Minutes of LHC-CP Link Meeting 20

Subject : LHC Controls Project

Date : 4 December, 2001

Place : 936-R-030

Participating Groups :

EST-ISS	P. Martel,
LHC-ACR	apologies,
LHC-ECR	no representative,
LHC-IAS	J. Brahy,
LHC-ICP	apologies,
LHC-MMS	no representative,
LHC-MTA	L. Denian replacing L. Walckiers,
LHC-VAC	I. Laugier, R. Gavaggio,
PS-CO	F. DiMaio,
SL-AP	no representative,
SL-BI	no representative,
SL-BT	E. Carlier,
SL-CO	A. Bland,
SL-HRF	E. Ciapala,
SL-MR	R. Billen,
SL-MS	no representative,
SL-OP	M. Lamont,
SL-PO	apologies,
ST-MO	no representative.

Others :
R. Lauckner (Chair),
B. Puccio (Machine Protection),
M. Tyrrell (Alarm Project),
M. Vanden Eynden (Core Team),
J.. Wenninger (Real Time),
T. Wijnands (Real Time),
M. Zuin (IT-CS).

Distribution :
Via LHC-CP website: **http://cern.ch/lhc-cp**
Notification via: **lhc-cp-info@cern.ch**

Agenda :

1. Matters arising from Previous Meeting	
2. LHC-CP News	R. Lauckner
3. Status of Real Time Controls	T. Wijnands
4. Data Required for LHC Operation	R. Billen
5. AOB	

1. Matters arising from Previous Meeting

As P. Gayet was absent no report was available on the urgent actions from October 9th concerning fieldbus cables and ergonomics for the vacuum supervision.

ACTION: P. GAYET

R. Lauckner has contacted teams building control systems involved in the QRL reception tests in 2003 and asked them to consider their support needs. Responses have been received from Logging and Alarms. He has also had some discussion with E. Hatziangeli who is negotiating the support role of IT is closely related areas: W2000, Linux, Oracle, PVSS, PLC engineering tools, configuration management.

There was no feedback from people with interfaces to RAMSES.

2. LHC-CP News R. Lauckner

The Controls Interdivisional Working Group has presented its interim report to Task Force 5, approval system. The slides indicate the scope of the studies, the number of staff members involved and the initial points arising from he discussions.

The main topics for the next LHC-CP meeting are:

18/12	Future Front Ends, Requirements for Analogue Signals	Vanden Eynden, Ciapala

3. Status of Real Time Controls T. Wijnands

T. Wijnands presented the work that has been done on LHC Global Orbit Feedback in order to illustrate real time controls with the most complicated example. Feedback control has matured through a requirements phase from 1997 to 2000. In the past 12 months formal methods of control system design have been used and the orbit feedback problem has been cast in a standard Computer Aided Control System Design. This work has been a collaboration between CERN, mainly J. Wenninger and T. Wijnands and EPFL, B. Srinivissan. The design study has concluded that within the performance constraints of the LHC Control System and components as proposed, global orbit correction will operate robustly with a gain of 0.8 at 0.1 Hz.

T. Wijnands reviewed the classical and modern approaches to design. Modern systems increasing use the state space time domain approach, e.g. SLAC. However for the LHC orbit problem the resulting matrices get very large and the present model employs the z transform frequency domain approach.

An important component of the feedback model is the variable time delay between the beam state and the applied correcting fields. Components are measurements times, network delays, computation times and power converter delays.

The dynamics in the system does not come from the beam but from the power converter and magnet and from the beam pipe. The power converter voltage loops use the "RST" algorithm to accelerate the natural response of the system. All voltage not used to compensate the resistive losses is available to change the current. Reducing the individual orbit correction kicks also reduces the time constant. Using the SVD algorithm to perform the correction can keep kicks below 2 μrads during snapback giving a time constant of 0.1s for the power converter/magnets response. The time constant of the beam pipe is a factor 10 less important.

The final component of the system that has been included in the model is the noise arising from the BPM system and the perturbations to the orbit due to magnet imperfections and ground motion. The fastest perturbations at low energy, with time constants around 0.1 Hz, are expected during snapback.

The system can be controlled with a discrete PI controller and the stability and robustness of the resulting system was demonstrated with Bode plots and the root locus. The system has no gain at 1 Hz and it would be interesting to sample the orbit at 20 Hz to improve this situation.

A. Bland asked where these controls techniques are used. J. Wenninger explained that all light sources use feedback on the orbit to control ground motion and other effects. They operate in a much higher frequency regime.

