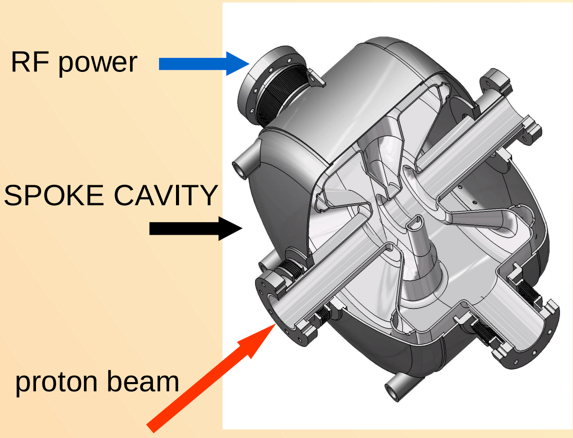
UPPSALA UNIVERSITET

# Amplitude and Phase Control of the Accelerating Field in the ESS Spoke Cavity

V.A. Goryashko* , V. Ziemann, R. Yogi, R. Ruber, Uppsala University;
vitaliy.goryashko@physics.uu.se;




We report about numerical simulations of the accelerating field dynamics in the ESS spoke cavity in the presence of the beam loading and Lorentz detuning. A slow feedforward is used to cure the Lorentz detuning whereas a fast feedback through a signal oscillator and cavity pre-detuning technique are applied to eliminate the beam loading effect. An analysis performed with a Simulink model shows that a combination of feedforward, feedback and cavity pre-detuning result in a substantially shorter stabilization time of the field voltage and phase on a required level as compared to a control method using only the feedforward and feedback. The latter allows one to obtain smaller magnitude but longer duration deviations of the instantaneous voltage and phase from the required nominal values. As a result, a series of cavities only with feedforward and feedback needs an extra control technique to mitigate a cumulative systematic error rising in each cavity. In addition, a technique of adiabatic turning off of the RF power in order to prevent a high reflected power in the case of a sudden beam loss is studied.

$$t_F \frac{\mathrm{d}A}{\mathrm{d}t} + A(1-2i\delta Q_L) = 2Q_L \frac{R}{Q}\left[I_i(t) - I_b^{DC}(t)F_b \mathrm{e}^{-i\phi_c}\right],$$

$$\frac{\Delta\omega^{opt}}{\omega} = \frac{(R/Q)I_b^{DC}F_b\cos\phi}{V_c}$$

$$I_r(t) = \frac{1}{2Q_L(R/Q)}\left[A(1+2i\delta Q_L) - t_F\frac{\mathrm{d}A}{\mathrm{d}t}\right] - I_b^{DC}(t)F_b \mathrm{e}^{-i\phi_c}.$$

$$P_{i,r} = \frac{R/Q}{2}Q_{ext}|I_{i,r}|^2.$$

$$\tau_m \frac{\mathrm{d}\Delta\omega}{\mathrm{d}t} = -[\Delta\omega(t) - \Delta\omega_T(t)] + 2\pi K_L E_{acc}^2,$$

$$Q_{ext}^{opt} = \frac{V_c}{2(R/Q)I_b^{DC}F_b\sin\phi}.$$

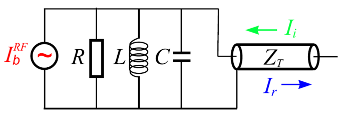



Figure 1: The lumped model: cavity modeled by an RLC circuit, the coupler by a connected transmission line of impedance $Z_T$ and the beam by a current source.

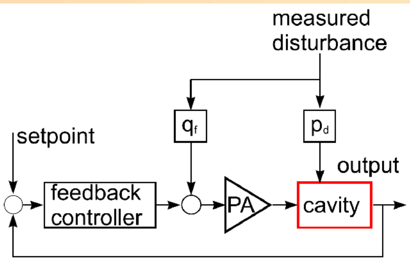



Figure 2: Feedback and feed-forward control of the accelerating voltage of a cavity fed by a power amplifier (PA).

We found that that a combination of feedforward, feedback and cavity pre-detuning allows one to stabilize the ESS spoke cavity voltage and phase within 10 microseconds on the nominal level such that the voltage magnitude error and phase error do not exceed 0.5% and 0.2º, respectively. The maximal required additional power is around 4.2%.

