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# First integrated test of the superconducting magnet systems for the Levitated Dipole Experiment (LDX)

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**Abstract**

The Levitated Dipole Experiment (LDX) is an innovative approach to explore the magnetic confinement of a fusion plasma offering the possibility of an improved fusion power source. In this concept, a magnetic dipole (a superconducting solenoid) is magnetically levitated for several hours at the center of a 5 m diameter, 3 m tall vacuum chamber. The Floating coil (F-coil) is designed for a maximum field of 5.3 T. A $Nb_3Sn$ conductor was selected to operate the coil when it warms from an initial temperature of below 5 K up to about 10 K at the end of the experimental run. The Levitation coil (L-coil) made from high temperature superconductor electromagnetically supports the F-coil in the center of the plasma volume. There are no electric or cryogenic feeders serving the coil through the plasma because the F-coil must operate in a levitated position. The coil is cooled by retractable feeds and inductively charged/discharged in a lower charging station (CS). The NbTi charging coil (C-coil) surrounds the CS and induces the current in the F-coil. The L-coil and C-coil have each been independently tested. This paper describes the first integrated test of the F-coil and C-coil.


*Keywords:* Superconducting coil; Cryostat; Levitation; Vacuum chamber; Charging station

## 1. Introduction

The Levitated Dipole Experiment (LDX) is a collaborative project between Columbia University and the Massachusetts Institute of Technology to develop and investigate steady state, high beta plasma in a dipole magnetic field. The experiment is based on the superconducting solenoid levitated inside a large vacuum chamber to maximize magnetic flux expansion. Fig. 1 shows the LDX arrangement. An overview of the experiment and the magnet system [1,2] and details of magnets including F-coil [3,4], C-coil [5], and L-coil [6] have been published. This paper describes the first inductive charging of the F-coil. The floating coil (F-coil) levitates without any connection extending through the plasma volume. The F-coil is

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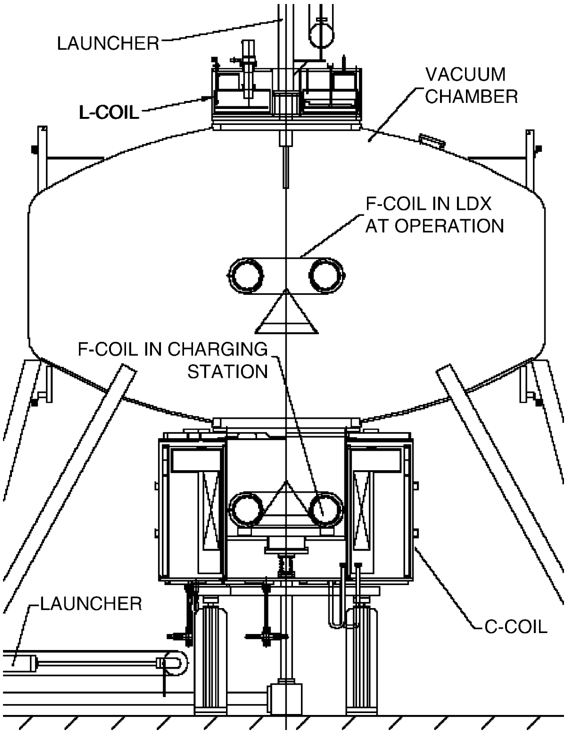


Fig. 1. LDX installation.

charged/discharged inductively when it is located in the charging station (CS) attached to the bottom of the LDX vacuum chamber. A mechanical launcher brings the F-coil to the center of the vacuum chamber and back. The F-coil remains superconductive with a near constant operating current for several hours per experimental run.

The sequence of operation is as follows. The C-coil is charged when the F-coil conductor is in the normal state. Then the F-coil is cooled below 5 K using the retractable transfer lines and it is charged inductively by the C-coil discharge. At the end of operation, the F-coil is discharged by the C-coil charge. Then F-coil is warmed by a flow of warm helium above its superconductive state. Finally, the C-coil is discharged.

The C-coil was designed, built, and tested by Efremov Institute, St. Petersburg, Russia. The critical current of the coil immersed in LHe was determined as 440 A. The C-coil stores 8 MJ of energy at an operating peak field in the winding pack of 4 T. The 8 ton C-coil with the CS in its bore was moved below the LDX vacuum chamber. The CS was bolted to the LDX vacuum chamber. Then the C-coil was centered with respect to the CS and fixed at the permanent supports. During the acceptance tests at MIT, the C-coil was energized at 0.36 A/s to 400 A without a quench.

## 2. Floating coil and charging station

The F-coil (OD/ID of 764/526 mm, 720 turns) was wound at Everson Electric Co. (now Everson-Tesla) on a stainless steel form using about 1500 m of pre-reacted $Nb_3Sn$ Rutherford cable soldered into a copper channel. Three copper rings are built into the coil and epoxy impregnated with the winding for a more uniform heating of the coil during a quench. After manufacturing, the coil was tested during a current driven test at MIT in a liquid helium cryostat. The coil was charged at 12.5 A/s to 2200 A without a quench. Then the 800 mm long lap joint was fabricated at the coil OD. An epoxy impregnated fiberglass tape reinforced the coil and the joint.

The finished coil was then transferred to Ability Engineering, where its cryostat was manufactured. The coil is installed inside of a toroidal, Inconel 625 helium vessel. The vessel is designed to store about 1.2 kg of helium at room temperature and 12.5 MPa to supplement the magnet's heat capacity during operation between 5 and 10 K, at which the helium pressure drops to 0.14–0.35 MPa. A high heat capacity fibreglass–lead composite radiation shield surrounds the helium vessel with about a 5 mm gap. Eight 12 mm Pyrex glass balls support the shield at the vessel. The shield is wrapped with a multi-layer insulation. Then the magnet and shield assembly is installed in a vacuum shell made of two halves. The helium vessel is supported in the vacuum shell by 8 sets of top, bottom, and side supports comprised of 0.1 mm thick laminated cold rolled steel washers. Installed in eight frames the stacks are thermally anchored to the shield, and designed to withstand an impact load of 50 kN each in case of levitating failure. The full mass of the F-coil is 550 kg (400 kg, helium vessel with magnet; 60 kg, shield; 90 kg, vacuum shell). A tube heat exchanger serves to cool first the coil, then the He gas in the vessel, and finally the shield. The heat exchanger inlet and outlet ports as well as the instrument connector are located at the bottom of the cryostat. The pump-out port and the high-pressure helium fill port are installed in the upper part