LHC Orbit FB

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- Some feedback concepts
- Magnets & power converters for feedback
- Sampling, delays…
- IR layout
- Conclusion

The scene

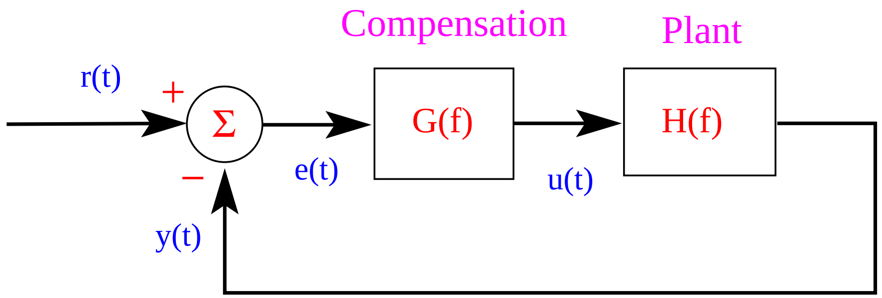
The role of the orbit feedback is to maintain the orbit as close as possible to a given reference. The starting point is :

- A good CO has already been established by the operation crews.
- The collimators have been positioned & adjusted around that CO.

Feedback I

The key roles of a feedback :

- Tracking of a reference r(t).
- Disturbance rejection (noise,…)



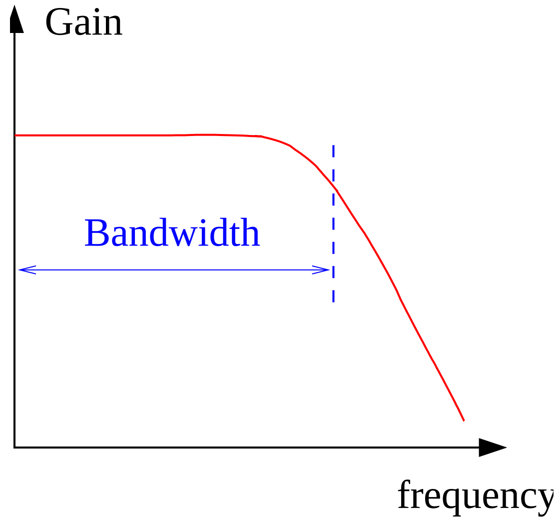
A classical feedback acts on a plant (car, plane..) with some internal dynamics represented by a transfer function H(f). The dynamics is the key to the design of the compensation G(f) which evaluates the actuator settings u(t) (for us the corrector magnets).

In accelerators there is (in general) almost no dynamics, except for magnets and power converters. The design is mostly driven by the noise i.e. disturbance rejection, because usually one chooses very fast actuators (correctors) → this is somewhat different for LHC !

Feedback II

Characteristics of the feedback

- Bandwidth BW
- Gain
- Robustness
- …



For a digital feedback, the signal sampling frequency f_s should be significantly larger than the desired BW :

$$f_s \approx (6 - 30)\ BW$$

Digital Control

Many designs for control loops with sampling interval T.

The classical way is to use a PID controller :

$$u_k = K \left(e_k + (T/T_I) \Sigma e_k + (T_D/T)(e_k - e_{k-1}) \right)$$ at step k..

Proportional **I**ntegral **D**ifferential

K, T_I and T_D are adjusted to obtain a good FB response.

A somewhat different but attractive and powerful design is based on a ***State-Space formalism*** which is used as a standard in ~ all SLAC digital feedback loops.

