VERY EARLY FIRE DETECTION FOR HIGH POWER PULSED SYSTEMS

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Abstract

Equipment racks containing high current power supplies and solid-state electronic switching circuits associated with accelerator kicker installations at CERN can fail in ways that risk fire outbreak, and building and tunnel fire detection systems may not be well placed to detect fire outbreaks in such racks until the fire is well established. The risks associated with late fire detection can be worse in normally unmanned surface buildings and normally non-accessible underground areas and accelerator service tunnels. Very early fire detection directly in the racks is, therefore, highly desirable to give local power interlock in the event of smouldering, with interlock levels being configurable as determined appropriate for each individual environment. This paper describes the specific risk situations and circumstances, and the detection technologies considered. The final choice of detection and interlocking strategy is demonstrated to be successful in detecting the very early incipient stages of a fire and drastically reducing the risks of covert fire development leading to major fire outbreak with all its associated consequences. Several of these early fire detection systems have already been installed in LHC and SPS accelerator kicker installations, with many more planned.

INTRODUCTION

Beam Injection and Extraction Kicker Systems

CERN's accelerator beam transfer kicker systems inject particles into a circular accelerator, or extract particles from an accelerator to a transfer line or beam dump. A Kicker magnet is a pulsed dipole magnet which produces a rectangular field pulse with very fast rise and/or fall time (typically 50 ns to 1 us). The magnet pulse may be several kA. To achieve this, for each kicker magnet a kicker system uses high current power supplies known as the DCPS which charge capacitor banks. This charge is then discharged via a thyristor to a step up transformer, the secondary of which charges the Pulse Forming Line (PFL) or Pulse Forming Network (PFN) to the required kick strength. The combination of these stages is called the Resonant Charging Power Supply (RCPS), and the resultant charge is then rapidly discharged into the magnet via fast, high power switches (thyratrons or solid-state electronic switches) called the Main Switch and the Dump Switch which act together to produce a clean rectangular pulse [1] (see Fig. 1).

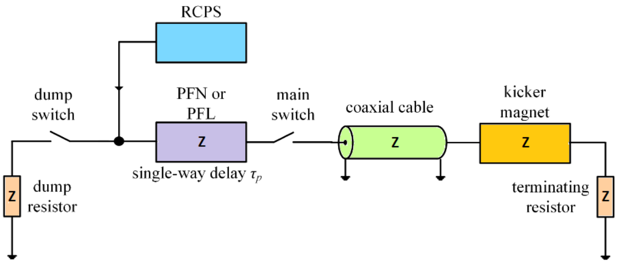


Figure 1: Simplified schematic of a kicker system.

Kicker Racks and Fire Risk

Enclosed cabinets can be considered micro-climates, being somewhat isolated from their surrounding environment to protect personnel from hazardous voltages and charges, populated with power electronics and busbars, in some cases electrically noisy, containing a mixture of signal and high voltage and/or high current cables, some with locking/interlocking door mechanisms, sometimes featuring forced air circulation . The high energy power supplies and associated solid state switching electronics and interconnecting cables, under certain fault conditions such as a degrading power component, a loose connector, material fatigue of a connector or cable, damage to a connector or cable or disconnection of a cable resulting in a short circuit, arcs and abnormal heating effects can occur, potentially causing smoldering and even igniting of nearby flammable material. In such a contained environment, any breakout of fire, especially at the early smouldering stages, may remain covert for some time. Building/Tunnel smoke and fire detection, due to the lack of propagation of smoke from the cabinet, is often not capable of detecting such fires until they are well established, meaning significant damage can already occur before any alarm is raised or extinguishing action is carried out. If the zone in which kicker racks are installed is underground, this may also be inaccessible during accelerator operation, further complicating the detection and identification of fire situations. Such a situation occurred in the AD Horn installation (see Fig. 2). The probable cause of this fire was a loose trigger cable for the ignitron such that the power capacitor energy was shorted to ground and the resulting electric arc ignited nearby cables and oil hoses. The loose cable was caused by material fatigue or damage of the connector. While the occurrences of such fires have so far proven to be rare, the consequence can be significant damage to equipment resulting in long machine shutdown for repair, and therefore having impact on CERN's scientific programs. To mitigate the in-rack fire risks and non-optimal conditions for the main building/tunnel fire systems to be able to detect the early stages of such fires, a more localised and rapid detection strategy is needed which can detect the incipient stages of smouldering and cut power to the rack in order to prevent an actual fire. In order to interface to and cut power to the kicker system and considering the accessibility issues during accelerator operation, the chosen technology must feature good diagnostic and alarm reporting capability via standard industrial 4-20 mA and dry contact type interfaces that can be connected to the local kicker control system PLC (Programmable Logic Controller), and due to dust accumulation from tunnel surfaces, must feature excellent dust/smoke particle discrimination, particularly for typical concrete/cement dust particles.

