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Informal Report

THE TRANSVERSE RESISTIVE WALL INSTABILITY FOR A WARM ISA

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MASTER

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ABSTRACT

The transverse dipole resistive wall instability is considered. A comparison is made between a "cold" and "warm" ISA design. It is concluded that there are strong constraints on the amount that the synchrotron radius can be increased and on the amount that the magnet gap can be decreased when the warm case is designed. A reasonable warm design, from the point of view of economically achievable magnetic field, is chosen as an example. It is concluded, however, that such a design is untenable. Although, when the beam width is larger than the magnet gap, the requirement on ν-spread is reduced, it is found that the reduction is not sufficient to compensate for the effect of increased radius and decreased gap.

A transverse dipole instability can be excited in a sufficiently intense beam if the walls have a non-zero resistivity. This instability, which arises from image forces created by the resistive walls, can be avoided if the ν-spread in the beam is large enough. Thus, the instability threshold can be stated as a limit on the ν-spread. In particular, if the vertical half-spread, d, is less than some specified value, a vertical instability will set in -- or, for stability[1]

$$d > T \tag{1}$$

where

$$T = \frac{2r_p IR^2}{e\nu\beta\gamma h^3}\sqrt{\frac{2\epsilon_o\rho}{|\omega|}}\, f(a/h) \quad . \tag{2}$$

The various quantities are given as follows:

I is the beam current, in A,

R is the radius of the synchrotron ring,

r_p is the classical radius of the proton, $= 1.54 \times 10^{-18}$ m,

ν is the vertical tune,

β is the proton velocity in units of c,

γ is the energy in units of proton mass,

h is the chamber half-height,

ρ is the chamber resistivity in units of ohm-m,

$\omega = \Omega|k - \nu|$, the frequency of the unstable dipole mode,

k is the mode number, with respect to azimuth, of the instability,

Ω is the proton angular velocity, $= \beta c/R$,

e is the proton charge, $= 1.602 \times 10^{-19}$ Coulombs,

ϵ_o is the free space dielectric constant, $= 1/36\pi \times 10^{-9}$ sec/ohm-m, and

a is the beam half-width.

This expression is only approximate, but it should give a rough estimate of the instability threshold. It has one valuable feature for us in that it is applicable to both circular and parallel plate geometry, with the proper choice of the form factor, f. For a roughly circular beam in a circular geometry, we can choose $f = 1$. For a parallel plate geometry, (chamber width large compared with height), $f(a/h)$ is plotted in Fig. 1. This curve is taken from Ref. (1).

Let us use (1) and (2) to compare the cold ISA case with the warm ISA case, where we take the design parameters from Ref. (2). If we assume that the current I, the vertical tune, ν, the energy, γ, and the chamber resistivity are the same for both cases, we may write for the warm threshold,

$$\frac{d_w}{d_c} > \left(\frac{R_w}{R_c}\right)^{5/2} \left(\frac{h_c}{h_w}\right)^{3} f(\alpha_w) \qquad (3)$$

where the subscripts w and c refer to warm and cold respectively

$$\alpha_w = a_w/h_w$$

and d_c is a number corresponding to the threshold for the cold case.

With the values, $I = 15$ A, $R_c = 385.5$ m, $\nu = 20.25$, $\beta \sim 1$, $\gamma = 30$, $h_c = 3.5$ cm, $\rho = 1.6 \times 10^{-8}$ ohm-m (for 273^o K Cu), and $k = 21$, we compute $d_c = 1.2 \times 10^{-3}$. If we further put $R_w = 7/3\ R_c$, $h_w = 1.35$ cm, then the stability threshold in the warm case becomes

$$d_w > (8.3)(17.4)\ d_c f(\alpha_w), \qquad (4)$$

or

$$d_w > 145\ d_c f = 0.17\ f(\alpha_w) \quad .$$

From Fig. 1, we have

$$d_w > 0.09, \text{ if } a_w = 2h_w ,$$

and

$$d_w > 0.05, \text{ if } a_w = 4h_w \quad .$$

These two examples correspond to full beam widths of 5.4 cm and 10.8 cm respectively. It would thus appear that to reduce the threshold ν-spread to a reasonable value, say 0.01, would require an unacceptable beam width. We must therefore reject the basic design parameters; in particular, we conclude that the radius is too large and the magnet gap is too small.

