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Transverse Damper

Outline of Presentation

- Principle and performance specification
- Implementation, layout, controlling and interlocking
- Abort gap cleaning
- Worst case faults and protection
- Conclusions

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- **JINR (Dubna, Russia) -> collaboration for power amplifiers and kickers**

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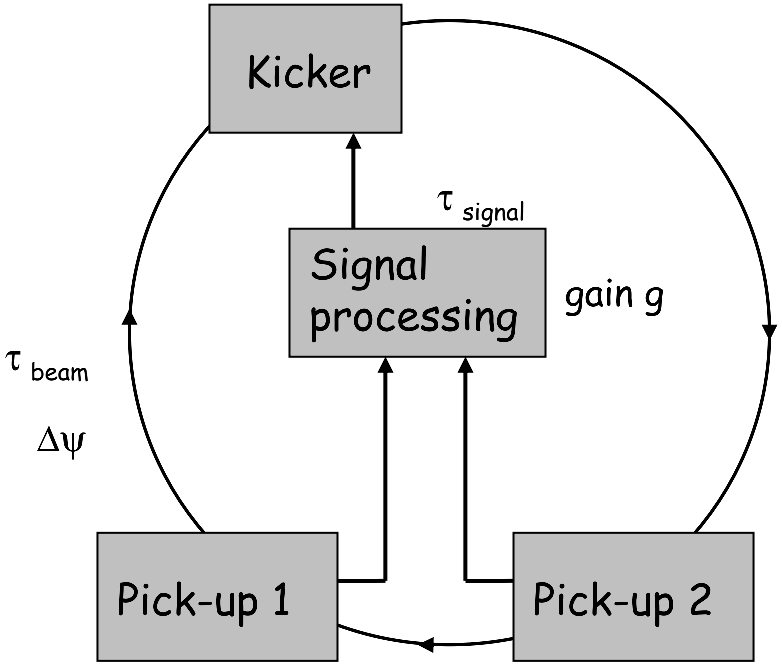
Transverse damper/feedback



Need real-time digital signal processing

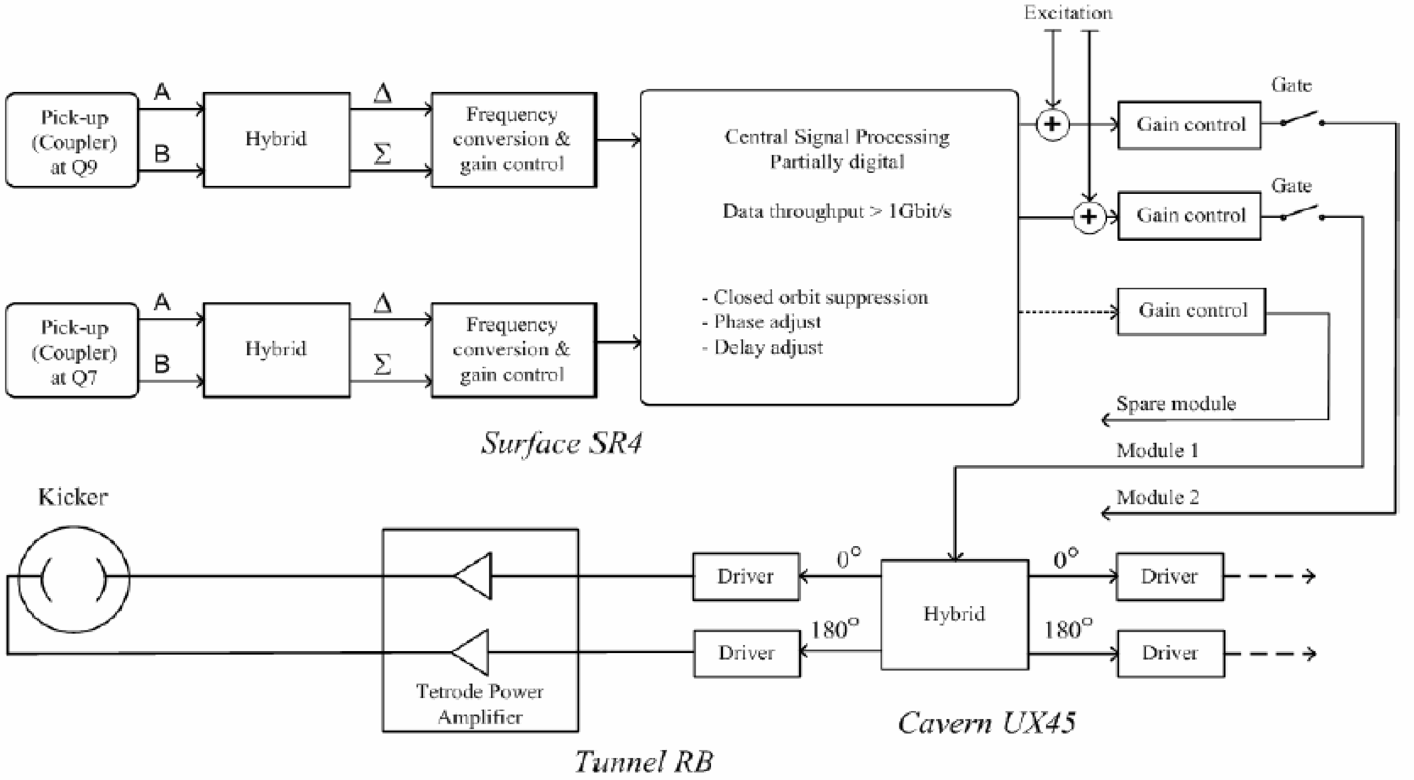
Match delays:
$\tau_{signal} = \tau_{beam} + MT_0$

