THE SL ANNUAL REPORT FOR 1990

by SL Division Staff
1. INTRODUCTION

The first year of existence of the SL Division saw the intense exploitation of both LEP and the SPS. Following the winter shutdown in January and February the SPS started a full year of operation, two hundred and sixty days, including eighteen weeks of fixed-target operation with protons followed by five weeks with sulphur ions. Simultaneously the SPS supplied LEP with electrons and positrons at 20 GeV/c on acceleration cycles inserted into the dead time of the fixed-target cycle.

At the end of August the SPS started a fifteen week period of proton-antiproton collider operation with a new low-beta insertion in LSS4 giving a factor of two increase on peak luminosity for the UA2 experiment compared with previous years. After a difficult commissioning period the new insertion proved its value; in a single four week period more than 5 inverse picobarns was produced. Unfortunately, unusually severe weather conditions in December resulted in a much larger number of critical days than usual and effectively brought the run to an end three weeks earlier than scheduled. Nevertheless more than 7 inverse picobarns of integrated luminosity was produced (compared to 3.6 in 1988 and 4.1 in 1989).

LEP, in its first full year of routine operation produced 12 inverse picobarns, enough to allow the four experiments to record nearly a quarter of a million \( Z^0 \) events. The peak luminosity came within a factor of two of the design luminosity. The major limitations to machine performance, synchro-betatron resonances and the expected problems with the beam-beam interaction were clearly identified and significant progress was made in their understanding and cure.

One important milestone was the observation of a small but significant amount of transverse polarisation literally in the last few hours of the run.

At the end of August, LEP was shut down for maintenance and for the first steps in the LEP200 upgrade programme. As well as the installation of new hardware, a considerable amount of civil engineering work was scheduled, mainly in preparation for new klystron galleries in points 4 and 8, but also a large effort was needed to reinforce the tunnel in the region of the difficult geological structure (the so-called "renard") under the Jura mountain.

In addition to the exploitation of the SPS and LEP, the SL groups have been heavily involved in design and development work on LEP200, LHC and CLIC.

The CERN Accelerator School (CAS) remained active throughout the year, organising a number of seminars and meetings.

2. ACCELERATOR PHYSICS

2.1 LEP Performance

Several machine problems were studied in dedicated machine development sessions as well as during operation.

The coupling due to the nickel layer on the vacuum chamber was studied by making horizontal local orbit deformations and observing the effect in the vertical plane. Some variation of the coupling strength between octants as well as between sections of the same octant were observed. Furthermore, horizontal bumps to the inside and outside of the machine gave different effects. The coupling was also measured in a section where the vacuum chamber had no nickel layer as well as in a section with nickel layer but where the chamber had been demagnetised. The measurements showed that in both cases the coupling had been reduced by about a factor of three, proving that demagnetising the chamber is practically identical as replacing it with a Ni-free chamber and that, even in the absence of the Ni, there is a residual coupling of about 30% at injection energy. The newly installed skew quadrupoles could be used to reduce the coupling and to make dispersion bumps. The rms vertical dispersion at the beam position monitors was typically 0.2 to 0.3 m. It could be reduced to about 0.13 m with very good orbit correction down to about 0.5 mm rms. This indicates that the residual dispersion is of a distributed nature, probably driven by vertical orbit errors in the chromaticity correction sextupoles.

Measurements of the machine optics showed that the dynamic aperture was smaller than expected. It was improved considerably by moving the working point to a zone free of third order resonances. An optical asymmetry was discovered for low values of the beta function at the interaction points. The cause of this is not yet clear but seems to be connected with small errors in strength and positions of the interaction region quadrupoles. Some machine development was spent to reduce the beta function at the interaction points from its design value of 7 cm. Values down to 3.2 cm were obtained although for normal operation a more forgiving beta of 5 cm was adopted.

Synchro-betatron resonances were shown to limit the accumulated beam current, and thereby the machine performance. During ramping the machine tunes had to be tightly controlled in order to not to cross one of these resonances and lose all or part of the beams. During the course of the year a "Q-loop" was developed in order to continuously feed back corrections to the power converters during ramping. This allowed the tunes to be kept constant to better than 0.01 and resulted in much more stable operation. These resonances were shown to be mainly driven by the residual vertical dispersion and to a lesser extent by orbit distortions in the RF cavities.

The broadband longitudinal impedance of LEP was obtained from the observation of the turbulent bunch lengthening. The measured value, \( Z/n = 0.25 \Omega \), is smaller than expected. A transverse impedance of about 2 \( \Omega \) was determined from betatron frequency shifts with current. Predictions for the transverse mode coupling threshold were verified experimentally.

The beam-beam limit occurred at smaller currents than expected, with a maximum achieved tune shift of 0.02, about half the design value. This was shown to be partially due to optical errors in the machine, producing different phase advances between interaction points and partly due to residual dispersion at these points. In addition, the machine tunes had been chosen during the early commissioning to
minimise coupling, and were not optimised for the beam-beam effect. A different set of tunes, just above the integers 71 (horizontal) and 76 (vertical) looked promising in simulations but could be tried on the machine only for a very limited time.

Work on the lattice with 90 degree phase advance per cell, which is needed for high-energy operation, has been started. The optics was basically correct, however the injected beam was limited to rather low intensity for reasons not yet understood. In general the operation of the machine with this optics turned out to be rather more difficult than foreseen and will receive high priority during the coming year.

Some time was spent in calibrating the energy of LEP at its injection level by comparing the revolution frequencies of leptons and protons on the same orbits. The relative accuracy of this measurement was about 0.005% at 20 GeV. Since the protons could not be accelerated to 46 GeV, the scaling from 20 to 46 GeV was obtained from the voltage induced in a flux loop during magnetic cycling. The accuracy of the energy calibration at 46 GeV was 0.025%.

2.2 LEP Energy Upgrade

A number of studies related to the LEP energy upgrade have been performed, mainly related to machine layout and to the influence of the superconducting cavities on the various collective effects.

A new layout based on a reference lattice with 90 degrees phase advance per cell and with a maximum energy of 100 GeV has been produced. The geometry of the interaction points IP2 and IP6 has been modified to allow for the installation of 32 superconducting cavities at each point. The interaction points IP4 and IP8 have also to be modified to allow for the installation of 38 superconducting cavities around each of these points. Consequently the geometry of the interaction points 4 and 8 will be different from 2 and 6 and the present 4-fold symmetry of the machine will be lost. The consequences of this loss of supersymmetry are under study.

In the odd straight sections, the magnets saturate above 65 GeV in the present configuration. A new configuration has been found which preserves the desirable characteristics of the insertion, at the same time allowing a large tunability and incorporating favourable features for future implementation of the multi-bunch (pretzel) scheme. The related optics files and layout drawings have been produced.

