Design process of the Interlock Systems

CLIC Workshop 2013
- Accelerator / Parameters & Design activities Session -
Topics

Introduction
Principles
Requirements and Challenges
Specifications
  • Interface
  • Design, Functions and Architecture
Validations ongoing
  • First Experience at CTF3
  • Prototype
Wrap-up

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Introduction

Basic Concepts

- As for LHC, CLIC Interlock Systems are defined at the machine design level
- Backbone of machine protection: ability to stop the operation
- Aim to increase the **Machine safety** and do not decrease the **Machine availability**

Linear Collider Challenge

- Cannot stop the beam in flight: the Beam Permit inhibits the next pulse
CLIC Interlock System Principles

– Critical Equipment:
  • Look for any equipment failures
  • Inhibit the next pulse => Beam Permit

– Post-Pulse Analysis:
  • Perform beam quality analysis: assert the next pulse quality
  • Inhibit the next pulse => Next Cycle Permit

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Requirements and Challenges

- **Equipment Interlock**: able to inhibit the next pulse in less than **2ms**
- **Post Pulse Analysis**: **6ms** to process data

Response time

- Pulse
- **Inter-cycle: 10 ms**
- Next Pulse
- **Equipment Interlock covering**
- **2 ms**
- **Data reception**
- **Post Pulse Analysis processing**
- **Next Cycle Permit delivering**
Requirements and Challenges

- Risk identification

- Risk analysis, based on two methods:
  - Assumption on availability
  - Operational statistics

- Risk reduction: Failure mode
  - False PASS decision: **Machine safety**
  - False VETO decision: **Machine availability**

- Dependability attributes to be reached
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Interface with acquisition system

CLIC Main Linac

CLIC Module (CLIC CDR chap 5.13 Control)

Acquisition and Control Module

X 22 000

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# Interface with acquisition system

## Example

<table>
<thead>
<tr>
<th>Subsystem/Element</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLM: 10-100m Fiber + PD</td>
<td>DB (2ch/fiber), 2 fibers</td>
</tr>
<tr>
<td>BLM: 10-100m Fiber + PD</td>
<td>MB (2ch/fiber), 2 fibers</td>
</tr>
<tr>
<td>Power Converter</td>
<td>2ch / Trimmer</td>
</tr>
<tr>
<td>RF Beam instrumentation</td>
<td>Module 0 (4xRF Unit)</td>
</tr>
<tr>
<td>RF: WakeField Monitor</td>
<td>All modules, config 0</td>
</tr>
<tr>
<td>RF: WakeField Monitor</td>
<td>Configuration 2</td>
</tr>
<tr>
<td>Stabilization: Positionning</td>
<td>Relative displacement</td>
</tr>
<tr>
<td>Vacuum Valve</td>
<td>status</td>
</tr>
</tbody>
</table>

## Interface:

- 48 alcoves => 48 Machine Protection FECs
- Requirements from Machine protection to Acquisition system:
  - Redundancy on critical data
  - Low data corruption rate

*FEC: Front-End Computer
**ACM: Acquisition and Control Module
Beam Permit Loop
- Master node: frequency generation
- Other nodes (FEC): switch
- Redundancy: defined regarding dependability study

Thresholds comparison
- Standardized procedure for all data (equipment and beam quality related)
- Thresholds managed as Configuration Data

Global analysis
- Concentrator
- Glitch mitigation, local rules (masking)
Architecture

Target Systems

- Drive Beam: Gun
- Main Beam: extraction kicker damping ring

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Post-Pulse Analysis at CTF3

Beam sequencer based on post-pulse analysis

- Feasibility of Post-Pulse Analysis and first experience
- Software only (JAVA application)
- Applying the Post-Pulse Analysis Concept to ramp up the beam

Related Document=> EDMS 1182876

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Interlock Systems Prototype

- Response Time
  - Beam permit
  - Post-Pulse analysis

- Dependability
  - Node characteristics (Failure rates)
  - Extrapolate to determine beam permit loop redundancy
Wrap up

System engineering process

- Concepts => requirements => specifications => validation
- Many iterations

Status

- Proof of concept at CTF3:
  - Test on going
  - Prototype:
    - Response time reached: 320 µs to inhibit the next pulse

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Thanks for your attention

Questions and remarks are welcome
Spare slides
CLIC Layout

- 326 klystrons
- 33 MW, 139 µs
- Drive beam accelerator
- 2.38 GeV, 1.0 GHz

- Circumferences delay loop 73.0 m
- CR1 146.1 m
- CR2 438.3 m

- Decelerator, 24 sectors of 876 m
- Booster linac, 6.14 GeV

- e⁻, e⁺ main linacs, 12 GHz, 100 MV/m, 21.02 km

- CR combiner ring
- TA turnaround
- DR damping ring
- PDR predamping ring
- BC bunch compressor
- BDS beam delivery system
- IP interaction point
- dump

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CTF3 Layout

- Magnetic chicane
- Pulse compression frequency multiplication
- 30 GHz test stand
- 150 MeV e⁻ linac
- 3.5 A, 1.4 µs
- CLIC experimental area (CLEX) with two-beam test stand, probe beam and test beam line
- Delay loop
- Combiner ring
- 28 A, 140 ns
- Total length about 140 m

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Dependability concept definition

Adapted from: “Functional Concepts of Dependability”, A.Avizienis, J.C.Laprie, B.Randell

MTL Application Note: An introduction to Functional Safety and IEC 61508
Requirements for Control system: Machine Safety

• Failure mode: data corruption on critical interlock request
• **Tolerable risk** of 1 catastrophic event every $10^4$ years ($1.39 \times 10^{-13}$/pulse)

• Method 1 (based on operational year 2011)
  – 48.7% of missions (10h) aborted by critical equipment failures
  – 6% of missions (10h) aborted by beam instabilities
  – Probability of Interlock request: $3 \times 10^{-7}$/pulse

• Method 2 (based on assumptions on availability) – For comparison (don’t include equipment failure)
  – 1 instable pulse leads to 10s downtime (interlock and ramp up)
  – Less 10% downtime is acceptable => 1 instable pulse every 100s
  – 1% of instable pulses are critical (leading to structure damage)
  – Probability of Interlock request due to critical instable pulse: $2 \times 10^{-6}$/pulse

• **Probability of Control system to corrupt data must be lower than:**
  – $4.6 \times 10^{-7}$/pulse (method 1)
  – $7 \times 10^{-8}$/pulse (method 2 – no equipment request)