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INVESTIGATION OF GLOBAL ALFVÉN INSTABILITIES IN TFTR

BY

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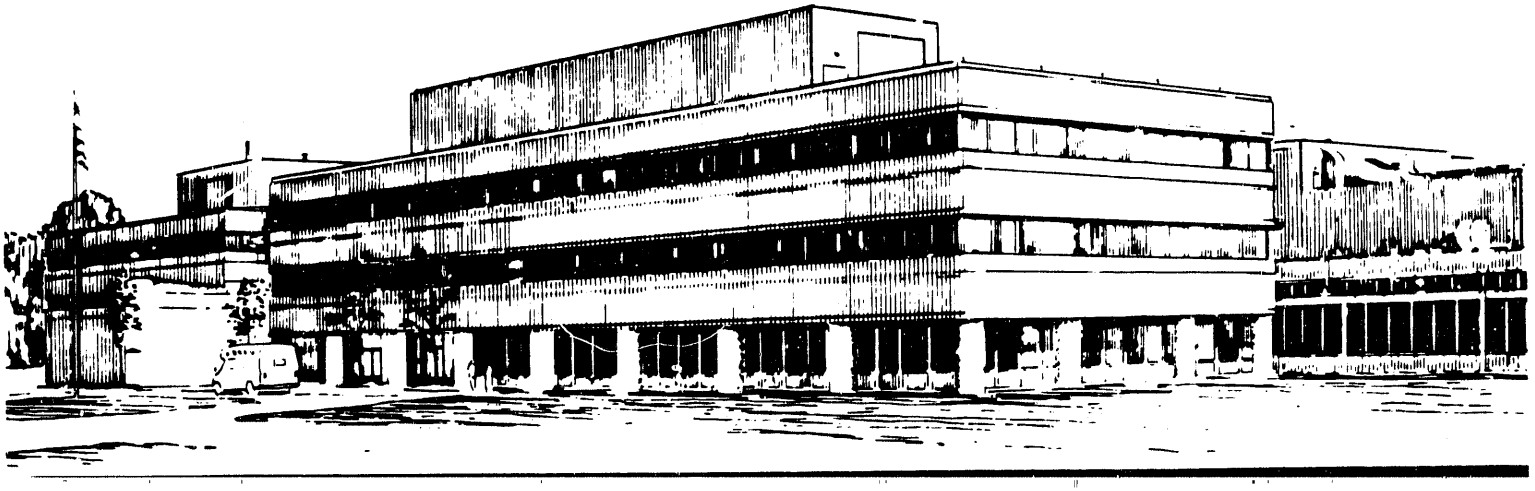
PPPL PRINCETON PLASMA PHYSICS LABORATORY



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INVESTIGATION OF GLOBAL ALFVEN INSTABILITIES IN TFTR

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Abstract

Toroidal Alfven Eigenmodes (TAE) were excited by the energetic neutral beam ions tangentially injected into TFTR plasmas at low magnetic field such that the injection velocities were comparable to the Alfven speed. The modes were identified by measurements from Mirnov coils and beam emission spectroscopy (BES). TAE modes appear in bursts whose repetition rate increases with beam power. The neutron emission rate exhibits sawtooth-like behavior and the crashes always coincide with TAE bursts. This indicates ejection of fast ions from the plasma until these modes are stabilized. The dynamics of growth and stabilization was investigated at various plasma current and magnetic field. The results indicate that the instability can effectively clamp the number of energetic ions in the plasma. The observed instability threshold is discussed in the light of recent theories. In addition to these TAE modes, intermittent oscillations at three times the fundamental TAE frequency were observed by Mirnov coils, but no corresponding signal was found in BES. It appears that these high frequency oscillations do not have direct effect on the plasma neutron source strength.

MASTER

1. INTRODUCTION

In an ignited d-t tokamak fusion reactor, the 3.5 MeV alpha particles produced from the fusion reactions are expected to be born with velocities faster than the Alfven speed, so they can interact strongly with shear Alfven waves[1]. In tokamaks, toroidal Alfven eigenmodes[2] (TAE) can go unstable easily because their frequencies lie within the frequency qap between two Alfven continuum bands thus avoiding continuum damping. This instability can eject the fast alpha particles from the tokamak before they thermalize with the bulk plasma[3]. It is also important to reactors which rely on energetic neutral beam current drive, like the International Thermonuclear Experimental Reactor (ITER), which plans to employ 1.3 MeV neutral beams to drive the plasma current. Substantial reduction in current drive efficiency can occur if the beam particles are expelled by excited TAE modes.

