Final Report: Alfvén Waves and Coronal Heating

Grant # DE-FG02_06ER54895
PI: Christopher Watts
15 February 2010

Summary

The grant funded a three year project to investigate the role of Alfvén waves as a possible mechanism heating plasmas, with relevance to solar coronal heating. Evidence suggests that there is strong coupling between the solar photosphere, corona and solar wind through Alfvén wave interaction with the neutral gas particles. A laboratory experimental and solar observational plan was designed to investigate in detail this interaction. The proposed research made use of the HelCat (Helicon-Cathode) experimental facility, and the National Solar Observatory (NSO) at SunSpot to address the following

- Investigate the evolution of the steady-state mode structure of Alfvén waves in bounded plasma columns in collisional and collisionless current-free plasma discharges
- Study the effect of neutral particles on the Alfvén wave dispersion relation and measure the neutral density profile independently to corroborate theoretical models
- Compare the experimental findings with solar atmosphere observations in collaboration with the National Solar Observatory, SunSpot

Although some of these goals were met, difficulties in detecting the Alfvén wave signature in the HelCat device meant that much of the research was stymied. The following difficulties were encountered that lead to and unsatisfactory conclusion of the project.

- Helicon pulsed discharges was found to be unable to access the same parameter regimes (easily) as steady state discharges, and this avenue was thus abandoned.
- RF noise dominated the detected signal, and thus considerable time was spent in rectifying this problem.
- Alfvén waves were not detected (convincingly) in pulsed argon discharges
- Detection issues meant that the major goal of measuring wave damping and neutral particle interaction could not be addressed

The project was, however, able to achieve the following:

- Development of a new wave exciter and detector design, along with a filter circuit to suppress the helicon RF noise
- Measurements of Alfvén wave signatures in helium pulsed plasma discharges
- Measurement of Alfvén waves in steady state plasmas

Given that the major issues surrounding Alfvén wave detection in HelCat have been resolved, we

anticipate, under separate funding, to continue this effort and pursue the goals of the original proposal.

Specific Project Accomplishments

Pulsed mode operation and probe design

One central component of the research was to excite and detect Alfvén waves in pulsed helicon discharges (~250 ms). Previous research funded by DOE had successfully measured Alfvén waves in steady state helium helicon discharges. However, the proves used in that project were bulky because they had to be water cooled. Pulsed-mode operation reduces the heat load to the detector, and allows for smaller probes to be used.

In the end, however, the perturbative effect of the probe itself makes the use of pulsed mode impossible. The presence of the probe causes the discharge initiation to be unstable, and it is difficult to reliably and reproducibly attain consistent plasma parameters. At issue is constructing a suitable pulse waveform to drive the plasma generation circuitry. The automated system is not sufficiently flexible to tailor the discharge waveform such that it achieves the same plasma parameters with and without the probe present. A human operator can easily adjust the plasma power and discharge parameters … but on the timescale of seconds, rather than the 100s of milliseconds desired for pulsed operation (again, to reduce the heat load to the probes). This realization came after only extended testing and troubleshooting; over two years into the grant cycle it was decided to abandon pulsed mode operation, and return to water-cooled probes in steady state. The new probe design is nonetheless significantly smaller than the original water-cooled probes. We have used small glass tubing and miniature Teflon tubing to supply the cooling water, to give an overall probe diameter of ~0.6 mm.

New Emitter Design

We have redesigned to Alfvén wave driver and circuitry to maximize excited wave amplitude. To this end, a program was created in Mathematica to determine the best number of windings to current ratio for a hand wound inductor; it was found that the best choice would be a 10 turn inductor coil that could handle 8A of current. Magnet wire, MIL-W-583B, was wound by hand around a Q-tip with a 2.5mm diameter. The coil was wound with 5 turns up and 5 turns back, with the second 5 on top of the first 5 so that the leads were at the same end of the coil. These leads were then twisted using a drill motor to form a twisted pair. The twisted pair was then inserted into a ceramic tube until the coil was in contact with the end of the tube. The part of the twisted pair that extended from the other end of the ceramic tube was then covered with metal braid, to try to shield it from the 10MHz signal from the helicon antenna, and fiber braid over that, to keep it from grounding to the stainless steel of the feedthrough shaft. The twisted pair was then soldered to Lemo vacuum feedthroughs. The coil was then covered with a Pyrex cap to protect it from the plasma. JB Weld was used to hold the Pyrex in place. Figure 1 shows the completed coil side by side with the receiver coil. The upper coil wire is the emitter.

