Plasma Quenching by Moving Limiter (Divertor Group)

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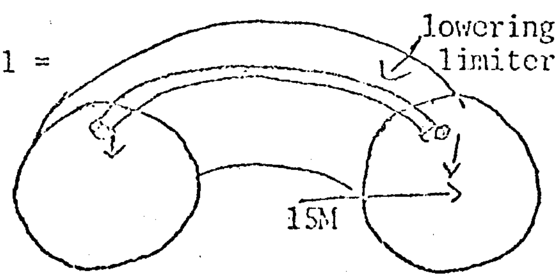
Can a niobium limiter be moved into plasma at the end of the pulse to take over the energy of the plasma instead of purging the vacuum chamber with gas? This limiter would be expendable and it would evaporate or sputter and it would provide an evaporated coat for the wall which would replace erosion from the wall.

If we have a plasma at 15 Kev and density 10^{14} of volume 300 M^3 and minor radius 3 meters, 15 M major radius, the energy of the plasma is

$10^{14} \times 300\ M^3 10^6 \frac{cm^3}{M^3} \times 15{,}000 \times 1.6\alpha 10^{-19}$ coul =

7.2×10^7 joules or 72 mega joules must be dissipated. Niobium seems to have heat of



fusion $\sim 6 \frac{K_{cal}}{GM\ mole}$

and an approximate heat of vaporization $\sim 70 \frac{K_{cal}}{GM\ mole}$

$76 \times 1000 \times 4.2 \frac{joules}{cal} = 32 \times 10^5 \frac{joules}{mole}$

This gives:

$\frac{72 \times 10^6\ joules}{3.2 \times 10^5 \frac{joules}{mole}}$ = 225 moles evaporate per shot, With 93 GM/mole we would evaporate 20_0 kilograms per pulse.

This is the maximum possible loss. If some energy goes into radiation or very high speed sputtered niobium atoms, then less niobium evaporation would be required to remove the heat. This is a more complicated calculation as follows:

If the niobium boils, T = 5200°K and the energy radiated is $\frac{dE}{dt} = \varepsilon\sigma T^4$. The emissivity, ε, is ∼ 0.24 and $\sigma = 5.76 \times 10^{-5}$ ergs $cm^{-2} dec^{-4} sec^{-1}$. So

$\frac{dE}{dt} = 1.45 \times 10^{-12} \frac{joules}{cm^2 dec^4 sec} \times (5.2)^4 \times 10^{+12} = 1050\ joules/(cm^2 sec) \approx 1 \frac{Kw}{cm^2}$:

The major circumference of a limiter is 10^4 cm so we could, with radiation, dissipate $1\ \frac{Kw}{cm^2} \times 10^4$ cm = 10 megawatts/cm Band. Thus if plasma could be made to heat a band 1 cm wide and if the limiter were moved in so that 7.2 seconds were consumed in wiping out the plasma, then the niobium would be just brought up to its boiling point - but all the energy would leave by radiation instead of evaporating any niobium. If the limiter were pushed in faster, niobium could be evaporated in any amount desired up to the 20 kilograms per pulse.

If gas purging could extend over 7 seconds, the heat flux rate to the vacuum wall would be the same as with radiation and particles from this niobium moving limiter. If the limiter could be moved in slowly enough so its thermal conductivity (0.3 watts/$_{(cm\,^oK)}$) would spread the heat throughout and hold it off the wall, we would need a limiter of a mass M to not melt at 2468°C.

$$MC_p \times 2000^\circ_{rise} = 72 \text{ megajoules},\ C_p = .064\ \frac{cal}{GM^\circ} \rightarrow M = \frac{72 \times 10^6}{2000 \times .064 \times 4.2}$$

M = 130 kilograms of niobium in the hoop. At a density of 8.5 GM/$_{cm}$3 and a hoop circumference of 10^4 cm we have only 1.5 cm^2 cross section for the hoop. For only a 200°K temperature drop halfway through this limiter, it would require 1.2 megawatts or ∿ 50 seconds for purging and that is slow. If we allow 1000° drop we get 10 seconds and if some melting and evaporation is allowed we may get to 5 seconds.