Dynamic Stabilization Experiments on a Screw Pinch with Standing Wave Magnetic Fields

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Abstract: The growth of the helical m = 1 mode of the screw-pinch is not reduced by application of standing wave magnetic fields, although stabilizing conditions of theory are well fulfilled. Application to the theta pinch does not cause parametric excitation.

Introduction: Dynamic stabilization of the nonlocalized m = 1 mode by superposition of an oscillating, homogeneous B_z -field and by superposition of oscillating z-currents on a screw pinch has been reported by the authors /1/. To complete these studies spatially modulated, oscillating B fields ($\tilde{B}$) in form of a standing wave configuration are now applied. This scheme was treated theoretically by Berge and Freidberg /2/.

Apparatus and plasma properties: The B_z component (B_{zo}) of the screw pinch with 18 kG amplitude(T/4 = 4 μs, crowbar time constant ≈ 30 μs) is produced by a theta pinch coil with 175 cm length and 10.8cm diameter. The I_z current is fed into the plasma by cylindrical electrodes and is in phase with B_{zo}. The circuit for the generation of the standing wave magnetic field is sketched in Fig.1. High Q capacitors and foil switches with metal to metal contact are used. The HF coil system consists of 10 loops connected so that neighbouring loops oscillate in counterphase. The system produces a standing wave field of relative amplitude $\epsilon = (\tilde{B}_z/B_{zo})_{max}$ up to .12, of frequency $\omega_s = 6.6\text{x}10^6 s^{-1}$ and with a wave length λ_B = 29cm. The Q of the circuit is 35. The loops are placed in gaps of the main compression coil and are wrapped around special field shaping coils. These coils homogenize the B_{zo} field and reduce the radial gradient of $\tilde{B}_z$. The latter is necessary because too high a $\tilde{B}_z$ at the tube wall would cause breakdown in the plasma adjacent to the wall /1/. ($\tilde{B}_z$) as function of z, measured at two radii, is shown in Fig.2. For comparison with theory $\tilde{B}_z(z)$ is considered to be sinusoidal. In most of the experiments the pinch plasma had a $k(T_e + T_i)$ of 120 eV, β on axis ≃ 0.3 and a density of some $10^{16} cm^{-3}$.

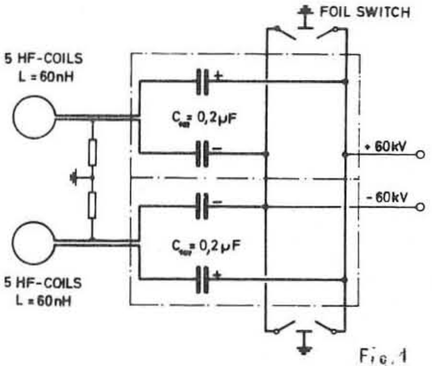

Fig. 1

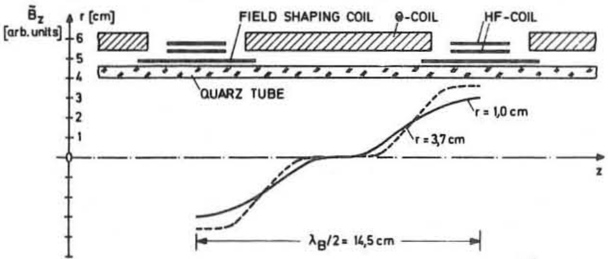

Fig. 2

Experiments: First the standing wave field was applied to the pure theta pinch. An oscillatory motion of the plasma under the loops, but not halfway between the loops is well visible on stereoscopic streak pictures. There was in no case any influence on stability or lifetime of the pinch, i.e. parametric excitation of otherwise stable modes did not occur (Fig.3).

The test instability for the stabilization experiments is the helical m = 1 mode of the screw pinch. Its growth-rate ω_i and its wave length $\lambda = 2\pi/k$ were found to be well in agreement with sharp boundary theory and they can be adjusted by variation of I_z. For most of the experiments ω_i was $3.5\text{x}10^5 sec^{-1}$ and λ about 460 cm. Applied to the screw pinch $\tilde{B}$ was switched on between 2 and 6 μsec (c.f. arrow in Fig.4) and ε was varied between .04 and .12. Fig.4 gives examples of streak pictures with and without stabilization and a plot of the radial m = 1 displacement of the plasma column as function of time. The plasma radius was well modulated spatially and in time and side effects (e.g. wall breakdown) did not occur. m = 1 growth is not appreciably influenced neither for the parameters of Fig.4 nor in any of the discharges with the mentioned variations. This result does not agree with expectations of theory.

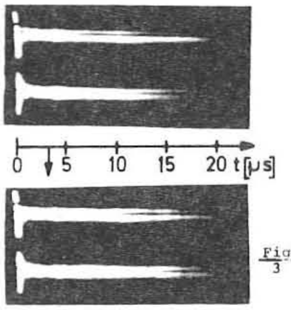

Fig. 3

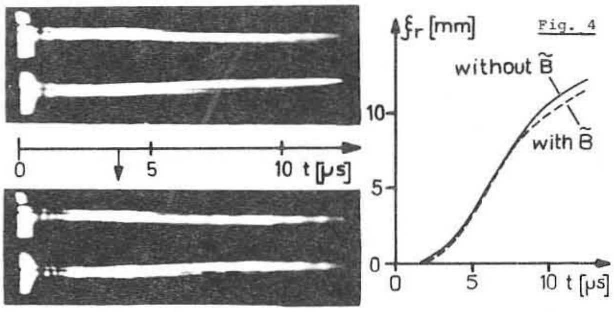

Fig. 4

Discussion: The stability condition derived from sharp boundary, linearized MHD theory /2/ is

$$\frac{1+Y^2}{4} h^2 \delta_o^{\ 2} > (2-\beta) k^2 \qquad 1)$$

Inserting the experimental values: $h = 2\pi/\lambda_B = .22$; $k = .0135$ (with $k = \mu/(2-\beta)$ and $\mu = (B_\theta/B_z a)_a$, plasma radius a ≈ 1.5 cm) $\beta \approx .15$ averaged over plasma cross section ; Y = 2 (insensitive function of plasma parameters cf/2/) the above condition reads:

$$\delta_o > .074; \qquad 2)$$

δ_o is the distortion of the plasma radius normalized to a.

Taking $\epsilon = \delta_o$, found in previous experiments /1/ with homogeneous $\tilde{B}_z$ and the same ω_s, condition 2) is well fulfilled. (For adiabatic compression $\delta_o = \epsilon/2$ and 2) would be approximately fulfilled). Assumptions for the derivation of 1) are: $\lambda/\lambda_B \gg 1$ and $\omega_s/(hV_a) \gg 1$ (no pressure relaxation over λ_B). Both of them are met in the experiments. To clarify the discrepancy test experiments are underway, including experiments with substantially increased ε, but reduced plasma length, which will be reported.

References:

/1/ G.Becker,O.Gruber, H.Herold, Plasma Physics and Contr. Nucl.Fus.Res. Vol.I, 277 (1971)

/2/ G.Berge and J.P.Freidberg, Phys.Fluids 14, 1035 (1971)

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