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ON THE STABILITY LIMITS OF THE PINCH-CONDUCTOR CURRENT RATIO IN EXTRAP

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ABSTRACT

A first attempt is made to take the special stability features of the Extrap confinement scheme into account, thereby including kinetic large Larmor radius (LLR) effects. This approach predicts Extrap to be unstable outside a domain defined by a lower and an upper ratio $\bar{a}/a_x$ between the average pinch radius $\bar{a}$ and the axial x-point distance a_x of the magnetic separatrix. The ratio $\bar{a}/a_x$ is related to the ratio J_p/J_v between the pinch current J_p and the conductor current J_v. Stability within the predicted domain seems to agree with so far performed linear and toroidal experiments, and can explain the observed increase in J_p/J_v and in the plasma temperature, in terms of an increased ratio $\bar{a}/a_x$. According to present analysis, an optimum value of the conductor current J_v should further exist with respect to pinch equilibrium and stability, as given by the condition $\bar{a} \simeq a_x$.

1. Introduction

During the last decade a series of linear and toroidal experiments has been performed on the Extrap concept, defined by a Z-pinch which is immersed in an octupole field due to currents in external conductors. All these experiments have shown that Extrap is at least macroscopically stable within certain parameter ranges [1-6].

Several attempts have been made to explain the observed stability of Extrap, as summarized in a number of reviews [3-5]. The situation of Extrap theory can shortly be described as follows [5]:

- All approaches elaborated so far on the basis of linearized pure MHD theory predict instability in contradiction to the experiments.

- MHD theory, as well as its amended form including small kinetic corrections due to finite Larmor radius (FLR) effects, does not fully apply to high-beta systems such as Extrap. The reason for this is that the wave lengths become smaller than or comparable to the ion Larmor radius for a considerable part of the spectrum which forms an integral part of any instability mode.

- Irrespective of the question whether large Larmor radius (LLR) effects could provide a key mechanism for stability or not, such effects will modify plasma dynamics considerably and have to be included. This requires a rigorous kinetic theory to be applied which takes proper account of the non-MHD plasma features due to large ion excursions and phase-mixing. Such a theory cannot be based on a conventional normal mode analysis [7], but must be elaborated in terms of a Fourier-Laplace transform and its inversion, or by some other relevant kinetic method.

At this stage a fully kinetic approach to Extrap stability is judged to become a comprehensive and difficult task. Also a number of ways still remain open in the attempts to understand the experimental results [5]. This paper presents a first step towards an integration of kinetic LLR effects into high-beta plasma theory, aiming at an outline of the stability limits of Extrap. Thus, earlier discussions on kink [3,8] and ballooning [9,10] modes will be reconsidered, with the special aim of relating the resulting stability limits to the corresponding ratios between the pinch and conductor currents. Since not all instability modes are treated in this context, the obtained limits will only represent sufficient conditions for the plasma to become unstable. Consequently, this gives a first hint of the ranges within which the plasma could possibly become stable, but further investigations are necessary in the analysis of unconditional stability.

2. Lower and Upper Stability Limits of the Pinch Radius

Before proceeding with the theoretical analysis, we shall start with some general physical considerations on the Extrap configuration, as being outlined in the linear case of Fig.1. Among the class of possible Extrap geometries, the figure shows one type, here being used to demonstrate the expected stability limits which should arise within the range of a varying average pinch radius $\bar{a}$. The currents J_v in the four external rod conductors, being at a distance a_v from the axis of symmetry, are all antiparallel to the pinch current J_p. A magnetic separatrix is created which has four x-points, at the axial distance a_x. Later in this context we shall also discuss the cases where J_p and J_v are coparallel, and when an approximation is made of toroidal geometry, in which case J_v and a_x will stand for average values of the configuration, at not too small aspect ratios.

It should first be noticed that a steady equilibrium of a linear pinch with a circular cross section, i.e. without a superimposed external field, can be described by six equations for six unknown variables [11]. This applies to the case where the pinch is surrounded by a neutral gas blanket. The pinch radius $\bar{a}$, defined as the characteristic radius (the "bulk") of the current density profile, is then uniquely determined by these equations which represent the balance of particles, momentum and heat. The introduction of a magnetic separatrix imposes an additional constraint. It results in a non-circular pinch cross section, but does not change the general features of the plasma balance, as long as the x-point distance a_x exceeds the pinch radius $\bar{a}$ by a sufficiently large margin. Classical transport at moderately large non-circularity has also been shown to deviate only slightly from that of a circular case, since the deviations in the resulting confinement times are of second order in the non-circularity [12]. However, when the x-point distance a_x is forced to become smaller than the "natural" radius $\bar{a}$, as determined by the conventional

MHD equilibrium equations, the plasma balance becomes overdetermined by the imposed separatrix, and thus has to be reconsidered.

