INSTABILITY COMMENTS

S.L. Wipf
Atomics International
A Division of North American Rockwell Corporation
Canoga Park, California

There has been considerable confusion in discussions of instabilities. This is mainly because the problem is rather complex and somewhat ill defined. I should like to summarize quickly a simplified way of looking at the whole complex without going too deeply into any specific detail.

The term magnetic instability or "flux flow instability" relates to the movement of flux lines into or out of a superconductor due to the changing external field (which may be the self-field of a current flowing through the superconductor). If this flow is stable (flux flow or flux creep) the flow velocity v_{dr} is proportional to the rate of change of the external field

$$v_{dr} \propto dH/dt \quad . \qquad (1)$$

(The proportionality factor would depend mainly on geometry and j_c.) We should talk about an instability as soon as this relation is no longer valid.

The following picture may illustrate what can happen (see Fig. 1): Starting with H from 0 one would encounter stable flux flow up to a threshold field H_{fi}; formulae for H_{fi} have been given by Hancox,[1] Swartz and Bean,[2] Lange,[3] and Wipf.[4] They are of the form $H_{fi} = A\, c^{\frac{1}{2}}\, f(T)$, where A is a constant, c the specific heat per unit volume, and f(T) is $\{-F_p/(\partial F_p/\partial T)\}^{\frac{1}{2}}$ which is usually a temperature function independent of F_p itself (F_p = pinning strength per unit volume).

Above H_{fi} we encounter flux jump activity until a field H_{ST} is reached, above which stability is reached again. H_{ST} has not been calculated in general, but, roughly, it may be proportional to $D \cdot j_c$, where D is a characteristic distance given by the geometry. There is also a dependence on dH/dt, a large value of dH/dt may raise H_{ST}.

A real or catastrophic flux jump is an event which makes the whole or portions of the superconductor temporarily normal. In a coil this gives the degraded critical current while other instabilities or "limited flux jumps" give voltage spikes or noise at the terminals. The flux jump field, H_{fj}, again is very difficult to calculate.*

How do we improve our materials with regard to instabilities? There are several methods either proposed or actively pursued in the fabrication of materials now used for magnet construction.

*For small dH/dt, i.e., thermal diffusivity D_{th} > magnetic diffusivity D_{mag} (which is proportional to dH/dt), we have $H_{fj} \propto$ const - log (dH/dt), and a large D_{th} increases the constant.[4]

1. R. Hancox, Appl. Phys. Letters 7, 138 (1965).

2. P.S. Swartz and C.P. Bean, to be published.

3. F. Lange, Cryogenics 6, 176 (1966).

4. S.L. Wipf, Phys, Rev. 161, 404 (1967).

1. Obviously the simplest idea is to produce a material which is inherently stable (a trivial case being a low field superconductor whose critical field $H_c < H_{fi}$). The solution to the problem is a material with $\partial F_p/dT > 0$ (or $\partial j_c/\partial T > 0$); then the function f(T) mentioned above becomes imaginary and H_{fi} does not exist. Livingston[5] mentioned this method in his talk.

2. A less radical method consists in raising H_{fi} or lowering H_{ST} or both, thus narrowing down the instability region or making it disappear altogether. H_{fi} is raised by reducing $\partial F_p/\partial T$, or by increasing c. The porous Nb_3Sn cylinder of Corsan and Hancox[6] has a c which is two orders of magnitude larger due to the presence of liquid He in the pores. H_{ST} can be lowered by decreasing the diameter of the superconductor and this is partly the reason for the popularity of the multifilament conductors.

3. Most magnet builders have successfully tackled the problem of <u>preventing</u> the catastrophic jump by efficiently <u>limiting</u> the instabilities, while they got used to the idea of living with instabilities. The methods developed have different reasoning for a background. The instabilities are accompanied by the growth of various interdependent quantities: $d\Phi/dt$, flux admitted to the superconductor, or to the coil; $\partial T/\partial t$, rise in temperature; $\partial\rho/\partial t$, rise in the resistivity (electromagnetic diffusivity) of the superconductor. By controlling, or limiting any of these quantities the catastrophic flux jump is prevented. The practical solutions are summarized in the table:

Controlled Quantity	Remedy	Practical Terms
$\frac{d\Phi}{dt}$	Provide shorts	Shorting strips in RCA[7] coils
$\frac{\partial\rho}{\partial t}$	Cu bypass	"Stabilization" (AI,[8] Stekly[9]) (full or partial) "Current Sharing"
$\frac{\partial T}{\partial t}$	High specific heat High thermal conductivity (by adding liquid He or Pb, Cd)	"Enthalpy Stabilization"[10] "Adiabatic Stabilization" "Transient Stabilization"[11] (Hancox) "Dynamic Stabilization"

5. See also J.D. Livingston, Appl. Phys. Letters <u>8</u>, 319 (1966).

6. J.M. Corsan, G.W. Coles, and H.J. Goldsmid, Brit. J. Appl. Phys. <u>15</u>, 1383 (1964).

7. E.R. Schrader, P.A. Thompson, and W. Coles, J. Appl. Phys. <u>39</u>, 2652 (1968).

8. C.N. Whetstone and R.W. Boom, in <u>Advances in Cryogenic Engineering</u> (Plenum Press, 1968), Vol. 13, p. 68.

9. A.R. Kantrowitz and Z.J.J. Stekly, Appl. Phys. Letters <u>6</u>, 56 (1965).

10. R. Carruthers, D.N. Cornish, and R. Hancox, in <u>Proc. First Intern. Cryogenic Engineering Conference, Kyoto, 1967</u> (Heywood-Temple, London, 1968), p. 107; R. Hancox, to be published in <u>Proc. Intermag Conference, 1968</u>.

11. J.R. Hale and J.E.C. Williams, J. Appl. Phys. <u>39</u>, 2634 (1968).

Naturally this table only provides a very sketchy summary of a very complex situation which also includes the cooling process and the thermal diffusivity.

Using the third method one still has instabilities in the sense that Eq. (1) is not fulfilled. But they may be so small or so slow as not to be detectable in practical cases.

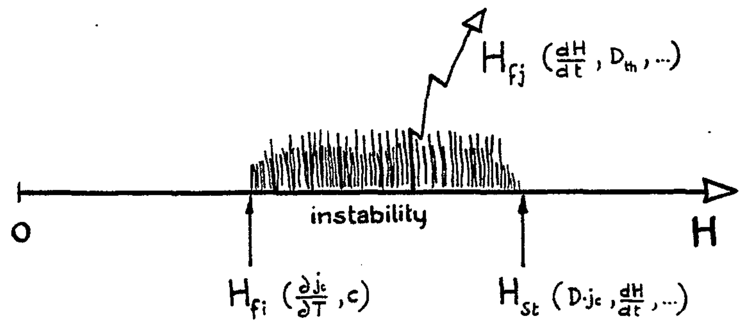

Fig. 1. Instability in a superconductor as a function of applied field.