In response to a question from R. Lauckner about varying delays T. Wijnands said that the system can be optimised to operate in the worst case but this does not give the best performance in typical operation. An alternative is to build a more complicated controller which compensates for varying delay.

The next step in this work is to complete and study a prototype orbit control in the SPS using 4 LHC type pickups and the SPS mugefs.

4. Data Required for LHC Operation R. Billen

R. Billen reminded the meeting of the importance of good data management to the success of the LEP Control System. The issue had been treated at a breakout session during the 2nd LHC-CP workshop and it had been concluded that the LHC-CP must tell the machine builders what data is required from them for machine operation. The situation at LEP had been presented by M. Albert at the workshop; this presentation was an attempt to extrapolate to the LHC.

He divided the LHC requirement into two areas. Data needed to access equipment and data needed to support the operational model of the machine. In the first area hardware groups are required to provide information such as equipment parameters, calibration information and the services supported by their control software. In the second area machine parameters and optics are needed and this must come from the accelerator physics and operations groups.

Although not exhaustive he stated that the requirements are fairly well defined. Moreover the policies and supporting tools exist for equipment builders to meet these requirements. The QRL control is probably not a good test to see if groups have understood what is needed of them and the subject must continue to be monitored.

R. Lauckner said that this is a difficult subject and that we will certainly sharpen our ideas as the LHC project proceeds.

There was a discussion about the need to feed forward the data from measurements of the magnets during the construction. The refinement of the requirements here is the job of the multipole factory builders.

P. Martel said he did not want the MTF to become a repository for private information only of interest to project engineers. Only public information should be managed in a publicly visible structured manner. Private information could be deposited but would not be structured within the MTF. The information coming from the cryostat instrumentation will be of interest for operation in learning how to increase the machine performance. The post mortem system designers must decide how construction information might be used and supplied.

5. AOB

There was no further business.

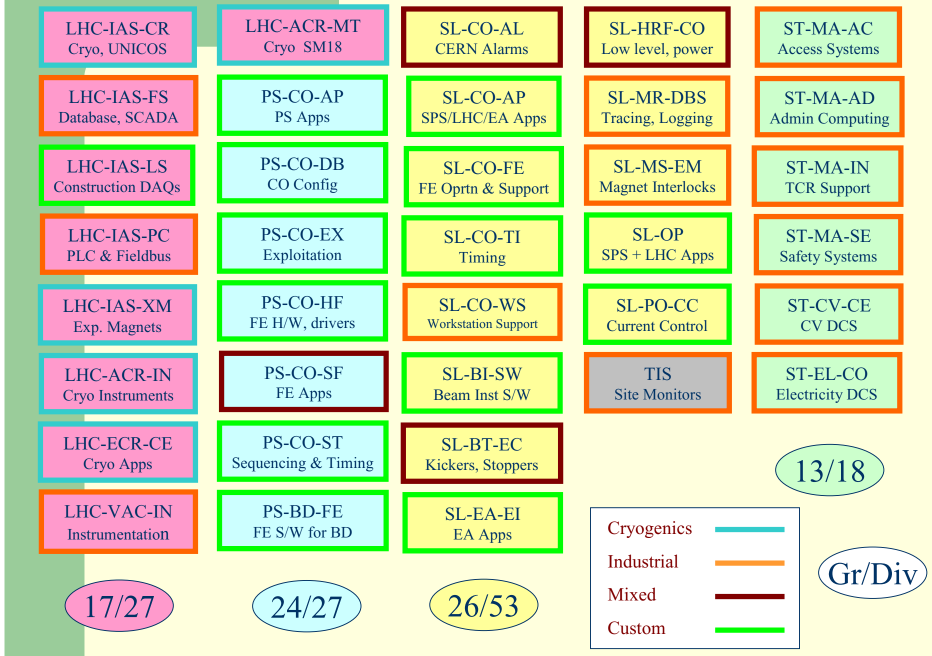
Long-Term Actions	**People**
Underground Control Rooms requested	R. Lauckner
Establish Post Mortem sub-project	R. Lauckner
Clarify Middleware Services to be used by LHC-CP	Core Team

Reported by R. Lauckner

Controls & Automation Working Group

LHC-CP (R. Lauckner),
LHC/IAS (C.-H. Sicard),
PS/CO (B. Frammery),
SL/CO (P. Charrue),
ST/MA (P. Ninin)

Accelerator and Technical Sections involved with Controls & Automation



LHC-IAS-CR Cryo, UNICOS
LHC-IAS-FS Database, SCADA
LHC-IAS-LS Construction DAQs
LHC-IAS-PC PLC & Fieldbus
LHC-IAS-XM Exp. Magnets
LHC-ACR-IN Cryo Instruments
LHC-ECR-CE Cryo Apps
LHC-VAC-IN Instrumentation
17/27

