LRP 342/88 January 1988

SIMULATION OF PLASMA EVOLUTION AND SHAPE CONTROL IN THE TCV TOKAMAK

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Presented at the
29th Annual meeting of the Division of Plasma Physics of the American Physical Society, San Diego, U.S.A.
November 2 - 6, 1987

Simulation of Plasma Evolution and Shape Control in the TCV Tokamak, F.B. MARCUS, F. HOFMANN, G. TONETTI, CRPP-EPFL, Lausanne, Switzerland*, and S.C. JARDIN, Princeton University**. -- It has been demonstrated with the Tokamak Simulation Code (TSC) that a tokamak plasma can be evolved continuously from a near-circular cross-section to a highly elongated racetrack [1]. Detailed studies of plasma position and shape control are being made for the TCV tokamak (currently under construction) with parameters: B = 14.3 kG, R = 87 cm, a = 24 cm, b/a up to 3/1, I up to 1200 kA. Using the TSC code with a current moments control method and a thyristor power supply model, plasmas have been evolved to 3/1 elongated racetrack and dee shapes in the TCV geometry. Other control methods are also being investigated. Sensitivity to various physical and numerical parameters will be discussed.

[1] F.B. Marcus, S.C. Jardin, and F. Hofmann, Phys. Rev. Lett. 55 (1985) 2289.

* Supported by the Association Euratom-Confederation Suisse and the Fonds National Suisse.

** Supported by U.S. DOE Contract No. DE-AC02-CHO-3073.

SIMULATION OF PLASMA EVOLUTION AND SHAPE CONTROL IN THE TCV TOKAMAK

OUTLINE

1) DESCRIPTION OF TCV

2) RESISTIVE GROWTH RATES USING TSC CODE

3) CONTROL METHODS AND POWER SUPPLY MODEL INCORPORATED IN TSC FOR TCV

4) RANGE OF CONTROLLABLE PLASMAS

5) COMPLETE EVOLUTION FOR RACETRACKS AND DEES

TCV (TOKAMAK A CONFIGURATION VARIABLE)

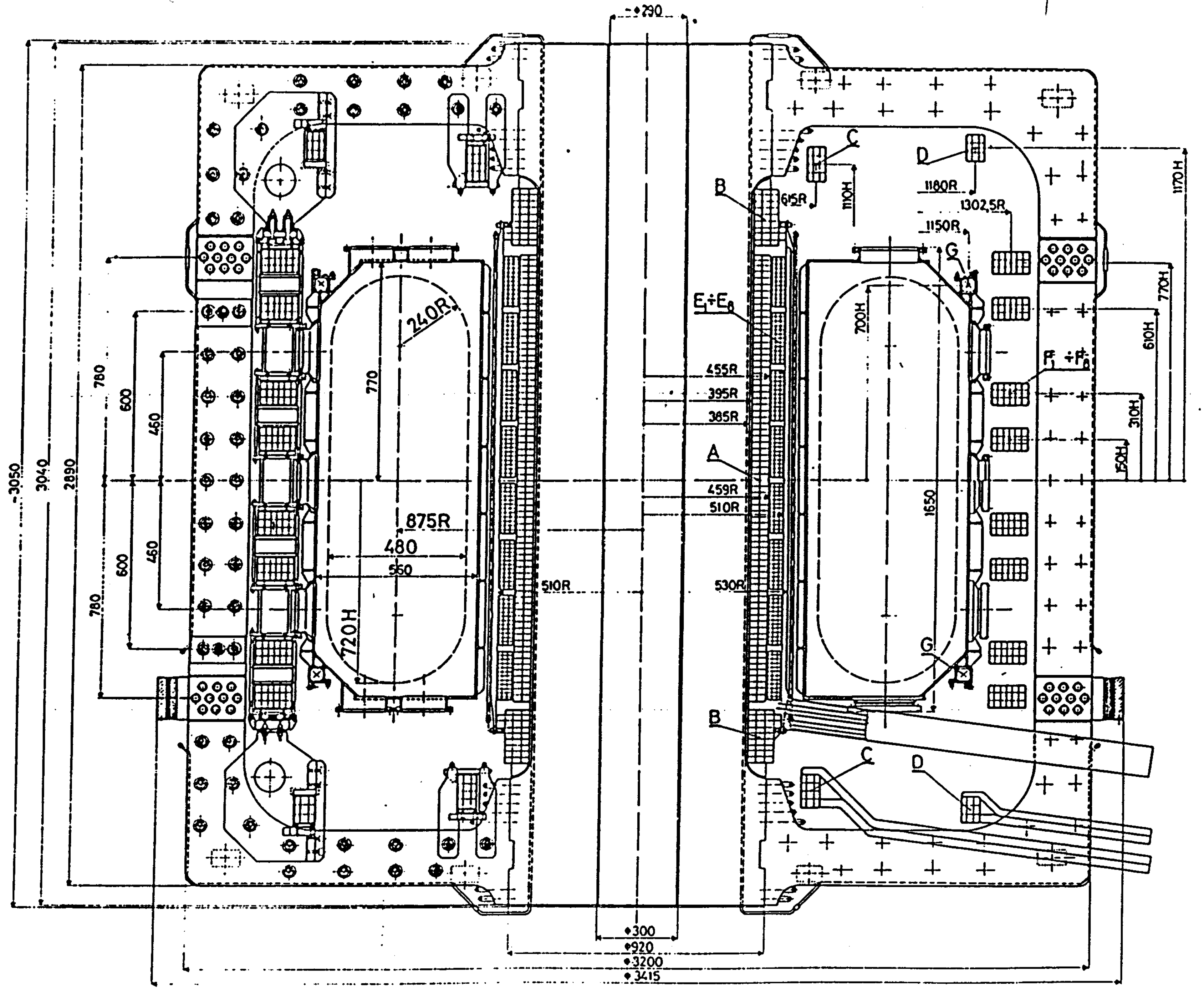
TCV PARAMETERS:
(UNDER CONSTRUCTION AT CRPP-EPFL, LAUSANNE, SWITZERLAND)

MAJOR RADIUS 87.5 CM
MINOR RADIUS 24. CM
TOROIDAL FIELD 14.3 KG
MAXIMUM PLASMA HEIGHT 144 CM
MAXIMUM FULL SIZE PLASMA ELONGATION 3/1
FLUX SWING 4. VOLT SECONDS
MAXIMUM DESIGN PLASMA CURRENT 1.2 MILLION AMPERES

SPECIAL FEATURES:

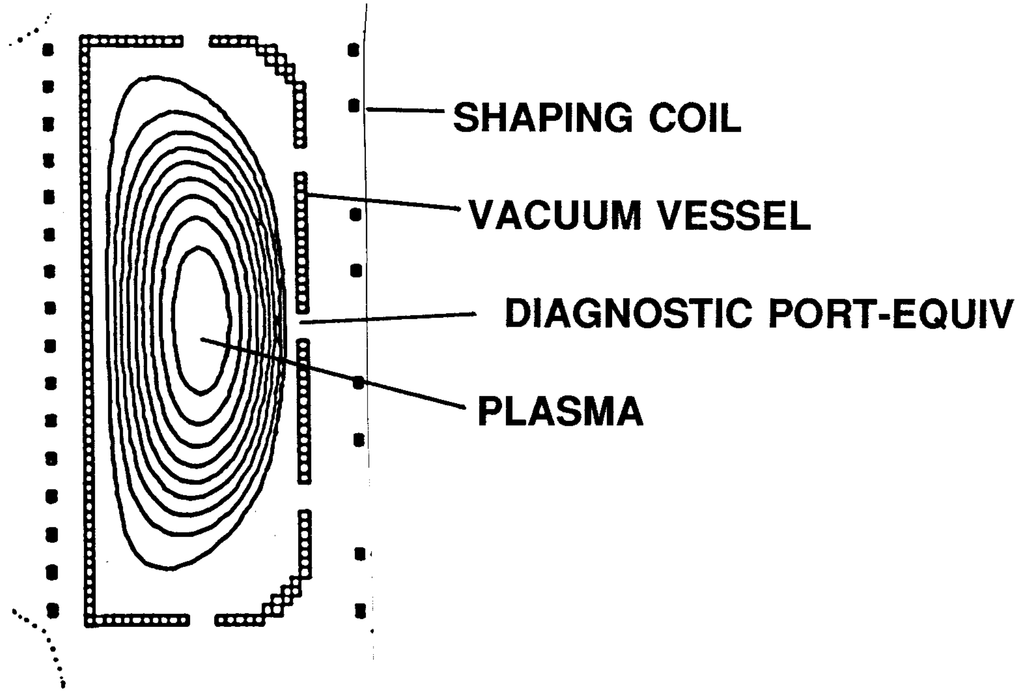
LARGE VARIETY OF SHAPES AND SIZES:
    RACETRACK,DEE,BEAN,DIVERTOR,DOUBLET,TRIPLET,ETC.
18 INDEPENDENT SHAPING AND OHMIC COILS AND POWER SUPPLIES
THYRISTOR POWER SUPPLIES, 96-120 HZ,12PULSE,4QUADRANT
12.5 V/TURN INSIDE, 25 V/TURN OUTSIDE
CONTINUOUS VESSEL, TAU=6.7 MILLISECONDS

TCV (TOKAMAK À CONFIGURATION VARIABLE)



RESISTIVE GROWTH RATES USING TSC CODE

TOKAMAK SIMULATION CODE (TSC):
(DEVELOPED AT PPL BY S.C. JARDIN)
-RESISTIVE EVOLUTION OF FREE-BOUNDARY, AXISYMMETRIC MHD EQUILIBRIUM
-ALFVEN TIME MULTIPLIED BY FACTOR "FFAC" TO REDUCE COMPUTATIONAL TIME
-INCLUDES PLASMA, VESSEL, THYRISTOR-DRIVEN SHAPING COILS



CALCULATION OF RESISTIVE GROWTH RATES

-THE EQUILIBRIUM TO BE STUDIED IS SPECIFIED WITH SHAPING COIL CURRENTS, PLASMA CURRENT PROFILE, LIMITERS, AND SHAPE CONTROL MOMENTS.

