# ION CYCLOTRON HEATING IN THE WISCONSIN SUPPORTED TOROIDAL OCTUPOLE AND QUADRUPOLE

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## ABSTRACT

Ion cyclotron heating at the fundamental frequency in the supported octupole has produced ∿600 eV ions at densities $10^{10}$ $cm^{-3}$. Conversion to a quadrupole configuration has demonstrated comparable temperatures, but at reduced densities and with higher wall reflux. The launching structure consists of a single turn, insulated, unshielded loop, coaxial to the four/two confining field producing hoops. ICRF techniques for the Tokapole II device are also considered.

## INTRODUCTION

Recent work[1] in the supported octupole has provided substantial increases in ion temperatures, ∿600 eV, for low density $\leq 10^{10}$ $cm^{-3}$ hydrogen plasmas. Conversion to a quadrupole configuration has shown unfavorable trends in confinement and coupling efficiencies, suggesting the advantages of higher order multipoles.

## EXPERIMENTAL APPARATUS

The basic launching structure throughout has been a flat, copper hoop 5 cm wide, supported 1.7 cm above the vacuum tank floor by a teflon insulator. The hoop is parallel to the main hoops, extending 327° around the machine, and is fed through the floor via teflon feedthroughs. The antenna has been insulated from contact with the plasma by both a glass and later, in an attempt to reduce reflux, a MACOR top cover. No matching device is needed between the antenna and transmitter, as the hoop is the tank circuit inductor, paralled by external capacitors. This insures tracking of the plasma reactance, preventing detuning. Frequency shifts were ∿.1% of the unloaded frequency.

The transmitter, Fig. 1, itself is currently operable over a frequency range from 1.9 MHz to 2.6 MHz. It consists of a two tube push-pull water-cooled oscillator, and a delay line type power supply, storing 4 MJ. The output power pulse from the delay line is a square wave, selectable in 100 μs steps up to 1 ms. RF power levels of 1.8 MW out have been achieved, though power supply voltage limitations have prevented regular use of this level. The two tube version will also drive lower impedances, and hence higher plasma densities than the single tube oscillator that we previously used.

The principle diagnostic consisted of a 127° curved plate electrostatic analyser[2], samping the velocity distribution from the field null on the machine minor axis through a high permeability extractor tube. Repeated shots at high reproducibility allow point by point plotting of the distribution. Plasma loading of the tank circuit could also be measured. Density, both neutral and plasma, could not be measured directly during the pulse because of RF interference, but could be inferred from after-glow measurements.

Fig. 2a and 2b show the locations of the hoops, launching device, and ion extractor pipe in the octupole and quadrupole, respectively. The unusual diagonal configuration of the quadrupole was necessitated by the requirement for the field null to be accessible to the ion extractor pipe while simultaneously placing the highest density plasma near the launching structure.

## EXPERIMENTAL RESULTS

Fig. 3 gives the actual achieved ion temperatures for the heated component versus the electric field at the antenna surface. The two modes of operation are comparable in terms of temperatures. However, the density of heated ions was reduced for several reasons in the quadrupole case. Particle confinement times in the unoptimized quadrupole were ∿300 μs, about ¼ that of the octupole.[3] Most important was the large spatial separation of the launching structure from the densest plasma. The ECRH pre-ionization plasma peaks much nearer the hoops than in the octupole case. It has been shown[3] that even the vacuum RF field is attenuated sharply by separation from the antenna. Because the plasma density peaks further off the separatrix than in the octupole case, it is spaciatially further from the antenna, and hence samples a weaker rf field, with reduced heating efficiency. Also contributing to the lower density is the dependence of the $|B|$ of the quadrupole on the distance from the minor axis. The enhanced losses at high temperatures, primarily to charge exchange and hoop supports, requires supplemental ECRH heating to maintain the plasma density. This was supplied by a 5 KW 2.45 GHz and a 10 KW 9.0 GHz source. But $|B_e| / |B_p| \sim .67$ and 2.45 for the respective microwave resonance zones, thus causing a spatial separation of the plasma generating and heating zones. The density of ions inferred from the electrostatic analyser shows a larger component of cold ions than is found in the octupole case.