With respect to a growing ratio $\bar{a}/a_x$ between the pinch radius and the x-point distance, three ranges and two stability limits are expected to exist [10]. These are related to the ratio

$$M = B_{pa}/B_{va} \tag{1}$$

between the magnetic field strengths, B_p and B_v, due to the pinch and conductor currents, J_p and J_v, measured at the average pinch radius $\bar{a}$. The qualitative physical arguments are as follows:

(i) For very small ratios $\bar{a}/a_x$ a conventional unstabilized Z-pinch arises, because the imposed octupole field strength B_v increases as the third power of the distance from the axis of symmetry and then becomes very weak within the entire plasma body, i.e. for $M \gg 1$.

(ii) As the ratio $\bar{a}/a_x$ gradually increases, the ratio M decreases. Sooner or later a sufficiently small value of $M = M_c$ is reached, for which the imposed octupole field becomes substantial within the plasma body and in its boundary region. The pinch is then stabilized, as observed in the experiments. The value M_c corresponds to a lower stability limit of $\bar{a}/a_x$ predicted e.g. by the analysis on the kink mode [3,8].

(iii) As the ratio $\bar{a}/a_x$ becomes further increased, and M decreased, a stable range is being traversed, up to a point where $\bar{a}/a_x$ and M approach unity. When there is a tendency for $\bar{a}/a_x$ to exceed unity, there is also a tendency for the plasma pressure profile to become steepened in the plasma boundary region, as shown later in Section 3. Then the pinch balance becomes disturbed by the imposed separatrix which "scrapes off" part of the plasma boundary layer, and ballooning instabilities are also expected to arise in the weak-field regions of the x-points [9,10]. This corresponds to an upper stability limit of $\bar{a}/a_x \simeq 1$ for which $M \simeq 1$.

3. The Equilibrium State

In connection with the lower and upper stability limits of $\bar{a}/a_x$, the plasma profiles and the pressure balance near the x-points have first to be discussed.

3.1. The Plasma Profiles at Small Non-Circularity

Near the lower limit of $\bar{a}/a_x$ the effects of non-circularity become small [12], and the corresponding Bennett relation can be discussed in terms of a nearly circular cross section, in a first approximation. Even here profiles of a rather sophisticated form could be chosen, to take a low current density and a resulting small pressure gradient into account, in a cool boundary region. However, for a first indication of the profile variations with $\bar{a}/a_x$ and with the pinch current J_p, a special class of profiles is used here as a demonstration. This class is defined by the current density

$$j = j_o\left[1-(r/\bar{a})^{\alpha}\right] \tag{2}$$

where $r = (x^2+y^2)^{1/2}$ is the distance from the axis in Fig.1 and the constant $\alpha > 0$. The resulting Bennett relation has the form [13]

$$n_o T_o \bar{a}^2 = \mu_o F(\alpha) J_p^2/(8\pi^2 K) \tag{3}$$

where n_o and T_o are values of the plasma density n and temperature T at the axis $r = 0$, K stands for Boltzmann's constant and

$$F(\alpha) = (3+\alpha)(2+\alpha)^2/(1+\alpha)(4+4\alpha+\alpha^2) \tag{4}$$

A class of profile shapes can here be traversed, by varying α. Thus $F(\alpha)$ ranges from $F \simeq 3$ for the case $\alpha \ll 1$ of a profile being strongly peaked towards the axis $r = 0$, to $F = 1$ for the case $\alpha \gg 1$ of a square-shaped profile of j being infinitely steep at the boundary $r = \bar{a}$.

From these results two conclusions can be drawn:

(i) The dependence of $\bar{a}$ on $J_p/(n_o T_o)^{1/2}$ becomes an insensitive function of the profile shape, as given by $\sqrt{F}$ which only varies from $\sqrt{3}$ to 1 in the range between the extreme cases $\alpha \ll 1$ and $\alpha \gg 1$. On account of a surrounding gas blanket, it is likely that the profile becomes somewhat flatter than a parabola. Thus, near the lower stability limit we put $\alpha \simeq 4$ and $F \equiv F_k \simeq 7/5$ with good approximation, also for a slightly non-circular cross section.

(ii) Starting from a given equilibrium state, but introducing the constraint of a fixed pinch radius $\bar{a}$ and assuming $n_o T_o$ to increase more slowly with J_p than J_p^2, it is seen from eq. (3) that $F(\alpha)$ has to decrease as J_p increases. Then α has to increase, thereby increasing the steepness of the current and pressure profiles near $r = \bar{a}$ as J_p increases. However, this is possible only up to the point where F approaches unity, and α goes to infinity. A further increase in J_p at a fixed radius $\bar{a}$ does not become reconcilable with the pinch balance equation (3). We will return to this question later in Section 5.