In typical tokamak parameters, the Alfven velocity $V_A=B/(\mu_o n_i m_i)^{1/2}$ is very high; its magnitude is comparable to the velocity of MeV ions, e.g., in a 5 tesla magnetic field, deuterium density of 10^{20} m^{-3} gives V_A = 7.7×10^6 m/s which corresponds to the velocity of 1.2 MeV aplha particles. Therefore, it was generally perceived that one could only investigate this instability in an ignited tokamak. Careful consideration of tokamak operation characteristics revealed that it might be possible to simulate this type of alpha particle physics[4] with existing neutral beams. In order to excite TAE modes with neutral beam injection, it is necessary to have the beam injection velocity V_b comparable to V_A. The Alfven velocity can be reduced by lowering the magnetic field and raising the plasma density. The maximum density achievable in a tokamak is approximately

proportional to the magnetic field. The Murakami parameter[5], defined as $n_e R/B_T$, has an upper bound which is limited by disruption. Its value is machine dependent, and it varies with methods of plasma fueling and auxiliary heating. In TFTR with neutral beam heating and gas fueling, we can have $n_e R/B_T$ up to 6×10^{19} m^{-2} $tesla^{-1}$. The tangentially injected beam ions are passing particles in the tokamak. We prefer the orbit shift to be less than half the minor radius so that they are reasonably well confined, i.e., $\Delta \sim 2q\rho < a/2$. Some of the beam particles may be scattered into trapped particles before they are slowed down, and we prefer to have their banana width $\Delta_b \sim 2q\rho\varepsilon^{-1/2} < a/2$ in order to avoid strong localized heating on the limiter. This is more restrictive than the previous condition on passing particles.

With all these contraints taken into account, Fig.1 shows a small operating region for TAE excitation in TFTR. We have assumed 100keV deuterium beam ions (V_b = 3.1×10^6 m/s) in a deuterium plasma with q(a)=2.3 . Within the small area with B~1 tesla, $n_i \sim 2.5\times10^{19}$ m^{-3}, we have $V_b \geq V_A$, $n_e R/B_T \leq 6\times10^{19} m^{-2}$ $tesla^{-1}$ and $\Delta_b \leq a/2$. We believe that this is a feasible operating point to excite TAE modes. It should be pointed out that the boundaries of this region are "soft" boundaries. TAE modes can be excited with V_b slightly below V_A, and sometimes we can have plasmas with $n_e R/B_T$ slightly above 6×10^{19} m^{-2} $tesla^{-1}$. In our experiment, we found that the plasma disrupted too often at q(a)=2.3, and we operate mostly at q(a)>2.7 . Nevertheless, Fig.1 shows that we can expect to see TAE modes only in a very small operating parameter space, and there is no doubt about where to look for them.

2. MODE IDENTIFICATION

TAE modes have the following characteristics:

a. Excitation requires $V_b \sim V_A$.

b. The mode frequency is approximately $\omega \approx V_A/2qR$ where V_A and q are taken at the location at which the mode has maximum amplitude.

c. Each eigenmode consists of many poloidal harmonics[6] and the dominant m-th harmonic changes with q approximately following the relationship $m \sim nq$.

In our experiment, up to 14 MW of deuterium neutral beams at energies below 110 keV were injected into plasmas with the following parameters: $B \geq 1$ tesla, $q(a) \geq 2.7$, $R_o = 2.4$m, $a = 0.75$m, $n_e \sim 3 \times 10^{19}$ m^{-3}, $T_e(0) \sim 2$keV, $\langle \beta_p \rangle \sim 1$. Bursts of coherent oscillations were observed by Mirnov coils and beam emission spectroscopy[7] (BES). These oscillations have the characteristics of TAE modes as summarized in the following:

a. With q(a) fixed at 2.8 and $\langle \beta_p \rangle$ kept around 1, we raised the toroidal field from 1 tesla to 2 tesla. V_b/V_A dropped from 1 to 0.6 and those oscillations disappeared.

b. By varing the plasma density and magnetic field, we managed to change V_A over a factor of 2 and the oscillation frequency followed the theoretical prediction $\omega \approx V_A/2qR$ over the entire range with q=1.3 . Doppler shift in frequency was minimized by nearly balanced neutral beam injection.

c. The mode structure was measured by BES. Cross-phase spectra showed a radial standing wave structure with reasonably good phase coherence between signals from various locations. The coherence is less than

perfect, and its variation corresponds to the mode amplitude profile. This indicates that a coherent global mode structure is superimposed on some incohenent fluctuations. Poloidal mode number measurements indicate that the dominant poloidal harmonic number m increases with minor radius while m~nq holds only approximately. As expected, the direction of poloidal propagation is the same as the ion diamagnetic drift velocity .

In our experiment, $<\beta>$ ~ 1%, about half the Troyon limit. One shot has been analysed for ideal ballooning instability. It was found that the plasma is everywhere stable against ideal ballooning modes, except near the very edge of the plasma. Based on the above results, we conclude that these are TAE modes. Some of these experimental data have been published recently[8]. Concurrent experiments[9] on the DIII-D tokamak also produced evidence of TAE modes under similar conditions.

