On Possibilities of Reactive RF Control

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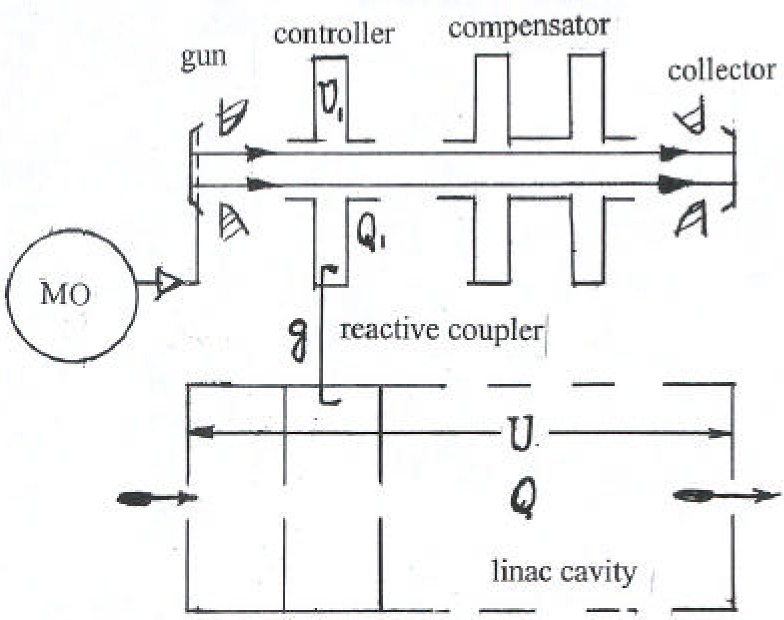
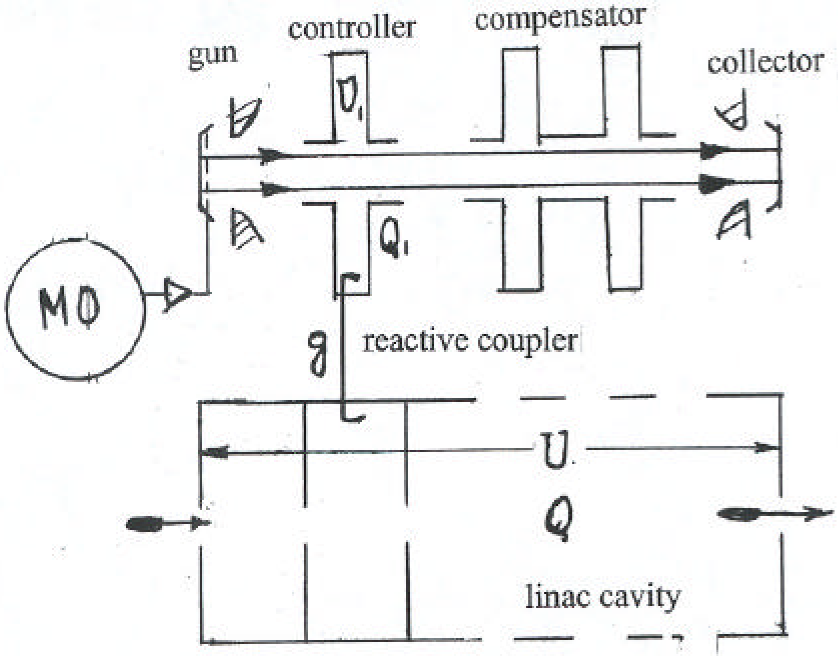
Reactive RF control principles



Abstract

A concept for reactive RF control is considered implementing a power-recovered current source (reactive klystron on superconducting cavities). The klystron is driven by the master oscillator and coupled reactively (i.e. conservatively) with the linac cavity. It stands locked (i.e. at zero voltage in its cavities) when the accelerator cavity is tuned perfectly to the master oscillator and beam under acceleration / deceleration. While detuned, the linac cavity excites the klystron cavity; the back influence results in effective compensation for the dephasing between linac cavity and master oscillator. The reactive klystron concept is the most adequate to the energy-recovered linac, but it also is extendable naturally to the active power source with the feature of automatic RF control in a wide frequency range.