-AN EQUILIBRIUM IS CALCULATED, AND THE CURRENTS ARE FROZEN IN THE SHAPING COILS (BUT NOT IN THE PASSIVELY STABILIZING VACUUM VESSEL).

-THE PLASMA THEN EVOLVES IN TIME, AND THE VERTICAL HEIGHT OF THE MAGNETIC AXIS VERSUS TIME IS USED TO MEASURE THE RESISTIVE GROWTH RATE.

-THE NUMERICAL SOLUTION FACTORS, FFAC AND THE RESISTANCE OF GRID ELEMENTS IN THE VACUUM REGION (VACUUM TEMPERATURE), ARE VARIED TO CHECK THE ACCURACY OF THE RESULTS.

-WITHOUT A VACUUM VESSEL, THE PLASMA GROWS MANY TIMES FASTER THAN THE RESISTIVE GROWTH RATE, AT AN "IDEAL" RATE DETERMINED BY FFAC.

-WITH THE VESSEL PRESENT, THE PLASMA MAY BE EITHER IDEALLY STABLE, IN WHICH CASE IT GROWS WITH THE RESISTIVE GROWTH RATE, OR IDEALLY UNSTABLE.

-THE HIGHLY ELONGATED PLASMAS STUDIED HERE ARE ALL VERTICALLY UNSTABLE DUE TO THE SHAPE OF THE EQUILIBRIUM FIELD.

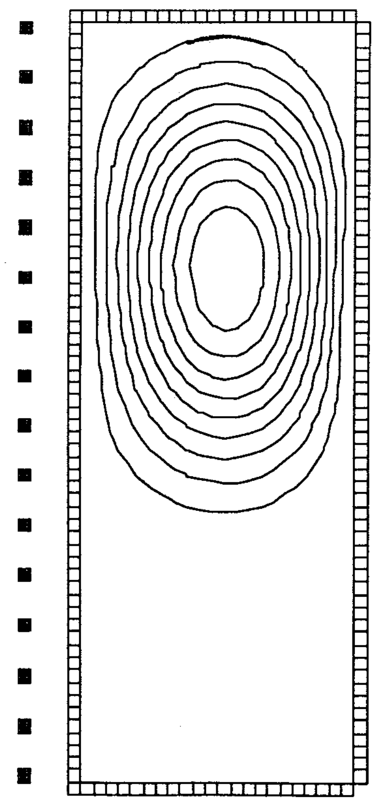
EXAMPLE OF RESISTIVE GROWTH OF IDEALLY STABLE PLASMA

-THE EQUILIBRIUM HAS 2/1 ELONGATION WITH A RATIO OF Q-LIMITER/Q-AXIS=3.3

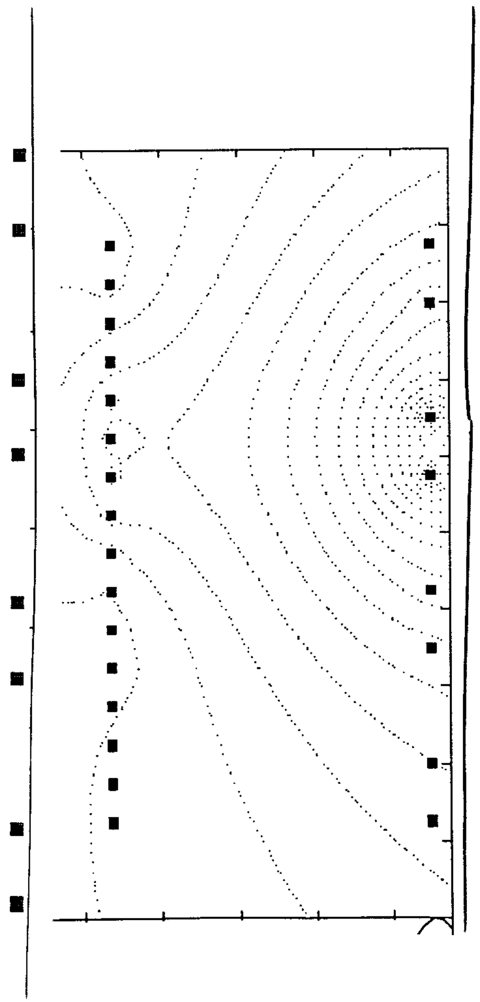
-THE VACUUM EQUILIBRIUM FIELD HAS A HIGHLY DESTABILISING FIELD CURVATURE

-IDEAL STABILITY (ERATO, FBT(HOFMANN)) SHOWS THIS EQUILIBRIUM IDEALLY STABLE.

EQUILIBRIUM



VACUUM FIELD



COMMENTS - RESISTIVE GROWTH RATES

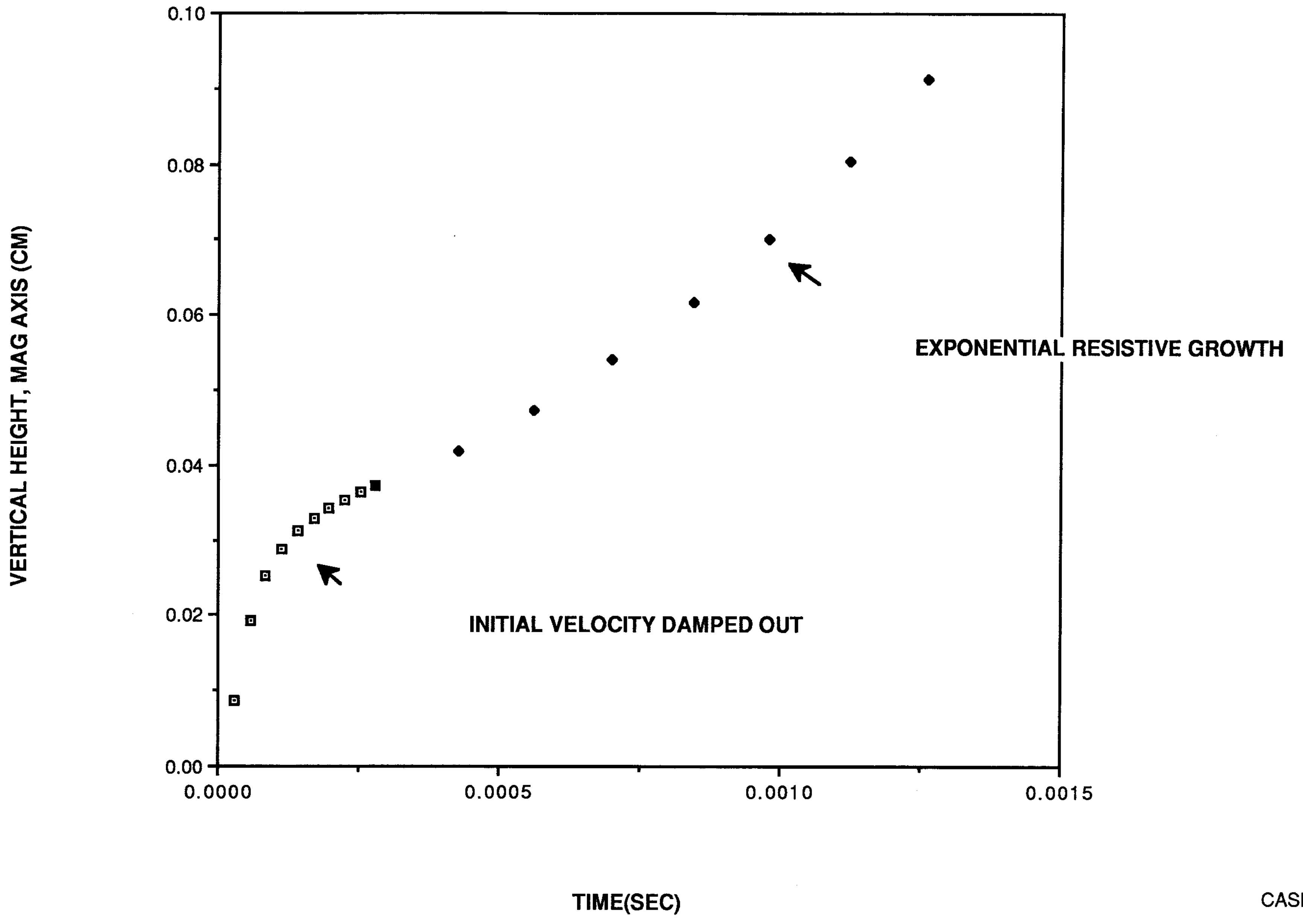
-THE GROWTH RATES CONSIDERED HERE ARE MUCH FASTER THAN THE INVERSE VESSEL TIME, WHICH CORRESPONDS TO A GROWTH RATE OF (1/6.7 MSEC)= 149 SEC-1.

-THE PLASMA TO CONDUCTOR-CENTER GAP CONSIDERED HERE IS 4 CM.
IDEAL STABILITY STUDIES SHOW THAT GAPS MUCH LARGER THAN THIS RESULT IN IDEAL INSTABILITY. WE THEREFORE EXPECT THAT EXTERNAL SHAPING COILS WILL HAVE LITTLE STABILISING EFFECT IN THIS REGIME WHERE GAMMA(PLASMA) >> GAMMA(VESSEL).