3.2. The Pressure Balance near the X-Points

Regardless of the detailed plasma transport mechanisms, the local pressure balance is in the MHD approximation given by

$$\underline{j} \times \underline{B} = \underline{\nabla} p \tag{5}$$

where $\underline{B} = \text{curl}\underline{A} = \underline{B}_p + \underline{B}_v$ is the total poloidal magnetic field strength, $\underline{j} = \text{curl}\underline{B}/\mu_o$ the current density, and $p = 2nKT$ the plasma pressure. An analogous equation for the momentum balance can be deduced from kinetic theory for a steady state [14].

Introducing a rectangular frame (x,y,z) in the plane case of Fig.1, the vector potential becomes $\underline{A} = [0,0,A(x,y)]$. Conventional equilibrium theiry then yields $j = j(A)$ and $p = p(A)$. Further

$$|\underline{\nabla}p| = |dp/dA| \cdot [(\partial A/\partial x)^2 + (\partial A/\partial y)^2]^{1/2} \qquad (6)$$

$$B^2 = (\partial A/\partial x)^2 + (\partial A/\partial y)^2 \qquad (7)$$

Consequently $j, p, (dp/dA)$ and $|\underline{\nabla}p|/B$ become constant along any field line of the non-circular plasma cross section of Fig.1. For every field line, the strength B and the pressure gradient $|\underline{\nabla}p|$ have minimum values in the planes which pass through the x-points. The current and pressure profiles of the non-circular pinch are given within the entire plasma volume, if they are given along a certain line which passes through the origin ($x=0$, $y=0$) of Fig.1.

Integration of eq. (5) in terms of the variable A yields

$$p_o = 2n_oKT_o = \int_{A_o}^{A_a} j\,dA \qquad (8)$$

where the pressure has been assumed to become small at the plasma boundary, and (A_o, A_a) are the values of A at $r=0$ and at the pinch surface. Introducing the meanvalue of j within the plasma cross section, and relating this value and $A_a - A_o$ to the total current, it is easily seen that a relation analogous to eq. (3) is obtained also for a pinch with non-circular cross section.

The corresponding profile factor F will likewise be of the order of unity, and $\sqrt{F}$ becomes an insensitive function of the profile shape. Consequently, when the ratio $\bar{a}/a_x$ is forced to approach unity, we put $F \equiv F_b \simeq 1$ and use eq. (3) in a first approximation of the force balance.

4. The Lower Limit of the Pinch Radius

When considering the earlier treated limit of kink instability, the deviations from a circular cross section are assumed to be small, in the sense that the parameter M defined by eq.(1) should exceed unity by a sufficient margin. Combining the conventional analysis in terms of the energy principle [3] with a hybrid LLR-MHD model [8], the resulting stability condition for a system with four external conductors can be written as

$$L \equiv n_o^2 a_v^4 (J_p/J_v) < (\mu_o F_k Q/4\pi^2 K)^2 [M_c \pm (J_p/4J_v)] \tag{9}$$

Here $F_k \simeq 7/5$ according to Section 3.1.(i),

$$Q = J_p^2/T_o \simeq [\theta_i (8\pi^2 m_i K)^{1/2}/(\mu_o e f_i f_t)]^2 \tag{10}$$

and the plus and minus signs refer to the cases of coparallel and antiparallel pinch and conductor currents. Further

$$M_c = -a + [b + (c f_t^2/Q)]^{1/2} \tag{11}$$

with $a \simeq 1.74$, $b \simeq 3.81$, $c \simeq 2.53 \times 10^5$, $f_t = [1+(B_t/B_{pa})^2]^{-1/2}$, and the profile factor $f_i \simeq 0.75$ [8]. In eq. (10) θ_i is the number of ion Larmor radii contained within the pinch radius, and M_c defined by eq. (11) is the critical value of M for kink instability.

If the deviations from non-circularity are limited by restricting the critical M-value to $M_c \gtrsim 2$, say, this leads to $\theta_i \lesssim 18$, in a range $0 \leqslant B_t \leqslant B_{pa}/2$ of superimposed toroidal fields B_t.

The lower stability limit obtained from condition (9) with $B_t = 0$ is shown in Fig.2. The same limit is also introduced in Fig.3 for $M_c >> (J_p/4J_v)$ which is a good approximation in the application to so far performed experiments. A superimposed axial field $B_t = B_{pa}/2$ changes this limit as shown by the broken line in Fig.3. The features of the lower limit are uncertain for $\theta_i \gtrless 18$.

