CONF-8411121--3

TI85 003683

ORNL HELICAL-AXIS STELLARATOR STUDIES

J. H. Harris
Oak Ridge National Laboratory

Presented at US-USSR Stellarator Workshop
Kharkov, USSR
November, 1984

DISCLAIMER

*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Incorporated.

CONTRIBUTORS:

J. L. CANTRELL
B. A. CARRERAS
L. GARCIA
J. H. HARRIS
T. C. HENDER
V. E. LYNCH
R. N. MORRIS

MOTIVATION:

(i) Study new stellarator configuration

(ii) Joint Spain-US program to develop design for advanced toroidal device (TJ-II) to be built at Junta de Energia Nuclear (JEN) in Madrid

OUTLINE

I. HELIAC CONFIGURATION.

II. EFFECT ON THE EQUILIBRIUM OF A RESONANCE NEAR THE PLASMA

III. THE FLEXIBLE HELIAC:

CONTROL OF THE TRANSFORM AND SHEAR

IV. REDUCTION OF THE TOROIDAL SHIFT:

i) HIGH ASPECT RATIO
ii) LARGE NUMBER OF FIELD PERIODS
iii) TOROIDAL MODULATION OF THE COIL CURRENTS
iv) TILTING OF THE COILS

HELIAC CONFIGURATION

- STABILITY RESULTS FOR THE STRAIGHT, HELICALLY SYMMETRIC HELIAC MAKE THIS CONFIGURATION VERY ATTRACTIVE.

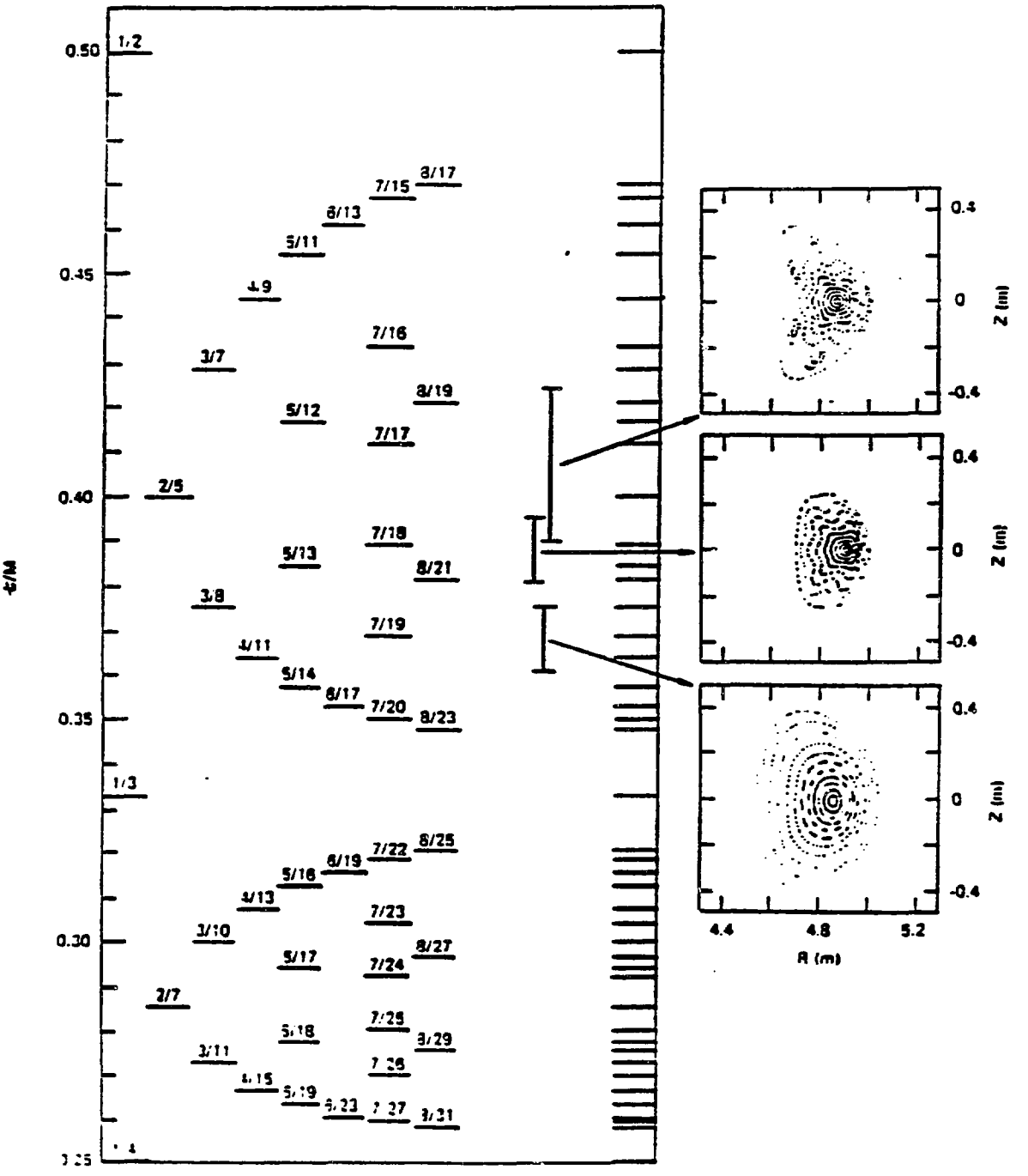
- MAIN THEORETICAL CONCERN IS THE POSSIBLE EQUILIBRIUM LIMITATION, BY MAGNETIC SURFACE BREAKING FOR FINITE ASPECT RATIO CONFIGURATION.

- IT IS VERY IMPORTANT TO FIND THE RIGHT ι-WINDOW FOR THE CONFIGURATION, KEEPING THE TRANSFORM AWAY FROM LOW m RATIONAL SURFACES.

LOCATION OF DOMINANT RESONANT SURFACES

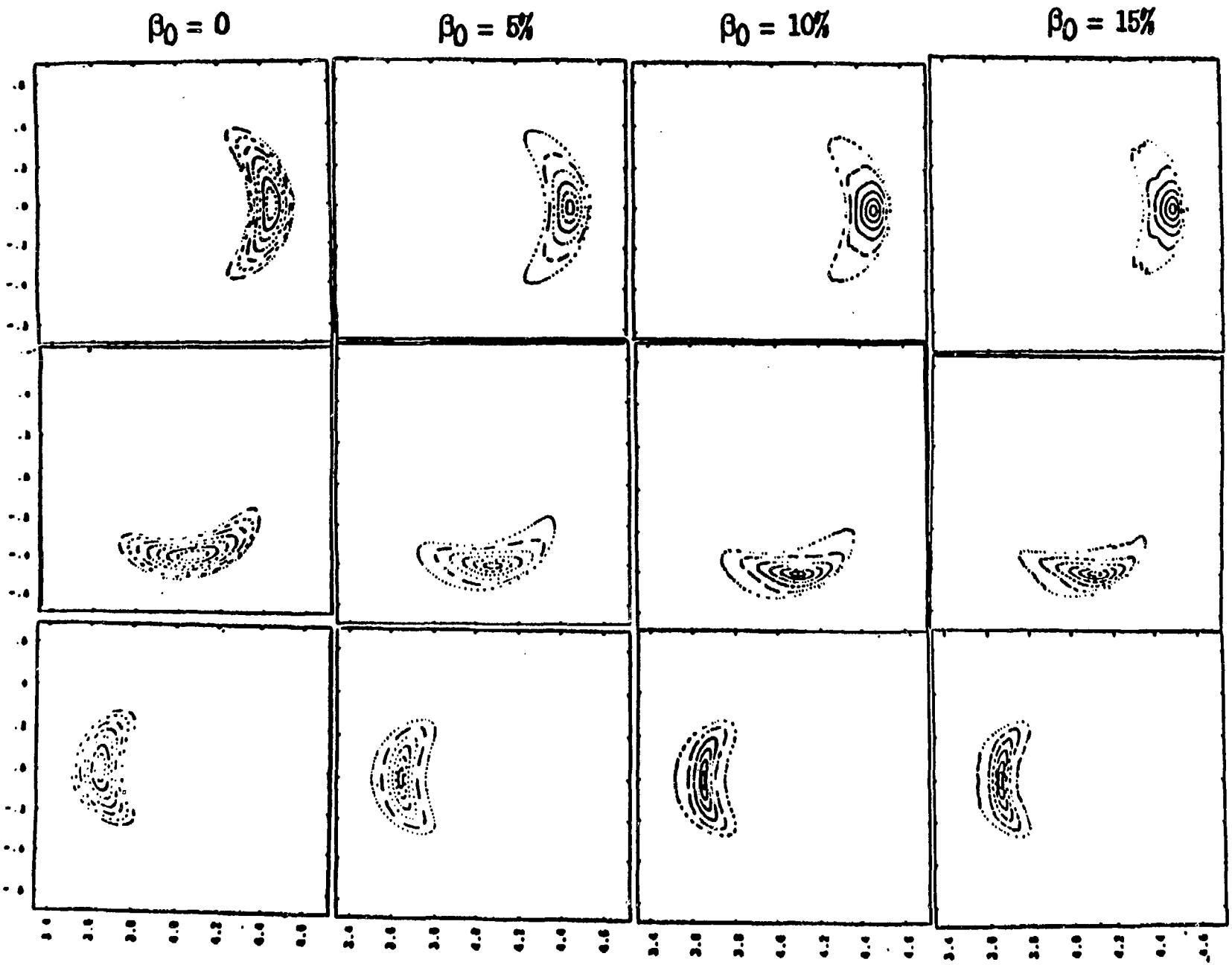
AND

3-D EQUILIBRIUM FLUX SURFACES FOR DIFFERENT ι RANGES AT FIXED β (β = 5%)