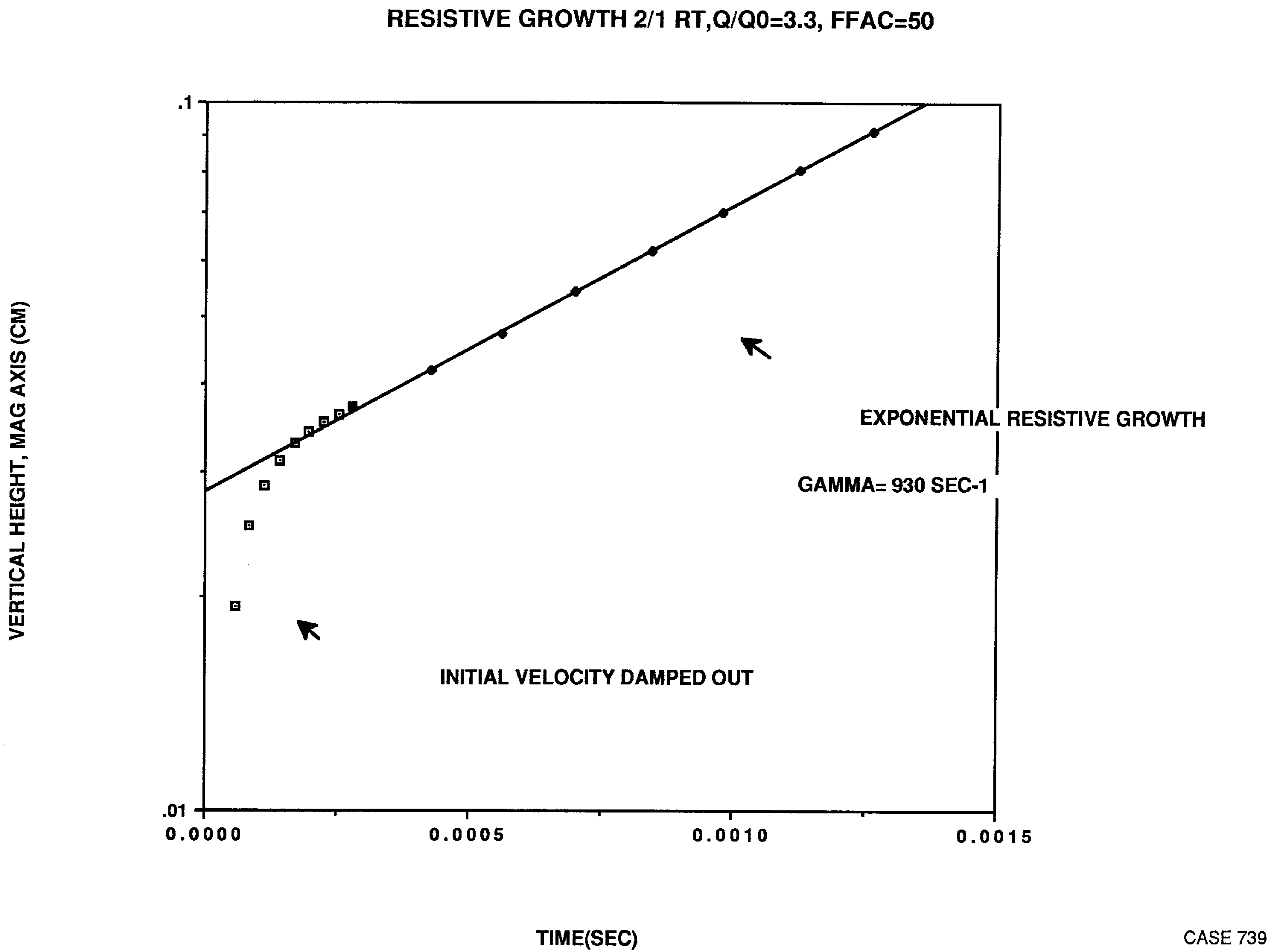
-THIS EXPECTATION WAS CONFIRMED BY RESISTIVE GROWTH RATE MEASUREMENTS WITH TSC. THE SAME RESISTIVE GROWTH RATES WERE OBTAINED WITH EITHER CONSTANT VOLTAGE OR CONSTANT CURRENT CONTROL ON THE SHAPING COILS DURING THE PLASMA GROWTH WITHOUT FEEDBACK.

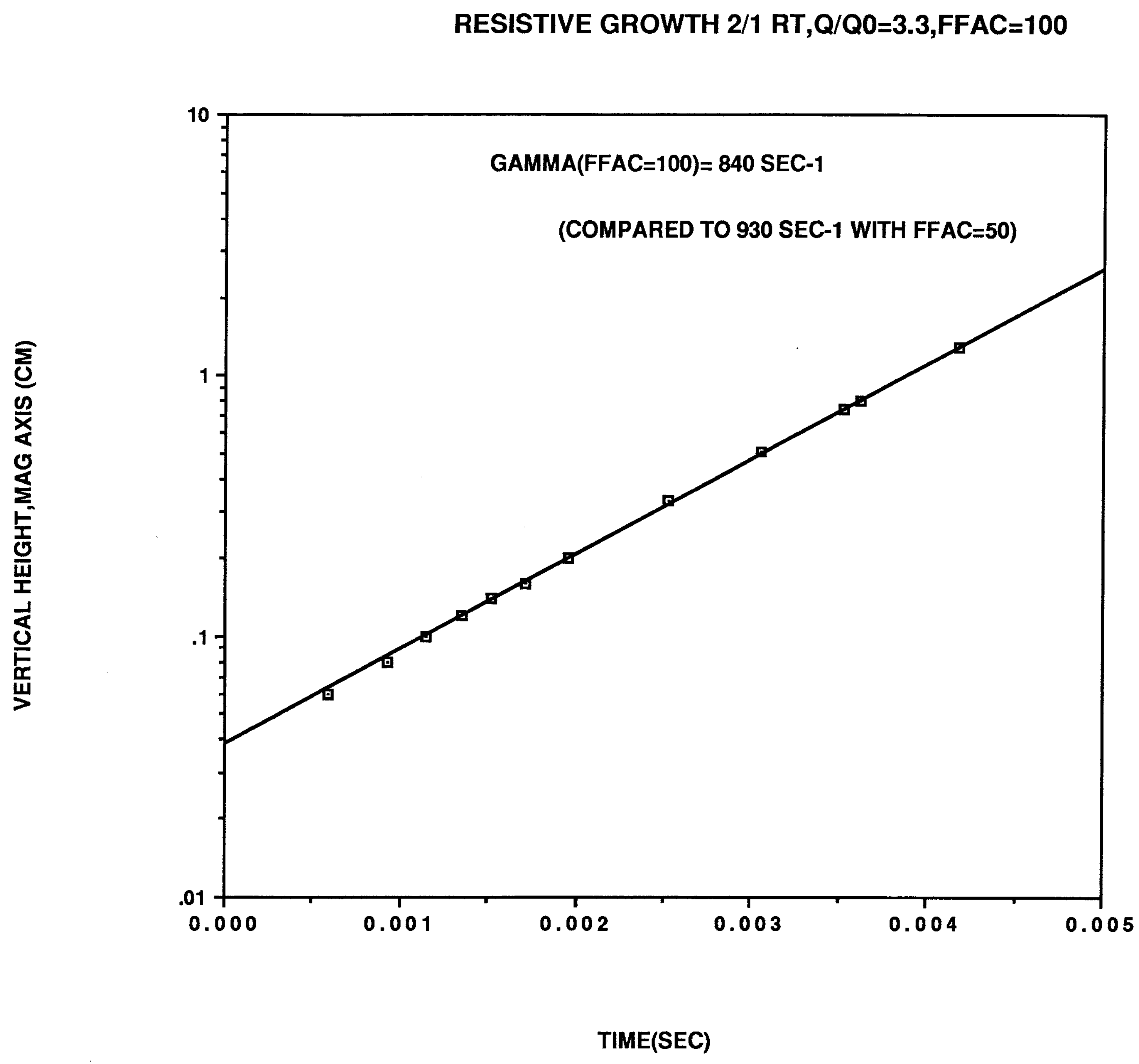
-THIS IMPLIES THAT THE CHOICE OF CURRENT CONTROL OR VOLTAGE CONTROL WITH FEEDBACK HAS NO INFLUENCE ON FEEDBACK STABILITY IN THIS REGIME.