LHC-ACR-MT Cryo SM18
PS-CO-AP PS Apps
PS-CO-DB CO Config
PS-CO-EX Exploitation
PS-CO-HF FE H/W, drivers
PS-CO-SF FE Apps
PS-CO-ST Sequencing & Timing
PS-BD-FE FE S/W for BD
24/27

SL-CO-AL CERN Alarms
SL-CO-AP SPS/LHC/EA Apps
SL-CO-FE FE Oprtn & Support
SL-CO-TI Timing
SL-CO-WS Workstation Support
SL-BI-SW Beam Inst S/W
SL-BT-EC Kickers, Stoppers
SL-EA-EI EA Apps
26/53

SL-HRF-CO Low level, power
SL-MR-DBS Tracing, Logging
SL-MS-EM Magnet Interlocks
SL-OP SPS + LHC Apps
SL-PO-CC Current Control
TIS Site Monitors

ST-MA-AC Access Systems
ST-MA-AD Admin Computing
ST-MA-IN TCR Support
ST-MA-SE Safety Systems
ST-CV-CE CV DCS
ST-EL-CO Electricity DCS
13/18

Cryogenics
Industrial
Mixed
Custom

Gr/Div

C&A restructuring …

- will enable PS-CO to meet the goals after 2002
- is a good opportunity to rationalize resources for the LHC Controls Project
- must emphasize motivation, client proximity and centers of excellence
- requires a Common Control Room
- impacts upon money, manpower and time
- with ST is not favored: collaboration preferred to integration

LHC global orbit FB

J. Wenniger, B. Srinivissan, T. Wijnands

Disclaimer

February 1997	Workshop on LHC dynamic effects and their control [P. Proudlock]
March 1997	SPS Fast Controls [P. Anderssen]
April 1997	Summary on Communication Requirements for Fast Feedback [J. Pett]
May 1998	SPS Q-Loop [L. Jensen]
December 1998	Orbit Control in SPS using ATM [T.Wijnands]
May 1999	Functional Requirements for LHC Power Converter Control [RECCS]
October 1999	Requirements for real time correction of decay and snap back [LHC Note]
Real-time meetings [M. Lamont]	
8th November 2000	SL-TC. LHC-CP
January 2001	visit to SLAC [T. Himmel, L. Hendrickson]
9th February 2001	Brainstorming meeting to follow up on reactions to LHC-CP proposal.
16th February 2001	2nd Brainstorming meeting
9th March 2001	3rd Brainstorming meeting
16th March 2001	4th Brainstorming meeting
23rd March 2001	Meeting with MTA to discuss multipoles factory
30th March 2001	6th Brainstorming meeting
27th April 2001	7th Brainstorming meeting
8th June 2001	Meeting to discuss SPS prototyping with dedicated pickups
6th July 2001	Meeting to discuss SPS prototyping with dedicated pickups
16th July 2001	Start collaboration EPFL [B. Srinivissan]

….

This presentation

- Concerns feedback *global* LHC orbit
- Aim : gain 10 at *f* < 0.1 Hz
- Cast the problem in standard CACSD
- Made a plant model
- SVD correction algorithm
- Designed a PI controller

Results

- If ….
  total time delay = 100 ms
  orbit sampling at 10 Hz (100 ms)
- Then …
  PI controller gain 0.8 at 0.1 Hz
  no gain at 1 Hz
  Robust (gm = 1.6, pm = 40 degrees)
  at injection

Refresher - I

	Continuous	*Discrete*	*Techniques*	*Literature*
Frequency Domain	Laplace transform	z-transform	Transform techniques	Classical Control
Time Domain	Differential equations	Difference equations	State space	Modern Control

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Refresher - II

- *Open loop* :
  measurements from the output (the sensors) are not used to tune the inputs (the actuators)
- *Feed-forward* :
  actuator settings are changed in accordance to changes in reference or other settings - the correction has no direct effect on the reading of the sensor
- *Feedback control or closed loop* :
  actuator has a direct effect on the sensor reading to compensate for disturbances entering the system

