CONTROLLING MODE AND PLASMA ROTATION WITH A ROTATING FIELD ERROR

Poster presented at the American Physical Society
Division of Plasma Physics 38th Annual Meeting
November 11-15, 1996
Denver Colorado

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PLP 2001

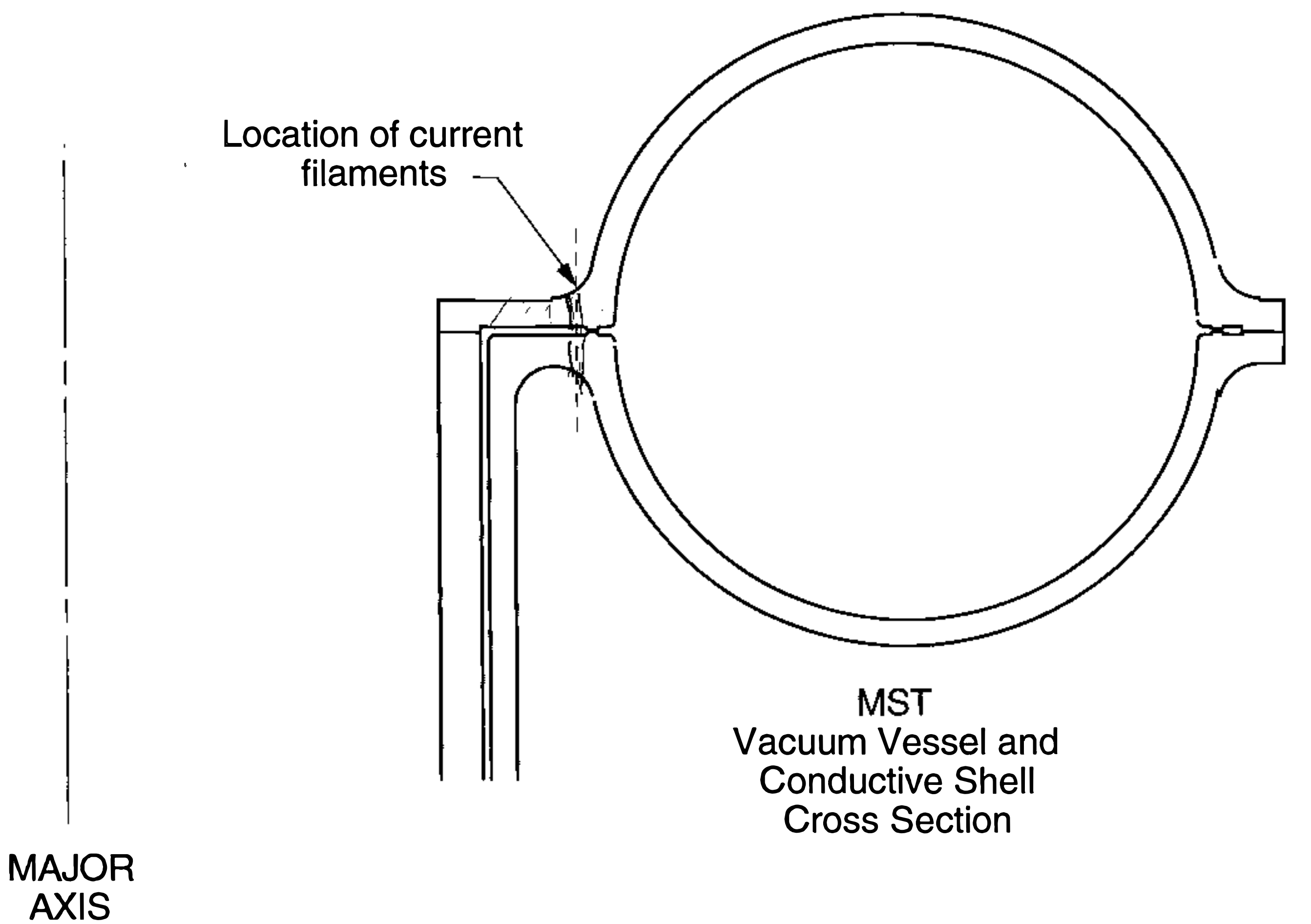
Abstract

A rotating $n = 6$ radial magnetic field perturbation can now be applied through the toroidal gap in the conductive shell of the MST Reversed-Field Pinch.[1] Initial low power experiments (a perturbation of a few gauss) at fixed frequencies of 11 and 23 kHz indicate that slight acceleration or deceleration can be applied to the natural 10 to 15 kHz rotation of the $n = 6$, $m = 1$ global tearing mode. Locking of tearing modes to stationary field errors generally results in increased inpurity influx and poor confinement. Our near-term experimental plan is to raise the size of the perturbation to cause the tearing mode to rotate at a fixed frequency and resist locking. In the future, variable frequency control and additional perturbations ($n = 7, 8$) will be added with the aim of studying the response of the plasma flow and mode rotation as the slip frequency is varied. Eventually we will investigate independent control over the rotation of each of the major tearing modes; this will allow examination of the mode coupling mechanism and may allow for reduction of magnetic stochasticity in the plasma.

[1]This work was supported by the U. S. Department of Energy.

The Apparatus

In order to produce a rotating field perturbation at the toroidal gap of the MST, conductors distributed with densities $j_z = \sin(n\phi+\pi/4)$ and $j_z = \sin(n\phi-\pi/4)$ pass through 6 mm diameter holes in the inner toroidal flange of the combination VCV and conductive shell. Series connection of the vertical filaments by wires outside the thick conducting shell ensure that the current density across the gap varies only as the spatial distribution of turns. These two orthogonal field coils are then driven in quadrature to produce the rotating field.