RESISTIVE GROWTH 2/1 RT,Q/Q0=3.3, FFAC=50

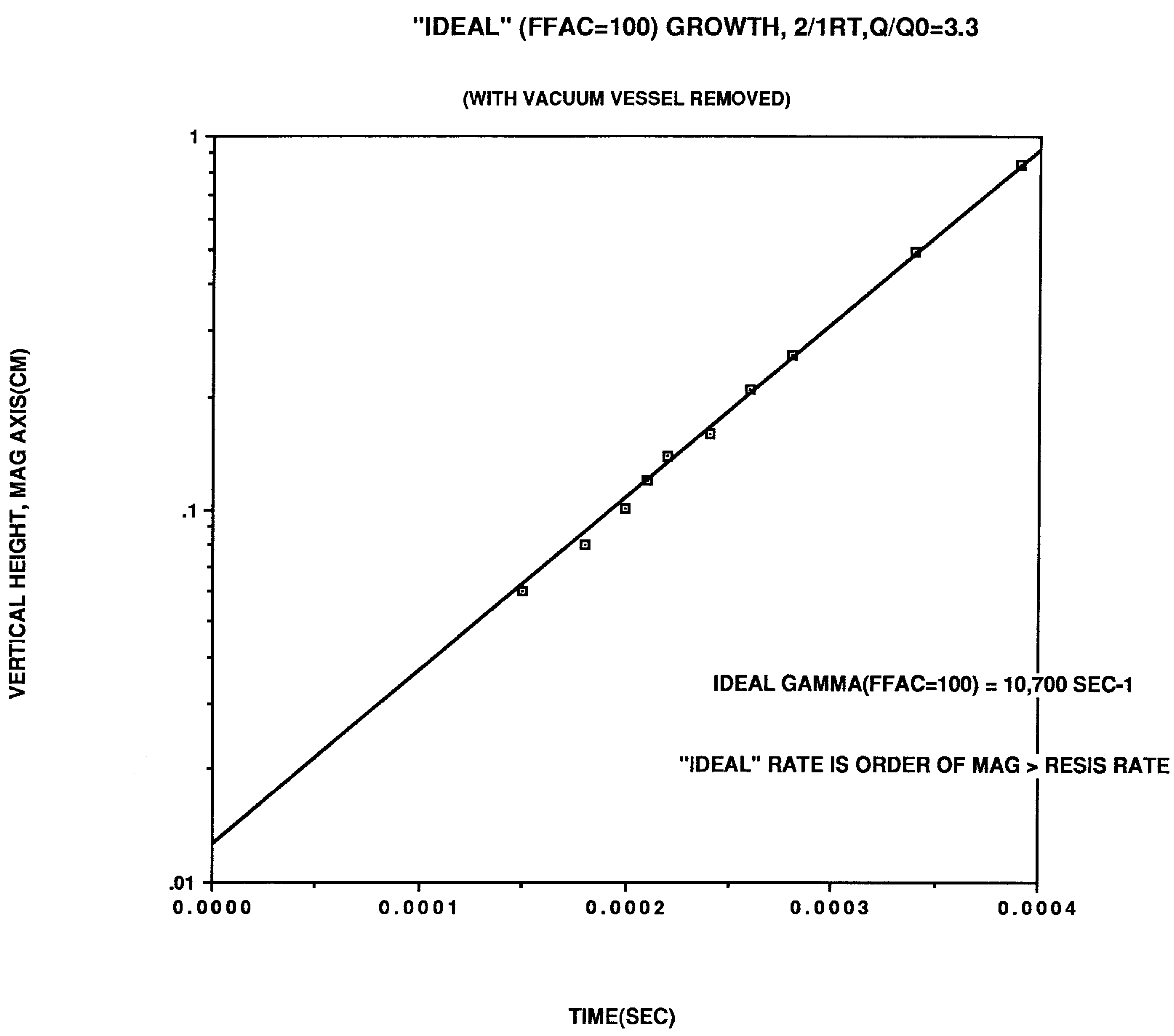


CASE 739


RESISTIVE GROWTH 2/1 RT,Q/Q0=3.3, FFAC=50
.1
.01
VERTICAL HEIGHT, MAG AXIS (CM)
0.0000
0.0005
0.0010
0.0015
TIME(SEC)
EXPONENTIAL RESISTIVE GROWTH
GAMMA= 930 SEC-1
INITIAL VELOCITY DAMPED OUT
CASE 739



RESISTIVE GROWTH 2/1 RT,Q/Q0=3.3,FFAC=100
GAMMA(FFAC=100)= 840 SEC-1
(COMPARED TO 930 SEC-1 WITH FFAC=50)
10
1
.1
.01
0.000
0.001
0.002
0.003
0.004
0.005
VERTICAL HEIGHT,MAG AXIS (CM)
TIME(SEC)


"IDEAL" (FFAC=100) GROWTH, 2/1RT,Q/Q0=3.3
(WITH VACUUM VESSEL REMOVED)
1
.1
.01
0.0000
0.0001
0.0002
0.0003
0.0004
VERTICAL HEIGHT, MAG AXIS(CM)
TIME(SEC)
IDEAL GAMMA(FFAC=100) = 10,700 SEC-1
"IDEAL" RATE IS ORDER OF MAG > RESIS RATE

CONCLUSIONS - RESISTIVE GROWTH RATES

-THE RESISTIVE GROWTH RATES OF IDEALLY STABLE PLASMAS IN A RESISTIVE VACUUM VESSEL CAN BE MEASURED WITH THE TSC CODE, AND THE RESULTS ARE IN GOOD AGREEMENT (10%) WITH A SEPARATE CALCULATION BASED ON THE FBT AND ERATO CODES DEVELOPED AT CRPP-EPF-LAUSANNE.

-THIS METHOD SERVES AS A BASIS FOR IDENTIFYING THE RANGE OF PLASMAS WITH A GIVEN GROWTH RATE WHICH CAN BE STABILISED BY SHAPING POWER SUPPLIES.

CONTROL METHODS AND POWER SUPPLY MODEL INCORPORATED IN TSC FOR TCV

-MEASUREMENT, COMMAND, AND CONTROL FOR TCV:

A given flux measurement is in general an interpolated signal from two stationary flux loops. Thus, for example, if $t_1 < t < t_2$, then flux measurement number 1 would correspond to

$$\Psi_1(t) = \alpha\Psi(R_1, Z_1, t) + (1-\alpha)\Psi(R_2, Z_2, t). \quad (1)$$

where $\alpha = (t_2 - t)/(t_2 - t_1)$ and $\Psi(R,Z,t)$ is the poloidal magnetic flux at position (R,Z) at time t.

The state vector for the flux-loop measurements is denoted by

$$\Psi(t) = (\Psi_1(t), \Psi_2(t), \Psi_3(t), \ldots, \Psi_7(t)). \quad (2)$$

The orthogonal vectors corresponding to the four control systems are

$$\begin{aligned} \Psi_{RF} &= (0, +1, +1, 0, -1, -1, 0), \\ \Psi_{VF} &= (-1, -1, +1, +1, +1, -1, 0), \\ \Psi_{QF} &= (-2, +1, +1, -2, +1, +1, 0), \\ \Psi_{OF} &= (-1, -1, -1, -1, -1, -1, 6). \end{aligned} \quad (3)$$

Corresponding to each of the orthogonal flux-measurement vectors of Eq. (2) is a vector of current amplitudes $I(t)$,

$$I(t) = (I_1(t), I_2(t), I_3(t), I_4(t), I_5(t), I_6(t), I_7(t)). \quad (4)$$

The current vectors for each of the control systems are determined by selection of coils or groups of coils near the control-flux loops at each of the eight reference times. The inductance matrix $M(t)$ between these coil groups and the control-flux loops is inverted to obtain the control-current vectors at each of the eight times,

$$\begin{aligned} I_{RF}(t) &= M_{RF}^{-1}(t)\Psi_{RF}(t), \\ I_{VF}(t) &= M_{VF}^{-1}(t)\Psi_{VF}(t), \\ I_{QF}(t) &= M_{QF}^{-1}(t)\Psi_{QF}(t), \\ I_{OF}(t) &= M_{OF}^{-1}(t)\Psi_{OF}(t). \end{aligned} \quad (5)$$

Control-current vectors at intermediate times are again defined by linear interpolation.

MOMENT COMBINATION AND PID REGULATOR

- MOMENTS
  - MOMENT OF FLUX ERROR $\left[\vec{\psi}(t) \cdot \vec{\psi}_{x=RF, VF, QF, OF}\right]$
  - CORRECTION CURRENT VECTOR

$$\overrightarrow{\Delta I_x} = G_x \left[\vec{\psi}(t) \cdot \vec{\psi}_x\right] \vec{I}_x (t)$$

  - WHERE G_x ARE GAINS AND $\vec{I}_x = \overleftrightarrow{M}_x^{-1} \vec{\psi}_x$

- DESIRED CURRENT
  - ADD PREPROGRAM TO CORRECTION CURRENTS

$$\vec{I}_D = \vec{I}_P + \sum^{4} \overrightarrow{\Delta I_x}$$

  - COMPARATOR

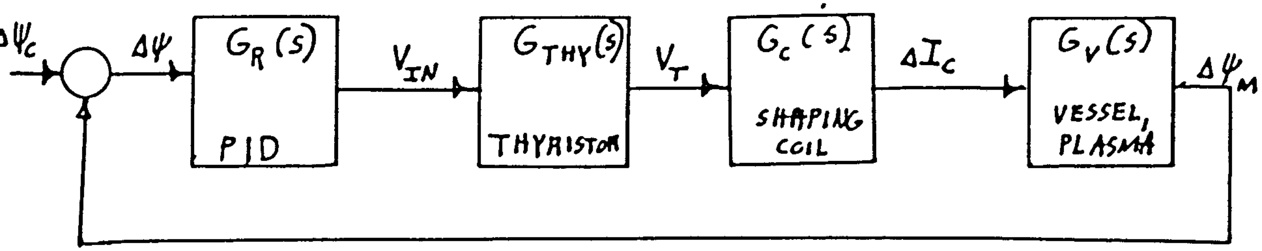
$$\vec{\Delta}. = \vec{I}_D - \vec{I}_{coil}$$

  - PID REGULATOR FOR COIL VOLTAGE

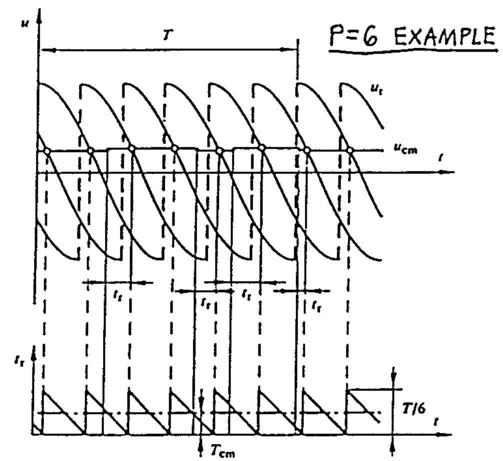
$$\vec{V} = P\vec{\Delta} + I\int \vec{\Delta}\, \partial t + D \frac{\partial \vec{\Delta}}{\partial t}$$

CALCULATION OF PID COEFFICIENTS FOR STABLE CONTROL WITH THYRISTOR RECTIFIER POWER SUPPLIES

-A SYSTEM BLOCK DIAGRAM IS DEVELOPED WITH A PID REGULATOR OF THE MEASURED FLUX INSIDE THE VACUUM VESSEL, SMALL AMPLITUDE VARIATION OF THE THYRISTOR VOLTAGE, A SHAPING COIL FIELD, AND A VESSEL DELAY FUNCTION. THIS GIVES A TEXTBOOK CASE FOR DETERMINING THE MOST RAPID STABLE RESPONSE OF THE SYSTEM. PLASMA MOTION IS NOT INCLUDED IN THIS DETERMINATION OF COEFFICIENTS.