Under investigation (with help of EPFL…)

PC bandwidth

Consider a Power Converter which should produce a current @ a frequency f :

$$I(t) = I_0 \sin(2 \pi f t)$$

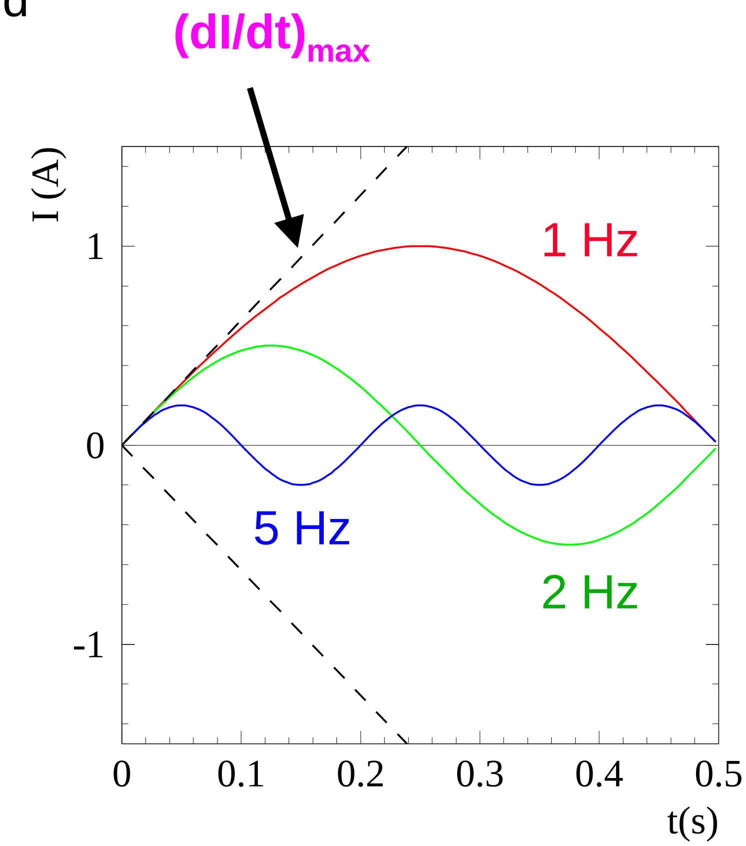
The peak current derivative is

$$(dI/dt)_{peak} = \pm 2 \pi f I_0$$

If the PC is limited by $(dI/dt)_{max}$, I_0 cannot exceed

$$I_0 = (dI/dt)_{max} / (2 \pi f)$$

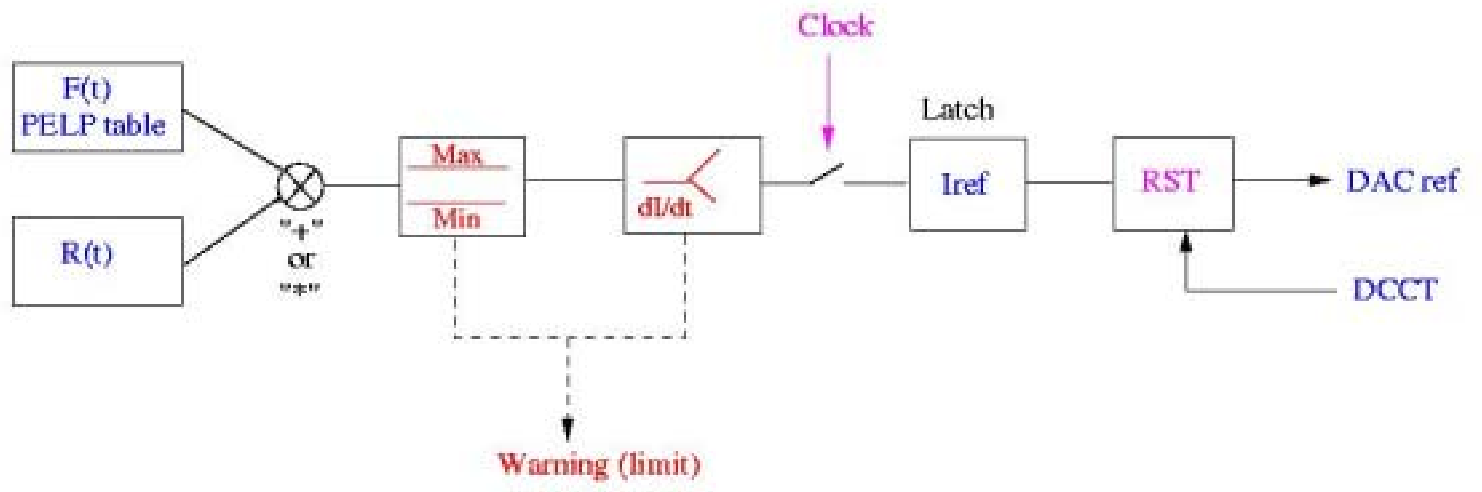
… or I(t) will be distorted (delays…)