3. EJECTION OF ENERGETIC PARTICLES

The most significant consequence of TAE instability is the ejection of energetic particles by these modes. Evidence of this can be seen from Fig.2. The neutron emission rate S_N has sawtooth-like behavior and there is very good correlation between the TAE bursts and the drop of neutron emission from the plasma. Since beam-target reaction dominantes in our plasma, a decrease in neutron emission rate is a strong indication of energetic beam ion loss. It appears that when the beam ion population reaches a certain level, TAE modes become unstable. They grow to a certain amplitude, eject

some fast ions, probably reduce the energetic ion density gradient at the same time, until they become stable again. This suggests that the beam ion pressure is clamped near the instability threshold. When the neutral beam injection power P_b is raised, the neutron source strength rises faster during the quiescent period. It takes less time to reach the instability threshold, and the TAE bursts appear more frequently with somewhat larger amplitudes. There appears to be a nonlinear relationship between the amplitude of the TAE burst and the change in S_N. Low amplitude TAE bursts seem to have no noticeable effect on S_N. This appears to support the existence of a threshold for orbit stochasticity which can cause significant fast ion loss[3]. More work is needed to quantify this for comparison with theory. Fig.3 shows the variation of neutron emission rate and central electron density with neutral beam power. They increase faster at higher magnetic field. However, the ratio $S_N/n_e(0)$ is not sensitive to beam power as depicted in Fig.4 . When we repeat this with I_p=530kA at B_T=1.2 tesla, $S_N/n_e(0)$ remains insensitive to P_b, but its numerical value is notably higher (by approximately 40%) than that for I_p=420kA.

The above observations can be explained as follows. Let us approximate the deuterium ion distribution function as the sum of a cold Maxwellian distribution (target plasma) and an energetic slowing-down distribution due to neutral beam injection. The neutron production rate from d-d reaction is the sum of beam-target, beam-beam and target-target reactions:

$$S_N = \int dV \{ n_b n_t \langle\sigma v\rangle_{bt} + 1/2\, n_b^2 \langle\sigma v\rangle_{bb} + 1/2\, n_t^2 \langle\sigma v\rangle_{tt} \} \qquad (1)$$

In our experiment, $T_i < 2$keV and the thermal reactivity $<\sigma v>_{tt}$ is practically zero. The beam-beam neutron rate is estimated to be 20-30% of the total. Therefore, S_N is mainly due to beam-target reactions:

$$S_N \approx \int dV\, n_b\, n_t <\sigma v>_{bt} \qquad (2)$$

We assume that the deuterium density profile is similar to the electron density profile which is flat across the plasma minor radius, and it is insensitive to beam power. Furthermore, we assume that the slowing-down distribution $f_b(v)$ for the beam ions is also insensitive to beam power. This is substantiated by the fact that the electron temperature and the effective charge number are not sensitive to beam power, and it leads to the result that $<\sigma v>_{bt}$ is independent of beam power. Therefore,

$$S_N/n_e(0) \propto S_N/n_t(0) \propto \int dV\, n_b = N_b \qquad (3)$$

where N_b is the total number of beam ions in the plasma. The fact that $S_N/n_e(0)$ is independent of beam power indicates that N_b is clamped by the TAE instability. It is interesting to note that with I_p=420kA, $S_N/n_e(0)$ has similar values at B_T=1 tesla and 1.2 tesla. The value becomes 40% higher when I_p was raised to 530kA, possibly due to better fast ion confinement at higher current. We should point out that the uncertainty on $S_N/n_e(0)$ is about +/-15%, and a 40% difference is barely outside the error bars. More careful analysis is needed before we can come to a definite conclusion.

4. INSTABILITY THRESHOLD

As noted in our previous paper, the observed instability threshold is an order of magnitude higher than that predicted by Fu and Van Dam[10] in which electron Landau damping due to the passing electrons is assumed to be the dominant damping mechanism. If we include the effect of the anisotropic beam-ion velocity distribution function[11], the disagreement is even larger. It was pointed out recently[12] that trapped electrons near the trapped/passing boundary can play an important role. The collisional damping rate due to trapped electrons is given as[12]:

$$\gamma/\omega = -2.1 \{\ln[8(2\varepsilon\omega/\nu_e)^{1/2}]\}^{1/2} \beta_e(\nu_e/\omega)^{1/2} \qquad (4)$$

where ε is the inverse aspect ratio and ν_e is the electron collision frequency. γ/ω is proportional to $(\nu_e/\omega)^{1/2}$ rather than ν_e/ω due to the electrons in the trapped/passing boundary layer[13]. For our experimental parameters, this damping rate is an order of magnitude larger than the electron Landau damping calculated by Fu and Van Dam[10]. Continuum damping[14-16] would also raise the threshold substantially. It depends on the details of q(r) which we cannot quantify at this moment. Ion Landau damping[17] due to the sideband resonance at $v_{\parallel} = V_A/3$ is also considered. It is not important for this experiment because of the low β plasma.

In our experiment, the n=2 mode dominates at B=1 tesla while the n=3 mode becomes dominant at B=1.2 tesla. This feature was qualitatively reproduced by the NOVA-K code[6]. We use the plasma pressure and q profiles obtained from transport analysis, and find that the n=2 mode has a lower

threshold at B=1 tesla, while the n=3 mode has a lower threshold at B=1.2 tesla. However, the absolute magnitude of the instability threshold is still an order of magnitude below the experimental value. Incorporation of collisional damping and continuum damping into NOVA-K code will be carried out soon.