- THYRISTOR TREATED IN REGIME OF SMALL VARIATION IN COMMAND VOLTAGE



- PID REGULATOR - TRANSFER FUNCTION

$$G_R(s) = (1+sT_n)(1+sT_v)\,/\,sT_i$$

- PID FOR FLUX ERROR TO COIL VOLTAGE

FOR $V_{IN} \equiv P(\Delta\Psi) + I\int dt(\Delta\Psi) + D\frac{d}{dt}(\Delta\Psi)$,

OBTAIN $G_R(s) = \frac{I}{s}\left(1 + \frac{P}{I}s + \frac{D}{I}s^2\right)$

$\Rightarrow$ EQUIVALENCES: $I \equiv \left(\frac{1}{T_i}\right)$; $P \equiv \left(\frac{1}{T_i}\right)(T_n + T_v)$; $D \equiv \left(\frac{1}{T_i}\right)T_n T_v$

- AVERAGE TIME DELAY IS $T_{cm} = 1/(2pf)$, $p \equiv$ NUMBER OF PULSES ; $f \equiv$ FREQUENCY
- FOR TCV: $f_{MIN} \approx 96$ HZ, $p = 12$, $T_{cm} = 0.434 \times 10^{-3}$ SEC
- THYRISTOR TRANSFER FUNCTION, UNITY GAIN

$$G_{THY}(s) = \frac{1}{(1+sT_{cm})}$$

CALCULATION OF PID COEFFICIENTS (CONT.)

HAPING COIL TRANSFER FUNCTION

- SINCE L/R TIME LONG > 100 MS, CONSIDER AS INDUCTANCE

$$G_c(S) = \frac{1}{SL}, \quad L \equiv \text{CHARACTERISTIC INDUCTANCE}$$

ESSEL-PLASMA TRANSFER FUNCTION

- $G_v(S)$ GIVES RATIO $\frac{\text{FLUX IN VESSEL}}{\text{CURRENT IN COIL}}$, WITH TIME DELAY DUE TO VESSEL.
- $G_v(S) = \frac{G_{vo}}{(1+sT_{vess})}$, $G_{vo} \approx 1.2 \times 10^{-5}$ Henry, $T_{vess} \approx 6 \times 10^{-3}$ sec
- COMBINED SYSTEM TRANSFER FUNCTION

$$G_{RS}(S) = \frac{(1+sT_n)(1+sT_v)}{sT_i} \frac{1}{(1+sT_{cm})} \frac{1}{(sL)} \frac{G_{vo}}{(1+sT_{vess})}$$

- REDUCE ORDER BY CHOOSING $T_v = T_{VESS}$
- DEFINE $T_p \equiv T_{cm}$; DEFINE $T \equiv 1/(G_{vo}/L) = \frac{1}{2}$ (DIMENSIONLESS)
- REDUCED TRANSFER FUNCTION

$$G_o(S) = \frac{1+sT_n}{sT_i} \frac{1}{sT(}$$

$G_o(s)$ IS TEXTBOOK CASE (EQ. 7.49) USING PI REGULATOR TO CONTROL SYSTEM WITH INTEGRAL BEHAVIOR. TEXTBOOK ANALYSIS GIVES

$$\frac{T_n}{T_i} = \frac{1}{2} \frac{T}{T_p} = 576 \text{ sec}^{-1}$$

CHOICE OF T_n/T_p DETERMINES OVERSHOOT. FOR STEP FUNCTION.

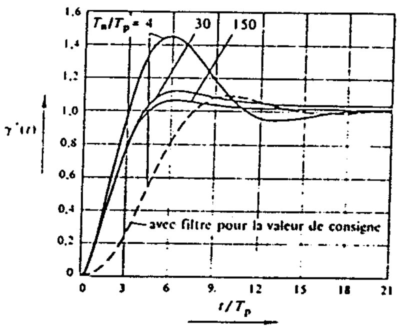


Fig. 7.22 Réponse indicielle du circuit de réglage fermé par rapport à des variations de la valeur de consigne.

$T_n/T_p = 4$ GIVES RAPID RISE, DAMPED AFTER $\approx 10T_p \approx 4$ MSEC

MODEL VALUES FOR $T_n/T_p = 4$:

	PID
$T_n = 1.7 \times 10^{-3}$ sec	$I = 3.3 \times 10^5$ sec^{-2}
$T_i = 3 \times 10^{-6}$ sec	$P = 2.6 \times 10^3$ sec^{-1}
$T_v = 6 \times 10^{-3}$ sec	$D = 3.4$

REFERENCE: "ELECTRONIQUE DE RÉGLAGE ET DE COMMANDE", H. BÜHLER, EPFL, SUISSE

RANGE OF CONTROLLABLE PLASMAS IN TCV

-IN THE TSC CODE MODELLING OF TCV, EACH OF THE 16 SHAPING COILS IS DRIVEN SEPARATELY BY A 96 HZ, 12 PULSE POWER SUPPLY WITH APPROPRIATE (15V/TURN INSIDE, 30V/TURN OUTSIDE) VOLTAGES, AND A PID REGULATOR AND CONTROL SYSTEM AS DESCRIBED.

-IN THESE STUDIES, THE SIMULATION STARTS WITH A PLASMA EQUILIBRIUM WITH A KNOWN EXPONENTIAL RESISTIVE GROWTH RATE IN THE ABSENCE OF FEEDBACK. THE PLASMA EVOLUTION IS BEGUN WITH THE POWER SUPPLIES AND FEEDBACK ACTIVATED TO SEE IF THE GIVEN POWER SUPPLY AND REGULATOR SYSTEM IS ABLE TO STABILIZE THE PLASMA.

-IF THE PLASMA IS STABILIZED, THIS INDICATES THAT PLASMAS OF THIS RANGE OF GROWTH RATES MAY BE STABILISED.

-IF THE PLASMA GOES UNSTABLE, THEN THE CAUSE MAY EITHER BE BECAUSE THE SYSTEM IS TOO SLOW OR WEAK, OR BECAUSE OF NON-OPTIMUM CHOICE OF FEEDBACK COEFFICIENTS.

-WE WOULD EXPECT TO BE ABLE TO STABILIZE GAMMA'S OF AT LEAST 1000 SEC-1, BECAUSE:
- -THE AVERAGE FIRING TIME FOR THYRISTORS IS 1/PF = 1/ 1150,
- -IN JFT-2M WITH 50 HZ, 12 PULSE THYRISTORS, GAMMA UP TO 500 SEC-1 WERE STABILISED.

-IT MAY BE POSSIBLE TO DO BETTER THAN 1150 SEC-1, BECAUSE:
- -THE AVERAGE TIME TO MAKE A SMALL AMPLITUDE CHANGE AND TO FIRE A THYRISTOR IS 1/2PF=1/2300.
- -EACH OF THE COILS HAS ITS OWN SUPPLY, EACH WITH DIFFERENT FIRING ANGLES, SO A PART OF THE RESTORING MOMENT DISTRIBUTION IS PRODUCED WITH SMALL DELAY.

EXAMPLE OF CONTROLLED PLASMA IN TCV

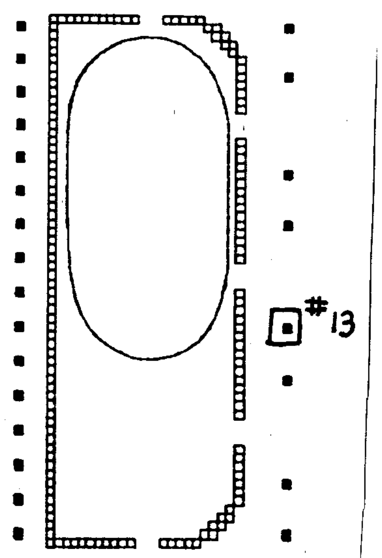
-THE PLASMA CHOSEN HERE IS A 2/1 RACETRACK WITH Q/Q0=4.1 AND A RESISTIVE GROWTH RATE OF 1180 SEC-1 (FFAC=250). THE FEEDBACK IS TURNED ON TO STABILISE THE PLASMA.

-THE PLASMA IS EVOLVED FOR 25 MILLISECONDS, OR 30 GROWTH TIMES.

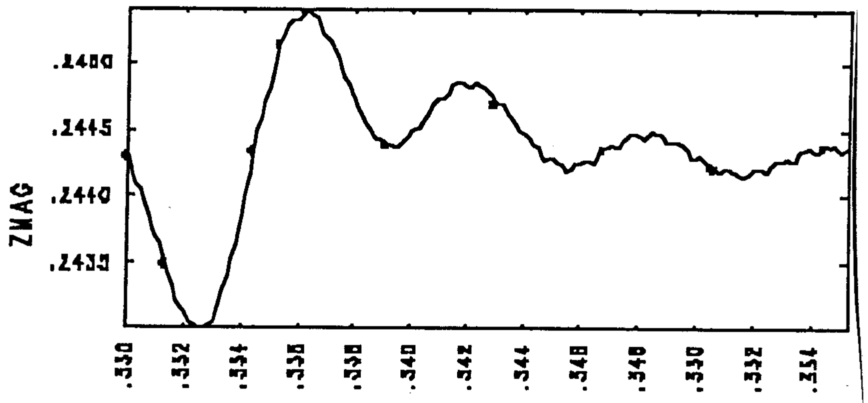
-THERE IS AN INITIAL EXCURSION OF 1 MILLIMETER WHICH IS DAMPED OUT BY THE FEEDBACK SYSTEM.

(IN CASES WITH LOWER GROWTH RATES, THE EXCURSION IS IMMEDIATEDLY DAMPED OUT, AND THE PLASMA IS HELD STATIONARY.)

