Quantitative fault tree analysis of the beam permit system elements of RHIC at BNL

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Objective
To find hazard rates for adverse failures occurring in beam permit system modules

Introduction
- Beam permit system is a centralized safety system that ensures the equipment and personnel safety at all the times
- This work calculates the failure rate of adverse failures occurring in BPS modules
- Also provides a quantitative comparison of basic component failure rates and identifies the failure-prone components

BPS modules
- BPS consists of 37 modules that can be put in two major categories: Permit Modules (PM) and Abort Kicker Modules (AKM)
- PM concentrates the health inputs from RHIC support systems and takes decision regarding system safety
- AKM upon seeing a failure, waits for the beam abort gap and sends dump signals to kicker magnets to dump the beams

Fault tree analysis

Quantitative FTA
- Fault Tree Analysis (FTA) is a deductive approach that translates a physical system into a structured logic diagram and resolves an undesired event into its causes.
- The exponential distribution is used to model the lifetime of electronic components, and has a reliability function equal to:

\[ S(t) = e^{-\lambda t} \]

Below is a Fault Tree with a higher level event E resolved into n basic events, which are independent and exponentially distributed.

Represented as a series system, the reliability function of E:

\[ S_E(t) = S_1(t)S_2(t)\ldots S_n(t) = \prod_{i=1}^{n} S_i(t) = \prod_{i=1}^{n} e^{-\lambda_i t} = e^{-\sum_{i=1}^{n} \lambda_i t} \]

The failure rate function of E:

\[ \lambda_E(t) = \sum_{i=1}^{n} \lambda_i \]

No redundant components in system makes all the top level failure rates for modules as exponential.

The analysis (continued)
- Levels of hierarchy in tree represent stages of detail
- Number of levels depends on the constituents boards' complexity.
- At board level, the circuit is divided into signal paths relating inputs and outputs of a top level failure
- Failure rates are divided for common paths of failures

Component failure rate prediction: The exponential failure rates are obtained from manufacturer for newer components and from MIL-HDBK-217F for older components. Environmental factor of \( \lambda_b \), ambient temperature of 30°C and a 60% confidence interval is used.

Component failure mode prediction: The failure rate is further divided into failure mode rates through apportionments given by FMD-97™. The normalized distribution data is used, which excludes non-inherent failures.

Component contribution: A component common to all the signal paths will cause an FO in PM:SQ and FB in PM:SNQ. Component is ignored if: active at initialization or beam-abort, diagnostics, having zero failure rate, inactive in a variant. Failure mode is ignored if unknown consequence, early life failure mode or parametric failure.

Results

Top failure modes of PM:M and PM:SQ

Top failure modes of PM:SNQ and PM:S

Top failure modes of AKM

Discussion
PM-M (07) and PM-SQ
- \( \lambda_{SQ} \) and \( \lambda_{SNQ} \) are largely contributed by the fiber optic elements having failure rates of the order of 10^{-4} FIT.
- \( \lambda_{SQ} \) is highest: having optical elements for both blue and yellow link
- \( \lambda_{SNQ} \) is almost half of \( \lambda_{SQ} \): having optical elements for permit link only
- \( \lambda_{PM} \) for PM-M is very low: absence of optical elements
- \( \lambda_{PM} \) is an order less than other two, contributed by the optocoupler malfunction in V120 board

PM:SNQ and PM:S (24)
- No FO mode: no quench inputs or blue/yellow carriers
- \( \lambda_{SNQ} \) is higher than PM:SQ: fault in common circuits causes an FB rather than an FO
- \( \lambda_{PM} \) is slightly lower than PM:SQ: no quench inputs and corresponding elements

AKM
- \( \lambda_{PM} \) is very small for all modules except the 33rd: optical elements
- \( \lambda_{PM} \) is almost equal to PM: largely contributed by oscillator malfunction and power failures on board
- \( \lambda_{PM} \), \( \lambda_{FB} \) largely contributed by oscillator malfunction and power failures on board

Conclusion
The MIL-HDBK-217F is fairly conservative in its approach which is suitable for safety analysis of components that are not supplied with data from manufacturer. The maximum values of \( \lambda_{FB}, \lambda_{DD}, \lambda_{B} \) and \( \lambda_{Q} \) are 1987, 3332, 290 and 195 FIT. The corresponding MTTFs are 57, 34, 393 and 585 years. Due to multiple modules and their interaction dynamics, a system failure can occur in RHIC operational life of 20 years. This evaluation is done through a Monte Carlo simulation of the BPS.

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References
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