Technical Report of Research Progress

High Beta Tokamak Research

February 24, 1993 – August 24, 1993

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by

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Summary

During the past 6 months, experiments have been conducted with the HBT-EP tokamak in order to (1) test and evaluate diagnostic systems, (2) establish basic machine operation, (3) document MHD behavior as a function of global discharge parameters, (4) investigate conditions leading to passive stabilization of MHD instabilities, and (5) quantify the external saddle coil current required for DC mode locking. In addition, the development and installation of new hardware systems has occurred. A prototype saddle coil was installed and tested. A five-position $(n, m) = (1, 2)$ external helical saddle coil was attached for mode-locking experiments. And, fabrication of the 32-channel UV tomography and the multipass Thomson scattering diagnostics have begun in preparation for installation later this year.

1. Introduction

The primary goal of the newly assembled HBT-EP tokamak is to conduct experiments investigating the use of passive and active techniques to extend the operating range of high beta tokamaks through the stabilization and control of MHD instabilities. HBT-EP is able to operate over a wide-range of parameters, and it has been built with an adjustable conducting shell, good diagnostic access, and the capability to accommodate up to 10 external saddle coils around the torus for MHD mode control. These features give HBT-EP an unique opportunity to advance the basic understanding of MHD instability control in a small, well-diagnosed research tokamak.

This report summarizes our progress towards this goal during the first six months of the present grant period. Significant progress has occurred to advance our understanding of the occurrence and control of MHD instabilities and to fabricate and install new

hardware systems. To date, all of our proposed physics and hardware objectives have been achieved on or ahead of schedule, and the fabrication of two new major diagnostics are proceeding on schedule.

The following two sections describe the scientific and technical progress of the HBT-EP experiment. Section 2 summarizes our experimental activities and presents two significant results:

- The growth rate of the MHD disruption precursors decrease in the presence of a close-fitting conducting shell, and
- A segmented $(n, m) = (1, 2)$ external saddle coil system can be used for mode locking even in the presence of a conducting shell.

Section 3 summarizes our hardware activities. These include:

- Installation and testing of a prototype $m = 2$ saddle coil,
- Installation and operation of a 5-section, $(n, m) = (1, 2)$ helical saddle coil for mode locking experiments,
- Final design and fabrication of a 32-channel UV tomography diagnostic, and
- Fabrication of a multipass Thomson scattering diagnostic by the Ioffe Physical-Technical Institute, St. Petersburg, Russia.

Finally, we note in Section 4 that progress has been on or ahead of schedule, and the outlook for next year's research is positive. An appendix is attached listing publications and participation in conferences and workshops.

2. Physics Progress

We have conducted five experimental tasks in order to develop understanding of HBT-EP operating parameters and to advance our understanding of excitation and control of tokamak MHD instabilities. These experiments are (1) test and evaluate diagnostic systems, (2) establish basic machine operation, (3) document MHD behavior as a function of global discharge parameters, (4) investigate conditions leading to passive stabilization of MHD instabilities, and (5) quantify the external saddle coil current required for DC mode locking. Three of these activities are physics program objectives:

Objective	Date Proposed	Date Achieved
Passive stabilization experiments begin	Feb. – May, 1993	April, 1993
Quantify conditions leading to passive stabilization	May – Aug., 1993	Aug., 1993
Quantify external current required for DC mode locking	Nov. – Feb., 1994	May, 1993

The following subsections summarize these activities.

2.1 Test and evaluate diagnostic systems

Experiments have been performed to verify basic diagnostic systems and to determine diagnostic sensitivity. These include:

- Calibration of the cosine Rogowski coil with the internal magnetic probe enabling fast determination of the major radius of the plasma's current centroid.
- Develop techniques to reduce poloidal-field pick-up on the diamagnetic loop.
- Conduct plasma density scans to determine the sensitivity of the CO₂ laser interferometer.

