Plans for initial operation of the Levitated Dipole Experiment


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Abstract

The goals of initial experiments of the Levitated Dipole Experiment (LDX) are to establish reliable operation of the superconducting coils during plasma experiments and to provide a physics baseline for following experiments. As appropriate for a first-of-a-kind experiment, LDX will be operated in a staged manner, with systems added progressively. To insure safety during initial experiments, the dipole coil will be mechanically supported rather than levitated. The initial RF heating will be 3 kW at 6 GHz, and the second, 10 kW at 10.5 GHz, source to be added soon afterwards. In order to remove impurities before first plasma, as well as between experimental operations, a glow discharge cleaning system is being constructed. The base-case diagnostic set includes external equilibrium magnetics and internal Mirnov coils, an emissive electrostatic probe, an X-ray pulse-height analyzer, and a microwave interferometer. In addition, an X-ray imaging camera will be provided through a collaboration with PPPL. This work was supported by USDOE OFES.
What’s New

- The systems required for initial operation of LDX are being made ready.
- Construction of the initial set of diagnostics is underway.
  ➢ Varying stages of readiness.
Outline

• Operations Systems
  ➢ Lifting fixture
  ➢ ECRH
  ➢ Helmholtz coils

• Diagnostics
  ➢ Magnetics
  ➢ Electric probes
  ➢ X-ray camera
  ➢ Interferometer
Operations Systems
Lifting Fixture
LDX will first operate with a supported internal coil.

- Allows for plasma operation while levitation and feedback systems are made ready.
- There will be enhanced losses on field lines that intersect the supports.
  - The support is designed to minimize interactions, however.
- The supported mode provides a benchmark with which confinement by a levitated coil may be directly compared.
  - Note: there is an X-point when the coil is levitated, which is absent in supported operation.
    - This is only the case when the coil is levitated from the top.
The supported dipole campaign will provide the physics baseline for LDX.

- Low density, quasi steady-state plasmas formed by multi-frequency ECRH with mirror losses.

- Areas of investigation:
  - Plasma formation
  - Density control
  - Pressure profile control
  - Characterization of equilibrium
  - Supercritical profiles & instability
  - Compressibility scaling
  - ECRH and diagnostics development
The support is designed to make a minimal perturbation to the plasma.

- The floating coil rests on a conformal ring.
- Field lines close to the coil intercept the lifting fixture at the struts.
- Shown:
  - Support loaded with shell of same minor radius as the floating coil
  - Struts shown are not the real ones that will be used.
    - 1” wide shields
ECRH
Using multiple frequencies of electron cyclotron heating provides a mechanism for pressure profile control.

- Use multiple sources with different resonant zones to tailor the pressure profile to marginal stability.

- Results from the SM-1 symmetric mirror:
  - Multiple frequency electron cyclotron heating with large frequency separation.
  - Elimination of low frequency fluctuations in cold electron population with multiple sources.
  - Order of magnitude increase in stored energy in hot electrons.

- Results from CTX supported dipole:
  - Hot electron interchange mode “bursts” with only one source.
    - D. Maslovsky, invited talk QI2.004 (Thursday morning).
The pressure profile can be controlled via the multiple resonances.

- Effective way to create high-temperature hot electron population.
- Measure single frequency response.
  - X-ray pulse-height analyzer
  - X-ray camera (collaboration with S. Zweben, PPPL)
- Tailor multi-frequency heating power to produce ideal (stable) pressure profile with maximum peak.

Individual Heating Profiles

Tailored Pressure Profile

Freq. (GHz)

- 1st Harmonic resonances
- 2nd Harmonic resonances
Instabilities and confinement can be investigated with ECH.

- Instability should exist when: \( p' > p'_\text{critical} \).
- Investigate nature of instability.
  - How does it saturate?
  - How much transport is driven?
- Maximize \( \beta \) when: \( p' < p'_\text{critical} \) everywhere
- What is maximum attainable \( \beta \) and what is limit?
The initial ECRH sources will be at 6.4 and 10.5 GHz

- The 6.4 GHz supply is currently operable.
- The 10.5 GHz system requires a few additional components and testing.
Helmholz Coils
A Helmholz coil pair will be used to change the plasma volume.

\[
\frac{P_{\text{core}}}{P_{\text{edge}}} \left\langle \frac{V_{\text{edge}}}{V_{\text{core}}} \right\rangle \quad \text{where} \quad V = \frac{d l}{B}, \quad \text{and} \quad \frac{d l}{B} = \frac{5}{3}
\]

Helmholtz Coil Current: 0 kA
Vedge/Vcore: 228
Pcore/Pedge: 8500

Helmholtz Coil Current: 80 kA
Vedge/Vcore: 14
Pcore/Pedge: 85

Compressibility can be adjusted to change marginal stable pressure by factor of 100!
Vertical support elements for the Helmholtz coils have been attached to the vacuum vessel.