Figure 2: Cabinet Fire.

FIRE DETECTION METHODS AND CONSIDERATIONS

The following detection technologies were considered:

Rack Mounted Point Smoke Detectors Two types – optical and ionisation. Ionisation types have a radioactive element producing alpha particles which ionise the air in the chamber, resulting in a flow of positive and negative ions between two charged plates. The smoke alarm triggers when smoke affects the flow of ions.

Optical detectors, which operate on the principle of light obscuration, where the presence of smoke blocks some of the light from the light source, typically through either absorbance or light scattering, are much better at detecting the more advanced smoldering stages.

In-Rack IR Imaging Good for detecting overheating components when set up correctly and with good calibration (machine learning) so could give very early warning of fire hazard.

Rack Mounted CO (Carbon Monoxide) Detectors Carbon monoxide is a tasteless, odourless, colourless and toxic gas. It is produced by the incomplete combustion of various carbonaceous substances without sufficient oxygen supply. The response times of CO sensors has been shown to be significantly faster than for optical smoke detectors at the incipient smouldering phase of a fire, while remaining immune to many sources of false alarms, and is therefore an interesting option for early fire detection.

Rack Mounted Heat Detectors Suitable mainly for the later stages of a fire which has already developed significantly and is generating sufficient heat.

Aspirating Smoke Detectors ASD systems draw air samples continuously from a pipe network fitted with sampling holes or nozzles at regular intervals. The air samples are captured and filtered, removing any contaminants or dust to avoid false alarms and then analysed for smoke particles in a sampling chamber based on a nephelometer, detecting the presence of airborne smoke particles by detecting the light scattered by the smoke particles within the chamber. An ASD can detect fires at a very early stage (up to 100 times more sensitive than traditional point type smoke detectors), often before visible smouldering (see Fig. 3).

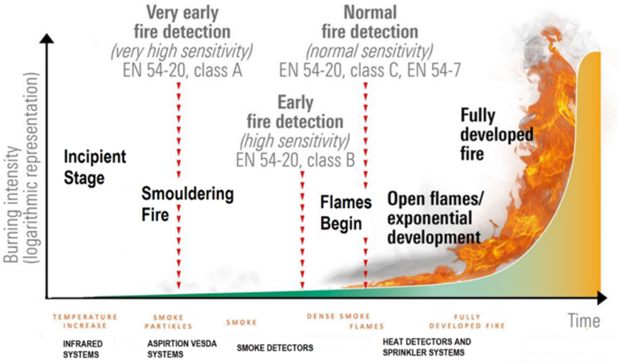


Figure 3: Detection Methods and Stages of a Fire.

CHOICE OF DETECTION METHOD

The main factors to be considered in determining the effectiveness of smoke detection are the path of smoke transported from the fire source to the detector location, the degree of smoke dilution during transportation, and the detector sensitivity. The various components inside the cabinet, including large power supplies, will restrict the flow of smoke, and when several cabinets are installed side by side creating one much larger volume, any smoke will be more diluted. Internal fan cooling systems will also dilute and cool the smoke so that it may not have sufficient thermal buoyancy to rise to a point detector in the top of the cabinet. These factors will prolong the time for smoke to reach a point type smoke detector and therefore increase the response time.