T_0 : beam revolution time

M=1: very common ->
"One -Turn-Delay" feedback

- damping: of transverse injection oscillations
- feedback: curing transverse coupled bunch instabilities
- excitation: of transverse oscillations for beam measurements & other applications

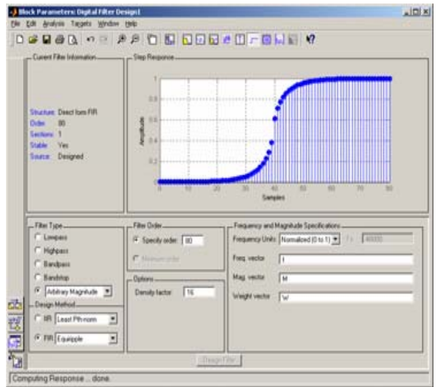
LHC: **Four** transverse damper systems (one per plane and beam)



Nominal performance specification (1)

Equipment nominal performance specification:

choice:	electrostatic kickers ("base-band")
aperture	52 mm
kickers per beam and plane	4
length per kicker	1.5 m
nominal voltage up to 1 MHz at β=100m	+/- 7.5 kV
kick per turn at 450 GeV/c	2 μrad
rise-time 10-90%, DV= +/- 7.5 kV	350 ns
rise-time 1-99%, DV= +/- 7.5 kV	720 ns
must provide sufficient gain from	1 kHz to 20 MHz



rise time fast enough for gap of 38 missing bunches

noise must be less than quantization noise due to 10 bit / 2σ
σ is the rms beam size

This performance specification is frozen

For more details see LHC design report CERN-2004-003, chapter 6.4

Performance specification (2)
(LHC Design Report)

Beam parameters and requirements for nominal LHC beam intensity:

Injection beam momentum	450 GeV/c
Static injection errors	2 mm (at β_{max}=183 m)
ripple (up to 1 MHz)	2 mm (at β_{max}=183 m)
resistive wall growth time	18.5 ms
assumed de-coherence time	68 ms
tolerable emittance growth	2.5 %
Overall damping time	4.1 ms (46 turns)
bunch spacing	25 ns
minimum gap between batches	995 ns
lowest betatron frequency	> 2 kHz
highest frequency to damp	20 MHz