Table I. Beam and spoke cavity parameters.

| Parameter | Symbol | Value |
|---|---|---|
| Nominal DC beam current | $I_{b,DC}$ | 50 mA |
| Nominal beam power | $P_{b0}$ | 240 kW |
| Nominal cavity voltage | $V_c$ | 4.974 MV |
| Beam form-factor | $F_b$ | 1 |
| Accelerating phase (LINAC convention) | $\phi_e$ | 15.2 deg |
| Bare cavity $Q$-factor | $Q_0$ | $1.2\cdot10^{10}$ |
| Ratio of shunt resistance to total $Q$-factor | $R/Q$ | 426 Ω |
| Frequency | $f$ | 351.8 MHz |
| Optimal frequency detuning | $\Delta f^{opt}$ | −395 Hz |
| Optimal external $Q$-factor | $Q_{ext}^{opt}$ | $1.21\cdot10^5$ |
| Filling time | $t_F$ | 72 μs |

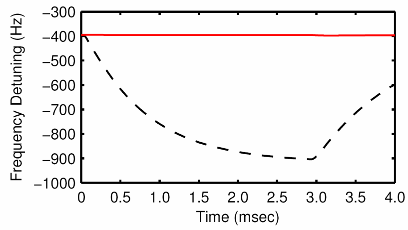



Figure 4: Dynamic detuning of the frequency caused by the electromagnetic pressure vs. time. The red solid curve and the black dashed curve stand for the cavity with and without control, respectively.

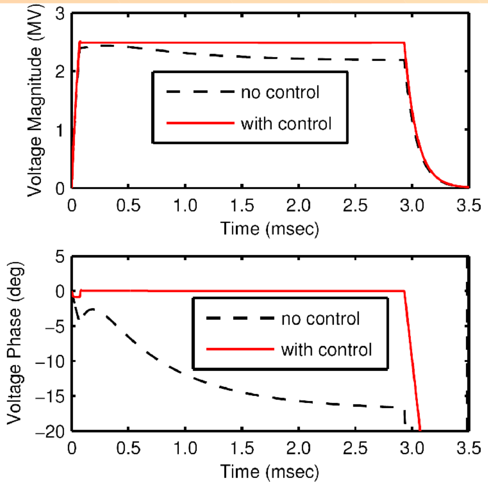



Figure 3: The cavity voltage magnitude and phase vs. time. The solid red curves stand for the spoke cavity with the implemented feedback and feed-forward control whereas the dashed black curves stand for the case with no control.

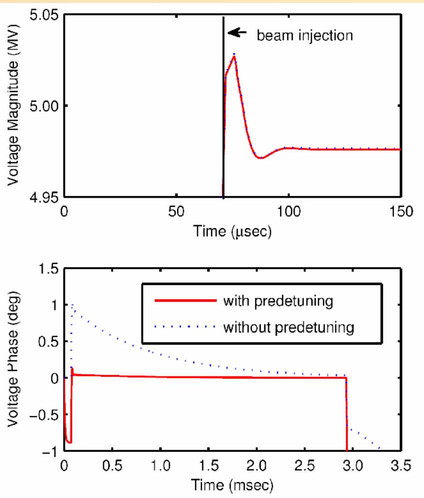



Figure 5: The voltage magnitude and phase of the controlled cavity with (red solid curve) and without (blue dotted curve) the cavity predetuning vs. time. Note that the time scales are different.

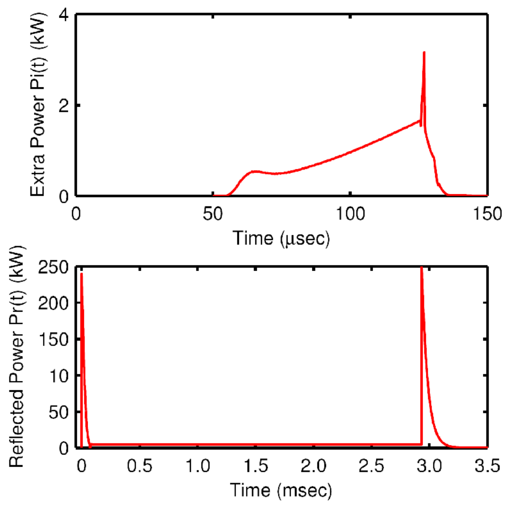



Figure 6: The extra incident power $P_i(t)$ required to compensate the beam loading and the reflected power $P_r(t)$ vs. time. Note that the time scales are different.

If the beam is lost, then the cavity is charged to the voltage that is twice of the nominal voltage and the stored energy becomes four times higher. As a result, the reflected power is four times of the incident power at the moment of the cavity emptying if the generator is turned off on a time scale much smaller than the filling time. Such a high reflected power is a stress for the coupler and transmission line. It turns out that by shaping the RF pulse tail one can substantially decrease the reflected power during turning off the generator RF pulse. If the turning off time is more than $5t_F$, then the reflected power almost does not exceed the incident power.