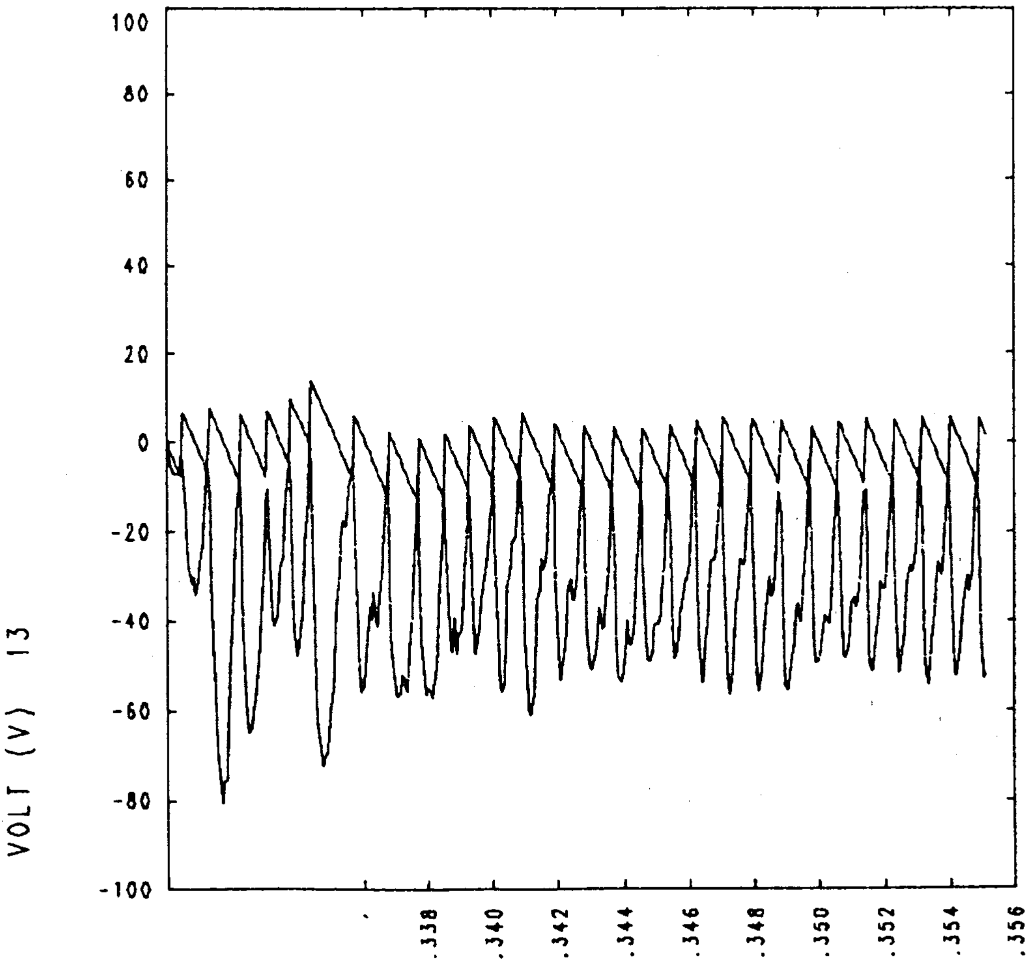
THE OUTER SUFACE EVOLUTION SHOWN AS A FUNCTION OF TIME



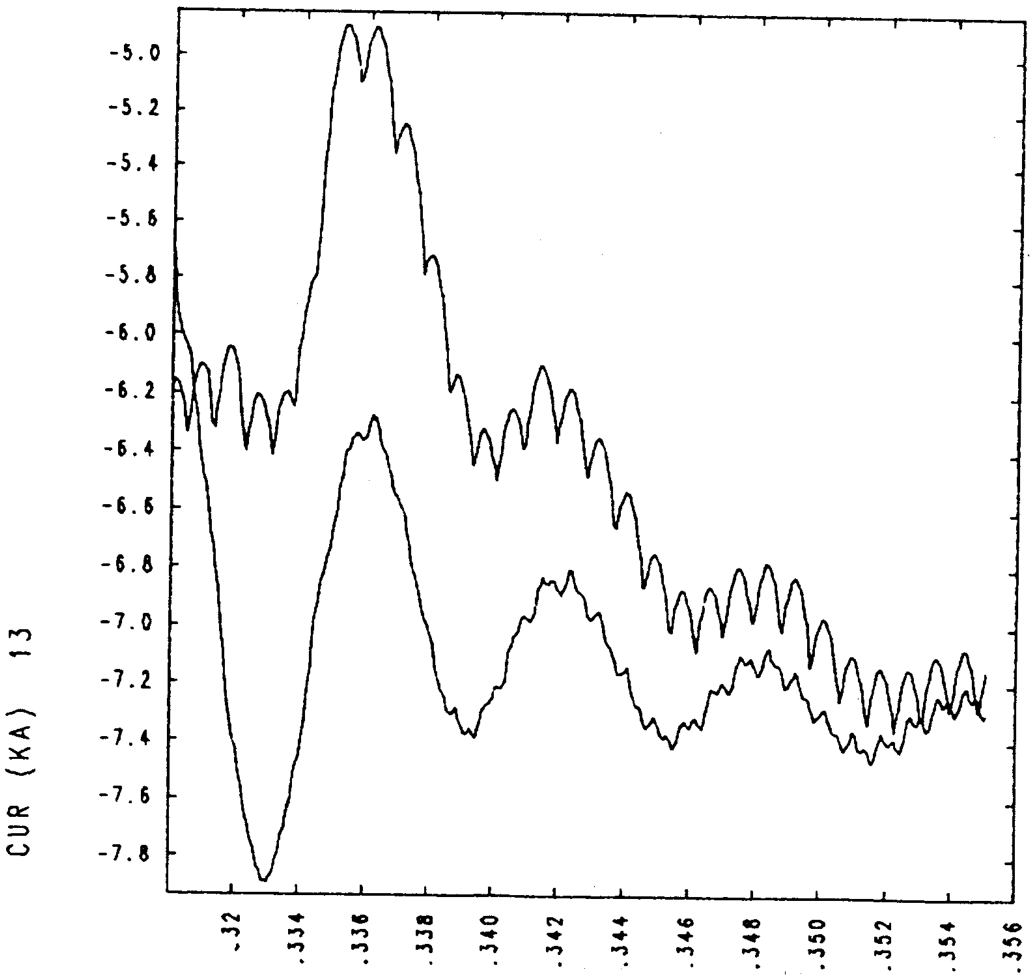
MAGNETIC AXIS HEIGHT VS. TIME



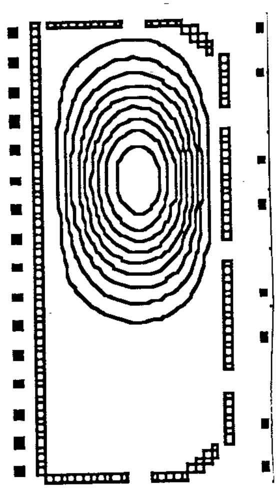
THYRISTOR OUTPUT VOLTAGE/TURN(UPPER), AND FILTERED, OSCILLATING PID COMMAND VOLTAGE(LOWER) FOR COIL NUM. 13.



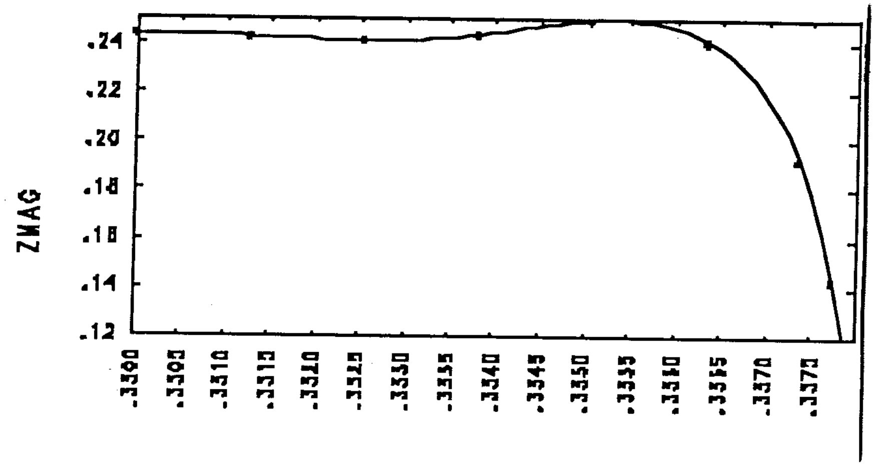
CURRENT IN COIL (UPPER) , COMMAND CURRENT (LOWER)



SAME PLASMA WITH WALLS
MOVED OUT ANOTHER 2.5 CM



THE PLASMA IS NOT
CONTROLLABLE, AND
MOVES DOWNWARDS.



COMMENT: USING THESE METHODS, WHILE AT THE SAME TIME TRYING TO OPTIMIZE THE CONTROL METHOD, WE ARE IN THE PROCESS OF ESTABLISHING THE OPERATIONAL LIMITS OF TCV WITH THYRISTOR POWER SUPPLIES.

COMPLETE EVOLUTION FOR RACETRACKS

-USING THE CONTROL METHODS DESCRIBED, A COMPLETE EVOLUTION HAS BEEN OBTAINED FROM A NEAR CIRCULAR PLASMA IN THE UPPER HALF OF THE VESSEL (FOR INCREASED STABILITY) TO A FULLY ELONGATED RACETRACK.

-TO ACCOMPLISH THIS EVOLUTION, THE FORM OF THE STABILISING MOMENT FIELDS IS ALSO EVOLVED IN TIME, WHICH IS POSSIBLE WITH THE 16 INDEPENDENT SHAPING COILS.