For more details see LHC design report CERN-2004-003, chapter 6.4

Maximum achievable performance

LHCADT performance in LHC optics version 6.4 compared to original assumptions (at 450 GeV/c), assuming 7.5 kV maximum kick voltage

	β=100 performance	Optics 6.4 performance
	Kick per turn in σ	Kick per turn in σ @ β in m
ADTH beam 1	0.2 σ	0.277 σ at β=193 m
ADTH beam 2	0.2 σ	0.273 σ at β=187 m
ADTV beam 1	0.2 σ	0.309 σ at β=239 m
ADTV beam 2	0.2 σ	0.316 σ at β=250 m

Estimate of maximum capabilities (usage as beam exciter, abort gap cleaning etc.), assumes optics 6.4 as in table above, 450 GeV/c and running with ~15 kV DC for tetrode anode voltage

	100 kHz	1 MHz	10 MHz	20 MHz
ADTH	0.47 σ	0.43 σ	0.14 σ	0.05 σ
ADTV	0.47 σ	0.43 σ	0.14 σ	0.05 σ

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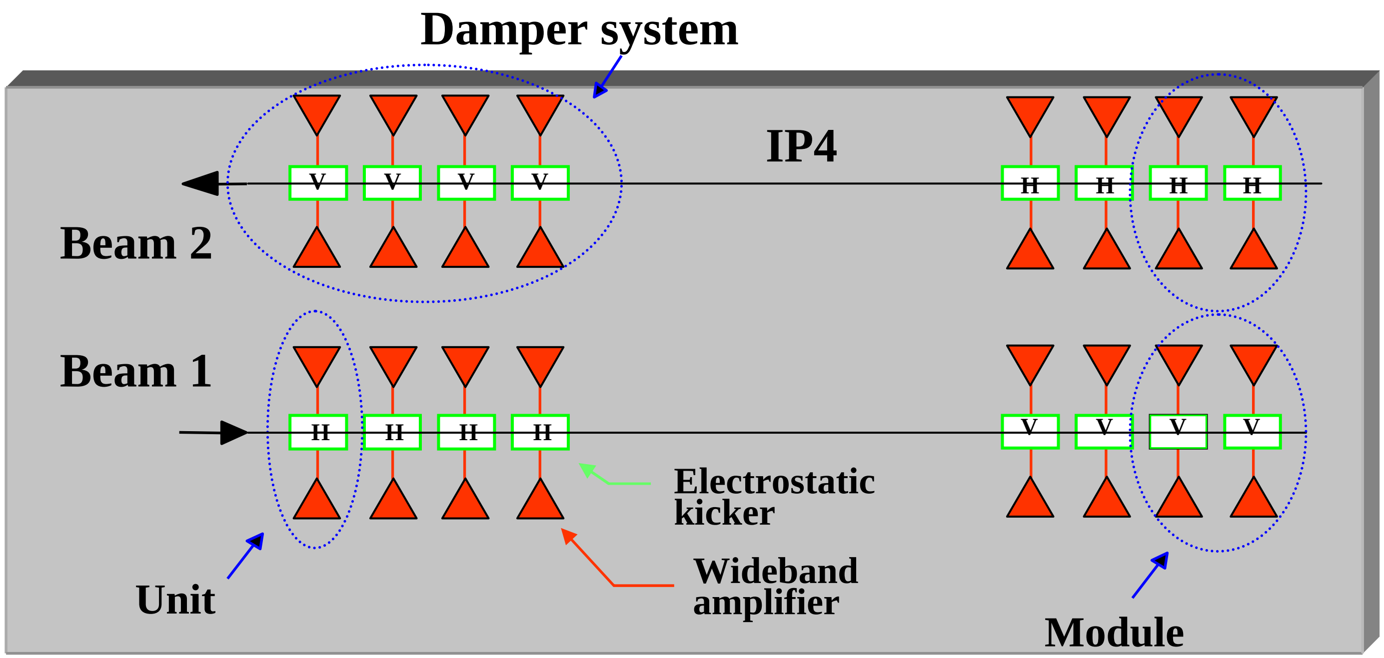
The LHC Transverse Damping System (high power part)



