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Variable Frequency Drive (VFD) Control of Fans for Laboratory and Animal Research Facilities (ARFs)

Introduction

Variable Frequency Drives (VFDs) are typically used at NIH to control air handling units (AHUs) and exhaust fan systems. Advantages of VFDs include reduced energy cost from operating fans at reduced speeds in response to system load, the ability to set up and manage fan arrays or parallel or redundant fans, reduced motor inrush current during startup as VFDs start at lower speeds and ramp up, and a quick return on investment, typically achieved in less than 5 years.

Seamless Integration

The BAS shall provide for seamless integration with the control of VFDs and associated systems. The interface may be either hardwired (via point-by-point wiring to an applicable termination on the drive's interface board) or connected through digital communications via a controller network (e.g., a Siemens P1 chip or similar by Johnson and others included with the drive, a Modbus interface to the drive, or through BACnet communication protocol), or a combination of both.

At a minimum, the BAS shall hardwire interface with the AHU/exhaust VFDs for On/Off, speed control, and status.

Hand-Off-Auto (HOA) switch

An HOA switch shall be provided on the VFD. Any applicable fireman's override shall override any HOA switch function. Otherwise, the HOA shall control the fan as follows:

1. In the Hand position, the fan shall start and run continuously at a speed manually set on the drive unless a safety device trips. A mechanism shall be provided to open the dampers when the HOA is in the Hand position and will be proofed in the BAS.
2. In the Off position, the fan shall stop, and the dampers will shut.

BAS Fan Control

In the Auto position, the BAS shall control the fan as indicated below.

1. The VFD drive may have a bypass (across the line). The bypass position shall be monitored and annunciated as an alarm on the BAS. The application in bypass must include appropriate consideration of the operation in the bypass mode, such as operating point, ductwork pressurization, and noise.
2. On a direct drive operating in bypass mode (non-fan array), fans shall not be allowed to operate above their rated class RPM. Where fan operation with the VFD in bypass mode is not feasible, a backup VFD shall be provided to operate the direct drive motors in bypass mode.
3. On AHUs with multiple direct drive fans arranged in a fan array (fan wall), and where one fan is redundant (N+1), a backup VFD for each fan is not required. A bypass option is not recommended for VFDs serving direct drive fans arranged in a fan array.
4. Multiple fans within the AHU should not be controlled with common VFDs.
5. The BAS program shall control starting and stopping of the fans. Fans shall start at minimum speed and ramp up under a controlled rate to the required capacity. When fans stop, they shall ramp down from the control speed to minimum at a controlled rate prior to stopping.
6. Parallel fans powered by the VFD shall operate as lead/lag devices. When one device is commanded by the BAS to start, the lead device shall start and gradually ramp up in speed to maintain control set point.
7. When one fan fails, the VFDs start running the remaining fans at higher speeds to maintain control setpoint.

Fan Capacity Modulation

The BAS shall modulate the drive to maintain the design static pressure setpoint based on static pressure sensors located in the ductwork system. The response shall be based on the most demanding of multiple duct pressure sensors. The set point shall be reset based on terminal unit requirements.

Drive Configuration

Drive configuration shall include the following:

1. Automatic restart on power interruption
2. Acceleration and deceleration rates appropriate to the application
3. The drive shall catch the freewheeling fan and accelerate or decelerate to the required control frequency without stopping or going to a minimum speed first. This helps the fan to ride through the momentary power loss or voltage sag.

Communication Failure

Appropriate protections shall be programmed for communication failures. For instance, on loss of communication from the drive controller, the unit shall be controlled from last batch of data and the BAS shall provide an alarm. The BAS will also provide an alarm on failure of the VFD.

Conclusion

Proper control of the VFD-driven supply and exhaust fans is required to ensure efficient operation, proper airflow, and static pressure. In addition, the BAS ensures orderly startup, shutdown, and smooth operation.

References

1. NIH *DRM*, Chapter 7

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Sustainable Concrete Strategies

Introduction

Concrete is one of the most versatile and widely used construction building materials due to its strength, durability, and flexibility in design. Its fire resistance, vibration-dampening characteristics, and other properties make concrete a good choice for the design of research buildings, including on the NIH campus. This article therefore focuses on the implementation of sustainable strategies that can significantly reduce the environmental impact of concrete.