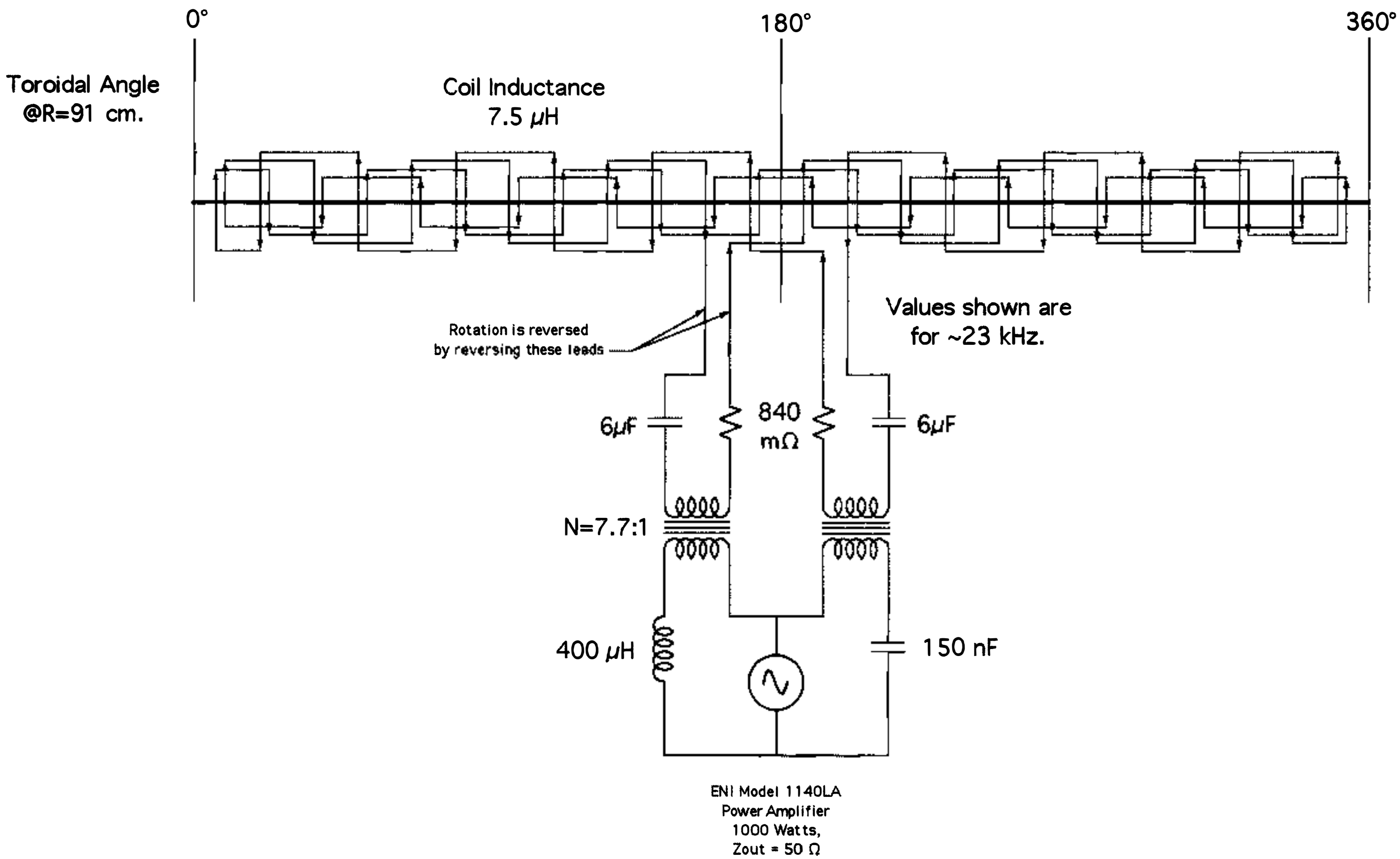


The Apparatus

The following figures show the toroidal distribution of current filaments around the inner toroidal gap, their calculated field patterns and mode spectra, and a schematic illustrating a typical connection of the coils to obtain quadrature currents. While for purpose of illustration the arrows indicating direction of current flow point radially outward (inward) the actual direction of current flow across the gap is up (down). In addition to the original $n = 6$ coils, an $n = 1$ set was later added to attempt to rotate the $m = 0, n = 1$ mode which is resonant at the toroidal field reversal surface and is usually stationary except near the sawtooth crash.

The use of resonant circuits to compensate for the coil inductance and achieve the desired $\pm\pi/2$ phase difference between coils had the positive effect of lowering their impedance so that more current could be obtained from the available amplifiers, but caused retuning for different rotation frequencies to be unpleasantly difficult. The need for higher drive power and easily variable frequency has led us to begin designing current amplifiers which will be capable of driving the inductive load directly over a wide band of frequencies. A block diagram of the system is shown here.

MST n=6 coils, Schematic



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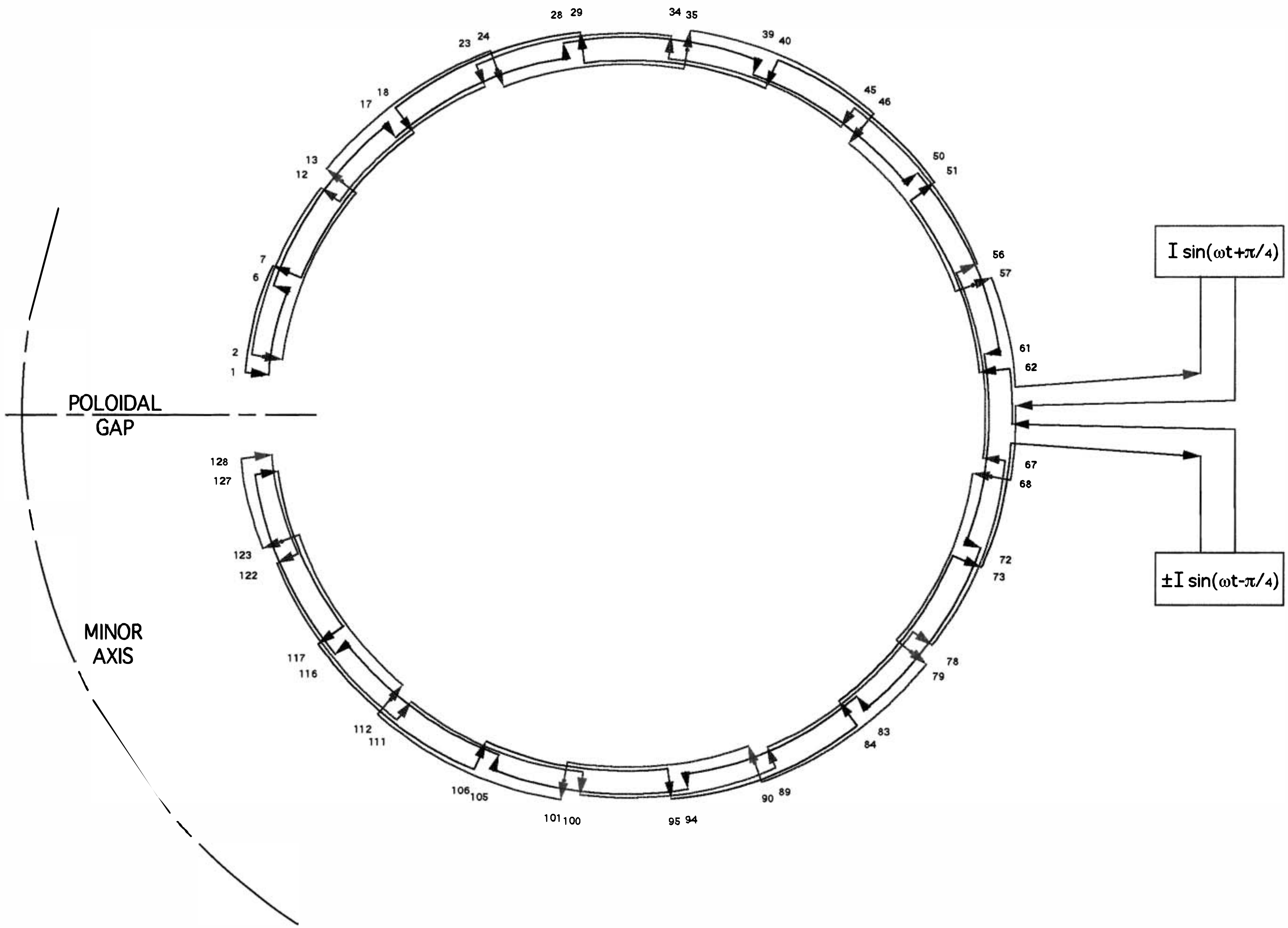
MST n=6 coils, Top View



