Electron Bernstein Wave heating for the TJ-II stellarator

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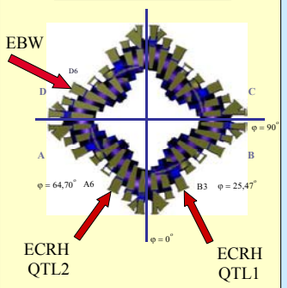
Introduction

- ✓ The electron Bernstein wave (B-mode) is a longitudinal electrostatic wave, which has no density barriers and can penetrate deep into the plasma, where it can be absorbed via the electron cyclotron mechanism. The excitation of the B-mode is based on the O-X-B mode or the direct X-B mode conversion.
- ✓ EBW experiments have been succesfully carried out in W7-AS and in Heliotron-J [1, 2].
- ✓ A 3D beam/ray tracing code (TRUBA) has been developed to study the microwave behaviour in the specific TJ-II plasma geometry. The calculations show that Bernstein waves excited by either X-B other O-X-B conversion scheme in the first harmonic (28GHz) can be used to create and heat a dense plasma in TJ-II [3].
- ✓ The utilization of the B-mode heating in the target plasma will significantly increase the efficiency of NBI.
- ✓ Physics issues in TJ-II plasmas heated by EBW:
  - Characterization of this heating method
  - Density limit studies
  - Neoclassical studies
  - Kinetic studies

TJ-II stellarator

4-period helical axis stellarator
B ≈ 1 T
R = 1.5 m

Launching ports

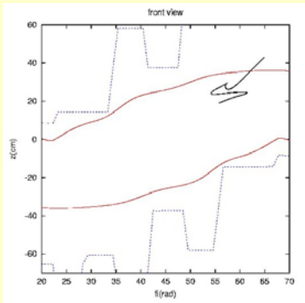


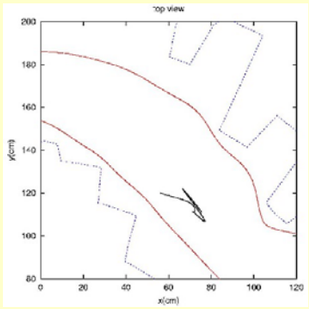
Calculations

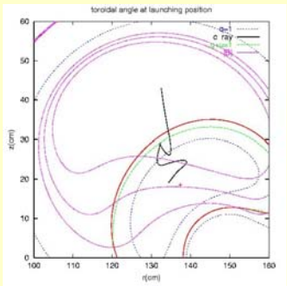
Although both scenarios: X-B and O-X-B in the first harmonic are feasible in the TJ-II from the theoretical point of view [4] the O-X-B1 has been chosen to carry out the experiments due to accesibility restrictions of the launching position inside the TJ-II vacuum vessel.

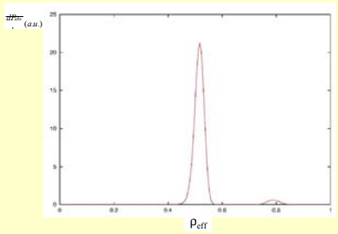
The optimum launching direction has been determined by single ray tracing calculations. Several positions on the O-mode cut-off surface, with total transmission efficiency (T=1) and covering a wide range around the injection port, have been considered. The chosen position has the most centered (closest to the plasma center) and localized power deposition. (The calculations have been carried out with the magnetic field configuration optimized for present ECRH) [5].

$$n_e = 1.7(1-\psi^{1.375})^{1.5} \quad 10^{13}\ \mathrm{cm}^{-1}$$
$$T_e = 0.7(1-\psi^{1.125})^{1.25} \quad \mathrm{KeV}$$





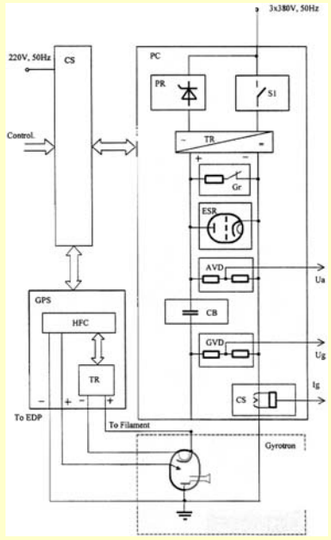




Gyrotron parameters

- ✓ Frequency: 28 GHz
- ✓ Power: 300-350 kW
- ✓ Pulse duration: 100 ms
- ✓ Cathode voltage: 60-70 kV
- ✓ Beam current: 13-25 A
- ✓ Filament voltage: 30-32 V
- ✓ Filament current: 19-20 A

High voltage power supply



- ✓ Output pulsed voltage: 20-70 kV
- ✓ Maximum load current: 25 A
- ✓ Pulse duration: 0.1 – 100 ms
- ✓ Repetition rate: 0.3-2 pulse/min
- ✓ Maximum leading edge: 20µs
- ✓ Maximum trailing edge: 20 µs
- ✓ Admissible instability of amplitude: ±1%
- ✓ Total voltage amplitude variations: 1%
- ✓ Supply voltage: 3x380±20 V, 50 Hz
- ✓ Maximum power consumption: 20 kW

