A Test Stand for Ion Sources of Ultimate Reliability

R. Enparantza[a], L. Uriarte[a], F. J. Bermejo[b], V. Etxebarria[b], J. Lucas[c] J.M. Del Rio[d] , A. Letchford[e] , D. Faircloth[e], M. Stockli[f], P. Romano[a], J. Alonso[a], I. Ariz[a] and M. Egiraun[a]

[a]*Fundación Tekniker-IK4, Eibar, Spain*
[b]*University of the Basque Country, Dpt. Electricity and Electronics, Leioa, Spain, and Consejo Superior de Investgaciones Científicas, Inst. Estructura de la Materia*
[c]*Elytt Energy, Portugalete, Spain*
[d]*Jema Group, Lasarte, Spain*
[e]*ISIS Accelerator Division, Rutherford Appleton Laboratory, Didcot, UK*
[f]*Spallation Neutron Source, Oak Ridge National Lab, Oak Ridge, USA*

Abstract. The rationale behind the ITUR project is to perform a comparison between different kinds of $^{-}$H ion sources using the same beam diagnostics setup. In particular, a direct comparison will be made in terms of the emittance characteristics of Penning Type sources such as those currently in use in the injector for the ISIS (UK) Pulsed Neutron Source and those of volumetric type such as that driving the injector for the ORNL Spallation Neutron Source (TN, U.S.A.). The endeavour here pursued is thus to build an Ion Source Test Stand where virtually any type of source can be tested and its features measured and, thus compared to the results of other sources under the same gauge. It would be possible then to establish a common ground for effectively comparing different ion sources. The long term objectives are thus to contribute towards building compact sources of minimum emittance, maximum performance, high reliability-availability, high percentage of desired particle production, stability and high brightness. The project consortium is lead by Tekniker-IK4 research centre and partners are companies Elytt Energy and Jema Group. The technical viability is guaranteed by the collaboration between the project consortium and several scientific institutions, such the CSIC (Spain), the University of the Basque Country (Spain), ISIS (STFC-UK), SNS (ORNL-USA) and CEA in Saclay (France).

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INTRODUCTION

A consortium of research centres and industrial companies, partially supported by both the Basque and Spanish administrations, is carrying out an ambitious research programme that started with R&D work on ion sources. As it is well known, the beam current required from the ion source and LEBT depend strongly on the beam emittance, because the RFQ transmission decreases rapidly with increasing emittance and increasing beam current. For example, the ESS requirement of a current of 150-

mA at the beginning of the medium-energy beam transport requires an RFQ input current between 85 and 95 mA for a normalized rms emittance between 0.20 and 0.35 π.mm.mrad, which put into different words indicates that developing a low-emittance source is a must. The aim is to develop high-current, low-emittance ion sources and a LEBT that inflicts minimal emittance growth. The first phase of such a research programme which is financed through ministries of Industry and Education & Science [1] is well underway and consists on a test stand able to compare the emittance characteristics of $^{-}$H arc-discharge sources such as the Penning trap used at ISIS [2] and RF driven sources such as the multicusp $^{-}$H source being at present in use at SNS [3]. In the future, other types of sources, even proton sources as the CEA-Saclay [4] will also be able to be mounted and measured in the test bench.

The strategic goal for the coming three years will consist on the construction of a complete accelerator Front-End Test-Stand able to diagnose ion beams generated by the set of ion sources referred to above. The effort is conceived as a genuine R&D endeavour which will be financed by both Basque and Spanish Central Governments. The ion source test stand is being built at the University of the Basque Country. For that, several of its main constituents are being designed, specified and some of them are already being built. It is expected that the test stand will be operative by the end of 2009. The expected beam features on the test stand are summarised in Table 1. It is considered that going beyond 65 mA would require a serious effort to compensate for the space charge effects [5].

TABLE 1. Beam features

Parameter	Value
Max Pulse $^{-}$H	65 mA
Max Pulse e-	1A
Pulse Frequency	50 Hz
Duty cycle	6 %

Several parts or main areas can be distinguished in the project: the Faraday cage, the power sources, the ion sources and the diagnostics.

