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THE 13TH INTERNATIONAL STELLARATOR WORKSHOP

INITIAL RESULTS FROM BIASED ELECTRODE EXPERIMENTS IN HSX.

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Initial experiments using a biased electrode in HSX have been performed. A radial current is transiently drawn from the plasma, causing plasma rotation. A Gundestrup probe was used to measure local plasma rotation with good time and space resolution. Initial results show that it is possible to excite and measure a flow in both the QHS and Mirror modes of operation. From the rise and fall times of the flow when the bias is turned on and off, as well as the total change in flow speed, the damping rates can be measured. The damping rates are higher in the Mirror mode than in the QHS mode, consistent with neoclassical expectations.

The HSX stellarator and viscous damping.

In traditional stellarators, there are |**B**| variations in all directions on a magnetic surface. This leads to deleterious neoclassical effects, including large parallel viscous damping in all directions on a flux surface. In quasi-symmetric stellarators, there exists a direction (helical, toroidal, or poloidal) with minimal variation in |**B**|. The parallel viscosity is very low in this direction.

The Helically Symmetric Experiment (HSX[1]) is the first quasi-symmetric stellarator in the world. In the quasi-helically symmetric or QHS mode, the dominant contribution to the variation in |**B**| on a surface is the n=4, m=1 helical mode. This helical symmetry is broken in the Mirror mode by the introduction of a large n=4, m=0 mode using a set of auxiliary magnets. Hence, HSX is capable of studying the physics of both quasi-symmetric and conventional stellarators.

Description of equipment and measurement techniques.

A biased electrode is used to accelerate the plasma. The electrode itself consists of a 1" diameter Molybdenum cylinder, with .25" inches extending outside a boron nitride shroud. The assembly is placed inside a welded bellows, and mounted to HSX via a precision slide. The bias supply consists of a 10mF capacitor bank, switched on and off by transistors capable of supplying 300A of bias current. The current can be turned on and off in ≈20 µs.

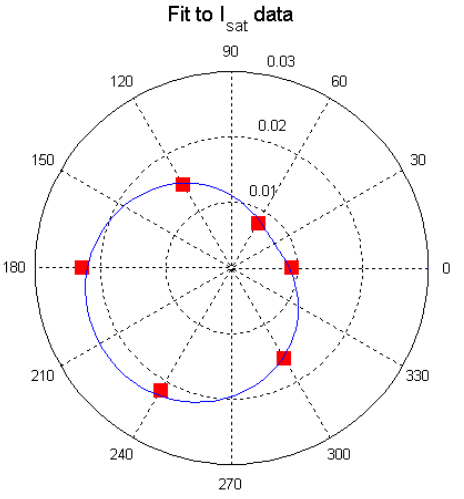
Fit to I_{sat} data

Figure #1: Fit to the I_{sat} data for a biased discharge.

The primary flow diagnostic is a multi-pin Langmuir probe[2], or "Gundestrup" probe. The probe consists of 6 tips facing radially outward, separated by 60°, with each tip biased at –180 V into I_{sat}. The boron nitride probe head shields each tip, so that they are sensitive to plasma from only one direction.

The sum of the upstream and downstream tips is largely independent of the angle of the probe with respect to the field. This observation implies that an unmagnetized treatment of the plasma is appropriate.

Using the unmagnetized model of Hudis and Lidsky[3] (valid for $T_e > T_i$), the current to each of the six tips can be related to the flow speed as:

$$I_{sat}(\theta_p) = X_1(1 + X_2 \cos(\theta_p - X_3)) \tag{1}$$

Where X_1 is related to the average I_{sat} collected by each tip, X_3 is the angle from which the plasma is flowing, and X_2 can be related to the plasma flow speed V as:

$$X_2 = \frac{V}{c_s} \frac{\sqrt{2T_i(T_i + T_e)}}{T_e} \tag{2}$$

where c_s is the plasma sound speed. In practice, 6 I_{sat} signals are collected as a function of time. At each time point, expression (1) is fit to the data using a nonlinear Levenberg-Marquardt routine, yielding the 3 fit parameters and the uncertainties in each. An example of this fit is shown in figure #1, for a biased QHS discharge (averaged from .816 sec. to .817 sec. of discharge in figure #2). The fit matched the data well, indicating the appropriateness of the theory. Fit parameter are X_1=15.4 mA, X_2=.517 and X_3= 3.17 radians. For T_e=50eV and T_i=20eV, this corresponds to approximately 9000 m/s.