- 16 electrostatic kickers installed
- 32 amplifier tetrodes (30 kW each) installed

Official equipment names right of IP4:

ADTGR.A5R4	**ADTGR**	**A5R4**		**Transverse Damper Module Righthand type**
ADTKH.A5R4.B2	ADTKH	A5R4	B2	Horizontal Transverse Damper Kicker
ADTKV.A5R4.B1	ADTKV	A5R4	B1	Vertical Transverse Damper Kicker
ADTKH.B5R4.B2	ADTKH	B5R4	B2	Horizontal Transverse Damper Kicker
ADTKV.B5R4.B1	ADTKV	B5R4	B1	Vertical Transverse Damper Kicker
ADTGR.B5R4	**ADTGR**	**B5R4**		**Transverse Damper Module Righthand type**
ADTKH.C5R4.B2	ADTKH	C5R4	B2	Horizontal Transverse Damper Kicker
ADTKV.C5R4.B1	ADTKV	C5R4	B1	Vertical Transverse Damper Kicker
ADTKH.D5R4.B2	ADTKH	D5R4	B2	Horizontal Transverse Damper Kicker
ADTKV.D5R4.B1	ADTKV	D5R4	B1	Vertical Transverse Damper Kicker

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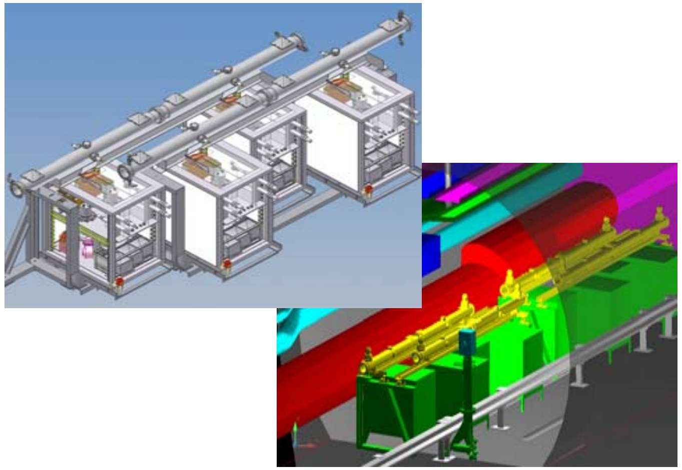
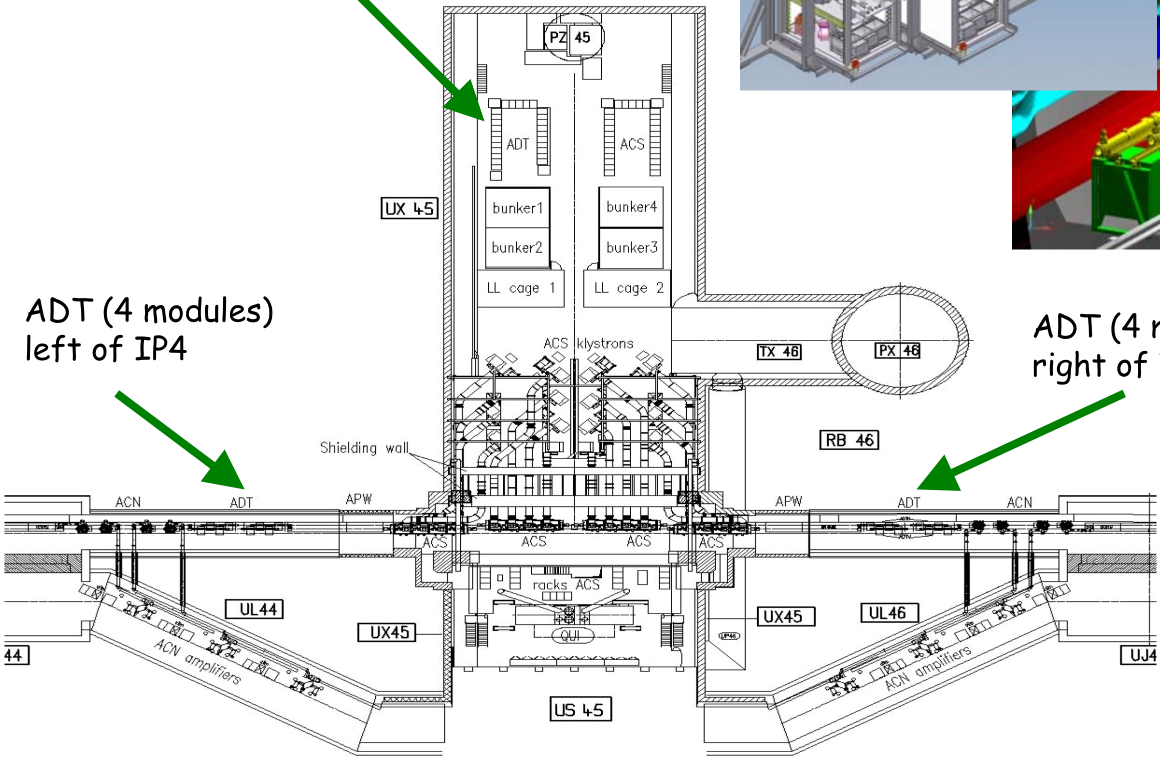
Physical layout in point 4 underground LHC

