m = O INSTABILITIES IN A HIGH - ENERGY THETA PINCH+)

by

M. Kaufmann, J. Neuhauser, H. Röhr
INSTITUT FÜR PLASMAPHYSIK
Garching bei München, Germany

1) The velocity distribution of the ions in a high energy theta pinch is in general anisotropic. In the fast compression phase all the ions are accelerated towards the axis. In the adiabatic compression phase that follows only the temperature $T_\perp$ perpendicular to the axis is increased, provided that relaxation can still be neglected.
The relaxation of this strongly anisotropic plasma is due to collisions [1] and instabilities. The relaxation due to Coulomb collisions is usually of the order of the confinement time of the plasma, allowance having to be made for ion-electron collisions. In addition, however, a major contribution to relaxation is to be expected from instabilities.
Low frequency instabilities which already occur at relatively low degrees of anisotropy are the familiar mirror type [2,3]. For large anisotropy, instabilities have the frequency of the ion cylotron frequency and its harmonics. In high temperature theta pinches the criterion for the onset of mirror instabilities in the adiabatic phase may sometimes be exceeded. In a homogeneous plasma with superposed magnetic field these instabilities should occur when the ratio $\eta = \frac{p_\perp}{p_\parallel}$ exceeds a critical value $\eta_k = \frac{1}{\beta}$ [2]
The influence of wall stabilization should be negligible under theta pinch conditions [4]. The instabilities should be of the m = O type.

2) The experimental detection of these mirror instabilities in the Isar I high energy theta pinch is reported in this paper. The essential parameters of this device are:
E_{max} = 2.6 MJ, B_{max} = 146 kG, $\tau/4$ = 11 µsec, coil length 1.5m, vessel diameter = 9 cm. The energy was varied between o.5 and 2.6 MJ, the filling pressure between 6 and 90 micron. As a result the collision times of the adiabatic phase varied over a wide range (Fig.1, hatched region) and were both larger and smaller than the heating time.

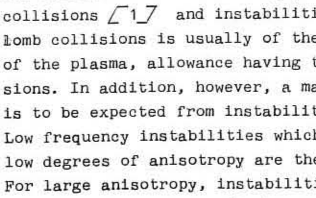

Fig. 1

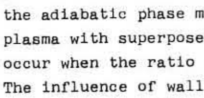

Fig. 3

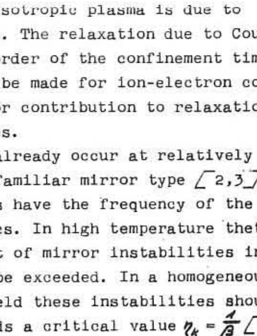

Fig. 2

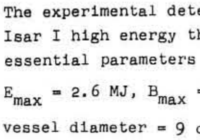

Fig. 4

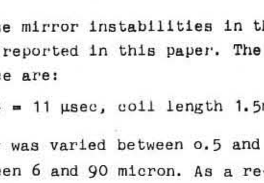

Fig. 5

Fig. 4: Electron density on the axis end-on (I) and side-on (K)
Fig. 5: Continuum signal (1), neutron signal side-on (2) and neutron signal integrated over the coil (3)

Mirror instabilities were observed in discharges with collision times greater than about 1 µsec. Observation was made by:
1) Side-on measurement of the continuum radiation
2) 90° laser scattering
3) Measurement of the magnetic field between the vessel and coil
4) Measurement of the local neutron rate.

All measurements showed correlated disturbances of the plasma column in time and space.

Time developments of the side-on continuum radiation are represented in Fig.2. Under discharge conditions leading to large collision times (left-hand side) there are distinct spikes in the time development. The frequency distribution of these irreproducible spikes (Fig.3) shows that they only occur during the rise of the field and hence of the temperature. The electron density was determined from the side-on measurement of the continuum radiation. The time development of the electron density on the axis showed distinct, irreproducible deviations from interferometric end-on measurements (Fig.4).
Laser scattering measurements of the electron density exhibited equally pronounced fluctuations of the local density which were correlated with the simultaneously measured continuum. Spikes correlated with the continuum were also observed in side-on measurements of the fusion neutrons (Fig.5). Measurement of the magnetic field between the coil and vessel revealed that the spikes were accompanied by a field rise of up 1 %. It should be noted here that the field rise near the plasma must have been much larger since the disturbance extended only a few centimetres in the axial direction.

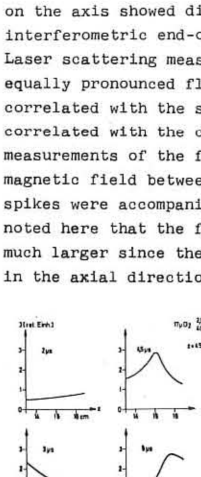

Fig. 6

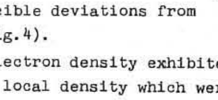

Fig. 7

The extension of the disturbation in the axial direction was measured by means of the continuum radiation. The intensity over a 3 cm section of the axis is plotted in Fig.6. A disturbance is observed to pass through in the time from 3 to 5.5 µsec. The velocity of the disturbances in the z-direction $u_\parallel$ increased almost linearly with the distance from the midplane and corresponded to the outflow velocity (Fig.7, t = 5.5 µs).

3) Calculations from the bounce model [3] for β = 1 yield values of the rise time for m = O instabilities at anisotropic pressure that are about five times as high as the transit time of the ions across the colums (η = 2). For $T_\perp$ = 2 keV this would yield a value of 0.2 µsec. The rise time lapses several times before the adiabatic phase starts. The further development of the instabilities is governed by the development of η. As empiric condition for instabilities to occur with certainty it was found from the observations that the collision relaxation time has to be about 5 µsec, this being approximately the heating time.

For β = 1 and η = 2 the calculations in [3] would yield wavelengths with maximum growth rate that are of the order of the diameter. This agrees with the observation.

In this investigation the β-value could not be varied independently of the collision times. With rising collision time there was a decrease of β. At full bank energy and filling pressure 6 µ the value attained by β on the axis was 0.1. This should explain the fact that it is not at the lowest pressures that the instabilities are most frequent and pronounced.

The instabilities resulted in increased relaxation and increased end losses. This was clearly demonstrated by a premature increase of velocity $u_\parallel$ of the disturbances themselves. After the relaxation was increased by instabilities, the development of the discharge was highly irreproducible.

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[4] S. Chandrasekhar, et al.; Proc. Roy.Soc. 245A, 435,(1958)

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