The skew quadrupoles used to compensate the experimental solenoids have been redistributed taking into account the experience gained so far and the constraints of the new lattice.

2.3 LEP High Luminosity

The luminosity of LEP will increase in the future as a result of the continuous efforts being made to better understand the machine. The current per bunch will be raised, the beta value at the crossing points will be decreased and the value of the limiting beam-beam tune shift will increase as various machine imperfections are eliminated. However, further substantial gain in luminosity is possible if the number of bunches per beam can be increased beyond the present 4 for which LEP was designed. In order to do this the bunches must be separated at all crossing points outside the interaction regions.

A scheme similar to that used at CESR and at the SPS proton-antiproton collider has been studied using horizontally deflecting electrostatic separators to deform the orbits of electrons and positrons in such a way that they are separated at all crossing points except at the experimental insertions. Machine studies with deformed orbits have given promising results and computer calculations have shown that the many additional constraints on the optics can be satisfied.

This "pretzel" scheme will be partially implemented for machine studies during 1991 using separators recuperated from the SPS collider. If no unforeseen difficulties are encountered a full pretzel will be installed in 1992 and will allow the number of bunches per beam to be increased from 4 to 8.

2.4 Polarisation

After years of speculation and several machine studies the signature of polarisation was observed at the very end of the LEP running period. The detected level of polarisation of about 9% is consistent with theoretical predictions. It strengthens the expectation of a considerably higher level of polarisation once the optics is spin-matched.

The feasibility of spin rotators to provide longitudinal polarisation on the Z0 peak has been completed and a project proposal is being prepared.

2.5 LHC Studies

The work on the specification of the LHC lattice has been pursued. The geometry of the LHC has been fixed in such a way that the transverse occupancy of the LEP tunnel is optimised. Version 1 of the optical layout is now available.

Studies on multipolar corrector schemes to compensate both systematic and random multipole errors in the LHC dipoles have been made. Compensation procedures based on the correction of the high order chromatic effects have been incorporated into the accelerator design program MAD. In addition, a programme of evaluation of the dynamic aperture by computer tracking simulation using a realistic LHC lattice model including systematic multipole correction, ordering of the dipoles according to their random imperfections and closed orbit errors is underway.

The experiments performed on the SPS to simulate the nonlinear dynamic aperture of the LHC with strong sextupoles have been continued. Attention has been focussed on the reduction of the dynamic aperture caused by tune modulation as well as the effect of compensating the amplitude dependence of the tune using octupoles. The stability of the beam is found to be strongly dependent on the depth of tune modulation whilst the effect of the modulation frequency is hardly visible in the range between 1 and 500 Hz.

The potential to collide heavy ions in the LHC is attracting growing interest. After consultation with the experimenters a new parameter list has been drawn up for the case of lead-lead collisions. The possibility of obtaining higher luminosities with lighter species is under study.

Quantitative studies of beam losses have been made. A very efficient absorption of the beam halo will be necessary for a safe operation of the s.c. magnets. A collimation system with adequate performance has been designed and partially tested in the collider.
2.6 MAD Development

Considerable modifications have been made to the general purpose machine design program MAD in order to cater for increasing requirements from both LEP and LHC studies.

The tracking speed has been increased by a factor of 5 on the Cray and 2 on the IBM using the vectorisation facilities. Tracking results can now be written on a binary file for postprocessing. Working versions of MAD have been built for Cray-UNICOS, IBM-VM, VAX-VMS and Apollo UNIX systems. The program SFTT, developed at DESY to calculate the level of polarisation in lepton storage rings has been implemented in MAD as a module. This will be used on-line for tuning LEP during machine development.

3. BEAM INSTRUMENTATION

Since the beginning of the year a single group has become responsible for a very wide range of instrumentation for the SPS, LEP and the SPS experimental areas.

After the first shutdown of LEP the beam instrumentation resumed operation without major problems. The Beam Orbit Measurement system (BOM) allowed the possibility of good orbit corrections needed to reduce the vertical dispersion to a tolerable value. Despite the excellent performance of the overall system, the gain calibration of individual pickups and the reproducibility of position measurements near the collision points showed some shortcomings which have been investigated in situ and in the laboratory. Three significant hardware modifications are planned to be implemented during the 1990/1991 winter shutdown. In addition work is in progress to upgrade the BOM controls hardware and software to allow more speed and reliability and to allow the full potential of the BOM system to be exploited during 1991.

The system for measurement of the machine tunes, in operation since the beginning of LEP commissioning has been further improved by the introduction of a phase-locked mode allowing recording of tune history and the provision of a closed-loop correction of the tunes during ramping.

Beam size measurements have made considerable progress during the year. Wire scanners have been used routinely and four synchrotron light telescopes have been available to transmit live TV images of the beam cross-section to the control room. First results of single shot UV images were obtained from one of the telescopes. Towards the end of the year a vertical profile measurement of individual bunches could be obtained from a solid-state detector receiving X-rays from a main dipole. This detector will be further improved during 1991.

A wide-band sampling oscilloscope located in the tunnel has allowed measurement of bunch lengths down to 80 ps FWHM. For faster response a streak camera observing the synchrotron light has given promising results.

The eight Bhabha monitors have become fully operational and were regularly used to monitor and optimise the luminosity during machine developments. In addition, the forty-eight collimators have been routinely used to provide good background conditions during physics data taking.

The electron polarimeter has been successfully commissioned and used to measure the polarisation of the LEP beam by observing the vertical asymmetry of Compton photons produced by the interaction of a circularly polarised laser with the electron beam.

In the SPS considerable effort was devoted to supporting the wide range of instrumentation needed for the full exploitation of the machine in its various modes of operation. In addition the development of special high-sensitivity instrumentation for the observation of very low intensity ion beams was undertaken.

In the SPS fixed-target experimental areas the very specialized and ageing equipment needed to instrument the beams to fourteen fixed-target experiments and six test beams needed continuous support. A study was undertaken to analyse the most cost effective way both in material and human resources to modernise the controls and equipment in the areas in order to be able to respond to the evolving requirements in the coming years.

4. BEAM TRANSFER

4.1 Extraction systems

A slow movement of the floor of the SPS tunnel in the region of the extraction system in LSS2 has been recorded over several years. The resulting misalignment of the extraction channel causes increased beam loss. In 1990 it was necessary to entirely dismantle, modify and reinstall the girder which supports the septum magnet for extraction. After this, the beam loss was then reduced to a tolerable level. The lead screens installed upstream of the electrostatic septa in LSS2 and 6 in order to reduce the radiation dose on the HV feedthroughs proved to be very effective. Not a single feedthrough has been lost since this action was taken.