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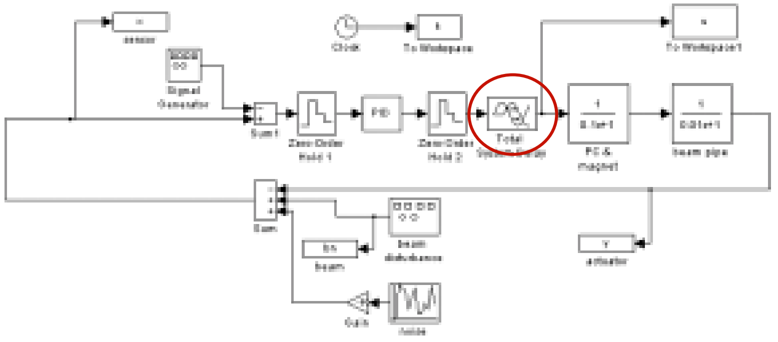
Global Orbit feedback



Pure time delay

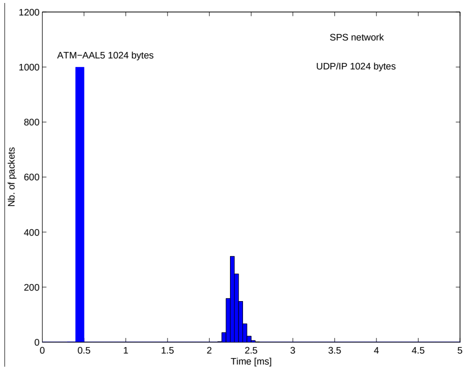
- *Always* system stability reduction
- Delay of 1 sampling period $H(z) = z^{-1}$
- Compensation :
  - *Adjust gain*
  - *Lead/lag compensation*
  - *Gain scheduled control*
  - *Smith predictor*

Delay source	*Min* [ms]	*Max* [ms]
Data Acquisition	**20**	**20**
Network	**2.5**	**20**
Correction algorithm	**10**	**30**
PC Control	**20**	**50**
Total	**52.5**	**120**

BPM data aquisition

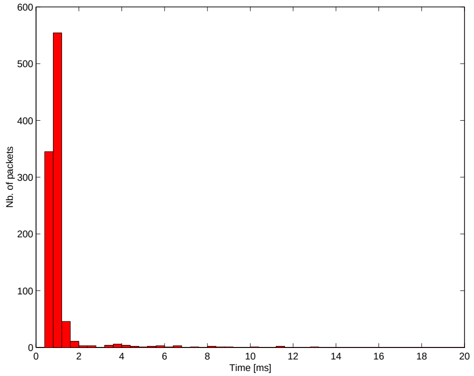
- 224 turn average or 20 ms
- “sliding average” (single turn resolution ?)
- 500 BPMs at 10 Hz sampling = 50 kBytes/s
- Sampling at 20 Hz possible !

Network delay - I



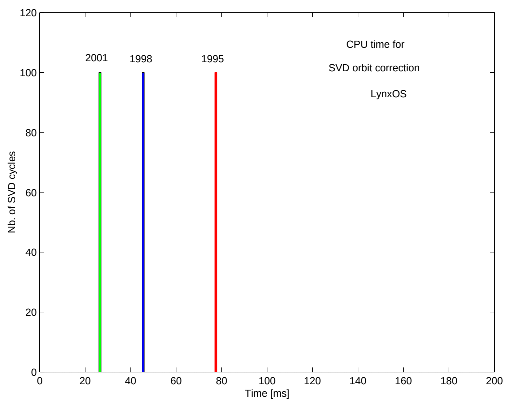
- UDP/IP 1024 bytes
- PPCs 200 MHz
- LynxOS 2.5.1
- SPS network BA3-BA5
- Real Time
- GPS - synchronised

Network Delay - II



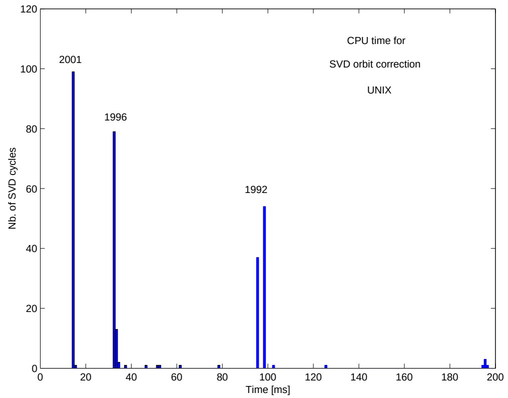
- TCP/IP 1024 bytes
- PPCs 200 MHz
- LynxOS 2.5.1
- SPS network BA3-BA5
- Real Time
- GPS - synchronised

Correction Algorithm - I



- Matrix multiplication
- Size matrix 500 x 250
- PPC LynxOS 2.5.1
- 166, 200, 300 MHz
- Real Time
- On board clock and VME analyzer

