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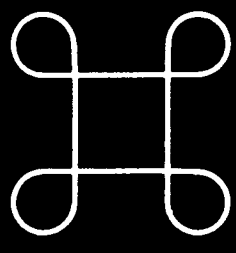
PLASMA PHYSICS

INITIAL OPERATION OF THE MST REVERSED FIELD PINCH

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ABSTRACT

During the initial operation of the MST reversed field pinch, plasmas have been obtained with current of 500 kA and reversal duration of 28 msec. Discharges typically are initiated with a loop voltage of 150 volts and attain a loop voltage of about 20 volts at the time of peak current. Density up to 2 x 10^{13} cm^{-3} is obtained, and electron temperature is measured to be about 300 eV for 400 kA plasmas. The plasma parameters are improving steadily with wall conditioning and field error reduction. Sawtooth-like oscillations and magnetic fluctuations are characterized.

I INTRODUCTION

The Madison Symmetric Torus (MST) is a new reversed field pinch which commenced operation in June, 1988. We describe here initial results obtained during the first five months of operation on the equilibrium features of the plasma, sawtooth-like oscillations, and magnetic fluctuations. The scientific goals of MST are (1) to explore the effect of the boundary condition on RFP equilibrium, dynamo, fluctuations and transport, and (2) to investigate physics issues of a large RFP. The latter goal can provide direct input to the upcoming ZTH and RFX experiments which are of similar size as MST (but with higher current and longer pulse length). The initial plasma and operational characteristics are of interest since MST (minor radius a = 0.52 m and major radius R = 1.5 m) is significantly larger than other existing RFP devices and contains several unconventional design features.

II MACHINE DESCRIPTION

The design of MST (Fig. 1) was driven by the need for efficient machine disassembly and small magnetic field errors. A single, 5 cm thick aluminum torus serves as vacuum vessel, toroidal field winding (by driving poloidal current through the vessel), and stabilizing conducting shell. The poloidal field winding is placed tightly around the 2.0 weber iron core. The absence of field field windings surrounding the device facilitates machine disassembly and

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diagnostic access. The toroidal field system also yields a with small ripple; the radial error field that enters the toroidal gap produces a dominant Fourier component of m=0, n=4 with a magnitude of about 0.2% of the equilibrium toroidal field. The design necessitates voltage gaps exposed to the plasma for both the toroidal and poloidal fields. These gaps are protected by ceramic insulators which have proved reliable for steady voltages up to 200 volts (and transients of 400 volts). The field error at the poloidal gap is reduced by a special flange. A winding used to reverse-bias the iron core is distributed so as to produce a DC error field within the plasma of less than one gauss (which is less than 0.1% of the poloidal field). At present, the final poloidal field winding is not yet installed. The bias winding functions as the ohmic heating coil, with the result that the pulsed field errors accompanying this temporary setup are significant. The radial field at the poloidal cut can be of the order of the poloidal field. The vessel is pumped through an array of 193, 3.8-cm-diameter holes in order to provide very high pumping speed while eliminating the deeply penetrating field errors that would otherwise be produced by large pump ports.

III EQUILIBRIUM CHARACTERISTICS

Reversed field plasmas have been attained through self-reversal with a peak plasma current of 0.5 MA, discharge duration of 37 msec, and reversal duration of 28 msec (which is less than the discharge duration since the toroidal voltage applied to the insulated gap is not yet optimally programmed). For the discharge shown in Fig. 2, the toroidal loop voltage, V_L, is 20 V at peak current and requires about 150 volts for startup. The reversal parameter is $F = -0.1$, at a pinch parameter of $\theta = 1.5$. The line-averaged density is typically 1×10^{13} cm^{-3}, although shots are obtained at 2×10^{13} cm^{-3}. The resistance is presently high, with a conductivity temperature of about 80 eV. In lower current plasmas (400 kA) the central electron temperature measured by Thomson scattering is about 300 eV. A similar estimate is inferred from the time sequence of oxygen line emission. The plasma evolves in time along an F-θ trajectory as observed on other devices. In addition, both weakly nonreversed and deeply reversed plasmas (up to $F = -0.6$, $\theta = 2.1$) are obtained with electrical properties similar to those reported above. To date, the machine has been operated without limiters (except for various one-cm-deep ceramic protectors of the insulated gaps and internal coils). Thus, the plasma-wall interaction is strong, as indicated by Al I radiation from the edge and observation of wall erosion.