Four extraction septum magnets were lost due to a design weakness in the current feedthroughs. All installed magnets will be repaired in the coming shutdown. Because of this, the programme launched 2 years ago to replace radiation-damaged septa and to build an adequate stock of spares will be somewhat delayed.

4.2 Electrostatic separators

The electrostatic separators installed in the SPS worked reliably during the last high-luminosity collider run. In the winter shutdown they will be modified to be installed in LEP. Initially, 4 modules will be installed in order to produce a half-pretzel for machine studies purposes. If the results prove satisfactory a further 4 modules will be installed in the next winter shutdown so that LEP can start operating with 8 bunches in 1992.

For the energy upgrade of LEP the existing vertical separation system needs to be reinforced. The construction of 8 additional units has been launched, to be ready for operation in 1993.

4.3 Kickers and dumps

The kicker systems for both SPS and LEP worked very reliably. Work has started on the design of a kicker magnet for the beam damping system for LEP which will
become necessary when the energy and intensity are increased so that the beams can be dumped cleanly without quenching the superconducting cavities.

Studies of the kicker systems needed for the LHC were continued. Most of the effort went into the design of a prototype of the extraction kickers for the beam dumping system. These magnets have to operate at very high field, 0.85 Tesla, and are powered by pulsers of novel design producing current pulses of 30 kA with a risetime of 3 microseconds and a flat top of 90 microseconds. The collaboration with an outside institute on the development of a new type of low pressure gas switch which has several advantages for LHC compared with conventional thyristors or spark gaps was pursued and encouraging first results were obtained.

Targets, dumps and collimators worked reliably. A study was made of overhauling the proton beamline leading to the target T9 and of the target station itself in view of a continuation of the neutrino programme was made.

5. CONTROLS

The activities of the Controls Group during the past year mainly concerned three areas: consolidation of the LEP control system, maintenance of the SPS control system and preparation of an upgrade project for the latter system which approaches the end of its useful lifetime.

5.1 LEP controls

The LEP control system was commissioned in July 1989 and it is quite natural that some consolidation was necessary during the first year of operation, in the light of the experience gained and of an improved understanding of the requirements to be met.

The system consists of three logical layers: the control room layer with its consoles and central servers, the front end computing layer in the local areas and the equipment control layer with its ECA crates which are close to or form part of the equipment.

Communication within and between the two top layers is based on the Token Ring local area network. The ECA crates of the lower layer are connected to the PCA's (Process Computing Assemblies) of the middle layer via the 1553 field bus.

The control room layer which provides the operator interface and some general services (alarms, modelling, archiving, etc.) is based on Apollo workstations. 21 of these workstations have been upgraded from DN 3000 to the more powerful DN 3500. At the same time, three nodes were upgraded from DN 4000 to DN 4500 and 35 additional workstations were bought, mainly for user groups. This purchase included a powerful DN 10000 for modelling work in the area of accelerator physics.

The total number of Apollo nodes connected to the control system is now 85 and at the end of 1990 the installation had 500 accounts shared by 428 users.

The increasing number of users led to the need for higher disk capacities of the file servers for application program development and for operation. Three 700 Mbyte units were bought, bringing the capacity of the development server to 3x700 Mbyte and the operation file server to 2x700 Mbyte.

The beginning of the year 1990 saw the introduction of version 10.2 of the Aegis operating system running in the Apollos. This brought important changes, notably an increase in strictness of the C compiler, and a considerable effort was required to recompile all Apollo software with the necessary modifications.

Major improvements have been made to many application programs used for the operation of LEP, of which only a few can be mentioned here. The ramp generation software has been extended with the addition of the ramp editor package. This allows the introduction of empirical corrections into all settings tables of the LEP power converters. Other improvements concerned the LEP separator package, to allow the beams to remain separated during the low-b squeezing process, and high level application software for beam monitors. Three dimensional displays of the LEP beams are now available on the control room workstations.

The LEP alarm system has been consolidated. More than 10,000 states are surveyed, mainly concerning the power converters and safety and service equipment. Connection of the general safety surveillance system for the 4 LEP experiments to the central alarm system was completed.

The heart of the front end computing layer are the PCA's (Process Computing Assemblies) of which some 60 are distributed around LEP in service buildings and in the underground areas (pits and alcoves). A PCA generally consists of an Olivetti PC of the type 380 C to which a VME crate is linked via a 1553 field bus connection. The main components of the VME crate are the equipment directory unit and the controllers of the 1553 field bus segments which connect the equipment control crates to the PCA.

One of the major modifications in 1990 concerning the PCA's was the suppression of the VME crates in the 16 LEP alcoves where a single 1553 field bus can be controlled from the PC directly. The PC consoles in the alcoves, installed for local access to the equipment, could also be removed, whereas all other 286 based PC consoles have been replaced by more powerful 386 type PCs.

During the past year, it turned out that the hard-disks of the PC's, in particular those of the PCA's, were a weak point and often developed faults. Nearly one third of the PCA disks broke down and had to be exchanged. During the 1990/1991 winter shutdown all hard-disk units will be systematically replaced by a more robust type.

A major addition to the local area control network of LEP are the Ethernet segments installed in pits 1, 2 and 6 for the control of the wirescanners and of the radiofrequency system. Such segments will be added in all pits and in the control centre during the coming months. The reason for this implementation is the fact that hardware components, such as workstations, personal computers and VME crates are readily available for connection to the Ethernet LAN, while the market for equipment with Token Ring connectivity is much more restricted.

Another important improvement of the network is the installation of filtering gateways which permit disconnection of the accelerator control system from the outside world if needed and grant selective access only.

Communication over the network largely relies on the Remote Procedure Call (RPC) package. This package was completely re-written, making the RPC twice as fast and more reliable and improving its error recovery capabilities.
Software management tools for both the PCA's and the network have been improved and completed during the past year, allowing good surveillance and diagnostics of the system.

Communication between the control room and the 4 LEP experiments was considerably extended and new displays have been installed which provide the LEP operator with background and luminosity information. Beam position information from one of the experiments is also available.

5.2 SPS controls

The SPS control system was conceived and implemented some 15 years ago. Many of its components have become obsolete and difficult to maintain. In 1990, more than 200 interventions were necessary on the Nord 100 computers, their peripherals and the TITN star network interconnecting the computers. In particular the 10 Mbyte Hawk disk units, of which 5 are in operation, have become very unreliable. 8 crashes occurred and two of these resulted in completely unrepairable units. Only 4 spares are left, while the disks can no longer be acquired on the market. The installation of disk units of a new type must therefore be envisaged, but will require a major software effort on the level of the Syntron operating system which is completely out of date and only marginally understood by any more in the Controls Group.