Main units of the HVPS

- ✓ *Primary regulator (PR)*
- ✓ *Transformer rectifier (TR)*
- ✓ *Transformer rectifier (TR)*
- ✓ *Capacitor bank (CB)*
- ✓ *Booster*
- ✓ *Electronic switch-regulator (ESR)*
- ✓ *Gyrotron filament power supply*
- ✓ *Monitoring system*
- ✓ *Auxiliary system*
- ✓ *Control system*

Operation of the HVPS

The supply voltage is fed through a power switch (SI) to the voltage rectifier, which consists of a primary regulator (PR) and a transformer rectifier (TR).
The controlled direct current from the output of the TR charges the capacitor bank (CB) up to the required voltage. Voltage decrease up to 50% at the CB allows using of 75% of stored energy. Such over drop in an input voltage at ESR should be compensated with pulse power booster. The booster consists of low voltage small power regulator, low voltage capacitor bank and high power converter with HV output rectifier connected in series to the CB to produce the boosting voltage
After triggering the ESR, the stabilized voltage pulse is supplied to the gyrotron.

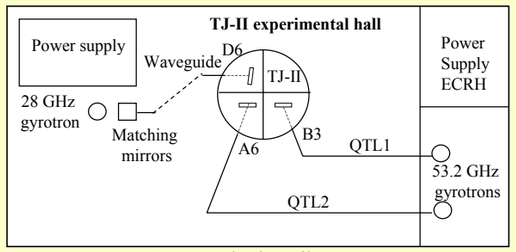
Protections

The ESR provides the high speed commutation and stabilization of the load voltage by a command from the control stand and ensures the fast switching-off of the load in case of breakdown.In the case of simultaneous breakdowns of the gyrotron and the ESR, the protection of the load electrodes from damages is provided by the vacuum-gap crow-bar protection system (CPS), which discharges the CB through a shunting circuit bypassing the gyrotron and the tube.

Conclusions

- ✓ A new system to carry out experiments on plasma heating by Electron Bernstein Waves in the TJ-II stellarator is designed.
- ✓ A 3D beam/ray tracing code (TRUBA) has been developed to study the microwave behaviour in the specific TJ-II plasma geometry.
- ✓ The scenario O-X-B1 has been chosen to start the experiments due to accesibility restrictions in the TJ-II vacuum vessel.
- ✓ A 28 GHz gyrotron (300 kW, 100 ms) is used to excite BW's in the first harmonic.
- ✓ A 45-mm oversized corrugated waveguide transmit the 300 kW-power at atmospheric pressure. An internal movable mirror is used to obtain the optimal beam parameters.

Lay-out in the TJ-II experimental hall



Transmission line

✓Quasi-optical components:
- Two curvature mirrors are necessary to optimise the Gaussian beam parameters at the input of the corrugated waveguide to achieve minimal matching losses.
- Two corrugated mirrors that actuate as elliptical polarizer and polarization twister.

✓Oversized corrugated waveguide:
- 45-mm inner diameter at atmospheric pressure.
- Length: 7m. Two continuous curvature bends with an estimated overall transmission loss of about 2 to 3%.
- Arc detectors, power monitor.

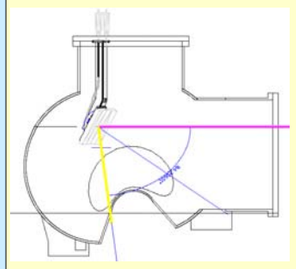
Launching scheme

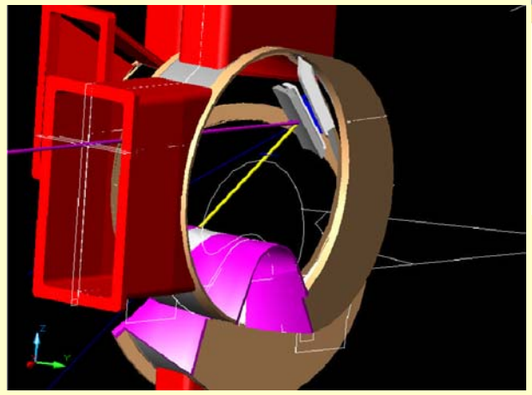
II. O-X-B1 heating scenario

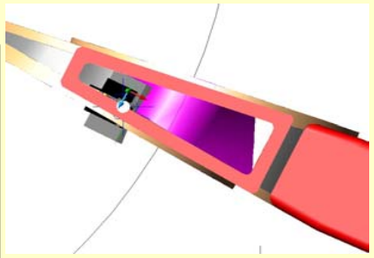
Mirror location:

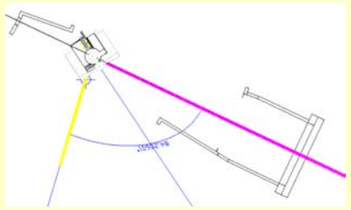
X = 122 cm	R = 135.2 cm
Y = 58.3 cm	φ = 25.5°
Z = -45 cm	

Size in toroidal direction: ~17 cm
Size in the plane of incidence: ~19 cm
Focal distance[1]: ~50 cm









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