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OVERVIEW OF THE STATUS AND DEVELOPMENTS ON PRIMARY ION SOURCES AT CERN*

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Abstract

CERN has 2 operational primary beam ion sources, that are presently used for the production of beam for LHC as well as several other facilities. Protons are produced by a duoplasmatron source, and ions from the GTS-LHC ECR ion source. In addition, new sources are required for a new 160MeV H- Linac, and development has been made on a high power RF plasma generator which could serve for a future high power Linac.

In this report, the present status will be given, along with operational statistics and experience for the operation sources, and the development programme reported for the future sources.

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CERN has 2 operational primary beam ion sources, that are presently used for the production of beam for LHC as well as several other facilities. Protons are produced by a duoplasmatron source, and ions from the GTS-LHC ECR ion source. In addition, new sources are required for a new 160MeV H- Linac, and development has been made on a high power RF plasma generator which could serve for a future high power Linac.

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INTRODUCTION

CERN's LHC injector complex is able to supply fixed-target experiments with protons of different energies, as well as protons and ions for collisions in LHC.

At the beginning of the injector chain, the protons are delivered by a duoplasmatron source, accelerated to 50MeV in Linac2 using a RFQ and Alvarez drift tube Linac. It is planned to switch to a 160MeV H- beam in 2014 or 2017. This project (called Linac4) is underway and aims to start commissioning with beam in its underground tunnel in 2013. In addition, as part of a study for a high power Superconducting Linac (SPL) – for the production of radioactive ions for a new generation of Isotope Online Separation facilities, or production of neutrinos both as super-beams or for a neutrino factory – development towards a 50Hz repetition rate RF H- ion source has been ongoing.

The primary lead ion beam is delivered from an Electron Cyclotron Resonance Ion Source (ECRIS) and accelerated in Linac3 to 4.2MeV per nucleon using a RFQ and Interdigital-H structure.

PROTONS

The primary proton beam at CERN is delivered by a duoplasmatron source, the present version of which was installed in 1992/93 when the source was moved from the 750kV Cockcroft Walton pre-accelerator, to a 90kV platform for injecting into an RFQ. The scheme of the source is shown in Figure 1, and the main parameters are listed in Table 1.

The source principle is to make an electrical discharge in hydrogen gas between a hot thermionic oxide cathode and anode. The discharge is pinched just before the anode plate by the concentration of a solenoid magnetic field by using magnetic electrodes. The plasma from the discharge flows through a 0.6mm hole in the anode plate, into an expansion cup (which has its own solenoid field) and the plasma density reduces to a sufficient level to allow extraction of the protons though an aperture of 20mm.

The cathode is made from a nickel mesh, painted in two stages with a solution containing BaCO3, SrCO3 and nickel powders, with a grain size of approximately 1µm, mixed with amyl acetate [1]. Once painted, the cathode is cured in vacuum at high temperature, before the addition of hydrogen gas and final discharge training. In the finished cathode, the ratio of the oxides should be BaO: 43% SrO: 57%, a fraction that changes during cathode use, as the barium oxide evaporates more quickly. Cathodes are then stored in a sealed chamber under air before installation onto the source, after which the cathode heating must be ramped up to the nominal value over about 8 hours, to allow it to fully degas.

The plasma chamber surrounding the cathode, and the supporting plate for the anode are made from Armco, while the main source body is made from low carbon steel, all are coated with nickel to avoid oxidisation. The anode plate of the source is made from molybdenum, while all the extraction parts are made from titanium.

The extraction is made between the source and 91kV and the intermediate electrode at -3kV, through apertures spaced 16.5 mm apart. Hydrogen gas is delivered to the source using a mass flow controller, with the 10 litre, grade 6.0 bottle being installed on the high voltage platform.