THE FARADAY CAGE

The ion source test stand is situated in a 5 m x 6 m base and 3.5 m high conducting aluminium container, which acts as a Faraday cage to isolate the ion sources from any type of electromagnetic interference and to avoid any accidental access to the high voltage components. The cabin is air conditioned to keep the inside temperature and humidity within acceptable limits. The main reason to choose a closed Faraday cage is to provide a stable environment to the main ion source components, so that the comparisons performed in the different kind of ion sources are reliable and not dependant on ambient conditions.

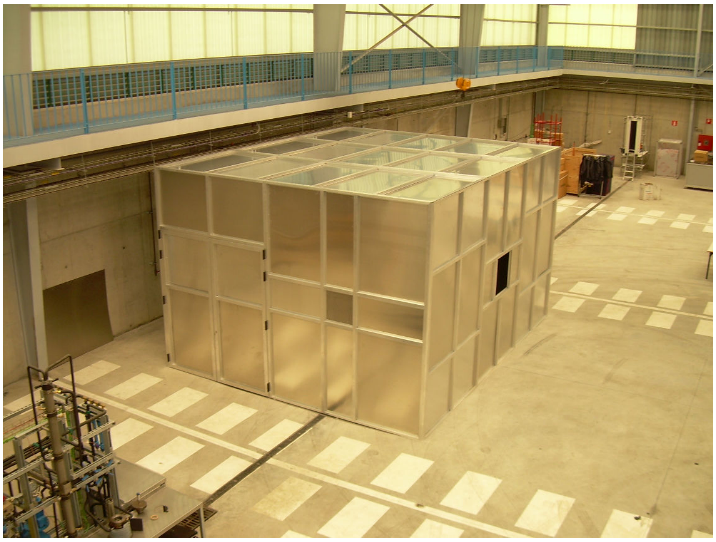

FIGURE 1. Faraday Cage of the ITUR ion source test stand at the Univ. Basque Country.

The Faraday cage also allows for:

1. Screening the residual electric field of the HV platform (see next chapter) so that it does not affect the rest of the components out of the cage.
2. Preventing human access to platform when in HV operation.
3. Protecting from X-rays or gamma rays, if required.

The roof is removable to allow for easily introducing heavy equipment and it has three 50 cm x 50 cm windows covered by 8 mm diameter hole perforated lids.

The cage is serviced from outside by the following supplies:

1. Hydrogen. Hydrogen gas tanks are situated outside the building and connected to the ion source through a seamless copper pipe that, inside the cage, is rubber made to provide galvanic insulation to the platform and the devices on it. A gas flow meter cuts the supply as soon as it increases beyond a limit.
2. Air. Three pipes of 0,5” diameter at 10 bar pressure have been planned.
3. Power. 400V 200kW
4. Air conditioned. An air condition system will be installed to control temperature and humidity inside the cage.
5. Exhaust tubes for turbopumps. 3 inch pipes outside the building. Air would contain H_2 and Cs, although in very low quantities.

THE PLATFORM

A High Voltage platform of dimensions 2,3 m x 4,3 m is mounted inside the cage and supported on 15 insulators separated some 900 mm from each other. The platform will be set to reach 100kV, thus kept at 800 mm distance from the cage walls and as well as from the ground. Insulators are made of C130 porcelain and are able to withstand 325 kV lightning impulse. The platform is made of an aluminium profile grid covered by aluminium sheet plates and with all edges rounded to prevent zones where the electric field may concentrate. It is calculated to bear more than 4 kN/m^2 weight.