References

1. L.J. Laslett, V.K. Neil and A.M. Sessler, Rev. Sci. Instr. 36, 436 (1965).
2. M. Month, Brookhaven National Laboratory, Informal Rept., CRISP 73-3 (1973).

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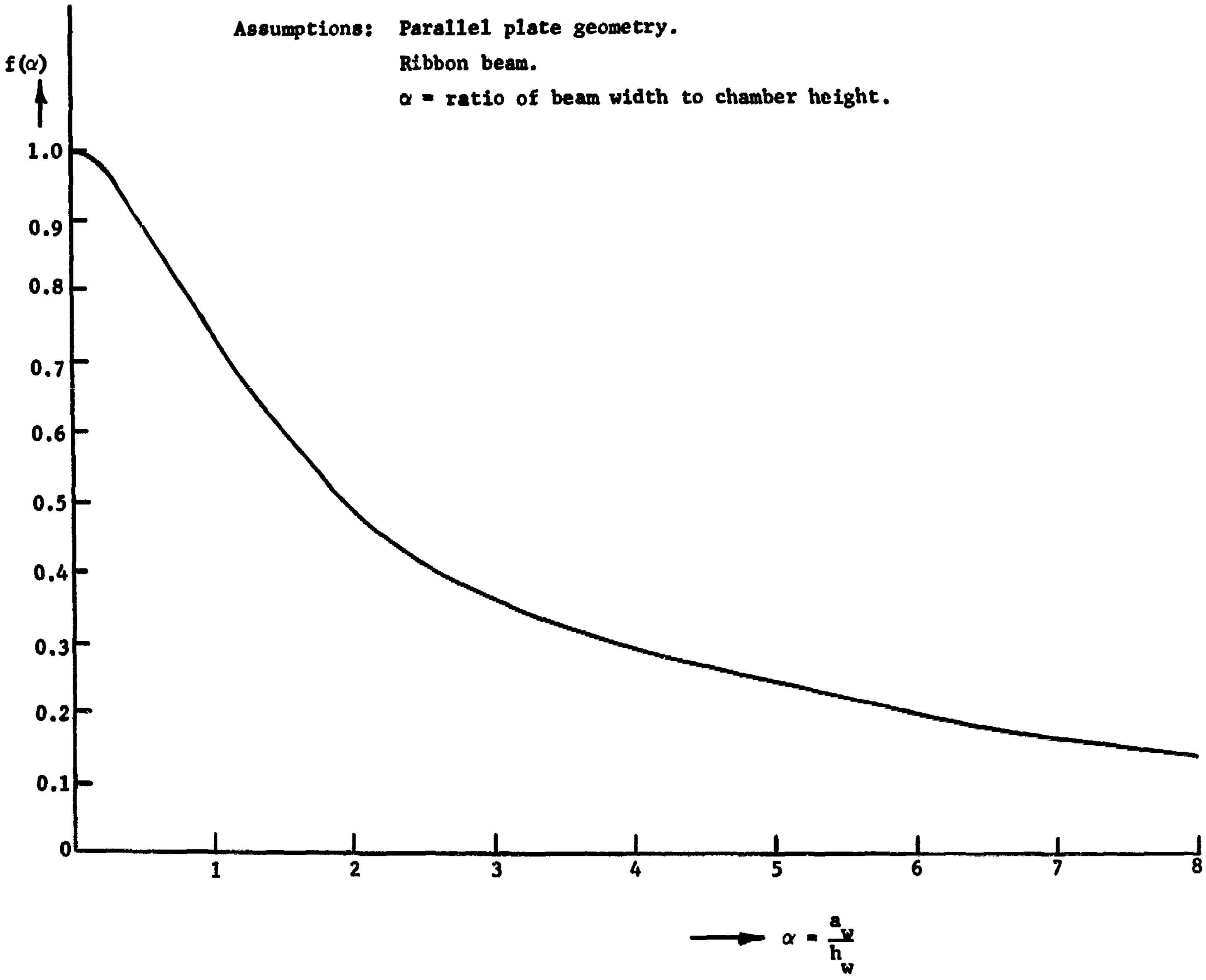
Fig. 1: Form Factor: Transverse Resistive Wall Instability.



Assumptions: Parallel plate geometry.
Ribbon beam.
α = ratio of beam width to chamber height.