OPERATION OF THE SMALL OCTUPOLE WITH TWO HOOPS REMOVED

J. C. Sprott

D. J. Holly

A. P. Biddle

R. J. Groebner

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On October 23, 1977, during routine operation of the small octupole, difficulties were experienced with the ICRH experiment, and the machine was let up to air to repair the ICRH coupling coil. At that time it was noticed that the lower inner hoop was completely broken in two at the place where the hanger closest to the antigap was attached. There was evidence of arcing across the break, indicating that the poloidal field had been operated after the failure, although no unusual noises had been heard when the field was operated at ∿4 kV with 12 - 240μF capacitors on the 10 msec period. For several months previous to the failure, it was known that the hoops were bent by as much as ½" by the large magnetic forces resulting from repeated pulsing at the maximum (5 kV) amplitude while running Tokapole discharges.

The magnitude of the calamity was greatly abated by the fact that after fourteen years of operation as an octupole, the schedule called for removal of the hoops on about December 1, 1977, for operation as a tokamak for about a month before disassembling the octupole and replacing it with the Tokapole II device. After briefly considering methods of repairing the broken hoop, it was decided instead to operate the machine as a quadrupole for a month prior to its conversion to a tokamak. The lower inner hoop was cut in two additional places and removed through the 4½" port on the outer wall. The upper outer hoop was removed in similar fashion. The diagonal configuration was chosen as being the most suitable for ICRH and possibly Tokapole experiments as well.

When the poloidal field was pulsed with only two hoops, the half period was 7.5 msec with the 60:1 turns ratio and 12 capacitors, indicating that the inductance had approximately doubled. Measurements with a flux loop indicated that the flux linkage between the wall and the minor axis was ∿30% of the flux linked by the hoops, indicating that ∿70% of the flux is private. Since the inductance doubled, for a constant energy (36 kJ), the quantity $\frac{1}{2}LI^2$ is unchanged, and the total hoop current was thus decreased to ∿70% of the corresponding value for the octupole. However, this current is shared by two rather than by four hoops, and so the current per hoop is about 40% greater for the quadrupole, doubling the magnetic forces. To partially counteract this greater force, the hoops were moved vertically ∿½" farther from the walls. Above about 4 kV, the core saturates at a value where $\int_o^t V_{PG} dt \simeq 0.10$ volt-seconds.

The quadrupole was operated as a tokapole with all parameters identical to those described in PLP 712. The toroidal field was a 2 msec crowbarred half sine wave with a peak value of ∿3 kG on axis. Preionization was provided by 50W of 2.45 GHz and 10 kW of 9.0 GHz ECRH, and the poloidal field was pulsed on 500 μsec after the toroidal field. The toroidal current was measured by the method described in PLP 712. The optimum pressure was $\sim 1.3 \times 10^{-4}$ torr (true), the same as for the octupole. The output from the current sample circuit was surprisingly similar for the octupole and quadrupole, but after the appropriate calibration factors were applied, the currents were significantly smaller for the quadrupole, as shown in fig. 1. Ohmic heating produced by poloidal currents was more noticeable in the quadrupole than in the octupole, and it was for that reason that the toroidal field was crowbarred.

The machine was also operated as a simple quadrupole, i.e., with no toroidal magnetic field. A j_{SAT} profile for this case is shown in fig. 2. The plasma is confined mainly to the region near the hoops. The peak electron density observed is roughly 2×10^9 cm^{-3} (assuming $T_e = 2$ eV). On another run with identical operating conditions, a similar probe gave j_{SAT} values corresponding to densities about 5 times higher.

The ion saturation current signal was quite noisy everywhere in the plasma, with no well-defined surface across which the noise level changed abruptly. Fig. 3a shows a plot of signal-to-noise ratios ($j_{SAT} / \delta j_{SAT}$) where the darker areas correspond to quiet regions; the quietest area corresponds to a s/n ratio of about 25. A typical j_{SAT} trace is shown in figure 3b, c, d (This trace was taken with the octupole line-average probe in the bridge region, but is similar to what is seen on a local probe). The expanded scale traces show the noise on j_{SAT} to have a fairly periodic nature.

The plasma confinement time was examined by turning off the (S-band) microwave power at approximately peak magnetic field and monitoring j_{SAT}. This is shown in Fig. 4a, b (taken at the point labelled A in Fig. 2) and Fig. 4c, d (taken at the point labelled B in Fig. 2). The plasma is seen to decay in a few hundred microseconds at point A, with a somewhat faster decay at point B.

An attempt was made to observe the density limit as a function of (S-band) microwave power (as in PLP 652 for the octupole), but no density limit was seen at power levels up to about 4 kW. The reflected power was also low ($P_{reflected}$ / $P_{forward} \lesssim 15\%$) up to these power levels, as in the octupole case.

