World Brightest (Class)
J-PARC RF-Driven H$^-$ Ion Source for High Energy Accelerators

Akira Ueno, K. Ohkoshi, K. Ikegami, A. Takagi, S. H. Asano, and H. Oguri

J-PARC Center, Tokai-mura, Naka-gun, Ibaraki-ken 319-1195, Japan
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• J-PARC STATUS
• EXPERIMENTAL SETUP & METHODS
• EFFECTS OF IMPURITY ELEMENTS
• CONCLUSIONS

* NIBS2016 Poster Presentations on J-PARC-IS: TueP23 & 22
  “Status of the RF-driven H⁻ ion source for J-PARC linac”
  “Emittance Evaluation Admissible as Standard Method of
  J-PARC RF-Driven H⁻ Ion Source”
  :base cor., 100&95%beam def.
J-PARC (Japan Proton Accelerator Research Complex)

Materials and Life Science Experimental Facility

Hadron Experimental Facility

LINAC (330m)
- 50mA (40mA)
- 500μs × 25Hz
- IS: 58mA (45mA)

25Hz 3GeV Synchrotron
- 1MW (0.5 → 0.2MW)

0.4Hz 30GeV Synchrotron
- 0.75MW (0.4MW)

to Super-Kamiokande (Neutrino Experimental Facility)
Cross-sectional view of setup of IS-TS. Thick PE(16mm-45°:1.5I₇⁻), AMFC(1.1I₇⁻), Tₚₑ~70 °C(0.75εₕₚₑₓ/γ), 50W-CW-30MHz RF igniter(large φₚₑ=9mm,17SCCM,pulse H₂)
EFFECTS OF IMPURITY ELEMENTS
bursty fluctuations (Ar and N\textsubscript{2}) of pressure (P)

Observed bursty fluctuations of vacuum pressure (P) shown as relationship between time after TMPs start and vacuum pressure.

→ No bursty P fractuation
& 2~3 times improved pumping speed
from 1 atm→5×10\textsuperscript{-5} Pa

Photo of O-ring groove of end-plate and cross-sectional drawings of O-ring groove with and without ventilation pathway for confined Ar and N\textsubscript{2}.
Drawings of half-sets of various RFMs:

(a) for #2~6: operated stably with intermittent slight Cs injection,

(b) for #7': with O-ring groove ventilation pathways: easy operated at TS,

c) for #6': with inv. ext. mag. O-ring groove vent. 700°C, 24h baked PCH (less impurity) slightly difficult to operate

d) for #6: operated stably with intermittent slight Cs injection,

#2 ~6 → #7'

Ar&N₂  Ar&N₂

stable stable

Measured horizontal magnetic field (Bx) on beam axis produced by RFMs and ESMs for #0~#2~6 (blue or dark-gray in gray scale dashed line) and #7' (red or gray solid line).
EFFECTS OF IMPURITY ELEMENTS
with Ar&N$_2$ → without Ar&N$_2$ & low RFF

#4
Ar&N$_2$
0.291π
0.925
41.6kW

#7'
0.269π
0.936
26.4kW
EFFECTS OF IMPURITY ELEMENTS
with Ar&N$_2$→ without Ar&N$_2$ & low RFF

Waveforms of 2 MHz-RF forward and reflected voltages (trace1 and trace2), H$^-$ ion beam intensity (IH- 20mA/Div. : trace3) and extraction current (I$_{ext}$ 100mA/Div. : trace4)

* $\phi_{PE}$=9mm, $Q_{H2}$=17SCCM by CW30MHzRF(50W)

#2~6 with Ar&N$_2$
~10% I$_H$- claimed by ring-groups
due to large Cs reduction

#7' without Ar&N$_2$
very flat flat-top
due to small Cs reduction

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EFFECTS OF IMPURITY ELEMENTS

pre-conditioning procedure & 8h 50kW&5%duty cond.

(pre-cond. day) Set $T_{PE} = 300^\circ C$ and wait $P = 1.5 \times 10^{-5} \text{ Pa}$ (2~3 h), keep $T_{PE} = 300^\circ C$ and $P_{2MHz} = 25\text{kW}&2.5\%\text{duty cond.}$ & RFs&$H_2$ off(1.5\times10^{-5}\text{Pa within 15min}) →32\text{kW}→38\text{kW}→42\text{kW}→46\text{kW}→50\text{kW}$ (6~5 h)

(1st beam day) Set $T_{PE} = 300^\circ C$ and $50\text{kW}&5\%\text{duty}$ ~20min, set $T_{PE} = 70^\circ C$, ~15\text{kW}&2.5\%\text{duty}$ and $I_{H^-}$ extraction with $I_{ext} < 300\text{mA}$ →(gradually increase $P_{2MHz}$ by 2~4h)~26~30\text{kW}$ and $I_{H^-} = 66 \text{ mA}$

(2nd beam day) “same procedure”

(3rd beam day) “same procedure”

(50kW&5%duty cond. day) Set $T_{PE} = 300^\circ C$ and 8h 50kW&5%duty cond.