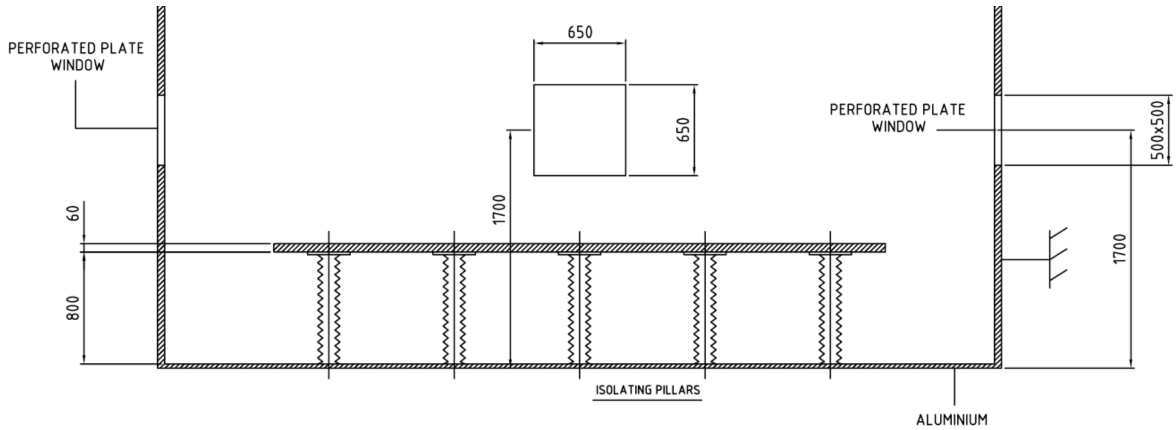

FIGURE 2. Sketch of the HV platform on 800 mm insulators

THE POWER SUPPLIES

Several power supplies are required to run the ion sources test stand. As said, at least in a first stage, the test stand should be able to accommodate two types of ion sources, namely, the $^{-}$H pulsed source of ISIS (Penning type) and that of SNS (multicusp RF powered). Thus, power sources implemented should be able to generate the energy required for both types of sources.

The DC Platform Power supply

The DC platform power supply is designed to keep the platform at a maximum voltage of 100 kV in order to generate the potential required to extract and accelerate the ions from the ion source itself. The main features of this power source are gathered in Table 2 below.

TABLE 2. Platform DC power supply.

Parameter	Value
Maximum Voltage	100 kV
Intensity	20 mA

Drop	0,10%
Precision	0,10%
Electron return to extraction voltage	25 kV
Condensators capacitance	1 μF
Polarity change (manual)	Yes
Discharge time	2 s
Charging time	30 s

It should be noted that, as shown in the table, electrons do not return to earth voltage but only to the extraction one, ie, 25kV (post acceleration is as large as 75 kV), so the post acceleration is restricted to the 65 mA ion intensity.

As seen, the platform is prepared for changing the polarity in case the source is required to change to a $^{+}$H source. This is thought to be a manual polarity change rather than automatic.

In order to keep the drop at 0,1% during the 1,2 ms pulse (50 Hz, 6% duty cycle), a bench of condensators is required to be put in parallel with the DC power supply. Considering that electrons are extracted only up to 25kV, a 1μF capacitance is considered enough. A discharge time of 2 s is estimated necessary from the point of view of safety, so that nobody accesses the platform before discharge is complete. Discharge would be passive with a resistance in parallel with the output capacity that would give time constant (RC) equal to 0,25 s, for example. A circuit breaker will be put in series with the resistance to unload the capacitors. Another circuit breaker will also be installed in case the resistance would not work. This would be an external circuit breaker that would short circuit the condensators and that would be installed in the doors lock, so that the door cannot be opened without the platform been disconnected and discharged.

Along with the capacitors, an isolating transformer is required to supply the systems on the HV platform, which have an earth at platform level. Therefore, it is necessary that the isolation between primary and secondary is at least equal to 100kV. Concerning power requirements, estimations indicate that the maximum required instantaneous power could be around 300 kW, although the average power for the 20 ms cycle would not be higher than 35 kW. Thus, a 100kVA transformer should be enough, assuming that the different elements operating in pulses have enough condensators in their power supplies as to not transferring the consumptions peaks to the mains. Three-phase 400 V seems to be the most appropriate voltage, a secondary in star being required to connect the neutral to the platform earth. Transformation ratio is 1:1. The transformer will be oil filled.

The plasma formation power supplies

The power supplies required to form the plasma are different for different types of ion sources. The ISIS Penning type ion source has a Pulsed discharge power supply together with a DC one. In the case of ITUR, a single power supply capable of providing pulsed and DC current will be implemented. The pulsed current should have 50 Hz repetition rate and 0,15 duty cycle, whereas the DC current should provide a maximum voltage of 800 V (at 10 mA) and a maximum intensity of 2 A (at 80 V). The characteristics of this power supply are shown in Table 3.

