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ACCELERATION AND STACKING OF α PARTICLES IN THE CERN LINAC, PS AND ISR

M. Boutheon, R. Cappi, H. Haseroth , C.E. Hill, J.P. Koutchouk
CERN, 1211 Geneva 23 - Switzerland

ABSTRACT

The CERN Intersecting Storage Rings (ISR) have been successfully operated with sufficient α particles for experiments at total center of mass energies up to 120 GeV. Initially, the small beam currents obtainable from the (old) Linac hampered machine studies with the PS so that conclusive experiments similar to those done with deuterons were not possible. Recent attempts to increase the intensity by stripping a He^+ beam at 520 keV succeeded and gave 10 mA of α particles from the Linac. Multiturn injection and acceleration in the PS produced 2×10^{11} particles/pulse and stacking in the ISR resulted in a maximum stored beam intensity of 4.2 A at 52 GeV. After further acceleration by phase displacement in the ISR, luminosities of $4\times10^{28}\,cm^{-2}s^{-1}$ for α-α and $9\times10^{29}\,cm^{-2}s^{-1}$ for α-p experiments were obtained.

INTRODUCTION

As the usual proton production for the CERN accelerator complex has been successfully taken over by Linac II (new Linac), Linac I (old Linac) was available for machine studies. This encouraged a group of high-energy physicists to ask for a repetition of a machine experiment of 1976 which resulted in accelerated beams of a few 10^{10} α particles per pulse in the PS[1]. Most of the effort, at that time, was spent on deuteron acceleration in the Linac and PS with subsequent stacking and post-acceleration in the ISR. α particles were produced in the normal duoplasmatron and were accelerated up to 40 GeV in the PS only. The low intensity available from the Linac (2mA) caused problems, and therefore high losses, in the PS. Additionally, later measurements on the linac beam (activation analysis) showed that, under the conditions of that run, the chances of producing a high deuteron contamination of the beam were very high. In spite of these difficulties, the PS division agreed to reproduce the achievement of 1976 for α beams and to transfer them to the ISR.

PRODUCTION OF THE α BEAM

Detailed analysis of beams produced under conditions similar to those of 1976 showed that the deuteron contamination came from the simple fact that a deuteron beam was used to set up the linac. Deuterium stored in the ion source (absorbed in the walls) is sufficient to provide quite a few milliamperes during 100μs pulsed at a repetition rate of a few Hertz. Certain settings of the source parameters would reduce the deuteron content but would not necessarily increase either the α production or the beam stability. Therefore the deuteron setting-up was abandonned and a clean source was installed to provide a deuteron free α beam. Attempts to obtain more than 2 mA at the end of the linac failed because the beam stability was unsatisfactory[2]. Initially, the original idea of stripping a He^+ was not pursued because of a lack of an adequate stripper arrangement. The preinjector vacuum system was inadequate to handle the gas load of a continuous gas jet stripper. However, the availability of a fast acting gas valve capable of handling the required pressures and flow rates reliably drastically changed the situation. The piezoelectric valve (Vecco PV10) was mounted (Fig. 1) as near as possible to the centre of a 400mm long, 20mm diameter tantalum tube. In operation, the opening of the valve was controlled by a 95V square pulse 900μs long starting 1.2 ms before the passage of the beam. Starting the valve was usually delicate due to ageing effects and sticking seals. A 516 keV He^+ beam of 320 mA produced by a standard duoplasmatron, modified for optimum He^+ production (Fig. 2), yielded α currents of more than 10 mA at the linac output[2]. Stripping efficiency at 516 keV on nitrogen (as used in the stripper) is[3] around 30%.

ACCELERATION IN LINAC I

As described previously[1] acceleration in the linac used the 2βλ mode (i.e., two RF periods for the α particles to move from one gap to the next). The focusing of the first tank was changed from the usual ++-- to a +- scheme and the focusing strength in all three tanks increased by some 20%. Tank field tilts were adjusted around values similar to those used for deuterons.

The fact that no preliminary setting up with deuterons was carried out made the adjustment of the machine fairly complicated. Actually, it was only possible because of the wealth of experience gained during previous deuteron runs. The whole linac had to be optimised on the signals from the high energy end because either the standard measuring equipment was insufficiently sensitive or, up to the entrance of the Alvarez, not very useful because the presence of the He^+ beam which made in particular, adjustments of the LEBT and Tank I difficult.

BEAM QUALITY AFTER LINAC I

A rough check of any possible deuteron contamination was made by inserting a 1mm thick aluminium foil in the high energy beam. This foil stopped the full beam, proving that there were no deuterons (at 25 MeV) present. Final confirmation of the intensity of the α beams was obtained by activation analysis.