An upgrade project for the SPS control system was actively prepared during the year 1990, in close collaboration with the PS Controls Group in order to ensure the necessary convergence of the control systems of all CERN accelerators. The technical proposal was discussed with and agreed upon by the controls users and a request for project money, based on a detailed cost estimate, was submitted.

The architecture of the proposed new control system is very similar to the architecture of the LEP control system which was described above and will permit the use of modern industry standards and of commercial products.

The only notable difference from the LEP system is the replacement of the PCA's on the front end computing layer by so-called Device Stub Controllers (DSCs). These are VME crates with CPUs based on Motorola 68030 microprocessors and running under the diskless, real-time operating system OS-9. Dedicated file servers will provide secure disk space for applications and data and will be used as boot and disk servers for the DSCs, local diskless workstations and X-terminals.

Development of a final version of the DSC is well under way. Several UNIX utilities have been ported to OS-9 and UNIX-like libraries for OS-9 are being created. Shared libraries for 1553 field bus access under OS-9 have also been studied. Finally, development of a software package (library and driver) has started which will allow access to existing SPS-MPX modules from the DSC via a non-intelligent 1553 field bus interface board.

Other software efforts in the context of the new project concern the translation of Nord 100 data-modules for implementation in the DSC's and the completion of a NODAL interpreter under UNIX, which was developed in collaboration with PS Division.

A total of 63 field buses of the 1553 type have already been installed in the SPS auxiliary buildings, partly connected to VME crates controlled by Nord 100 computers and partly connected to PCA's which had been installed during the LEP construction period, mostly for test purposes. Thirty 1553 field bus/MPX interface modules have been constructed in 1990, the first of a series which will allow the control of old MPX crates via the 1553 field bus.

The upgrade of another crucial component of the SPS control system, the timing system, had already started when the SPS was prepared as a LEP injector, requiring pulse-to-pulse modulation of the magnetic cycle and of many other parameters. An entirely new, modern timing system was implemented in parallel with the old MPX based system of the SPS. Conversion of the latter is now under way and will be completed by the end of the 1990/1991 winter shutdown.

In addition to the above specific control activities, a number of general service were provided by the SL Controls Group, such as an electronic drawing office, an electronic workshop, an instrument repair service and the implementation of the TDM (Time Division Multiplex) network for the CERN-wide digital telephone exchange which saw its completion during the past year.

6. EXPERIMENTAL AREAS

6.1 Fixed-Target Areas

In addition to physics with beams derived from protons, 1990 has seen a return to the exploitation of beams of sulphur ions. In the North Area, two such ion experiments shared the H2 beam: NA35, with the introduction of a new TPC, and NA36, which could be completed. Prior to the ion run, these detectors were supplied with calibration beams as well as with 200 GeV/c protons for comparison data. The H2 beam was also used for calibrating UA2 detectors and for tests of the prototype SPACAL calorimeter of interest for LHC. A major rearrangement of a 100 m long stretch of the beam upstream of NA35 allowed a new experiment, NA46, to search for "Darmstadtoms", possibly produced in the interaction of a highly parallel photon beam with an aligned crystal and thereafter decaying into e+e- pairs in a long field-free region.

In the H4 beam the new pion-interferometry experiment NA44, intended for ion running, was able to set up and take first data with 450 GeV/c protons. The spectrometer has been mounted on a platform allowing for it to be swivelled out of the beam. Transmitted pions or electrons could then be used by the NA31 collaboration for detector tests.

The H6 beam was used for tests of P24 and P238 silicon detectors. Calibration of the H1 (HERA) calorimeter was continued and a new liquid argon calorimeter prototype for LHC was also introduced into this beam.

The H8 line was operated in its micro-emittance proton beam mode for data-taking by the neutral particle spectroscopy experiment NA12, which allowed a short time to be devoted to the bent-crystal tests, started in 1989. The new NA45 detector was brought into the proton beam to be ready, together with the NA34/3 muon detector, to profit from the ion run.

The M2 beam delivered muons to NA47, a new experiment setting up to measure spin-dependent structure functions of the nucleon with a polarised muon beam and a polarised target. For the physics data, to be taken from 1991 onwards, a smaller vertical
beam size will be required all along the hall EHN2. Design studies for an upgraded, dispersion-free muon beam were performed, leading to a rebuild of the muon section of the beam. The upgrade also includes reconditioning of the beam momentum station, which has suffered from ageing effects.

The ion run constituted the main reason for running the P0-H10 beam to the dimuon experiment NA38, installed in the high-intensity area.

The activity in the West Area was mainly centred around calibration and R&D activities in the test beams in addition to physics data-taking in the H1 and H3 beams.

The H1 beam was operated in all three of its principal modes corresponding to the different kinds of particles to be transported i.e hyperons, protons and ions. The hyperon mode was commissioned in 1989 and was used in 1990 for data taking by the WA89 collaboration. To increase the intensity, some improvements were made to the shielding, and to reduce the background of soft photons, a new tungsten collimator was designed. In the ion mode, the beam was used by the WA85 collaboration looking for strangeness enhancement as a possible signal of quark-gluon plasma. WA85 also used the proton mode in order to compare with "conventional" proton interactions.

During the fixed-target run the H3 beam served as a parent for the test beams X1, X3, X5 and X7. The UA1 TMP calorimeter R&D programme continued in the X1 beam and the X3 beam was principally used for calibration of the end caps of the L3 detector. The X5 beam was mainly used for the calibration of the ZEUS (HERA) uranium calorimeter, but also a new transition radiation detector was tested in the beam. The X7 beam delivered electrons, pions and muons for ALEPH, DELPHI, UA4 and UA6 collaborations as well as for some small wire chamber tests.

The heavy ion experiment WA80 was completely reconfigured for the 1990 sulphur run in the H3 beam. Moreover, a new experiment, WA90, studying pair production and electron capture in heavy ion interactions was installed just upstream of WA80 and took data in series. Traditionally, one full day of the H3 programme was devoted to emulsion exposures by ten different experimental groups.

Design studies for simultaneous, nearly collinear long and short-lived neutral Kaon beams contributed to a proposal for a new precision CP-violation experiment. In the light of this proposal as well as a possible new neutrino experiment, the planned leadjet project and the need for test beams for LHC detectors, a working group on the future of the SPS experimental areas was formed and has reported to the Research Director.

6.2 Collider Areas

The major change in the SPS underground areas was the installation of a new low-beta insertion in LSS4. Associated with the new quadrupoles installed close to the UA2 experiment, a tight iron shielding was constructed in order to protect the experiment from beam loss. In addition, a new collimator scheme installed in LSS1 allowed very low background conditions to be maintained. The 2-stage collimator scheme previously used was replaced by a more effective 3-stage scheme. This work was also of interest for prototyping the collimator scheme for the LHC. The UA2 detector was improved by the addition of a second layer of silicon strips around the beam pipe.

