LA-UR- 02-6814

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Submitted to: 44th Annual Meeting of the Division of Plasma Physics
November 11-15, 2002
Orlando, Florida

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Overview of the Diagnostic System on the Reconnection Scaling eXperiment at LANL

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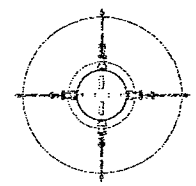
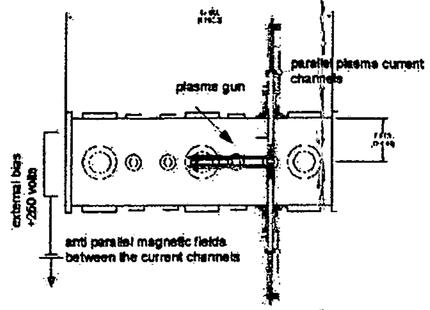


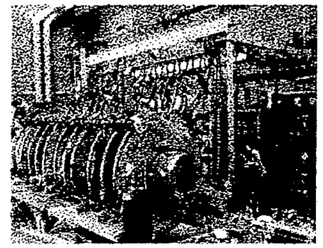
Introduction

The Reconnection Scaling Experiment (RSX) is a high β, non-MHD linear geometry experiment that is exploring the sub-millimeter geometry of magnetic reconnection. We use up to four plasma guns to create streams of high density plasma in a 4m long vacuum vessel. A variable arc voltage is used to ionize the hydrogen gas and a variable bias voltage is applied between the gun's cathode and the external anode to create a current in the plasma. The following diagnostics have been used on the machine: a Langmuir probe, a 3-dimensional B-dot probe, a miniature Rogowski, a CCD camera, and a photomultiplier tube. A fully-automated, 3D probe drive has been designed to map the magnetic field, current and voltages of the plasma channels on a sub-millimeter scale. The design, construction and theory of the different diagnostics will be discussed. Highlights from the results are presented, including density measurements, radial current density profiles of the plasma streams, and pictures of the two plasma streams at varying positions in the vacuum vessel.

RSX: A Linear Device

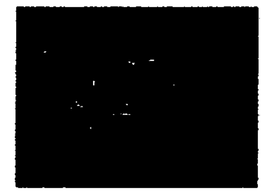


RSX is a unique linear device that was designed to study aspects of magnetic reconnection. Four plasma guns can be fired simultaneously to create parallel plasma current channels. A background magnetic field can be applied which tends to collimate the current channels. The 5 meter long vacuum chamber provides multiple ports of access for diagnostics. The arc voltage used to create the plasma in the plasma guns can be adjusted, as can the external bias voltage. When the gun is biased negative relative to an external anode, the electrons acquire a velocity relative to the ions, and a net current results. Due to the adjustable variables of the experiment, several important plasma parameters can be scaled, which will allow RSX to observe unexplored aspects of reconnection.

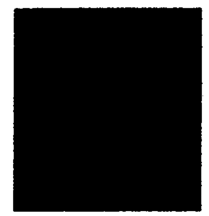


CCD Camera Pictures

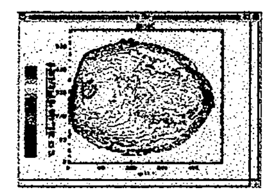
CCD picture of two plasma current channels at z = 1m in vacuum vessel. Picture taken with two neutral density filters (2 and 0.33).



Contour plot of the two streams, which show a convergence angle of 4°.



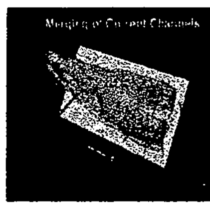
CCD picture at z = 2.25 m (downstream from the plasma guns) where the two plasma streams have merged.



Contour plot of the previous picture, where only one plasma stream can be observed.

The CCD camera points radially through a window port into the vacuum vessel. The camera is a digital Kodak DC265, and must be shielded with aluminum foil from the magnetic fields created during a shot. Two objectives focus the image of the plasma onto the camera's lens. The data is acquired using Kodak software and triggered manually.

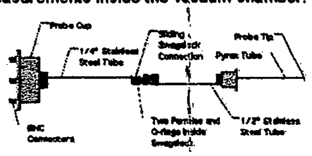
Magnetic Reconnection



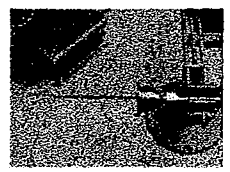
Magnetic reconnection powers many events in the universe: solar flares, galactic jets and the aurora borealis. In magnetic reconnection, the magnetic fields annihilate and the energy in the magnetic fields is transferred to particle jets. Magnetic reconnection occurs when two current channels merge: in the fork where the two channels meet, the opposite magnetic fields are squeezed until they reconnect to form a single magnetic field around the new current channel. The existence of magnetic reconnection is now widely accepted, but the details are still unknown. The Reconnection Scaling eXperiment is using miniature probes and a simple, reproducible geometry to map the magnetic fields from two merging current channels.

Probe Design

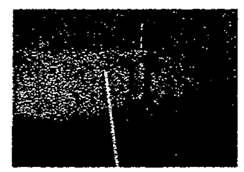
The B-dot, Rogowski, Langmuir probes and 3D probe drive are modularly designed for insertion into an access port on the vacuum chamber. The probe can be pushed through a sliding swagelock seal and rotated on a bellows for two-dimensional measurements inside the vacuum chamber.

