel, so that the pumping stations can already be used for acceptance tests of various vacuum components when no controls network is yet available.

A residual gas analyser and a ionisation gauge will be mounted on some of the mobile pumping stations. They will be used to monitor the vacuum obtained after the bake-out. The gas analysers will also provide an interlock for the power supply to the NEG pumps, by monitoring mass 40 (i.e. atmospheric argon which is not absorbed by the NEG) in order to detect leaks during activation. A commercial power supply with a serial interface will be used for the gas analyser and a subset of the supply mentioned earlier will be used for the ionisation gauge. The latter could also temporarily supply any gauge head mounted on the vacuum chamber, but for which a permanent cabling had been considered too expensive.

11. SECTOR VALVES

In order to keep the vacuum system manageable, it will be split into 127 sectors, separated by bakeable all metal valves. The supplier of the latter will deliver the valves with a simple control unit. An intelligent interface is required to connect these units to the general control system. The same chassis will also house the sector valve interlocking.

12. INTERLOCKS

There are several types of interlocks which should be taken care of by the LEP vacuum control system. The primary interlockscheme is for the sector valves which isolate the vacuum sectors from each other. The information source will be the current delivered by the sputter ion pump power supplies. Each sector valve will be interlocked with the pumps which are adjacent to it. As the valves need a long closing time (typically 6 seconds), it would be of advantage to close immediately all sector valves of the LEP machine in case of a catastrophic pressure rise, so as to limit the damage from the propagating shock wave to a maximum of about 2 km. However, to avoid that every local non-catastrophic pressure increase automatically closes all the valves (e.g. due to the degassing by synchrotron radiation), it will be required to incorporate a pressure rate of rise detection.

The pressure will be used to interlock other machine equipment, like RF cavities or electrostatic beam separators. For these purposes, level sensitive contacts are made available from the sputter ion pump power supplies. The control system message transfer possibilities can be used as an alternate interlock path, for example for preliminary warnings of an abnormal situation.

Various external interlocks will be required in special cases. For instance, most of the vacuum gauges can not be operated in the very high magnetic field of the particle detectors used in the experiments, requiring that these gauges be interlocked with the experimental magnets. A special requirement exists during the commissioning of the RF cavities, where it is foreseen that the sector valves serve as a dump to catch free electrons which could have been accelerated to harmful energies. Most of these interlocks will be hardwired.

REFERENCES

1. LEP Design Report, Vol II, June 1983.
2. Radiation and Fire Resistance of Cable-insulating Materials used in Accelerator Engineering, CERN 75-3, H. Schonbacher and M.H. Van de Voorde.
3. A Comparison of the Radiation Damage of Electronic Components irradiated in different fields, CERN 75-4, K.P. Lambert, H. Schonbacher and M.H. Van de Voorde.
4. Radiation Damage to Electronic Components, CERN 75-18, S. Battisti, R. Bossart, H. Schonbacher and M.H. Van de Voorde.
5. The Radiation Protection System for LEP, LEP Note 446, 25 May 1983, CERN RP Group.
6. The Control System for LEP, CERN LEP-DI/83-20, M.C. Crowley-Milling.
7. Distributed Digital Control of Accelerators, CERN/LEP-DI/83-52, M.C. Crowley-Milling.
8. CERN EF, J.P. Orlic, to be published.
9. A New Pumping Approach for the Large Electron Positron Collider (LEP), CERN-ISR-VA/82-11, C. Benvenuti, June 1982.
10. The LEP/SPS Acces to Equipment, LEP Controls Note 54, the LEP-SPS Controls Group.
11. ORACLE is a trade mark of Oracle Corporation, California, USA.
12. Multi-Microprocessor Architecture for the LEP Storage Ring Controls, CERN SPS/85-28, J. Altaber, P.G. Innocenti and R. Rausch.

SCHEMATICAL LAYOUT OF THE CONTROLS FOR THE LEP VACUUM SYSTEM

- 10 -