MEASUREMENTS OF IMPROVED CONFINEMENT DURING MAGNETIC LEVITATION IN THE LEVITATED DIPOLE EXPERIMENT (LDX)

A.C. BOXER, J.L ELLSWORTH, J. KESNER
MIT

D.T. GARNIER, M.E. MAUEL
COLUMBIA UNIVERSITY
Main Results

First 6 months of data with a levitating coil
Levitation triples the density
Levitation doubles the stored energy
Observations of density self-organization
Observations of densities above cutoff
Plasma densities are power limited
THE LEVITATED DIPOLE EXPERIMENT
A NEW APPROACH TO NUCLEAR FUSION
LDX is part of a long tradition of dipole study.

Are there “natural” dipole profiles?

\[ \delta(pV^\gamma) = 0 \]
\[ \delta(nV) = 0 \]
\[ \Rightarrow p \sim r^{-20/3} \]
\[ \Rightarrow n \sim r^{-4} \]
THE LEVITATED DIPOLE EXPERIMENT
Levitation is a success!
Levitation is a success!

Coil floats for nearly 3 hours
Levitation is a success!

Coil floats for nearly 3 hours

Vertical excursions are only a few mm
Levitation is a success!

Coil floats for nearly 3 hours

Vertical excursions are only a few mm

Over 200 levitated shots
DIAGNOSTICS SET

- 4-Channel Microwave Interferometer
- Moveable Probes
- Magnetics
  - Flux Loops
  - Mirnov Coils
- Visible Light Detectors
  - Photodiode Array
  - Fast Cameras
  - Spectrometer
- X-Rays
  - X-Ray camera
  - Pulse Height Analyzer
- V-Band Radiometer
- Ion Gauge
A 4-Channel Interferometer (60 GHz) Measures the Plasma Density Profiles
Chord Measurement Locations

Magnetic Field in LDX

Z (cm)

R (cm)
Chord Measurement Locations

Chord Locations

Interferometer Ch.1 (R = 77 cm)
Chord Measurement Locations

Interferometer Ch.1 (R = 77 cm)
Interferometer Ch.2 (R = 86 cm)
Chord Measurement Locations

- Interferometer Ch.1 (R = 77 cm)
- Interferometer Ch.2 (R = 86 cm)
- Interferometer Ch.3 (R = 96 cm)
Chord Measurement Locations

Interferometer Ch.1 (R = 77 cm)
Interferometer Ch.2 (R = 86 cm)
Interferometer Ch.3 (R = 96 cm)
Interferometer Ch.4 (R = 125 cm)
Chord Measurement Locations

- Interferometer Ch.1 (R = 77 cm)
- Interferometer Ch.2 (R = 86 cm)
- Interferometer Ch.3 (R = 96 cm)
- Interferometer Ch.4 (R = 125 cm)

And a probe
Chord Measurement Locations

- Interferometer Ch.1 (R = 77 cm)
- Interferometer Ch.2 (R = 86 cm)
- Interferometer Ch.3 (R = 96 cm)
- Interferometer Ch.4 (R = 125 cm)
- Probe (R = 175 cm)
Main Results

First 6 months of data with a levitating coil
Levitation triples the density
Levitation doubles the stored energy
Observations of density self-organization
Observations of densities above cutoff
Plasma densities are power limited
Plasma Parameters are Strongly Affected by the Neutral Pressure in the Vacuum Chamber

Line-Integrated Density vs. Vacuum Pressure

ECRH
6.4 GHz (2.5 kW)
2.45 GHz (2.5 kW)

vessel ion-gauge pressure reading (μTorr)
Levitation Triples the Density

Line-Integrated Density vs. Vacuum Pressure

- ECRH
  - 6.4 GHz (2.5 kW)
  - 2.45 GHz (2.5 kW)

levitated

non-levitated

vessel ion-gauge pressure reading (µTorr)
Main Results

First 6 months of data with a levitating coil
Levitation triples the density
Levitation doubles the stored energy
Observations of density self-organization
Observations of densities above cutoff
Plasma densities are power limited
Levitation Doubles the Stored Energy

Stored Energy vs. Vacuum Pressure

- ECRH
  - 6.4 GHz (2.5 kW)
  - 2.45 GHz (2.5 kW)

- Levitated
- Non-levitated

Diamagnetism (mWb) vs. Vessel Ion-Gauge Pressure Reading (μTorr)
Main Results

First 6 months of data with a levitating coil
Levitation triples the density
Levitation doubles the stored energy
Observations of density self-organization
Observations of densities above cutoff
Plasma densities are power limited
Density Self-Organization

Line Integrated Density vs. Time

ECRH Heating Sequence

Shot: 80322030
Ch.1 (r = 77cm)
Ch.2 (r = 86cm)
Ch.3 (r = 96cm)
Ch.4 (r = 125cm)
Probe (r = 220cm)
Density Self-Organization

Line Integrated Density vs. Time

- $C_i$ (r = 96 cm)
- $C_e$ (r = 125 cm)
- CDE (r = 220 cm)

Spontaneous!
Density Self-Organization

Line Integrated Density vs. Time

Shot: 80322013

Ch. 1 (77cm)
Ch. 2 (86cm)
Ch. 3 (96cm)
Ch. 4 (125cm)
Probe (220cm)

ECRH Heating Sequence

6.4 GHz
2.45 GHz

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Density Self-Organization

Line Integrated Density vs. Time

Spontaneous!
The Transition Equalizes the Particles per Flux-Tube

Plasma Density per Flux-Tube (Shot: 80322030)

- \( \times 10^9 \)
- \( 3 \)
- \( 2.5 \)
- \( 2 \)
- \( 1.5 \)
- \( 1 \)
- \( 0.5 \)
- \( 0 \)

radius (cm)

before

after
Inverse Sawteeth Precede Self-Organization
A Coherent Mode Sustains the New Profile
Main Results

First 6 months of data with a levitating coil
Levitation triples the density
Levitation doubles the stored energy
Observations of density self-organization
Observations of densities above cutoff
Plasma densities are power limited
Plasmas are Overdense with 2.45 GHz ECRH

Plasma Density Profile (Shot: 80322030)

2.45 GHz cutoff density

radius (cm)

plasma density ($cm^{-3}$)

$10^{11}$
Main Results

First 6 months of data with a levitating coil
Levitation triples the density
Levitation doubles the stored energy
Observations of density self-organization
Observations of densities above cutoff
Plasma densities are power limited
Something is limiting the density...

Line-Integrated Density vs. Vacuum Pressure

ECRH
10.5 GHz (10 kW)
6.4 GHz (2.5 kW)
2.45 GHz (2.5 kW)

vessel ion-gauge pressure reading (μTorr)
but is not the ECRH cutoff since...
Helium Plasmas Have Twice the Density

Line-Integrated Density vs. Time: Interferometer Ch.1

ECRH Heating Sequence
Summary

First 6 months of data with a levitating coil
Levitation triples the density
Levitation doubles the stored energy
Observations of density self-organization
Observations of densities above cutoff
Plasma densities are power limited
THE
END