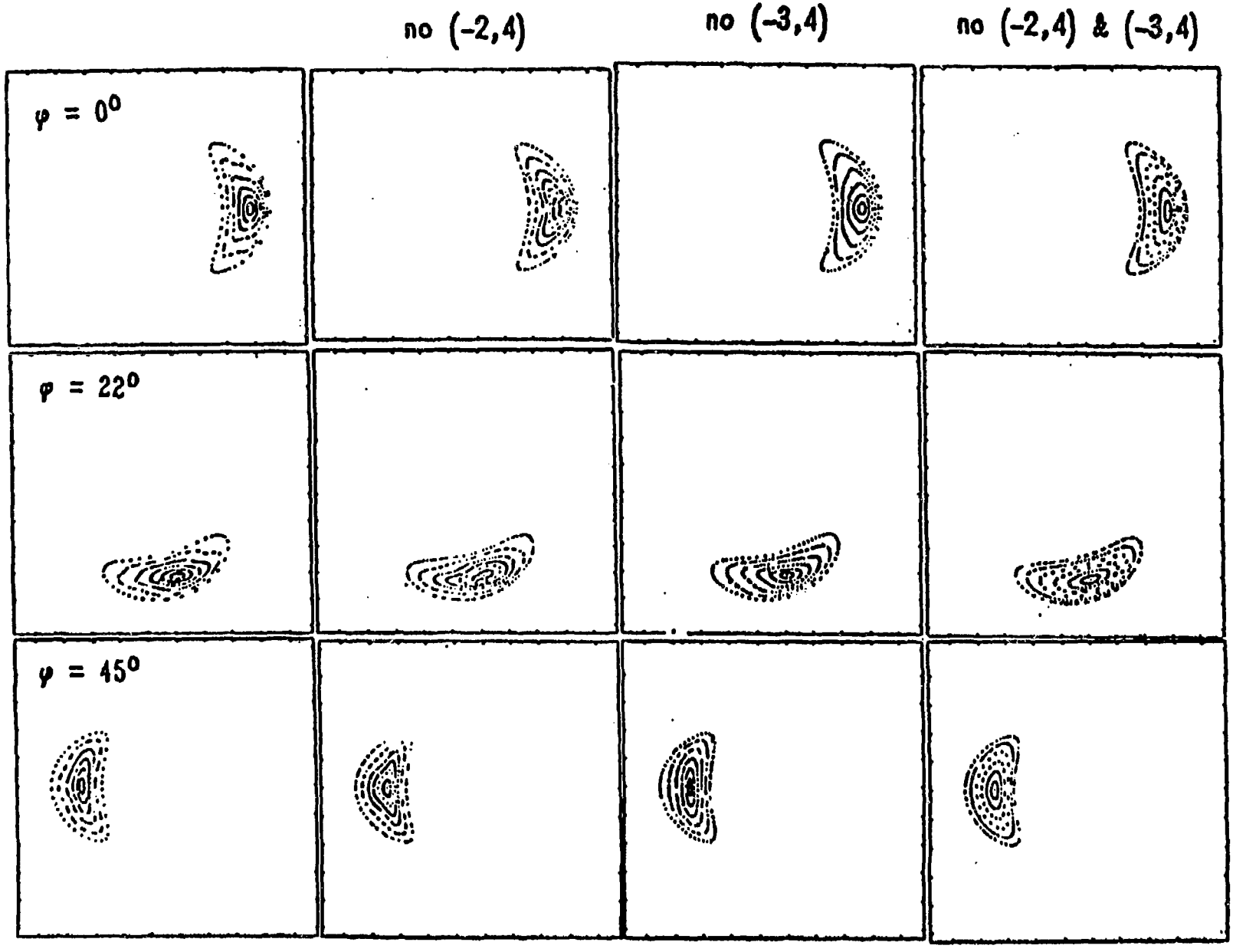


- THE PROXIMITY OF A LOW m RATIONAL SURFACE CAN CAUSE DEFORMATIONS OF THE MAGNETIC SURFACES.

THESE DISTORTIONS INCREASE WITH INCREASING β



- THE DISTORTIONS TO THE FLUX SURFACES ARE CAUSED BY NEARLY RESONANT HARMONICS, IN THIS CASE THE (-3,4), (-2,4) AND (-5,8) HARMONICS.



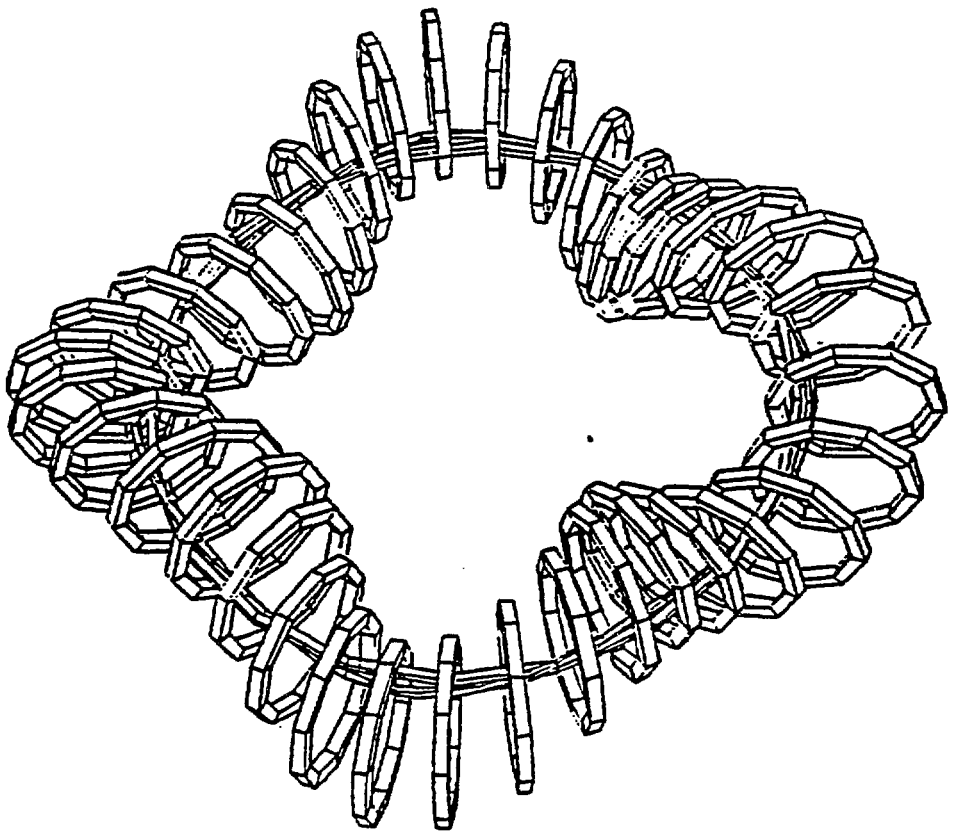
- FLUX SURFACE DESTRUCTION FOR LOW ASPECT RATION HELIACS IS PROBABLY DUE TO THE NONLINEAR INTERACTION BETWEEN TOROIDAL SHIFT AND VACUUM HELICAL FIELD HARMONICS (REIMAN AND BOOZER).

- THEREFORE, TO IMPROVE THE CONFIGURATION WE NEED:

  1) REDUCE THE SHEAR AND CONTROL THE TRANSFORM
  2) REDUCE THE TOROIDAL SHIFT

FLEXIBLE HELIAC

- THE ADDITION OF AN $\ell = 1$ HELICAL WINDING TO THE CENTRAL CONDUCTOR



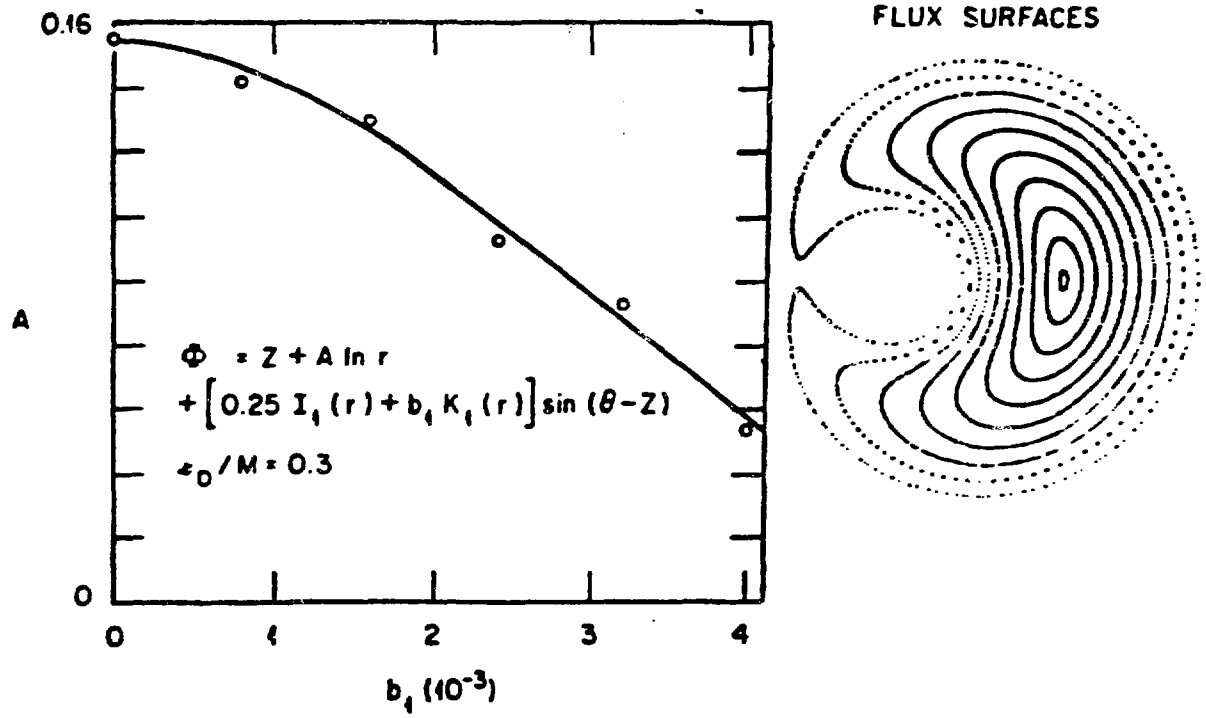
PERMITS TO CONTROL ι AND TO REDUCE THE SHEAR.

FLEXIBLE HELIAC

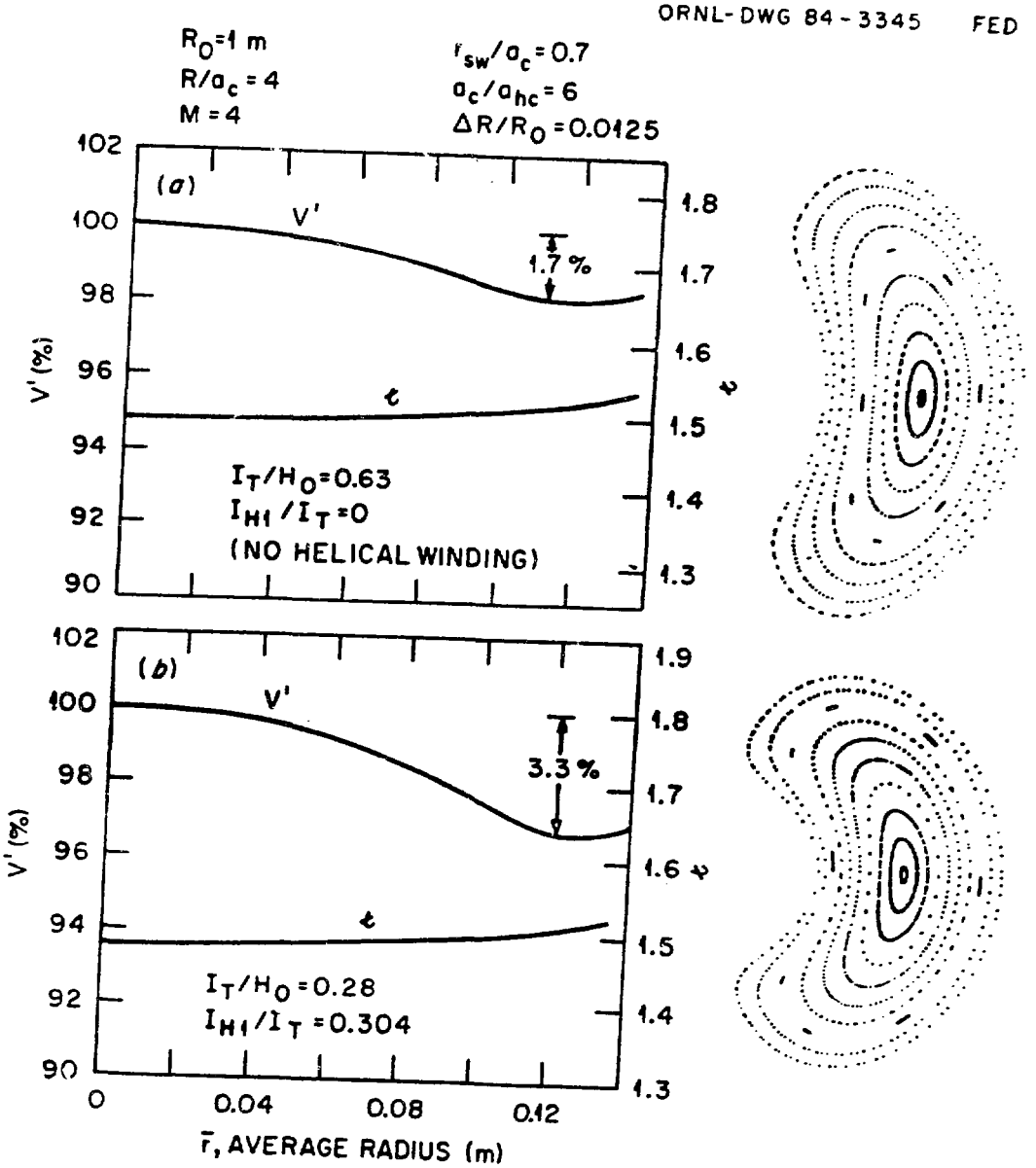
- THE PROPERTIES OF THE FLEXIBLE HELIAC MAY EASILY BE UNDERSTOOD IN THE INFINITE ASPECT RATIO, HELICALLY SYMMETRIC LIMIT