Correction Algorithm - II



- Matrix multiplication
- Size matrix 500 x 250
- HP Workstations
- Time sharing
- On board clock

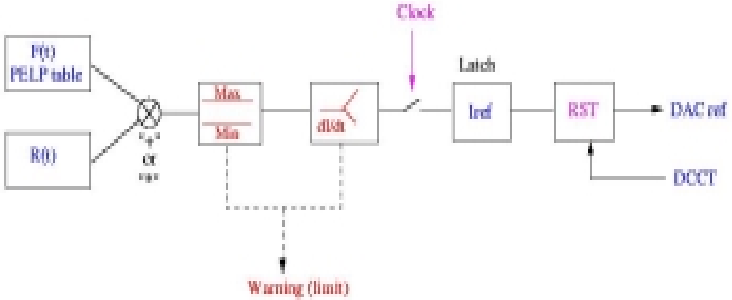
Computation speed

Machine	*CPU*	*Clock*	*OS*	*Cache*	*SVD* [ms]
PPC	1	166 MHz	LynxOS	no	77.3
PPC	1	200 MHz	LynxOS	L2 1 MB	42.1
PPC	1	300 MHz	LynxOS	L2 2MB	20.1
HP-29	1	100 MHz	HP-UX	no	83.5
HP-26	2	?	HP-UX	128 MB	42.1
HP-DEP	2	L-Class	HP-UX	512 MB	10.5
CPCI	1	333 MHz	LynxOS	128 MB	45.6
PC	1	666 MHz	Linux	128 MB	33.6
PS/PSE2	1	700 MHz	Linux	128 MB	22.4

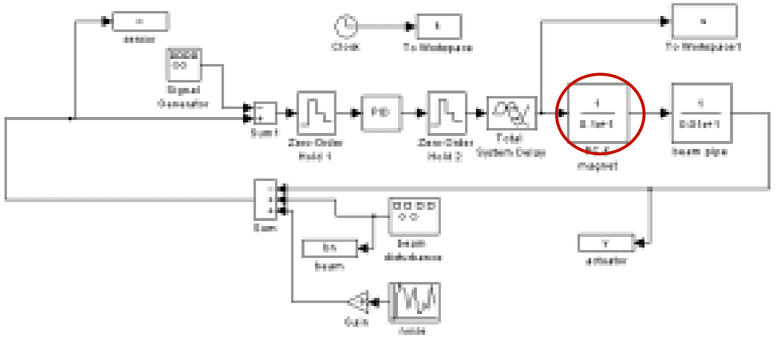
Internal Delay power converters

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).



Global Orbit Feedback



Power Converter & Magnet

- First order transfer function

  $H(s) = 1/(L/R\ s + 1)$ [±60A, ± 8V]

  $\tau_{pc} = L/R = 30\ m\Omega / 7\ H = 230\ s$
- Warm cable resistance $V \approx 30\ m\Omega \times 60\ A = 1.8\ [V]$

Cascade Loop accelerates system :

- RST algorithm for I, V
- Umax/Ustat = 2000 2 μrad / 0.1 A @ 450 GeV
- Umax/Ustat = 4 20 μrad / 1 A @ 450 GeV