ADT racks (driver amplifiers, PLC controls, fast interlocks)





ADT (4 modules) left of IP4

ADT (4 modules) right of IP4

Beam 1

Beam 2

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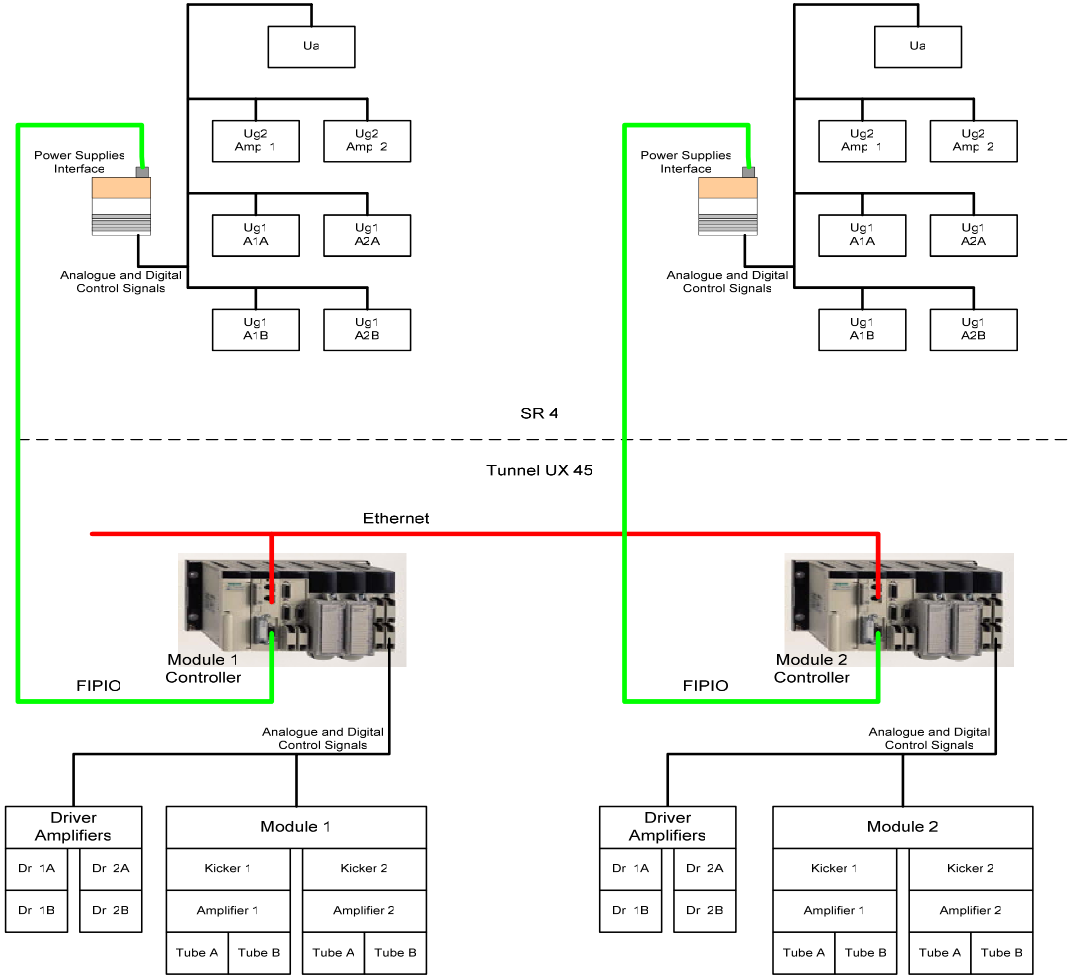
PLC Controls of one damper system (4x)