Point smoke detectors, while being the workhorse of standard smoke detection, may not, therefore, achieve the desired sensitivity levels. For Ionisation types, although radiation propagation from the head is negligible and nonharmful, they do present storage and disposal issues, and are susceptible to false alarms and less sensitive in detecting more advanced smoldering stages of a fire. Optical point smoke sensors can suffer false alarms due to dust particles and are less sensitive to the incipient stages of a fire. Both ionisation and optical type point detectors only have one fixed point of sensitivity and work on voltage thresholds not compatible with PLC (programmable logic controller) type input modules and so would need special interfaces (base units). They also need annual cleaning and testing implying access inside the enclosed racks, and may also be prone to electromagnetic interference from the kicker systems. **IR based detection** is difficult to implement within a rack environment due to several obstacles e.g. crates, cables and mechanical frames blocking the optical path, and also the presence of other (albeit safe) heat sources e.g. power supplies and solid state switches and body heat from human investigation/intervention. For this reason, they are more suited to unmanned storage areas. **CO detectors**, while promising for early smouldering detection, are not so good at detecting flaming fires with a lower degree of CO production, and this combined with thermal buoyancy effects which may allow smoke particles to rise towards a smoke detector faster than CO molecules diffusing through an equipment rack environment, suggest that use of CO detectors should be backed up by additionally fitting an optical smoke detector, their primary purpose being to detect toxic gas harmful to life. **Heat detectors** are really only suited to detect actual fire producing heat, and not the incipient stages of a smouldering electrical component, so not a good candidate for early fire detection. **Aspirating type Smoke Detection** has the advantage of extremely high sensitivity, the possibility to run sampling pipework inside a rack to the most at risk areas/zones as necessary, to sample from more than one hole and to mount the detection electronics away from the kicker equipment if necessary to avoid potential electromagnetic interference effects caused by noisy kicker pulses. It is also very easy to expand the sampled areas/zones by making additional sample points in the pipes or adding additional pipe. ASD has, therefore, been selected as the preferred method for early fire detection for kicker related equipment racks.

In consideration of environmental issues, a manufacturer was found who had implemented optical dual-wavelength blue and infrared light scattering techniques for detection, which enables particle sizes of typical smoke particles, particularly those smaller than 1 µm, to be clearly discriminated from dust particles such as concrete and cement [2] (see Fig. 4) and report the levels of both separately via an industrial interface. This minimises risk of false alarms with consequent downtime of the kicker system and associated accelerator.

ASD and Pipework Material Constraints and Installation

Industrial applications for Aspirating Smoke Detectors use PVC or ABS pipework as the sampling medium. Both of these materials are forbidden for CERN installations due to their toxic off-gassing in the event of fire, particularly hazardous in underground areas. In this application, a method was developed at CERN using 25 mm diameter aluminium pipes (flow calculations in the various software tools for configuring ASD systems are based on a pipe diameter of 25 mm which is used as standard in industrial ASD applications) which are cut to length using a standard handheld pipe cutting tool, and these are then glued to pre-formed bends and elbows using a two component, high strength, room temperature curing structural adhesive, achieving the necessary routing and tightness very efficiently (no need for welding or expensive couplings). The final sampling nozzle is screwed into a hole made in the top section of the rack, which is then connected to the main pipe via a short section of flexible hose (these short sections of non metallic hose are acceptable in the same way that plastic covers and module housings are accepted in small quantities) and a metallic 'T' piece. The ASD is small enough to mount comfortably on the end panel of one of the racks to be monitored. A dust filter is mounted in-line before the ASD but at sufficient distance to minimise risk of creating turbulent air flow at the ASD inlet (see Fig. 5 and Fig. 6).