Acceleration natural response I

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

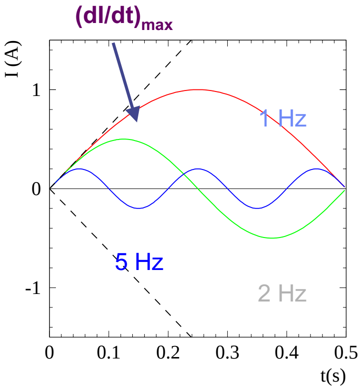
$$I(t) = I_0 \sin(2\pi\omega t)$$

The peak current derivative is

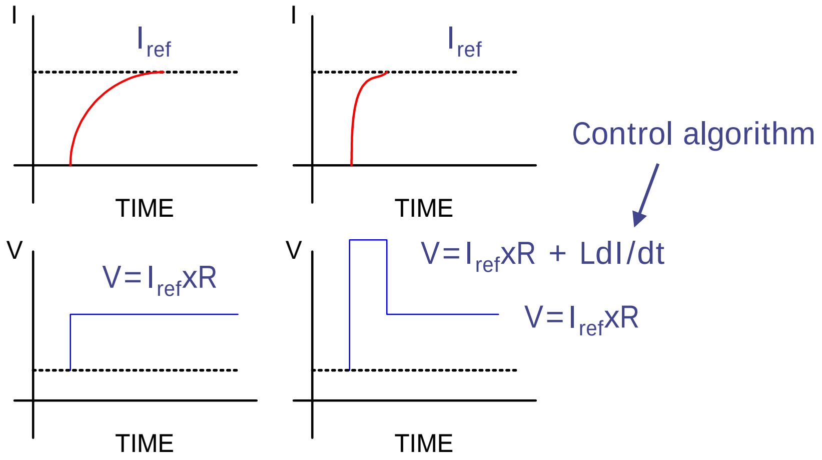
$$(dI/dt)_{peak} = \pm 2\pi\omega I_0$$

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

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

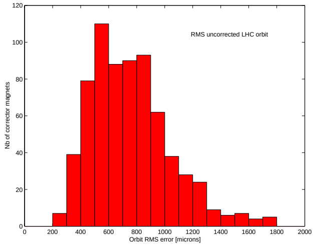


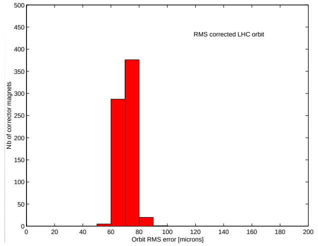
Acceleration natural response II

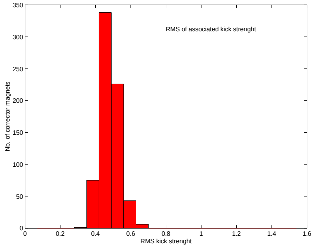


Control algorithm

Kick strengths

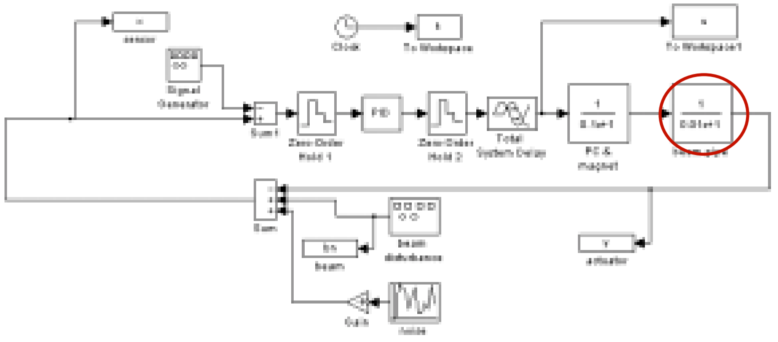






- assume b1 random 0.75 units
- orbit RMS = 800 microns
- Kick strength 0 – 2 μrad
- 2 μrad => 0.1 A at 450 GeV
- V_{max}/V_{stat} =2000 => τ_{pc} =0.1 s

Global Orbit Feedback



Beam Pipe

- First order transfer function

  H(s) = 1/(τ *s* +1)

- Time constant = 12 ms (cold) 2 ms (warm)

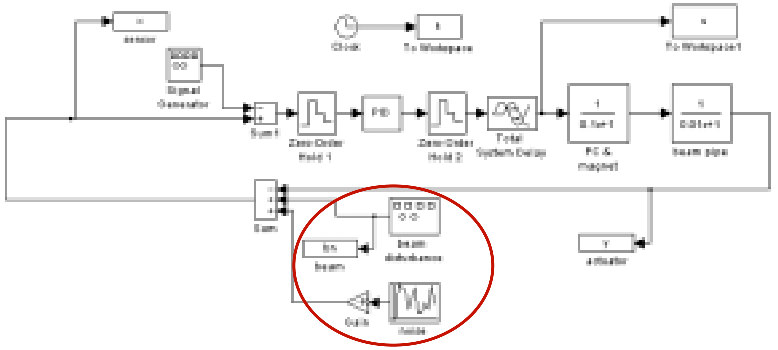
$$\tau = \frac{\mu_o \pi b d}{2\rho}$$

b = radius vacuum chamber = 2 cm (cold) 4 cm (warm)

d= thickness copper plating = 50 μm (cold) 0.85 mm warm)

R = resistivity = 1.7 10^{-10} Ω (cold) 1.7 10^{-8} Ω (warm)

Global Orbit Feedback



BPM Noise & orbit disturbances

- Movements of low β quads

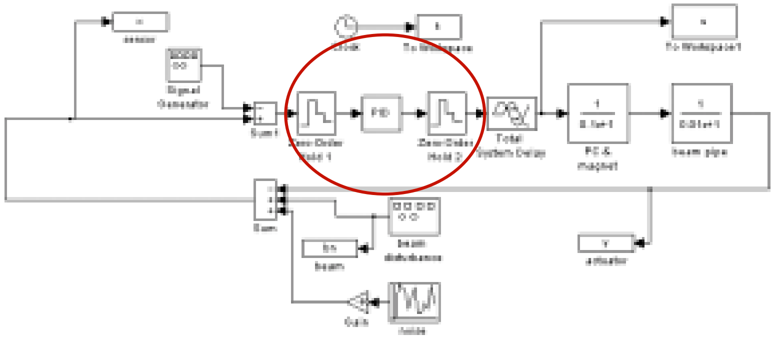
  (LEP : 2 corrections/minute in coast)
- Decay of persistent currents

  - injection

  - start of ramp
- Ground movements
- BPM noise ?

