noise requirements for LHC transverse damper

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references:

K. Ohmi, CARE-HHH LUMI’06 and PAC’2007

Y. Alexahin, NIM-A paper 1997

effect of random kick

- (part of) initial oscillation filaments due to large beam-beam tune spread
- kick leads to offset at IP which results in second order beam-beam kick that can also filament, and possible third, fourth order etc.
- relative magnitude:

$$\sqrt{\beta^*}\Delta x' = -4\pi\xi \frac{x}{\sqrt{\beta^*}} \approx 0.1 \frac{x}{\sqrt{\beta^*}}$$

- initial term dominant for hadron colliders

LHC feedback system (W. Hofle)

- 14 bit resolution, 2^{14}=16384.
- area covered is Δx=+-2 mm at β=100-150 m, resolution is $\boldsymbol{\delta X_{mon}=0.001\sigma}$
- ***G***: damping rate of feedback system (feedback gain) for betatron amplitude
- electronic kicker noise $\boldsymbol{\delta X_{kick}}$ negligible?!

K. Ohmi, LUMI'06

coherent betatron amplitude with feedback system (no beam-beam):

$$X_{i+1} = X_i - G\left(X_i + \delta X_{mon}\right) + \delta X_{kick}$$

fluctuation of betatron oscillation amplitude:

$$\left\langle X^2 \right\rangle = \frac{1}{2G}\left(G^2\left(\delta X_{mon}^2\right) + \left(\delta X_{kick}^2\right)\right)$$

K. Ohmi, PAC'07

optimum gain:

$$G_{opt} = \frac{\delta X_{kick}}{\delta X_{mon}}$$

example:

G~0.1, δX_{mon}~10^{-3} σ_x, δX_{kick}~0

→ $\Delta X/\sigma_x$~2.2×10^{-4}

→ $\Delta x/\sigma_x$~1.6×10^{-4}

analytical theory of emittance growth from noise

w. decoherence & feedback [Y. Alexahin, NIMA391, 73 (1997)]:

$$\frac{1}{\varepsilon}\frac{d\varepsilon}{dt} \approx f_{rev}\frac{1-s_0}{4}\frac{(\Delta x)^2}{\sigma_x^2}\frac{1}{\left(1+\frac{G}{2\pi|\xi|}\right)^2}$$

G~0.1 feedback gain, ξ~0.01 total beam-beam parameter, s_0~0.645 related to the fact that only a small fraction of the energy received from a kick is imparted on the continuum eigenmode spectrum

1% emittance growth per hour ↔ Δx^*=1.4 nm ($\Delta x/\sigma_x$~9×10^{-5}) w. feedback ↔ Δx^*=0.9 nm w/o feedback (σ_x^*=16 μm, $\Delta x/\sigma_x$~6×10^{-5})

strong-strong beam-beam simulations of LHC emittance growth from noise (code BBSS)

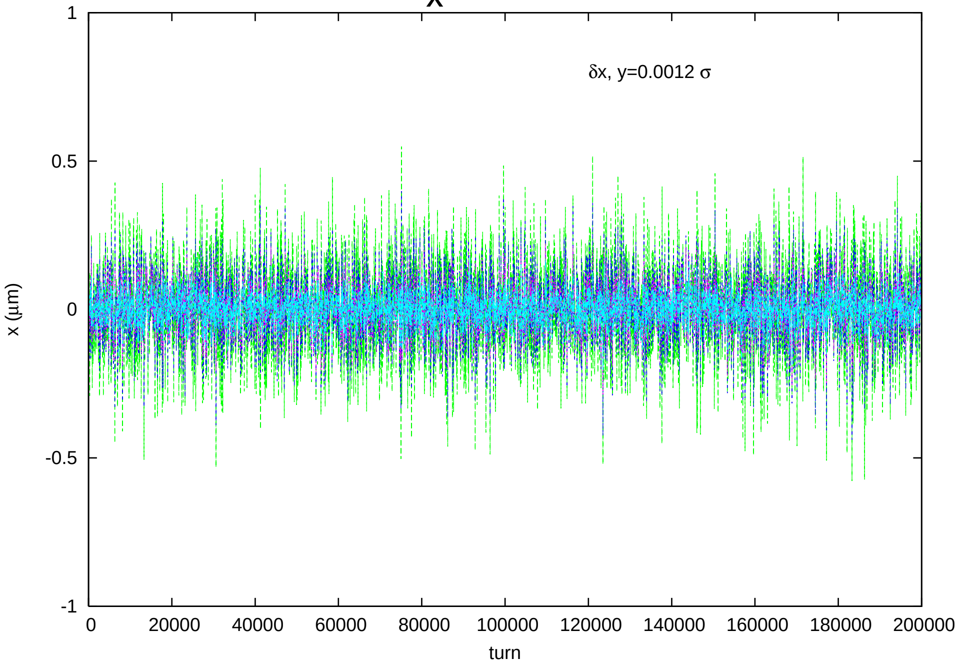
[K. Ohmi, LUMI'05, LUMI'06, BEAM'07,PAC07]:

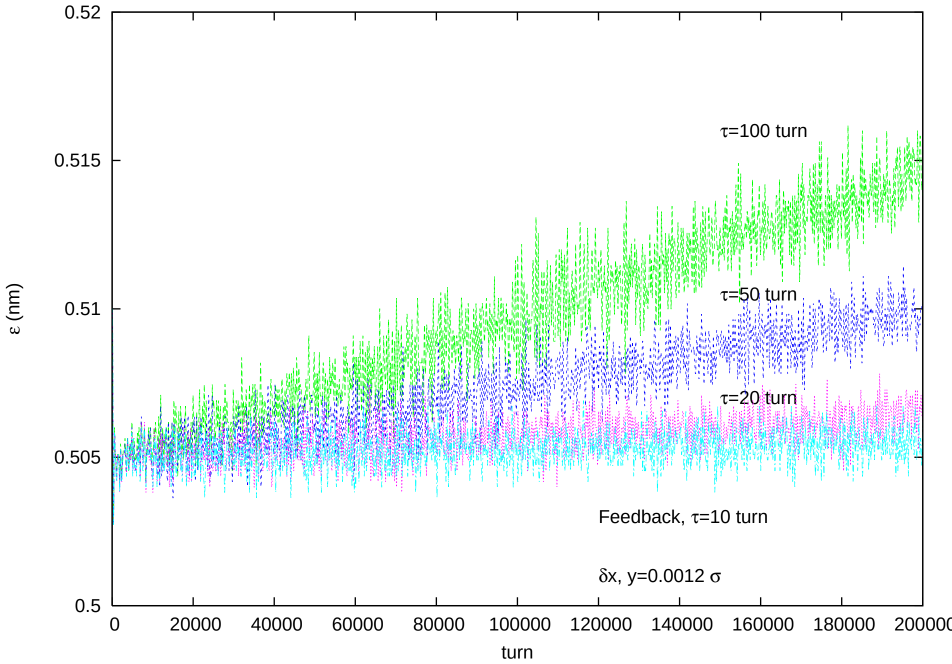
simulation with 10^6 macroparticles / beam

nominal LHC?, 1 IP?