2.2 Establish basic machine operation

HBT-EP operation is controlled by (1) adjusting the quantity of deuterium gas injection, (2) adjusting the plasma current waveform by adjusting the OH breakdown voltage and plasma current ramp-rate, (3) adjusting the plasma position by adjusting the VF current waveform, and (4) adjusting the limiter locations. Experiments have been conducted which parameterize HBT-EP operating regimes while also determining the roles of discharge cleaning and the proximity of the conducting shell to the plasma surface. Particularly noteworthy experiments are listed below:

- Determine the minimum deuterium injection permitting breakdown and measuring the intensity of run-away induced x-rays.
- Compare small diameter plasmas ($a \leq 15$ cm) with large diameter plasmas ($a \leq 22$ cm).
- Determine the maximum discharge current and lowest edge safety factor.
- Determine the maximum discharge pulse length by optimizing all discharge control "knobs".
- Determine the scaling of plasma resistance, D_α emission, radiated power, and vertical field current required for major radial equilibrium as a function of deuterium gas injection.
- Reconstruct free-boundary equilibria using by finding the "least-squares" best-fit to poloidal field measurements. Analyze the equilibria characteristics at the extreme positions of the conducting shell.
- Measure the axisymmetric part of the shell eddy currents (*i.e.* those currents effecting equilibrium) and compare to predictions made with TSC and equilibrium reconstruction codes.

As an illustration of one of these experiments, Figure 1 shows a comparison between the measured and reconstructed internal poloidal field profiles for two HBT-EP equilibria, one having the conducting shells fully retracted and one with the shells fully inserted. Excellent fits are obtained demonstrating our ability to reconstruct free-boundary equilibrium while including self-consistently the effects of shell eddy currents.

2.3 Document MHD behavior

A variety of MHD instabilities and fluctuations have been observed in HBT-EP. As found with other tokamak devices, the nature of these instabilities depend upon current, gas injection, and plasma cross-section. Experiments have been conducted to quantify MHD activity as all three of these control variables were adjusted. To date, our primary mode identification techniques have used the following diagnostics:

- Fourier-analyzing Rogowski coils, *e.g.* $\cos(2\theta)$, $\sin(3\theta)$.
- 15-channel poloidal array of poloidal field sensors.
- Toroidally-distributed radial field detectors.
- Fluctuations of a chord-integrated soft x-ray detector.

The magnetic diagnostics are able to identify the dominant magnetic field fluctuations external to the plasma while the soft x-ray detector can measure changes in the temperature of the hot plasma core. The loop-voltage monitors, changes in the major radial position, and D_α light emission has aided in the determination of the effects of the MHD activity on plasma confinement.

The usual MHD activity observed in HBT-EP are:

- Low- n and low- m helical perturbations preceding minor and major disruptions. (Here, we define a "minor" disruption as strong MHD event which rapidly cools the plasma core but does not lead to termination of the plasma current, and we define a "major" disruption as one which leads to plasma current termination.) These instabilities were the subject of the passive stabilization experiments described in subsection 2.4.
- Quasi-continuous, or saturated, low- n and low- m helical perturbations. These instabilities do not lead to rapid plasma cooling. These instabilities were the subject of the mode locking experiments described in subsection 2.5.
- "Bursty" MHD instabilities appearing within 1 or 2 msec from plasma startup. These instabilities may be the usual double tearing type associated with the initial, faster-than-classical toroidal current penetration.

Other MHD activity has been observed at very low levels of gas injection, and interesting high-frequency ($f > 50$ kHz) magnetic perturbations have been observed associated with actual disruptive events.

2.4 Investigate passive stabilization

This subsection describes the results of experiments that demonstrate the stabilization and growth rate reduction of $n = 1$ instabilities that usually precede disruptions.

The conducting shell consists of twenty aluminum segments, each of which subtend a toroidal angle of 25° and a poloidal angle of $\sim 90^\circ$. The segments are mounted on the large major radius side of the plasma, ten above the horizontal midplane and ten below. Each shell segment is mounted on an independent actuator which moves on a 45° angle to the horizontal through an 8 cm stroke. The adjustment is manual. The shell segments have a effective major radius of 92 cm, and a minor radius of 16 cm, and are coated with .002" of pure nickel.

The modular nature of the shell segments is important for two reasons. First it is necessary if the shells are to be movable along the plasma minor radius. Second, it is important to future tokamak designs that have segmented vacuum vessels that any internal structures also be segmented to maintain ease in assembly.

Fluctuations are measured using two arrays of Mirnov Coils, one distributed toroidally, one poloidally. Fluctuation data is analyzed by first integrating the signal from the Mirnov coils and then subtracting the boxcar averaged integrated signal. The resultant signal is then boxcar averaged over a shorter time scale and local maxima and minima are calculated between zero crossings. The peak to peak distance is calculated, which gives the waveform envelope. A function of the form $a + be^{(t-t_0)/\tau}$ is fit to envelope data.

