

CESAR

1960-1967

The CERN Electron Storage and Accumulation Ring, CESAR, will be closed down this month. This article on the history and achievements of CESAR has been written by M.J. Pentz, Leader of the CESAR Group since 1962.

"I come to bury Caesar, not to praise him. The evil that men do lives after them; the good is oft interred with their bones".

— From Mark Antony's oration over the body of Caesar (Shakespeare).

At the end of this year, independent research in accelerator physics is to be discontinued at CERN, at least for some years to come. This closes a chapter in the history of CERN which opened in 1956.

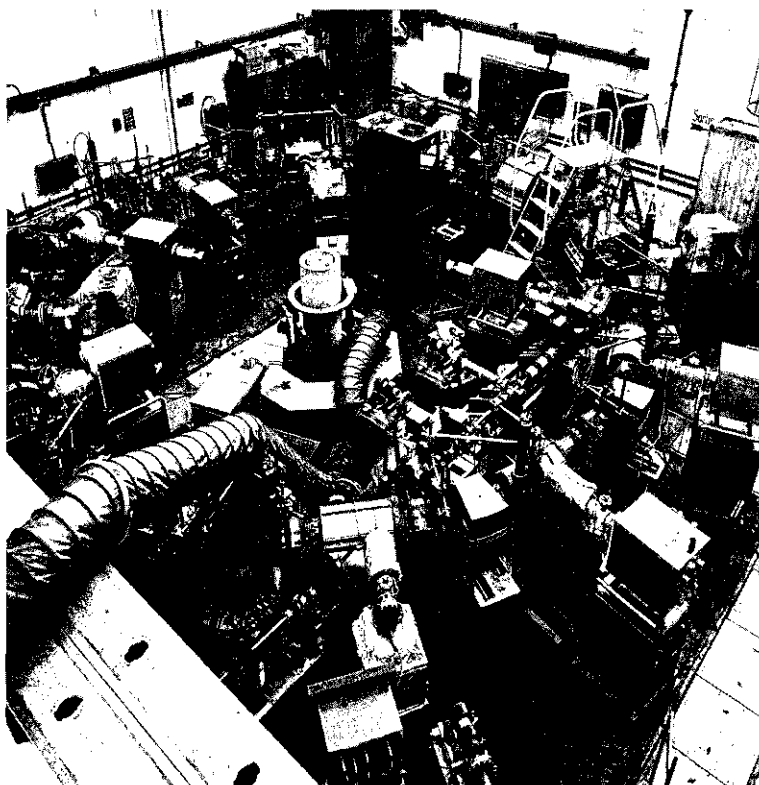
Accelerator research began in the Proton Synchrotron Division, graduated to a separate Division (the Accelerator Research Division) and finally was absorbed as a Group in the Intersecting Storage Rings Department. The work with CESAR has been an important part of this research, accounting for about 50% of the total expenditure on accelerator research (about 22 million Swiss francs) during the years 1960-67. Now it is running on its last experiment before being closed down. This is the moment therefore to write its obituary.

The story of CESAR begins in 1960 when the performance of the CERN synchrotron had improved to the point where the addition of storage rings could be seriously considered. Studies of plasma betatrons and of a two-way beam stacking electron accelerator had been going on previously, and the latter had reached a fairly advanced stage. But the new possibility of proton storage rings led to the decision to construct instead a storage ring for 2 MeV electrons, in which it would be possible to study the basic problems of design and operation of the proton storage rings.

The storage ring was christened CESAR (CERN Electron Storage and Accumulation Ring). The immediate purposes for which it was constructed were:

- a) to provide an experimental verification of the theory of radio-frequency beam stacking
- b) to investigate certain beam instabilities that could be of importance in the operation of proton storage rings
- c) to study the technological problems of producing ultra-high vacuum (pressures of less than 10^{-9} torr) in complicated vacuum chambers.

In 1961, the design of the electron storage ring was finalized and its main components were ordered. The construction



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was completed in the spring of 1963 and, after a long and difficult running-in period, a circulating beam was obtained at the beginning of 1964. During the four years since then, development and refinement of the machine have gone in parallel with its exploitation for experimental research. It may be said, however, that only in its final phase of operation (June-December 1967) has CESAR become an experimental tool which is sufficiently well understood and sufficiently amenable to manipulation to open the door to its full exploitation as such. The most important experimental results were obtained in 1966 and 1967.

It has undoubtedly fulfilled all three purposes for which it was built, and a number of others besides.

The basic theory of radio-frequency stacking was experimentally verified, and the possibility of achieving high 'stacking efficiency' even with high values of the stable phase parameter (as envisaged for the ISR) was demonstrated. A new phenomenon, due to radio-frequency noise, was observed and a series of experiments verified a theoretical interpretation of it.

The possibility of three exercises in what may be called 'radio-frequency gymnastics' (all of them of interest to the ISR) was experimentally confirmed. In the jargon of the specialists, these were stacking with 'missing buckets', stack-shaping by phase displacement, and stacking with phase-lock. A pronounced blow-up of the beam energy-spread at injection was observed, with the practically certain inference of the so-called 'negative-mass instability'.