Table 1. Parameters of the Duoplasmatron proton source at CERN's Linac2

Cathode Heating	50	A
H_2 Gas Flow	~4	sccm
Discharge Current	50	A
Discharge Voltage	140	V
Solenoid Magnet Field	90	mT
Extraction Voltage	91	kV
Intermediate electrode Voltage	-3	kV
Proton Beam Current	>200	mA
Maximum Pulse Length	150	µs
Repetition Rate	0.83	Hz

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The cycle time of the first synchrotron at CERN is 1.2s, and therefore the proton source pulses with a repetition rate of 0.83Hz. All systems of the source operate DC or CW (including the H_2 gas injection) except for the cathode to anode discharge, which is pulsed when beam is required. The discharge begins 20µs before the injection into the synchrotron, this “head” beam, whose intensity is rising to the maximum, is accelerated by the linac and dumped at the entrance to the synchrotron. The pulse length is adjusted by the length of the cathode to anode discharge, depending on the intensity required by the synchrotron. This intensity (and therefore the source pulse length) is varied from pulse to pulse depending on the final user requirements.

The source is fully dismantled, cleaned and the cathode replaced just once per year. On reinstallation, the total leak rate must be below 10^{-9} mbar.l/s, as impurities cause cathode erosion that can significantly shorten the life of the cathode.

In recent years, the proton source has been started up in January, a few weeks before the main physics run in order to be sure of stable operation, the source then runs almost continuously (for 43 weeks in 2010) with a pulse every 1.2s. During each year’s run, limited maintenance can be carried out in short technical stops (there were 5 in 2010), which last typically 8 hours, these can be used to exchange the hydrogen bottle, clean around the source and fixed minor electronics issues. Outside these scheduled stops, the proton source has an availability of 99.8% averaged over the period 2000-2010.

High voltage flashovers from the source are auto-reset (unless 5 occur in a period of 5 minutes), and about 15 seconds of beam is lost while the high voltage recovers. These flashovers happened at a rate of 1.3 per day in 2010, but can peak to very large numbers in faulty conditions, as the electromagnetic noise generated by the flashovers can also cause other equipment to fail, the noise emission has been reduced by the addition of a current limiting resistance between the source backing capacitor and the source.

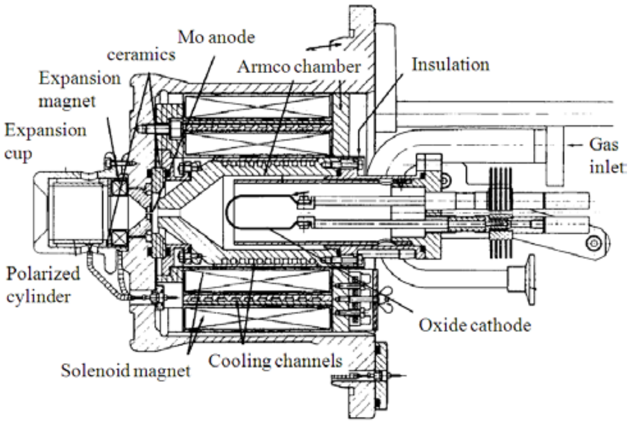

Figure 1. The duoplasmatron proton source.

NEGATIVE HYDROGEN IONS

Low repetition rate for Linac4

For negative hydrogen ion beams required for the future Linac4, CERN is pursuing the development of low frequency RF ion sources, which have already found service in other laboratories. A first version was copied from the DESY 2MHz external antenna ion source, which is caesium free. The source uses a solenoidal 5 ½ turn antenna around an alumina ceramic plasma chamber, a dodecapole multi-cusp permanent magnet arrangement confines the plasma, while forward of the antenna a permanent magnet dipole field allows a lower temperature plasma to exist in front of the extraction region, essential to allow H- to form and not be re-neutralised before extraction. A bias on a funnel and plasma electrode can be applied, before the extraction gap.

After extraction, the co-extracted electrons are separated from the ions with a permanent magnet dipole, and the electrons are dumped in a graphite cup. CERN’s source used an identical design of the source to DESY, with a different configuration on the mounting of the source and its connection to the LEBT.

The source was originally designed for 35kV extraction potential, whereas CERN’s Linac4 requires 45keV injection into the RFQ. It has not been possible to create a plasma from this source and stably extract the beam across 45kV. On pulsing the RF and generating a plasma the source high voltage breaks down within a few pulses, even after weeks of conditioning, no more than a few short pulses could be held. Inspection showed a high amount of damage on the graphite dump, leading to the conclusion that the higher electron energy leads to strong evaporation of the graphite dump, which in turn leads to a breakdown. Simulation of the heating of the dump surface with a high intensity electron beam, shows that the evaporation temperature of carbon is reached with a few tens of microseconds.