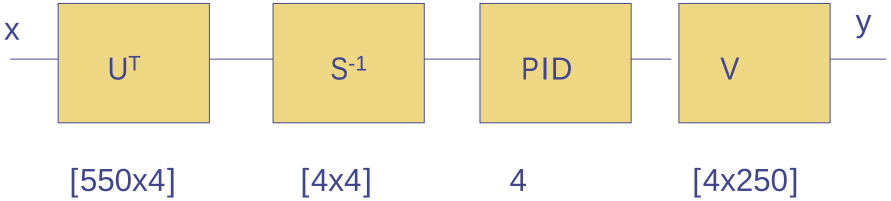
Important for loop shaping !

Global Orbit Feedback



Dimension reduction

- Orbit correction : $(x\text{-}x_{gold}) + Ay = 0$
- $A = USV^T$ or $A^{-1} = VS^{-1}U^T$ SVD algorithm
- $y = -A^{-1}(x\text{-}x_{gold})$



PID control

$$F(z) = K_p + \frac{K_i}{T_i}\left(\frac{z}{z-1}\right) + K_D T_d\left(\frac{z-1}{z}\right)$$

- Proportional	gain Kp to choose, no dynamics
- Integral	gain Ki to choose, pole at z=1
- Differential	gain Kd to choose, zero at z=1
- PI control	gain to choose, zero to choose, pole at z=1
- PID control	gain to choose, pole at z=1, zero at z=1, 2 zeros to choose

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Controller design

$$H(s) = \frac{1-e^{-st}}{1+e^{st}}\,\frac{1}{\tau_{pc}s+1}\,\frac{1}{\tau_{bp}s+1}$$

Using Padé approximation

$$G(z) = \frac{0.6z+0.04}{z^2(z-0.37)}$$

Discrete ...

$$F(z) = K_p + \frac{K_i}{z-1} = K_p\,\frac{z-\left(1-K_i/K_p\right)}{z-1}$$

PI controller

Select Gain

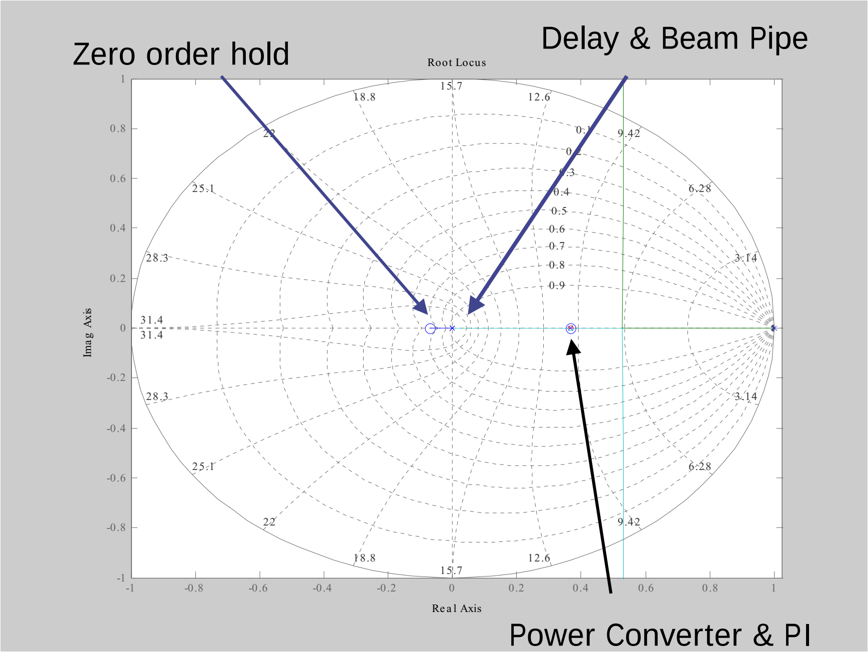
1. Choose Ki : $z-\left(1-K_i/K_p\right)=z-0.368$