The unprocessed Mirnov coil data for an example disruptive instability with the conducting shells retracted is shown in Figure 2, which also shows the plasma current trace for this case. In Figure 3, overlaid on the current trace is another shot (prepared differently) that did not disrupt. Figure 4 shows the calculated global parameters as a function of time for this base case. The parameters shown are calculated from MHD equilibrium relations using magnetic measurements (loop voltage, plasma current, vertical field). These calculations are based on assumed values for the plasma internal inductance, and employ a model for the equilibrium currents that flow in the shell.

One of the major concerns for the design of this experiment was that if, as the shell moves in toward the plasma, not only the electromagnetic boundary conditions change significantly but also the atomic physics boundary conditions change, the resultant increased impurity influx would drastically change the equilibrium profile parameters. This result would then limit the validity of the growth rate comparison, since the growth rate of MHD modes depends sensitively on the current and pressure profiles. In order to determine whether or not this effect occurred the total radiated power emitted from the plasma was measured using a broad band photo-diode. The output from this diode for three of the four shots with differing wall positions is shown in Figure 5. (The data shown are from the shots with the wall closest to the plasma.) The total radiated power does not vary significantly as a function of wall position.

Figure 6 shows the mode growth data for a series of shots where all of the experimentally controllable parameters (coil currents, fill pressure, vacuum conditions) are held fixed. The growth times increase monotonically with decreasing plasma-wall distance with a total variation of 50 to 200 μ s. Figure 7 shows the plasma current traces for each of these cases. Figure 8 shows the plasma current traces from four shots where

the bank voltages were adjusted so that the plasma current was closer to constant. For these cases the growth times also increase monotonically, but the increase in growth time is more dramatic. Figure 9 shows the growth times for both of these cases as a function of normalized wall position.

These experiments have shown a systematic shot to shot increase in the growth time of $n=1$ disruptive instability precursor as the position of an external conducting structure is moved closer to the plasma edge. The growth time was increased in spite of the fact that the shells are multiply segmented, both toroidally and poloidally. The ultimate growth time is increased by more than a factor of four as the shell is moved from a normalized radius of 1.73 to 1.2. These results are encouraging for future experiments designed to actively feedback on this mode, and they were presented at the Workshop on Control of the $n = 1$ External Kink Instability for TPX in San Diego, June, 1993.

2.5 Quantify mode locking current

Experiments with a five-section, 10-turn $(n, m) = (1, 2)$ external saddle coil have demonstrated the reduction and elimination of $m = 2$ magnetic fluctuations in a plasma during the application of a stationary resonant magnetic perturbation.

Application of increasing levels of saddle coil current to a series of identically-prepared discharges demonstrates the dramatic reduction in the amplitude of saturated magnetic field fluctuations often present in HBT-EP discharges. The fluctuations have a strong $m = 2, n = 1$ component, and appear similar to the saturated tearing modes observed in other tokamak experiments. This is illustrated in Fig. 10, where a Fourier analyzing Rogowski coil, wound directly around a quartz section, provides a signal proportional to $\dot{B}_\theta (m = 2)$ outside the plasma. The value of $q^* \equiv 2 \pi a^2 B_0 / \mu_0 I_p R_0$ is about 3.5 prior to the saddle coil discharge. The fluctuating field as measured by magnetic probes mounted on the plasma-facing surface of the conducting shells (for this experiment located ~ 5 cm from the plasma surface) is $\delta B_\theta = 2.4$ G, giving $\delta B_\theta / B_\theta \approx 2\%$. The fluctuating mode amplitude drops to zero when the applied saddle coil current, I_{sc} , exceeds 750 A. The non-sinusoidal appearance of $\dot{B}_\theta (m = 2)$ just before the oscillations cease has been observed in other tokamaks (*e.g.*, JET, Tokoloshe) and is a signature of mode slippage when conditions approach those required for mode-locking. The disappearance of the fluctuations is therefore likely to be due to mode-locking ($f_{mode} \rightarrow 0$) rather than mode stabilization ($\delta B_\theta \rightarrow 0$). This supposition is presently under investigation. As the saddle current falls below the 750 A threshold, the fluctuations resume, albeit at a somewhat higher frequency. This frequency increase is observed in most discharges and appears to be unrelated to saddle coil operation.