$$\Phi = Z + A \ln r + [0.25\, I_1(r) + b_1 K_1(r)] \sin(\theta - Z)$$

HELICAL POTENTIAL — TOROIDAL FIELD — CENTRAL CONDUCTOR — HELICAL MOTION OF T.F. COIL — $\ell=1$ WINDING

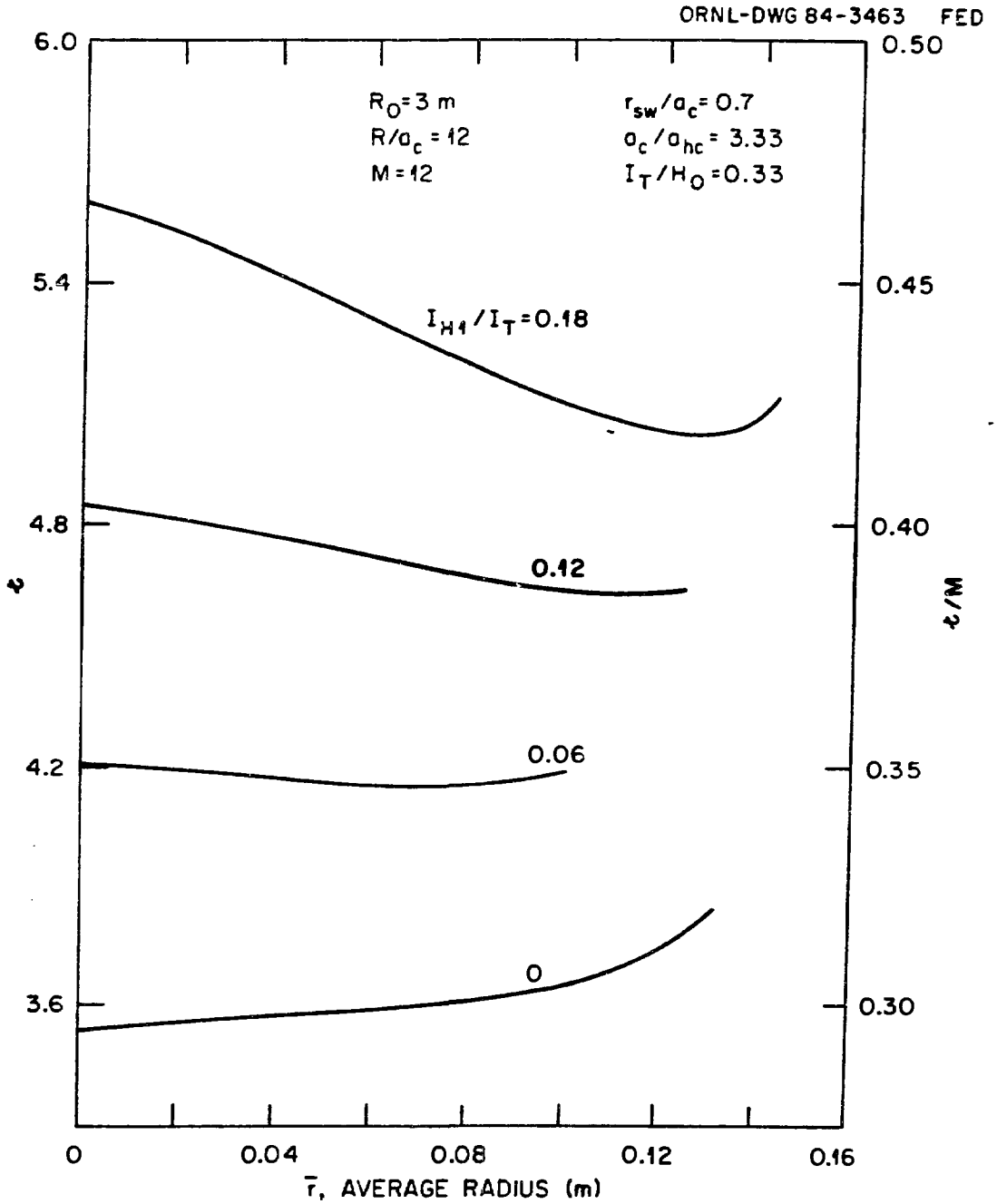


- THE CENTRAL CONDUCTOR CURRENT (αA) DECREASES RAPIDLY AS THE $\ell=1$ CURRENT (αb_1) RISES

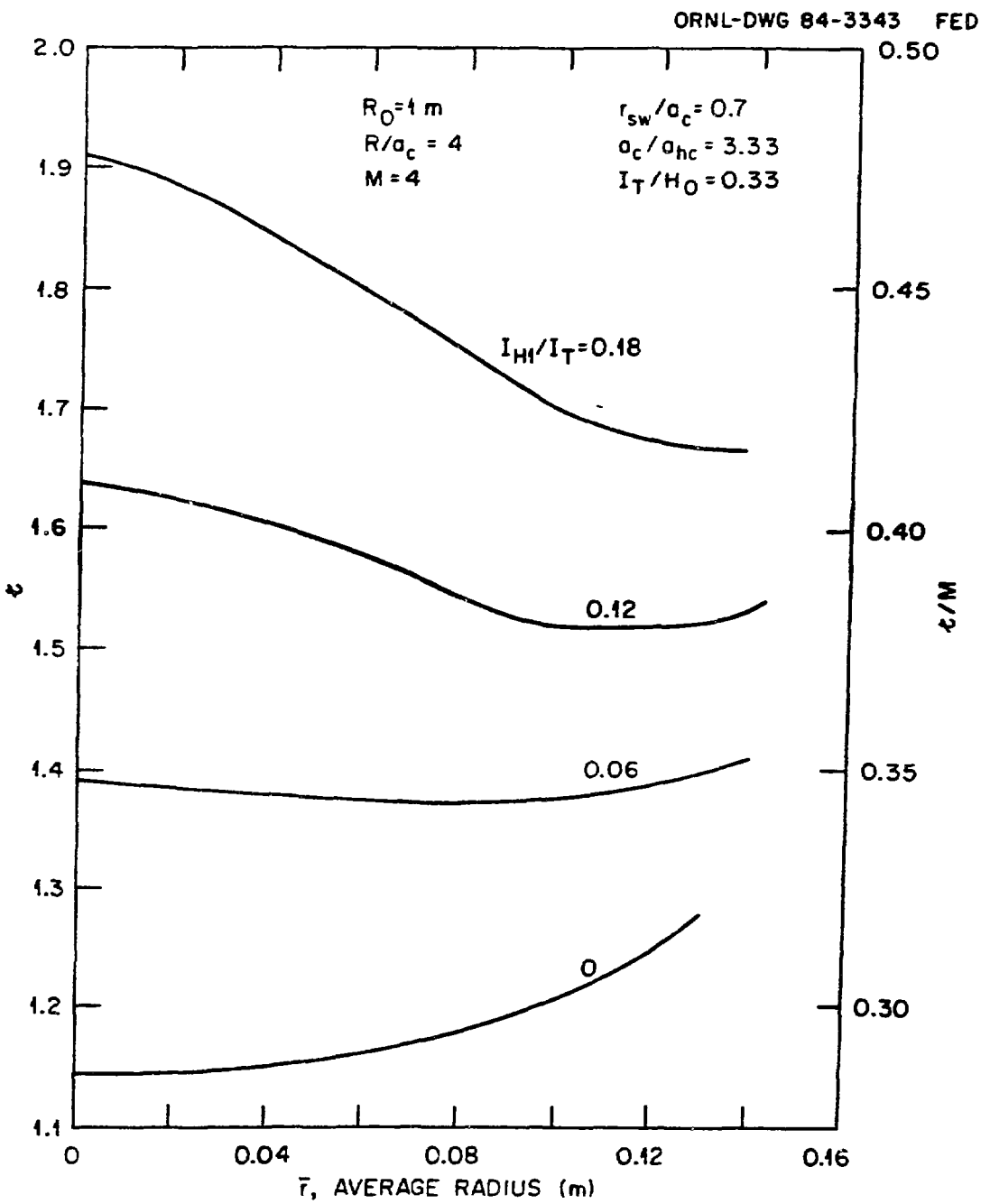


I_T = (circular coil current) + (helical coil current)
↑ I_{H1}

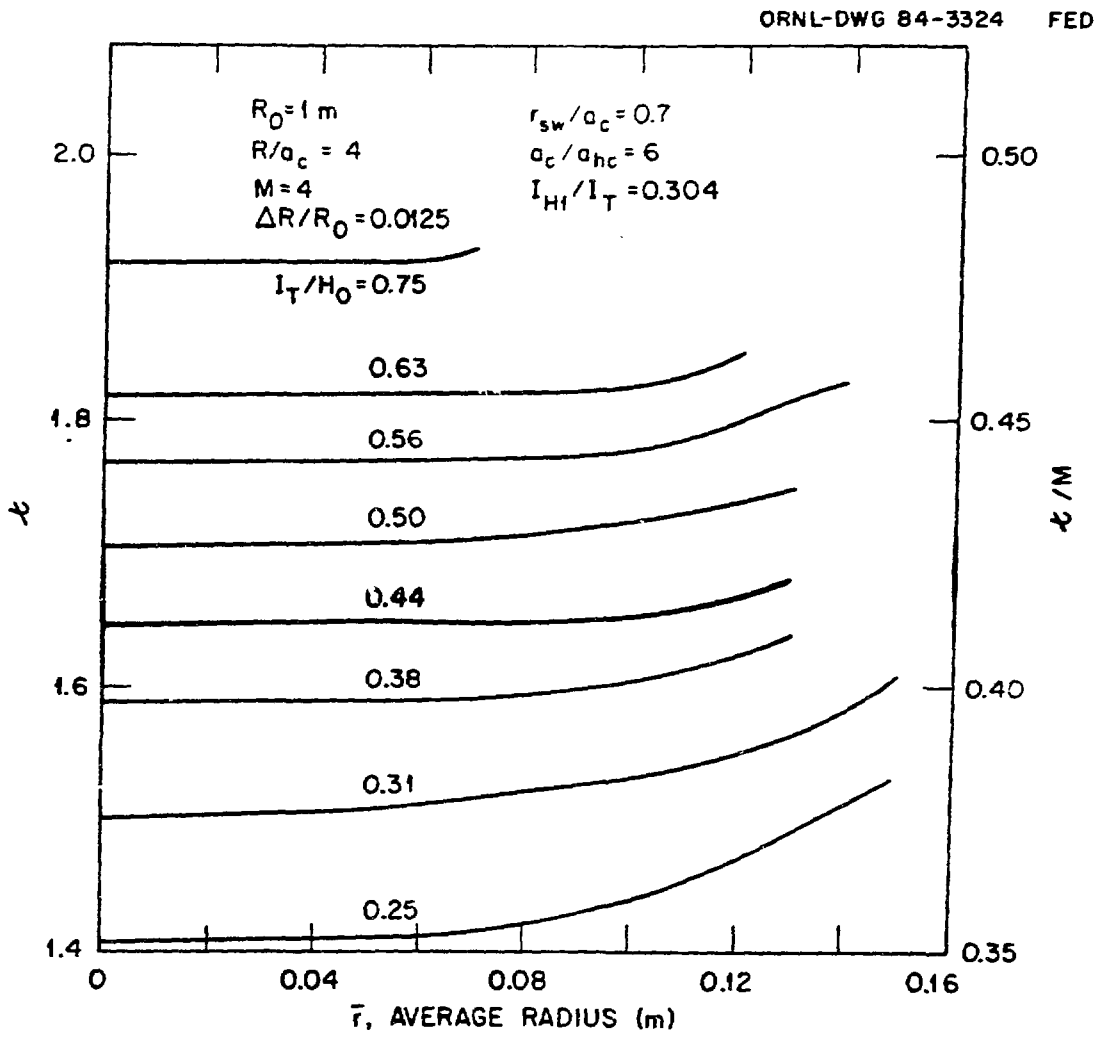
HELICAL CURRENT SCAN