Reactive RF control principles



Basic equations

$$U = |U| e^{i\psi}; \qquad \varepsilon = \omega_0 - \omega; \quad \varepsilon_1 = \omega_1 - \omega$$

$$\hat{\varepsilon} = \varepsilon + i\Lambda; \quad \hat{\varepsilon}_1 = \varepsilon_1 + i\Lambda_1$$

$$\dot{U} - i\hat{\varepsilon} U = g(C_1/C)^{1/2} U_1 - J_b/C$$

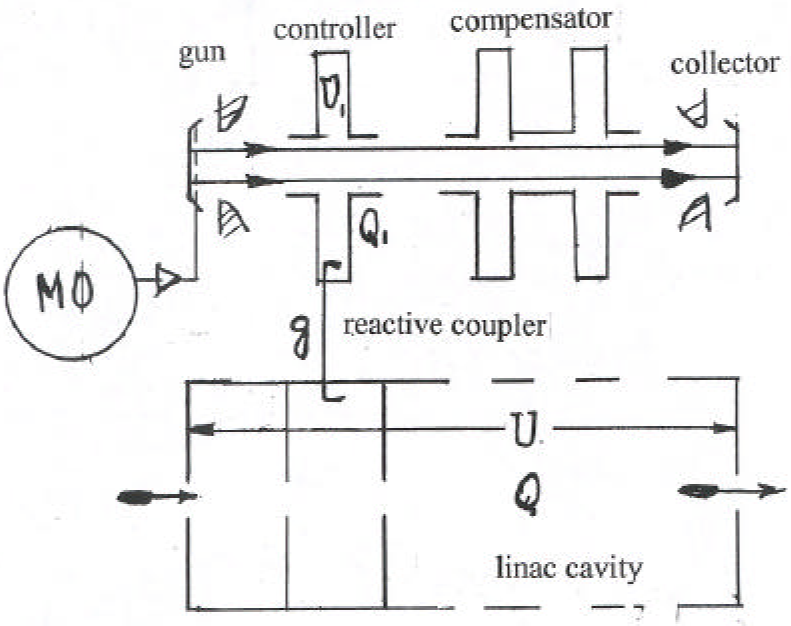
$$\dot{U}_1 - i\varepsilon_1 U_1 = -g^*(C/C_1)^{1/2} U + J_1/C_1$$

Ordered regime: $\varepsilon = 0, \ \varepsilon_1 = 0, \ U = U_0$

Then: $$J_1 = g^*\left(1 + \frac{\Lambda_1 \Lambda_0}{|g|^2}\right)\sqrt{C_1 C} \cdot U_0 \quad \text{(ordered)}$$

$$U_1 = \frac{\Lambda_0}{g}\left(\frac{C}{C_1}\right)^{1/2} U_0; \qquad \Lambda_0 \equiv \Lambda + \frac{J_b}{C U_0}$$

Reactive RF control principles



Control equations $(\varepsilon \neq 0,\ \varepsilon_1 \neq 0)$

Coupled modes relaxtion:

$$\omega_{\pm} = \omega + \frac{\hat{\varepsilon} + \varepsilon_1}{2} \pm \sqrt{|g|^2 + \frac{(\hat{\varepsilon} - \varepsilon_1)^2}{4}}$$