ICRH heating was not qualitatively different from previous octupole efforts but reduced confinement times and unfavorable locations of the resonance zones with respect to the coupling coils resulted in densities an order of magnitude lower. Wall reflux was also increased about 10% at comparable hoop voltages. More details on the ICRH are given in PLP

After the hoops were removed from the machine, a vacuum ultraviolet (VUV) monochromator was connected to the toroid. This instrument allowed us to observe the VUV spectrum of our discharges, something which had previously never been done on the octupole. Principally, we observed the hydrogen L_α line which is produced by the n = 2 to n = 1 transition. When the quadrupole was operated as a tokapole, we also observed and tentatively identified lines belonging to N I, N II, N III, C II, C III, O II, and O III. (C II, C III, O II, and O III lines have been observed in the visible spectrum of tokapole discharges on the octupole).

Some measurements were taken of L_α intensity as a function of ohmic power input to the quadrupole tokapole discharge. Figure 4 is a plot of L_α intensity vs. ohmic heating power input for the range of input power which could be achieved on this device. L_α intensity increases fairly rapidly with increasing ohmic power. This suggests that the plasma is not fully ionized for any ohmic power level which we could apply. For if it were, one would expect L_α to saturate at the higher power levels. This clearly does not happen.

Further evidence that the plasma is not burned out can be found by comparing figures 5 and 6. Figure 5 is a time history of L_α and ohmic power input for the highest power tokapole discharge available on the quadrupole. Figure 6 is a time history of H_β and ohmic power input for the highest power discharge possible with the octupole. (H_β is used here since we were not equipped to measure L_α on the octupole. However, H_β and L_α are expected to show the same qualitative behavior.) Note that the capacitor banks were charged to essentially the same voltage for both cases.

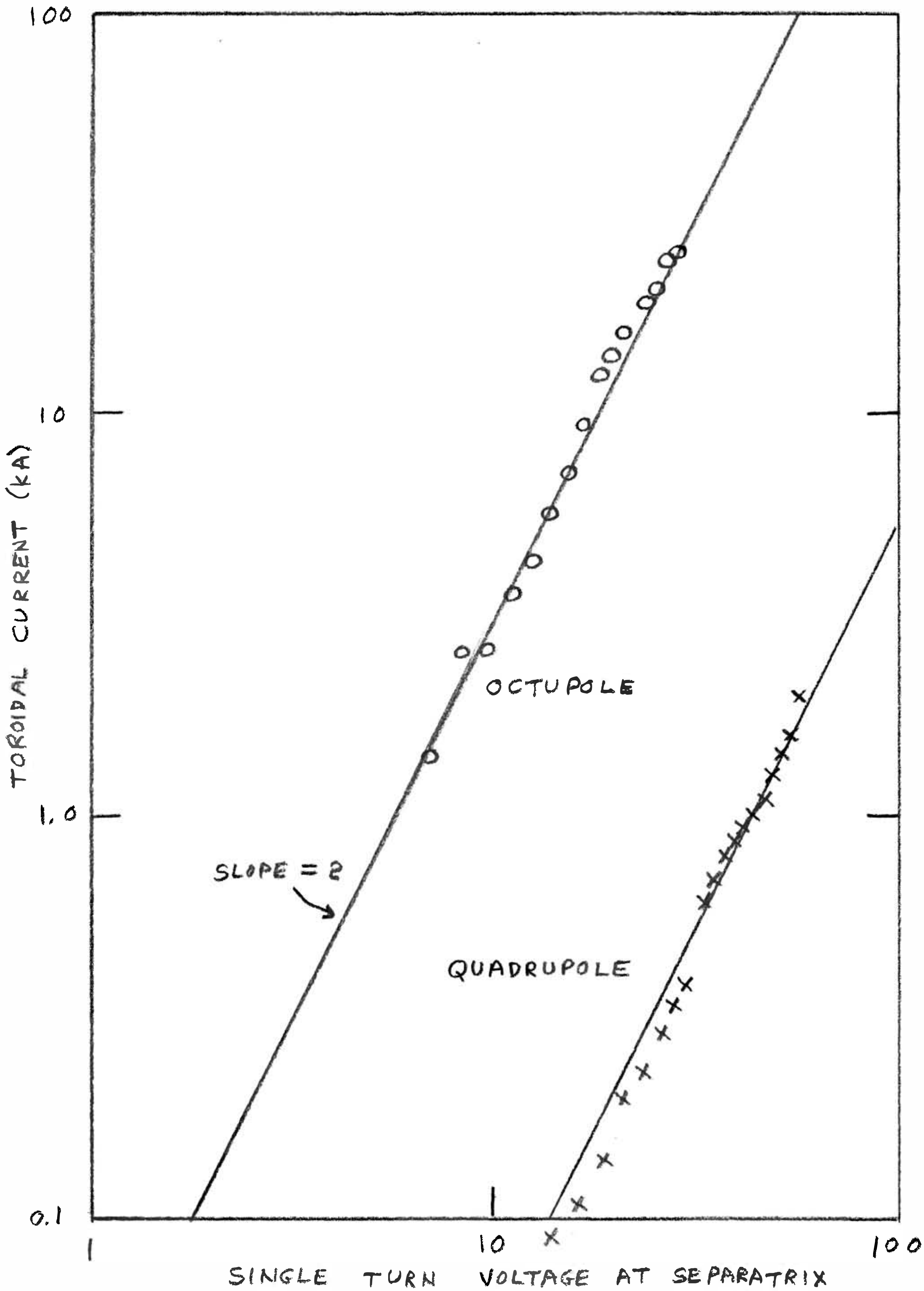
For the octupole discharge, it can be seen that the H_β peaks early in the discharge and then drops quickly even though the ohmic power is still increasing. This behavior indicates that the hydrogen is quickly ionized so that little neutral gas is available to produce spectral light. This graph is good evidence that the plasma is nearly fully ionized.