Results

The basic evolution of a biased discharge (QHS) is shown in figure #2; this discharge is representative of all discharges presented in this data set. In this discharge, the bias is pulsed twice, at .815 and .825, for .003 seconds each time. The increase in flow speed is manifest as the separation of the 6 I_{sat} signals. There is a rise in the density with each bias pulse, with no large rise in H_α brightness.

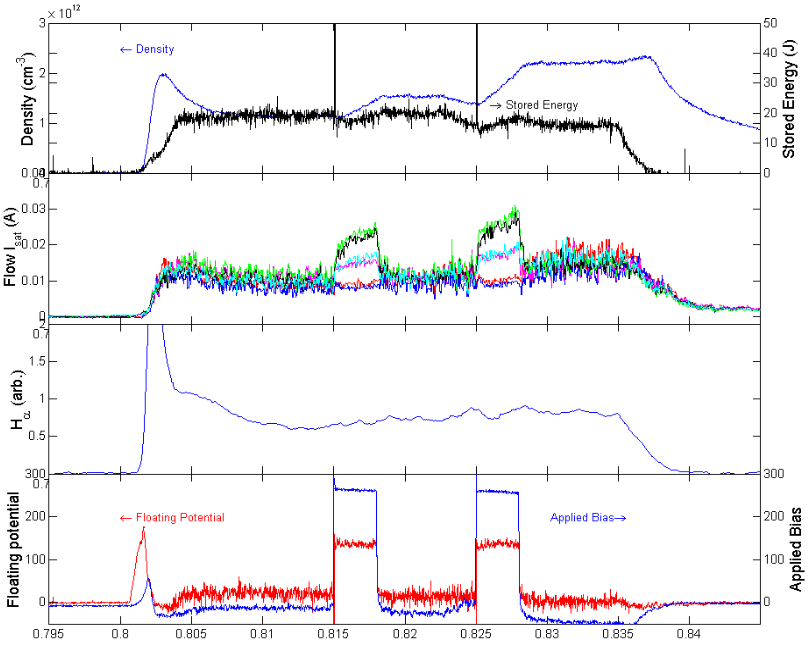

Figure #2: Evolution of a QHS biased discharge.

In figure #3, the profiles of the floating potential for the two different modes are shown. The applied bias is 400V for both the Mirror and QHS case. The separatrix is at ≈2cm from the wall for the QHS case and at about 3cm from the wall for the Mirror. The bias voltage is dropped over a few centimeters in the plasma in each case. The Mirror mode has a steeped gradient in the potential than the QHS mode.

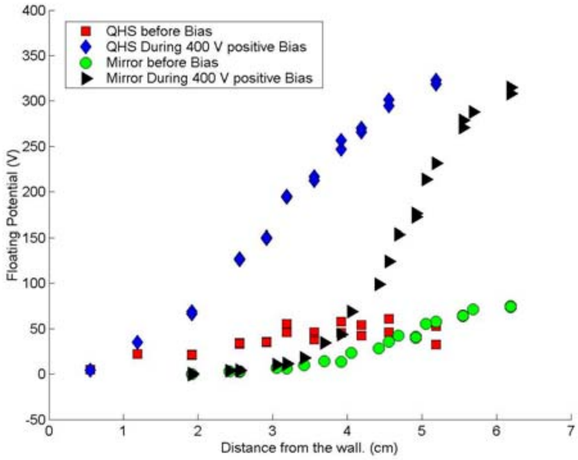

Figure #3: Profiles of the Floating Potential

In figure #4, the flow speed is shown for the QHS discharge in figure #2 and for a similar Mirror mode discharge. The probe is moved in for the Mirror case to account for the inward shift of the surfaces. In each case, the rise and fall times are fit to exponentials, which are plotted in black over the traces. It is very clear that the QHS mode both spins up and slows down more slowly

As a consistency check on the calculation, the damping rate was also estimated from the change in flow speed as $\tau_{\Delta U}=m\Delta U/qjB$, where ΔU is the change in flow speed, j is the current density drawn by the probe, B is the magnetic field strength, q is the ion charge, and m is the ion mass. For the rise times we calculate .38ms for the QHS and .16ms for the Mirror shots. For the damping time based on the change in speed, we estimate .43ms for the QHS shot and .078ms for the Mirror.