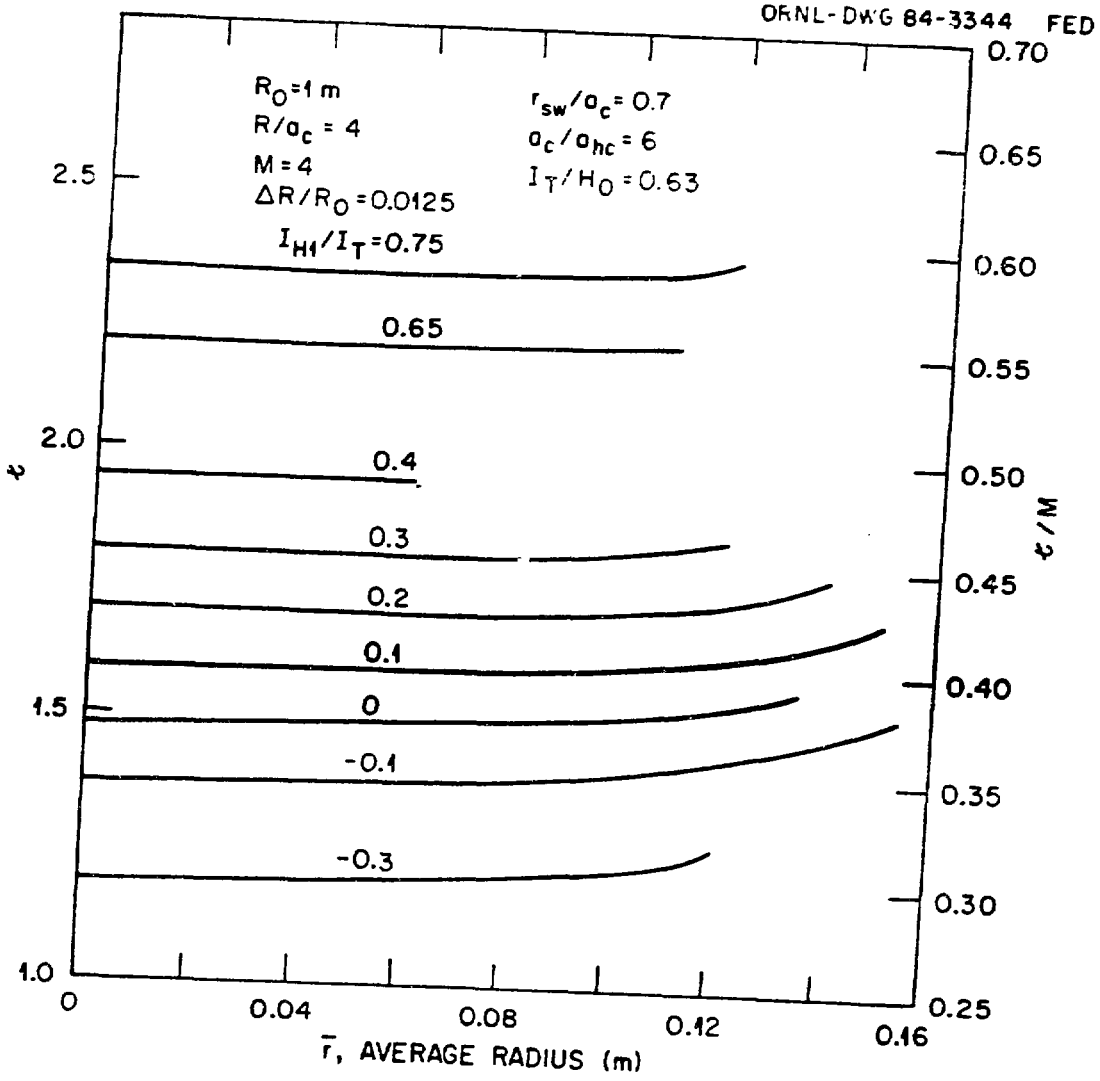
HELICAL CURRENT SCAN

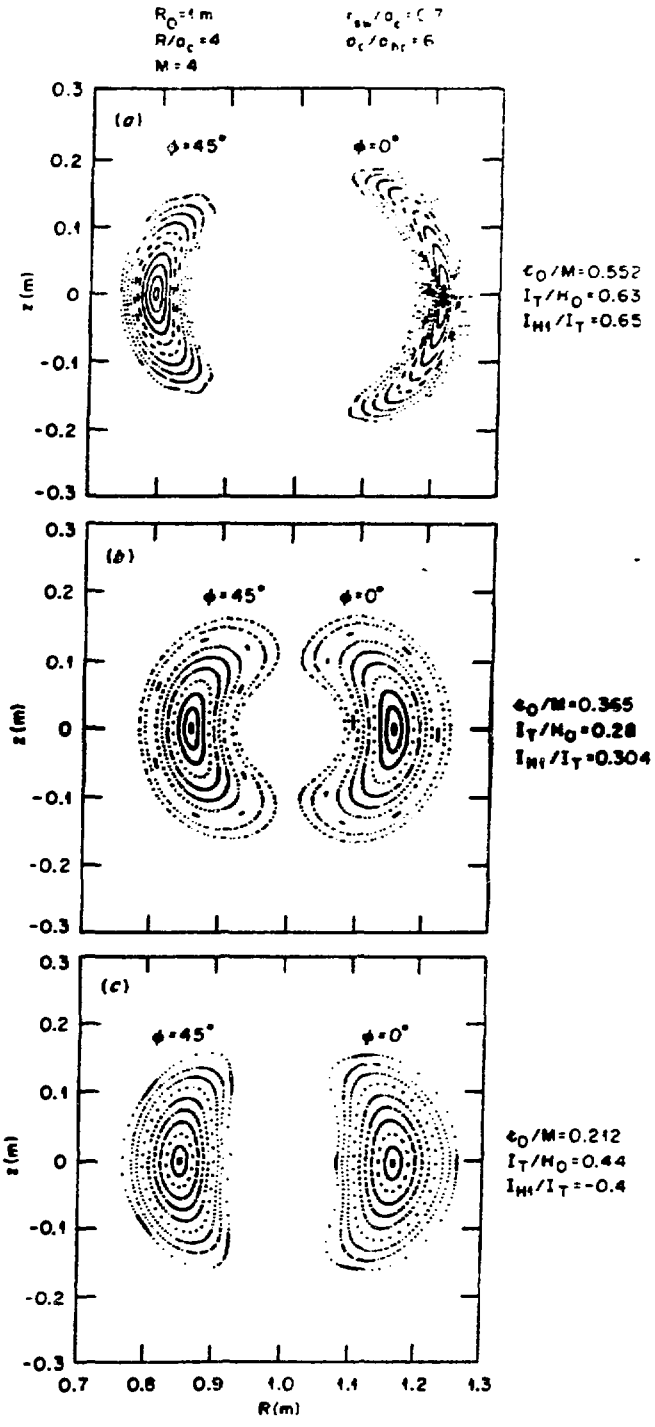


TOTAL TOROIDAL CURRENT SCAN



HELICAL CURRENT SCAN




R_0=1 m
R/a_c=4
M=4
r_{sh}/a_c=0.7
a_c/a_{hr}=6
(a)
ϕ=45°
ϕ=0°
ϵ_0/M=0.552
I_T/H_0=0.63
I_{H1}/I_T=0.65
(b)
ϕ=45°
ϕ=0°
ϵ_0/M=0.365
I_T/H_0=0.28
I_{H1}/I_T=0.304
(c)
ϕ=45°
ϕ=0°
ϵ_0/M=0.212
I_T/H_0=0.44
I_{H1}/I_T=-0.4
z (m)
R(m)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0.7
0.8
0.9
1.0
1.1
1.2
1.3

- ADDITIONAL $\ell = 1$ CENTRAL WINDING GIVES :