5. The Upper Limit of the Pinch Radius

Provided that n_oT_o increases more slowly than J_p^2 with J_p, the pinch radius $\bar{a}$ will increase with J_p. The position of the x-point distance is given by [15]

$$a_x = a_v \{ 1/[4(J_v/J_p) \pm 1] \}^{1/4} \tag{12}$$

in the case of four conductors, where the plus and minus signs refer to the cases of coparallel and antiparallel pinch and conductor currents. From expression (12) is seen that a_x increases only slowly with J_p/J_v. We shall therefore from this point on assume that the ratio $\bar{a}/a_x$ can be made to approach unity.

According to the behaviour outlined in Section 3.1.(ii), an increased pinch current at a fixed plasma boundary should lead to increased gradients of j and p near the boundary. Thus when $\bar{a}/a_x$ tends to exceed unity, this enhances the derivative dp/dA in the boundary region, all along a field line and also in the planes $y=0$ and $x=0$ which contain the x-points.

In the conventional theoretical model of the ballooning mode, instability occurs for a fixed connection length and a radius R_B of curvature of a field line, provided that the quantity $|\underline{\nabla} p|/B^2R_B$ exceeds a certain critical value. As the ratio $\bar{a}/a_x$ tends to exceed unity, it is seen from eqs. (6) and (7) that this quantity becomes strongly increased within the parts of the plasma which are close to the x-points.

As soon as the condition $\bar{a} \geq f_a a_x$ is violated it is then expected that the pinch equilibrium either ceases to exist and the plasma losses become strongly enhanced in the boundary region, or that a ballooning instability arises. Here f_a is a constant of order unity. In combination with eq. (12) the condition for pinch equilibrium and/or stability thus becomes

$$U \equiv n_o^2 a_v^4 (J_p/J_v)\{1/[1 \pm (J_p/4J_v)]\} \geqslant (\mu_o F_b Q/4\pi^2 K f_a^2)^2 \qquad (13)$$

for the upper limit of the pinch radius. Here $F_b \simeq 1$ according to Section 3.2. This limit is plotted in Figs. 2 and 3 for $f_a = (2)^{1/4}$.

6. Comparison with Experiments

The experimental data on Extrap are few in number at this stage, in particular for toroidal geometry. With the reservation of rather wide limits of error in some of the measured and estimated parameters, we now make a comparison with the present theory, as shown by the rectangular areas in Fig.3. These areas refer to the range of the highest pinch currents J_p being imposed in each experiment, under macroscopically stable conditions. Approximate values of some relevant experimental parameters are given in Table 1.

6.1. Earliest Linear and Toroidal Sector Experiments

The earliest linear [1,16] and toroidal sector [2,17] experiments were largely performed without an axial (toroidal) external magnetic field component, and with J_p and J_v being antiparallel. In both these experiments a macroscopic stability limit was observed for a certain critical value $(J_p/J_v)_c$ of the pinch-conductor current ratio. This is consistent with the positions of the rectangular areas in Fig.3 which are close to the lower pinch radius limit. Here LO denotes the linear and TO the toroidal sector experiments.From Table 1 can clearly be seen that the ratio $\bar{a}/a_x$ is smaller than unity in both experiments. As a consequence, the lower stability limit is reached already at comparatively small pinch-conductor current ratios $(J_p/J_v)_c$.

In the linear experiment [1] the superposition of an axial magnetic field $B_t \gtrsim 0.5\ B_{pa}$ was further found to impair stability. Also this observation appears at least to be in qualitative agreement with the lowered position of the broken line in Fig.3.

6.2. Recent Linear and Fully Toroidal Experiments

Recently experiments have been carried out at increased pinch currents, both in linear [18] and fully toroidal geometry [19], apparently under macroscopically stable conditions and without reaching a stability limit so far.

In the experiment with the linear device Extrap-L1, denoted by L1 in Table 1 and Fig.3, temperatures as high as $T_o \approx 6x10^5K$ have been recorded for antiparallel pinch and conductor currents and at ratios $J_p/J_v \approx 2.3$. These current ratios are about 9 times higher than those leading to macroscopic instability in the earliest linear experiments with LO. For L1 the ratio $\bar{a}/a_x$ is seen from Table 1 to be larger than for LO and TO, thus leading to an enhanced influence from the superimposed octupole field.

The experiments with the fully toroidal device Extrap-T1 are performed with coparallel pinch and conductor currents. They have given results as listed in Table 1 and shown in Fig.3. The corresponding values of $\bar{a}/a_x$ are rather close to unity. A moderately strong toroidal field, up to $B_t \approx B_{pa}$, has been imposed in some of these experiments, to expedite breakdown. All these experiments so far appear to be macroscopically stable, i.e. no macropscopic instability limit has yet been observed.