Pulsed saddle coil experiments have been carried out for a number of different discharge conditions in HBT-EP. Reduced thresholds ($I_{sc} \leq 500$ A) for mode-locking have been observed for plasmas operating at $q^* < 3$, where the resonant $q = 2$ magnetic surface is closer to the surface of the plasma. Disruptions have been apparently stimulated by the application of sufficiently large saddle coil current ($I_{sc} \geq 1$ kA), although this phenomenon has not been studied extensively. Finally, no mode locking was observed for non-resonant excitation of the saddle coils (*e.g.* when the current through the saddle coil set is reversed.)

3. Hardware Progress

We have made progress on all four major hardware-related tasks proposed for the present grant period. These tasks correspond to the four hardware objectives:

Objective	Date Proposed	Date Achieved
Install and test prototype saddle coil	May, 1993	April, 1993
Attach external saddle coils	Oct., 1993	June, 1993
Install 32-channel UV tomography diagnostic	Nov., 1993	on schedule to meet objective
Install multipass Thomson scattering diagnostic	Jan., 1994	on schedule to meet objective

In addition, we have made progress in testing and optimizing existing diagnostic systems. The following subsections summarize these activities.

3.1 Prototype saddle coil

Figure 11 shows a schematic representation of our prototype, 2-turn $m = 2$ saddle coil. The arrows indicate the direction of the current flow in the wire. The magnetic field generated by a 4-turn coil of this configuration (rotated poloidally by 45°) was measured during an up-to-air period when internal access to the HBT-EP vacuum chamber was possible. The measurements were performed by supplying an AC current to the saddle coil and measuring the response with a magnetic probe mounted on a carriage at the midplane of the vacuum chamber. The probe was oriented so as to measure the radial component of $\mathbf{B}$ as a function of saddle coil current, frequency and radial position. The toroidal location of the probe corresponded to the center of the midplane of the saddle coil. This measurement was performed for each potential location of the coils: at a quartz section, a bellows section and a spool section (see Fig. 12). (The vacuum chamber sections were considered to be unfavorable saddle coil locations because of the expected distortion of the applied field due to the presence of the aluminum conducting shells.)

The advantage of locating the saddle coils at the quartz sections is evident in Fig. 13. Here B_r , measured at a fixed position and normalized to the coil current, is plotted as a function of the frequency of the AC saddle coil current. The measured field from a saddle coil located at the bellows section (0.05 inch-thick stainless steel) and spool section (0.25 inch-thick stainless steel) is severely attenuated relative to that measured at a quartz section. This effect is prominent at 5-30 kHz—the range of frequencies characteristic of the magnetic fluctuations observed in HBT-EP. Each set of measurements was performed with the adjustable conducting shells in the adjacent vacuum chamber sections in both the inserted and withdrawn positions. A slight reduction in field ($< 5\%$) is observed when the shells are inserted.

The radial profile of B_r is shown in Fig. 14a. These measurements are taken at a fixed frequency (5 kHz) and again display the shielding effects of the bellows and spool sections. Note that the field null is at the geometric center of the vacuum section. Small

variations from the expected linear scaling of the field with r indicate that the coils generate some higher- m field components. The radial variation of the amplitude of the $m = 2$ magnetic field component was measured in a spool section using a 3 inch diameter Rogowski coil constructed with the turns density varying as the cosine of the poloidal angle. The measurement was performed at 8 kHz and shows a peak mode amplitude near $R = 94$ cm (Fig. 14b).

3.2 Installation of external saddle coils

The magnetic field attenuation measurements described above motivated us to install first a five-section saddle coil array with a multiple-turn saddle-coil located at each of the five quartz sections. We believe this saddle coil will be an initial step in the study of active mode control in HBT-EP, and we expect other coil configurations to be installed in the future. Each saddle coil in the array consisted of 10-turns was wound on the tokamak and poloidally rotated at each toroidal location in order to provide an $n = 1$ toroidal structure to the saddle coil field (see Fig. 2). When energized with positive polarity, the sense of the applied helical magnetic field is equivalent to that produced in the plasma by $m = 2$, $n = 1$ kink and tearing instabilities, thus the coils provide a resonant perturbation to the plasma. When the polarity is reverse, an $(n, m) = (1, -2)$ non-resonant perturbation can be applied. The five saddle coils are connected in series to a 400 μ f, 4 kV capacitor bank capable of providing a 1 ms pulse of $I_{sc} > 2$ kA to the coils. At $I_{sc} = 1$ kA, the saddle coils provide a local radial field perturbation of $B_r \approx 65$ G $\sim 50\% B_{\theta}(a)$ at the surface of a typical HBT-EP plasma ($I_p = 10$ kA, $a = 15$ cm, $R_0 = 94$ cm). This field magnitude greatly exceeds the field required to affect instabilities as reported by groups using helical coils (*e.g.* Tokoloshe, COMPASS-C). However, it was anticipated that the modular nature of the HBT-EP saddle coil system (spanning $\sim 10\%$ of the plasma circumference) would impose higher local field requirements.