  - INDEPENDENT VARIATION OF SHEAR AND TRANSFORM OVER A WIDE RANGE

  - DEEPER MAGNETIC WELLS

  - SIMILAR CONFIGURATIONS WITH LESS TOTAL CURRENT

REDUCTION OF THE TOROIDAL SHIFT

1) ASPECT RATIO

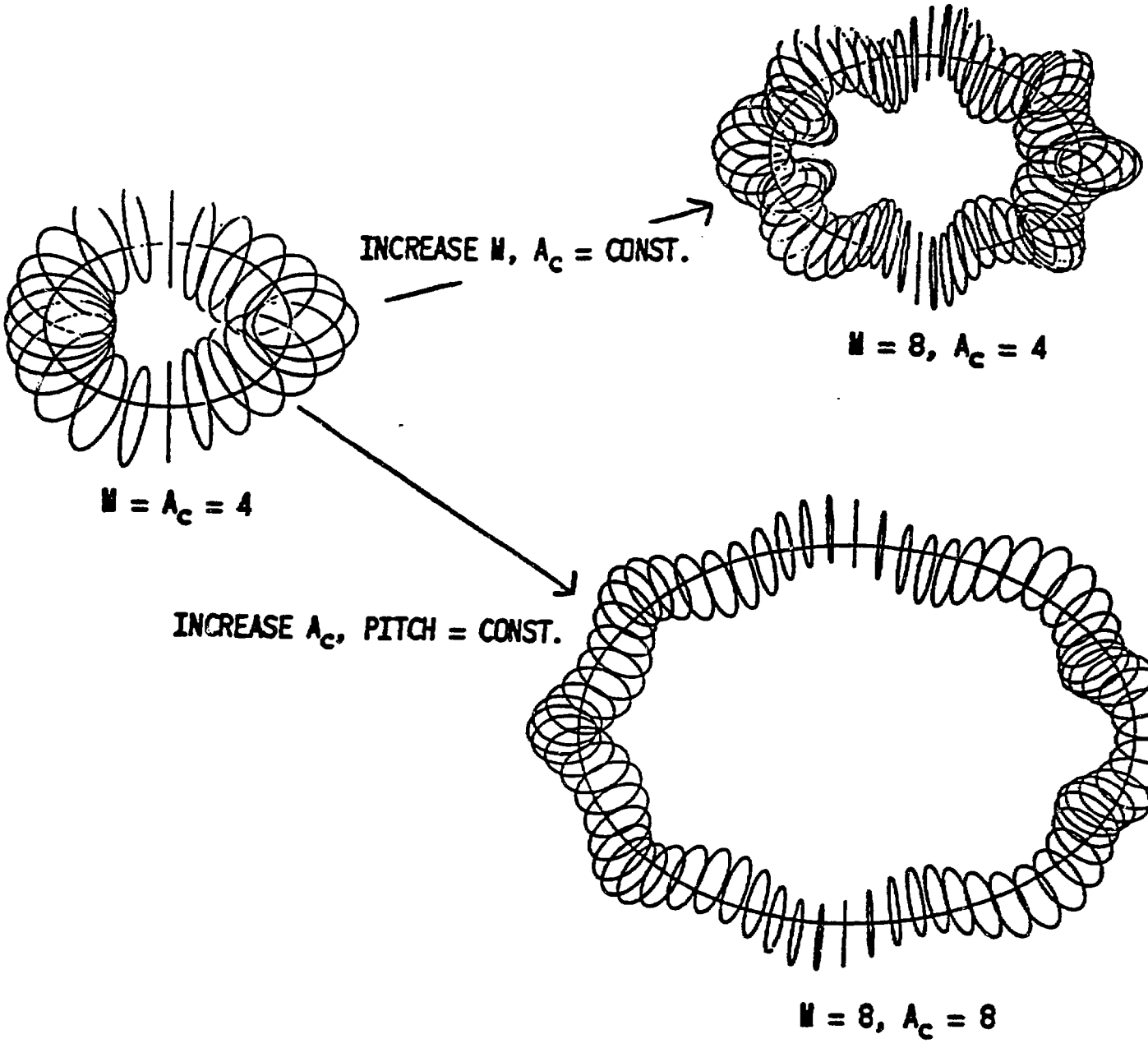
2) TOROIDAL FIELD PERIODS

3) TOROIDAL MODULATION OF THE COIL CURRENTS

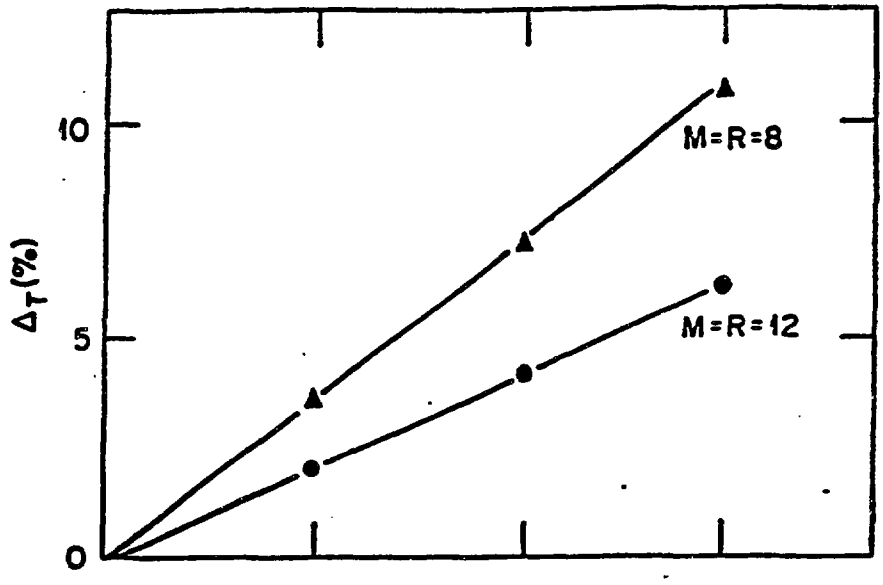
4) REDUCTION OF THE $\int d\ell/B$ VARIATION

REDUCTION OF THE TOROIDAL SHIFT

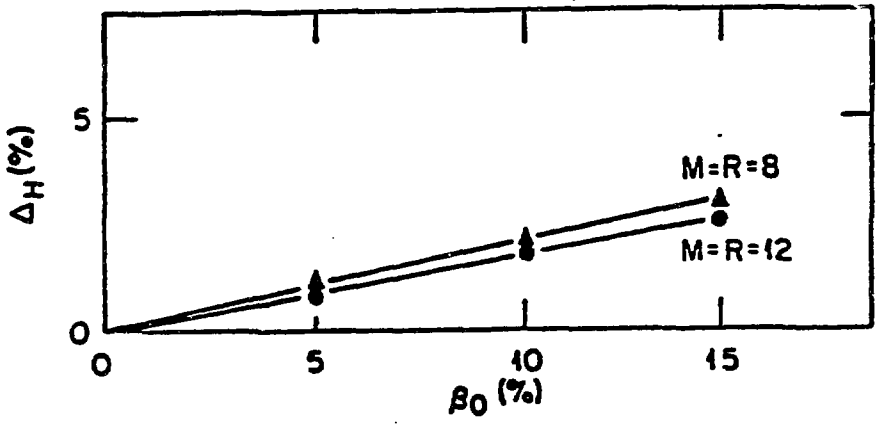
- TO STUDY THE EFFECT OF ASPECT RATIO (A_c) AND NUMBER OF FIELD PERIODS (M) ON THE TOROIDAL MAGNETIC AXIS SHIFT (Δ_T) TWO TYPES OF CONFIGURATION SCANS HAVE BEEN MADE



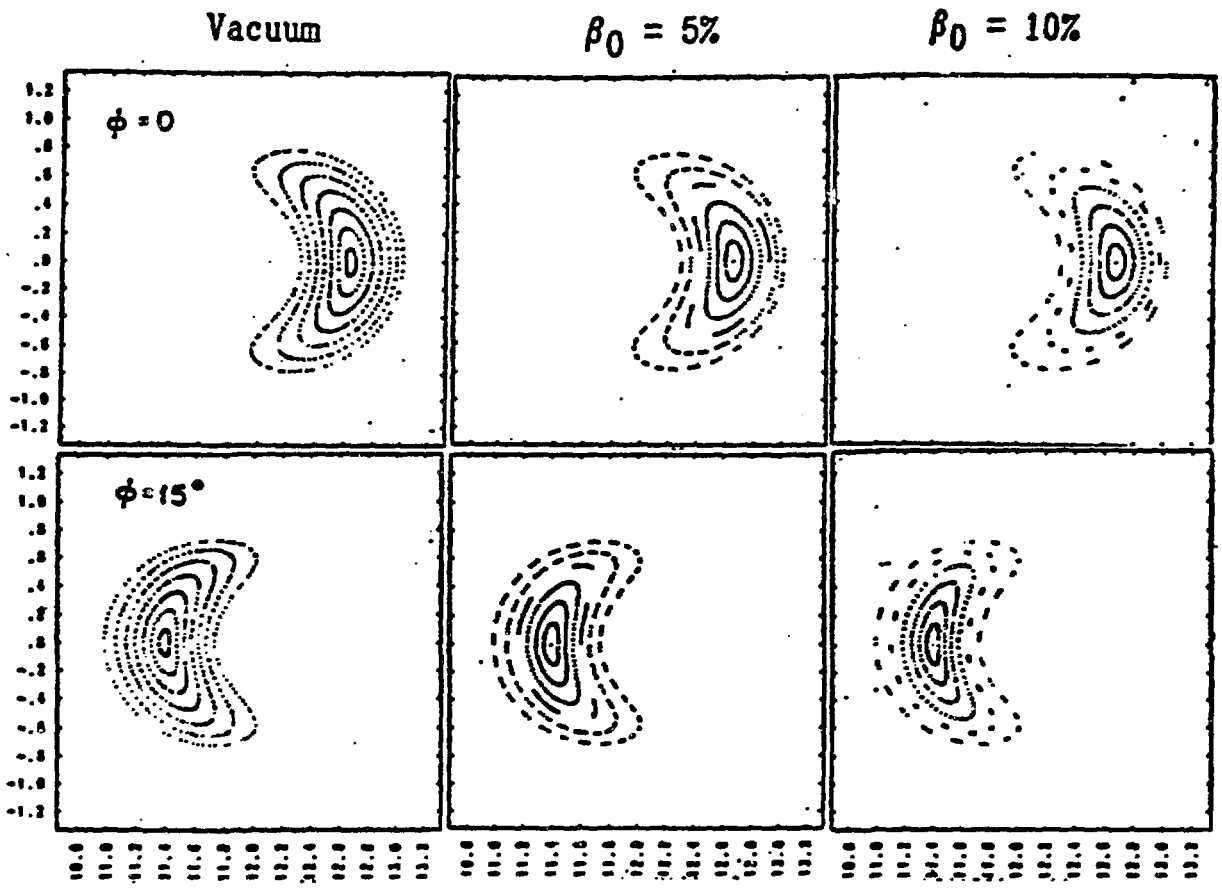
Increasing the aspect ratio at constant pitch lowers toroidal shift (Δ_t)



but no effect on helical shift (Δ_H)

