Simulation of H⁻ ion source extraction systems for the Spallation Neutron Source with IBSimu

Taneli Kalvas¹, R. F. Welton², O. Tarvainen¹, B. X. Han² and M. P. Stockli²

1. Department of Physics, University of Jyväskylä, Finland
2. Spallation Neutron Source, Oak Ridge National Laboratory, USA

14 September, 2011

Contact: T. Kalvas <taneli.kalvas@jyu.fi>

ICIS11, Giardini-Naxos, Italy
Presentation outline

- Introduction to IBSimu
- SNS baseline extraction
- Proposed high-current extraction
- Magnetic LEBT for SNS
IBSimu is an ion optical code package made especially for the needs of ion source extraction design. The code can model

- Systems of electrostatic and magnetic lenses
- High space charge beams (low energy)
- Positive and negative multispecies 3D plasma extraction

The code is made in C++ and is released* freely under GNU Public Licence.

- Highly versatile and customizable.
- Can be used for batch processing and automatic tuning of parameters.

Plasma parameters

Previously, the same plasma parameters were used as in other published simulation work. Fine tuning was now made to match results to experimental emittance data.

- Transverse temperature of $e^-$ and $H^- \ T_t = 2.0 \text{ eV}$
- Plasma potential $U_P = 15 \text{ V}$
- Emitted electron to ion ratio $I_{e^-}/I_{H^-} = 10$
- Thermal positive ion to negative ion ratio $\rho_{X^+}/\rho_{H^-} = 0.5$
- Initial energy of particles $E_0 = 2.0 \text{ eV}$
Angle and Offset

A parametric scan was done to find an optimum delivering beam centered and straight in the RFQ in IBSimu:

Optimum at 1.4° (24.4 mrad) source angle and 0.8 mm offset. These parameters were as a reference point in simulations.
Emittance results

Experimental data at RFQ (y,y')
Simulation data at RFQ (y,y')
Simulation data at RFQ (x,x')

Experimental emittance data: B. X. Han, RSI 81 02B721 (2010)
Plasma meniscus asymmetry

15 mA

25 mA

50 mA
Linac beam of $\sim 60$ mA will likely be required by a future power upgrade.

- Beam is approaching the acceptance limit of the RFQ near these current levels.
Idea: Do electron dumping downstream at higher, intermediate energy

- Enables use of high E-field, low B-field, flat meniscus extraction leading to low emittance. *R. Keller, S. K. Hahto, PNNIB-06*

- RFQ injection done by magnetic LEBT, which is under development at SNS. Simpler extraction is sufficient.

- Preliminary design made at Oak Ridge using PbGuns and Lorentz, IBSimu was used to refine the system and analyze it with greater detail.
Proposed design
Proposed design

First gap optimized for flat meniscus

Up to 100 mA of H- current
Baseline extraction, 60 mA
900 V/mm at 1 mm from meniscus

New extraction, 60 mA
1600 V/mm at 1 mm from meniscus

New extraction, 100 mA
2100 V/mm at 1 mm from meniscus

Extraction field
Proposed design

First gap optimized for flat meniscus

Up to 100 mA of H- current
Proposed design

First gap optimized for flat meniscus

Up to 100 mA of H- current

Up to 1 A of electrons dumped inside Einzel at fixed 10 keV energy.
Thermal considerations

Surface temperature for 2.0 mm thick copper dump

Copper melting limit at T=1357 K

Surface temperature (K)

Time (s)

Pin=1000 W/mm²
Pin=500 W/mm²
Pin=250 W/mm²
Power density on dump

Assuming 100 mA of H\(^-\) and e\(^-\) to H\(^-\) ratio of 10

Back surface power density (W/mm\(^2\))

\( y \) (mm) \hspace{2cm} \( xz \) (mm)

0 5 10 15 20 25 30 35 40

0 50 100 150 200 250 300 350 400
Proposed design

First gap optimized for flat meniscus

Up to 100 mA of H- current

Up to 1 A of electrons dumped inside Einzel at fixed 10 keV energy.
Proposed design

First gap optimized for flat meniscus

Up to 100 mA of H- current

Adjustable puller electrode voltage

Up to 1 A of electrons dumped inside Einzel at fixed 10 keV energy.
Puller voltage adjust
Emittance comparison

![Graph showing RMS emittance comparison](image)

- Experimental data at RFQ (y,y')
- New extraction (y,y')
- New extraction (x,x')
- Baseline puller (y,y')
- Baseline puller (x,x')

**Y-axis:** RMS emittance (mm mrad)

**X-axis:** Extracted H⁻ current (mA)
Magnetic LEBT

Designed at SNS and is currently at prototype stage
Magnetic LEBT simulations

• Magnetic LEBT simulated with IBSimu using particle data from
  1. Baseline extraction up to puller electrode with angle and offset
  2. New extraction
• Particle distributions were centered with a pair of parallel plates.
• Magnetic field data calculated with FEMM.
• High degree of compensation was assumed.
• Solenoid currents were optimized to get Twiss $\alpha = 1.7$ and $\beta = 0.06$ m.rad at RFQ.
Magnetic LEBT simulations

Baseline extraction, 60 mA, 90 % compensation

New extraction, 60 mA, 90 % compensation

New extraction:

- 80 mA inside RFQ acceptance with 90 % compensation
- 100 mA inside RFQ acceptance with 95 % compensation
- New extraction is compatible with magnetic LEBT.
Emittance comparison at RFQ

Comparisons of emittance numbers should be done with caution.
Summary

**Bottom line:** New extraction has more potential than baseline extraction.

- Gives lower emittance beam at currents higher than 40 mA.
- Possibly increases beam intensity from source.
- Work need to be done to increase safety factor of electron dump.
- Hopefully **prototype** will be soon built.
Thank you for your attention!

Please notice that the 3rd International Symposium on Negative Ions, Beams and Sources is at Jyväskylä in September 2012.

http://www.nibs2012.jyu.fi/