Typical properties of the α beam were :

Intensity	:	10 mA
Energy spread	:	±250 keV
Emittance	:	∿3.5πmm mrad (normalised)

A peculiarity was that the shape of the vertical emittance changed quite drastically from one setting up to the next.

INJECTION INTO THE PS

The nearly identical e/m ratio allowed the hope that the tuning of several elements in the transverse phase space would be as for deuterons.

The obstacle of lack of instrumentation for low intensities was overcome by a factor of five increase in α particle currents available for injection.

A four turn injection was adjusted. With 7.5 mA (3×10^{11}α) upstream of the electrostatic septum, a stack of 15 mA could be produced and 10 mA were trapped in the transversal phase plane (Fig. 3). The short experimental time did not allow improvement of this result, but one has confidence in improved performance when incoming beam emittances will be known better and improved matching is possible.

PS BETATRON TUNES AND ACCELERATION

With more than 4×10^{11} α particles one is already in the PS space charge zone at injection energy. A dynamic working point from injection to harmonic change-over energy had to be used, with a range from Q_V=6.45 to 6.31, with Q_H=6.23. Stop bands $2Q_V$=13 and $2Q_V+Q_H$=19 were compensated up to 2.1 GeV/c, leaving nevertheless a transverse loss during longitudinal trapping and the initial part ($\bar{h}$=40) of the acceleration process, estimated at 20%. At the harmonic change-over energy (2.1 GeV/c), the usual transverse emittances values for the intensity of 2×10^{11} α's were found : 18,2πmm mrad horizontal and 7.7πmm mrad vertical.

As the PS linac must work in a 4π mode to accelerate α particles their speed is half that of protons ($\beta_\alpha = v_\alpha/c = 0.157$, $\beta_p = 0.314$). Actual tuning of PS-RF cavities allows a frequency variation of a factor of 3 only (3 to 9 MHz) and not of 6 as required for acceleration of α's up to β=1. A change of the harmonic number h is therefore necessary at some time during acceleration.

α particles in the PS were accelerated on h=40 from injection (.6 GeV/c) up to a 2.1 GeV/c (β_α=0.5) flat top.

On this flat top the beam was debunched, then adiabatically recaptured on h=20 and finally accelerated up to the ejection momentum of 52 GeV/c (Figs. 4 and 5).

Maximum intensity at final energy was 2.10^{11} α/pulse (∿30 mA).

Most of the losses (∿50%) were concentrated at injection and only a few per cent during the intermediate flat top.

Longitudinal emittances (ΔφxΔβγ) were :

0.6 GeV/c (injection) = 4 mrad
2.1 GeV/c (before deb.) = 6 mrad
2.1 GeV/c (after deb.) = 7 mrad
44.0 GeV/c = 10 mrad

TRANSFER, STACKING AND ACCELERATION IN THE ISR

Alpha particles, like protons or deuterons, are accelerated by the CPS to the same standard magnetic rigidity, corresponding to a proton momentum of 26.05 GeV/c. The transfer trajectories, closed orbits and tunes are therefore identical whatever the type of accelerated particles. The principles of ISR operation are thus unchanged[4].

The high mass of the alpha particle results however in different relativistic parameters α, β and η (revolution frequency spread per unit of momentum spread), leading to different longitudinal phase plane parameters (RF frequency, bucket and stacking parameters).

Other beam dynamics parameters of particular importance in the ISR are the incoherent space charge tune shift, the transverse stability against coherent oscillations and the overlap knock-out resonances : for vanishing neutralization and ultra-relativistic particles, the indirect tune shift is predominant and, to a very good approximation does not depend on the rest mass. The space-charge compensation program based on the measurement of the beam current and longitudinal density distribution was therefore used without modifications.

The same argument is valid for the transverse stability criterion : the expected low beam current made it possible to reduce the chromaticity Q', whilst keeping a strong Landau damping ; non-linear resonances could be avoided and the working line could be relocated far from the linear coupling resonance :
The tune parameters were : Qh=8.920, Qv=8.885 Q'h=Q'v=1.2. For these tune values, strong vertical overlap knock-out resonances are excited when colliding a bunched beam of protons with a beam of alpha particles. Stacking and accelerating the strong proton beam before the weak alpha beam allowed use of the standard steel low β optics.

A change of the particle rest mass has repercussions in a large number of modules of the ISR control system. However, in line with the control system principles[5] all modules retrieve such basic items as the particle rest mass from a data bank. The conversion of the software from protons to alpha particles takes less than one minute.

PERFORMANCE

Some difficulties were encountered during stacking at 52 GeV/c due to violent longitudinal instabilities ; they could be cured by powering a third harmonic cavity, thereby increasing the bunch length. A maximum beam current of 4.3A was reached (4.3 E13P). After data taking at 52 GeV/c the beams were accelerated by phase displacement to 62 GeV/c, making available a total maximum c.m. energy of 126 GeV. The remaining current was 3.8A. The machine performances are summarized below.