TABLE 3. Discharge power supply (Penning)

Parameter	Value
High Current Discharge Voltage	400 V
High Current Discharge Intensity	80 A
Frequency	50Hz
Duty cycle	0,15
Low Current Discharge Voltage	800 V
Low Current Discharge Intensity	2 A
Power	250 W

The RF ion source requires a couple of discharge power supplies for plasma formation: a pulsed one and a continuous wave (CW) one. These are defined by their parameters in Table 4.

TABLE 4. Discharge power supplies (RF multicusp)

Type	Parameter	Value
Pulsed RF power supply	Power Frequency	20-60 kW 2 MHz
CW RF power supply	Power Frequency	200 W 13 MHz

The extraction power supply

The Penning type ion source requires, in addition, a pulsed extraction power supply, which is not needed by the RF multicusp ion source. The features of this extraction power supply are gathered in Table 5.

TABLE 5. Extraction power supply (Penning)

Parameter	Value
Voltage	25 kV
Intensity	2 A
Frequency	50 Hz
Duty factor	10 %

This is a critical element and a source of difficult to address problems. In operation, it easily shuts off due to demanding working conditions. So it has to be robust, protected against short circuits and voltages coming in and able to condition the electrodes. In ITUR, an up to date solid state power supply will be built.

THE ION SOURCES

In a first stage, as said, two types of $^{-}$H ions sources will be tested: the ISIS Penning type and the SNS multicusp RF source. Other sources, even proton ones, are also planned to be tested in the future.

Penning Type $^{-}$H Ion Sources

A Penning Type ion source will be developed from the sources currently being used in ISIS at the Rutherford Appleton Laboratory. In this type of sources, the beam is generated by discharges on a plasma hold on mutually perpendicular electric and magnetic fields. It is a surface plasma source that produces energetic $^{-}$H ions on the cathode surface of the discharge chamber. Caesium is used to increase the production of ions. The source works with high energy density emission [6], over 1 Acm^{-2}, far higher than what could be obtained in volumetric sources. Fig. 3 shows the ISIS Penning type source [7].

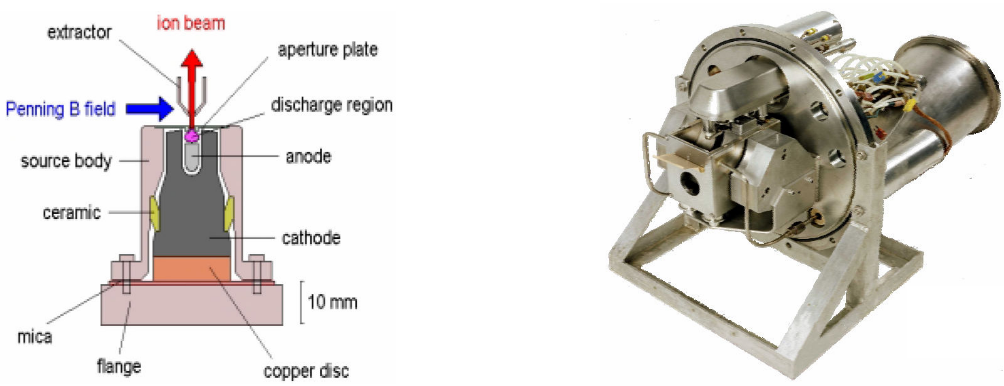

FIGURE 3 – Penning type source: (a) sketch; (b) source used in ISIS

Surface erosion is probably the most important factor limiting its useful life. In the ISIS Penning type source, anode and cathode surfaces are eroded and the erosion rate depends on the electrode material, the uniformity of the Penning discharge and the source operating conditions. All those parameters are being studied in order to maximise its life. Experience shows average duration values of 26 days and a maximum of 49 days [8].

Volumetric $^{-}$H Ion Sources

This type of sources are being used and tested at the Institute of Applied Physics (IAP) of Frankfurt (Fig. 4b) [9] and the SNS of the Oak Ridge National Laboratory as well as in DESY. The low electron temperature and the high energy densities that can be reached with these sources make them very attractive. The SNS source (see Fig. 4a) is based on a design of the Lawrence Berkeley National Laboratory (LBNL) [10].

