Development of Neutral Beam Injection System for VEST Tokamak Plasma Heating

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Developing the VEST NBI System

More than 0.5 MW NB Power
But Lower than 20 keV Beam Energy

High Efficiency Ion Source

- High Efficiency Plasma Generator
  - Arc Efficiency > 0.5 A/kW

- Extraction System with High Optimum Perveance
  - Optimum Perveance > 13 uP
    (20 keV / 35A)

Stable & Functional Power Supply System

- Arc, Filament, High Voltage
  - 80 kW, 12V/1200A
  - 20 keV / 40 A
  - 10 msec pulse

Simple and Conservative NB Beamline

- Beamline Components
  - Neutralization Efficiency > 80%
  - Power Loss < 5%

Vacuum System

- Stable discharge
  - beam extraction
- Not affect to Tokamak Plasma

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## Progress of Developing VEST NBI System

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1. Design of the VEST NBI System
1. VEST NBI Ion Source : Plasma Generator

- TFTR Type magnetic multi-cusp bucket
  + Modification of E-dump & Filaments
  → small cathode & floating area to increase arc efficiency & keep arc discharge

- Bucket : axial cusp 40 arrays : parallel to beam axis
- E-dump : checker board magnetic multi-cusp SmCo permanent magnet
- Diameter : 2.0 mm, hair-pin type W filaments 12 EA @ field free region
- Maximum arc power : **80 kW**
- Plasma uniformity : ± **10 %**
  (beam extraction area : **130 mm x 450 mm**)
- Target value of the arc efficiency : > **0.5 A / kW**
2. VEST NBI Ion Source : Extraction System(1)

- **Minimum target performance**: 20 keV / 35 A H ion beam extraction
- **Single stage beam system**:
  Plasma grid – Suppression grid – Ground grid  
  (PG) (SG) (GG)
  Al Mo G10 CuCrZr Peek CuCrZr Al
- **No Cooling channel** (Max. pulse length : 10 msec)
- **G10 insulator** (Viton O-ring sealing for vacuum)
- **Single segment** per grid : 77 Slots
- **Beam area** : 13 x 45 cm$^2$
  (Transparency : $\approx 58\%$)
- **Current Density** : $\approx 120$ mA / cm$^2$
- **Beam divergence angle** : $< 1.0^\circ$ (short direction)  
  $> 2.3^\circ$ (long direction)
- **Beamlets focusing by aperture displacement**

Maximum : $\sim 140$ kV/cm
2. VEST NBI Ion Source : Extraction System (2)

Beam Extraction Simulation by KOBRA3-INP

- Maximum focal angle : 2° (0.25 mm)
- Focal length : 2.3 m (beam duct : 1.8m from exit grid)
- Center 7 beamlets : Un-focusing
- 6 beamlets : 1° focusing
- 58 beamlets : 2° focusing
- Power loss into beamline components : < 10%
3. Power Supply System for VEST NB Ion Source

- **Filament power supply**
  - 2EA 12V, 100Ah Battery per filament

- **Arc power supply**
  - 2-stage : Super capacitor module(48V, 166F)

- **High voltage power supply**
  - 2-stage Marx generator : Variable Voltage within 10ms pulse
4. Beamline Components (1)

- **Beam port size**
  \[ R = 40 \text{ cm}, \ a = 30 \text{ cm} \]

- **Beam injection angle**

- **Beam transmission code simulation**
  - Beam Energy: 20 keV / 40 A
  - Beam divergence: 1° (horizontal) / 2° (Vertical)
  - Total transmission efficiency: 95%
4. Beamline Components (2)

- Time pressure calculation in the beamline components
3. Beamline Components(3)

- Cryo pump (~8000 L/sec)
- Rotatable calorimeter plate
- OMA port
- Neutralizer
- View port for beam diagnostics
- Gas feeding port
- Ion Source flange
- Additional port for DNB
- Telescope port for beam diagnostics
2. Manufacturing & Assembling
1. VEST NBI Ion Source