Additionally, the overall H- intensity reached at DESY has not been obtained on the CERN installation during tests done with 35kV extraction voltage. Therefore it has been decided to re-engineer the source in order to incorporate two major changes: to dump the electrons at a lower electron energy (below 10keV); and to inject caesium into the source to increase the H- yield, decrease the electron yield and reduce the beam emittance. The first change should be implemented in the next year for first tests with H- with Linac4’s RFQ

High Repetition Rate for SPL

Taking the same initial design concept as had been chosen for Linac4, i.e. a 2MHz external antenna, caesium free plasma generator (for future incorporation into the high voltage system required for an ion source), a complete thermal study was made in conjunction with a re-engineering of the source to be able to work with an average RF power up to 6kW.

The most important changes to the source design to cope with higher RF powers [2] were the following:

- The plasma chamber material was changed from aluminium oxide, to aluminium nitride (AlN).
- Water cooling channels were machined into the AlN chamber, and further channels were added into the RF antenna, ignition source and collar regions
- Electrically isolated electrodes were made from high thermal conductivity metals, and were brazed onto AlN insulators.
- The multi-cusp confinement magnets were placed in a copper shielding cage, to avoid heating by eddy currents induced by the RF.

A test stand was constructed and plasma could be generated at 50Hz using 1.2ms pulses at and RF power of 50kW. Additionally, further understanding on the RF impedance of the source has been made [3], as well as optical spectrometry of the plasma [4]. Langmuir gauge measurements are also underway.

OTHER IONS

The present ion linear accelerator (Linac3) has delivered Pb and In ions for either fixed target or LHC collisions, and oxygen ions for initial commissioning of the Low Energy Ion Ring (LEIR). At its construction, Linac3 used a 14.5 GHz ECRIS constructed by GANIL, France [5], called ECR4.

In anticipation of the the completion of the LHC, which is also built for Pb-Pb ion collisions, the source was exchanged in 2005 for a new design from CEA Grenoble (called the GTS-LHC source [6]) and the ion beam was accumulated and cooled in LEIR. This source has many modifications with respect to the former.

Both sources have the following common operational parameters: Lead is provided through a filament heated micro oven at the rear of the source, and oxygen is injected as an additional support gas, 14.5GHz micro-waves are injected for 50ms pulses (at 10Hz for better stability), at the end of the microwave pulse, the intensity of the high charge state ions from the source increases dramatically (called the afterglow mode of operation). The following linac can only operate up to 5Hz, therefore many source pulses are not accelerated.

The operation of the LHC Pb ion injection complex has required that the source runs for approximately 16 weeks for the injector chain to be set up for LHC (the long time is needed as setting up is done in parallel with proton operation) followed by typically 5 weeks for LHC (including setting-up and physics).

The GTS-LHC source is equipped with two micro-ovens for lead evaporation, and these are operated sequentially, typically both ovens need to be refilled (with a total of 2g of ^{208}Pb) after two to three weeks of source operation. The refill procedure, pumping and re-commissioning of the source takes a total of 24 hours. Even during stable operation, the source requires tuning every 24hours, with more interventions needed as the amount of Pb in the ovens begins to be exhausted.

The stability of the source has been improved by changing from an aluminium plasma chamber to a stainless steel version. Using stainless steel has lead to an increase in the microwave power requirement, from around 600W to 1800W for the production of Pb beams using 14.5GHz.

An 18GHz generator has been tested with the GTS-LHC source, for production of the standard Pb29+ ion beam it has not been possible to increase the intensity in the afterglow mode by the increase of the microwave frequency, neither with an aluminium or stainless steel plasma chamber. However, there is evidence that the change state distribution moves to a higher charge states, for example the intensity of charge-state Pb32+ can increase by approximately 60%.

Table 2: Ions tested in Linac3. The charge state chosen is optimal for the source and Linac (not the highest intensity from the source).

Ion	**Pb**	**O**	**He**	**In**
Source	GTS-LHC	GTS-LHC	ECR4	ECR4
Charge State	29+	4+	1+	21+
Intensity1 (μA)	200	220	500	80
Intensity2 (μA)	130	110	270	
Extraction Voltage (kV)	18.8	10.8	10.8	14.3
Reference	[8]		[7]	[9]

Intensity1: After post source ion separation spectrometer.
Intensity2: After RFQ.

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