ID: EX-H-P3152

Recent Experiments and Development of LHCD system on HL-3

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ABSTRACT

- 2MW/3.7GHz/3s LHCD system was installed and demonstrated on HL-3
- The coupled power reached 1MW with 5% RC in 2025
- Gas injection was applied for the coupling optimization
- 300 kA full LHCD phenomenon was obtained by 800kW coupled power
- For D-T phase, the ability of HL-3 LHCD system will be upgrade to 4MW
- Eight klystrons will be installed
- Mode converters will be involoved in the transmission lines
- Two new antennas were designed with $N_{//0}$ around 2.0

BACKGROUND

- 19.5 MW heating and current drive system has been installed on HL-3 for high performance operation, including 12MW NBI, 5.5MW ECRH and 2MW LHCD
- With the injected power, Te and Ti of HL-3 plasma reached 14keV and 10keV, respectively. H-mode was obtained at 1.5MA and $n_i\tau_E T_i$ reached 6.67×10^{19} $m^{-3}\cdot s\cdot keV$
- The heating system is on upgrading to 41MW, including 20MW NBI, 11MW ECRH, 6MW ICRH and 4MW LHCD

Main parameters of HL-3

Ip	R	a	Bt	NBI	ECRH	ICRH	LHCD
3 MA	1.78 m	0.65 m	3 T	12→20 MW	5.5→11 MW	0→6 MW	2→4 MW

LHCD SYSTEM OF HL-3

Development of LHCD system on HL-3

2017
- System design
- Equipment manufacture
- Klystron installation

2022
- Klystron commissioning
- Transmission line installation
- Antenna installation preparation

2023
- Antenna installation
- System commissioning
- First power injection
- 300kW power coupled
- First H-mode
- First 1MA H-mode

2024
- Coupling optimized
- First full non-inductive CD
- 360kW power in single WG
- 800kW power coupled

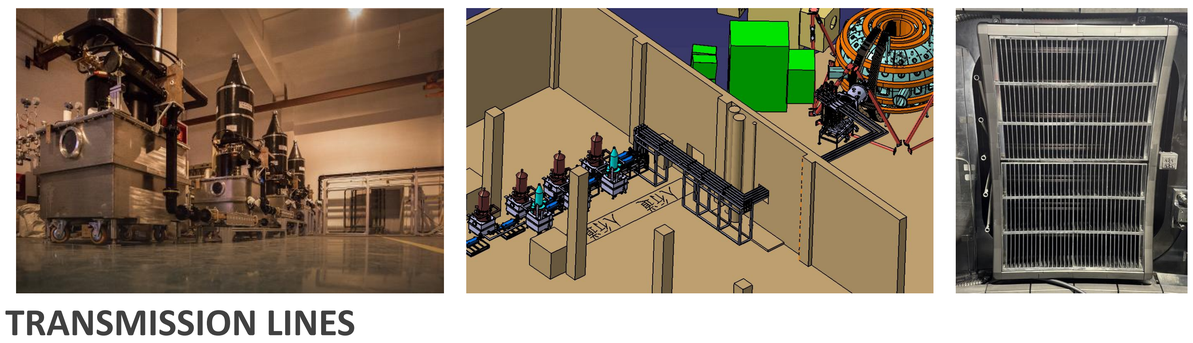
2025
- 490kW power in single WG
- 1MW power coupled
- New transmission line component tested

- 4×500kW/3.7GHz klystrons
- 4×40-meter-long transmission lines
- 6×32 FAM concept antenna

MICROWAVE SOURCE SYSTEM

- TH2103C-1 type klystrons located in the RF heating hall of SWIP
- Corresponding equipment: magnet, auxiliary PS, excitation source, PLC, cooling, protection, etc.

LHCD system of HL-3



TRANSMISSION LINES

- 4 independent transmission lines, each about 40-meter long
- Filled by nitrogen gas maintaining a pressure of 0.3 MPa