In LSS5 a "Roman pot" was installed at the interaction point. The pot was modified to accept a sophisticated double vacuum system. The two sides of the vacuum were separated by an internal chamber made from an undulated 250 micron thick aluminium foil. A set of silicon detectors was installed in the undulations to study the feasibility of a tracking device for triggering on and detecting B-particles in a hadron collider. The pot was approached to within 1.5 mm of the beam axis and the P238 collaboration was able to detect very clean proton-antiproton inelastic events.

7. MAIN RINGS

7.1 SPS ring

The main activity in the 1990 winter shutdown was the revamping of the LSS4 straight section for the installation of a new low-beta insertion for the UA2 experiment. This insertion uses existing high gradient beam transfer quadrupoles moved closer to the detector so that only 17 m is available for the experiment instead of 28 m as in the past. An important consequence of this is that the machine loses its periodicity since the new insertion quadrupoles do not exactly fall in the same place as the machine quadrupoles. As a result, it was necessary to power 5 quadrupoles independently even in fixed-target mode. In the 1991 winter shutdown this area will once more be reshuffled to install a high-beta insertion for the UA4-2 experiment and allowing normal lattice configuration in fixed target operation. The electrostatic separators will be removed to be used in the first phase of the LEP pretzel scheme.

Another region of intense activity was LSS1 where a campaign of replacement of radiation-damaged cables was undertaken. A total of 30 km of cable was replaced. This activity will become a regular feature of the winter shutdown work over the next few years. Already in 1991 it is foreseen to replace 112 km more of damaged cable.

7.2 LEP ring

LEP saw its first important shut-down during January-February, for which some 600 previously planned activities related to the consolidation of the construction programme as well as maintenance and repairs were coordinated. With the restructuring, which took effect at the beginning of the year, these activities, to a larger extent than previously, became the tasks of other Divisions such as AT, MT and ST. Accordingly, all effort was made to coordinate the shut-down work on an inter-diisional level, and as a result LEP was brought into operation again as scheduled in March. This was achieved in spite of a sizeable water leak which sprung in the tunnel under the Jura in the middle of February. The bad weather conditions and the increased water flow in the rock also flushed some 140 cubic metres of sand via the drains into the auxiliary tunnel TZ32. Although the main ring tunnel could be repaired provisionally and the sand removed, it was decided to later reinforce the relevant part of the tunnel as well as try to prevent any future influx of sand.

At the end of August, LEP was shut down for maintenance and for the first steps in the LEP2000 upgrade programme. The main activities of the planned shut-down work were the start of the excavations of the klystron galleries in point 8 (near DELPHI), the installation of 4 second generation vacuum chambers for the experiments, the displacement of 8 collimators/luminosity monitors, the installation of 12 polarisation Wiggler magnets around points 3 and 7, and the installation of two more superconducting RF cavity modules. In addition, the demagnetisation of the dipole
vacuum chambers was to be continued in Octants 2 and 3. Finally, the original shutdown planning included a major intervention in the main ring tunnel under the Jura aimed at injecting cement into the rock around the tunnel structure. This operation required that some 200 m of the machine, including the tunnel infrastructure, be demounted and removed. In the middle of October the implementation of the so-called Test Pretzel Scheme was approved with the consequent installation of 4 separator tanks adding to the ongoing shutdown work. Finally, at the end of October the repair of one of the superconducting low beta quadrupoles revealed that all eight units had to be demounted and modified in order to improve their built-in supports and, thus, assure the correct alignment of these units.

8. OPERATIONS

1990 proved to be the most heavily loaded year ever for the operations group. As well as the demanding task of operating LEP in its first full period of physics data taking, the SPS was run in the first half of the year in its fixed target mode, simultaneously accelerating leptons for LEP. This was followed by a month of running with sulphur ions and LEP, finally ending the year with a proton-antiproton collider run with a new machine configuration.

8.1 The SPS fixed-target accelerator

As in 1989, the proton operation was carried out with a supercycle of 14.4 s including 4 lepton cycles and a 450 GeV/c proton cycle with a 2.5 s flat-top producing simultaneously slow-extracted beams to the West and North areas. A total of $10.8 \times 10^{18}$ protons were delivered to all targets with an average of $2.45 \times 10^{13}$ protons per pulse. $6.8 \times 10^{18}$ protons were delivered to the neutrino area in fast-resonant extraction at 450 GeV/c, one burst just before the start of the flat top and the other at the end. The peak intensity accelerated was maintained at the same level as last year at $3.5 \times 10^{15}$ protons/pulse.

SPS performance statistics (protons on fixed target)

<table>
<thead>
<tr>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total hours scheduled</td>
<td>2705</td>
<td>2286</td>
<td>3067</td>
<td>3502</td>
<td>2926</td>
</tr>
<tr>
<td>Total hours physics</td>
<td>2163</td>
<td>2002</td>
<td>2635</td>
<td>3240</td>
<td>2404</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>80</td>
<td>80</td>
<td>76</td>
<td>71</td>
<td>74</td>
</tr>
<tr>
<td>Peak intensity at 450 GeV (in units of $10^{13}$)</td>
<td>34</td>
<td>32</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Average intensity per cycle delivered to targets ($10^{15}$)</td>
<td>24</td>
<td>21</td>
<td>28</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Total number of protons/year delivered to targets ($10^{15}$)</td>
<td>12.9</td>
<td>8.0</td>
<td>13.1</td>
<td>15.3</td>
<td>10.8</td>
</tr>
</tbody>
</table>

This was the first year since 1987 that heavy ion (sulphur) operation had been scheduled. A total of 34 days was allocated compared with 17 in 1986 and 1987. For ion operation the supercycle had to be increased to 19.2 s to allow for the extra time needed for injection and also for the extension of the flat top at 200 Gev/nucleon to 5 sec. This had some impact on the operation of LEP due to the longer duty cycle for lepton acceleration.

Compared to proton operation, the intensity of the sulphur beam is three orders of magnitude lower. Consequently the SPS must first be optimised with protons, then with reduced intensity oxygen ions and finally with the very low intensity sulphur beam. A steady operation was established with intensities of $1 \times 10^9$ (6 x $10^7$ ions) in the SPS but with relatively poor extraction and transfer efficiencies. A programme has been launched to upgrade the beam monitor system to allow more efficient operation with sulphur and finally lead ion beams in the future.