- Assembling beam extraction system

Installed at NB Test Stand
2. Power Supply System

- Filament & arc discharge power supply
  - Filament operation test
  - Tests of arc discharge to dummy load

- High voltage power supply
  - Tests High voltage power supply system (2-stage voltage and timing control)

- Overcurrent circuit
  - $I_{\text{norm}}$: <100A
  - Bandwidth: <100kHz
  - Circuit energy <10J (<1kA and 10us)
3. Experimental Results of the Beam Extraction Conditioning @ NBTS
Operational Properties of Plasma Generator
Beam Extraction Conditioning (1)

**Filament Voltage [V]**
- 0.0 to 11.7 V
- 0.0 to 11.0 V

**Filament Current [A]**
- 0.0 to 60.0 A
- 0.0 to 60.0 A

**Gas [V]**
- 0.0 to 3.9 V
- 0.0 to 3.9 V

**Arc Voltage [V]**
- 0.0 to 120.0 V
- 0.0 to 120.0 V

**Arc Current [A]**
- 0.0 to 600.0 A
- 0.0 to 600.0 A

**Beam Current [A]**
- 0.0 to 10.0 A
- 0.0 to 10.0 A

**Decel Voltage [V]**
- 0.0 to 10.0 V
- 0.0 to 10.0 V

**Decel Current [A]**
- 0.0 to 5.0 A
- 0.0 to 5.0 A

**Design Arc Efficiency**
- 600 ~ 800 sccm
- 400 ~ 500 sccm

**Arc Power [kW]**
- 0.5 A/kW
- 0.67 A/kW
Beam Extraction Conditioning (2)

High Voltage Holding Test

- High Voltage
- # of Notch Interrupt

Trial #

Beam Extraction Shot #

- Beam Extraction Shot #
- # of Trial Shot
- High Voltage

Beam Current [A]

Beam Energy

Arc Current [A]
Beam Diagnostics(1)

- **Operational Suppression Grid Voltage** [-kV]
- **Beam Energy** [keV]
- **Normalized I [a.u.]**
- **Relative Peak Width** [nm]
- **Extraction Ion Current** [A]

**Graphs:**
- Graph 1: Operational Suppression Grid Voltage vs. Beam Energy
- Graph 2: Extraction Ion Current vs. Behavioral Indices
- Graph 3: Normalized I [a.u.] vs. Operational Suppression Grid Voltage
- Spectrogram: Wavelength [nm] vs. Intensity [a.u.]

**Image:**
- Bending Magnet Scraper
- Neutralizer Cell at NB test stand
- Indicators: ~500 mm, ~2.8 m from exit grid
Beam Diagnostics (2)
Future Works

- **Ion Source**
  - Beam extraction conditioning up to 20 keV or 15 keV
  - Determination of the operation scenario for PW supply system
    : Jan. 2017

- **Power Supply System**
  - Determination of arc input power & charging system
  - Determination of HV input power & charging system
  - Manufacturing 20 kV switch for Marx generator & test
  - Final manufacturing and assembling the PW supply including Transmission line
    : Feb. 2017

- **Beamline**
  - Final design & manufacturing : vacuum test
  - Transport to VEST site @ SNU
  - Commissioning VEST NBI system
    : May 2017
VEST NBI System consisting of an ion source, power supply system, gas feeding and beamline components has been designed to support expanding physics experiments of the VEST tokamak plasma.

VEST NB ion source is being conditioned up to 10 keV / 30 A hydrogen ion beam extraction with 80 msec pulse length.

Optimum beam perveance of VEST NB ion source is around 28 uP which is much higher than that of the simulation results. But beam extraction above 10 keV beam energy was unstable and frequently makes arc notch.

Power supply system needs to modify and manufacture additional components after determinations of the operation scenario for arc discharge and beam extraction.

Design of the VEST NB beamline is in progress and the beamline will be installed at VEST site end of March 2017. Needs for additional components such as a beam bending system, an ion dump, a cryo-pump, and a gate valve are not yet determined.
Thank you for your attention!