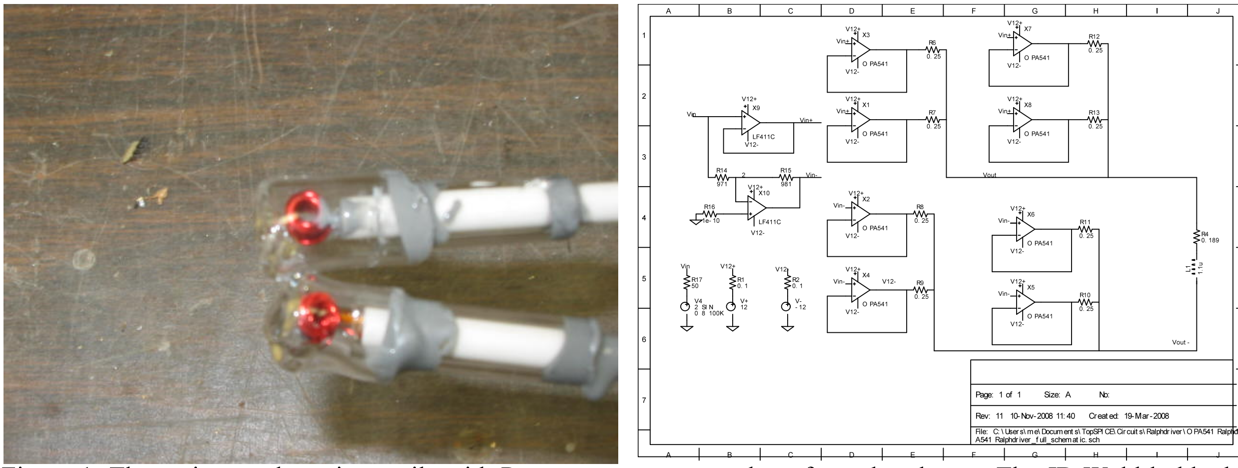

Figure 1. The emitter and receiver coils with Pyrex caps to protect them from the plasma. The JB Weld holds the Pyrex to the ceramic tube. Right: Circuit schematic for the emitter driver.

To drive the emitter coil a driver circuit was designed with help from Rich Compeau, see Figure 1. This circuit has a pre-driver circuit consisting of two LF411 op amps, and the main driver circuit consisting of eight OPA541 power amps wired a parallel series configuration such that the output should be approximately 8A. We used a Pearson coil to measure the output of the driver circuit. When connected to the emitter coil, we obtained as much as 24A at 100kHz.

New Receiver Design

The receiver/detector coil was also redesigned to eliminate electrostatic RF pickup. It is based on the design presented by Hanna G. Smith, *Construction and Calibration of a Tri-Directional Magnetic Probe for the VASIMR experiment on mini-RFTF* (Figure 2). This coil was wound differentially such that there were two coils, one on top of the other. Each coil had a total of 20 turns, ten in the forward direction, ten in the reverse direction so the leads extended from the coil at the same end. The second lead of the first coil was then connected to the first lead of the second coil. The two outer leads were then connected to

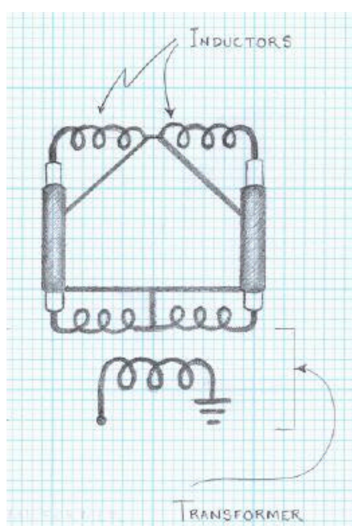

Figure 2. Illustration from Hanna G. Smith showing the differential connection of the coil to the transformer.

the outer pins of a center tap transformer. The inner lead was connected to the center tap of the transformed. We used a MET-61 transformer with frequency rating of 100 kHz. This design significantly reduced the electrostatic pickup of the coil.