IV "SAWTOOTH-LIKE" OSCILLATIONS AND MAGNETIC FLUCTUATIONS

The plasma exhibits oscillations of a sawtooth shape in many signals (Fig. 2), similar to those observed in ZT40M[1] and HBTX-1B[2]. These oscillations correspond to sudden changes in the magnetic field within the plasma as indicated by the sudden increase in the reversed toroidal field at the wall and the concomitant rise in the toroidal flux. These changes produce an excursion in F-θ space, as shown in Fig. 3, which suggests that the plasma suddenly

shifts closer to the Taylor state. A magnetic oscillation with poloidal mode number m=1 precedes the rapid part of the sawtooth oscillation (Fig. 4). The precursor oscillations are also seen and mapped in soft xray signals which invariably drop following the rapid part of the sawtooth. This drop corresponds to an overall cooling of the discharge rather than a profile modification. Measurements of the equilibrium field at the inside surface of the wall (with a poloidal coil array) and the error radial field at the poloidal gap imply that a nonrigid inward major radius shift of the plasma occurs over about 300 μsec. Although the oscillations are largest at high θ values, they occur in nearly all RFP discharges. They are deleterious in that they intensify the plasma-wall interaction, as indicated by Al radiation shown in Fig. 4. Since the oscillations mainly occur during the rising current portion of the discharge, it is anticipated that the oscillations will not be present during the constant current portion of flat-topped discharges (obtained with additional voltage programming).

Magnetic fluctuations are measured with a poloidal array of eight sets of tri-axial coils attached to the inner surface of the wall, distributed over half of the minor circumference. The magnitude of the magnetic fluctuations is about 1% ($\tilde{B}/B \sim 0.01$) during reversal and several times larger when nonreversed. The two-point correlation length in the poloidal direction is typically of order one-fourth of the minor circumference. The fluctuation power peaks between 6 kHz and 10 kHz and generally decreases at higher frequencies up to 250 kHz. The fluctuating toroidal magnetic field contributes about 80% of the magnetic energy with the remainder dominantly arising from the poloidal field. Radial field fluctuations contribute only 1% at the coil location of one cm away from the conducting wall.

V CONCLUSIONS

The initial five month operation of MST has produced plasmas with favorable gross equilibrium parameters, that is, the plasma current reaches 0.5 MA during the reversed field period of 28 msec. The loop voltage required for startup is about 150 volts; at peak current the voltage is typically 20 volts. The voltage requirements suggest that the upcoming experiments of similar size, RFX and ZTH, will readily attain their design current of 2 MA. The preliminary measurement of electron temperature (about 300 eV at 400 kA), when compared with temperature obtained in smaller RFP devices, indicates that the temperature is not scaling with current density (i.e., inversely with area for fixed current). This also is extremely encouraging for RFX and ZTH performance. Plasma quality in MST is presently limited by field errors, wall conditions, and available power supplies, all of which are steadily being improved. Limited temporarily by these factors, the global energy confinement time is on the order of 1 msec.

Sawtooth-like oscillations and magnetic fluctuations are measured and appear similar in gross features to those observed elsewhere. Plans for the next year include numerous machine improvements for parameter enhancement (including completion of the

poloidal field winding), initiation of detailed studies of edge fluctuations, beginning studies on global transport properties, and installation of movable, fully toroidal rail limiters for boundary condition studies.

This work is supported by the U.S Department of Energy.

(1) R.G. Watt, R.A. Nebel, Phy. Fluids 26, 1168 (1983); G.A. Wurden, Phys. Fluids, 27, 551, (1984); R.G. Watt, E.M. Little, Phys. Fluids, 27, 784 (1984).

(2) H.Y.W. Tsui, J. Cunnane, Plasma Physics and Controlled Fusion 30, 865 (1988).

Figure Captions

Fig. 1. The MST reversed field pinch device.

Fig. 2. Time variation of a typical 400 kA, self-reversed discharge in MST.

Fig. 3. Expanded scale view of sawtooth-like oscillations that occur in the equilibrium magnetic fields.

Fig. 4. Sawteeth-like oscillations showing the precursor magnetic oscillations in poloidal field and the resulting increase in aluminum radiation and soft xray signals.