8.2 The SPS collider

This year was to be the third and last year of high-luminosity operation of the collider after the successful upgrade of the accumulator complex and of the UA2 detector. In preparation for this run a new low-beta insertion was installed in LSS4 allowing the beta functions to be reduced from their previous values of 1 m (h) by 0.5 m (v) to 0.6 m by 0.15 m, giving a potential factor of about 2 increase in peak luminosity. This new insertion proved to be more difficult to commission than expected and as a result it took somewhat longer than usual to settle down into steady data taking.

All previous records of operational performance of the collider were broken. Table 7.1 gives a summary of the main performance parameters compared with previous years. Regular operation consisting of 2 fills per day with initial luminosities consistently around $5 \times 10^{30}$ cm$^{-2}$ s$^{-1}$ resulted in a new record integrated luminosity per week of 1356 inverse picobarns, to be compared with 561 in 1989 and 480 in 1988.

The reliability of SPS hardware was an important contributing factor to the high productivity. Only 10% of coasters were lost due to equipment failure compared to over 25% in previous years. There were 30 consecutive coasters without one being lost due to hardware faults. Unfortunately the exceptionally cold weather at the end of November resulted in 10 critical days. This coupled with interruptions to the electricity supply during the weekends and secondary effects due to the cold weather resulted in a very disappointing performance during the last three weeks of the run. Nevertheless, a final integrated luminosity of 7.2 pb$^{-1}$ was obtained (figure 1).
Collider performance and operational parameters 1988-90

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy (GeV)</td>
<td>315</td>
<td>315</td>
<td>315</td>
</tr>
<tr>
<td>Betag (m)</td>
<td>1.0</td>
<td>1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Beta y (m)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.15</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Protons/bunch (10^10)</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Antiprotons/bunch (10^10)</td>
<td>4</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Proton emittance (10^-6 rad.m.)</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>PbPb emittance (10^-6 rad.m.)</td>
<td>8</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Initial luminosity (10^30 cm^-2 s^-1)</td>
<td>2.5</td>
<td>2.95</td>
<td>6.05</td>
</tr>
<tr>
<td>Peak</td>
<td>1.3</td>
<td>1.8</td>
<td>3.13</td>
</tr>
<tr>
<td>Average</td>
<td>31.5</td>
<td>40</td>
<td>70</td>
</tr>
<tr>
<td>Integrated luminosity (nb^-1)</td>
<td>71</td>
<td>97</td>
<td>180</td>
</tr>
<tr>
<td>Peak per coast</td>
<td>480</td>
<td>561</td>
<td>1364</td>
</tr>
<tr>
<td>Peak per week</td>
<td>3375</td>
<td>4759</td>
<td>7241</td>
</tr>
<tr>
<td>Total per year</td>
<td>2415</td>
<td>2654</td>
<td>2256</td>
</tr>
<tr>
<td>Hours scheduled</td>
<td>1206</td>
<td>1434</td>
<td>1016</td>
</tr>
<tr>
<td>Number of failures</td>
<td>107</td>
<td>119</td>
<td>104</td>
</tr>
<tr>
<td>Average coast duration (h)</td>
<td>11.3</td>
<td>12.1</td>
<td>9.8</td>
</tr>
<tr>
<td>Percentage of coast lost</td>
<td>25</td>
<td>28</td>
<td>10</td>
</tr>
<tr>
<td>Number of EDF critical days</td>
<td>7</td>
<td>7</td>
<td>12</td>
</tr>
</tbody>
</table>

8.3 The LEP machine

During the long winter shutdown the main control room of the PCR was reorganised. The four SPS consoles were integrated into single unit one half of the room was thus liberated for LEP consoles for operation of LEP services and beams. The integration of all operation into a single room proved to be highly successful in improving communications between the SPS and LEP activities and better training.

The operation of LEP services from the PCR was consolidated with the completion of most of the applications programs. Control of access was limited to short periods during the physics operation. The first of the card readers have been successfully modified for motorised entry of the card; all readers will be systematically upgraded in this way during the first half of 1991. Following the recommendations of the CERN Access Working Group, it was decided to coordinate the technical responsibility of all CERN access equipment, accelerators, experimental zones as well as site access, in the ST Division. A decision was also taken to integrate the operation of all CERN site services in the Technical Control Room (TCR) of the ST Division on the LEP site. LEP type consoles have been installed in the TCR and training and staff changes have been carried out.

LEP was operated fully by the operations crews in 1990. After intensive training in 1989, the Engineer-in-Charge with two beam technicians and one LEP services technician operated both LEP and SPS. The two beam technicians were mostly responsible for the operation of the SPS, serving the fixed target physics community and operating the SPS for transfer of leptons to LEP. With the integration of all activities in the one room, the technicians spent many hours assisting the EIC and learning to operate LEP. Operations crews became increasingly involved in the machine development sessions.

The operation of LEP in 1990 was not yet a simple affair. With continuous effort from the equipment groups the reliability of components of LEP improved. However the longest average time spent in the cycle, recovery, accumulation, ramping, squeezing was during the accumulation phase. Reproducibility of the injection conditions was poor. An additional complication arose from the change of operation mode of the SPS in July, protons to heavy ions and a change of supercycle time from 14.4 to 19.2 seconds. With the improvement in lifetime coming mainly from the improved vacuum conditions, the length of the physics data taking was increased on average to about 9 hour per fill. During this time the crews optimised the luminosity and minimised background conditions by varying orbits and Q values. The understanding of the matching of the low beta insertions was greatly improved with a resulting increase and equalisation of the luminosities in all four experimental regions.

Fifty percent of the fills were done with nominal lepton energies of 45.625 GeV, the Z^0 peak. The other fills were done at energies of ±1, ±2 and ±3 GeV around the Z^0 peak.

A total of 66 fills lasting an average of 6.5 hours in coast produced 12.1 inverse picobarns (pb^-1), compared with 1.7 pb^-1 in 1989, the first year of LEP operation. The average current accumulated for physics operation was 3.1 mA (with a peak of 4.2) of which 2.5 mA (peak 3.6) was ramped and squeezed for physics. The average calculated initial luminosity was 5.1 10^36, due to the beam-beam effect the maximum seen by the experiments was about 3.5 10^37, see below for comparison of 1989 and 1990 performances. The beta star, at the start of the year 7 cm, was lowered to 5 cm and used successfully for the majority of the fills.
LEP Performance 1989 and 1990 during Physics Operation