RF Filters

Electromagnetic pickup of the helicon driver signal was still an issue with the new detector design. Thus, a new passive filter was designed, again, with much help from Rich Compeau. The filter settled on is a 6-pole Butterworth filter. Particular attention was paid to stray capacitance in the inductors, which can significantly distort the ideal filter characteristics. The final design is able to achieve a 40dB attenuation over the stop band. For details of the filter, see the report *Filters: A Report for Filters Designed, Built, and Tested for the HelCat Plasma Lab at UNM.*

Data

Because of unanticipated difficulties with both pulsed-mode operation and excessive RF pickup, detailed Alfvén wave measurements were not performed. Signatures of Alfvén waves have now been detected in HelCat. Shown in Figure 3 is the detected dispersion curve, which gives an Alfvén speed consistent with the plasma parameters. However, it remains for future work to carry out the measurements and data analysis originally proposed.

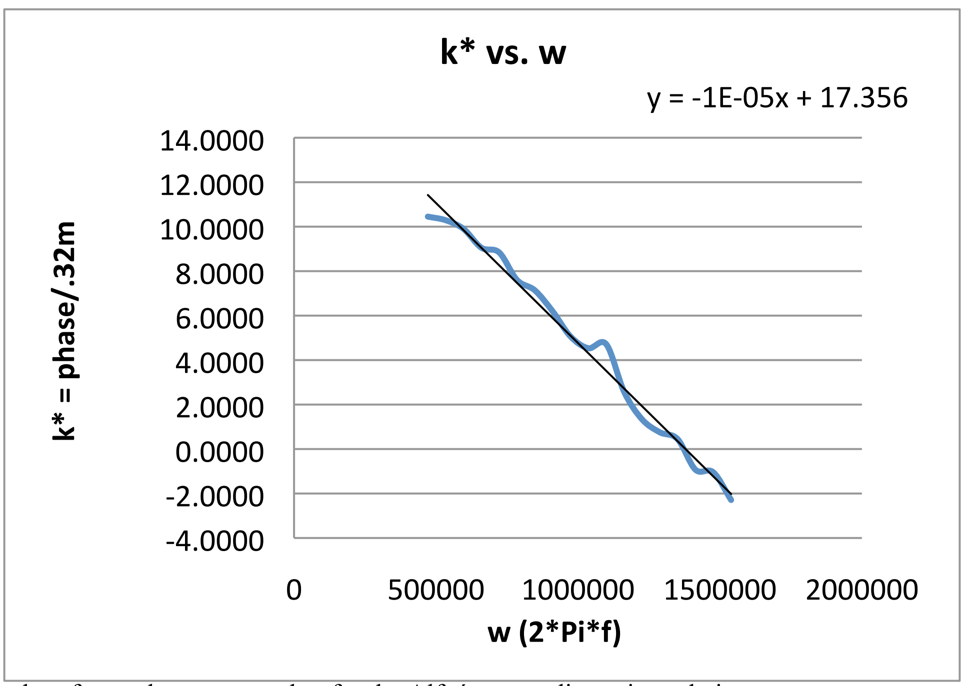

Figure 3. The plot of ω vs the wave number for the Alfvén wave dispersion relation.

Conclusion

Unfortunately, the overriding scientific goals of the project were not met. The reasons can in part be contributed to bad luck. Previous work at Auburn University had demonstrated Alfvén waves and interactions with neutral particles in *steady state* helicon discharges. It was not obvious that this should not work equally in pulsed-mode discharges. In addition, the HelCat device, being much larger, appears to be more susceptible to RF noise on the detected signals. At issue is also the lack of trained personnel. The grant only provided funds for the PI work a limited time on the project. Moreover, the student working on the project was inexperienced in sophisticated electronics design, as the project in the end required.