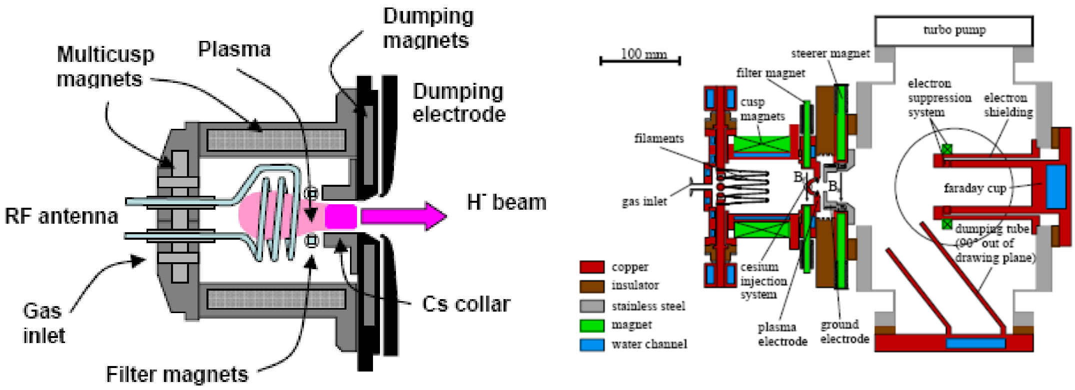

FIGURE 4 – (a) SNS (LBNL) source; (b) Source design for the ESS (IAP-Frankfurt)

The main difference between both types is the way in which energy is transmitted to the plasma. SNS uses a 2 MHz radiofrequency field generated by a RF antenna to heat the plasma. On the other hand, in the IAP design, it is the discharge of a filament arch which keeps the plasma. In both cases, Caesium is evaporated to favour forming negative ions. The DESY source is a multicusp Caesium-free source.

The duration of the source is limited in one case to the life of the antenna and, in the other, to the wear of the filament. At the moment, the life of this type of sources is smaller than the Penning one although developments are carried out to significantly increase it [11].

ECR type $^{-}$H and proton sources

Although not contemplated in the first version of the ion source test stand, this type of sources should also be able to be tested.

Specifically, ECR type proton sources such as the SILHI in CEA/Saclay have already shown that could meet the requirements of the ESS [12]. As it is reported, durations up to 6 months have already been achieved in CW mode, with good emittance and current values (>100 mA). As mentioned, the ion source test stand will be prepared to easily change the polarity of the platform power supply to allow proton sources to operate.

THE DIAGNOSTICS

A basic set of diagnostic elements have been selected to measure the parameters of the beam extracted from the ion sources. These will be kept in a diagnostic vessel in appropriate vacuum conditions by a couple of magnetic vacuum pumps. Table 6 shows the list of devices that will be used in a first stage.

TABLE 6 Diagnostics

Measurement	**Component**
Current	Slow Current Transformer
Current	Faraday Cup

Space charge effect	Buffer Gas delivery System, Flow controller
Emittance and profile	Scintillator, Interchangable Pepper Pot, CCD Camera
Degree of stripping	Diagnostic dipole
Energy spread	Retarding Potential Energy Analyser

Current measurement is firstly thought to be carried out by a Slow Current Transformer able to measure long pulses and macropluses up to some milliseconds. A fast current transformer for high frequencies is not considered strictly necessary at the stage of development of the ion source test stand. An extra current measurement will be registered by means of a Faraday Cup that will also act as a beam stop. This second measurement will allow testing the first one.

The space charge effect allows having an idea of the charge distribution in space. For that purpose, a Buffer Gas delivery System will be implemented with its corresponding gas flow controller.

Emittance is a key feature to be measured in a beam in order to assess its quality. There are a number of devices to measure it, such as slit wire scanners, slit grid scanners, Allison scanners and others. Although not as precise as others, an interchangable Pepper-pot type device with its scintillator and CCD camera will be installed in the diagnostic vessel and will allow to measure the emittance as well as the beam profile. The measuring device will be movable so that different measurements can be taken at different z distances from the ion source extraction area, this way overcoming the drawbacks of fixed emittance measuring devices [13].

The degree of stripping, percentage of neutral atoms to ions, will be obtained by a diagnostic dipole. Finally, the energy spread of the beam will be measured by a Retarding Potential Energy Analyser.

These measurements are considered as basic for the ion source test stand, the aim of which is to compare beams produced by different ion sources.

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