Surge & Transient Protection Systems For Wayside/Hot Box Detection Systems For Rail Safety

White Paper

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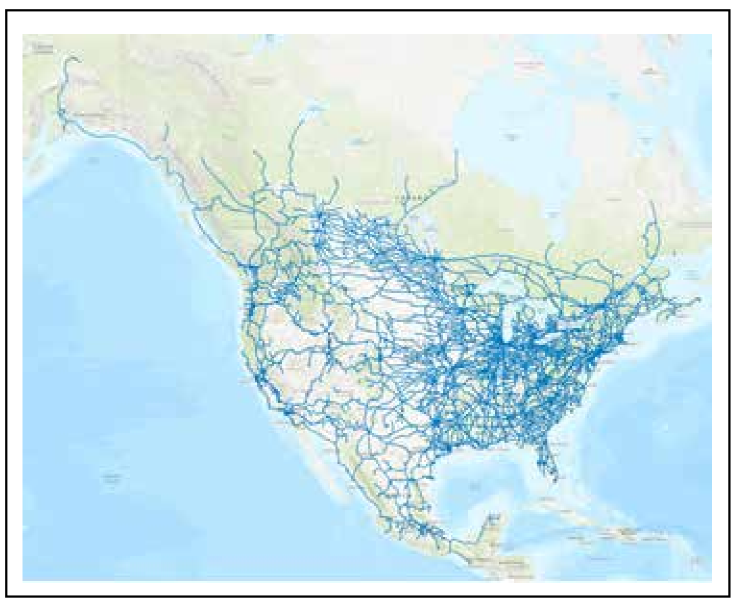
Introduction

Though train derailments and accidents have been relatively common since the development of vast networks of rail systems all across the United States and other countries, recent tragedies and rising concerns for rail safety standards have brought greater attention to railway safety and maintenance practices to the public eye and government officials. Recent Federal Railroad Administration (FRA) safety advisories and notices have pointed out several key areas of safety for railway operators to focus on, mainly the mechanical failures that could be the cause of many of the preventable derailments/accidents [1]. These advisories extend to recommending technologies and procedures to avoid these common failure modes that include hot bearing detectors (HBDs) and other wayside detector system (WDS) technologies **[1,2,3,4]**.

For these WDS technologies to be most effective, many of these systems require highly sensitive detector systems to be placed under, on, directly connected to, and alongside railways. This means that there needs to be electronics housings to power, process, and store the data that is being generated by these WDSs. Moreover, it is becoming increasingly common to use fiber optic, wireless communication systems, hardline ethernet, and coaxial transmission lines to carry critical WDS data from the WDS housings to networked railway communication hubs in order to store the information and to provide this data to railway operators to make use of it in real-time. Hence, these WDSs are not only the detection transducers and signal processing electronics, but a complete installation with power, storage, and communication. Many WDSs now include sensitive RF, analog, and digital electronics that are susceptible to damage from environmental or electrical disturbances compared to traditional analog or mechanical signaling and warning technologies (including human spotters).

Some of these systems are powered via renewable energy technologies, such as solar or wind. Many are powered from rechargeable batteries, generators, and/or utility power, depending on how remote the site is. Given the critical nature of these WDS sites, many also use some sort of backup power, be it a generator or rechargeable batteries, such as in an uninterruptible power supply (UPS).



[7]

Given the host of electronics and electrical systems needed for a reliable WDS and the often harsh environments where WDS systems must be placed, there are many potential failure modes for WDS, including a variety of potential electrical surge generators and electrical transient phenomenon. Hence, surge protection for the myriad of highly sensitive electronic and electrical systems that make up WDSs is essential in ensuring the operation of the WDSs and safety of the railways.

This white paper discusses wayside detector systems (WDSs) and presents the considerations for surge/electrical transient protection for WDSs.

Wayside Detector Systems Primer

The near constant use, harsh environmental conditions, and sheer magnitude of forces involved in railcar motion systems naturally lead to regular failures of several of the mechanical parts of railcars. The common failure parts include the wheel, wheel bearings, journals, wheel flanges, axels, wheel suspension, etc. Even with extremely robust design and material selection, the mechanical components of rolling stock that are used to ensure efficient motion are prone to failure, which if not caught and prevented, can and are often catastrophic. The complexity of the rolling stock mechanical systems mean that a single detector system is inadequate to detect all, or even the most common failure modes. Hence, there are a variety of different detector systems that can be built into the train car itself, or can be located on or near the tracks, such as wayside detector systems. The following table from the United States Department of Transportation Federal Railroad Administration (US DOT FRA, or FRA), lists some of the most common types of WDSs and their functionality:

Table 3-6. Summary of main requirements and specifications of HBD and HWD systems