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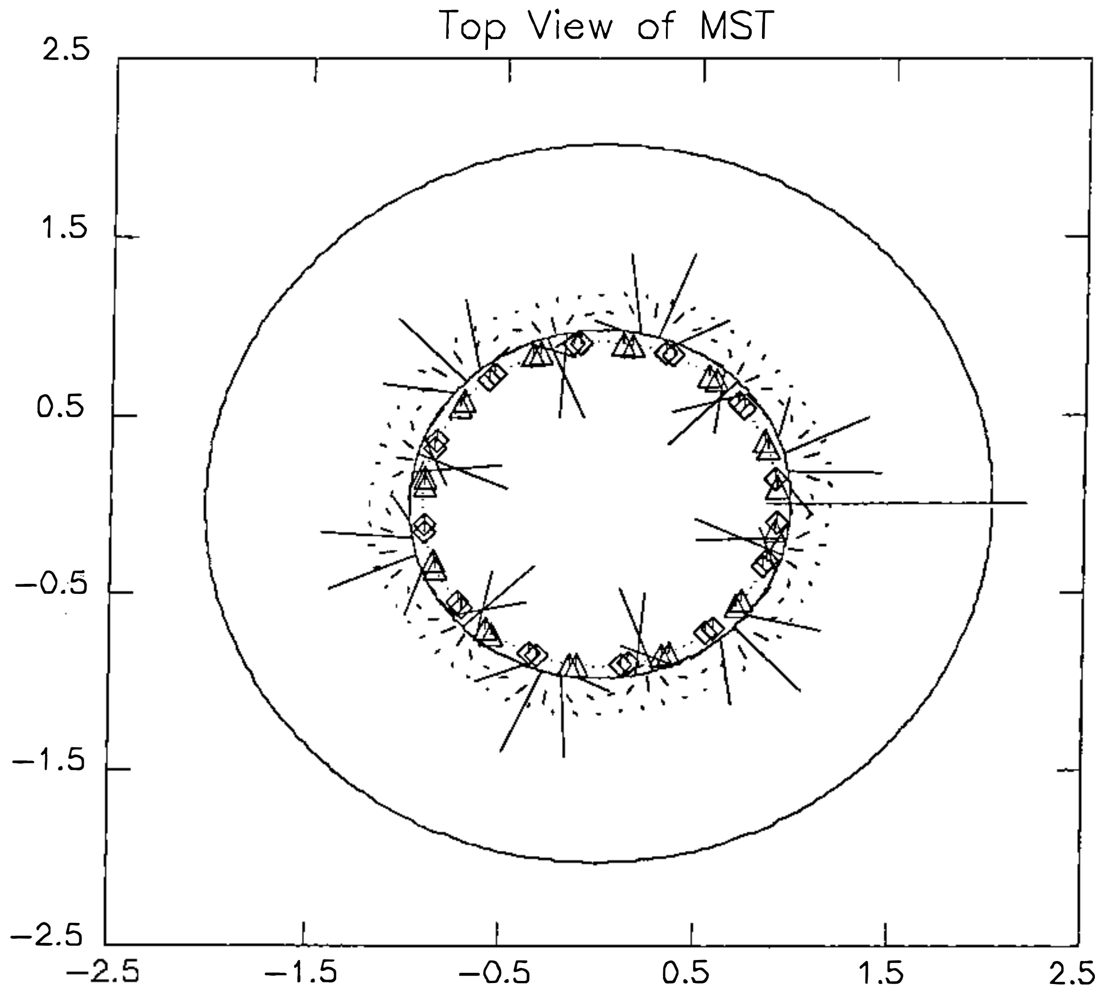
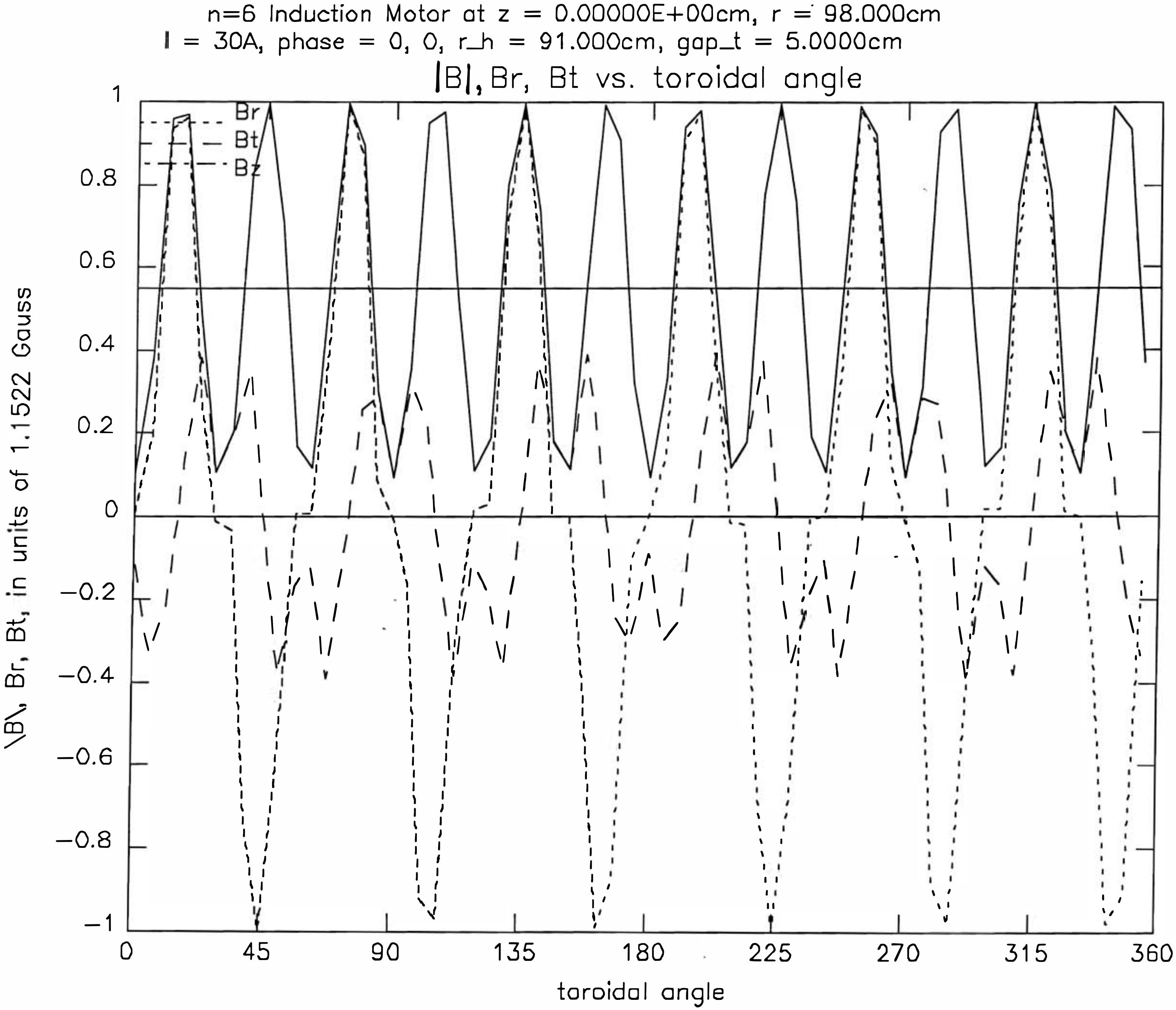
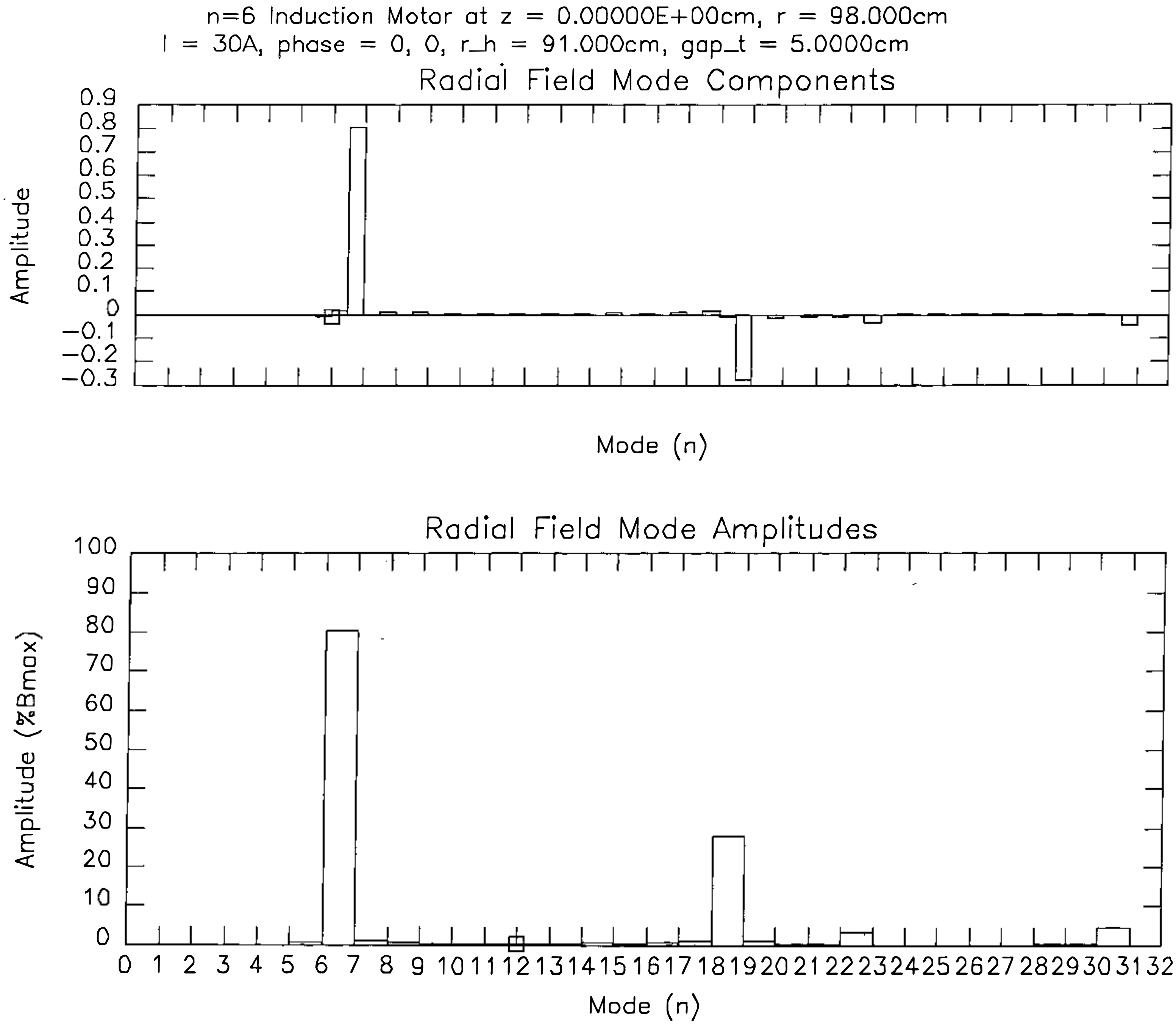