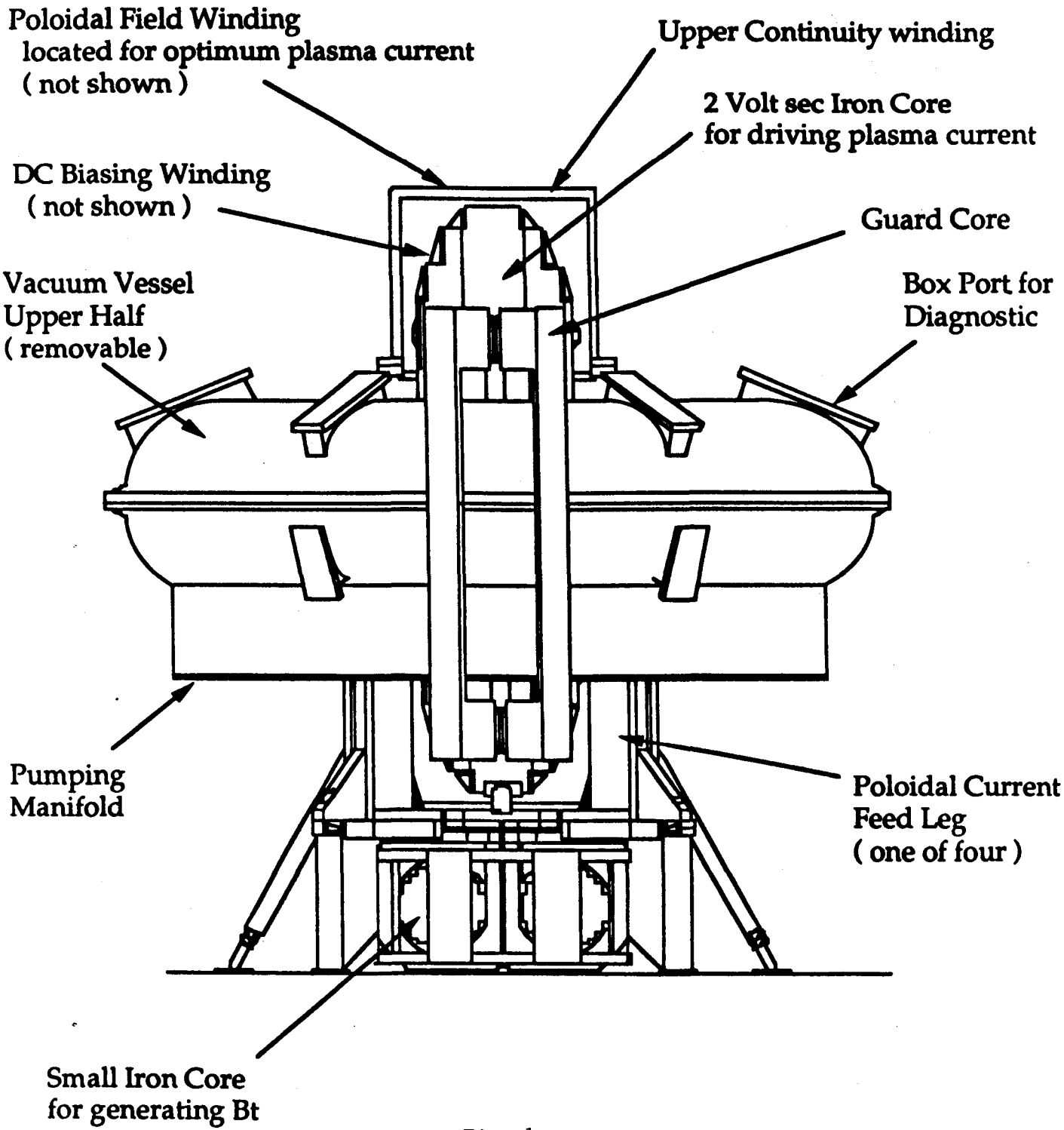

Poloidal Field Winding
located for optimum plasma current
(not shown)
Upper Continuity winding
2 Volt sec Iron Core
for driving plasma current
DC Biasing Winding
(not shown)
Guard Core
Vacuum Vessel
Upper Half
(removable)
Box Port for
Diagnostic
Pumping
Manifold
Poloidal Current
Feed Leg
(one of four)
Small Iron Core
for generating Bt