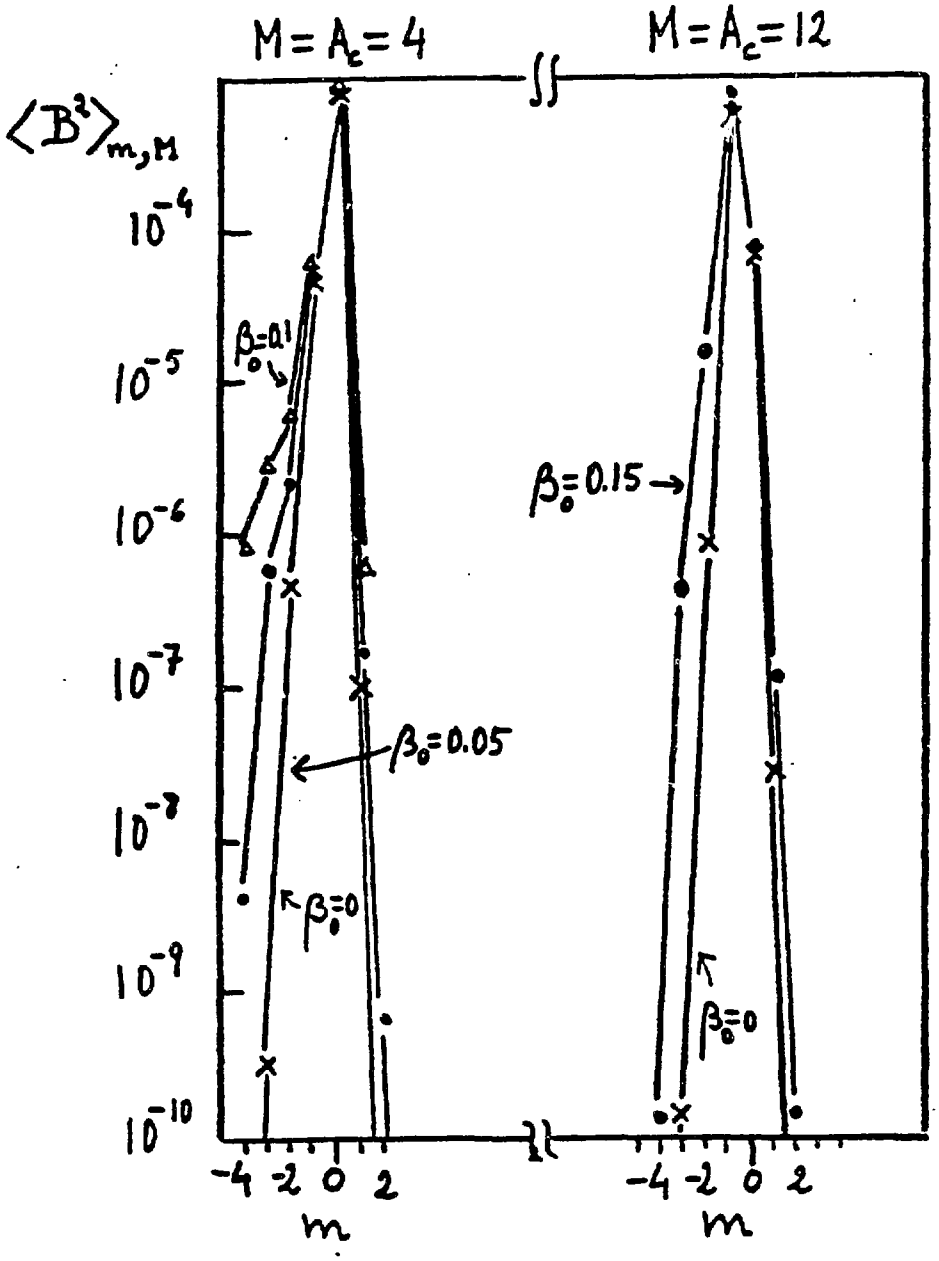


HELIAC EQUILIBRIUM

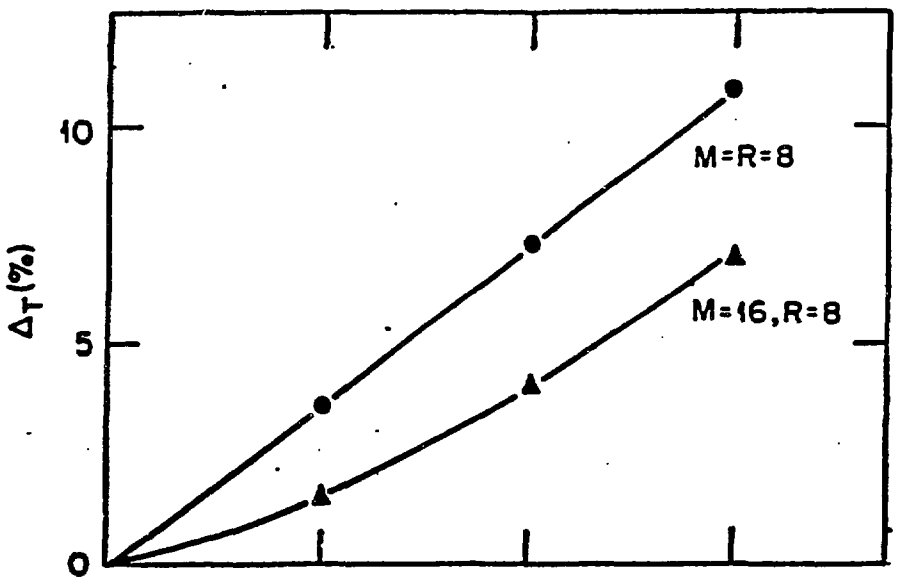


For M = R = 12 Heliac, good equilibria up to at least β_0 = 10%.

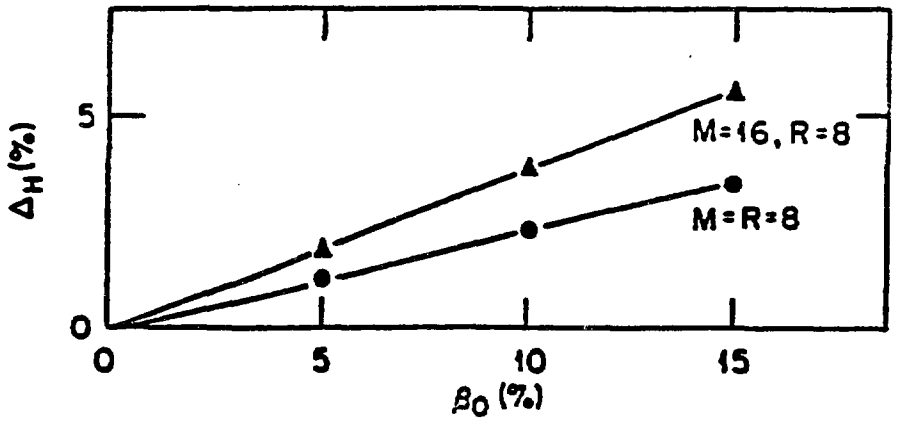
- THE SPECTRA OF THE $M = A_c = 4$ CONFIGURATIONS COMPARED TO THE $M = A_c = 12$ SHOWS MUCH GREATER BROADENING WITH β.



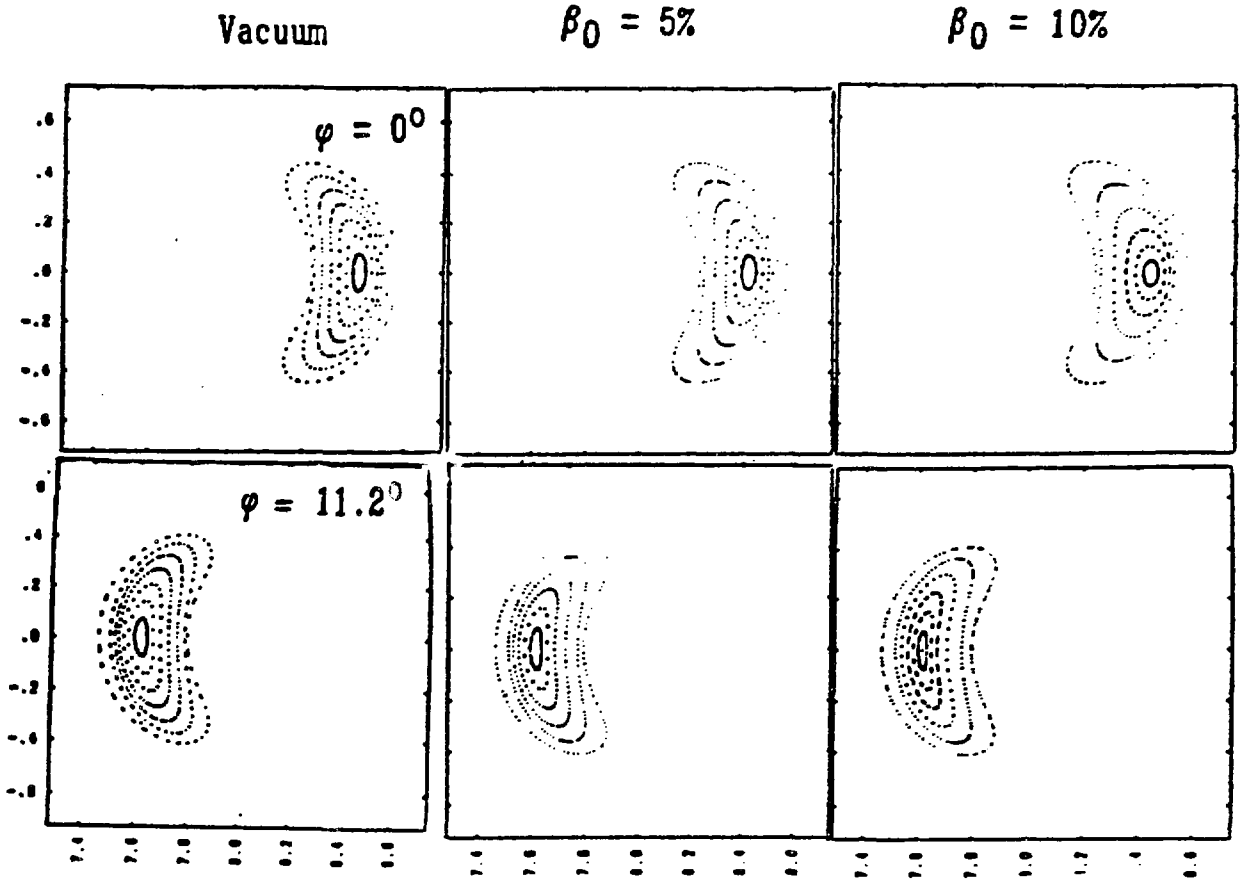
Increasing number of number of field periods at constant ϵ raises ι and lowers Δ_T