Criteria	Type	Value	Notes	Ref.
Site Selection	Site size	1 crib (infrared detectors) + 2 cribs for rail contacts	May vary based on manufacturer	[41, 44]
	Speed limits	- Lower limit: 10 mph - Upper limit of between 100 and 300 mph	May vary based on manufacturer	[10, 44]
	Track Requirements	On tangent and level track where braking is uncommon	certain manufacturer may require certain track specs (e.g., steel tie for the detector cribs)	[44]
Operating Parameters and Detector Technology	Type of Operations	Freight, Passenger, Commuter	Applicable for all types of rail operations	
	Resolution	± 1 K	May vary based on manufacturer	[41]
	Measurement Accuracy	HBD: ± 1 K HWD: ± 3 K	May vary based on manufacturer	[41]
	Temperature	(-22 °F) to 158 °F (-40 °F) to 160 °F	May vary based on different manufacturers	[39, 41]
	Sensor Technology	Infrared detectors		[13, 39, 40, 41]
Data Communication	Communication	Email, page, fax, WIFI, Radio	Talker feature is available	[15, 23]
	AEI, RFID?	Yes		[7, 23]
System Thresholds	HBD	- X> 170°F above the average bearings of train - X> 95°F above the mate bearing on the same axle	Depends on the RR rules	[15, 42]
	HWD	X >650°F (level 3) 500 < X< 650°F (level 2) X <500°F (level 1)	Depends on the RR rules	[15, 42]
Action Plan	HBD	Inspect the train, restricted speed; remove bad car from train at the next set-out location.		[15]
	HWD	Stop the train and inspect, the car continue the operations if problem resolved; otherwise cutout the brake on bad car up to the next set-out point. (for HWD level 1)		[15]
Calibration, Maintenance	Calibration Frequency	AAR S-6101 demands static calibration once every 3 years	Auto-calibration for some systems using a calibrated heat source	[21, 44]
	Maintenance Frequency			[21]

[4]

There has been significant focus on WDS technology over the past several years in the advent of more data driven predictive algorithms and machine learning/artificial intelligence (ML/AI) technology that may one day predict and prevent railway derailments and accidents due to mechanical failures of rolling stock equipment. The goal of WDS is to promote improved safety in operation of railways by automatically detecting and reporting rolling stock equipment performance, which can be used to identify maintenance needs for the rolling stock equipment. Some of these systems focus on measuring various aspects of the rolling stock along the track to determine if there are any operational defects, while others focus on specific components and behavior that could indicate a potential future failure.

[8]

According to government studies, bearing failure is the cause of approximately 20% of wheel removals across the North American rail network annually, which equates to roughly $160 million in costs. Hot box detectors (HBDs) are used to measure the thermal signature of the wheel journal bearing box to determine if damage or wear of the journal bearing has exceeded safety parameters. The idea behind HBDs is that damaged or degraded wheel bearings will result in additional friction, which produces higher levels of thermal energy than properly operating. By using precision calibrated thermal sensors that can monitor the wheel journal bearing box and processing information regarding a baseline for a properly operating bearing box and various ambient temperatures, it is possible to detect a poorly performing wheel bearing. If a wheel bearing box indicates a trending high value over several HBD WDS, then the bearing is likely failing and needs to be removed. Unfortunately, journal wheel bearings can fail dramatically in a very short period of time due to a variety of factors and WDS are often placed several tens of miles apart. Within the space between two WDS there is often adequate time for a journal wheel bearing to fail.

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	Track Requirements	On tangent and level track where braking is uncommon	certain manufacturer may require certain track specs (e.g., steel tie for the detector cribs)	[44]
Operating Parameters and Detector Technology	**Type of Operations**	Freight, Passenger, Commuter	Applicable for all types of rail operations	
	Resolution	± 1 K	May vary based on manufacturer	[41]
	Measurement Accuracy	HBD: ± 1 K HWD: ± 3 K	May vary based on manufacturer	[41]
	Temperature	(-22 °F) to 158 °F (-40 °F) to 160 °F	May vary based on different manufacturers	[39, 41]
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	Maintenance Frequency			[21]

[4]

Wheel bearings are just an example of the potential failure modes and limitations of WDS in detecting and properly signaling railway operations personnel to address these issues. Other common failure modes include wheel flange cracks and internal mechanical defects, sticking or locked brake shoes, worn suspension, etc. The complexity of the systems and number of rolling stock cars can be very difficult for railway operators to effectively evaluate, especially considering that many railway operators only see a small slice of time with a given car and generally don't monitor a car beyond their posting or once it has transitioned to another train. This is why there is a growing focus on using data driven algorithms and ML/AI systems to monitor rolling stock in rolling time and use predictive algorithms to mitigate failures and accidents. To achieve this, there needs to be systems in place to rapidly analyze WDS information in real-time and effectively communicate this information to cloud databases that can then be analyzed further by maintenance and safety predictive algorithms. The resulting electronics would likely benefit from additional WDS and higher levels of precision in the data, as more high precision data will likely improve the effectiveness of these algorithms.

These changes would likely necessitate more capable edge electronics at WDS, which would further the complexity of sensitive RF, analog, power, and digital electronics at WDS. This in turn would place a greater burden on the electronic and electrical protection technology in WDS installations.