Response time:
10-20 ms
Too slow for fast interlocking

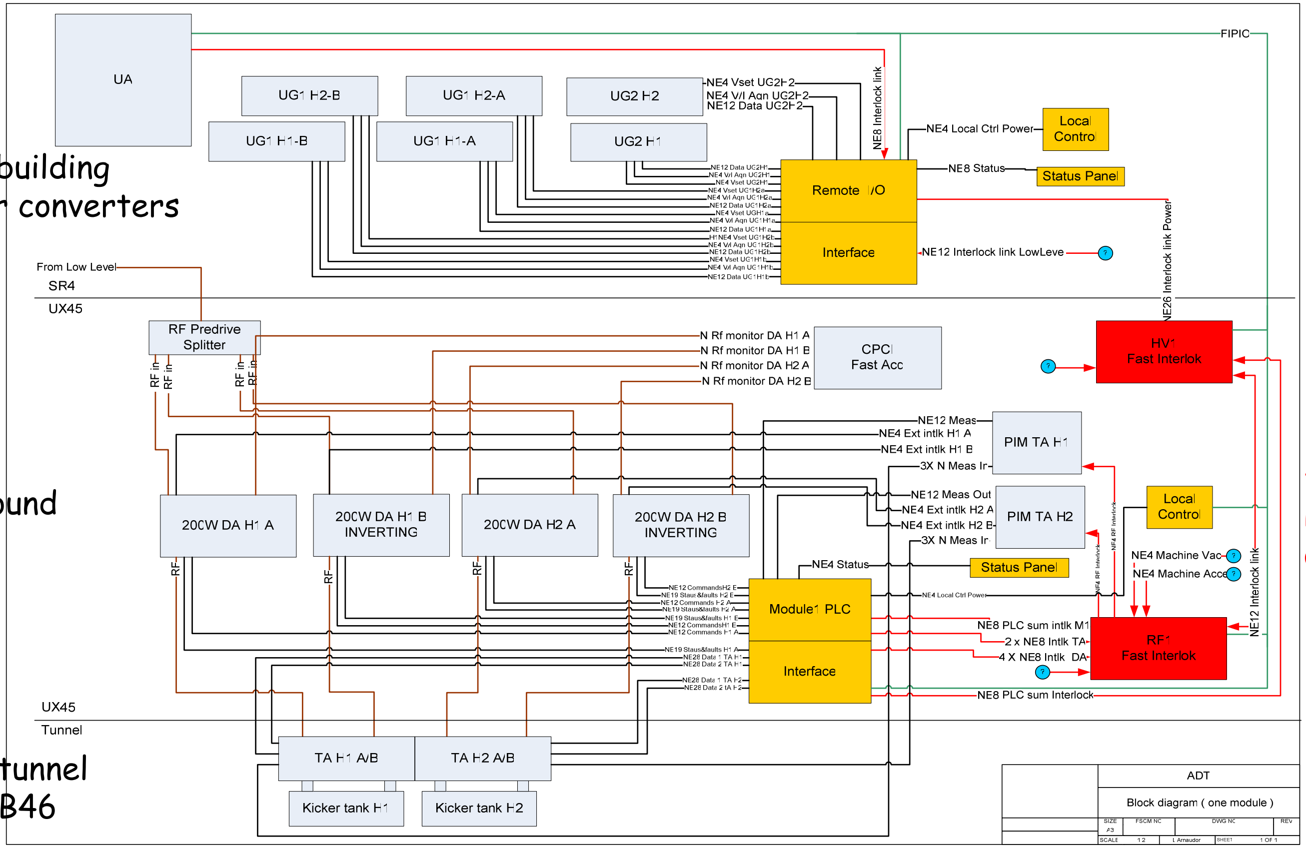
L. Arnaudon
F. Weierud

Fast equipment interlock system for equipment protection (shown is one of eight modules)

SR 4:
Surface building
HV power converters

UX45
Underground
cavern

Machine tunnel
RB44 - RB46



Response time:
100 µs
fast interlocking
Possibility to receive
and send signals to the
BIC via user module

L. Arnaudon
F. Weierud

Abort gap cleaning

- Transverse excitation of coherent betatron oscillations: 6 to 7 σ reached after ~55 turns (injection plateau 450 GeV/c)
- Method was successfully tested in the SPS accelerator
- Relies on revolution frequency signal indicating position of abort gap; captured beam close to abort gap edges cannot be acted on (limited rise-time of damper system)
- Abort gap monitor required (AB-BDI) to commission abort gap cleaning, monitor its functioning and protect the machine in case of failure of cleaning
- Reminder: Abort gap cleaning only thought to be required at injection energy during normal operation. At top energy momentum cleaning collimators will usually intercept beam before it reaches abort gap (energy loss by synchrotron radiation)

Damper failures and protection (1)

- In case of a damper failure there is no danger for the damper system itself
- Damper failure with loss of kick strength: example: loss of one damper module due to high voltage power supply trip or due to overload; risk: unstable beam, slower damping of injection oscillations -> shall be detected by position interlock system and BLM system. If considered useful, damper interlocks could request a beam dump or injection inhibit in this case
- Test signal is foreseen to check out the system before injecting beam, if detected in bad state -> inhibit injection or pull beam dump
- Loss of revolution frequency or clock frequency for digital processing: Will lead to malfunctioning of the system, if detected, system can shut itself down to avoid unwanted action on beam; abort gap cleaning must be stopped in this case
