ThomX LLRF

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Synchrotron SOLEIL

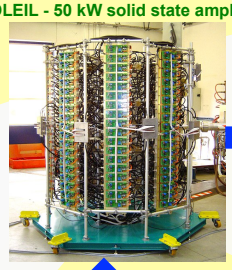
ABSTRACT

ThomX is a compact source of hard X rays relying on Compton Back Scattering (CBS). SOLEIL is particularly involved in the design of the accelerator complex, which consists in a high brightness electron LINAC injector and a 50 MeV storage ring where the electron bunch collides with a laser pulse inside an optical resonator. Preserving the electron beam quality in such a low energy storage ring without synchrotron radiation damping is quite challenging. That requires the use of efficient longitudinal and transverse feedbacks in order to stabilize the beam. In the transverse case that will be achieved by means of a four plate strip line broadband kicker, while the longitudinal kick will be generated through the main 500 MHz accelerating system. For this purpose the LLRF system, which is presented here, will include a high gain direct RF feedback and a fast phase loop.

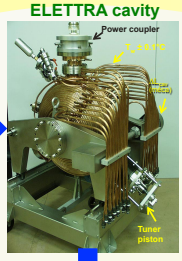
INTRODUCTION

ThomX is a compact source of hard X-rays relying on CBS. It consists in a 50 MeV LINAC, which injects a single bunch of electrons into a 15 m circumference storage ring (SR). At each turn, the electron bunch collides with laser pulses, accumulated in a Fabry Perrot optical resonator. The laser-electron interactions result in a fast degradation of the electron bunch quality, limiting its storage to duration as short as 20 ms. That requires an injection rate of 50 Hz; after 20 ms the electron bunch is extracted towards a beam dump and a new one is injected. Preserving the electron beam quality in such a low energy storage ring without synchrotron radiation damping is quite challenging. That requires the use of efficient longitudinal and transverse feedbacks in order to stabilize the beam. In the transverse case that will be achieved by means of a four plate strip line broadband kicker, while the longitudinal kick will be generated through the main 500 MHz accelerating system, which consists in a single cavity of ELETTRA type, powered with a 50 kW solid state amplifier of SOLEIL type. For this purpose the LLRF system, which is presented here, will include a high gain direct RF feedback and a fast phase loop.

SOLEIL - 50 kW solid state amplifier



ELETTRA cavity



The choice of the ELETTRA cavity was dictated by the need of limiting as much as possible the HOM excitations.

HOM tuning to prevent resonant excitations by the beam

→ **Combination of 3 tuning means :**

- f_{HOM} control by temperature ($30°C < T_w < 60°C \pm 0.05°C$)
- Mechanical system → ΔL_{cav} → Δf_o
- Piston tuner

→ **HOM damping by several 10^3**

LLRF
Digital or analog system for slow perturbations
+
Direct RF feedback and beam phase loop
for fast energy/phase oscillations (@ fs=500KHz)

Beam Position

Main sources of beam perturbations

- δE_i , $\delta \Phi_i$ errors at the injection
- Collective effects due to LINAC / AS mismatch
- HOM excitations
- Injection transient beam loading (I_b : 0 to 20 mA instantaneous)

Energy/ phase oscillations

Laser pulse duration: 5 ps rms
Bunch length: 20 – 30 ps rms

e⁻ / laser synchronization requirement:
$\Delta t < 5$ ps → $\Delta\phi < 1°$

$(\Delta E / E)_{inj} = \pm 0.5$ % (LINAC) → $\Delta\phi_{inj} = \pm 8°$ (AS) ⇨ Injection phase error amplified by mismatch and HOM

- τ_d ~ 1 s >> τ_{sr} = 20 ms → ~ There is no natural damping during τ_{sr}
- f_s = 500 kHz >> BP_{cav} = 25 kHz → no damping by RF cavity