5. HIGH FREQUENCY OSCILLATIONS

The TAE bursts appear very frequently at $\omega = \omega_A$ during neutral beam injection into plasmas at low magnetic field. They can be detected by Mirnov coils and BES. Intermittent oscillations at a higher frequency $\omega \approx 3\omega_A$ are also observed by Mirnov coils, but there is no corresponding signal in BES although its frequency bandwidth is wide enough for these oscillations. Fig.5 shows the amplitude modulation of these high frequency oscillations in the Mirnov coil signal. The period of modulation approximately equals the sawtooth period, but there appears to be a time lag between the sawtooth crash and the appearance of these oscillations which, unlike the TAE modes, have no instantaneous effect on the neutron source strength. As we know, there is a third order frequency gap in the Alfven continuum at the frequency $3\omega_A$ and it is tempting to relate that to these high frequency oscillations. The width of this gap is very narrow (proportional to ε^3), but the temporal variation of q(r) due to sawteeth activity may cause the gap to appear periodically which permits these intermittent oscillations. However, we have to point out that oscillations with similar appearance have been observed by Mirnov coils in plasmas with high magnetic field. More analysis and measurements of mode

numbers are necessary for their identification.

6. SUMMARY AND DISCUSSIONS

We have demonstrated that TAE modes can be excited by fast ions with velocities comparable to the Alfven speed. The TAE modes can effectively clamp the number of fast particles in the plasma, and therefore present an obvious danger to fusion reactors. Fortunately, the instability threshold is not as low as originally predicted, and it may be possible to operate a fusion reactor without exciting them. It is very important to find out the instability threshold in terms of plasma parameters. In the TFTR experiment, TAE modes can be excited only in a very small operating region, and the plasma is not well diagnosed because of the low magnetic field. Many of the plasma parameters are outside the design range of the existing diagnostics. Further experimental and theoretical studies are necessary to provide better understanding of this instability. If one can drive these modes with an external antenna and study their damping rates, it can provide valuable information on the instability threshold. In case the instability cannot be avoided in a reactor, we may have to find a way to stabilize it. Feedback stabilization may work for low-n modes, but probably will not be effective for high-n modes.

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REFERENCES

1. M. N. Rosenbluth and P. H. Rutherford, Phys. Rev. Lett. **34** (1975),1428.
2. C. Z. Cheng, Liu Chen, and M. S. Chance, Ann. Phys. (N.Y.) **161** (1985), 21; also C. Z. Cheng and M. S. Chance, Phys. Fluids **29** (1986), 3695.
3. D. J. Sigmar, Collection of Papers Presented at the IAEA Technical Committee Meeting on Alpha Particles in Fusion Research at Aspenas, Sweden (June 10-14,1991), Vol. II, p.624. Submitted to Phys. Fluids B.
4. K. L. Wong, Bull. Am. Phys. Soc. **33** (1988), 2098.
5. M. Murakami, J. D. Callen, L. A. Berry, Nucl. Fusion **16** (1976), 347.
6. C. Z. Cheng, Phys. Fluids B **3** (1991), 2463.
7. R. J. Fonck, P. A. Dupperex, and S. F. Paul, Rev. Sci. Instrum. **61** (1990), 3487.
8. K. L. Wong, R. J. Fonck, S. F. Paul, D. R. Roberts, E. D. Fredrickson, R. Nazikian, H. K. Park, M. Bell, N. L. Bretz, R. Budny, S. Cohen, G. W. Hammett, F. C. Jobes, D. M. Meade, S. S. Medley, D. Mueller, Y. Nagayama, D. K. Owens, and E. J. Synakowski, Phys. Rev. Lett. **66** (1991), 1874.
9. W> W> Heidbrink, E. J. Strait, E. Doyle, G. Sager, R. T. Snider, Nucl. Fusion **31** (1991), 1635.
10. G. Y. Fu and J. W. Van Dam, Phys. Fluids B **1** (1989), 1949.
11. H. L. Berk, B. N. Breizman, and Huanchun Ye, IFSR#507(July 1991), Institute for Fusion Studies, The University of Texas at Austin.
12. N. N. Gorelenkov and S. E. Sharapov, Collection of Papers Presented at the IAEA Technical Committee Meeting on Alpha Particles in Fusion Research at Aspenas, Sweden (June 10-14,1991), Vol. II, p738.
13. M. N. Rosenbluth, D. W. Ross, and D. P. Kostomarov, Nucl. Fusion **12**

(1972), 3; also V. A. Mazur, A. B. Mikhajlovskij, Nucl. Fusion **17** (1977), 193.