Fig. 4 is a typical analyser plot, showing the usual three component Maxwellian of the quadrupole. An octupole case is qualitatively similar, except as noted above. The lowest energy component consists of the weakly heated plasma and the reflux component. The intermediate is the strongly heated component, and the decrease above ~60 eV represents the point where the particles' gyrodiameter becomes comparable to the size of the machine.

Fig. 5 shows ion temperature as a function of time. The full 1 ms RF pulse is used here. One can see that the highest temperature is achieved almost immediately, and then falls steadily as wall reflux raises the neutral pressure. The wall cleanliness has been shown to be the critical factor in achievable temperature.[4]

## FUTURE EXPERIMENTS

This machine has recently been converted to a tokamak configuration for the purpose of gaining experience with a pure tokamak prior to replacing it with a device called TOKAPOLE II. This device, while similar to an octupole in that it contains four current-carrying rings, will also have a toroidal field ~4.4 kG on axis, and is expected to produce toroidal currents ~50 kA. It has been optimized to produce a tokamak topology embedded in that of an octupole, and will be the subject of eigenmode studies. Initial plans call for low power, 1 kW, loading measurements at 14 MHz. Initial calculations indicated that at least low order mode numbers should be attainable with moderate densities, $\sim 5 \times 10^{12}$ $cm^{-3}$. Preliminary work will be with a single turn, insulated unshielded loop, as well as with electrostatically driven antennas. After loading parameters are established, high power experiments will be done.

## CONCLUSION

Past experience has shown the ICRH heating in multipole geometry can be effective if proper design optimization is used. Fast wave ICRH should offer advantages in both loading efficiency and energy deposition controls though wall reflux is expected to continue as a major obstacle.

## ACKNOWLEDGEMENT

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2. C. W. Erickson, Ph.D. Thesis, University of Wisconsin (1970).

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4. J. D. Barter, Ph.D. Thesis, University of Wisconsin (1976).

