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FEEDBACK STABILIZATION OF A SCREW PINCH

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ABSTRACT

Results from a stabilization experiment operating on the kink mode of a screw pinch by means of a magnetic feedback loop are presented.

INTRODUCTION

The correct behavior of a thermonuclear reactor will require an evolved automatic control system, which allows for the adjustment of a great number of parameters. One of the most important feedback loops will have the task of maintaining plasma equilibrium and suppressing dangerous MHD instabilities. Our aim is to demonstrate the feasibility of stabilizing the fast kink mode of a screw pinch working above the Kruskal-Shafranov limit.

THE PINCH CONFIGURATION

The θ coil measures 142 cm and has a diameter of 9 cm. The main field reaches 16 kGauss in 3·8 μsec at which time the crow-bar is switched on. The quartz discharge tube has an inner diameter of 5 cm. On the discharge tube are mounted the feedback coils and the magnetic dipole probes. The time evolution of the axial J_z current is similar to that of the main B_z field. Two electrodes, 1.2 cm in diameter, are 142 cm apart, and are protected by limiters in order to concentrate the axial current on the front of the electrodes. In this way, precise boundary conditions exist for the pinch. Actually, probe measurements show a pinch with a sinusoidal displacement vanishing at the electrodes [1].

A sharp boundary plasma column experiences an external kink mode where the matter moves as a whole. In order to satisfy the conditions at the end of the column it is necessary [2] to superimpose two modes with different wave numbers. Hence the displacement of the axis is

$$\eta = \frac{y}{2}\exp(-ih_1 z + i\omega t) + \frac{y}{2}\exp(-ih_2 z + i\omega t) \qquad (1)$$

h_1 and h_2 determined by the necessity of total reflexion at the electrodes (the resulting axial energy transport is zero when both group velocities are equal but opposite in sign).

This statement leads to the following wave form

$$\eta = y\exp(ih_o z + i\omega t)\cdot\cos\frac{\pi z}{L} \qquad (2)$$

with

$$h_o = \frac{\pi q_c}{L\Delta q} \qquad q_c = \frac{1}{2-\beta} \qquad \Delta q = \frac{\pi a\, B_z}{L\, B_\theta} \qquad (3)$$

There are now two q values: $q_1 = q_c + \Delta q$; $q_2 = q_c - \Delta q$. The eigenfrequency of the kink takes the value

$$\omega^2 = \frac{B_\theta^2 \, q_c}{\mu_o \, \rho a^2} \left[\left(\frac{\Delta q}{q_c} \right)^2 - 1 \right] \tag{4}$$

We obtain a new definition of the Kruskal-Shafranov limit: $q = q_c$. The corresponding axial current J_z equals 2020 A for a plasma radius a = 0.8 cm measured from the luminosity profile, and with $\beta = 0.1$. The onset of the instability occurs very close to this calculated value.

The feedback coils have a $\ell = 1$ configuration. For acting at the m = 1, n = 1 mode in both degrees of freedom, the current distribution should be sinusoidal in θ and z, in the same way as the real and imaginary part of (2). For reason of simplicity we have choosen a short straight coil ($h_o = o$) built in two halves 30 cm long and 20 cm apart. The 12 turns are equally spaced, covering two 90° sectors. The other two sectors are covered with windings acting on the second degree of freedom. By Fourier analysis we find an efficiency of 45 % for the n = 1 mode and a finite excitation force of the harmonic n = 2. Below twice the Kruskal-Shafranov limit the n = 2 harmonic remains stable.

Magnetic dipole probes are used for detecting the displacement of the plasma in the two orthogonal directions [3]. Their windings are equally spaced and cover 120° sectors. They are placed near the mid-plane, at about 10 cm distance from the two parts of the feedback coils. At this distance the direct coupling between the enforcer coil and the probe is not negligeable and its value is negative. The theory shows that stability is only possible if the coupling is positive and relatively small. We compensate for this inconvenience with a loop connected in series with the probe, and coupled to the feedback current in a correct way.