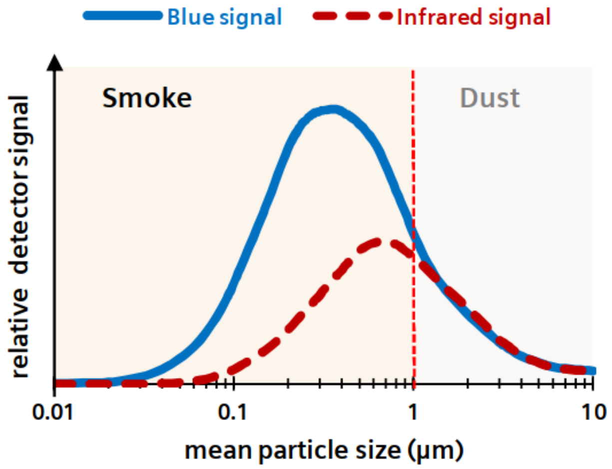


Figure 4: Use of both blue and infra-red light scattering techniques for highly sensitive smoke detection and excellent smoke/dust discrimination.

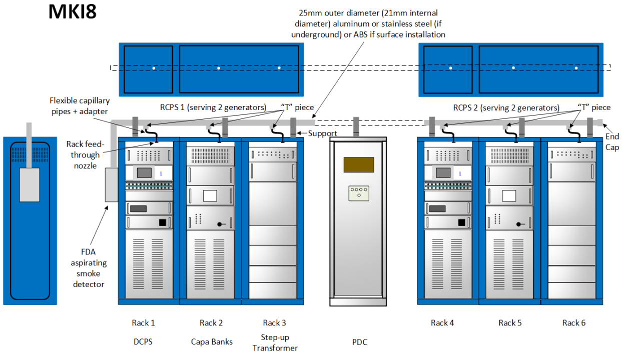


Figure 5: MKI Pipework Installation Planning.

Calculation of Nozzle Size and Flow Rate

The ASD comes with a software configuration tool to enable the flow rate and nozzle diameter to be calculated based on desired reaction time and need to equalise as much as possible the sampling air speed at each of the nozzles taking into consideration distance from ASD. Even the simplest arrangement featuring only a single rack to be sampled was fitted with two nozzles in order to allow for the possibility of one nozzle becoming blocked or restricted, and to distribute

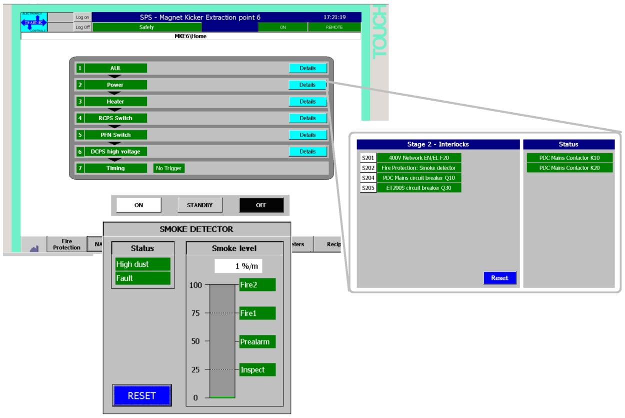
Figure 6: MKI Pipework and ASD Installation.

air sampling across the cross section of the rack so as to have better overall response.

MAIN KICKER CONTROL SYSTEM (PLC) INTERFACE AND LOGIC IMPLEMENTATION

The ASD features industrial interface for remote monitoring and alarm reset. A 4-20 mA output from the ASD is used for remote readout and trending of smoke level, while dry contacts for warning and alarm interlock levels are interfaced to the kicker control system. Kicker systems are based on a phased power up approach, passing from "OFF" via "STANDBY" to "ON" (NOMINAL) operational states, achieved via a State Machine implemented in the PLC (Programmable Logic Controller) code with corresponding HMI (Human Machine Interface) displays (see Fig. 7).