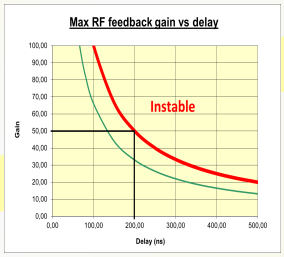
→ Only 3 solutions to damp (requirement => τ_d ~ 25 µs) :

1) additional longitudinal feedback system with a broadband kicker
2) Harmonic cavity → « Landau damping »
3) RF feedback in order to enlarge effective cavity band pass

=>no need for additional cavity

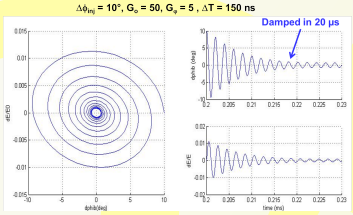
Simulink RF system simulation

Max RF feedback gain vs delay



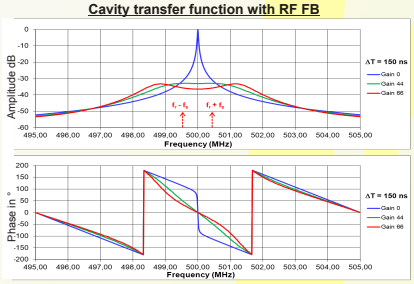
Phase oscillations / energy with RF FB + beam referenced phase loop

$\Delta\phi_{inj}$ = 10°, G_ϕ = 50, G_φ = 5 , ΔT = 150 ns

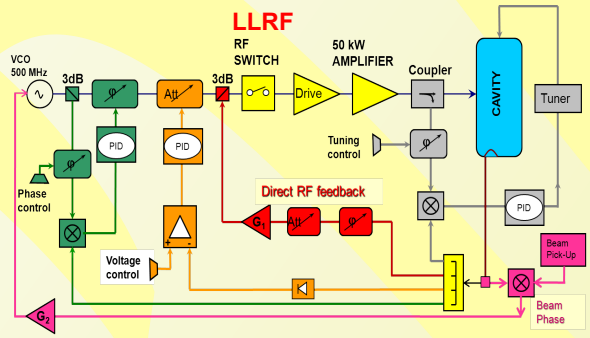


→ $T_{damping}$ = 3µs with $G\varphi$ = 30 (stability limit)

Cavity transfer function with RF FB



LLRF



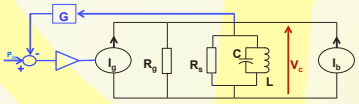
For "slow" perturbations (>> τ_f^{cav} = 40 µs) →
Conventional LLRF with 3 loops
→ Present SOLEIL LLRF system adapted to 500 MHz

- Frequency
- Amplitude
- Phase

For fast perturbations @ fs
→ $\Delta\varphi_{inj}$, HOM, ...

- Direct RF feedback (G ~ 50)
- Fast beam phase loop (BW > 500 kHz)

Direct RF feedback



With FB : $Z'(\omega) = \frac{Z(\omega)}{1 + G(\omega) Z(\omega)}$; $G(\omega) = \frac{G_0}{R_s} e^{-j\omega\Delta T}$ ← FB delay

$Z' = \frac{Z}{1+G_0}$ → $BP'_{cav} = BP_{cav} \times (1+G_0)$

Gain max (stability limit) → $1 + G_0 < \frac{\pi Q_L}{2\omega_s \Delta T}$

ThomX : ampli - cavity distance ~ 10 m → ΔT ~ 150 ns
→ G_{max} ~ 60 → BP > 1 MHz > f_s

SUMMARY

Preserving the beam quality in the ThomX SR requires damping the energy/phase oscillations within about 25 µs. That can be achieved through the main 500 MHz accelerating cavity. For this purpose the LLRF system shall consist in a conventional system including relatively slow loops for frequency, amplitude and phase control, complemented by a direct RF feedback of high gain (~ 50), aimed at widening the effective cavity bandwidth (> fs = 500 kHz) and a fast phase loop, itself with a bandwidth > fs. An additional four plate strip line broadband kicker will be implemented in order to damp the transverse oscillations.