3.3 32-Channel UV tomography diagnostic

The 32-channel UV tomography diagnostic consists of stainless steel vacuum segment with 32 separate tubulations providing the multiple views required for accurate emission tomography. Each tubulation interfaces to a quartz lens and light-pipe holder, and a filter holder and temperature-controlled PIN photodiode receivers. Filters can be easily interchanged allowing for reconstruction of UV impurity lines (*e.g.* C IV), D_{α} light, and IR bremsstrahlung.

The vacuum segment is presently being manufactured by Ability Engineering, Inc. (Chicago, IL), and progress is on schedule. A single completed channel has been constructed, and it is now under going bench calibrations. We have scheduled a vacuum vent beginning Sept. 7, 1993 for installation of the tomography vacuum segment, along with the Thomson scattering windows described below.

3.4 Multipass Thomson scattering

A multiple-pass Thomson scattering diagnostic has been designed in collaboration with the Ioffe Institute in St. Petersburg, Russia, for installation on HBT-EP. By utilizing two spherical mirrors with slightly offset centers of curvature, an unstable optical resonator can be constructed allowing the high power Q-switched ruby laser beam to pass up to 30 times through the plasma—greatly increasing our signal to noise and allowing

accurate measurement of the n_e and T_i profiles in the mid to low 10^{13} cm^{-3} range of density. A detailed description of the system was attached as an appendix to our original proposal submitted in September 1992.

The fabrication of the components for the multi-pass system was contracted to the Ioffe Institute and is proceeding on schedule. The larger Brewster window port for installation on the inside of the HBT-EP vacuum vessel has been received and arrangements have been made to modify the inner port on one of the HBT-EP vacuum vessel segments to accommodate the larger port. At the present time this modification is scheduled to take place in September 1993 when the HBT-EP will have a major vacuum opening.

The schedule for completion and installation of the multi-pass Thomson scattering system calls for testing the complete system at the Ioffe Institute this month and shipment to Columbia University in September 1993 for delivery in early October 1993. Two scientists from the Ioffe Institute will come to Columbia in October and November 1993 (Drs. Kantor and Razdobarin) to assist in the installation and testing of the system. Initial operation is expected to begin on schedule in December 1993.

3.5 Other Diagnostic Installation and Optimization

In addition to the major hardware activities described above, we have also made progress installing and optimizing new (relatively "minor") diagnostics. These activities include the (1) installation and testing of a poloidal array of poloidal field detectors, (2) installation and testing of the isolation amplifiers for the shell-mounted poloidal field detectors, (3) installation of a wide-band radiometer to determine the radiated power fraction and the temperature fluctuations with use of a thin beryllium filter, (4) development and testing of a diamagnetic loop with TF compensation and adjustable orientation to minimize poloidal field pick-up, and (5) parameterization of the useful operating range for the CO_2 laser interferometer.

4. Summary of Progress and Outlook for Next Year

During the first half of the first year, we have initiated our proposed scientific research plan for the HBT-EP tokamak. We have completed all of our physics objectives on or ahead of schedule. The installation of prototype saddle coil demonstrated our design goal of rapid penetration of helical fields from the outside of quartz vacuum segments, and a 5-section, 10-turn saddle coil system was quickly installed in order to demonstrate mode locking. The 32-channel UV tomography and the multipass Thomson scattering diagnostics are on schedule for installation later this year. In addition, we have conducted numerous experiments in order to characterize basic machine operation and the variety of MHD phenomena present as the gas injection, plasma current, and plasma cross section is adjusted.