Figure 5 shows that the case for the quadrupole discharge is far different. The L_α light peaks after the ohmic power does and it roughly follows the ohmic power curve. Apparently the plasma does not burn out and a good share of the ohmic power is always going into hydrogen radiation.

One wonders whether or not all of the ohmic power is converted into light from hydrogen. If so, the L_α intensity should be directly proportional to the ohmic power. This does not appear to be exactly the case in figure 5. Also, a line with slope 1 has been drawn through the data of figure 4. It does not appear to be the best line that could be drawn through the points, and so this also suggests that not all of the ohmic power is converted to light. However, considering the experimental errors involved in measuring the ohmic power, one cannot draw firm conclusions.

Preliminary measurements were also made to see if Doppler broadening of H_β could be observed during the ICRH experiments. If the ions are heated and transfer some of their energy to the atoms, then the radiation from these atoms will be shifted in wavelength as they move towards and away from the observer. The net result is that the profile of a spectral line should be broadened. We did observe Doppler broadening as is indicated in Figure 7. The FWHM of this line is 1.5 Å. This broadening corresponds to an atomic temperature of about 9 eV. An alternate measurement of the ion temperature was not available for this run.

FIG 1


100
10
1.0
0.1
TOROIDAL CURRENT (KA)
OCTUPOLE
QUADRUPOLE
SLOPE = 2
1
10
100
SINGLE TURN VOLTAGE AT SEPARATRIX

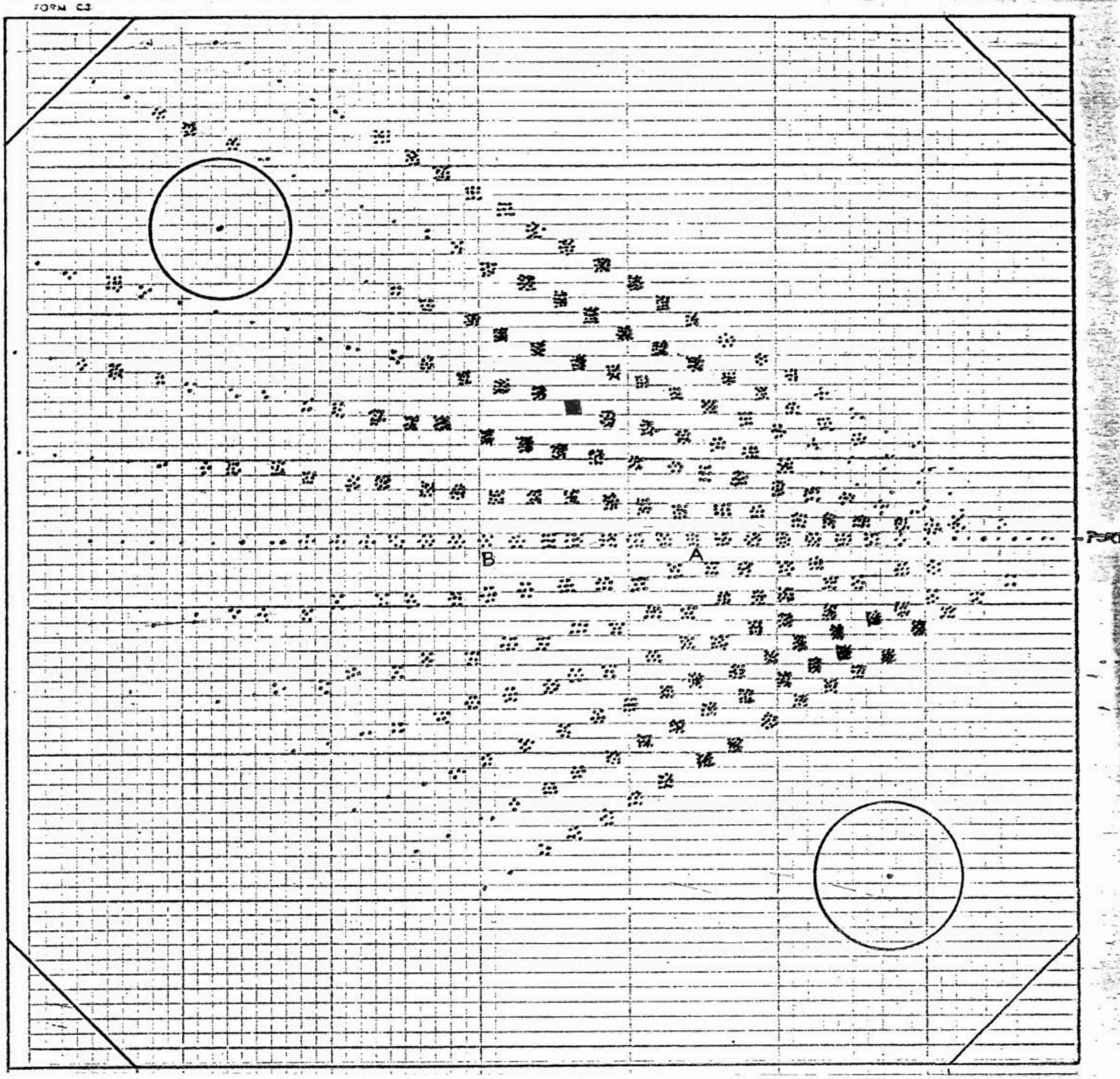


FIG. 2. j_{SAT} AT PEAK FIELD (POLOIDAL FIELD ONLY). EACH DOT REPRESENTS A CURRENT DENSITY OF 24 $\mu A/cm^2$. S-BAND ON FOR DURATION OF MAGNETIC FIELD.

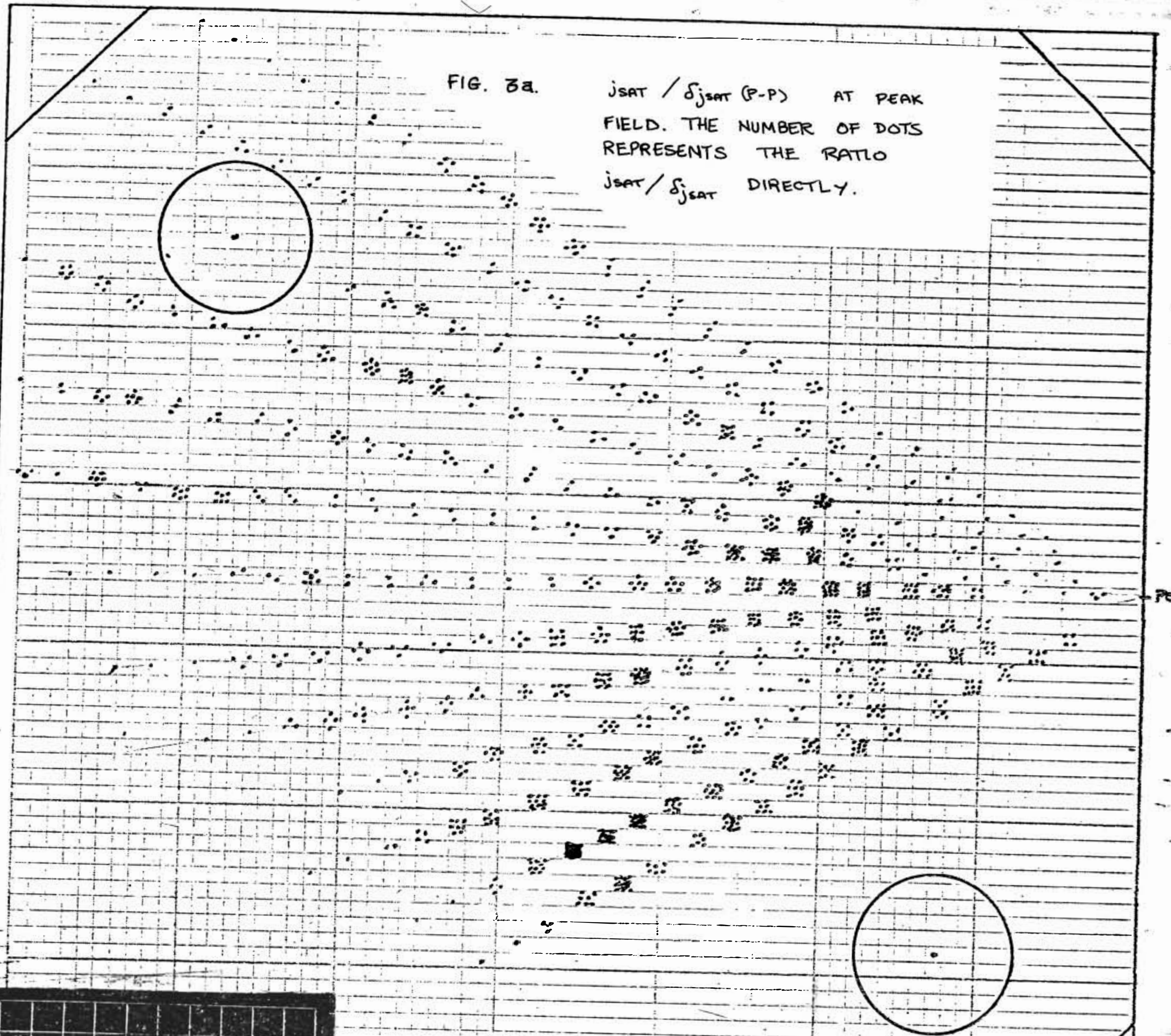
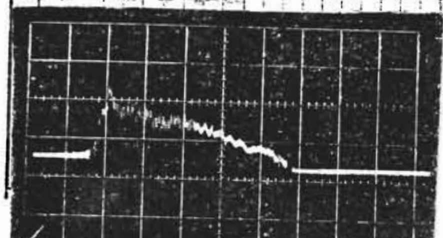
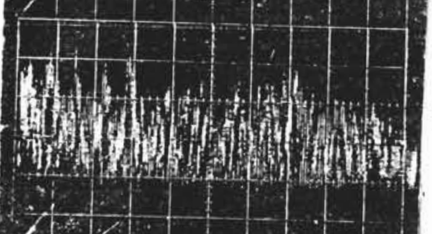