Fig. 1

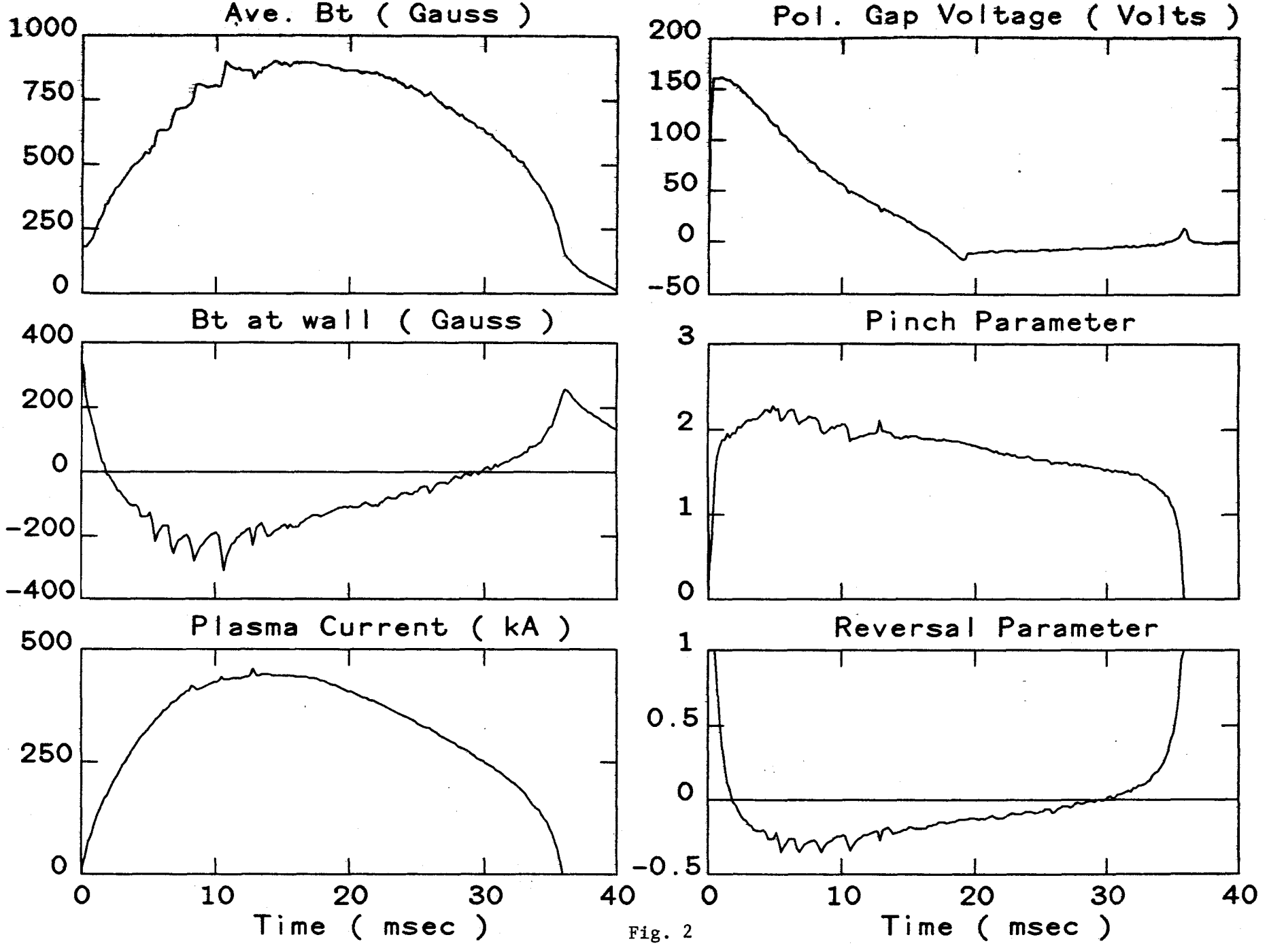

Ave. Bt (Gauss)
1000
750
500
250
0
Pol. Gap Voltage (Volts)
200
150
100
50
0
-50
Bt at wall (Gauss)
400
200
0
-200
-400
Pinch Parameter
3
2
1
0
Plasma Current (kA)
500
250
0
Reversal Parameter
1
0.5
0
-0.5
0
10
20
30
40
Time (msec)
Time (msec)