The primary focus of our second year research is the control of shell-stabilized MHD instabilities by the application of "asynchronous" or "synchronous" external magnetic feedback. This requires the purchase or assembly of a high power, high current power supply to operate within the audio frequency band, 5-20 kHz. Engineering efforts associated with this power supply are proceeding along three tracks:

- First, we are investigating the use of a large ignitron serving as a negative resistance switch to apply resonant helical fields asynchronously and to induce plasma rotation. This power supply consists of two high voltage capacitor banks: the first to produce a large DC current to bias the ignitron into its negative resistance region, and the second to produce a resonant tank circuit with the saddle coil. The first stage of a prototype power supply of this type has already been tested producing a 0.5 msec pulse near 10 kHz at 700 A peak current.
- Secondly, we are developing modular, multiple-transistor switch design using bipolar transistors operating in parallel as a "Binary Class D" amplifier as described in our proposal.
- Thirdly, we are considering testing a novel "smart-shell" concept. In this configuration, feedback currents would be driven through the close-fitting conducting shells. This may reduce the peak feedback power required for stabilization since the feedback currents would be located closer to the plasma surface and be more directly applicable to implementation in larger tokamaks like TPX.

The prospects for next years research plan is very positive. We plan to continue to follow our proposed project plan:

Second Year Proposed Schedule:

Physics Objective	Hardware Objective	Date Proposed
	Install 32-channel UV tomography diagnostic	Nov., 1993
	Install multipass Thomson scattering diagnostic	Jan., 1994
	Install active control power amp	Feb., 1994
Identify shell-stabilized modes and analyze eddy-currents		Jan., 1994
Begin "asynchronous" stabilization studies		May - Aug., 1994
Begin "synchronous" stabilization studies		Aug. - Nov., 1994
Prevent mode-locking with "asynchronous" coil system		Nov. - Feb., 1995

Figure Captions

- Figure 1. Measured and reconstructed internal poloidal field profiles. Reconstructions represent the free-boundary, least squares “best fit”, equilibria to plasma and coil measurements. They include *self-consistently* the eddy currents induced in the conducting shells. (a) With the shells fully retracted, (b) With the shells fully inserted.
- Figure 2. Illustration of a typical discharge used for passive-shell stabilization studies. Two Mirnov coils located at opposite sides of the torus show the disruption precursors and show the odd toroidal mode number (probably $n = 1$).
- Figure 3. This figure shows that when discharges are prepared so as to produce disruptions, the discharge pulse-length can be significantly reduced.
- Figure 4. Estimates of the global parameters of the discharges used for the passive shell stabilization studies.
- Figure 5. Radiometer signals proportional to the total radiated power for similar discharges as the conducting shell is moved to the edge of the plasma.
- Figure 6. Normalized growth rate of disruption precursors systematically showing the reduction of growth rate as the shells move closer to the plasma surface.
- Figure 7. The current waveforms are similar as the shells are moved closer to the plasma surface when the coil capacitor bank charging voltages are constant (*i.e.* “V constant”).
- Figure 8. Discharges similar to Figure 7 except the bank voltages are varied slightly in order to better equalize the plasma current waveforms (*i.e.* “I constant”).
- Figure 9. The measured growth times of disruption precursors as a function of normalized wall position for both the “V constant” and “I constant” cases.
- Figure 10. A summary of the experiments used to quantify the current required to mode lock $m = 2$ MHD oscillations.
- Figure 11. A schematic of the 2-turn prototype saddle coil used for field penetration studies and, later, as a basis for our five-section saddle coil system.
- Figure 12. A top view of HBT-EP showing the location of the five saddle-coil segments used for the mode-locking experiments.

Figure 13. Penetration of the $m = 2$ fields through the quartz and stainless-steel vacuum segments for the shells retracted and inserted positions.

Figure 14. (a) Radial profile of the saddle coil magnetic field, and (b) the radial component of the $m = 2$ component.

Appendix: Publications and Conference Participation

We have prepared the following publications and conference presentations.

1. Journal articles

"Initial High Beta Operation of the HBT-EP Tokamak", M. K. Vijaya Sankar, E. Eisner, A. Garofalo, D. Gates, T. H. Ivers, R. Kombargi, M. E. Mauel, D. Mauer, D. Nadle, G. A. Navratil, and Q. Xiao, to appear in *J. Fusion Technology*

2. Workshop participation

"New Plasma Diagnostics for HBT-EP," D. Gates, Paper Q171, US-Japan Workshop, Princeton Plasma Physics Laboratory, April, 1993.

"Stabilization of disruption precursors with an adjustable, conducting shell, and mode-locking experiments on HBT-EP," D. Gates, GA Workshop on Control of the $n = 1$ External Kink Instability for TPX, San Diego, June, 1993.