7. Conclusions

The following conclusions can be drawn from the present results:

(i) The theory given in this context represents a first attempt to take the special features of Extrap into account, including kinetic LLR effects. It predicts the domains outside the strip in the parameter space of Figs. 2 and 3 at least to represent instability for kink and ballooning modes, and a lack of pinch equilibrium.

(ii) Other instability modes, not being treated here, could change the situation and further restrict the domain of stability. On the other hand, the exact consequences of LLR effects cannot be surveyed at this stage, and the stabilizing influence of these effects may also have been underestimated, as well as that of other possible stabilizing mechanisms. Only experiments can verify whether the present simplified approach is relevant or not.

(iii) So far performed experiments seem to be consistent with this theory, as illustrated by Figs. 2,3 and Table 1. This suggests that the improved stability situation in L1 and T1, as represented by an increased temperature T_o and an enhanced current ratio J_p/J_v, is due to increased values of $\bar{a}/a_x$. This leads to reduced M-values and a stronger stabilizing effect of the octupole field in the boundary region of the pinch. The positions of the parameter ranges of L1 and T1 in Fig.3 then predict that higher current ratios J_p/J_v and temperatures than those given in Table 1 could be reached in devices Extrap-L1 and Extrap T1, before ending up at the lower pinch radius limit of the figure.

(iv) As seen from conditions (9) and (13), there should exist an optimum external conductor current J_v with respect to stability, when all other plasma parameters are at fixed values. This optimum current is given by the equality sign in expression (13) and corresponds to $\bar{a} \simeq a_x$, i.e. when the octupole field has its maximum influence at the pinch surface. A further enhancement of J_v, beyond this optimum, forces the separatrix to "scrape off" part of the boundary layer, and can also give rise to ballooning instability near the x-points.

(v) It should finally be noticed that part of the present approach [3,8] is based on results and arguments being similar to those being elsewhere presented [20,21]. This applies to the fact that rigid body displacements of the plasma in the external octupole field become linearly stable [3,8,22]. As a consequence, the m=1 mode could be stabilized by some internal plasma "shear-force" mechanism, such as by viscosity [30], LLR effects [3,8] or inertia [21], which makes the pinch perform nearly rigid displacements.

Stockholm, December 23, 1987

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Table 1. Measured and estimated plasma parameters in the earliest linear (LO), toroidal sector (TO), recent linear (L1) and fully toroidal (T1) Extrap experiments. The conductor currents J_v are antiparallel to the pinch current J_p in (LO, TO, L1) and parallel to the same current in (T1).

	LO	TO	L1	T1
J_p(kA)	9	9	28	29
J_p/J_v	0.25	0.36	2.3	2.0
$n_o(m^{-3})$	$2x10^{22}$	$2x10^{22}$	$3x10^{21}$	$1.5x10^{21}$
T_o(K)	10^5	$7x10^4$	$6x10^5$	$3x10^5$
a_v(mm)	28	28	30	78
a_x(mm)	14.2	15.7	32.3	59.3
F	7/5	7/5	7/5	1
$\bar{a}$(mm)	8.1	9.7	27	52
$\bar{a}/a_x$	0.57	0.62	0.82	0.88