14. M. N. Rosenbluth, H. L. Berk, D. M. Lindberg, and J. W. Van Dam, IFSR#518 (August 1991), Institute for Fusion Studies, The University of Texas at Austin. Submitted to Phys. Rev. Lett.
15. F. Zonca and L. Chen, Bull. Am. Phys. Soc. **35** (1990), 2069. Submitted to Phys. Rev. Lett.
16. H. L. Berk, J. W. Van Dam, Z. Guo, D. M. Lindberg, IFSR#499, Institute for Fusion Studies, The University of Texas at Austin. Submitted to Phys. Fluids B.
17. R. Betti and J. P. Friedberg, Collection of Papers Presented at the IAEA Technical Committee Meeting on Alpha Particles in Fusion Research at Aspenas, Sweden (June 10-14,1991), Vol. II, p.667.

Figure Captions

Figure 1. Determination of operating point for the TAE experiment.

Figure 2. Correlation between the drop in neutron source strength and TAE bursts.

Figure 3. Variation of neutron source strength and central electron density with neutral beam power.

Figure 4. The neutron emission rate normalized by the central electron density is not sensitive to beam power and magnetic field.

Figure 5. Intermittent oscillations observed by Mirnov coils at frequency $3\omega_A$.

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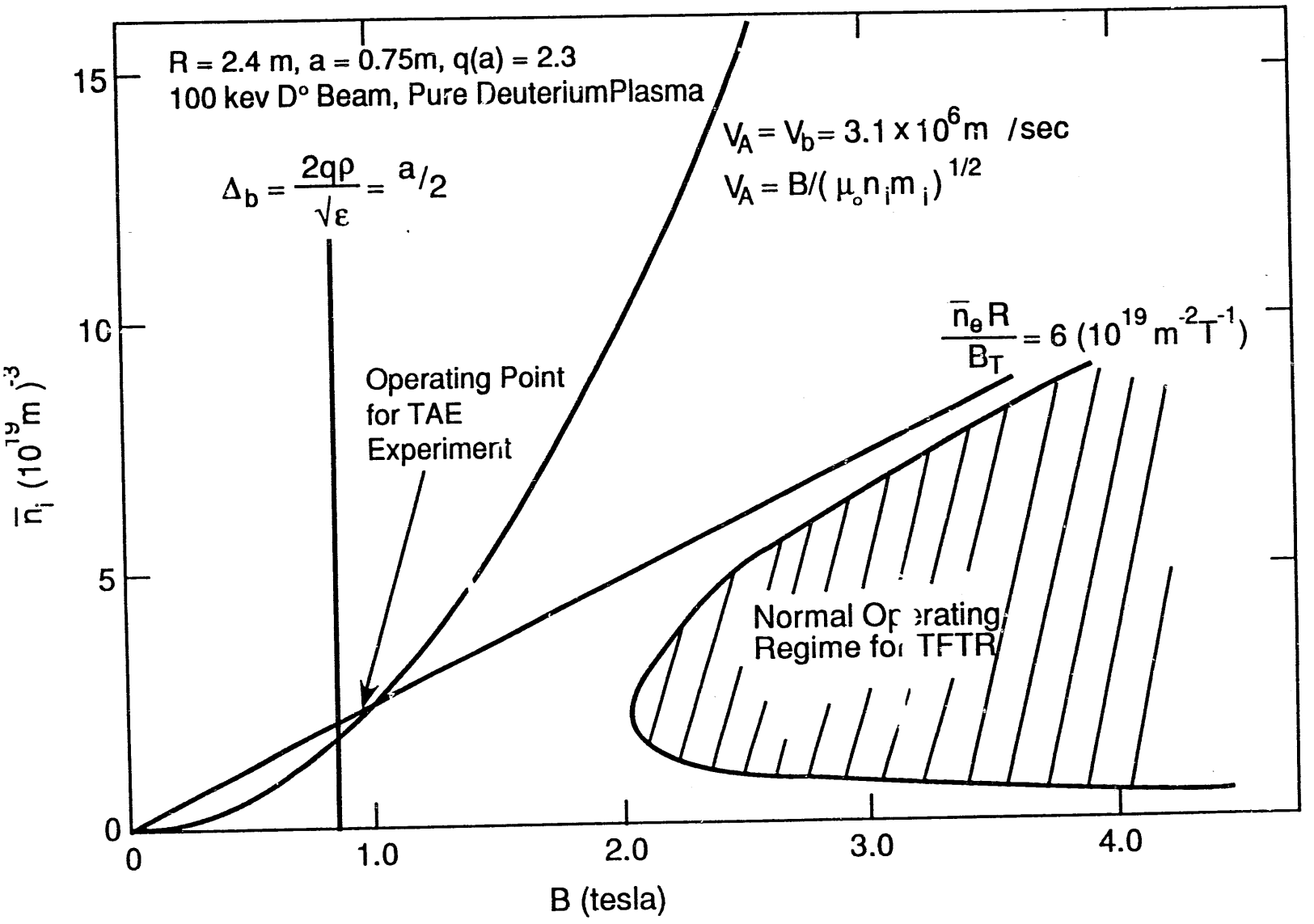
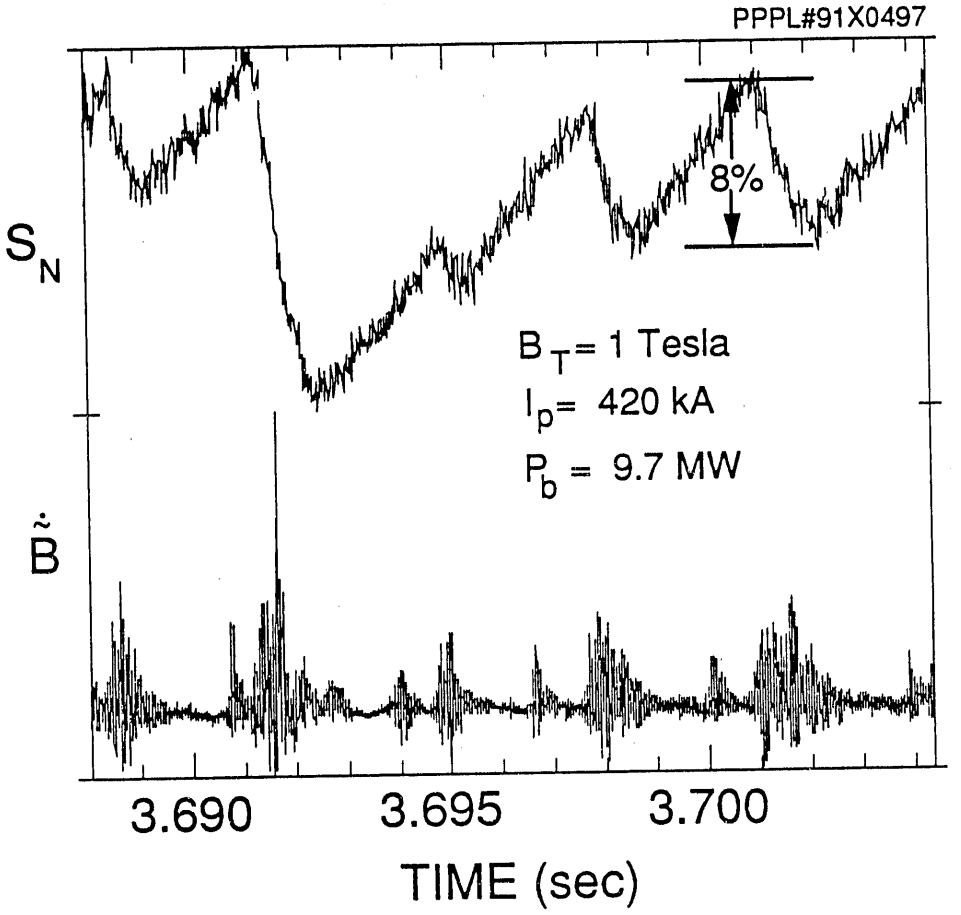