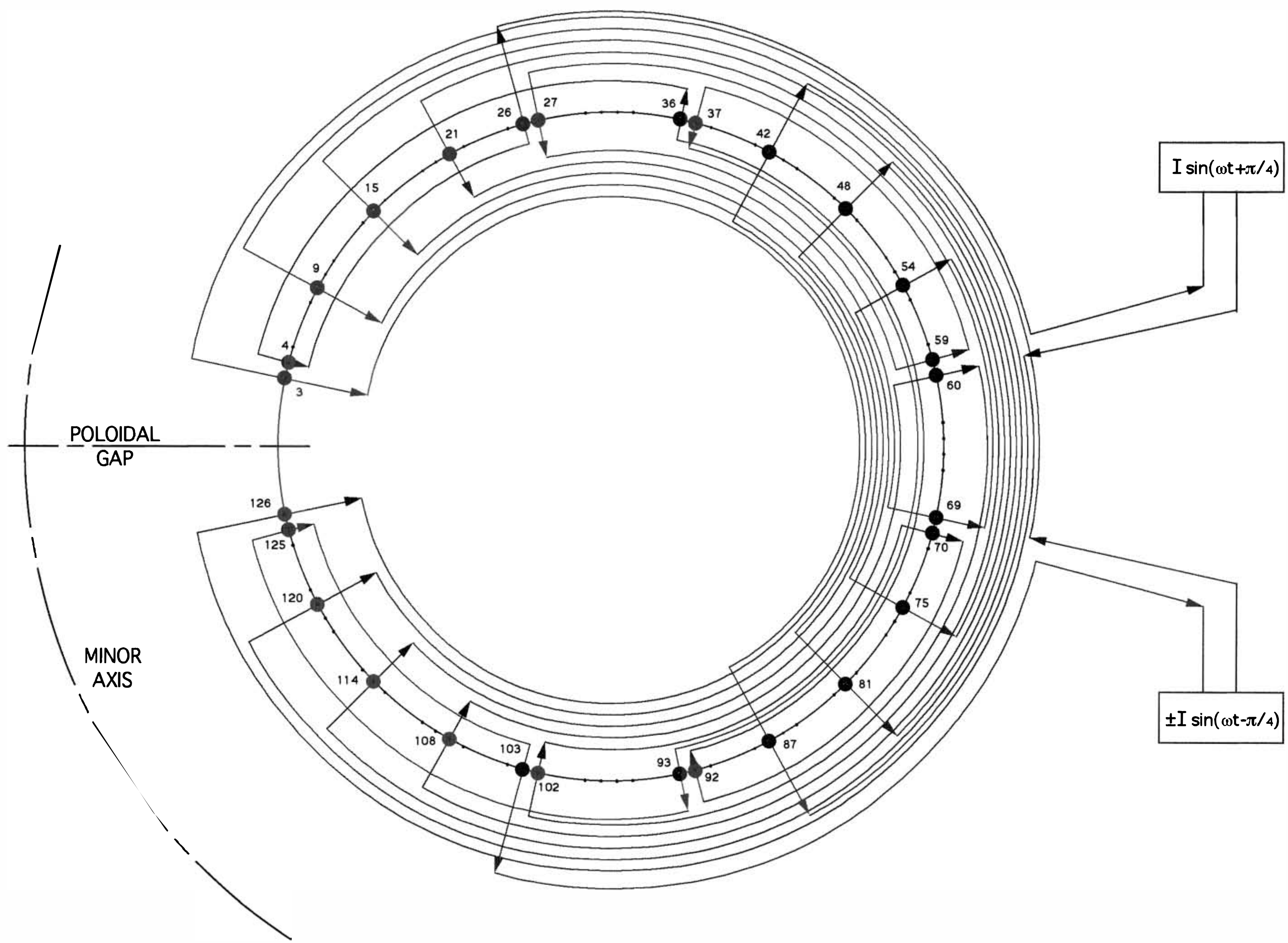
n=6 Induction Motor at z = 0.00000E+00cm
I = 30A, phase = 0, 0, r_h = 91.000cm, gap_t = 5.0000cm