residual dipole amplitude & emittance growth

$\delta x = 0.0012\ \sigma_x$

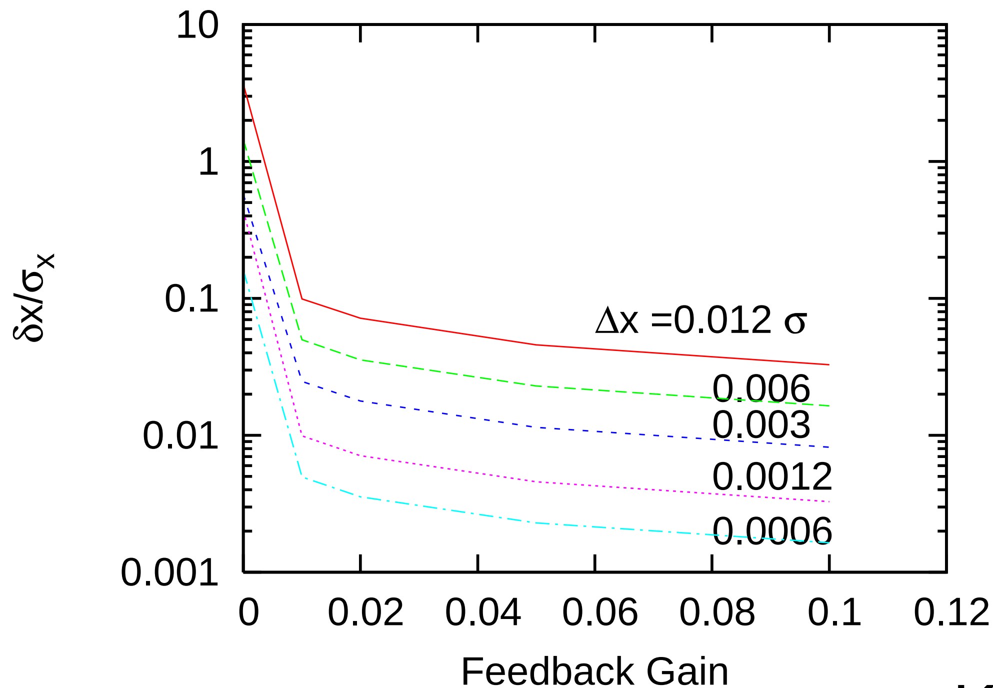




K. Ohmi, LUMI'06

residual dipole moment

- $<X^2> \sim \delta x_{kick}^2/(2G)$
- beam-beam interaction has little effect on the residual dipole motion



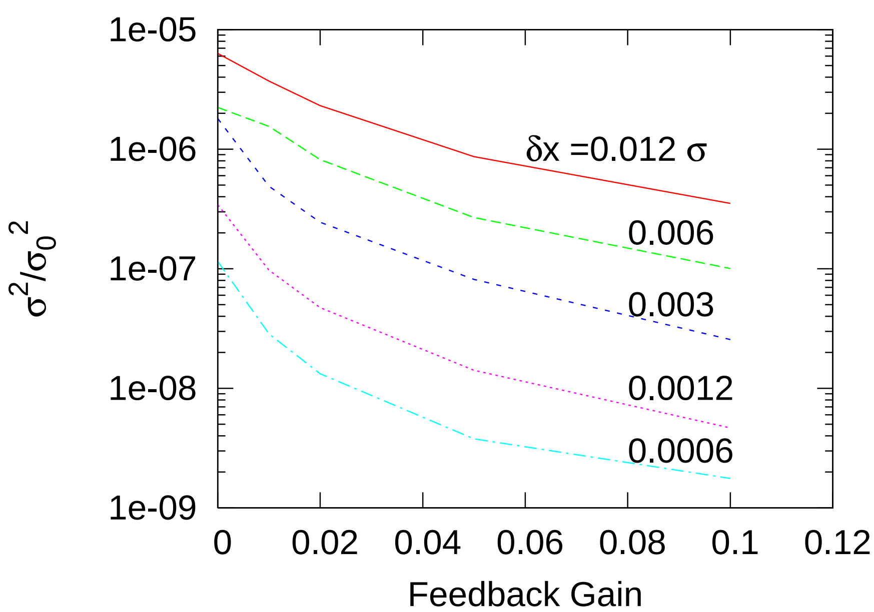
K. Ohmi, LUMI'06

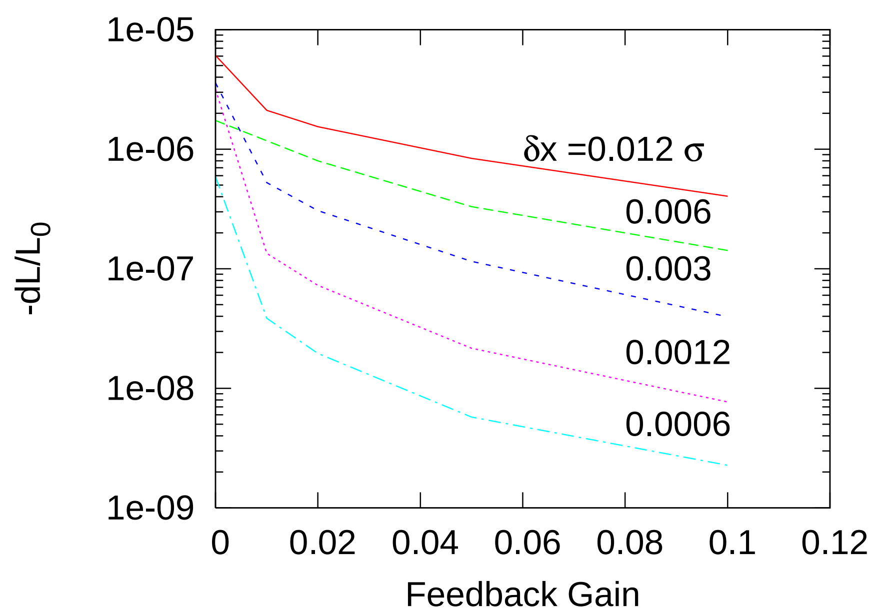
emittance growth rate (/turn) and luminosity decrement in the strong-strong simulation