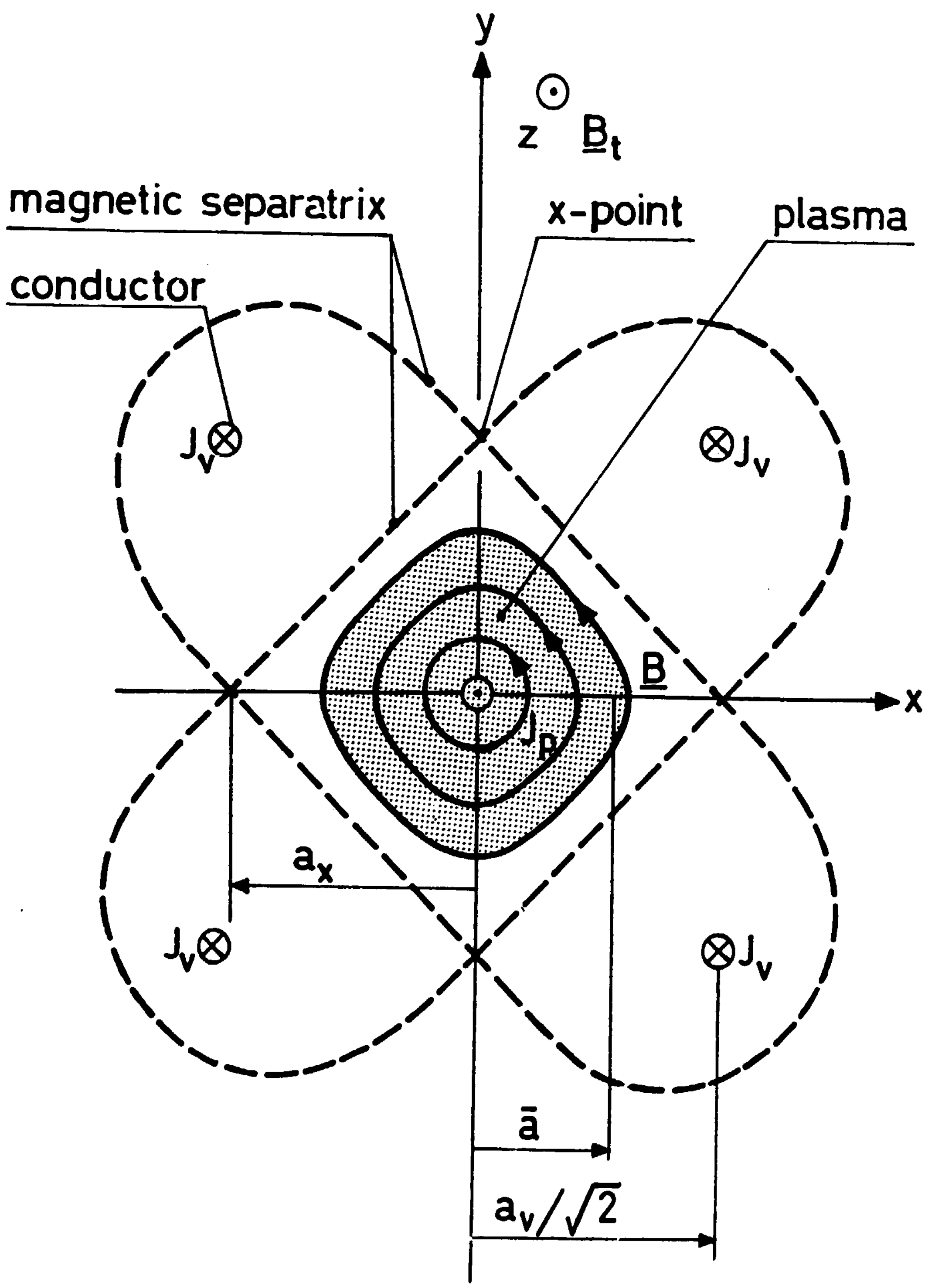
Figure Captions

Fig.1. Outline of the Extrap field geometry in a linear case where the pinch current J_p is antiparallel to the currents J_v in four external conductors situated at the distance a_v from the pinch axis. The magnetic separatrix has four x-points at the axial distance a_x, and the average pinch radius of the non-circular plasma cross section is $\bar{a}$. The total transverse field has the strength $\underline{B}$. A moderately strong axial field $\underline{B}_t$ can be superimposed in certain cases.

Fig.2. Expected lower and upper stability limits in a purely transverse (poloidal) magnetic field $\underline{B}$, as functions of the number θ_i of ion Larmor radii contained within the pinch radius, the pinch current J_p, the pinch-conductor current ratio (J_p/J_v), the axial plasma density and temperature n_o and T_o, and the average axial distance a_v of the external conductors. The figure refers to the case of antiparallel pinch and conductor currents.