PC controllers

The PC digital controllers :

- table [F(t)] + real time [R(t)] inputs.
- inputs are clipped according the I and dI/dt limits.
- clipped inputs are sampled every 1 to 500 ms (latch).
- the current loop runs at up to 10 Hz.
- internal delay for R(t) ~ 10-20 ms (depends on PC type).



Cold correctors I

Component	Parameter	Value
Magnet (MCBH/V)	L	7 (H)
	R	20 (mΩ)
	$\tau = L/R$	230 (s)
	$(BL)_{nom}$	1.9 (Tm)
	I_{nom}	55 (A)
	θ_{nom} @ 450 GeV	1.26 (mrad)
	θ_{nom} @ 7 TeV	81 (μrad)
PC	I_{max}	± 60 (A)
	U_{max}	± 8 (V)
PC ⊕ Magnet	$(dI/dt)_{max}$	0.9 (A/s)

Cold correctors II

The cold correctors have very long time constants τ corresponding to a natural (open-loop) frequency of :

$f_{ol} = 1 / (2 \pi \tau) = 0.5$ mHz → Difficult to run @ 1 Hz or more → Need a large voltage ! (L dI/dt)

At 1 Hz :

$\max(I_0) = 0.1$ A → kicks of 2 μrad @ 450 GeV
0.1 μrad @ 7 TeV

At 7 TeV a single corrector can move the orbit by ~ 10 μm (β = 100 m)

NB : the DISS orbit correctors have similar characteristics (τ,…)

Warm correctors I

Component	Parameter	Value
Magnet	L	~ 20 (mH)
	R	~ 25 (mΩ)
	τ = L/R	~ 0.8 (s)
	$(BL)_{nom}$	2.2 (Tm)
	I_{nom}	500 (A)
	θ_{nom} @ 450 GeV	1.46 (mrad)
	θ_{nom} @ 7 TeV	94 (μrad)
PC	I_{max}	± 600 (A)
	U_{max}	± 40 (V)
PC ⊕ Magnet	$(dI/dt)_{max}$	**1250 (A/s)**

Warm correctors II

The warm correctors have much shorter time constants τ corresponding to an open-loop frequency of :

$$f_{ol} = 1 / (2 \pi \tau) = \sim 0.2 \text{ Hz}$$

They will be able to run @ 10 Hz – potentially at 20 Hz…

At 10 Hz :

$max(I_0) = 20$ A → kicks of 58 μrad @ 450 GeV
3.8 μrad @ 7 TeV

At 7 TeV a single corrector can move the orbit by ~ 400 μm (β = 100 m)

Correction algorithms

The choice of the correction algorithms need not be done now. But there is some advantage of using corrections based on Singular Value Decomposition (SVD) :

- correction is extremely fast and flexible (the real number crunching is done in advance or in parallel by a dedicated process).
- can be configured to prevent building up local bumps.
- requires smaller kick strength but uses (many) more correctors than the MICADO algorithm – good with “slow” correctors !
- for local corrections, a closure must be enforced using 1 or 2 correctors on each side of the target area.

This algorithm is used with success in ~ all synchrotron light sources…

Sampling, delays

Some characteristics :

- Orbit sampling frequency of **10 Hz** → **BW < 1-2 Hz**
- Estimated delays in milliseconds (***for central FB***) :

Delay source	*Min*	*Max*
Data Acquisition	20	20
Network	2.5	25
Correction algorithm	<< 10	30
Power Converter Control	20	50
Total	52.5	125

A delay δ limits BW :
BW < ~ $1/(3\delta)$

→ **BW < ~ 6 Hz**

NB : for a frequency $1/f = 2\delta$ the correction would be 180 out of phase with the signal and drive the system into instability !