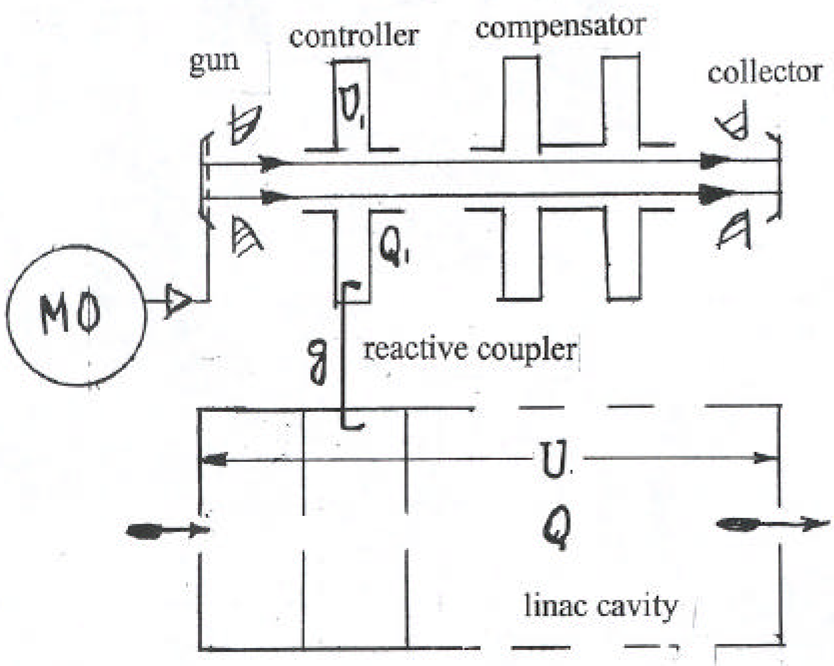
Frequency split

Frequency split stabilizes against electro-mechanical instabilities

$$|g| \gg |\hat{\varepsilon}|,\ |\hat{\varepsilon}_1|$$

Coupled cavities relax together...

Reactive RF control principles



(quasi) steady-state:

$$\Psi \approx (\Lambda_1 \varepsilon + \Lambda \varepsilon_1 - \dot{\varepsilon}) / |g|^2$$

$$\mathrm{Re}\, U \approx U_0 \cdot (1 + \varepsilon \varepsilon_1 / |g|^2)$$

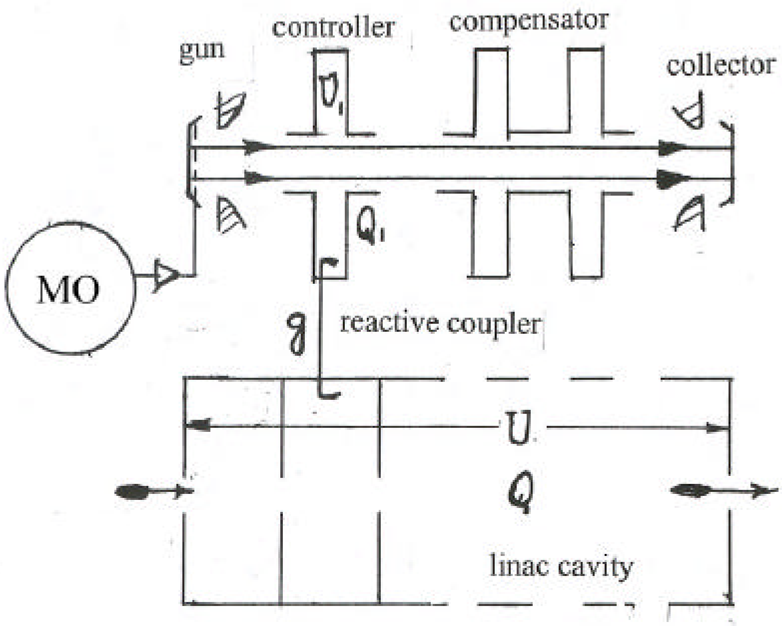
$$U_1 \approx \frac{\Lambda_0 - i\varepsilon}{g} \sqrt{\frac{C}{C_1}}\, U_0$$

Power consumption:

$$P = P_0 + P_1$$

$$P_0 = 2\Lambda_0 W_0 \; ; \qquad P_1 = 2\Lambda_1 W_0 \cdot \frac{\Lambda_0^2 + \varepsilon^2}{|g|^2}$$