- The upper supports are also supports for a guardrail for the walkway on top of the vacuum vessel.
  - This walkway provides access to ports on top of the vacuum chamber as well as to the levitation coil.
- The lower supports are independent.
- The coil will be 16 turns of copper wire.
  - Not technologically challenging!
- In addition, the coil will provide a vacuum magnetic field to use in recalibrating the sensor coils in situ after they are installed.
Glow discharge cleaning

- See poster GP1.029, S. Dagen et al., Tuesday afternoon
Importance of GDC for LDX

- LDX requires pure hydrogenic plasma --> experimental objective is to examine limits of stability in high pressure (high \( b \)) plasmas
  Large volume of plasma and limited power availability both limit the pressure obtainable in LDX
- Impurities on the interior of LDX vessel wall (such as oxygen, nitrogen, etc.) ejected into confined plasma by plasma and neutral bombardment
- Ejected atoms radiate power, causing the plasma to cool
- Impurities can dissipate power enough to severely lower confined plasma pressure
- Thus, LDX vessel must be free of impurities to obtain experimental objective!
GDC Anode Probe

Anode Support Shaft

- Biggest concern in design: arcing!
- Shaft design takes into careful account possibility of arcing
- 1/8” copper conductor shielded with 1/4” OD alumina tube
- 3/4” OD stainless steel main support rod shielded with 1”OD, 40” long alumina tube
- Steel rod is welded to a blank flange at lower end
- Shaft housed in bellows mechanism for insertion and retraction of GDC probe

- Stainless steel anode inserted into vacuum vessel for GDC
- View of shaft upper end-- will go inside probe
- Provides power to anode via copper wire- copper wire is attached to the inside of anode
Inside Anode Probe

- Key to inside of probe is boron nitride cylinder
- Cylinder provides insulated termination points for all shaft components
- 1/8” copper conductor exits top of cylinder and is attached to inside of steel probe
- BN cylinder is supported inside spherical anode via steel disk welded inside anode

Cross-section of anode probe

Half of steel anode
Diagnostics
We have a small diagnostic set planned for hot electron plasmas.

- **Magnetics (flux loops, hall probes)**
  - Plasma equilibrium shape, magnetic & stored energy

- **Edge electrostatic probes**
  - Potential; electron density, temperature, and pressure

- **Microwave interferometer**
  - Line-average density (for a single chord)
  - Density profile (multiple chords)

- **X-ray camera**
  - 2D imaging of x-rays from hot electrons

- **X-ray pulse height energy analyzer**
  - Hot electron energy distribution / profile

- **Visible camera**
Magnetics

- See poster KP1.116, I. Karim et al., this session.
Magnetics measurements on LDX will be used to compute equilibria.

\[ b_{\text{max}} = 50\% \]

- DC dipole field means standard integrator diagnostics can be used.
- Superconductor dipole “freezes-in” flux giving an internal boundary condition for GS solver.
- Diagnostics include flux loops, Mirnov coils, and Hall probes.
A number of pickup coils with Hall sensors have been constructed for external magnetic measurements.

- **Pickup Coil Specs:**
  - Effective area $\equiv NA \sim 5 \text{ m}^2$
  - Sensitivity: $5 \text{ V/(mT)}$ (connected to a 1 ms RC integrator)

- **Hall Sensor Specs:**
  - Field Range: +/- 50 mT
  - Sensitivity: 50 (mV)/(mT)
Mirnov coils will also be used on LDX.

- **Specs**
  - Effective area ≡ NA: ~ 0.06 m²
  - L/R₀: ~ 50 ps
  - f₀: ~ 20 GHz
- **Directly measures dB/dt**
- **Placed inside the vessel**
  - Shielded with boron nitride
- **Measures fluctuations in the microsecond range**

Boron nitride shield covers windings
Electric probes

- See poster KP1.117, E.E. Ortiz et al., this session.
Electric probes will be used for measurements beyond “standard” edge studies.

- Equilibrium and fluctuating quantities of interest
  - Electron density
  - Electron temperature
  - Potential

- New feature: convective cells
  - Non-axisymmetric, nonlocal transport.

Contours of electrostatic potential
The electric probes will be installed on top of the vacuum vessel

- **Linear motion vacuum interface**
  - Probe incursion depth of 60 cm
  - Allows for easy easy probe replacement without breaking vacuum.
  - **Physics benefits**
    - Measuring edge phenomena
    - Can bias single field lines with an emissive probe.

* Drawing by Eugenio Ortiz, November 10, 2002
Electric Probe Mounting

- Easy access via platform
  - Actual height ~ 4.5 ft (137 cm) from base flange
- 32.5” (83 cm) stroke bellows.
  - Max length ~ 42.25” (108 cm)
  - Min length ~ 9.75” (25 cm)
- Standard 2.75” conflat vacuum components.
- Rotatable lower interface flange allows for 48 distinct probing angles.
Interferometer
We have investigated possible initial designs for an interferometer.
X-Ray Camera
We are using an intensified X-Ray camera that is on loan from PPPL.
The camera is in the process of being calibrated.

- Tangential viewing pinhole camera.
- Device is a standard medical imaging camera borrowed from PBX-M.
- CCD camera films phosphor display of image intensifier. Data from CCD camera is digitized using video capture card.
- Spatial resolution depends on pinhole size, desired value is 10cm.
- Temporal resolution is set by CCD camera which has standard video output of 30 frames per second.

X-ray camera picture of Am$^{241}$ source viewed through 3”x3” pinhole. Because absorption of the detector in the camera is non-uniform, the Am$^{241}$ source will be used to calibrate the camera. The grid in the picture is a lead grid placed over the window of the camera.
Future work

- Finish building all operations systems and diagnostics
- First plasma!
- Begin supported campaign
- Beyond:
  - Levitated campaign
  - Thermal plasmas
Summary

- The operations systems for initial operation of LDX are nearing completion.
- The diagnostic set will provide valuable information for our initial runs.

LDX posters will be available at http://www.psfc.mit.edu/LDX/