<table>
<thead>
<tr>
<th></th>
<th>1989</th>
<th>1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total hours scheduled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(hours)</td>
<td>3107</td>
<td>3433</td>
</tr>
<tr>
<td>Hours scheduled for commissioning</td>
<td>1284</td>
<td>-</td>
</tr>
<tr>
<td>(hours)</td>
<td>48</td>
<td>240</td>
</tr>
<tr>
<td>Hours scheduled for setting-up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(hours)</td>
<td>454</td>
<td>689</td>
</tr>
<tr>
<td>Hours scheduled for MD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(hours)</td>
<td>1321</td>
<td>2504</td>
</tr>
<tr>
<td>Hours of beam in coast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(hours)</td>
<td>469</td>
<td>1048</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Units</th>
<th>1989 Peak</th>
<th>1989 Average</th>
<th>1990 Peak</th>
<th>1990 Average</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total current accumulated 20 GeV (mA)</td>
<td>2.8</td>
<td>2.2</td>
<td>4.2</td>
<td>3.1</td>
<td>6</td>
</tr>
<tr>
<td>Beta at the experiments (cm)</td>
<td>7</td>
<td>7</td>
<td>4.3</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Current in collisions 45 GeV (mA)</td>
<td>2.6</td>
<td>1.6</td>
<td>3.6</td>
<td>2.5</td>
<td>6</td>
</tr>
<tr>
<td>Calculated initial luminosity (10³³)</td>
<td>4.2</td>
<td>1.6</td>
<td>11.0</td>
<td>5.1</td>
<td></td>
</tr>
<tr>
<td>Calculated integrated luminosity (pb⁻¹)</td>
<td>1.7</td>
<td></td>
<td>12.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filling time (h:min)</td>
<td>0:50</td>
<td>7:35</td>
<td>1:20</td>
<td>6:57</td>
<td></td>
</tr>
<tr>
<td>Coast duration (h:min)</td>
<td>12:45</td>
<td>5:00</td>
<td>22:35</td>
<td>7:30</td>
<td></td>
</tr>
<tr>
<td>Total coast time/scheduled (%)</td>
<td>36</td>
<td></td>
<td>43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of coasts</td>
<td>97</td>
<td></td>
<td>143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of coasts lost (%)</td>
<td>35</td>
<td></td>
<td>33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* pb⁻¹ = inverse picobarns. Calculation based on intensities, emittance.

9. POWER CONVERTERS

As a result of the merging of the LEP and SPS groups, the SL/PC group now has responsibility for more than 2000 power converters and related electronics ranging from very old material recuperated from the ISR to the most modern equipment for LEP. Operation throughout the year has been relatively complex due to the frequent changes in operation mode of the SPS. The upgraded low-beta insertion involved modifications to the power converter electronics and the incorporation of microprocessor controlled function generators. Considerable rearrangement of both magnets and their associated power converters in the experimental areas was necessary at the beginning of the year. Reliability of equipment proved to be extremely high, including the LEP power converter system from which most of the early failures have been eliminated. Machine development on LEP enabled ramping and squeezing to be improved. In the light of this knowledge, further improvements are under way in preparation for the 1991 run.

Preparation of technical specifications for the additional power converters needed for the LEP200 project has had high priority throughout the year. The total installed power will be more than double the present figure, rising to 190 MVA when the project is complete. By December, the majority of the specifications for the high power converters had been sent to industry and some 20% of orders already placed. Work has started on the procurement of a special power converter for the klystron of the new longitudinal feedback system for LEP and also on a series of special converters for control of the superconducting cavities.

As part of a campaign to upgrade obsolete or ageing material a specification for a new converter to replace that of the FPS extraction septum was sent out in Autumn and an order will be placed shortly. A program to replace old circuit breakers is under way and some of the West and North area converters have already been equipped with modern material.

The group is actively engaged in common development agreements with industry. The first is with a Spanish company for the supply of a high current prototype converter for the LHC, which will be delivered early in 1991. The second is with industry from the USSR for the supply of a converter for the polarisation wigglers for LEP. Recently the possibility of acquiring oil-filled transformers from the USSR has been investigated and initial results seem promising.

10. LEP RADIO FREQUENCY

10.1 LEP Activities

Much effort has gone into operational improvements of the LEP RF system, both on hardware and software, in the light of operational experience obtained during 1989. During the winter shutdown an important consolidation programme was started. This effort was mainly orientated towards modification and simplification of the equipment that protects the high power klystrons and high-voltage interface equipment from damage. In addition, operating the RF system with beams has revealed an influence of circulating beams on the cavity tuning. This has lead to a modification of the tuning systems of all 128 copper cavities.

One unexpected result from the early commissioning days of LEP was the observation that the bunches were longitudinally unstable. In order to combat this, a simple longitudinal feedback system was quickly developed using the limited means available. This system has some limitations: it can only work with 4 bunches per beam and requires an otherwise undesirable synchrotron frequency split between the two beams. In order to improve the situation, a dedicated feedback system has been designed. Technical specifications for the 1 GHz klystron needed to power the feedback cavities and high-power circulators have been prepared and will soon go out to industry.

In order to make space for the horizontal electrostatic separators needed for the 8-bunch pretzel scheme, 8 copper cavities need to be removed and replaced with dummy loads. At present 4 cavities have been taken out. The other 4 will be removed during the 1992 winter shutdown.

The first module of four superconducting cavities made from sheet niobium was installed at point 2 and successfully brought into operation. At the end of the running period these cavities were fully integrated into the RF system. In November another
module of four cavities of the sputtered type was installed, also in point 2. These cavities will be brought into operation early in 1991. The installation of the infrastructure for the full complement of superconducting cavities for LEP200 in points 2 and 6 is well underway. Calls for tender for a large amount of control electronics for the LEP upgrade have been sent out.

10.2 CLIC activities

The LEP RF group also forms the nucleus of the interdivisional effort on the CERN Linear Collider (CLIC). As well as coordination of the overall CERN effort, a considerable R&D activity has been undertaken in the group.

Basic structure parameters and fabrication techniques have been established for the 25 cm long 30 GHz accelerating sections for the CLIC main linac. A 30-cell prototype section has been built and tuned. A maximum error of 2.5° in absolute phase over the length of the structure with respect to the design value of 2π/3 per cell was obtained. The group and phase velocity ratios were found to be 8.2% and 99.6% of c respectively and the measured attenuation of 0.9 dB corresponds to a Q value of 93% of theoretical. Two full length (11.7 ns) sections for high gradient studies at 80 MV/m in the CLIC Test Facility are being fabricated.

A realistic design using circular-aperture structures with oval bodies has been established for the CLIC microwave quadrupoles and prototype pieces with the necessary precision and surface finish have been produced.

A new concept for the 30 GHz transfer structure has been proposed based on a round overmoded and smooth beam chamber. The TEM wave accompanying the drive beam bunchlets couples energy through regularly spaced round holes into TE waveguides situated parallel to the beam chamber. Model work at X-band has shown that the required RF pulse length and level can be obtained without excessive excitation of the H₀₁ mode in the beam chamber. With a diameter of 15 mm, chosen to keep resistive wall effects reasonably low, the beam chamber is overmoded.