n=6 Induction Motor at z = 0.00000E+00cm, r = 98.000cm
I = 30A, phase = 0, 0, r_h = 91.000cm, gap_t = 5.0000cm
|B|, Br, Bt vs. toroidal angle
Br
Bt
Bz
\B\, Br, Bt, in units of 1.1522 Gauss
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
0
45
90
135
180
225
270
315
360
toroidal angle


n=6 Induction Motor at z = 0.00000E+00cm, r = 98.000cm
I = 30A, phase = 0, 0, r_h = 91.000cm, gap_t = 5.0000cm
Radial Field Mode Components
Amplitude
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
Mode (n)
Radial Field Mode Amplitudes
Amplitude (%Bmax)
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Mode (n)

MST n=1 coils, Top View



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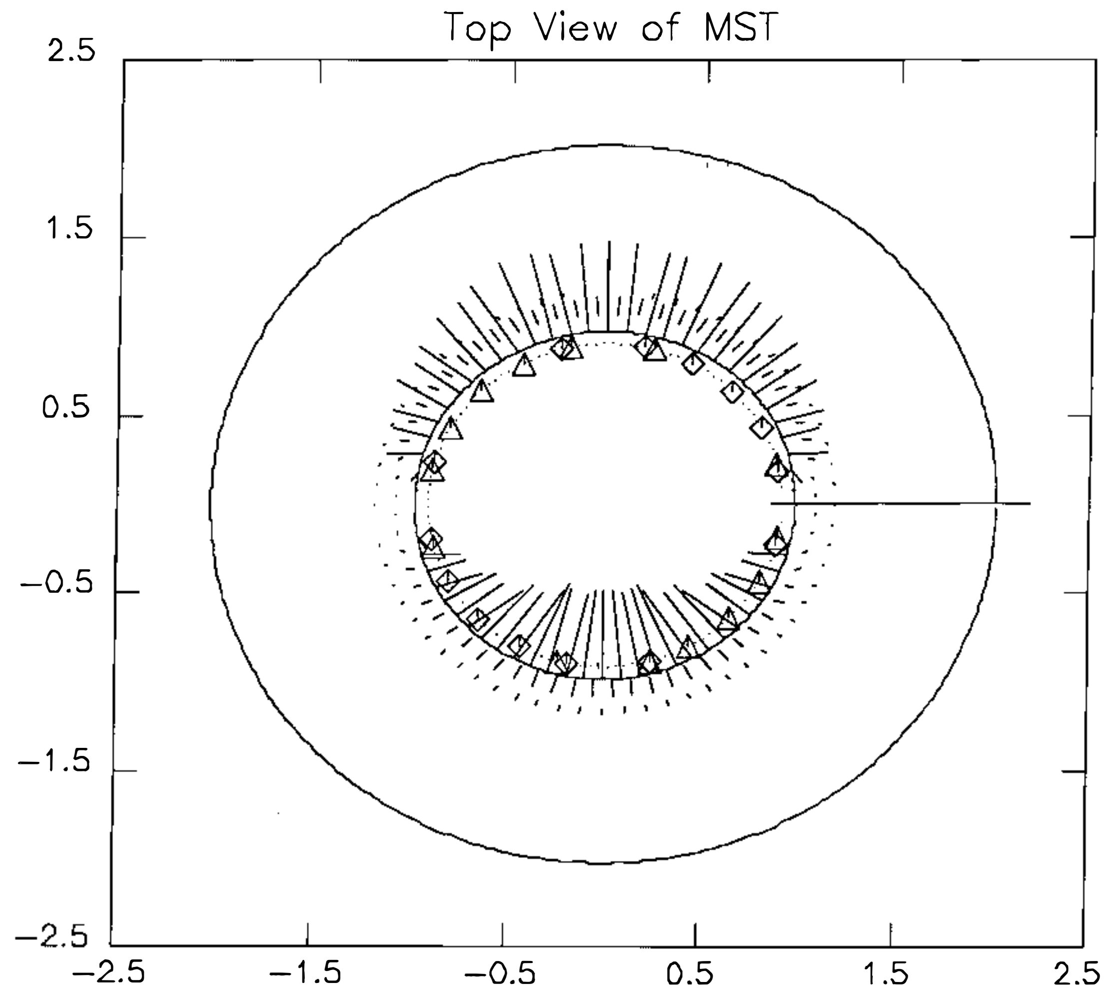
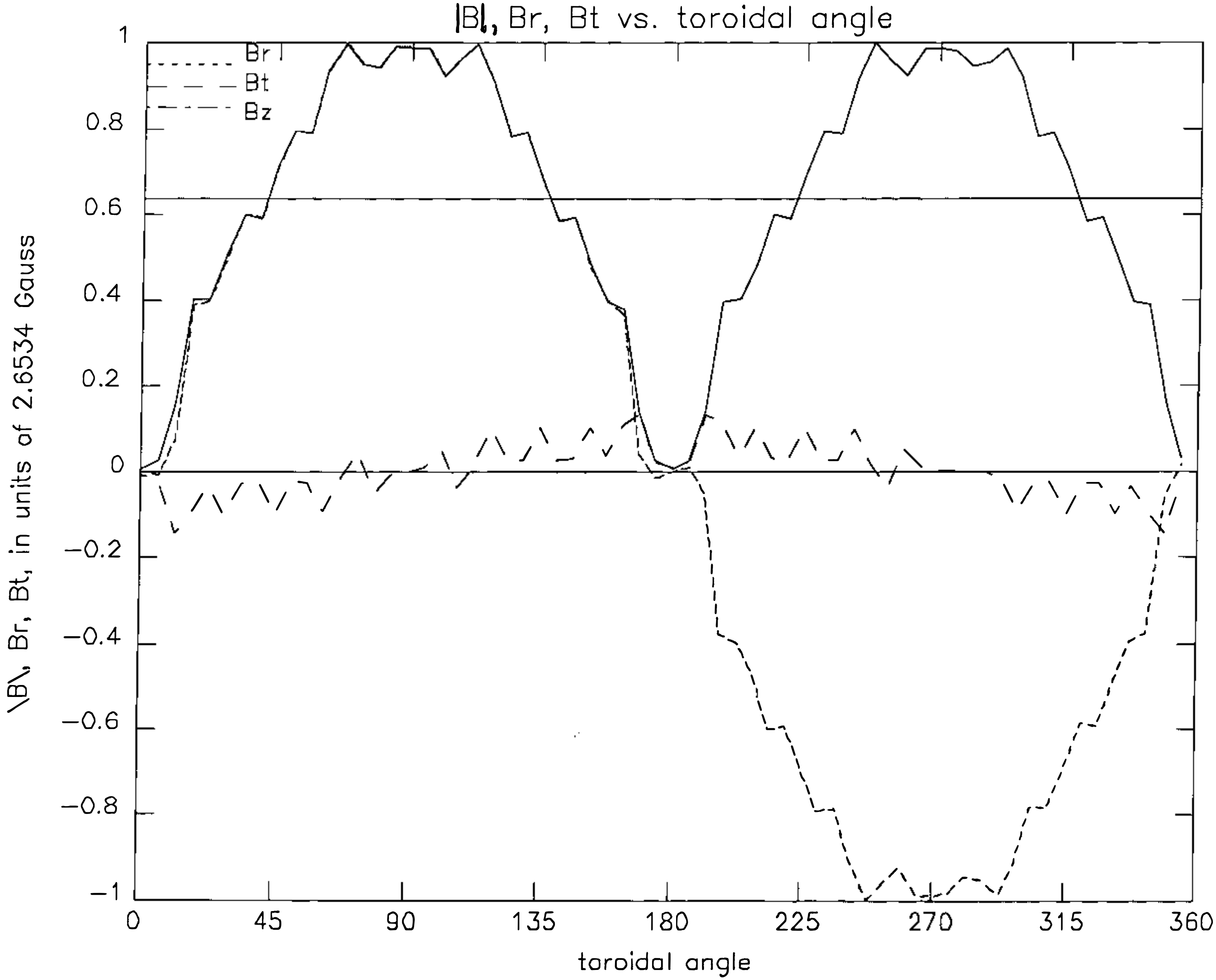
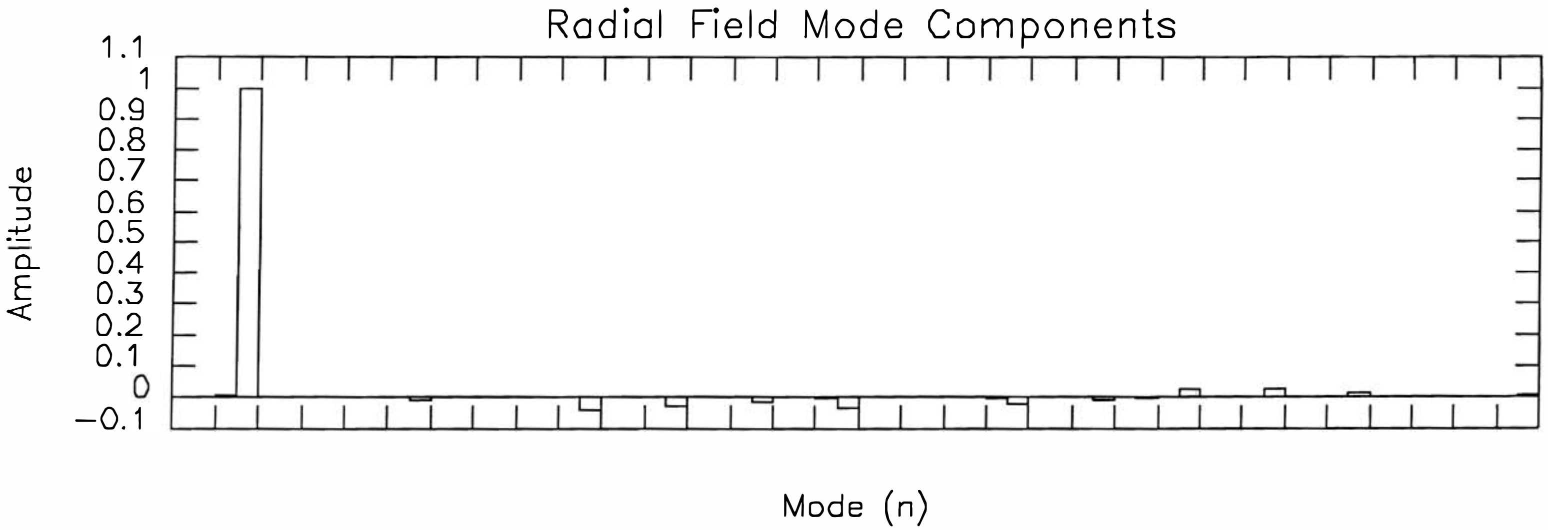
n=1 Induction Motor at z = 0.00000E+00cm
I = 30A, phase = 0, 0, r_h = 91.000cm, gap_t = 5.0000cm

