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Reliability Analysis for the LHC Machine Protection System

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Abstract

A complex Machine Protection System (MPS) protects the Large Hadron Collider (LHC) against damage in case of uncontrolled beam losses. “User Systems” detect abnormal conditions and request a beam abort. The request is transmitted via the Beam Interlock System (BIS) to the LHC Beam Dumping System (LBDS), which extracts and dumps the beam. The MPS must be safe, reliable and maintainable without causing spurious shut downs.

Established techniques for reliability analysis reach their limitations with highly complex systems like the LHC MPS. Latest studies at LSA indicate that agent-based models (ABM) are a promising approach to overcome these limitations [1].

1 LHC Machine Protection System

- The BIS is made up of 32 Beam Interlock Controllers (BIC)
- The BICs are distributed in the 8 insertion regions (IR) (Fig.1 and 2)
- They collect the user permit signal from the close-by User Systems (Tab.1) and transmit it to the LBDS which causes a beam abort .

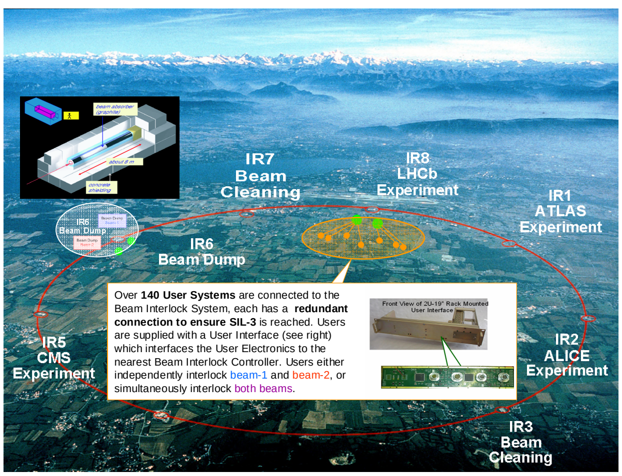

Fig.1: Aerial view of the LHC site

- Beam Abort Functionality is specified as **SIL3** (Mean Time Between Unsafe Failures 1000 to 10000 years) which is achieved by redundant architecture and full system testing.

User Systems	Description
Powering Interlock System	▪ based on industrial controllers (PLCs) ▪ protection of normal and superconducting magnets
Beam Loss Monitors	▪ several thousand ionisation chambers ▪ detection of fast and slow beam losses
Fast Magnet Current Change Monitors	▪ protection against fast beam losses caused by normal conducting magnets in critical optical positions
Vacuum system	▪ LHC operation requires four different vacuum systems
Beam Dumping System	▪ self-triggering in case of failure
Access System	▪ personnel safety system for tunnel access
RF System	▪ radio frequency system for acceleration
Experiments	▪ ATLAS, ALICE, CMS and LHCb

Tab. 1: Most Essential User Systems of the LHC Beam Interlock System

2 Reliability Analysis of LHC MPS: Agent-based Approach

1. Model the system’s components as software objects called “agents” with individual characteristics and behaviour rules
2. Run simulations of all components, generating scenarios
3. Analyse the resulting global system behaviour [1]

Modelling

The ABM approach is introduced with the BIS (Fig.2) as a core component of the LHC MPS.

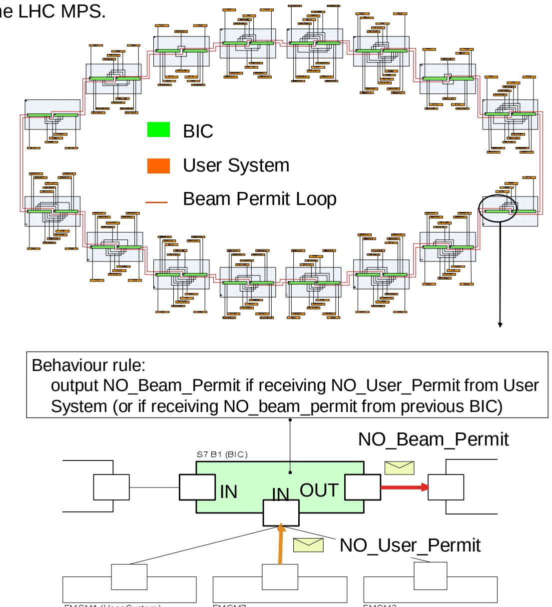

Fig.2: BIS (top), BIC modeled as an agent (bottom)

- The entire MPS can be modeled in any level of detail
- Humans or any kind of active objects [2] can also be incorporated as agents
- Refinements usually result in local changes which makes the model easy to maintain [2]
- Parts of the system may be modeled and analysed with established methods and the results can be used as inputs for a ABM

Simulation and Analysis

- Available reliability data are included through characteristics and behaviour rules of agents at lower model levels (e.g. number of NO_User_Permit messages generated by User System per time)
- Data gathered during simulation yield to statistics on the system’s behaviour [1]. Cascading effects are traced and components causing beam dumps are identified.
- Reliability numbers of the LHC and the LHC MPS may be extracted from these statistics.

3 Conclusions

ABM are not yet established in reliability analysis. Therefore, their feasibility for the analysis of the LHC MPS has to be shown. Uncertainties or the accuracy of the results need to be addressed. However, ABM shows promising properties. The simulation delivers new insights into the system’s dynamic behaviour. Results of previous studies on the MPS can be used as benchmarks.

References

1 Kaegi, M., Schläpfer, M.: “Application of Agent-based Modelling and Simulation for Risk Analysis” (internal), LSA, ETH Zurich, 2006
2 Borshchev, A., Filippov, A.: “From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools”, XJ Technologies and St. Petersburg Technical University, 2005