Reactive RF control principles



Evaluation of parameters:

Choice due to klystron demands:

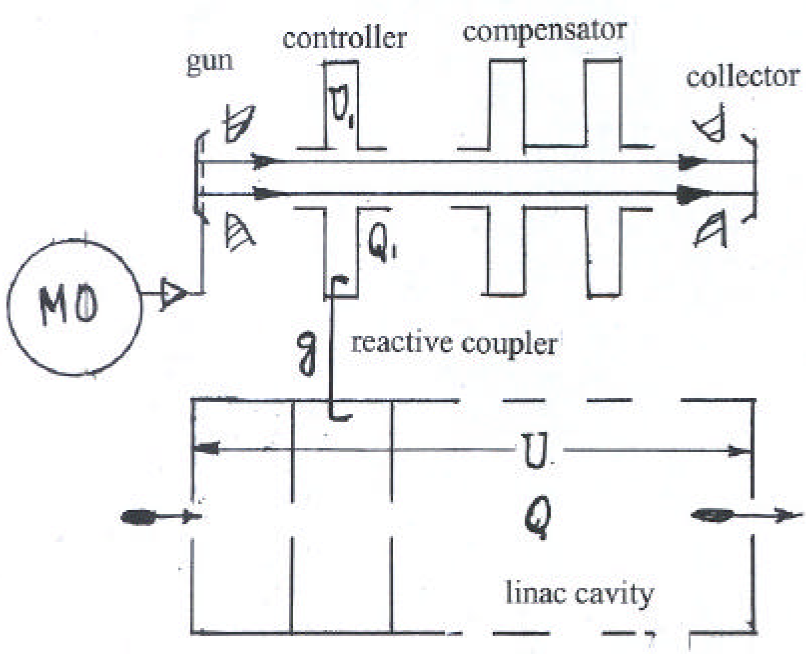
$$\left.\begin{array}{l} V_{DC} \sim 10-30\ kV \\ U_1 \lesssim 1-3\ kV \\ J_1 \lesssim 0.5\ A \end{array}\right\} \rightarrow g \sim 10^{-5} - 10^{-4}$$

$(C_1/C \sim 10-30)$

$/\ \varepsilon_{mph} \lesssim 2\cdot 10^{-8};\quad \varepsilon_{Lor} \lesssim 2\cdot 10^{-7}\ /$