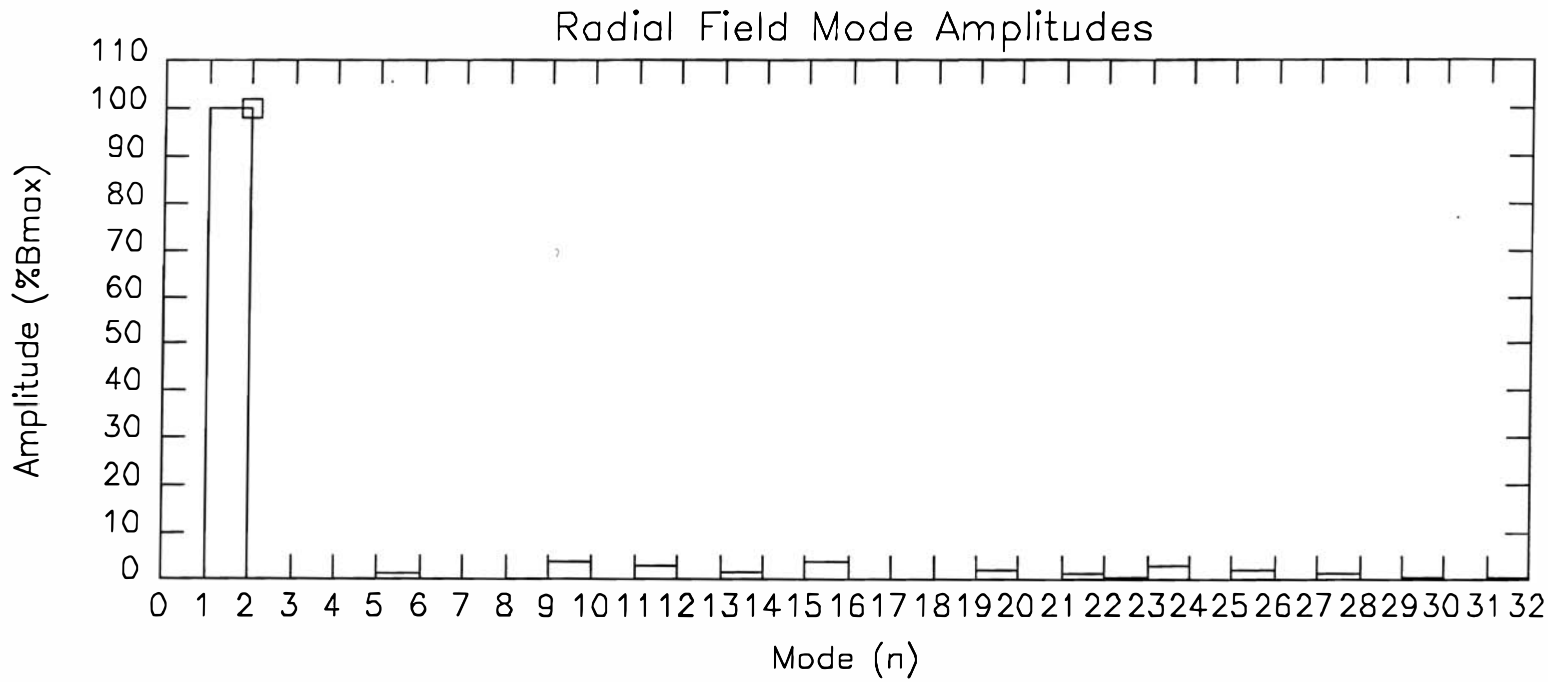


n=1 Induction Motor at z = 0.00000E+00cm, r = 98.000cm
I = 30A, phase = 0, 0, r_h = 91.000cm, gap_t = 5.0000cm



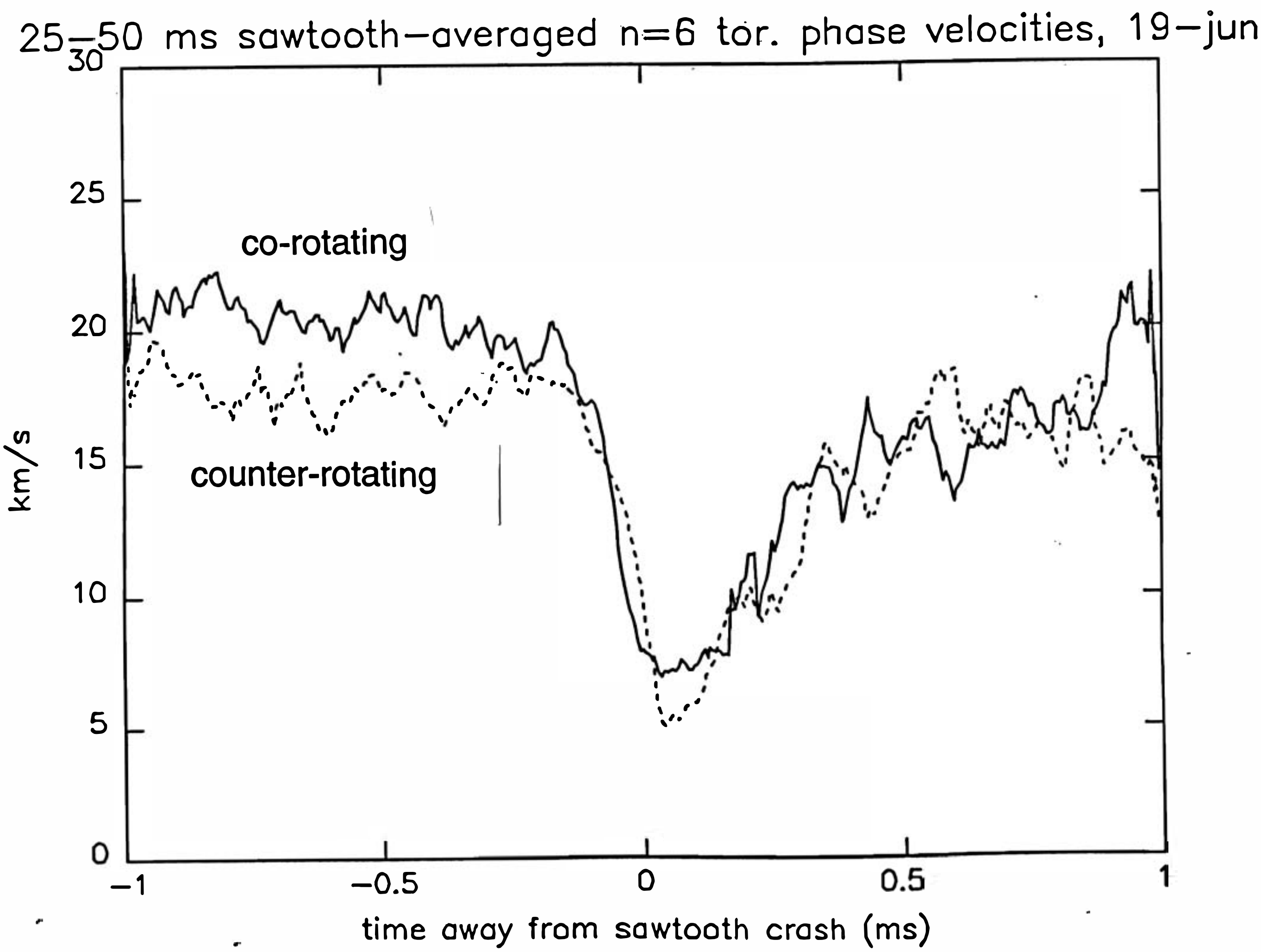
n=1 Induction Motor at z = 0.00000E+00cm, r = 98.000cm
I = 30A, phase = 0, 0, r_h = 91.000cm, gap_t = 5.0000cm