3. 1992 APS-DPP Posters

"Experimental Program and Plans for HBT-EP," G. A. Navratil, E. Eisner, A. Garofalo, D. Gates, T. H. Ivers, R. Kombargi, M. E. Mauel, M. K. Vijaya Sankar, and Q. Xiao, *Bull. Amer. Phys. Soc.* **37** (1992) 1575.

"Experimental Operating Regimes in HBT-EP," T. H. Ivers, E. Eisner, A. Garofalo, D. Gates, R. Kombargi, M. E. Mauel, G. A. Navratil, M. K. Vijaya Sankar, and Q. Xiao, *Bull. Amer. Phys. Soc.* **37** (1992) 1576.

"Stabilization of the radial instability in the HBT-EP tokamak," M. K. Vijaya Sankar, E. Eisner, A. Garofalo, D. Gates, T. H. Ivers, R. Kombargi, M. E. Mauel, G. A. Navratil, and Q. Xiao, *Bull. Amer. Phys. Soc.* **37** (1992) 1576.

"Analysis of High Density Discharges on HBT-EP," R. Kombargi, E. Eisner, A. Garofalo, D. Gates, T. H. Ivers, M. E. Mauel, G. A. Navratil, M. K. Vijaya Sankar, and Q. Xiao, *Bull. Amer. Phys. Soc.* **37** (1992) 1576.

"Thomson Scattering Measurements on the HBT-EP Tokamak," D. Gates, E. Eisner, A. Garofalo, T. H. Ivers, R. Kombargi, M. E. Mauel, G. A. Navratil, M. K. Vijaya Sankar, and Q. Xiao, *Bull. Amer. Phys. Soc.* **37** (1992) 1576.

"Visible Light Spectroscopy on HBT-EP," A. Ulmer, E. Eisner, A. Garofalo, D. Gates, T. H. Ivers, R. Kombargi, M. E. Mauel, G. A. Navratil, M. K. Vijaya Sankar, and Q. Xiao, *Bull. Amer. Phys. Soc.* **37** (1992) 1576. (This abstract represents the contribution of A. Ulmer, a National Fusion Summer Fellow.)

4. 1993 APS-DPP Posters (submitted)

"HBT-EP Experimental Program," G. A. Navratil, E. Eisner, A. Garofalo, D. Gates, T. H. Ivers, R. Kombargi, M. E. Mauel, D. Maurer, D. Nadle, M. K. Vijaya Sankar, and Qingjun Xiao, *Bull. Amer. Phys. Soc.* to be published.

"Instability Control Using a Modular Saddle Coil Array on HBT-EP," T. H. Ivers, E. Eisner, A. Garofalo, D. Gates, R. Kombargi, M. E. Mauel, D. Maurer, D. Nadle, G. A. Navratil, M. K. Vijaya Sankar, and Qingjun Xiao, *Bull. Amer. Phys. Soc.* to be published.

"Stabilization of MHD Instabilities using the HBT-EP Movable Conducting Shell," D. Gates, E. Eisner, A. Garofalo, T. H. Ivers, R. Kombargi, M. E. Mauel, D. Maurer, D. Nadle, G. A. Navratil, M. K. Vijaya Sankar, and Qingjun Xiao, *Bull. Amer. Phys. Soc.* to be published.

"Diagnostics for the HBT-EP tokamak," M. K. Vijaya Sankar, E. Eisner, A. Garofalo, D. Gates, T. H. Ivers, R. Kombargi, M. E. Mauel, D. Maurer, D. Nadle, G. A. Navratil, and Qingjun Xiao, *Bull. Amer. Phys. Soc.* to be published.

"Analysis of the Equilibrium and Stability of HBT-EP Plasmas," E. Eisner, L. Bai, A. Garofalo, D. Gates, R. Kombargi, M. E. Mauel, D. Maurer, D. Nadle, G. A. Navratil, M. K. Vijaya Sankar, and Qingjun Xiao, *Bull. Amer. Phys. Soc.* to be published.

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FIGURE 1

Shell Stabilization Experiment-Base Plasma

Figure 2

FIGURE 3

Shot 1535

Figure 10

Database Items vs Time

Shot 1681Sh

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Top View Of HBT-EP

Figure 12

Figure 13

Figure 14A

Figure 15B

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