OVERVIEW OF THE RECENT OPERATION OF THE AAC AND LEAR FOR THE LOW-ENERGY ANTIPROTON PHYSICS PROGRAMME

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Abstract

This paper reviews the recent performance of the AAC and LEAR. Activities on the AAC include the successful exploitation of a magnetic horn as an antiproton collector lens and an energy-saving mode of operation, which has been possible since 1992, when LEAR became the only client of the AAC. LEAR worked in its full momentum range between 100 MeV/c and 2 GeV/c, with performance (intensities, ejection modes and spill length) exceeding the design specifications. Improvements are described, which contributed to the quality of the beam delivered to experiments. The reliability and availability of the antiproton machines are also discussed.

1 INTRODUCTION

The operation for the period following the SPS Collider run in 1991 to the close-down of AAC and LEAR in December 1996 are reviewed. During this five-year period, the AAC was operated only for the low-energy antiproton physics [1]. Typically, the AAC ran for around 5 800 h/year and, as LEAR took a small fraction of the possible daily production, the antiproton complex has operated a third of the time in the “energy-saving mode”.

2 AAC OPERATION

2.1 Antiproton Production

In December 1991 the 20 mm lithium lens was reinstalled after a breakdown of the 400 kA magnetic horn. The cause of the failure was investigated and the mechanical reinforcement (stronger fixing flanges) was improved. One of the new horns was successfully tested over 1.3×10^6 pulses in the laboratory and, to complete the consolidation progamme [2], two cradles, specially studied to improve air cooling and the positioning of the collector after the target, were equipped with the improved horns.

The 20 mm lithium lens, which had been so reliable over three years, broke down in April 1995. A short-circuit developed in its primary transformer winding, and it had to be replaced by a magnetic horn. Such a horn collects about 15% less antiprotons, and the loss of $\bar{p}$ collection was compensated by running the production for a longer time.

The yield (Table 1) defined as the number of antiprotons measured on the injection orbit of the collector ring per incident 26 GeV/c proton, slowly decreases as the production beam intensity increases.

Table 1: Operational yields, measured for 1.5×10^{13} primary protons.

20 mm lithium lens (1992-1994)	53×10^{-7} $\bar{p}$/p
400 kA magnetic horn (1995-1996)	45.2×10^{-7} $\bar{p}$/p

2.2 AC and AA Rings

The different systems of the AC and AA rings have had fairly stable operation during the last five years. No major modifications or improvements have been carried out; however, a re-alignment of both rings had to be made because the gradual compacting of the ground had strongly restricted the vertical acceptances.

Machine development sessions on the AAC were mainly carried out simultaneously with normal running and aimed at maintaining the performance level of the machines. Deceleration of proton beams in the AC was studied in view of a simplified low-energy antiproton source [3].

2.3 Energy Saving Mode

With LEAR being the only consumer of the antiprotons produced in the AAC, there was a need to reduce the energy consumption. It was very efficient to accumulate $\bar{p}$ at maximum stacking rate and maximum number of PS-cycles during short periods. Once the AA was full, the AC ring, injection line elements as well as other elements used only for $\bar{p}$ production could be switched off or operated with reduced power, saving about 4 MW of electrical power. The PS production cycles were converted to other use or put in standby mode, further increasing the power savings. Antiproton transfers to LEAR from the coasting AA beam could continue as before. The AA to LEAR transfer efficiency actually increased due to a reduction in the transverse emittances of the AA stack.

3 LEAR OPERATION

A single bunch of antiprotons was transferred from the AA to the PS at 3.5 GeV, decelerated in the PS to 609 MeV/c and subsequently transferred to LEAR where through acceleration or deceleration and beam cooling, the beam was made available to physics experiments in the range of 105 MeV/c to 2 GeV/c.

At the extraction flat top(s), the beam was either fast extracted in single bunches or ultra slowly using third-order stochastic extraction [4]. LEAR could supply several physics experiments at a time either switching single bunch extraction, or through beam splitting in the transfer line during ultra-slow extraction. In this way, typically 5 physics experiments could take data in parallel.

3.1 Stochastic and Electron Cooling

Stochastic cooling is available in the entire energy range of LEAR. It is normally applied at the 609 MeV/c and above and optionally during ultra-slow extraction at the extraction momentum. Electron cooling is applied at momenta below 350 MeV/c.

There are two stochastic cooling systems comprising high-gain pick-ups connected to correction kickers through variable delays. The first system is reserved for operation above 200 MeV/c and the second only at 105 MeV/c and below. All 50 Ω matching resistors and the pick-up electronics of this last system are cryogenically cooled in order to increase the signal to noise ratio. In the last years, the low-energy stochastic cooling systems have been used as wide-band dampers, providing the extra power and bandwidth needed to stabilise the dense beams that are obtained by electron cooling. Stochastic cooling is also used during ultra-slow extraction to counteract the blow-up of the circulating beam due to scattering on the residual gas.

The electron cooling, inherited from the ICE experiment, has undergone a number of major overhauls before its fully operational configuration. LEAR is the only machine to use electron cooling [5]. The modifications include the development of a variable intensity electron gun which has made it possible to increase the electron current on the cooling flat tops, a major upgrade of the vacuum systems in the cooling section, a feedback system on the high-voltage power supply to compensate for any change in the electron beam space-charge potential and the improvement of the controls for more reliable operation. These changes provided the physics community with high-quality antiproton beams at low energy and with a much improved duty cycle (electron cooling is applied typically for 15 s on the flat top as opposed to 5 min with stochastic cooling).