Fig. 1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3.695
3.700
TIME (sec)

Fig. 2

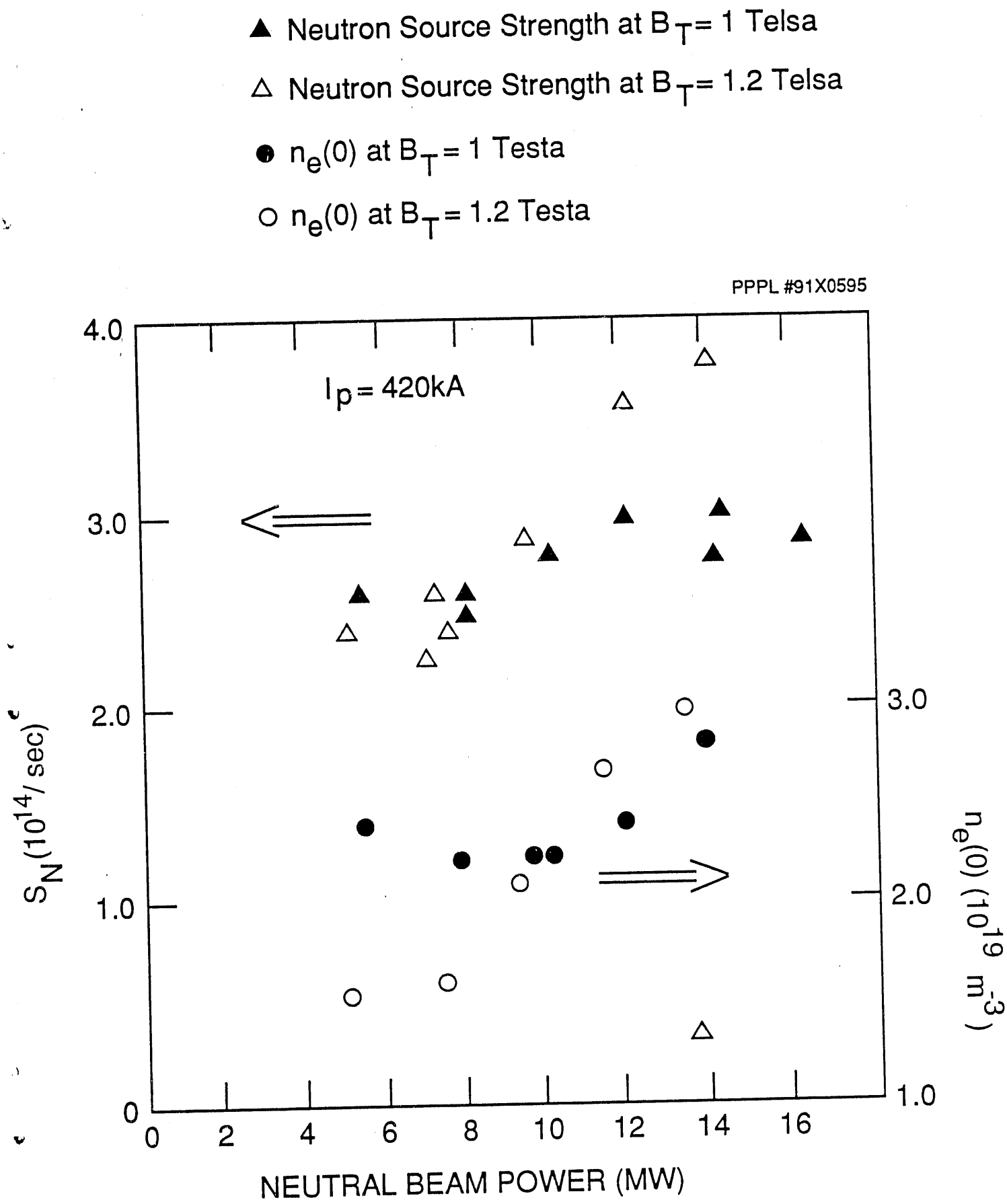
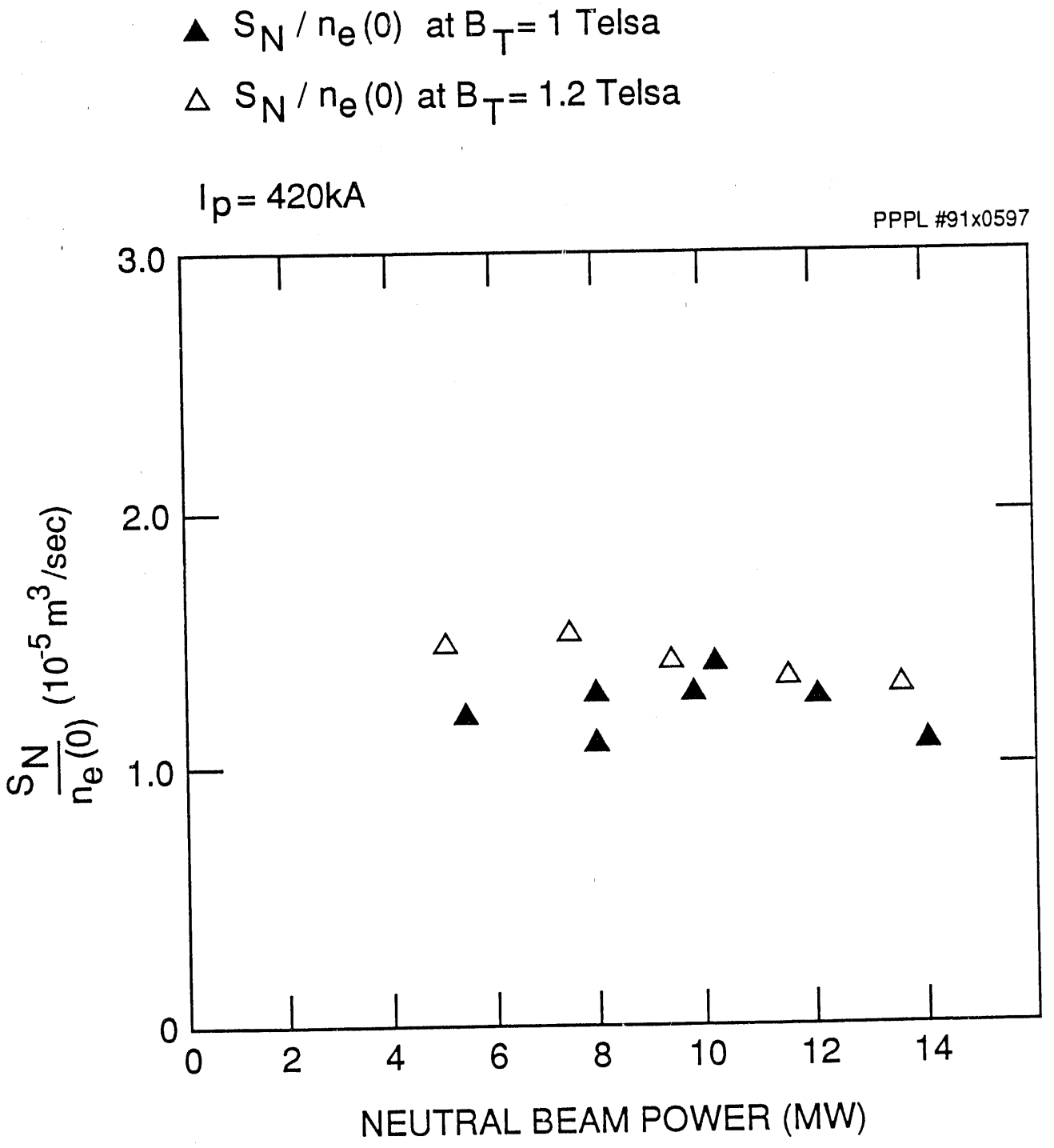