Railway Equipment That Is Commonly Protected Via Surge Protection Devices (SPDs)

- Utility Supply & AC Supply
  - Wayside Electrical Panels (AC)
  - Onboard Electrical Panels (AC)
- RF Communication/Radio Equipment
  - Voice Radio
  - PTC Radio
  - Onboard Radio
  - Wireless Networking
  - Cellular Networking
- Digital Communication/Radio Equipment
  - Ethernet Switches
  - Routers
  - Camera feed
  - Radio Data
- Railway Equipment Inputs/Output
  - Line Circuits
  - Axle Counters
  - Signal Lights
  - Hot Box Detectors *and other WDS detectors and systems
  - Crossing Equipment
  - Switch Machines
  - Track Circuits

Surge & Transient Considerations For Wayside Detector Systems

There are many considerations for the design and protection of electronic and electrical equipment for use in railway applications, which only compound if the equipment is placed on, near, or connected to the railway track. Rail systems in North America alone are subjected to wide temperature extremes from well below freezing to beyond boiling and from extremely dry desert climates to flooding conditions. Moreover, many rail systems use, or are located by, high voltage power systems in excess of 10s of kilovolts to megavolts. Given the conductive nature of the track and other conductive support and cabling often near railways, these systems are prone to conducting electrical energy and interference from nearby electromagnetic radiation, be it man made or natural. In terms of natural phenomenon, the extensive lengths of electrically conductive track can also couple in electrical energy from lightning strikes, geomagnetic storms, and coronal mass ejections (CMEs)/solar winds. The train itself moving at speeds is enough to cause eddy currents in the track itself.

All of these phenomena result in a high chance that electronic and electrical equipment near railways will be subjected to electrical surge events and potentially hazardous transients. Clearly, electrical surge protection equipment, or surge protection devices (SPDs), are an essential component of the electrical and electronic systems. Surge protection is needed at essentially every interface for these systems, as an electrical surge could travel from one system to another along the grounding/shielding of the interconnect or wirelessly couple from one device/housing to another. This includes the need to provide surge protection at the AC supply from the utility, DC supply power, and between the individual system components, especially if any are connected to the track or other railway equipment exposed to the track.

Given the industrial nature of the application, having SPDs that are DIN-Rail mounting compatible can be an extremely useful feature that eases installation, maintenance, troubleshooting, and potential retrofitting or replacement. This is due to many industrial systems having adopted DIN-Rail mounting systems for their electronics. Though DIN-Rail mounting is less common for AC electronics in the United States than in Europe, DIN-Rail mounting is still extremely common globally for DC circuits, especially power supplies and controls.

Other key considerations include having replaceable suppression modules in case a surge event exceeds the operating capability of the SPD. In this way, the system could be rapidly repaired and brought back to operation, which is crucial for rail systems which operate around the clock and virtually every day of the year. 24 Volt operation is also key for many WDS and railroad signaling equipment, as many of these systems operate on 24 V DC power supplies.

Lastly, one of the most significant considerations is what type of SPD technology to use. There are three main SPD technologies, namely gas discharge Tube (GDT), Metal Oxide Varistor (MOV), and Silicon Avalanche Suppression Diode (SAD/SASD). Each of the technologies presents a slightly different method of shunting excess electrical energy to ground, which results in different surge protection characteristics. An advantage of SASD/SAD compared to MOV and GDT is that these silicon-based diode devices have an extremely sharp curve in the breakdown voltage. Hence, these devices are able to clamp very close to the rated voltage of a system. This can be extremely beneficial in complex combinations of circuitry where power, analog, digital, and RF electronics are connected to the same supplies and where new information technology (IT) equipment, edge processing, or RF equipment, are generally highly susceptible to damage from voltage surges and transients that are even slightly above the devices operating voltage.

Both MOV and SASD/SAD devices exhibit sufficiently fast response times to account for typical lightning-induced surges or a variety of other surges from load-switching operations in AC electrical systems that have limited response times due to the high inductance of the wiring (often limiting surge rise times to tens/hundreds of nanoseconds), electrical surges and transients that travel along data lines, transmission lines, or are radiatively, inductively, or capacitively coupled could result in surges with much faster rise times than this. Theoretically SASDs/SAD devices have faster response times than MOV devices, though the effective response time is heavily influenced by the dynamics of the installation, especially interconnect. These are why SASD/SAD devices are generally preferred over MOV devices, both of which are orders of magnitude faster than GDT devices, which generally have response times in the microseconds.

Conclusion

Surge protection devices (SPDs) are an indispensable component of wayside detection systems (WDS) and other railway electronic and electrical equipment and systems. The harsh environmental conditions and host of potential electrical surge and transient generators result in SPDs being a necessary feature in ensuring uptime and operation of WDS and other railway systems. It is critical for a railway operator to select appropriate SPDs that meet the technical requirements of the equipment used in railway systems, which is becoming a greater challenge as more sophisticated electronics are being integrated into WDS and railway systems. To stay ahead of the game and to ensure SPD availability that is compatible with a given systems, it is crucial to choose SPD suppliers that are able to provide same-day shipping of a wide variety of AC and DC SPDs, as any down-time in WDS technologies could, unfortunately, result in railway derailments and accidents.

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