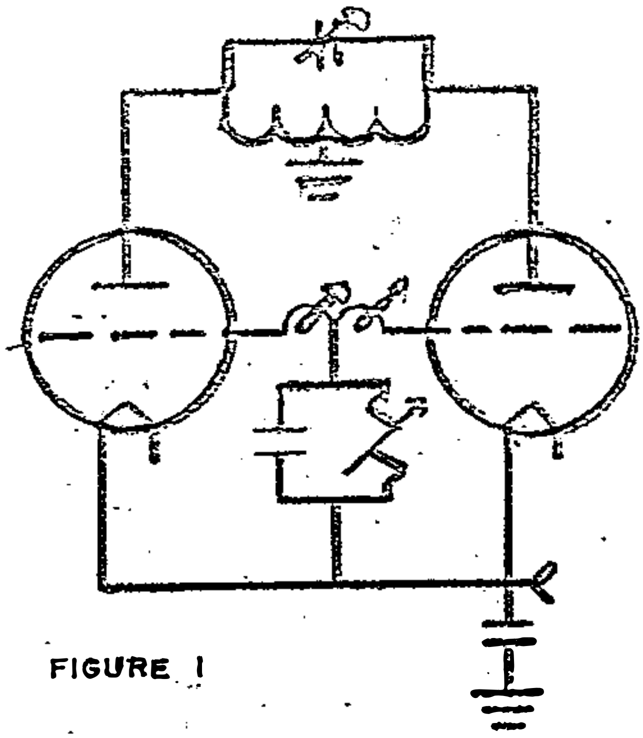

FIGURE 1

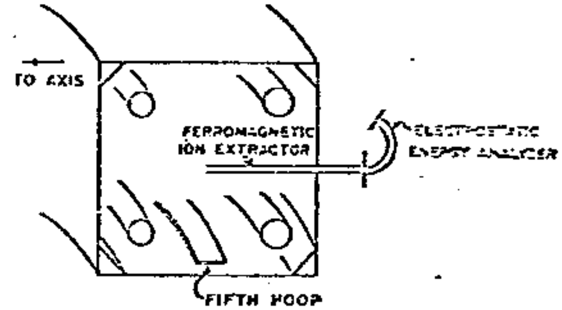


FIGURE 2a

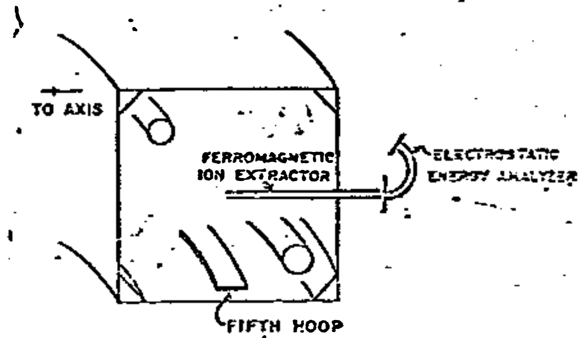


FIGURE 2b

FIGURE 3

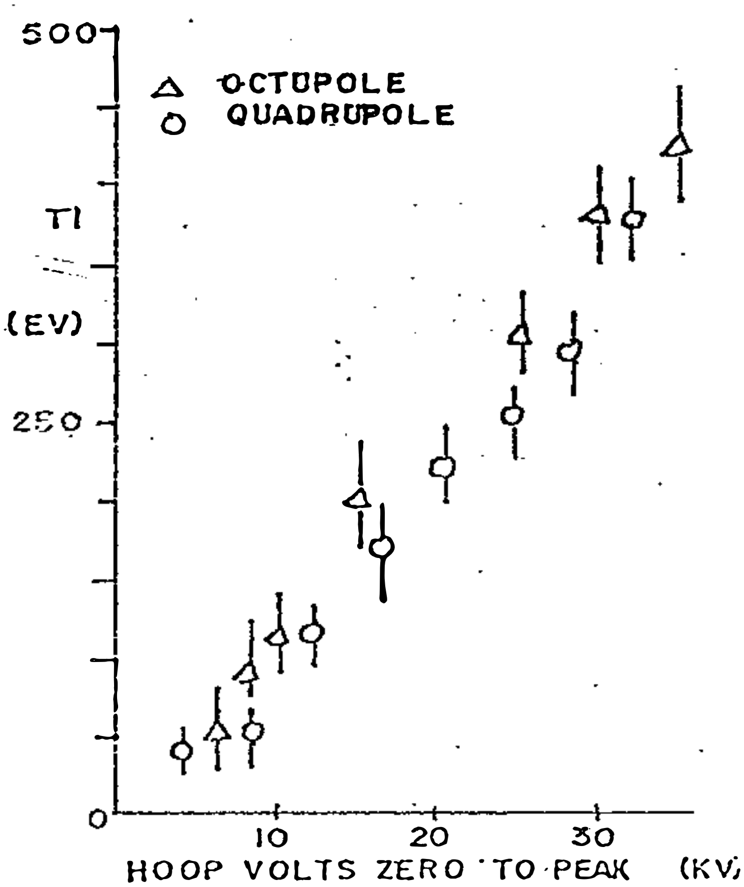


FIGURE 4

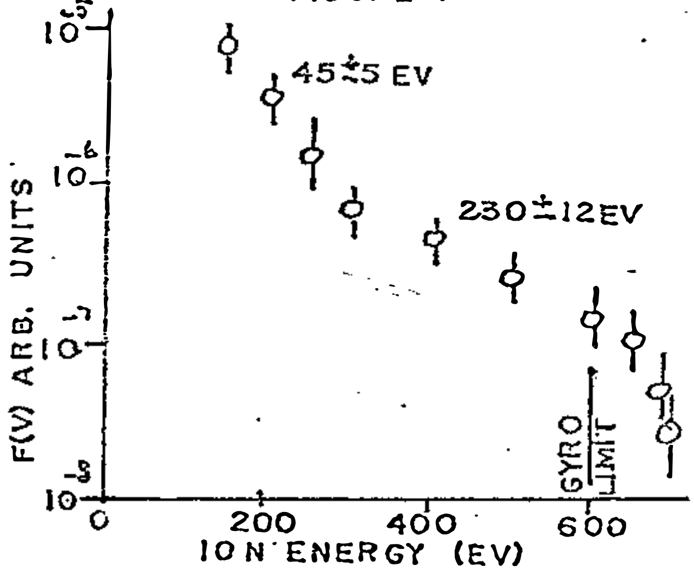


FIGURE 5