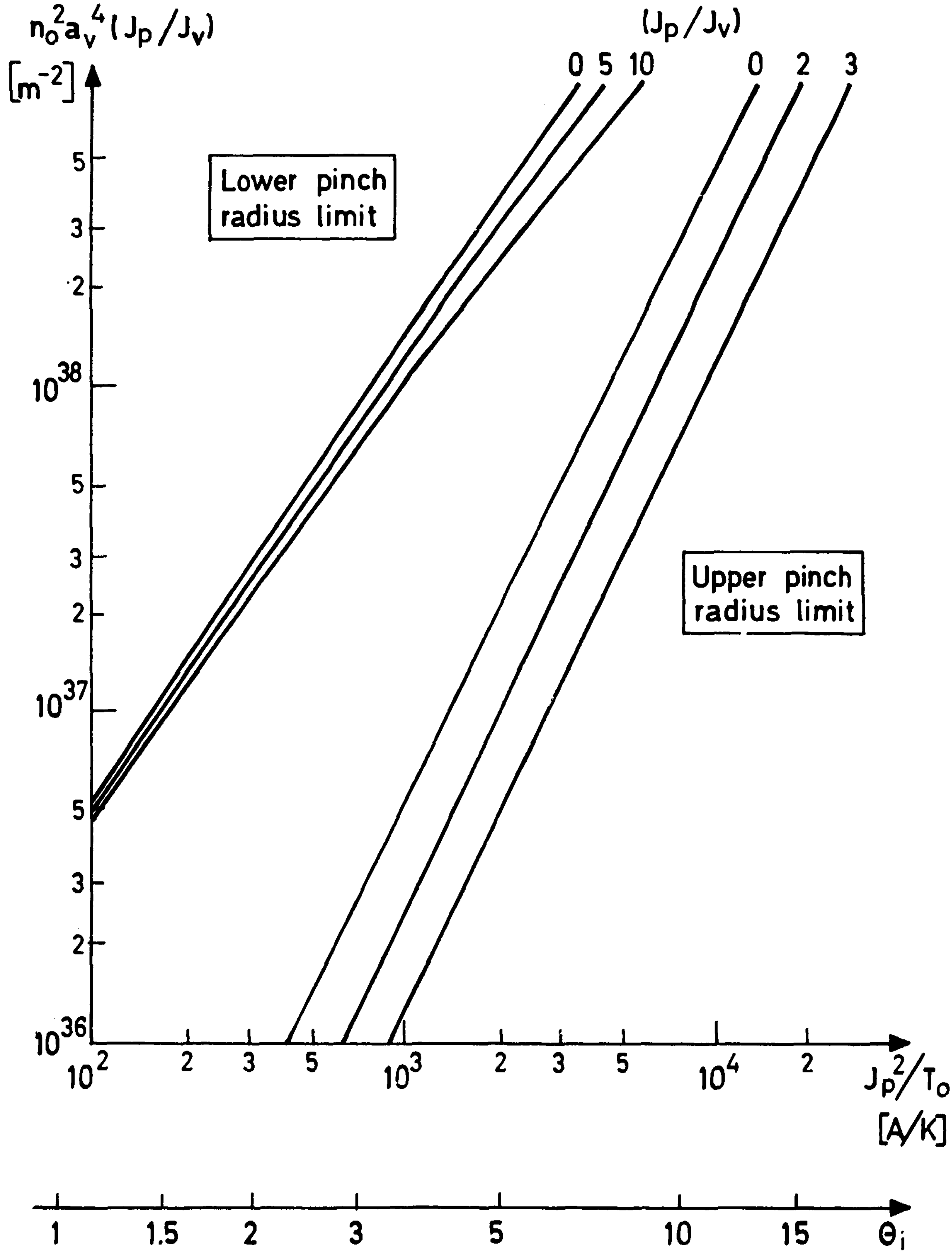
Fig.3. Diagram being analogous to that of Fig.2, and where $L = n_o^2 a_v^4 (J_p/J_v)$ refers to lower limit for $M_c \gg (J_p/4J_v)$ and $U = n_o^2 a_v^4 (J_p/J_v)/[1 \pm (J_p/4J_v)]$ refers to upper limit, both as functions of $Q = J_p^2/T_o$. The effect on the lower limit of a superimposed axial (toroidal) field $B_t = B_{pa}/2$ is demonstrated by the broken line. The parameter ranges of the linear experiments (LO, L1) and the toroidal experiments (TO, T1) are indicated by the rectangular areas, for observed data, in the ranges of the highest so far recorded pinch currents of a macroscopically stable state. The ranges of the earlier experiments (LO, TO) refer to the lower limit scale (L) of the vertical axis, and the ranges of recent experiments (L1, T1) to the upper limit scale (U) of the same axis. The parameters L and U are defined by eqs. (9) and (13).