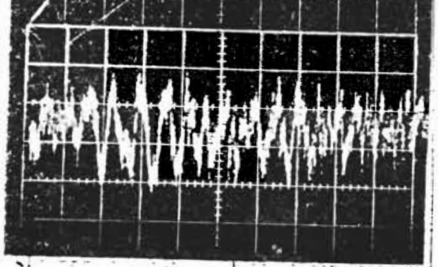
FIG. 3a. $j_{SAT} / \delta j_{SAT}$ (P-P) AT PEAK FIELD. THE NUMBER OF DOTS REPRESENTS THE RATIO $j_{SAT} / \delta j_{SAT}$ DIRECTLY.



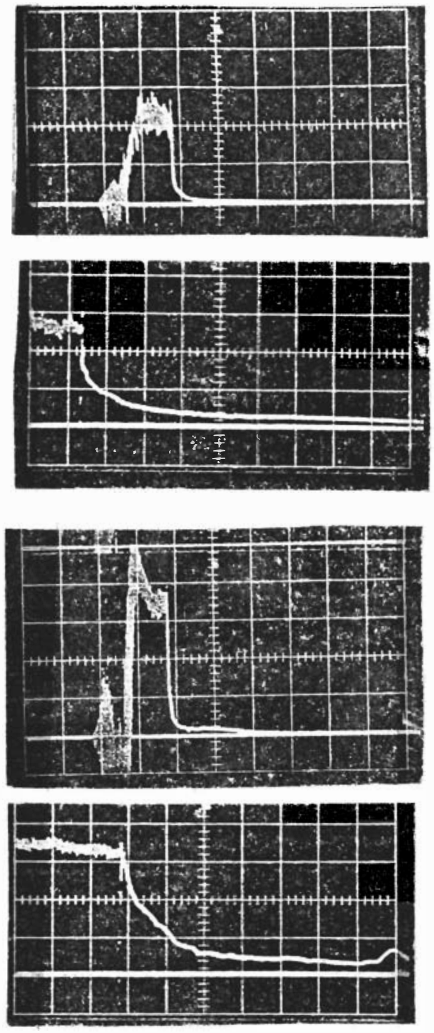
3b. j_{SAT}, 0.94 mA/cm². HORIZ. 1 msec/cm



3c. j_{SAT}, 0.24 mA/cm². HORIZ. 100 μsec/cm, DELAYED 3.0 msec FROM 3b.



3d. j_{SAT}, 0.24 mA/cm². HORIZ. 10 μsec/cm, DELAYED 3.0 msec FROM 3b.



a

b

c

d

Fig. 4. j_{SAT} WITH S-BAND TURNOFF AT PEAK FIELD. a,b ARE AT POINT A, FIG. 2; c,d AT POINT B.

a, C ARE WITH SWEEP OF 1msec/cm.

b HAS SWEEP 0.2 msec/cm.