- for G=0.1 and δx_{mon}=0.1%σ, δx_{kick}=0.0002σ, the luminosity life time is 1day

  (nominal LHC, 1 IP)

K. Ohmi, LUMI'06

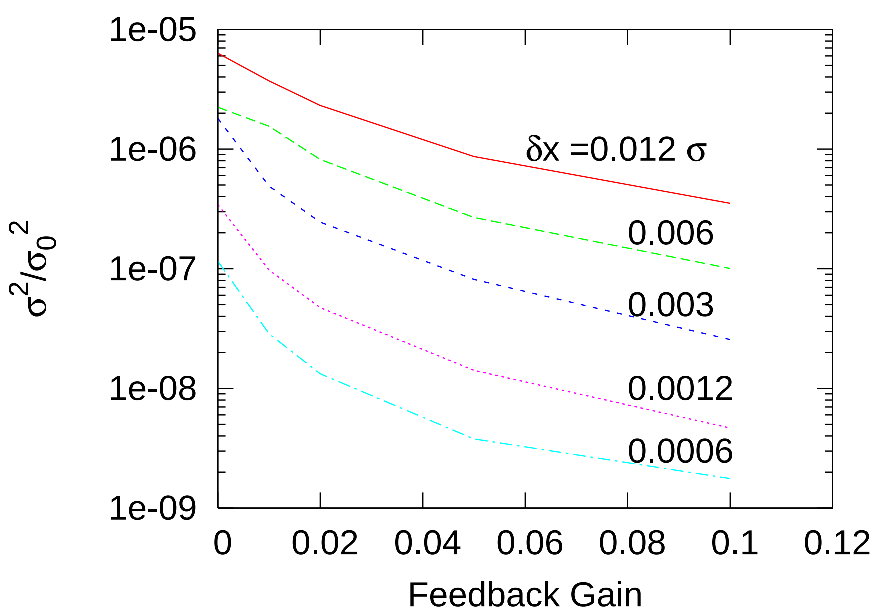


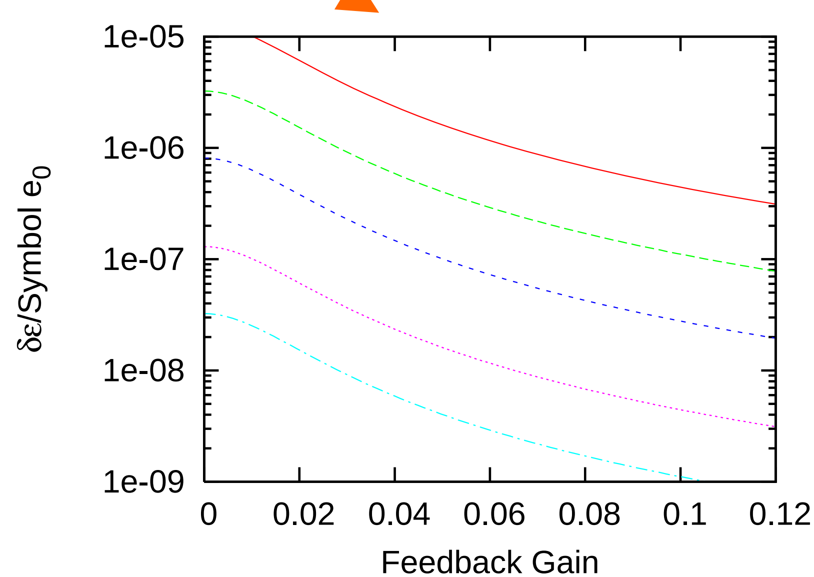


comparison with analytic theory

- agreement with formula of Y. Alexahin is very good.
- note: simulating down to luminosity decrements of 1e-9 is difficult because statistical fluctuation ~ random offset

$$\frac{1}{\varepsilon}\frac{d\varepsilon}{dN} \approx 0.09\left(\frac{\delta x}{\sigma_x}\right)^2 \frac{1}{\left(1+\frac{G}{2\pi\xi}\right)^2}$$





K. Ohmi, LUMI'06

LUMI'06 & PAC07 summaries by K. Ohmi (modified)

- emittance growth sensitive to feedback noise & feedback gain
- w/o kicker noise, the nominal monitor resolution from 14-bit system over 2 mm may be just sufficient
- higher feedback gain enhances effect of kicker noise, but reduces effect of monitor noise (an optimum gain value exists!)
- theory (Alexahin) and strong-strong simulation (Ohmi) are in good agreement