3.2 Stochastic Extraction

Consolidation of the noise generation hardware of the stochastic extraction system [6] improved the ultra-slow extraction of large stacks, of $\approx 10^{10}$ particles, at low momenta (<300 MeV/c). An extracted flux feedback system was put in operation to replace the parameter driven feed-forward system. This reduced the setting up time of the process and introduced the possibility to change the particle flux instantaneously at user request. It also allowed for very long low-intensity particle spills from large stacks. A typical spill is shown in Fig. 1. The longest constant flux spill lasted 14 hours.

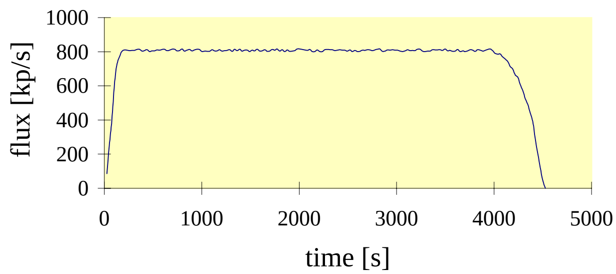

Figure 1: Antiproton spill with flux feedback.

Because of the improved spill control, the antiproton flux to the physics experiments could be kept close to the required value and as a result a net increase in the integrated flux was observed. This is one of the major factors in the improved performance of LEAR over the last 2 years.

4 OVERALL OPERATION PERFORMANCE

The total number of antiprotons injected into LEAR per year is shown in Fig. 2. The steady increase in the number of spills/year continued throughout the life of the machine. The small decrease seen in 1991 and 1992 was due to the push for increased spill length rather than any reduction in running time. The sharp dip in 1987 is due to the shutdown for the installation of the AC.

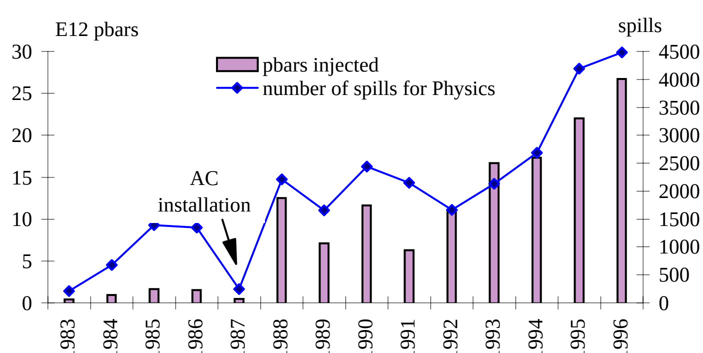

Figure 2: 1983-1996 LEAR running statistics.

After this installation, LEAR clearly profited from the increased antiproton flux available and the average intensity/spill continued to increase from 1988 right up to the end of the antiproton programme in 1996. A major effort was made to improve the overall efficiency of the AAC/PS/LEAR operation, leading to a very significant reduction in the time taken to refill LEAR. The use of the electron cooling helped to reduce the deceleration time by around 5 min/spill. These and other measures significantly reduced the waiting time between LEAR spills. As a result the number of spills was more than doubled for an increase of only 20% in time. In addition, the quality of each spill (peak intensity/average intensity) was also improved by careful adjustments of the extraction parameters, spill form and duty factors. All these factors provided a large increase in the total integrated antiproton flux to the LEAR users. The number of antiprotons injected into LEAR was almost tripled between 1992 and 1996, (Fig. 3). As antiprotons are expensive to produce, particular attention was paid to the overall efficiency of the transfer and deceleration process. One of the most critical areas was the injection of the antiproton bunch into the PS at 3.5 GeV/c. Any transverse emittance blow-up here, translates directly into beam losses during deceleration to 609 MeV/c. Therefore, the transverse injection oscillations were automatically measured and stored and any necessary corrections were automatically calculated and applied. A feedback system took care of small pulse-to-pulse variations in the PS injection process. It was also very important to monitor the beam trajectories from the AAC to the PS and from PS to LEAR, as any drift resulted in unwanted beam losses. At the end of the LEAR operation, the global transfer efficiency from the AAC to LEAR, i.e. the total number of antiprotons injected into LEAR divided by the total number ejected from the AAC in a year, was around 75%.

The actual time scheduled for the LEAR antiproton physics operation each year is shown in Fig. 3.

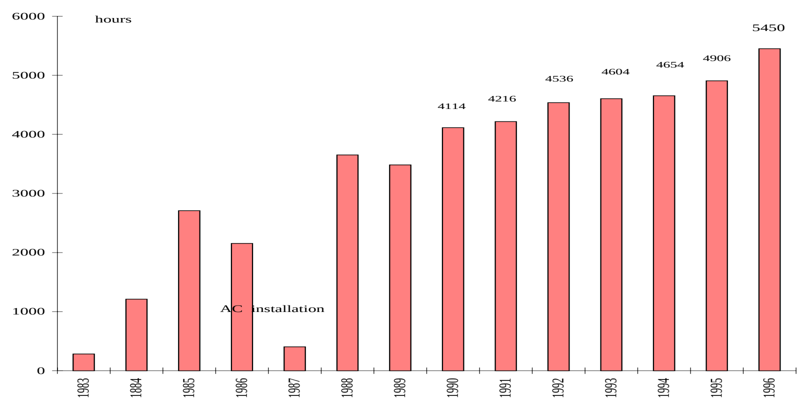

Figure 3: LEAR hours scheduled for antiproton physics (1983-1996).

5 CONCLUSION

This unique low-energy antiproton facility worked with good efficiency and reliability. The antiproton programme was completed in December 1996.

The machines involved will be reborn with a new lease of life. LEAR will be used as a lead ion accumulator ring (LEIR) for LHC and the AC ring converted into an ‘Antiproton Decelerator’ (AD). A new simplified antiproton source opens the possibility for a new antiproton programme at CERN.

6 REFERENCES

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