• Q_1 can be limited by stability condition

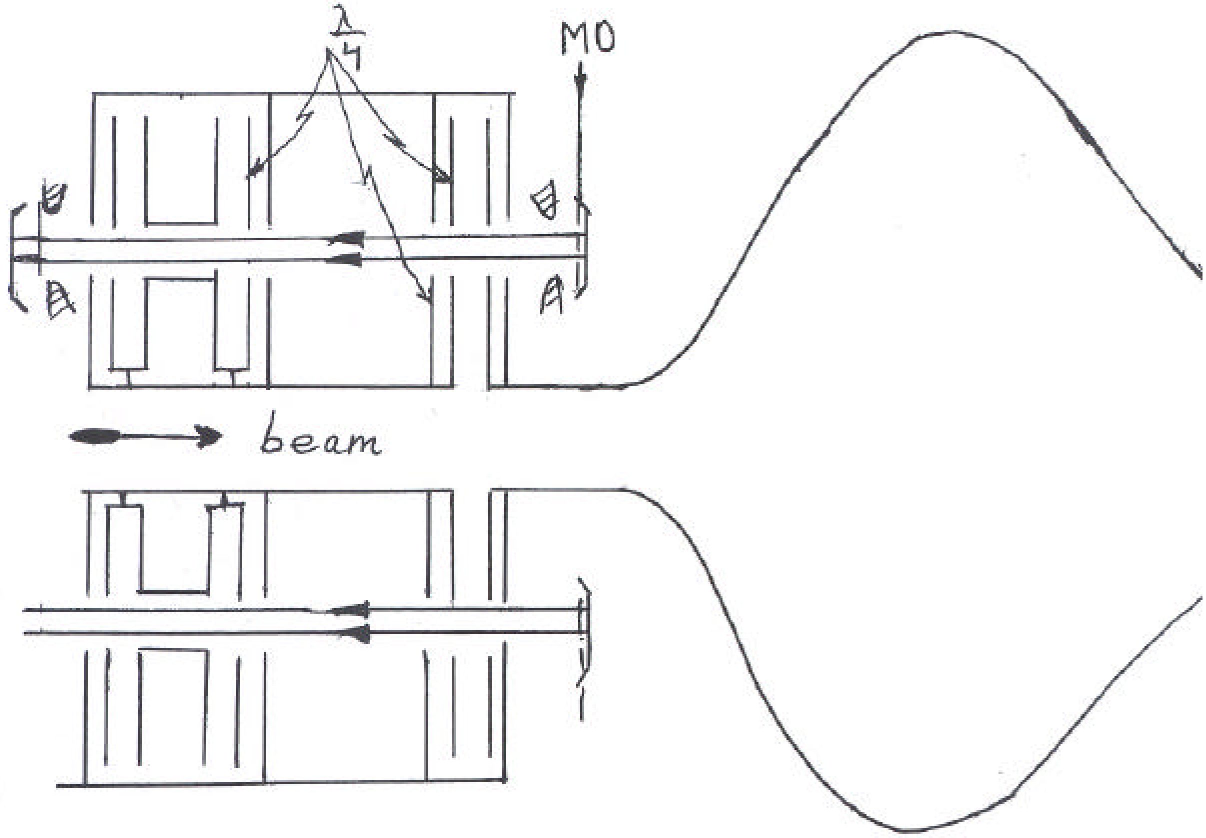
Reactive RF control principles



Ramp regime:

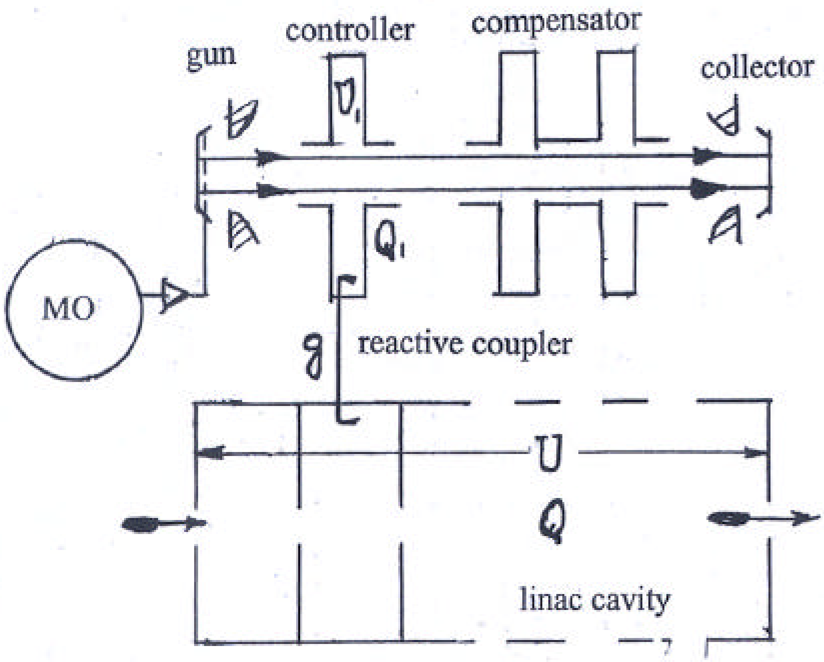
- Raise the cavities
- Raise beam current

} just ramp pre-amplifier gain



Conceivable (?) sketch design

Reactive RF control principles



Resume

- Very high Q_0 might be attainable
- Energy recovery could be stable
- Where is the limit of minimum power consumption?..