Global & local

The feedback could be split into more that one loop which could be :

- Global i.e. affecting the orbit in the whole ring.
- Local around collimation insertions → require closed corrections.

LEP experience ⊕ snapback & field decays in the LHC :

- A global orbit feedback is/will be very useful.
- This global feedback need not be ***fast*** (BW of 0.2-0.4 Hz).
- It will not differ much from a classical “measure-correct” sequence…

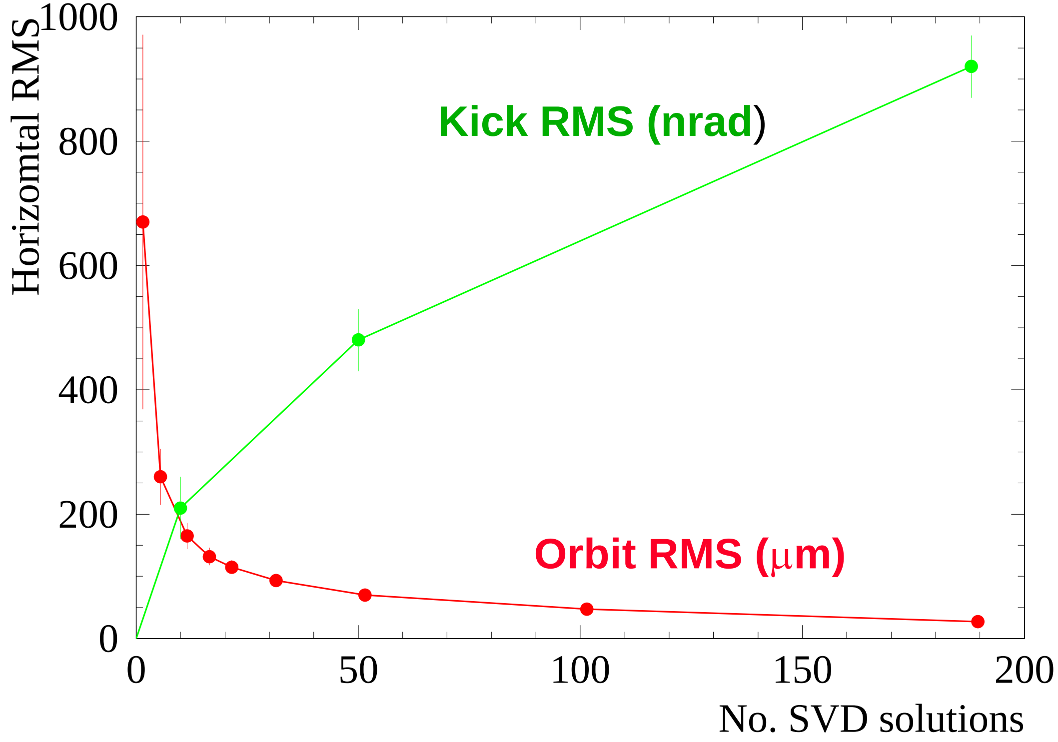
The global feedback could be complemented by FASTER local loops with BW of 1.0 Hz and more (?).

Such a frequency decoupling is a standard way to decouple the loops.