but raises helical shift Δ_H



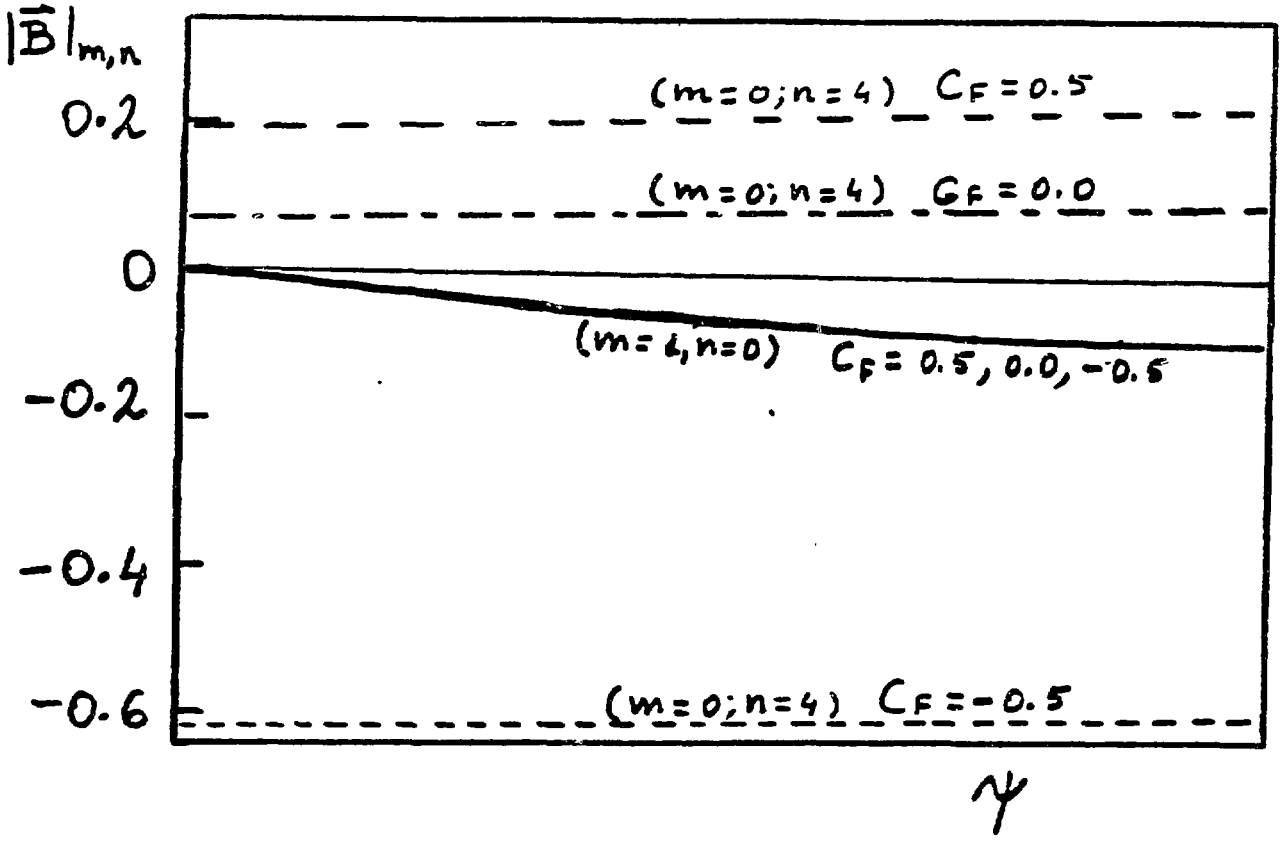
HELIAC EQUILIBRIUM



For M = 16, R = 8 Heliac, good equilibria up to at least β_0 = 10%.

TOROIDAL MODULATION OF THE COILS CURRENT

- MODULATING THE COILS CURRENT HAS LARGE EFFECT ON RIPPLE $(m = 0,\ n = M)$ BUT VERY LITTLE ON $(m = 1,\ n = 0)$.

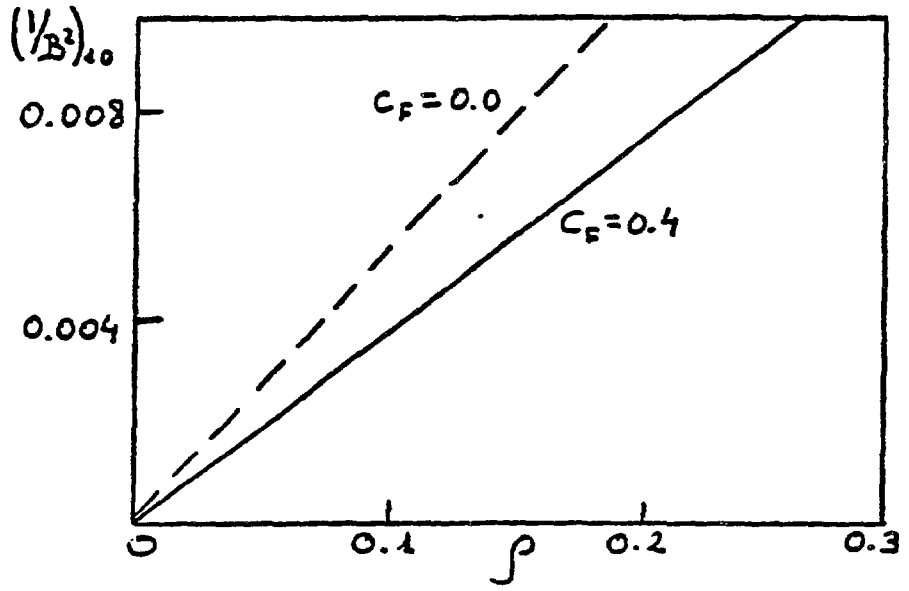


TOROIDAL MODULATION OF THE COILS CURRENT

- THE DOMINANT EFFECT IS TO ALTER THE $(m = 0,\ n = M)$ COMPONENT. THE BEATING OF THIS WITH THE $(m = 1,\ n = M)$ COMPONENT NONLINEARLY MODIFIES THE $(m = 1,\ n = 0)$ COMPONENT. (TOROIDAL SHIFT)

- AT LOW ASPECT RATIO ($A_c \sim 4$) THIS NONLINEAR EFFECT IS DOMINATED BY THE 1/R TOROIDICITY.

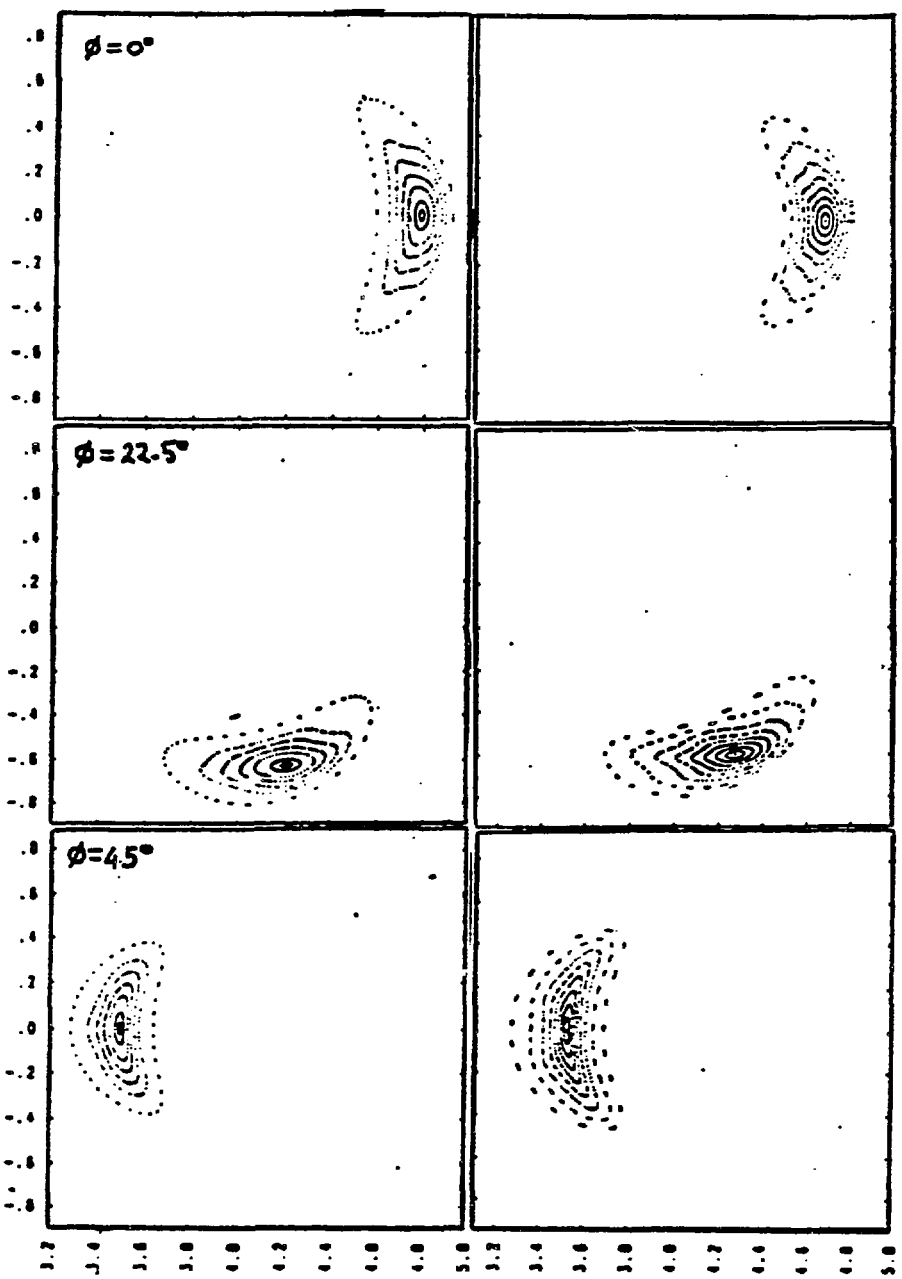
- AT HIGHER ASPECT RATIO ($A_c \sim 20$) THERE IS SOME REDUCTION OF THE TOROIDAL SHIFT.