Fig. 1

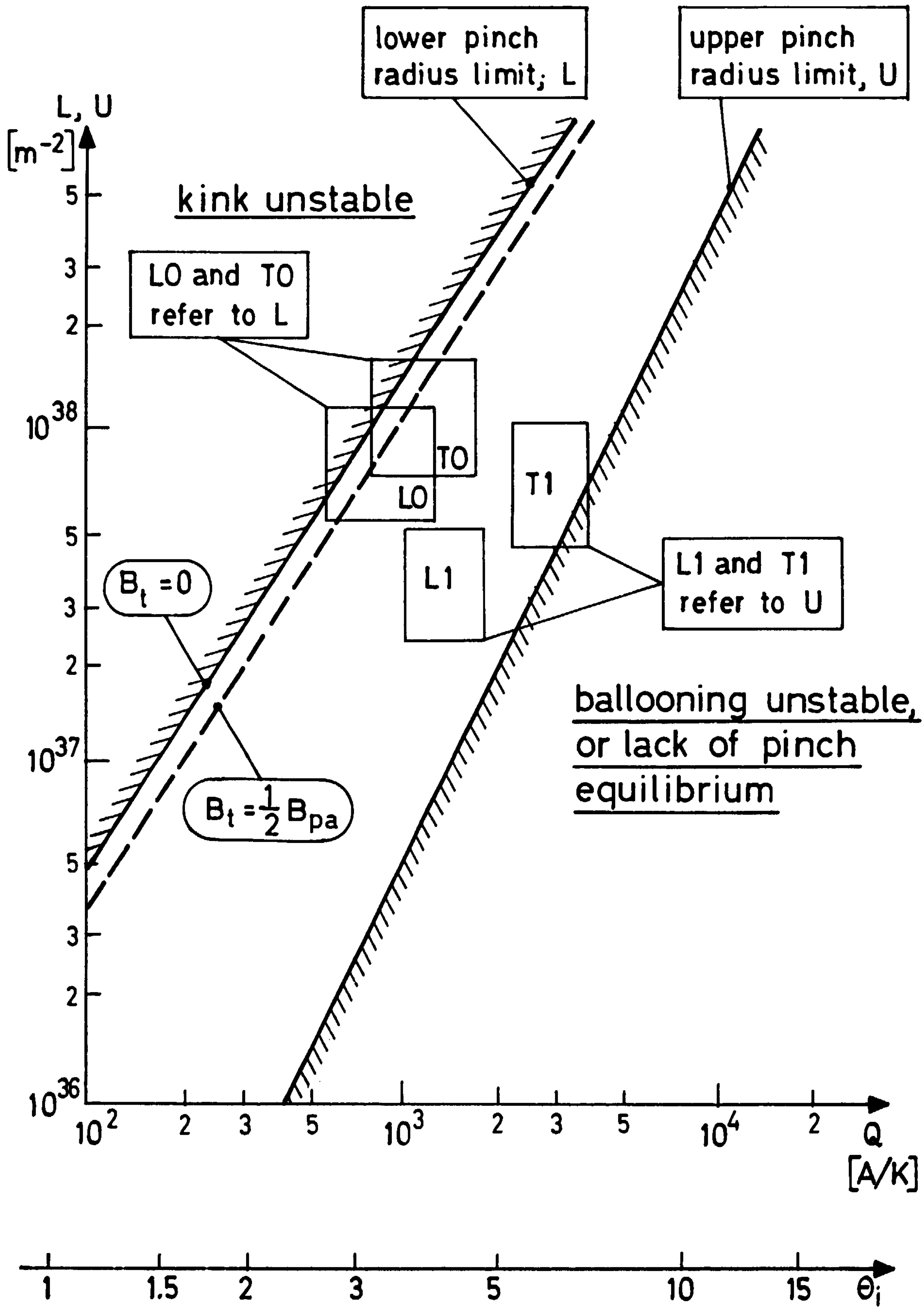


y
z
$\underline{B}_t$
magnetic separatrix
x-point
plasma
conductor
J_v
J_v
$\underline{B}$
x
J_p
a_x
J_v
J_v
$\bar{a}$
$a_v/\sqrt{2}$

Fig. 2



$n_o^2 a_v^4 (J_p/J_v)$
$[m^{-2}]$
(J_p/J_v)
0 5 10
0 2 3
Lower pinch radius limit
Upper pinch radius limit
10^{38}
10^{37}
10^{36}
5
3
2
10^2
10^3
10^4
J_p^2/T_o
[A/K]
1
1.5
2
3
5
10
15
Θ_i


lower pinch radius limit; L
upper pinch radius limit, U
L, U [m^-2]
kink unstable
LO and TO refer to L
TO
LO
T1
L1
L1 and T1 refer to U
B_t = 0
B_t = 1/2 B_pa
ballooning unstable, or lack of pinch equilibrium
5
3
2
10^38
5
3
2
10^37
5
3
2
10^36
10^2
2
3
5
10^3
2
3
5
10^4
2
Q [A/K]
1
1.5
2
3
5
10
15
Θ_i

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ON THE STABILITY LIMITS OF THE PINCH-CONDUCTOR
CURRENT RATIO IN EXTRAP

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A first attempt is made to take the special stability features of the Extrap confinement scheme into account, thereby including kinetic large Larmor radius (LLR) effects. This approach predicts Extrap to be unstable outside a domain defined by a lower and an upper ratio $\bar{a}/a_x$ between the average pinch radius $\bar{a}$ and the axial x-point distance a_x of the magnetic separatrix. The ratio $\bar{a}/a_x$ is related to the ratio J_p/J_v between the pinch current J_p and the conductor current J_v. Stability within the predicted domain seems to agree with so far performed linear and toroidal experiments, and can explain the observed increase in J_p/J_v and in the plasma temperature, in terms of an increased ratio $\bar{a}/a_x$. According to present analysis, an optimum value of the conductor current J_v should further exist with respect to pinch equilibrium and stability, as given by the condition $\bar{a} \simeq a_x$.

Key words: Extrap, stability limits, LLR effects