The lifetime of the circulating beams which is limited by gas scattering (hence the need for ultra-high vacuum in CESAR),

was found to agree with the predictions of scattering theory. The 'half-life' (which is the time at which the circulating current is reduced to half its initial value) at the lowest-pressure reached (7×10^{-11} torr) was 12 seconds. It would have been longer, but for the relatively high proportion of argon in the residual gas mixture; argon scatters electrons much more strongly than hydrogen does. Incidentally, the pressure of 7×10^{-11} torr was more than an order of magnitude lower than the design aim of 10^{-9} torr. This achievement, in a vacuum chamber full of joints, moving targets and various other undesirable objects from the vacuum engineer's point of view, gives further grounds for confidence that similar, or better, results will be achieved in the ISR.

CESAR turned out to be a highly 'non-linear' machine. In plain language, this means that the electrons 'saw' magnetic fields (and particularly field gradients, and gradients of field gradients) that were really not supposed to be there. This was because the average magnetic field around the ring was only 20 Gauss, and every kind of field error or stray field (such as the earth's magnetic field) produced a relatively large effect. This circumstance made CESAR extremely tricky to operate but it was exploited to carry out a wide range of experiments on higher order non-linear resonances, including their effects on beam lifetime, and from this work, tentative inferences can be made about the long-term stability of the beams in the ISR.

One of the pet bogeys of storage ring specialists — the 'coherent transverse instability' — was studied in some detail. The results agreed with theory up to a point, but a new phenomenon was observed

which is being investigated at this moment. It is hoped that it will be sorted out satisfactorily before the shut-down.

An exercise in beam gymnastics in the transverse phase plane (beam splitting on a third-order resonance) was successfully performed. This exercise is of interest for accelerators and storage rings in general, and for the booster-injector / PS / ISR / 300 GeV family in particular.

As can be seen from the above summary of the ten main experiments done with CESAR, it has more than fulfilled its purpose. Nevertheless, these represent only a fraction of the research which could be done with the machine, even in, essentially, its present form.

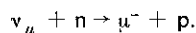
How much effort went into this project? Its financial cost has been mentioned — about 11 million Swiss Francs of which 42% went on salaries. It absorbed 144 man-years over the eight years of its life. But these are only quantitative measures. In the last analysis, it is the quality of people that determines the quality of the work they do, and in a scientific research group, the existence of a good group spirit is often more important than the individual brilliance of its members. From its first beginnings to the end of its life, the CESAR group has had an atmosphere of informality, co-operation and subordination of individual interests to those of the team as a whole, which will be recalled with satisfaction and pleasure by all who have participated in it.

To end on a personal note, I would like to place on record my profound appreciation of the work of all the people who made this group probably the most pleasant to work in, and certainly not the least effective in CERN.

Neutrino Experiments

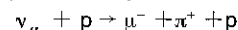
The first series of experiments using the new neutrino beam-line finished in November. The run was extremely successful. In the allotted seven weeks of proton synchrotron time, about 1 125 000 pictures were taken in the heavy liquid bubble chamber and preliminary examination of the photographs indicates that a harvest of about 1 000 neutrino events has been gathered. Possibly about 100 of these will be suitable for analysis as neutrino interactions with a 'free' proton — the first time that such events have been observed.

The previous experiments at CERN in 1963-64 were done with freon in the heavy liquid bubble chamber. They provided valuable information on neutrino interactions (it could be said that at that time any information on the interactions of the elusive neutrino was 'valuable' information) particularly concerning the 'elastic' interaction with a neutron to give a muon and a proton



Inelastic interactions, such as that yielding

a muon a pion and a proton



were much more difficult to investigate. The proton with which the neutrino collided, was bound in a heavy nucleus (carbon, fluorine or bromine) and the pion was likely to be absorbed by the nucleus, making the analysis of the interaction less accurate.

With the new neutrino beam-line, the flux of neutrinos which is fired into the chamber, is much higher and it is possible to fill the chamber with propane while still having a useful number of interactions in this 'thinner' liquid. In propane, there are 'free' protons, the nuclei of the hydrogen atoms (and there are more hydrogen atoms per unit volume than in liquid hydrogen itself). The neutrino interactions with these protons are then unaffected by the presence of other nucleons.

Analysis of the photographs has started and the first results are expected during 1968. The preliminary scanning went on as the experiment proceeded and almost kept pace with the very high rate of taking the photographs. More than 850 000 were



An example of a 'candidate' for a neutrino interaction with a 'free' proton. This interaction was observed for the first time in the recent series of neutrino experiments at CERN. The neutrino entering from the bottom of the photograph interacts with a proton (the nucleus of a hydrogen atom in the propane which filled the heavy liquid chamber) to give a proton (short track to the right) a muon (long upward track) and a positive pion which decayed eventually into a positron (the tight spiral).