The ASD interfaces to the kicker system in much the same way as any other emergency interlock, stopping the kicker system and removing power from all sub-systems, including the DCPS, via two main relay contactors, as well as closing earthing switches to discharge capacitor banks. In this way, potential fires are stopped in their tracks at the incipient stages of a smouldering component or an arcing connector, and at the same time alarms are raised at the CERN Control Centre.



Stage 2 - Interlocks		Status
S201	400V Network EN/EL F20	PDC Mains Contactor K10
S202	Fire Protection: Smoke detector	PDC Mains Contactor K20
S204	PDC Mains circuit breaker Q10	
S205	ET200S circuit breaker Q30	

Figure 7: Example of PLC HMI Screen Representing the ASD).

TESTING AND EVALUATION OVER ONE YEAR IN OPERATION

The ASD was first installed in a kicker test cage, and after initial smoke response testing and tuning using a small smoke pen, the flow rate and sensitivity levels were adjusted, and the ASD was then evaluated over a three month period for any EMI effect. No EMI issues were found, despite the noisy kicker environment, and this gave confidence to then install the ASDs on two fully operational kicker systems - one in the SPS accelerator and one in the LHC. Over a nine month period, one warning level was reported for the system in the test cage, one actual Fire detection trigger for each of the other two systems, and one warning level. In none of these cases was an actual fire or any level of smouldering found in the system being monitored. Thanks to the CERN wide alarm and monitoring infrastructure, the trended fire alarm indication from the ASDs could be cross referenced to other events:

System 1 (Test Cage) responded to oil vapour from an open PFN assembly 3 m away.

System 2 responded to a small smouldering fire in a motor in the air conditioning ducts coming from the surface down to the equipment service tunnel.

System 3 responded on one occasion to a component smouldering in a non related control rack some 5m away, but with a common floor void for cables (this gave a warning level), and on another occasion to a large fire in the neighbouring town 2-3 km away, causing smoke clouds to pass over the equipment building.

With the exception of the case of oil vapour from the PFN which had been left open for maintenance activities (this can be considered to be a non-operational state), no false alarms were suffered due to dust or other contaminants during normal operation. These fire events that did occur are the exception rather than the rule, but further evaluation is underway to determine over time whether reducing sensitivity would improve availability/up-time of the kicker systems while maintaining the very early fire detection sought in case of an actual in-rack fire.

CONCLUSION

The technology choice and the final choice of manufacturer/model have proven to be a very good fit for kicker system fire detection. The sensitivity to very low levels of non-visible smoke has been demonstrated, and the provision of means to adjust this sensitivity is of great use to set nominal detection conditions. The ability to filter out dust, diverting only a small sample of the aspirated air to the detection chamber and then to differentiate clearly between smoke and dust is desirable given the concrete/cement dust that can gradually accumulate over time in unmanned underground areas, and the excellent remote readout and diagnostic capability, both analogue and digital, means that remote assessment can be made of such areas before interventions are carried out. Naturally the only true test of the ASD would be the undesirable case of a genuine in-rack smouldering situation, both in terms of assessing speed of detection and success of the cutting of power strategy to prevent actual fire outbreak. However, the response to a smouldering component in an adjacent system rack, and response to a passing smoke cloud from a neighbouring town, give a high level of confidence to the reaction capabilities, as in both cases the smoke was invisible to the eye. Furthermore, the occurrence of spurious alarms or non-genuine interlocks to the kicker systems due to detector malfunction, dust or other environmental conditions including EMI noise, has been zero. Roll out of these detection systems is now foreseen for all kicker installations at CERN over the coming 2-3 years, and all installations will continue to be monitored for alarm quality and responsiveness in conjunction with kicker system up-time and any long term maintenance needs.

REFERENCES

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[2] Siemens, “Aspirating Smoke Detection - Very sensitive and reliable fire detection through differentiation between smoke and deceptive phenomena”, 2015. `https://sid.siemens.com/v/u/A6V10583600`