RF Heating and Current Drive Systems

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Comments on ICRF, LHCD and ECH in DEMO

(Aries-AT or Aries-RS are examples of US DEMO designs)

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Aspects of ICRF Heating and Current Drive

- **ICRF power is an attractive auxiliary heating and current drive method:**
  - **Can *directly* heat ions and/or electrons**
  - **Provide central current drive without density limit**
  - **Capable of heating from startup to full performance**
  - **Most efficient RF source (70% or better)**
  - **High power (2.25 MW), relatively inexpensive sources available**

- **Problem areas:**
  - **High Z impurity influx from walls due to RF produced sheaths (?)**
  - **Antenna matching network needs development to tolerate time dependent loads**
  - **Distant SOL plasma in ITER/DEMO (15 cm ?) may result in unreasonably high antenna RF voltages**

Proposed solutions to issues with ICRF in ITER and DEMO

ISSUES	ITER	DEMO
Coupling	Gas injection (??)	Novel antenna designs
Compatibility	Be	Lower sputtering fields
Reliability	Network tolerant of "time varying" load	Real time matching to maximize coupled power
Availability/ Modeling	Utilize current recipes	Lower voltages by improved antenna design

Novel Antenna design and development work will be needed for DEMO

Lower Hybrid Heating and Current Drive

- **Lower Hybrid Current Drive the most efficient current drive method**
- Drives current **well off-axis with high efficiency** as required for Advanced Tokamak (AT) operation (e.g., flat or reversed shear)

Status on ITER:

- LH System is ***not*** funded at present for “Day 1” Operation
- A ¼ module (full size) is ***being proposed*** for Day 1 operation by members of the heating and current drive design review working group
- Supplemental funding (~20 M$) is required and proposed to be pledged by parties interested in ITER having LHCD capability
- **Without LHCD, steady-state Q ~ 5 goal may not be achievable**

Issues for Lower Hybrid Current Drive in DEMO

- **Source development:**

~ 0.5 -1MW @ ~ 5 GHz should be developed-***not funded at the present time***

- **Coupling:**

- Wave penetration through the pedestal region requires $\omega < \omega_{pe}$ even in the SOL

- ***JET demonstrated formation of the required density by LHRF ionization of gas fed near grill***

- ***Scaling to DEMO needs model development and experimental verification***

- **Launcher design:**

- PAM (Passive-Active Multi-junction grill) the best design option for ITER

- ***Novel launcher design ideas for DEMO*** are welcome and be tested in ITER

- **Spectral control:**

-$n_{||}$, is restricted by wave accessibility and Landau damping

- For ARIES-AT (B_T = 5.8 T) $n_{||}$ is constrained to ~ 2, **limiting J(r) control**

- For ARIES-RS, (B_T = 8 T) the $n_{||}$ window is wider, $1.6 \leq n_{||} \leq 2$, **greatly improving J(r) control and results in higher current drive efficiency**

High field approach superior for wave accessibility and CD efficiency

ECH & ECCD for ITER and DEMO

Frequency	Power per Gyrotron	Total Power Delivered to Plasma
ITER Specifications (O-mode fundamental)		
170 GHz ($\omega_p < \omega_c$)	1 (2) MW	20 MW (40 MW ?)
ARIES RS (Proposing O-mode fundamental at 8.0T)		
220 to 250 GHz ($\omega_p < \omega_c$)	1 (2) MW	20 MW
ARIES AT (Proposing O-mode, (or X-mode 2nd harmonic at 5.8T))		
180 (360) GHz ($\omega_p \leq \omega_c$)	1 (2) MW	20 MW

- **ECH / ECCD were not included in the ARIES studies due to cost considerations and lack of high frequency sources; however, if successful in ITER , should be considered for deployment in DEMO**

ECH & ECCD R&D for DEMO

- **Higher Frequency gyrotrons needed (220 - 250 GHz for Aries RS and 180-360 GHz for Aries AT)**
- **Higher efficiency and higher power gyrotrons (2 MW ?) to reduce costs**
- **Frequency tunable gyrotrons desirable to work under a range of B fields or plasma locations; fast tuning enables tracking of instabilities**
- **Improved ECH launchers**

  - Plasma facing mirror capable of nuclear environment

  - Fast angular tuning for current drive and instability control

High field DEMO (8 T) more attractive to avoid density limit for ECH since lower frequency gyrotron is suitable and is far easier to develop

Summary

• Technical challenges must be solved in all frequency regimes to be DEMO ready, even if ITER is successful

• Need to explore novel launcher designs and further microwave source development

• In addition to ITER, further experimental tests of RF wave physics and technology at DEMO relevant magnetic fields and densities will have to be performed and relevant codes validated