TOROIDAL MODULATION OF THE COILS CURRENT

M = 4, $A_c = 4$ HELIAC EQUILIBRIUM $\beta_0 = 5\%$

$C_F = 0$ $C_F = 0.4$



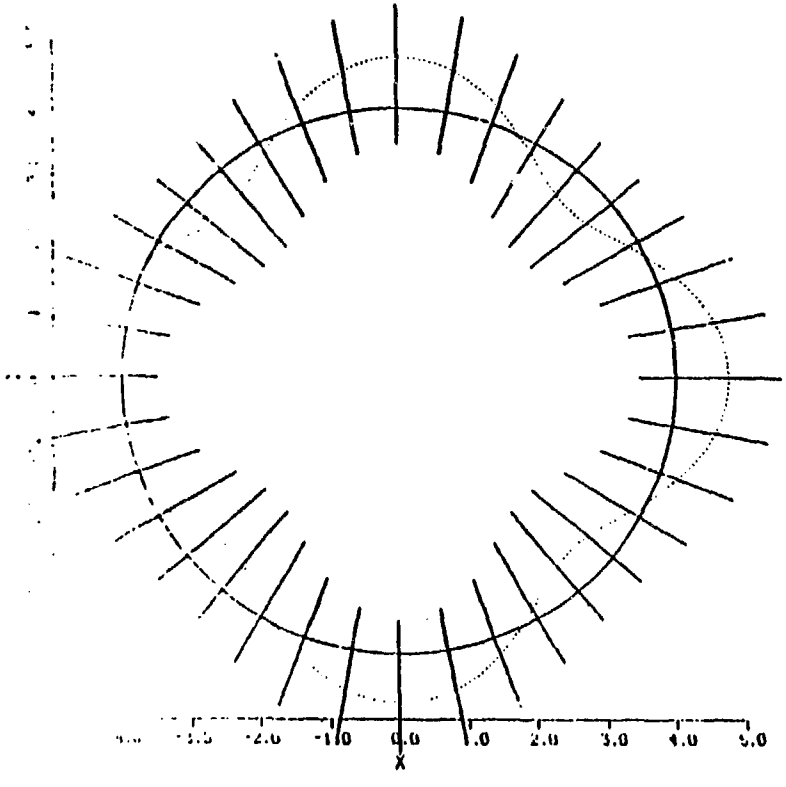
$\iota/M = 0.38$ $\iota = 0.41$

$\Delta_2 = 5\%$ $\Delta_2 = 7\%$

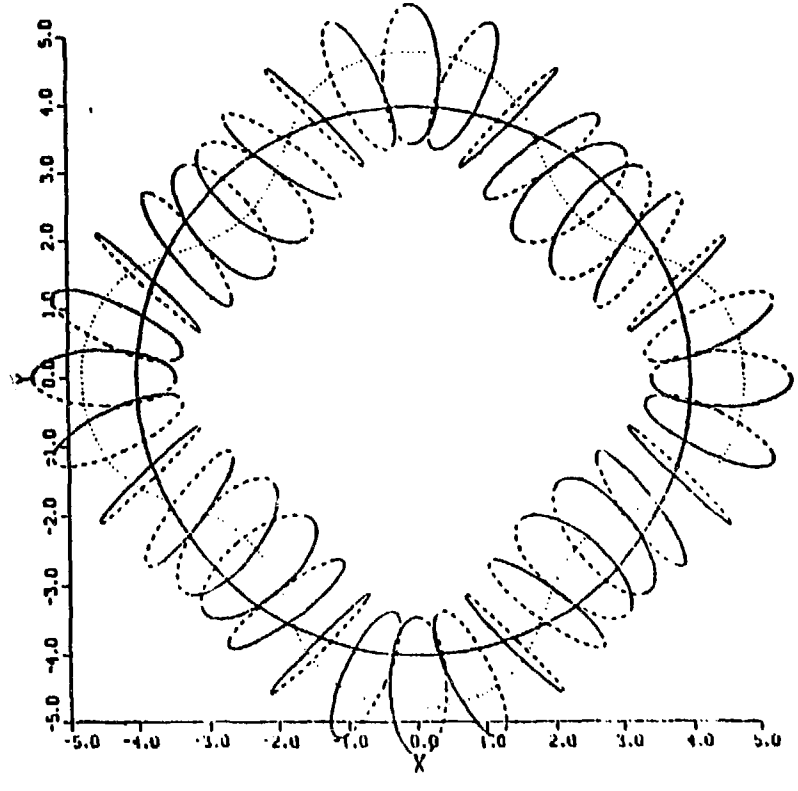
$\Delta_3 = 4.2\%$ $\Delta_3 = 3.3\%$

REDUCTION OF THE $\int d\ell/B$ VARIATION

- BY TILTING THE TOROIDAL FIELD COILS THE $\int d\ell/B$ VARIATION IS REDUCED.



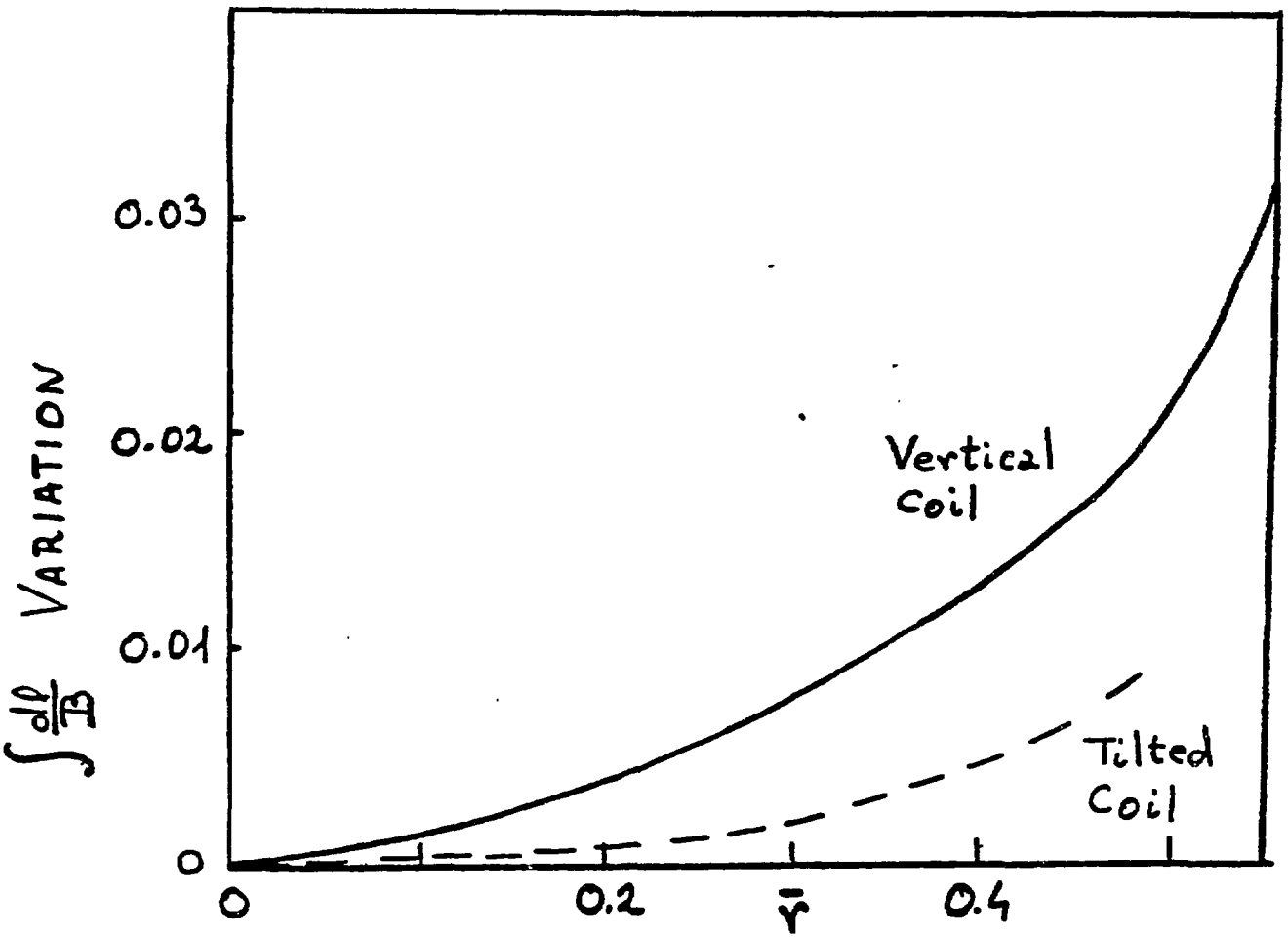
VERTICAL COILS



TILTED COILS

REDUCTION OF THE $\int d\ell/B$ VARIATION

- BY TILTING THE TOROIDAL FIELD COILS THE $\int d\ell/B$ VARIATION IS REDUCED.

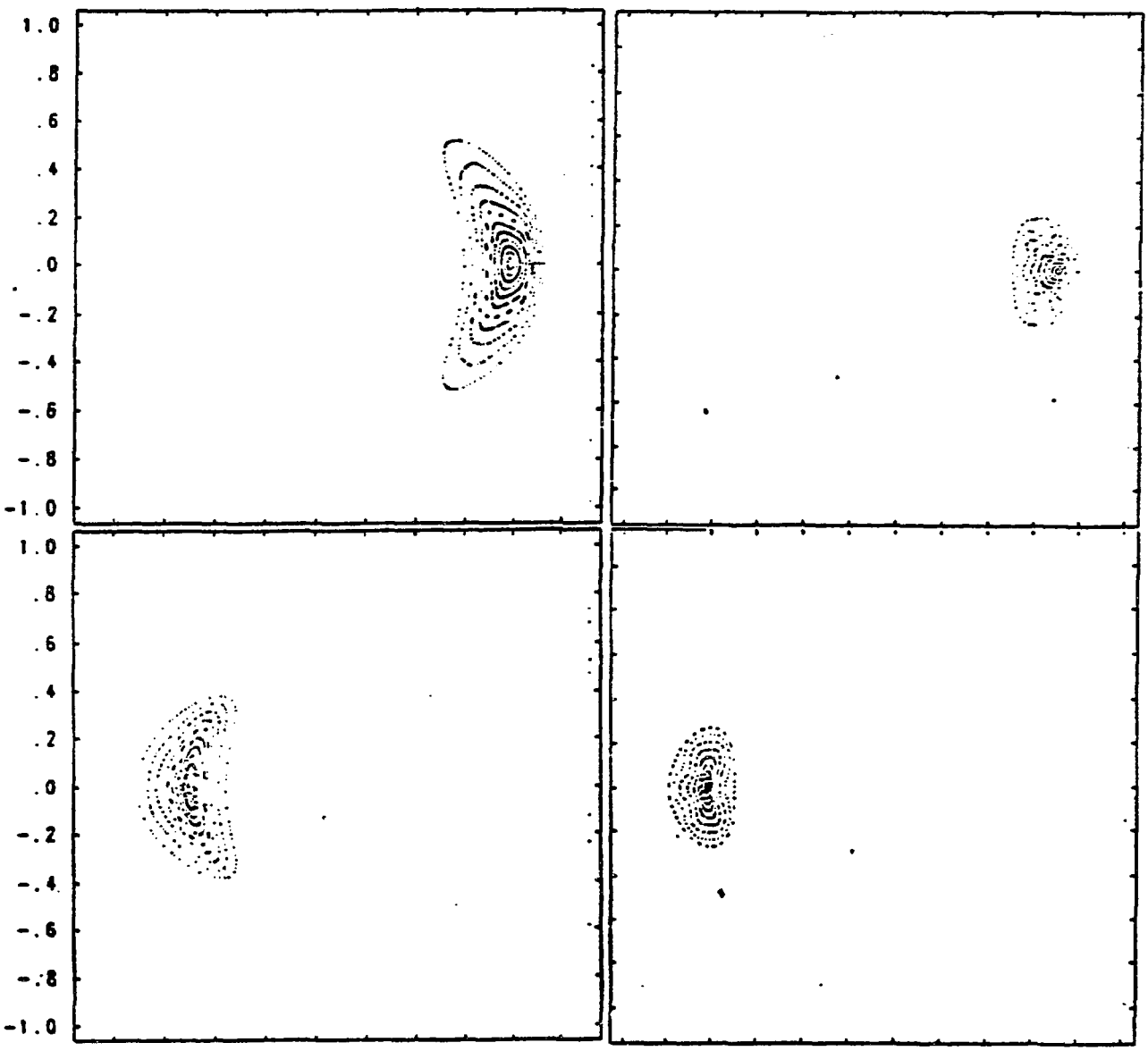


REDUCTION OF THE $\int d\ell/B$ VARIATION

M = 4, A_c HELIAC EQUILIBRIUM $\beta_0 = 5\%$

VERTICAL COILS

TILTED COILS



$\Delta_T = 12\%$

$\Delta_T = 10\%$

CONCLUSION

1) THE ADDITION OF AN $\ell = 1$ HELICAL WINDING TO THE HELIAC CENTRAL CONDUCTOR ADDS A SIGNIFICANT DEGREE OF FLEXIBILITY TO THE CONFIGURATION BY MAKING IT POSSIBLE TO CONTROL THE ROTATIONAL TRANSFORM AND SHEAR. SUCH CONTROL IS ESSENTIAL FOR AN EXPERIMENT BECAUSE THE PRESENCE OF LOW-m RESONANT SURFACES IN OR NEAR THE PLASMA CAN CAUSE BREAK-UP OF THE EQUILIBRIUM MAGNETIC SURFACES.

2) TO FURTHER IMPROVE THE EQUILIBRIUM β LIMITS FOR LOW ASPECT RATIO CONFIGURATIONS, IT IS NECESSARY TO REDUCE THE TOROIDAL MAGNETIC AXIS SHIFT. THE RESULTS INDICATE THAT AN INCREASE IN ASPECT RATIO AND NUMBER OF FIELD PERIODS IS THE MOST EFFECTIVE MEANS OF IMPROVEMENT.