▲ Neutron Source Strength at B_T = 1 Telsa
△ Neutron Source Strength at B_T = 1.2 Telsa
● $n_e(0)$ at B_T = 1 Testa
○ $n_e(0)$ at B_T = 1.2 Testa
PPPL #91X0595
I_p = 420kA
$S_N(10^{14}/sec)$
$n_e(0)$ $(10^{19}$ $m^{-3})$
NEUTRAL BEAM POWER (MW)
0
1.0
2.0
3.0
4.0
0
2
4
6
8
10
12
14
16
1.0
2.0
3.0

Fig. 3


▲ $S_N / n_e(0)$ at B_T = 1 Telsa
△ $S_N / n_e(0)$ at B_T = 1.2 Telsa
I_p = 420kA
PPPL #91x0597
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2.0
1.0
0
$\frac{S_N}{n_e(0)}$ (10^{-5} m^3/sec)
0
2
4
6
8
10
12
14
NEUTRAL BEAM POWER (MW)

Fig. 4

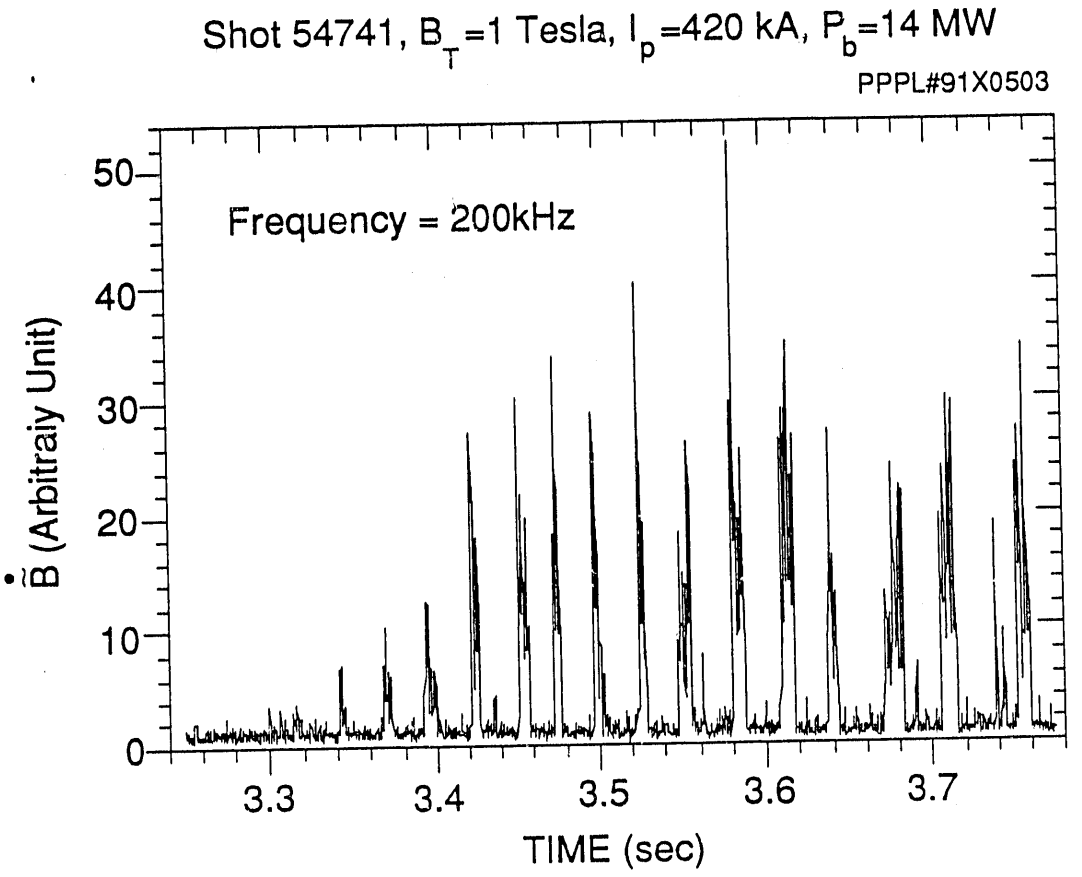
Shot 54741, B_T=1 Tesla, I_p=420 kA, P_b=14 MW
PPPL#91X0503
Frequency = 200kHz
$\dot{B}$ (Arbitraiy Unit)
50
40
30
20
10
0
3.3
3.4
3.5
3.6
3.7
TIME (sec)

Fig. 5

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