Antenna system

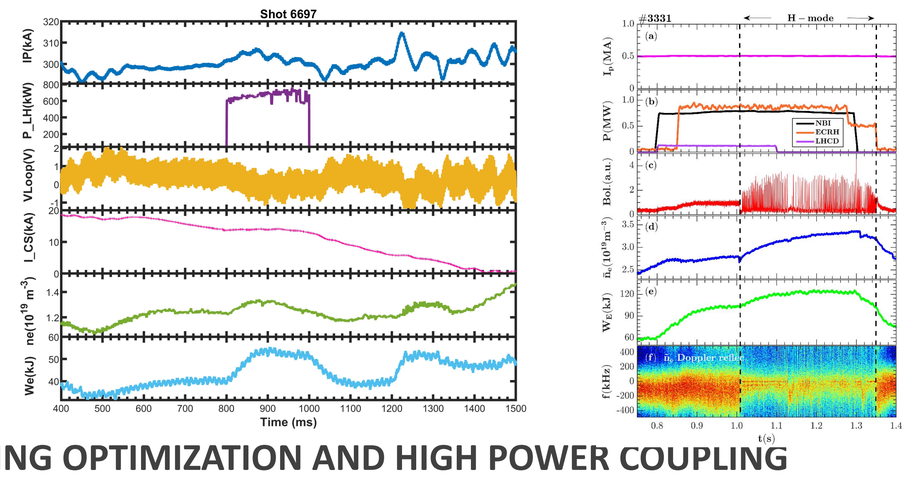
- 6×32 FAM concept antenna launching power from LFS via NO. 15 port
- The peak refractive index is designed as $n_{||0}$=2.25, with directivity D=0.75

LHCD EXPERIMENT ON HL-3

CURRENT DRIVE AND H-MODE EXPERIMENT

- Full LHCD phenomenon obtained in the experiments
- Zero loop voltage during LHW injection as same as gradient of CS current
- 300 kA driven by 800 kW LH power at density of 1.3×10^{19} m^{-3}
- $\eta_{CD}=ne\cdot R\cdot I_{CD}$ / P_{LH}, CD efficiency was estimated as 0.87×10^{19} $AW^{-1}m^{-2}$
- H-mode obtained in the duration of NBI, ECRH and LHCD

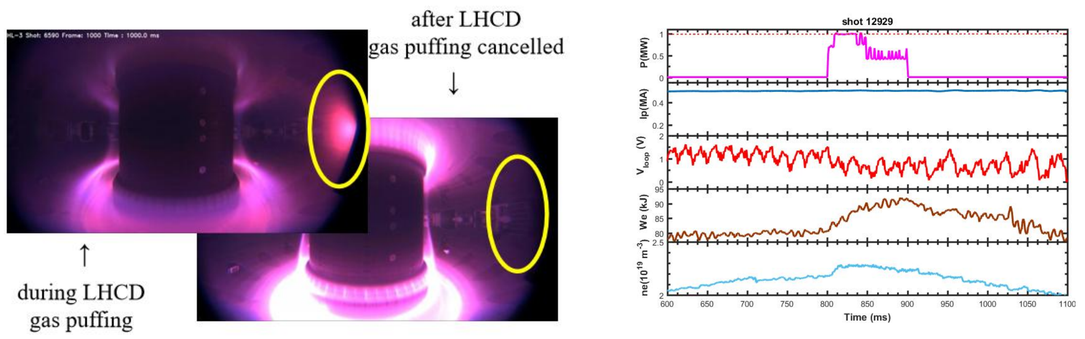
Fullnon-inductive CD and H-mode in LHCD experiments



COUPLING OPTIMIZATION AND HIGH POWER COUPLING

- HL-3 LHCD system is quite new, and needs a long term for conditioning
- Coupling optimization carried out via gas puffing nearby the LH port
- The adjacent gas puffing shows benefits to the coupling
- In shot 12929 (2025 experimental campaign), the coupled LHW power reached 1 MW with 5% RC in the case of 0.5 MA plasma current

Gas puffing benifit and 1MW LHW power coupling experiments



SYSTEM UPGRADE SITUATION AND PLAN

- LHCD system is on upgradating from 2 MW to 4 MW
- There will be 8 klystron, 8 transmission lines and 2 antennas
- 2 ceramic windows will be installed on 1 transmission line
- Higher harmonic mode will beinvolvled to the transmission
- Mode converter for TE11-TE01 and TE01 bend have been developed and tested and more than 450 kW power was passed

CONCLUSION

- A 2 MW / 3.7 GHz / 3 s LHCD system was developed on HL-3 tokamak and demonstrated well in the recent experiments.
- The coupled power reaches 1 MW and helped to obtain H-mode. Also non-inductive current drive phenomenon was obtained by LHCD.
- The system is now on upgrading and will reinstalled in 2026 for deuterium-tritium operation.

ACKNOWLEDGEMENTS / REFERENCES

- The authors gratefully acknowledge the support of the HL-3 Team at SWIP, in particular the Vacuum & Gas puffing group, the Probe diagnostic group and also the plasma operation group. This work is supported by the NSFC project and the domestic important research and development project of China.