The feedback loop is similar to the system used in the Scyllac experiment [4]. The probe signal is integrated and preamplified up to ± 20 V. The driver stage reaches a ± 400 V level at very low impedance, necessary to drive the two output triodes Siemens R S 1041 connected in push-pull. The available voltage and current sweep is ± 20 kV and ± 140 A. A ferrite transformer couples the power to the feedback coils. The power amplifier is switched on 5 μsec before the pinch, and a reset opens the preamplifier just when the kink starts growing. Only one feedback loop is installed for stabilizing the degree of freedom in which the kink is growing faster. The amplitude of the other degree of freedom may by held at a small value for an extended duration by feeding the second enforcer coil with a proper step function.

RESULTS

The measurements are performed at 1.8 times the Kruskal-Shafranov limit. To obtain stability the gain of the feedback loop must be set above unity. The stable range is relatively narrow, a gain exceeding 1.4 drives the system overstable.

The stereoscopic streak pictures of Fig. 1 and Fig. 2 show the plasma displacement at 85 μ D_2 filling pressure, without and with stabilization respectively. The upper traces correspond to the degree of freedom which is stabilized. In this case the overall response time of the amplifier is 0.9 μsec and the measured growth rate $\gamma = 0.33 \times 10^6$ sec^{-1}. Fig. 3 and Fig. 4 are similar pictures obtained at 40 μ D_2 filling pressure. The measured growth rate without stabilization is now $\gamma = 0.6 \times 10^6$ sec^{-1}. To achieve stability it was necessary to decrease the response time to 0.6 μsec, by changing the ratio of the output transformer. In both cases the upper degree of freedom continues to be stable when the lower trace already shows wall contact [5].

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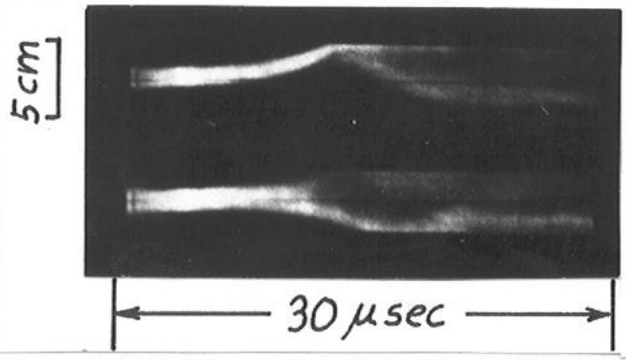

Fig. 1

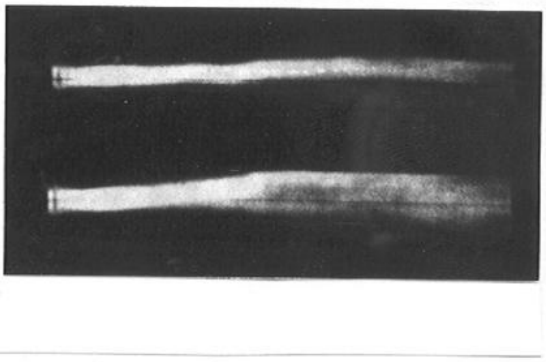

Fig. 2

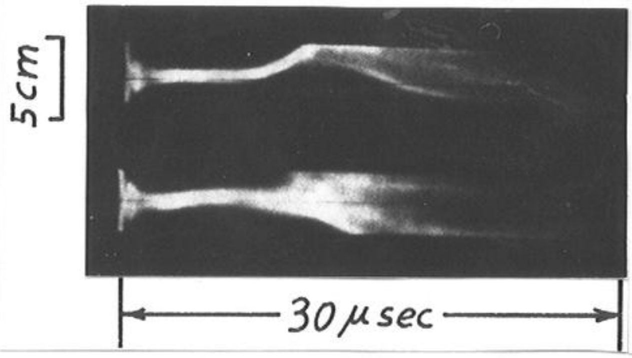

Fig. 3

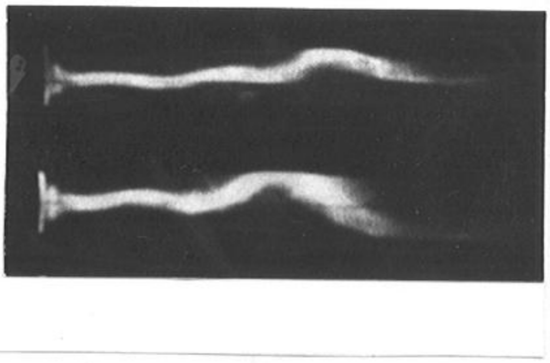

Fig. 4