- There is no check foreseen to protect against unwanted signals injected on the excitation input. This input is provided for AB-BDI to connect to planned measurement systems (for example the tune measurement system)

Damper failures and protection (2)
Worst case scenarios

- Abort gap cleaning not aligned with abort gap due to bad revolution frequency phase
- Large amplitude signal injected on external input provided to BDI group
- Badly injected beam outside capabilities of damper: system will saturate and not react correctly; collimation in transfer line at 5 σ will not help here as damper system will saturate at ~4 σ
- Partial or complete loss of clock frequency will lead to erratic kicks
- Bad settings or (tune, damper phase setting, delay setting) can lead to anti-damping
- Worst case: coherent excitation by damper: 1 σ reached after 4 turns (450 GeV/c)

Damper failures and protection (3)
Worst case protection

- Must rely on position interlock by external system to detect oscillating beam – only this can guarantee protection against "catastrophic" damper failures
- BLM system must react within a few turns to provide protection
- Inside the damper system a few checks can be provided to prevent continuation of the mission when there is a risk that this will lead to unusable physics beam
- a *procedure* needs to be established to decide whether to take into account the damper interlocks for a particular mission. The beam safe-flag is a good concept, but my feeling is that the complexity calls for more than two levels

Conclusions

- Transverse damper system must be very powerful for efficient injection damping and to minimize emittance blow-up
- A high degree of flexibility is demanded from the damper systems: use as beam exciters, abort gap cleaning etc.
- Worst case scenario (1 σ amplitude excitation reached in 4 turns …) cannot be excluded
- External protection by BLM system and position interlock required
- Procedures must be established in order to define which of the possible damper interlocks should be taken into account for a particular mission to improve operational efficiency