Fig. 2

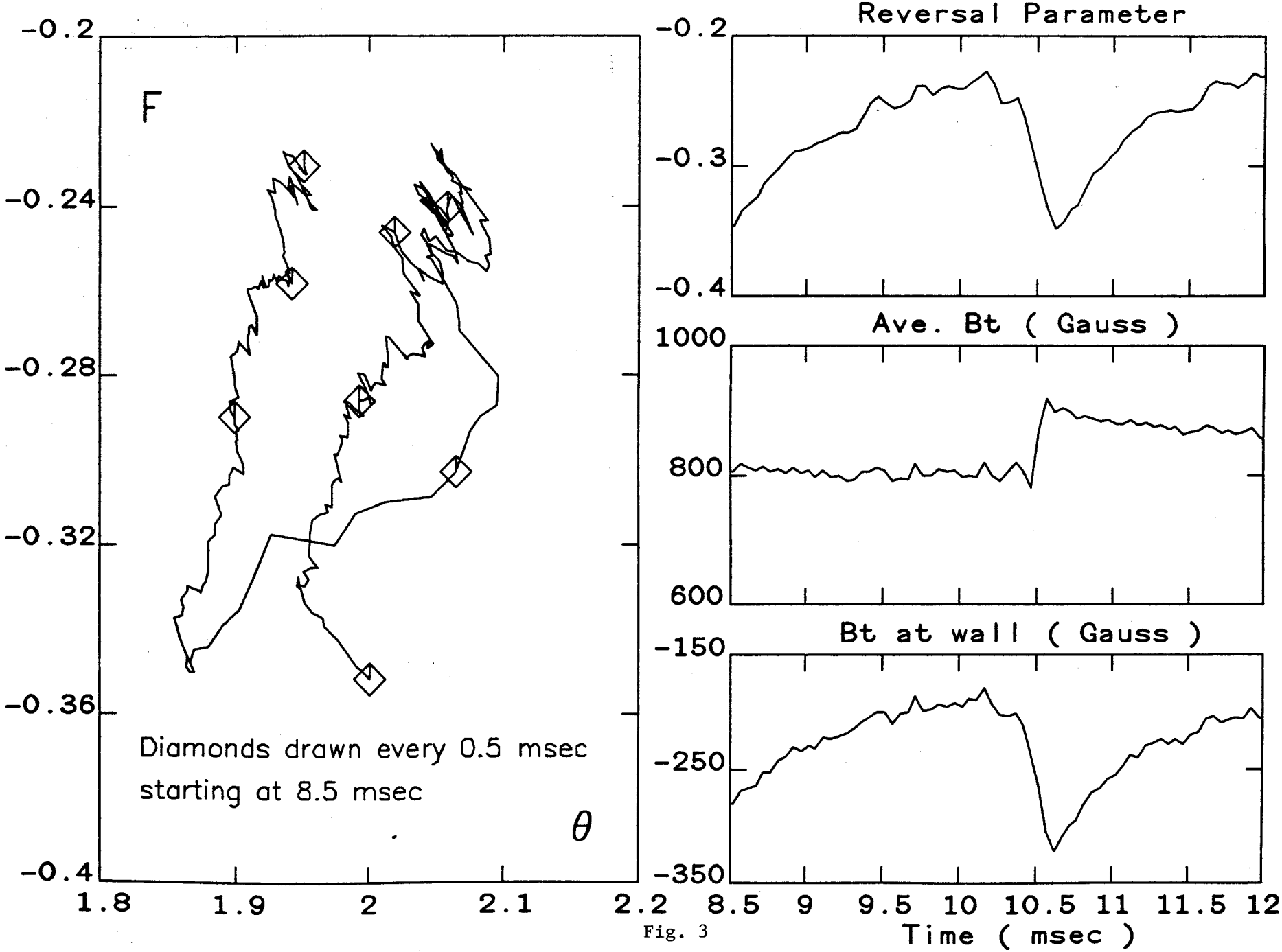

F
-0.2
-0.24
-0.28
-0.32
-0.36
-0.4
1.8
1.9
2
2.1
2.2
θ
Diamonds drawn every 0.5 msec
starting at 8.5 msec
Reversal Parameter
-0.2
-0.3
-0.4
Ave. Bt (Gauss)
1000
800
600
Bt at wall (Gauss)
-150
-250
-350
8.5
9
9.5
10
10.5
11
11.5
12
Time (msec)