(1st beam day) Set $T_{PE} = 300^\circ C$ and 50kW&5%duty ~20min, set $T_{PE} = 70^\circ C$, ~15\text{kW}&2.5\%\text{duty}$ and $I_{H^-}$ extraction with $I_{ext} < 300\text{mA}$ →(gradually increase $P_{2MHz}$ by ~4h)~26~30\text{kW}$ and $I_{H^-} = 66 \text{ mA}$

(2nd beam day) “same procedure”
EFFECTS OF IMPURITY ELEMENTS

before→after 8h 50kW & 5%-duty cond.

before cond. #7'
0.269\pi
0.936
26.4kW

after 8h
50kW
50Hz cond.
#7'
0.229\pi
0.942
29~28 kW
for 4h
EFFECTS OF IMPURITY ELEMENTS
brand-new #7' → 700°C 24h baked #6' (less impurity, inv. ext. mag.)

2MHz-RF Plasma emission spectrums for #7' (red solid line) and #6' (blue dashed line).

Please teach us the candidate for the element(s) emitting 250 or lower ~ 400 nm.

Drawings of half-sets of various RFMs:
(b) for #7' (with O-ring groove ventilation pathways) : easy operated at TS,
(d) #6' with inverse external filter magnets : slightly difficult to operate due to weak Cs reduction force.
EFFECTS OF IMPURITY ELEMENTS after 8h-50kw-50Hz cond. #7' & #6' RFF&inv.ext.

#7' 0.229π 0.942 29~28kW for 4h

#6' 0.233π 0.945 for 1h 26.1kW insuf. Cs red.
EFFECTS OF IMPURITY ELEMENTS

on 3rd beam day after 8h T_{PE}=300^\circ C cond. by insuf. H\textsubscript{2}Os

insuf. H\textsubscript{2}Os

#6'

0.396\pi

0.898

Trace2D back. trace

good agree. with BEAMORBT simu.

±100mrad

>>

±65mrad
Relationship between principal parameters effective to $\text{H}^-$ ion emittances and measured emittances ($\varepsilon_{95\%\text{nrm}sx}$ and $\varepsilon_{95\%\text{nrm}sy}$).

Photo of $\text{H}_2\text{O}$s feeder composed with 13 cm pipe as $\text{H}_2\text{O}$ reservoir of 1.6 cc, 15$\mu$m-filter (Swagelok SS-4FW-15), two stop valves, purge valve and double pattern metering valve (Swagelok SS-SS2-D) with $C_v$-value of 0.0004. $\rightarrow$ no emittance expansion
CONCLUSIONS

(1) Improvements by Ar and $N_2$ elimination & $\sim$half rod-filter-field
- $\varepsilon_{95\% \text{nrms} x/y} = 0.29 \rightarrow 0.27 \, \pi \text{mm} \cdot \text{mrad}$ by no chem. effects of $N_2$? (AlN)
- $P_{2\text{MHzRF}} \sim 40\text{kHz} \rightarrow 26 \sim 30\text{kHz}$ by low rod-filter-field $\rightarrow \sim 1 \text{ year life}$
- $10\% I_{H^-} \text{ tilt} \rightarrow \text{flat pulse} \quad \text{by smaller Cs reduction rate}$
  $\rightarrow 2 \sim 3 \times$ times faster pumping speed from 1atm $\rightarrow 15 \times 10^{-5}\text{Pa}$

(2) $T_{PE} = 300^\circ\text{C} \& 8\text{h} 50\text{kW} 5\% \text{duty conditioning}$
- $\varepsilon_{95\% \text{nrms} x/y} = 0.27 \rightarrow 0.23 \, \pi \text{mm} \cdot \text{mrad}$ for 4h by less impurity?

(3) Effects of $700^\circ\text{C} 24\text{ h} \text{ baking in vacuum furnace (less impurity)}$
  $\rightarrow$ RFFs for brand-new PCH + inv. ext. mag. near optimum
  *gapped RFFs instead of + inv. ext. mag. will be tested

(4) Slight $H_2\text{Os near plasma electrode beam hole for low } T_{PE} = 70^\circ\text{C}$
  $\text{deform meniscus} \& \text{reduce divergence-angle} \pm 100 \rightarrow \pm 65\text{mrad} \& \varepsilon$
  ($H_2\text{Os feeder with } 15\mu\text{m-filter etc. is supplying suitable } H_2\text{Os}$)
  *Deformation mechanism is expected to be solved by simulation.

Thank you for your attention.

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(a) #7: 95% beam distribution
- Fit norm $1.5 \pi e_l \alpha_x = 1.499, \beta_x = 0.221$
- $I_H = 46 \text{mA}, P_{2\text{MHzRF}} = 18.5 \text{kW}$
- $\gamma_{95\%\text{rms}} = 0.226 \pi \text{mm} \cdot \text{mrad}$

(b) #7: 100% beam distribution
- 95% fit norm $1.5 \pi e_l \alpha_x = 1.499, \beta_x = 0.221$
- 100% fit norm $1.5 \pi e_l \alpha_x = 1.290, \beta_x = 0.207$
- $I_{SFC}$ used to correct base
- $I_H = 46 \text{mA}, P_{2\text{MHzRF}} = 18.5 \text{kW}$
- $\gamma_{100\%\text{rms}} = 0.271 \pi \text{mm} \cdot \text{mrad}$

(c) #7: Frac in 100% beam with 95% fit el
- $f_{\text{in}}(1.5) = 0.937 (43.1 \text{mA})$
- $I_H = 46 \text{mA}, P_{2\text{MHzRF}} = 18.4 \text{kW}$
**S-SFC EMITTANCE MONITOR**

(movable Slit & movable Slit with Faraday Cup)

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Phot of a set of S-SFC emittance monitor heads.

Drawing of a set of S-SFC emittance monitor heads.