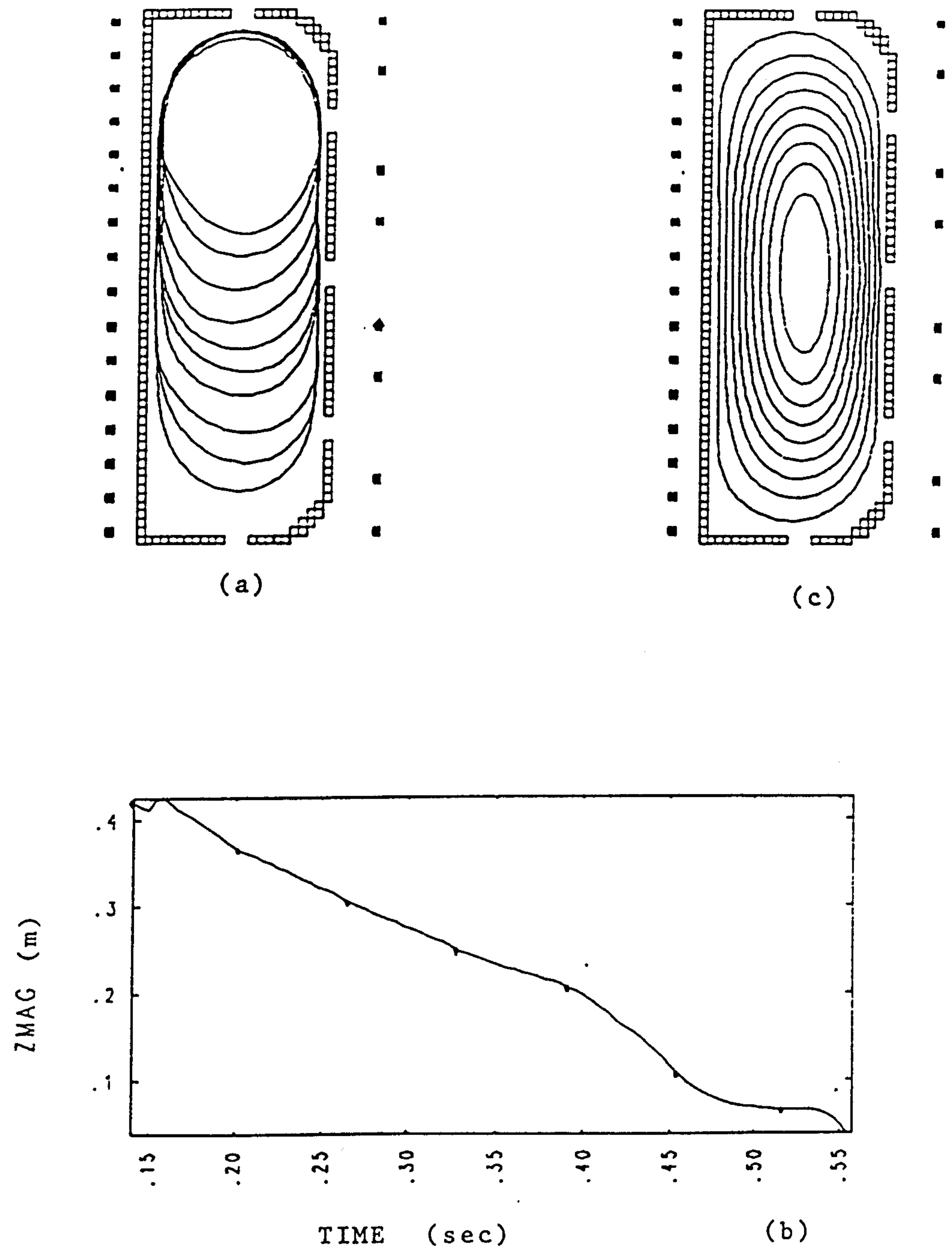


Fig. 1 Evolution of plasma from K=1.25 to K=30 with q_L/q_0=2 and vessel 1.88cm thick stainless

(a) Envelopes of MHD equilibria at selected times

(b) Temporal evolution from 0.14 to 0.55 sec. of vertical height of magnetic axis above machine midplane

(c) Final 3/1 elongated equilibrium

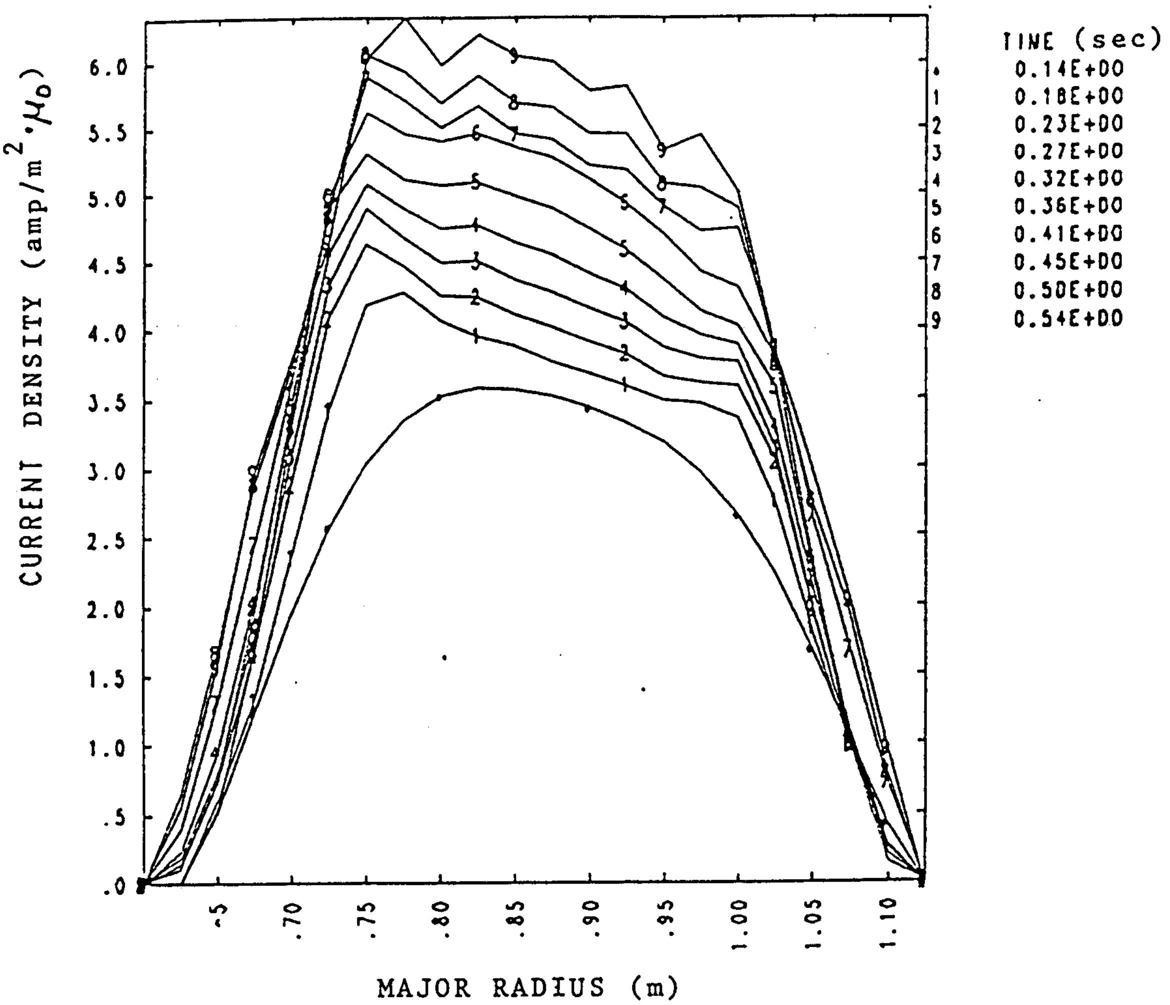


Fig. 2 Calculated plasma current. Density on a horizontal chord through the magnetic axis versus major radius at selected times.

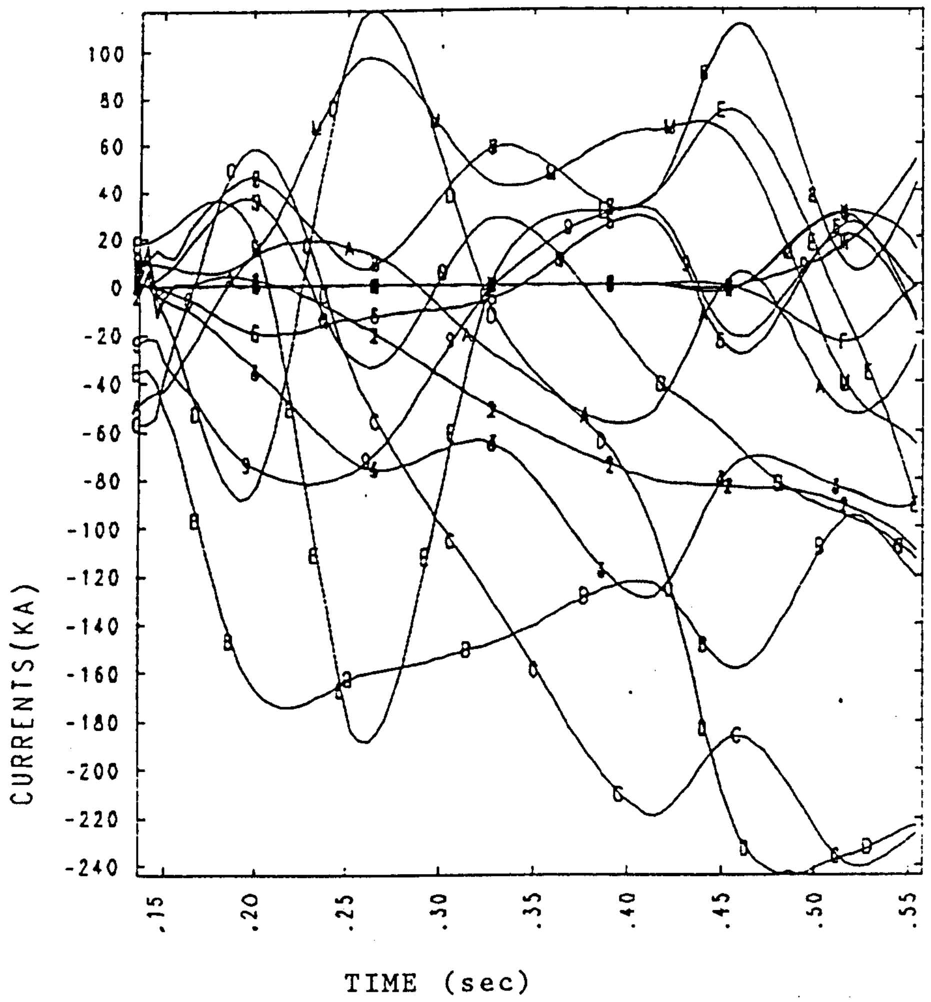


Fig. 3 Total currents in the shaping coils versus time. Coils 9, A, B, C, D, E, F, G are the outer coils, starting at the top and going down. Coils 1 - 8 and H - O are superposed pairs of inner coils.