d HAS SWEEP 0.1 msec/cm

Fig. 4

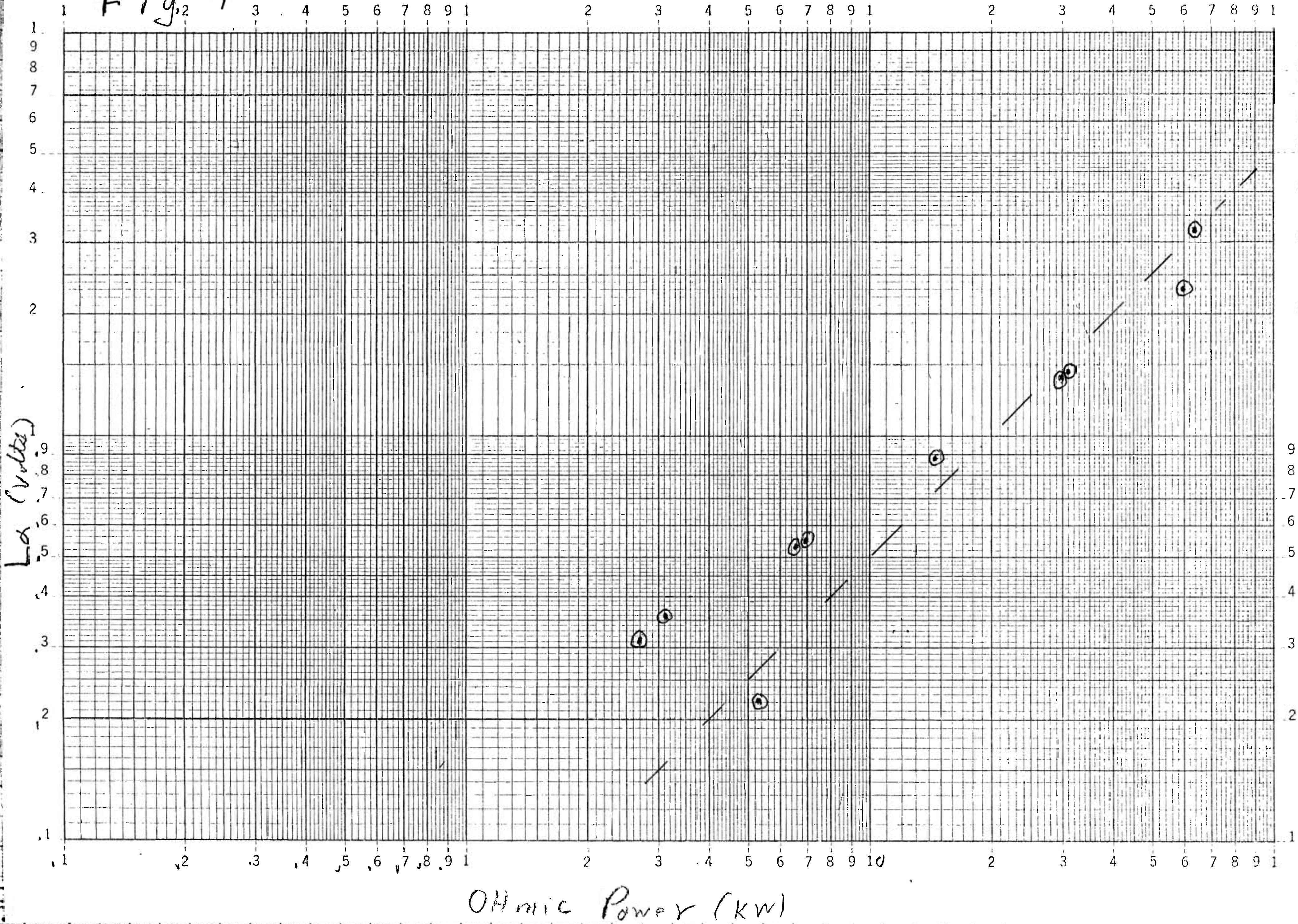
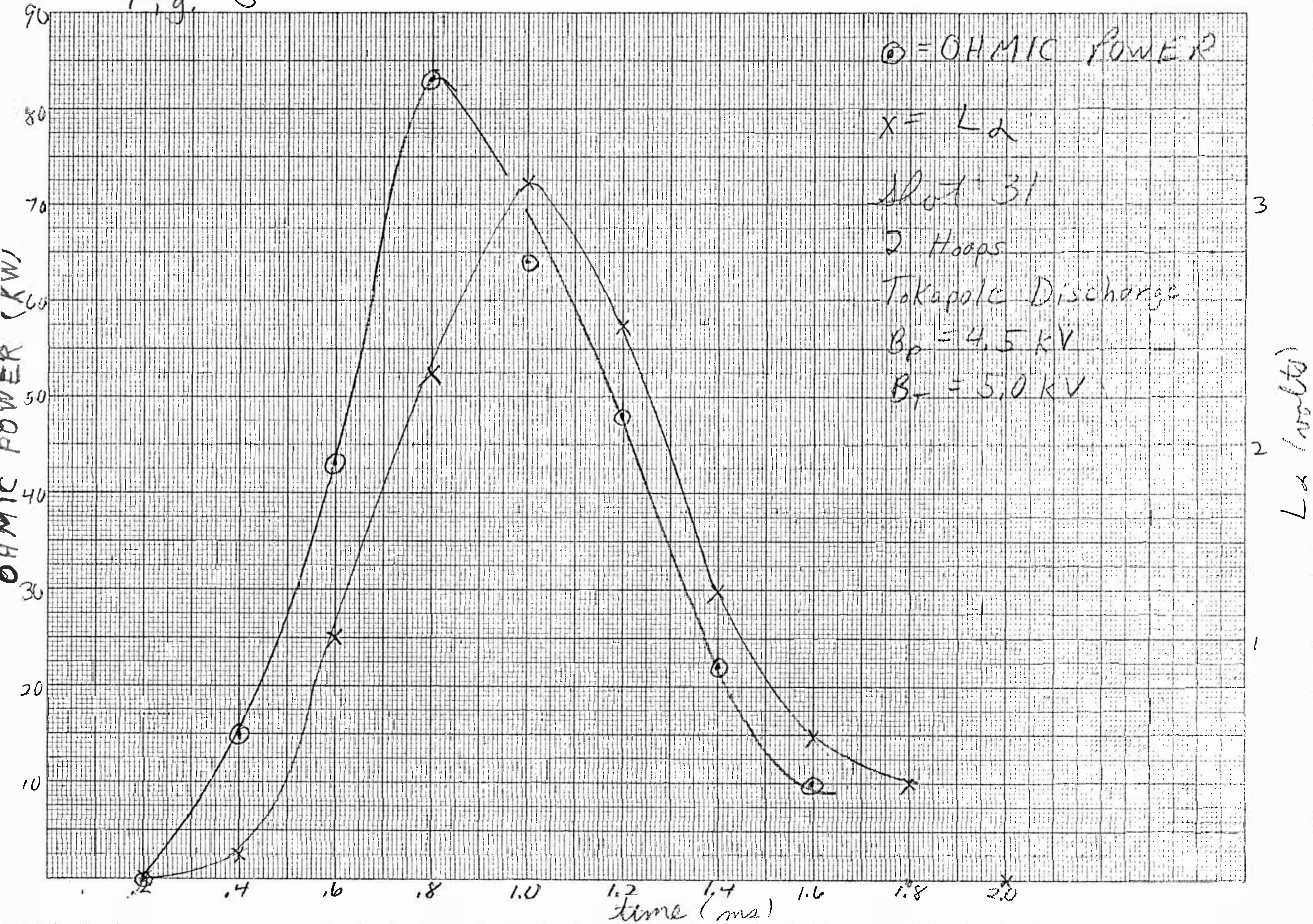