Fig. 3

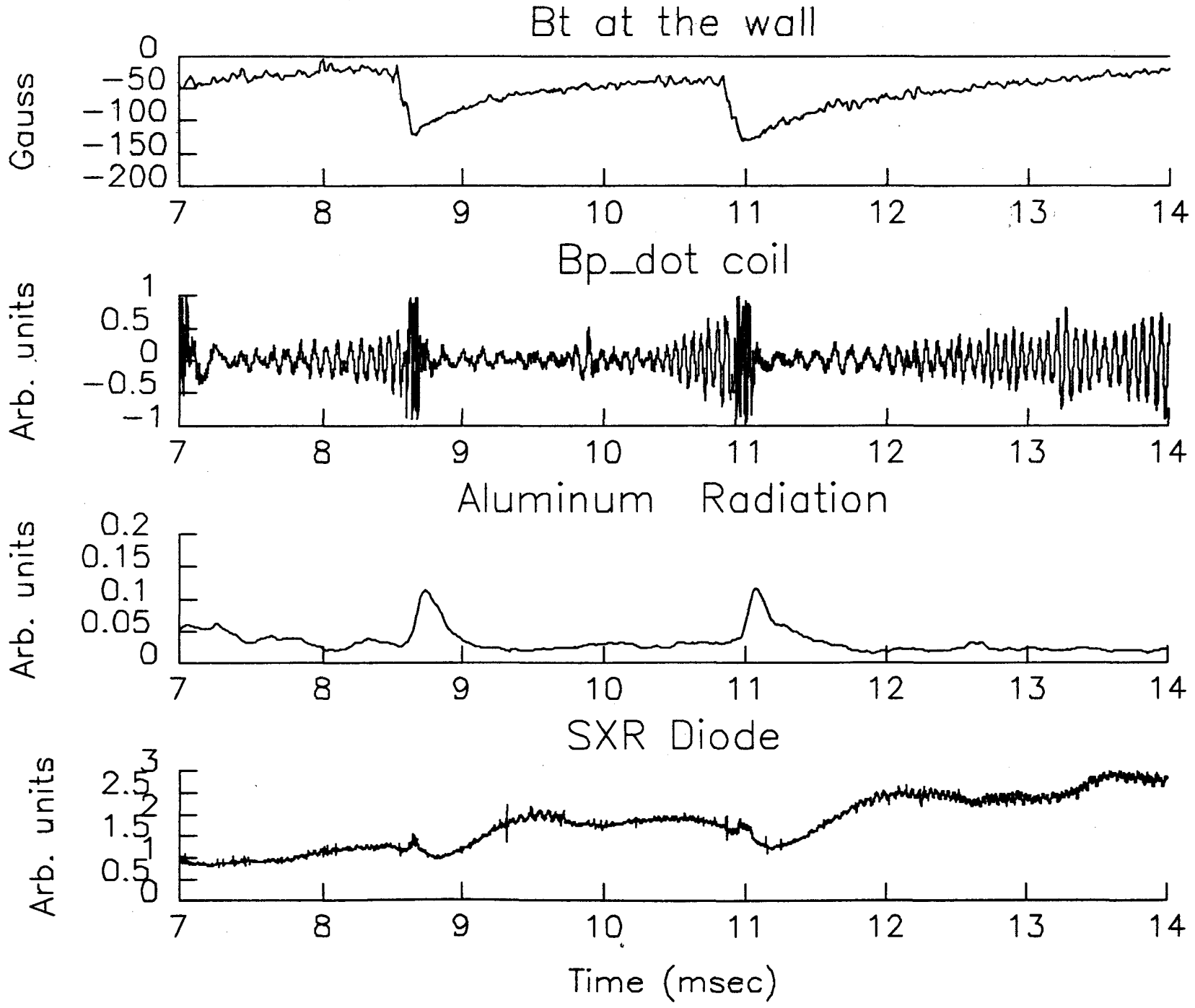

Bt at the wall
Gauss
0
−50
−100
−150
−200
Bp_dot coil
Arb. units
1
0.5
0
−0.5
−1
Aluminum Radiation
Arb. units
0.2
0.15
0.1
0.05
0
SXR Diode
Arb. units
2.5
1.5
0.5
0
7
8
9
10
11
12
13
14
Time (msec)

Fig. 4