Observations

An ensemble average of the $n = 6$ toroidal phase velocity over several shots in 2 ms intervals centered on sawtooth crashes indicates that the phase velocity is slightly higher before the crash when the rotation of the applied field error is in the same direction as the rotation of the tearing mode. It is our hypothesis that if the amplitude of the perturbation can be made sufficiently large, it should be possible to significantly affect the rotational velocity of the plasma.



Future Experimental Plans

- Higher current tests (> 200 A) with more powerful amplifiers using current feedback to counter the effects of field coil inductance without requiring resonant circuits so that the drive frequency may be changed easily.

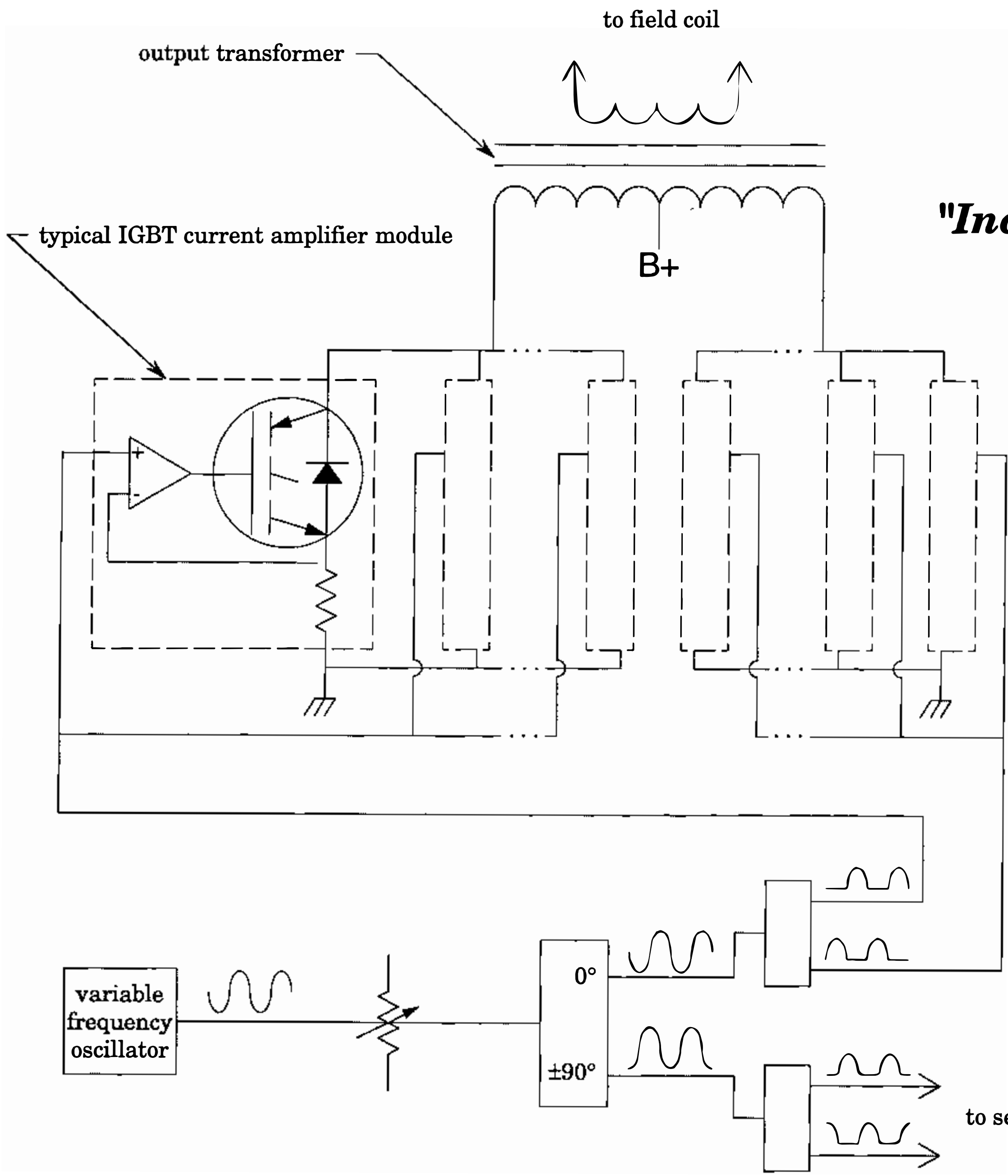
- Improved coil design replacing the present 8 gauge coarsely stranded wire with 6 gauge Litz wire to lower the resistance and leakage inductance.

- Rapid control of frequency and phase of the rotating field during a discharge in order to ramp the rotational speed of the plasma or to modulate the drive on short timescales to study damping and mode coupling.

- Rotating field error at the poloidal gap ($m=1$)

"*Induction Motor*" Drive Circuit

block diagram



- frequency agile

  maximizes torque on mode
- phase agile

  accelerate or decelerate mode
- amplitude agile

  use minimum power for minimum plasma perturbation
- modular

  ease of increase of power, adjustment of impedance, & maintenence
- current feedback

  no limit on number of parallel modules as well as constant current vs. frequency (Note: output transformer is nearly constant flux vs. frequency as long as load is dominantly inductive)

Conclusions

- It is feasible to generate rotating radial field errors in the toroidal gap of the MST which are on the order of the perturbations in the plasma due to global tearing modes ($m=1$, $n=6,7,8$), using sine and cosine field coils wound in small holes which cross the toroidal gap.

- Tests with a 1 kW amplifier show that more power is needed to raise the field error above the ~1-2 gauss level

- Some small differences in the average phase velocity of the rotating ($n=6$) modes between cases with the field error rotating with and against the background plasma rotation suggest that there is some torque on the plasma due to the rotating field and that experiments at higher power are worth pursuing.