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Vertical Stabilization of INTOR

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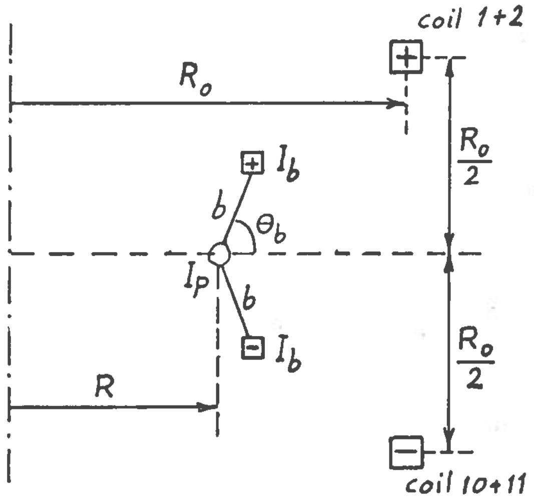
The new arrangement of the stabilization coil and of the vertical feedback coils (horizontal field coils) leads to a very similar response of the plasma as presented in our internal reports INT 101/80 and 101/80bis. We are referring to these two reports but for the sake of clarity, we repeat the essential points.

The situation is now the following :



We need the force/current ratio

$$F = \chi I_b \qquad \chi = \frac{2\mu_o R I_p}{b} \sin\Theta_b$$

$$b = 2.15$$
$$I_p = 6.5 \cdot 10^6$$
$$R = 5.3$$
$$\sin\Theta_b = 0.96$$

$$\underline{\chi = 40 \text{Vsec m}^{-1}}$$

The coefficient of elasticity in vertical direction is

$$K_h = \frac{n\mu_o \Gamma I_p^2}{2R}$$

Field index $n = -1.1$

Shafranov factor $\Gamma = 4.2$

$$K_h = -23 \cdot 10^6 \text{ AVsec m}^{-2}$$

The dynamic inductivity is given by

$$L_p = \frac{X^2}{K_h} = -70 \cdot 10^{-6} \text{ VsecA}^{-1} \quad \text{or} \quad L \equiv -L_p = +70 \cdot 10^{-6}$$

In order to create the analog feedback circuit we need the inductivity and the resistivity of the stabilizing loops. These loops form a one-turn coil with respect to the m = 1 mode. The inductivity L_s and the resistivity R_s are estimated to be 24 x 4 μH and 24 x $7 \cdot 10^{-5}\Omega$

$$L_s = 96 \cdot 10^{-6} \qquad R_s = 1.7 \cdot 10^{-3}$$

(see: 6th Meeting of the INTOR Workshop, March 1981)

The two horizontal field coils are supposed to have the same radius R_o, the upper coil is $R_o/2$ above the mid-plane and the lower coil is $R_o/2$ below the mid-plane. This is the most favourable case. Each coil has N turns. In the actual INTOR design, coils 1 + 2 and coils 10 + 11 are very close to the optimum position; they have a mean radius of $R_o = 11.5$. But the number of turns is different. In any case, an impedance matching depending on the number of turns has to be foreseen for the coupling to the feedback amplifier.

The transformer ratio N between the horizontal field coils and the stabilization coil is given by equating the field produced on the axis of the plasma if they were driven by the same current. The field of the stabilization coil is

$$B_h = \frac{\mu_o I_b \sin\Theta_b}{\pi b}$$

The field of the horizontal field coils is

$$B_h \cong 0.43 \frac{\mu_o R N I_h}{R_o^2} .$$

It follows $$\underline{N} = \frac{R_o^2 \sin\Theta_b}{0.43\pi \ Rb} \cong \underline{8.}$$

The inductivity will again be about $5 \cdot 10^{-3}$

$$L_d \cong 5 \cdot 10^{-3}.$$

It scales like R_o^4 because N scales like R_o^2. Here, the magnetic energy of L_s is no more negligible. In order to take this energy into account, we have to multiply L_s by N^2 and to add it to L_d :

$$\underline{L_d^*} = L_d + N^2 L_s \cong \underline{11 \cdot 10^{-3}}$$

We are now ready to introduce the new data in the expressions of the previous reports. The growthrate of the unstable plasma, when the feedback amplifier is disconnected, is

$$S_2 \cong \frac{R_s}{L} = 24,3 \text{ sec}^{-1}.$$

A logical assumption is to choose the FB gain in such a way as to create a rate of decay $-S_1$ equal to S_2. Thus we put

$$\frac{\alpha R_s}{2L} \equiv \frac{R_s}{L}$$

The position and the velocity FB gain become

$$\underline{g = \frac{R_s L_d^*}{L^2} = 3816 \text{ sec}^{-1}} . \qquad h + 1 = 3 \frac{L_d^*}{L} = 471 .$$

If ξ_o = 0.05m stands for the initial vertical displacement, the horizontal field current in each eight-turn coil behaves like

$$I_h = \frac{4\chi\xi_o}{L} \times e^{-x} \qquad (I_h)_{max} = \frac{4\chi\xi_o}{eL} = 42 \cdot 10^3 \text{ Amps} \qquad x = -S_1 t \ .$$

The voltage of both coils in series is

$$U_h = 4g\chi\xi_o(1 - x)e^{-x} \qquad (U_h)_{max} = 4g\chi\xi_o \ .$$

Finally, the switching power amounts to

$$P = 5.9\ R_s L_d^{\ *} K_h^{\ 3}\chi^{-4}\xi_o^2 \sim R_s n^3 b^4 R_o^{\ 4}.$$

Conclusions

1. With the above data the power amounts to

   P = 1280 MW.

2. The field index which we assumed to be n = -1.1 is more likely -0.5 (see: 6th Workshop INTOR III/2).

   Thus the power becomes
   P = 120 MW.

   The FB gain scales like n^2, which gives g = 788. This is still a fairly high power and a high gain.

3. The stabilizing loops have an unnecessarily high resistivity. By providing space for more loops, or by increasing the cross-section of the conductors, it may be possible to decrease the resistivity by a factor of 5. On the other hand, the inductivity will also be reduced, which leads to an L_d* of about $8 \cdot 10^{-3}$ instead of $11 \cdot 10^{-3}$. In this case, the power will be only

$$P = 18 \text{ MW}.$$

The FB gain is now g = 115, which is more confortable with respect to the backoff problem of the probes.