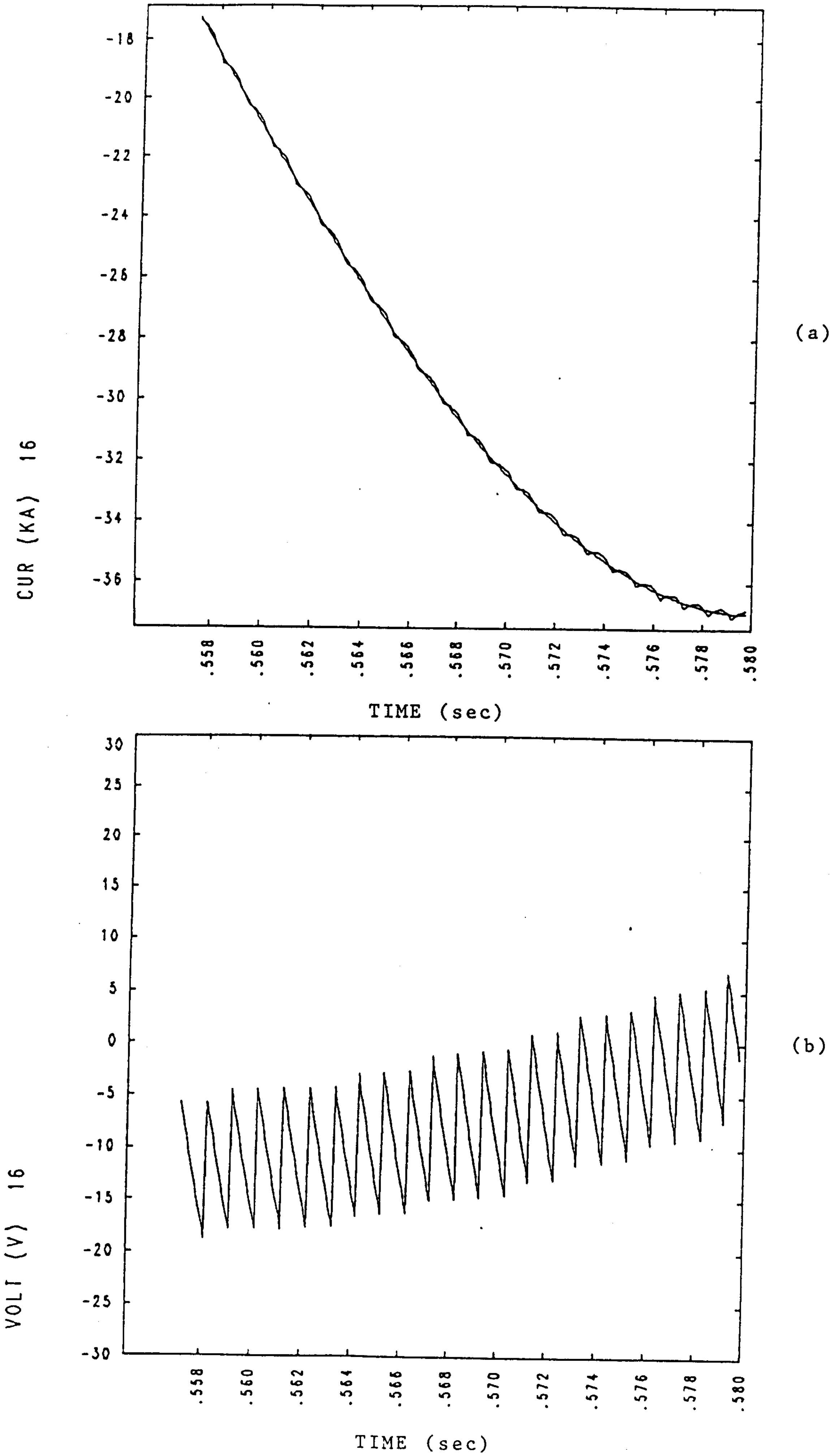
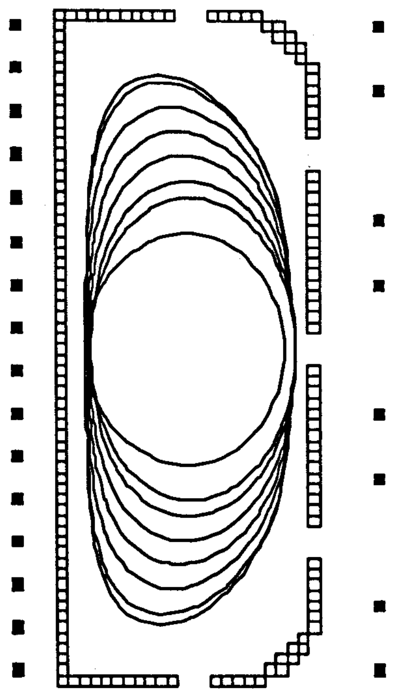


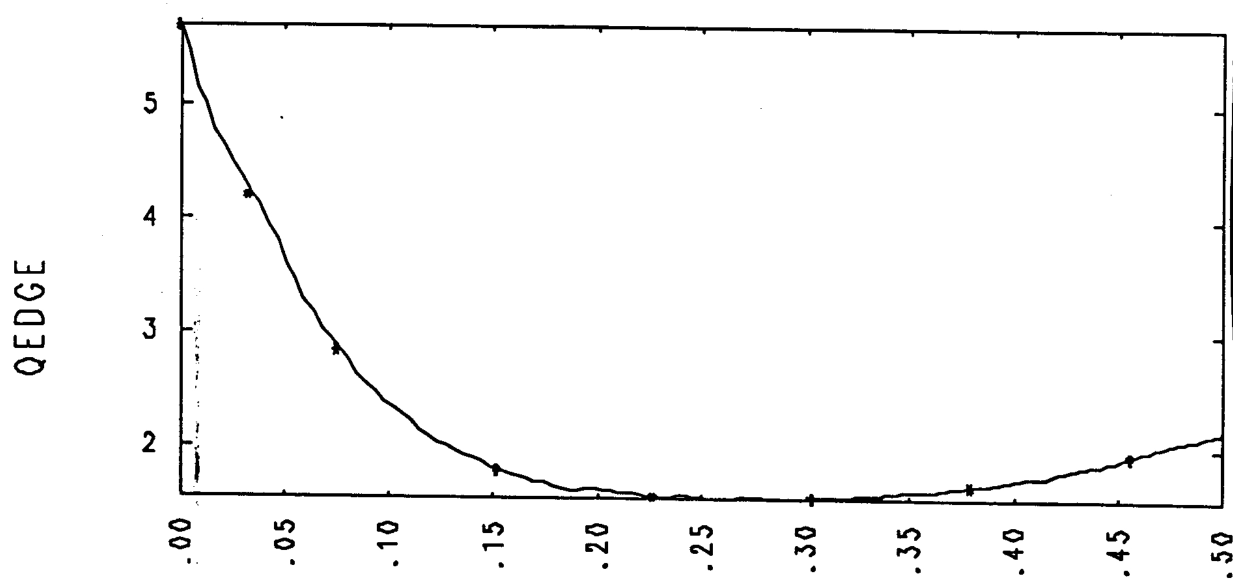
Fig. 4 Shaping coil, (a) command and actual current and (b) applied thyristor voltage.

COMPLETE EVOLUTION FOR DEE SHAPED PLASMAS

-ANOTHER EVOLUTION SCHEME IS BEING CONSIDERED IN WHICH THE PLASMA IS STARTED AT THE MIDPLANE AND EVOLVED SYMMETRICALLY. THIS MAKES THE PLASMAS SOMEWHAT LESS STABLE, BUT ALLOWS THE USE OF ONLY ONE SET OF FEEDBACK MOMENTS.

-Q AT THE CENTER IS KEPT AT 1. OR ABOVE. THE EVOLUTION OF QEDGE IS SHOWN AS A FUNCTION OF TIME.





CONCLUSIONS AND COMMENTS

-USING THE TSC AND FBT CODES, WE ARE ABLE TO ESTABLISH THE RESISTIVE GROWTH RATES FOR PLASMAS IN TCV.

-USING A POWER SUPPLY MODEL IN TCV, WE ARE IN THE PROCESS OF ESTABLISHING THE MAXIMUM GROWTH RATE THAT CAN BE CONTROLLED WITH THYRISTORS.

-PRELIMINARY RESULTS INDICATE THAT WE CAN STABLIZE PLASMAS WITH GAMMAS UP TO 1200 TO 1400 SEC-1, WHICH IS 1200/149= 8 TIMES THE VESSEL INVERSE TIME CONSTANT.

-CONTROL METHODS FOR EITHER SYMMETRIC OR NON-SYMMETRIC PLASMA EVOLUTION ARE BEING STUDIED.

COMMENT: PRELIMINARY RESULTS INDICATE THAT MANY INTERESTING PLASMAS WITH EITHER HIGHER Q OR HIGHER ELONGATION HAVE GROWTH RATES HIGHER THAN WE CAN CONTROL.

WE ARE THEREFORE INVESTIGATING:

- -IMPROVED COMMAND AND CONTROL ALGORITHMS
- -POSSIBILITIES OF FASTER POWER SUPPLIES
- -POSSIBILITIES OF AUGMENTING THE PASSIVE STABILISATION
- -PLASMAS WITH IMPROVED AXISYMMETRIC STABILITY.

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