Snapback

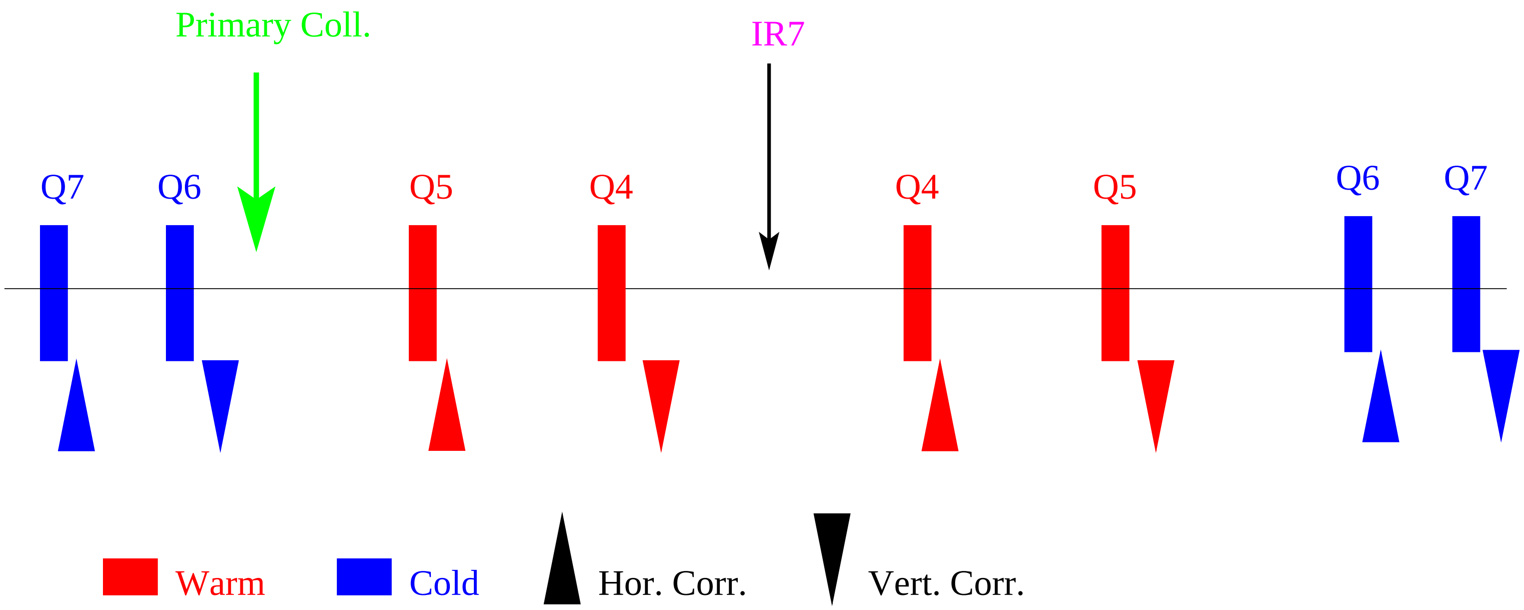
Global correction for b1 decay of 0.75 units using only cold arc correctors.

Kick strengths and orbit RMS are adequate…



IR7 layout

Example for beam 1 :



→ **too few warm correctors to take advantage of their "speed" !**

Local steering

To stabilize the **angle & position** @ **primary collimator** :

- Need 2 correctors/plane on each side (4 corrector bump).
- We must use correctors in the cryostat of Q7 & beyond :

  →limited by speed of cold correctors !

If we could replace the cold correctors @ Q6/Q7 by warm correctors :

- Try a local steering with 4 correctors (must be closed !!).
- Steer only position @ primary using a 3 corrector bump.
- Must check if that makes any sense !

Obviously the similar limitations due to cold correctors apply for local corrections around the entire IR7 (extending into the DISS).

Summary I

With the present layouts and hardware we are limited in BW :

- by cold correctors to **~ 1 Hz**
- by orbit sampling to **1-2 Hz**
- by delays to **~ 5 Hz**

We could increase the BW (to **5-10 Hz**) by :

- ***installing more warm correctors in IR3/7.***
- increasing the orbit sampling to 20 Hz or more (local ACQ).
- limiting the delays as much as possible (going local…).

to be evaluated !

Summary II

Global feedback :

- required to stabilize the orbit at injection, during snapback, ramp..
- bandwidth of 0.2–0.5 Hz is probably adequate.
- should not be a problem.

Fast local feedbacks :

- must clarify the requirements :
  - **position/angle @ primary ?**
  - **overall (local) correction over IR ?**
  - **….**
- do we need 10 Hz ?
- …