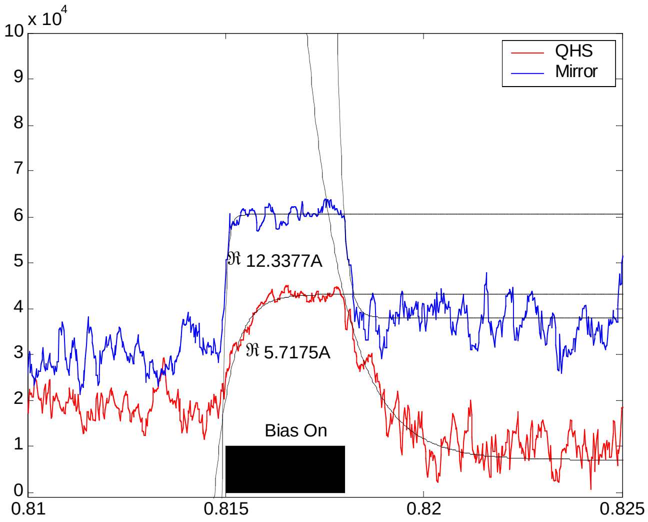

Figure #4: Biased flow evolution in QHS and Mirror Mode

We have begun to study the dependence of the damping rate upon various plasma parameters. In figure 5, the damping rate is shown as a function of density for both the QHS and Mirror modes with 400 V applied bias. The damping time is calculated from the change in flow speed. To make this plot, the electron temperature required for the Mach probe analysis was scaled inversely with the density. For this density range, the QHS mode has a uniformly longer damping time. The density scaling of the damping time is not fully understood.

Modeling Calculations

Calculations have been done of the flow damping rate due to parallel viscosity in these two modes, using the model of Coronado and Talmadge[4]. In the following calculation, n_e and n_i have parabolic profiles with core values of 1.6×10^{12} cm^{-3}. The neutral density is taken to be flat at 7×10^{10} cm^{-3}, a value inferred from edge neutral pressure measurements. A flat Ti profile at 25 eV has been used; this value is justified by Doppler spectroscopy. The magnetic spectrum used is the finite coil spectrum in Boozer coordinates. Figure #6 shows the calculated viscous damping rates for the Mirror and QHS modes, along with the neutral damping rate and the total damping rate. It can be seen that the calculated damping time is slower than the measured.

In the future, we will work on a number of ways to improve this calculation. In particular, the model uses the basis vectors for a large aspect ratio tokamak. We will study more appropriate basis vectors for a quasi-helically symmetric stellarator. We will also work on improving the neutral modeling through improved measurements of the edge pressure and H_α brightness. Finally, future work with triple probes and Thomson scattering will improve the “Gundestrup” probe data analysis.

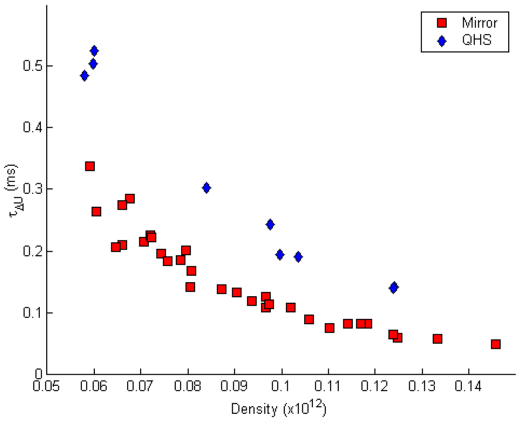

Figure #5 : Damping time as a function of density, for the QHS and Mirror modes

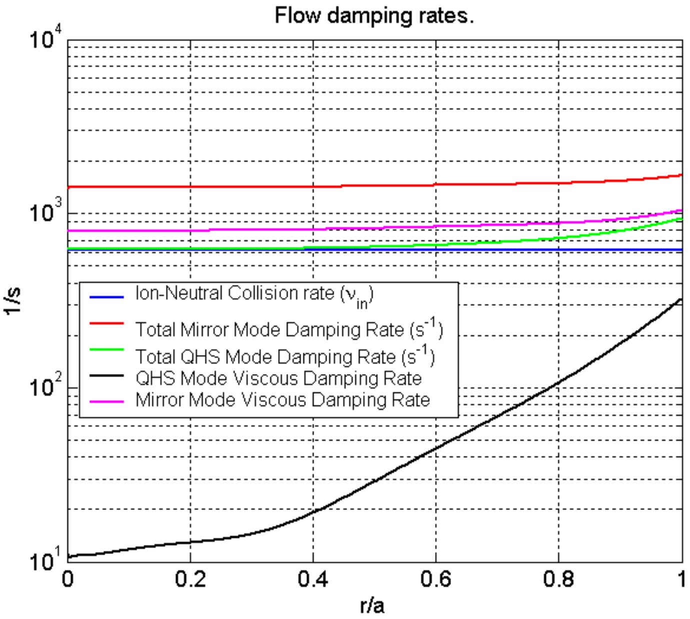

Figure #6: Initial calculation of the damping rates in the QHS and Mirror modes.

References:

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