Fig. 5



⊙ = OHMIC POWER
X = L_α
Shot 31
2 Hoops
Tokapole Discharge
B_p = 4.5 kV
B_T = 5.0 kV
OHMIC POWER (KW)
L_α (volts)
time (ms)
90
80
70
60
50
40
30
20
10
3
2
1
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0

Fig. 6

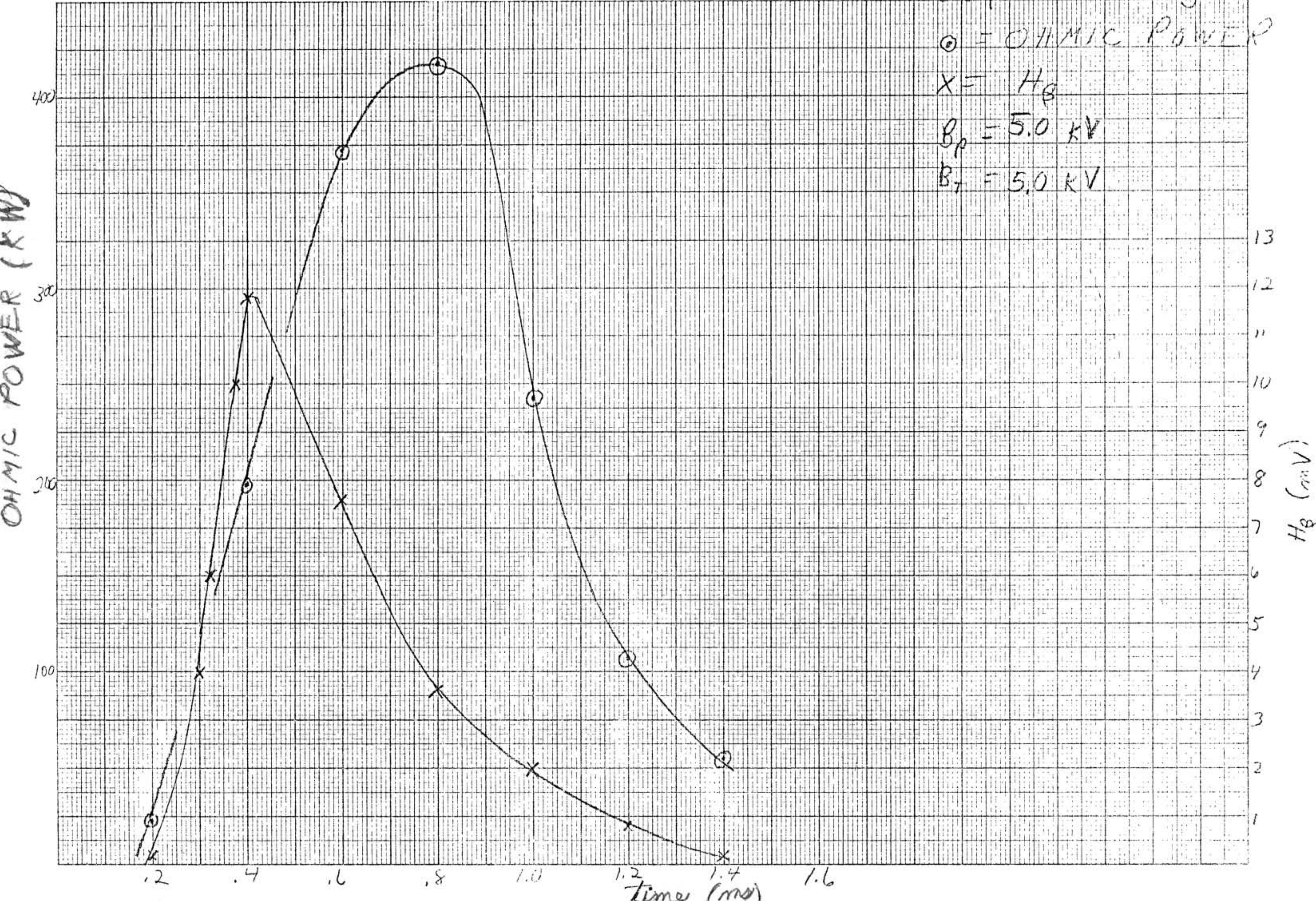
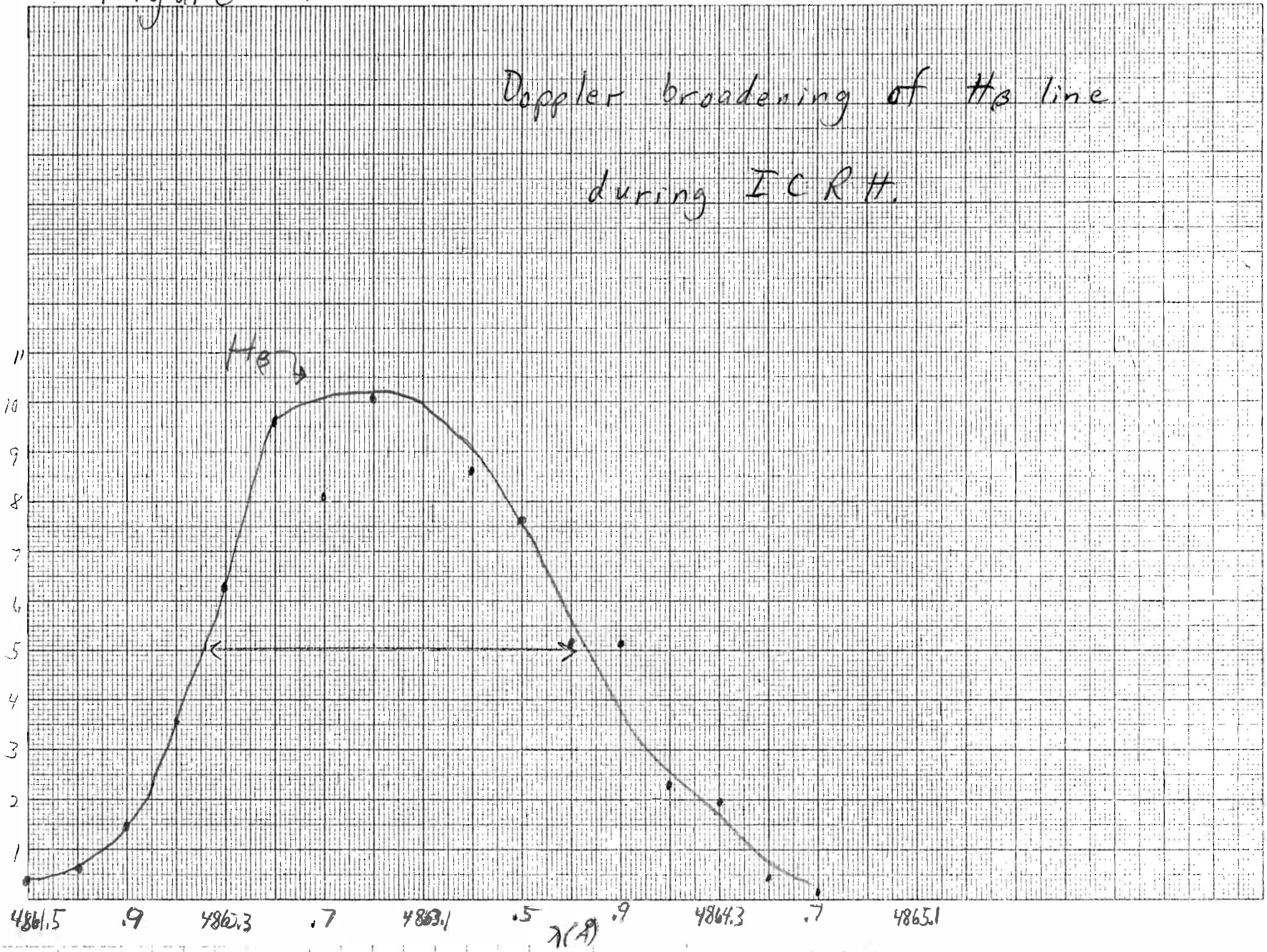

4 Hoops
Tokapole discharge
⊙ = OHMIC POWER
X = H_β
B_p = 5.0 kV
B_T = 5.0 kV
OHMIC POWER (KW)
100
200
300
400
H_β (mV)
1
2
3
4
5
6
7
8
9
10
11
12
13
Time (ms)
.2
.4
.6
.8
1.0
1.2
1.4
1.6

Figure 7.



Doppler broadening of Hβ line
during ICRH.
Hβ
1
2
3
4
5
6
7
8
9
10
11
4861.5
.9
4862.3
.7
4863.1
.5
.9
4864.3
.7
4865.1
λ(Å)