	α–α	α–p
Best initial luminosity ($cm^{-3}s^{-1}$)	$4\ 10^{28}$	$8.5\ 10^{29}$
Average luminosity decay %/hour	0,7	0,9
Duration (h)	58	68
Integrated luminosity (cm^{-2})	$7\ 10^{33}$	$1.8\ 10^{35}$

With the definition

$$L=0.1\ \frac{I_1 I_2}{Z_1 Z_2}\frac{1}{h_{eff}} - 10^{30} cm^{-2} s^{-1}$$

$I_1 I_2$ beam currents ; $Z_1 Z_2$ atomic numbers, h_{eff} effective height in mm. The beam conditions in intersections were reported to be excellent.

FUTURE PROSPECTS

There seems to be interest in more α runs in spite of the only partial analysis of the experimental data. Some improvement in intensity (up to a factor 2) should be possible provided longer running times are given, with some effort on the Linac as well as on the PS side. Even with the present intensities the ISR expect a possible gain by about a factor of 2 in luminosity.

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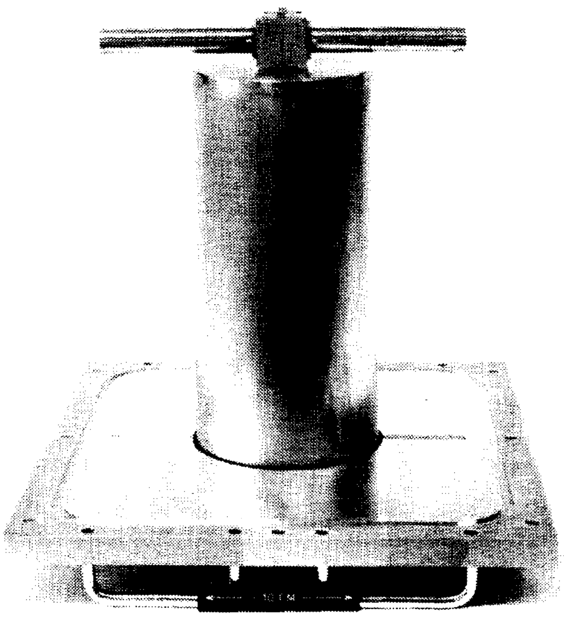


Fig. 1 - The gas stripper

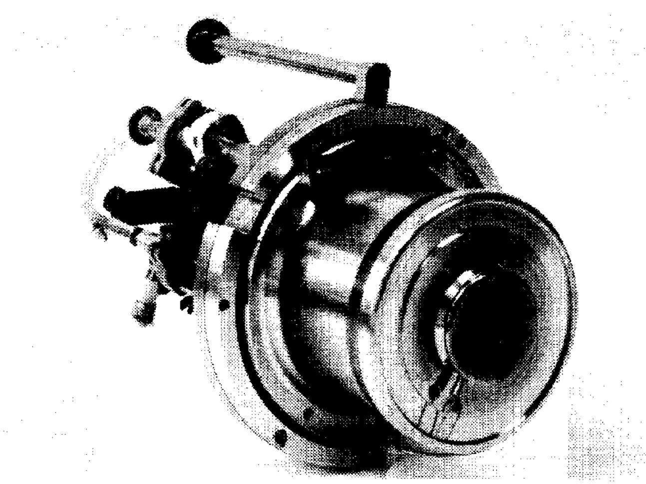
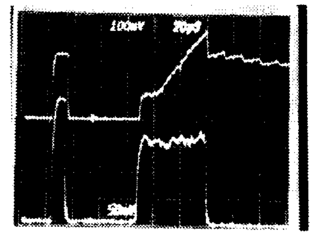


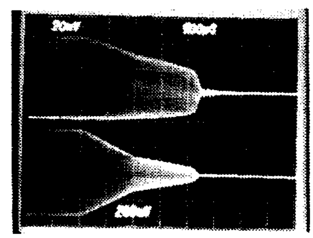
Fig. 2 - The modified duoplasmatron



BM50

BM48

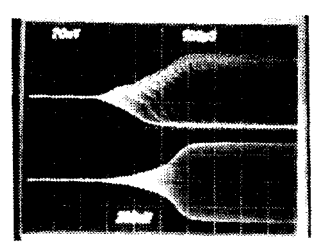
Fig. 3 - BM 48 - beam leaving Linac
BM 50 - multiturn injection into PS
(calibration pulse = 10 mA)



1)

2)

Fig. 4 - Adiabatic degrouping on intermediate flat top
B = 515 G, h = 40
1) Σ wide band pick-up
2) VRF



1)

2)

Fig. 5 - Recapture at h = 20
1) Σ wide band pick-up
2) VRF (0-175 kV)