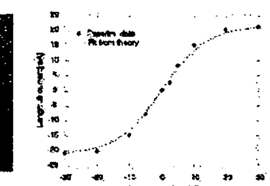


B-dot, Triple Langmuir Probe



A three-dimensional b-dot probe has been built to map the magnetic fields of the reconnecting current channels. Three bobbins, or coils of wire, are mounted in perpendicular directions, shielded with stainless steel foil, protected from the plasma with a glass tube, and assembled into a vacuum-safe radial probe.





A triple Langmuir probe has been used to measure the electron temperature of the plasma. A triple Langmuir probe applies a positive voltage between on three wires that are directly inserted into the plasma. The electron temperature measured for this shot was 7 eV and an electron density of 3.7×10^{16} cm^{-3}.

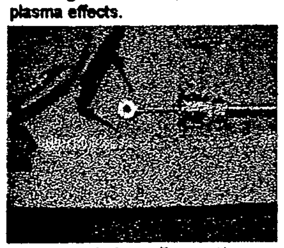
Miniature Rogowski Probe: Design and Results

Miniature Rogowski Design

A Rogowski coil measures current by detecting the toroidal magnetic fields an axial current produces. The coil encircles the toroidal magnetic flux and returns a voltage proportional to dI/dt:

$$V(t) = -\mu_0 \frac{nA}{l} \frac{dI}{dt}$$

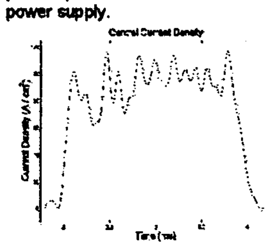
The Rogowski probe was designed to be inserted directly into the plasma stream, which requires robust, vacuum-safe shielding from thermal, electrical and plasma effects.



The Rogowski probe during calibration, with a current flowing through the detection area.

Measurement of Pulsed Current

The Rogowski measured a current density of 96 Amps/cm² for a 2 ms plasma pulse with 200 Volts on the bias power supply.



Quick Comparison of Rogowski Data to Global Measurement

For the shot shown above, the external anode measured an average current of 889 Amps. The current profile shown on the right for the same shot has a best fit curve of:

$$J = 126.03 / (r^2+1.57^2)$$

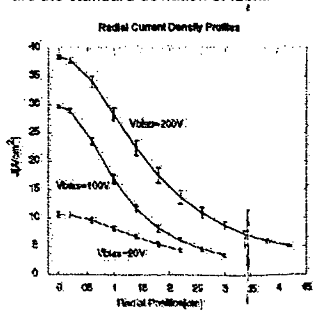
If this profile is integrated over a 10 cm radius, we can estimate a current of 926 Amps in the plasma channel.

Radial Current Density Scans

The miniature Rogowski probe can be used to measure the current density profile of the plasma channels. The Rogowski probe is able to accurately measure differences in the current to a 0.5 cm resolution. The best fit curves are fitted to a screw-pinch profile of:

$$J = A_0 / (r^2+r_0^2)$$

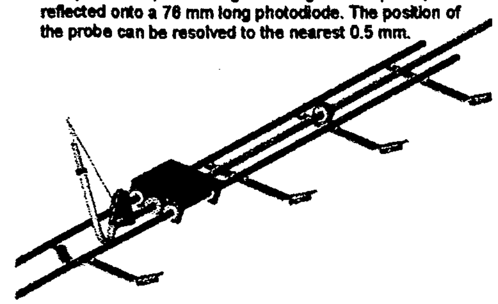
where A_0 is a constant and r_0 is the radius of the current channel. The error bars shown are the standard deviation of identical shots.



3D Probe Drive

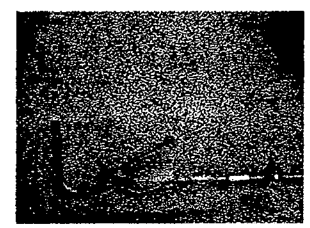
RSX's reproducible geometry allow a detailed, three-dimensional mapping of magnetic reconnection. A 3D probe drive has been designed and constructed to allow 1 mm precision in magnetic field, current and voltage measurements inside the vacuum chamber. The fully automated probe drive is controlled by three stepper motors via a computer interface. A sliding seal allows 1.5 meters of axial throw into the vacuum vessel and 120 degrees of rotary motion, and a telescoping spring system allows 15 cm of radial motion.

The error in radial positioning (due to uneven motion of the springs) requires an accurate position detection system. An optical fiber, run through the length of the probe, is reflected onto a 76 mm long photodiode. The position of the probe can be resolved to the nearest 0.5 mm.



Design Constraints

- Movement in three dimensions
- Positioning accuracy of 1 mm within vacuum vessel
  - Axial throw of 1.5 m
  - Radial throw of 15 cm
  - Rotary motion of 120 degrees
- Vacuum safe
  - Stainless Steel, aluminum, copper, glass, some plastics such as nylon, Vespel, Teflon, and Delrin
- Probe head:
  - Must be smaller than 0.5 mm
  - Must be non-conducting
- Probe leads must be electromagnetically shielded
- Forces can only be applied through sliding O-ring seals
- Must be modular to switch between different probes



Future Directions in Diagnostics

- An ultra miniature B-dot on a semiconductor chip is in construction, with a bobbin diameter of ~300 μm
- Installation of 3D probe drive with a 3D B-dot probe head in vacuum chamber, begin mapping of the merging of the two plasma current channels.
- Interferometer, ion doppler spectroscopy