A micro-movement test bench has been constructed to study the problems associated with the support and precise positioning in space of the main linac accelerator components. Commercially available micro-movers located at the ends of two interconnected silicon carbide support girders enable several dummy accelerating sections to be displaced with a resolution < 0.5 μm under closed-loop computer control.

11. SPS RADIO FREQUENCY

11.1 Operation

The various radiofrequency systems in the SPS generally performed reliably for all the modes of operation of the machine with one exception. At the beginning of the year a new bimodule copper sputtered niobium cavity was installed in place of the single module cavity used to supplement the e+ e- accelerating voltage of the 200 MHz copper system in 1989. This unit proved extremely valuable in compensating for the known weakness in the bellows of the damping loops of the copper cavities, allowing a number of cavities to be kept in reserve. Whilst the cavities themselves did not give any major problem, towards the end of the LEP+Fixed-target proton run the helium liquefier, known to be at the limit for this operation, gave considerable problems and forced the switching off of the system. Fortunately, this happened just before the SPS switched over to running ions+LEP. The ion beam intensity is so low that the copper system does not need to be damped during the ion cycle. Therefore the damping loops could be immobilised and the system then proved to be very reliable, giving adequate voltage for lepton acceleration to 20 GeV.

For 1991 the bimodule has been replaced by a single module, which is much less demanding on the refrigerator. Less voltage will be available but the system will be more reliable. In the meantime a call for tender has gone out for a new refrigerator to be ready in 1992 when a bimodule can be once again used.

11.2 Power plants

On the Siemens plant, ten 140 kW 200 MHz power amplifiers as well as two 1 kW and two 10 kW predrivers have been demounted, cleaned, and after replacement of worn out components, reinstalled. A modified version of the prototype 1.3 MVA dry transformer which failed during long term operation has been installed and is now working reliably. All 18 kV main circuit breakers of the four 1 MW power converters have been overhauled.

On the Philips plant, forty 25 kW power amplifiers have been completely dismantled, cleaned and reassembled. Extensive work was needed to check and clean other components such as HV filter boxes, RF and HV short-circuit devices and HV isolating and grounding switches on all 68 power amplifiers. Two dry 1.6 MVA transformers replacing the existing PCB transformers have been installed in the 10 kV power converters.

On the 200 MHz standing wave system for lepton acceleration the most critical part is still the bellows of the damping loops which have to move in and out every 14.4 sec machine cycle. New bellows from two different manufacturers have been installed but samples of both types have failed during operation. Detailed examination has shown that the faults were due to bad raw material rather than manufacturing errors. For the next batch the steel will be changed.

On the superconducting cavity system a second RF amplifier chain (350 MHz, 50 kW) was built to drive the second cavity of the bimodule. In addition, a 50 kW final amplifier has been built for the AT division to be used for testing of superconducting cavities and components. The passive damping system has been successfully tested with high-intensity proton beams. It consists of a motor-driven waveguide switch installed between the tetrode power amplifier and allows the cavity to be disconnected remotely from the amplifier in case of breakdown. Extensive measurements to identify and remove sources of noise in the signal source and system loops were made. As a result the power demanded from the amplifiers was considerably reduced, leading to more reliable operation at the nominal gradient of 5 MV/m.

On the 100 MHz system used for collider operation the main transformers of the six 20 kW power amplifiers have been replaced at the manufacturers expense since they did not prove to be sufficiently reliable in operation. Further improvements have been made on the 500 W transistorised driver amplifiers and the HV power converters. The exciters in each power amplifier have been modified to remove gain variation with temperature. During the coming winter shutdown the whole cavity system will be displaced as part of a renormalisation of LS54.
11.3 Beam control

Apart from ongoing operation and maintenance work a number of development projects have been undertaken.

New transmitters/receivers for the fibre optic SPS/PS link have been built. The other optical fibre link through the machine tunnel between BA3 and BA4 has been carefully monitored for radiation damage. No effect has been observed so far.

A sensitive 200 MHz pickup has been built to monitor the RF component of the weak ion beam. A new amplifying system for the ion phase pickup has been built.

Three counters for the synchronisation diagnostic system have been built and tested using new software. In addition a 500 MHz stable voltage-controlled oscillator for use as the counter clock has been developed and built.

The multichannel analyser (ASCOT) described in last year's report has been extended in frequency range by 0.8 GHz. The usefulness of the system has been limited by parasitic resonance on the pickup. A new pickup has been built and tests will be carried out in the next lepton run.

11.4 LHC RF system

Work on the LHC RF and feedback systems have continued. A detailed analysis of copper cavity structures using 2 and 3-dimensional computer codes has given detailed information on the higher order modes of the so-called bar and septum cavities. Low power models have been built and are being measured by classical perturbation techniques. Design work on a full size prototype cell at 400 MHz needed to study problems of multipactor and power dissipation has started. A 400 MHz amplifier for the prototype cell and auxiliary RF circuitry has been ordered. In parallel the possibility of using superconducting cavities common to both beams is under study.

A study aimed at optimising the RF power requirements for the various batch patterns in the machine is underway. The result will determine the architecture of the RF system depending on the acceptable RF window ratings. Contacts with the European RF window manufacturers are encouraging.

12. CERN ACCELERATOR SCHOOL

Since its foundation, CAS has alternated between two and three courses per year. In step with this pattern, there were three meetings during the year, starting with a specialised course entitled “Power Converters for Particle Accelerators”, held in Montreux, 22-27 March. Power conversion is a field in which CERN has strong links with industry and in which the developments are very much of mutual interest. It was therefore not surprising to find that industry was well represented among both students and lecturers. The course was held close to CERN so that participants were able to benefit from an organised visit to the recently-commissioned complex of power converters for the LEP machine.

Later in the year, the “General Accelerator Physics” course was held in Jülich, 17-28 September with the collaboration of the KFA-Jülich GmbH. This course, which was being repeated for the fourth time, attracted one hundred students, many of whom were new to the field of accelerators. For the first time, a small, two-day industrial exhibition was included in the meeting.

Still later in the year, CAS joined with the US Particle Accelerator School to organise a joint course on “Intensity Limitations” in the series “Frontiers of Particle Beams”. This course followed on naturally from the previous joint course on diagnostics and commissioning problems. Both of these courses were very convenient in their timing for the LEP project.

During the year, a total of three sets of proceedings were published and preparations were continued for courses in future years.

CAS also ran a small number of seminars which included the John Adams Memorial Lecture on “The LEP Collider from Design, to Approval and Commissioning”.

SPS COLLIDER PERFORMANCE

Figure 1

LEP OPERATIONS 1990

Figure 2