$$\Leftrightarrow K_i = 0.63K_p$$

2. Choose Kp :

-Discrete RL plot

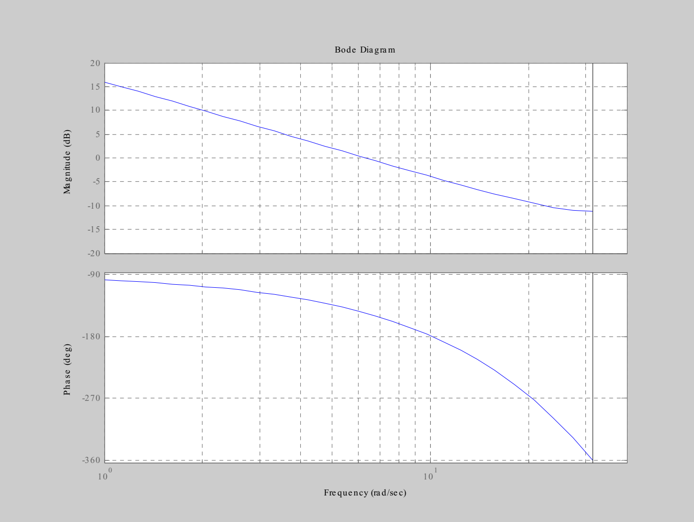
- Choose Kp
- Check ζ
- Check PM, GM


Zero order hold

Delay & Beam Pipe

Power Converter & PI

Bode Plots



Conclusion

- PI controller for Global LHC orbit :

  Assumed 10 Hz sampling

  Assumed 100 ms time delay

  Gain 8 at 0.1 Hz

  No error reduction at 1 Hz

  PM = 33 degrees, GM = 1.6
- Sufficient for snap back, ground motion, ...
- Sampling at 20 Hz gives some gain at 1 Hz

Operational Data Requirements

...in order to get LHC particle beams

& M. Lamont CERN-SL-95-114 (OP)

? What constitutes a good control system for operations?

Data management

Data visualisation

Equipment control

Equipment monitoring

In a standard environment.

2nd Workshop LHC-CP 5-6th April 2001

Conclusions on Database session, R. Lauckner:

F Need a Database forum for this community
  ~ PCR Oracle Committee addresses only general policy

F LHC-CP must tell LHC builders what data is needed
  ~ subject of this presentation

F 1st LHC Control Database 2003-Q1 for QRL
  ~ just over a year from today

M. Albert, LEP controls data and its sources:

F All equipment must be controlled through the database

F Data input mechanisms should be formalised

F Monitor data consistency across databases

~ *Static* & *dynamic* controls data, needed to control the machine through high level application software

M (My) Extrapolation for LHC requirements

Accelerator Equipment Data

Accessing LHC equipment

F HW addresses: to reach equipment via the network

F Layout: functional name, equipment type, position, magnet family, powering

F Configuration parameters: e.g. $\delta I/\delta t$, I_{max}

F Commands: IN/OUT data that can be exchanged, get/set, read/write

F Calibration curves: conversion tables between setting and physical data (e.g. I/B, U/kick angle)

G Network, computers, alarms: **SL/CO**

G Vacuum: **LHC/VAC**

G Cryo: **LHC/ACR-ECR-IAS**

G Machine protection: **LHC/ICP**

G Power converters: **SL/PO**

G Magnets: **SL/MS, LHC/MMS-MTA-ICP**

G RF: **SL/HRF**

G Kickers, septa, dumps: **SL/BT**

G Beam observation: **SL/BI**

G Collimators: **SL/BI**

Accelerator Physics Data

Higher level vision of LHC, implemented by the Application Software

F Physics parameters: $Q_{H/V}$, Q_S, $\xi_{H/V}$

F Optics: different configurations e.g. *Injection*, *Ramp*, *Physics*

F Magnetic strengths: correspondence B~K ; *but* multipole factory

F Ramp definitions: consecutive optics during LHC cycle

F Twiss parameters: MAD output $(\beta_{H/V}, \alpha_{H/V}, D_H) = f(\mu_{H/V})$

F Knobs: combinations of parameters e.g. Xing angle, bump, coupling compensation

G **LHC Analysis Working Group**

Architectural Model

~ **SL/AP:** Theory

~ **SL/OP:** Practice

~ **SL/CO:** Infrastructure

Conclusions

LHC Operational Data requirements are fairly well defined

For equipment builders, the *Policy* and *Tools* exist

& LHC QAP 309: All relevant data shall be stored in EDMS using the MTF Traveller and remain available for the duration of the LHC project

The “control system” for QRL involves only few “LHC builders”

The next steps are to be discussed...