Limitations of Conventional Concrete

The environmental impact of building construction faces more scrutiny than in previous years due to zero-carbon mandates and other green initiatives. Despite its many advantages, concrete's contribution to environmental degradation and CO_2 production is significant and must be recognized. Issues include:

- **CO_2 Generation:** Concrete is estimated to account for 8% of global CO_2 production.[1] Raw materials (chiefly limestone) are heated in kilns, which are traditionally fed with fossil fuel, releasing CO_2. This process (calcination) converts limestone to calcium oxide, releasing additional CO_2.[2]
- **Land Degradation:** Aggregate, traditionally sand and gravel, is extracted from the ground. The extraction, processing, and transportation of aggregate result in land degradation, habitat loss, water pollution, and CO_2 production.
- **Water Use:** Concrete production consumes large amounts of water, contributing to runoff and pollution. The concrete industry is among the top water-consuming sectors, requiring approximately 150 liters of freshwater per cubic meter of concrete. [3]

Environmental Benefits of Sustainable Concrete

The negative environmental impacts of concrete can be reduced by incorporating sustainable strategies which utilize the advantageous properties of concrete while reducing carbon production and water use. These strategies include:

- Implementing cement production techniques using renewable energy, biofuels, or other alternatives to fossil fuels.
- Reducing cement content by using supplementary cementitious material (fly ash, slag, silica fume) in concrete mixes. Supplementary cementitious materials (SCMs) are industrial by-products used as partial replacements of clinker in cements or Portland cement in concrete mixtures that provide strength and durability to cement applications.
- Reducing 'virgin' aggregate extraction with suitable locally-sourced recycled material, including recycled concrete aggregate, to conserve resources and reduce pollution from aggregate production.
- Reducing freshwater use via grey or recycled water and admixtures, which improves workability and reduces water demand to curtail the burden on our water supply.
- Implementing innovative structural design building systems that use less structural concrete, which may reduce as much as 40% of the total CO_2 emissions created during construction.

Future Advancements in Concrete

Concrete uses approximately 7-15% cement by weight, varying by performance requirements. Numerous promising advances are being developed which are expected to further reduce negative environmental impact, as well as the percent of CO_2 produced during manufacturing,[2] including:

- **Carbon Capture:** Carbon capture involves capturing emissions from concrete production before they enter the earth's atmosphere and storing the CO_2 either in the concrete or in geologic reservoirs.
- **Ultra High-Performance Concrete:** Ultra high-performance concrete adds fibers to the concrete mixture to improve strength, resulting in designs utilizing less volume of concrete.
- **Carbon Sink Additives:** Concrete admixtures in development will increase the atmospheric carbon absorbed in concrete.[3]
- **Artificial Intelligence Modeling:** Artificial intelligence (AI) is utilized to develop low-CO_2 concrete mixes. An AI model generates and analyzes various concrete formulas much faster than traditional methods. Adjustments are made in the model for variables such as local material availability and cold-weather conditions.[4]

Conclusion

Concrete will continue to be essential to structures that support our daily lives, so it is critical to mitigate its environmental impact. Innovative methods for reducing CO_2 production, such as carbon capture that turns carbon emissions into solid mineral for use in concrete, will help ensure that concrete remains a viable construction material. In order to increase the widespread adoption of sustainable concrete, proponents must seek to raise awareness of its environmental benefits and how they are worth initial higher costs, and the industry must continue to develop additional eco-friendly materials and production techniques.[5] We remain optimistic for the future of sustainable concrete as experts in the concrete industry are working toward energy-efficient cement production facilities, transportation systems, and construction methods.

References

1. Chandler, David L. "New Additive Could Turn Concrete into an Effective Carbon Sink." MIT News, March 28, 2023. https://news.mit.edu/2023/new-additives-concrete-effective-carbon-sink-0328
2. National Ready Mixed Concrete Association. "Concrete CO^2 Fact Sheet." NRMCA, June 2008. https://greenconcrete.info/downloads/11_ConcreteCO2.pdf
3. Miller, Sabbie A., Arpad Horvath, and Paulo J.M. Monteiro. "Impacts of Booming Concrete Production on Water Resources Worldwide." *Nature Sustainability* 1 (2018): 69-76. doi: 10.1038/s41893-017-0009-5
4. "Artificial Intelligence Produces a Recipe for Lower-Carbon Concrete." University of Illinois Urbana-Champaign, April 27, 2022. https://cee.illinois.edu/news/artificial-intelligence-produces-recipe-lower-carbon-concrete
5. "How is Sustainable Concrete Made? A Guide for Architects, Designers, and Builders." UGreen, April 1, 2024. http://ugreen.io/how-is-sustainable-concrete-made-a-guide-for-architects-designers-and-builders/

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Anchor Channels & Hanger Installations

Introduction

Anchor channels are metal insert channels with a C-shaped section which are cast into the underside of a concrete slab to allow for the attachment of hangers at any point along their length. Anchor channels reduce the need for traditional attachment methods (such as individual embeds, hammer drilling, or powder-actuated anchors), which facilitate hanger installation during initial construction and for the life of the building. This article will focus on the use of anchor channels and hanger installation systems for mechanical, electrical, and plumbing installations.

Case Study

Building 40A, a six-story addition to the Vaccine Research Center on NIH's Bethesda campus, was recently installed with an anchor channel system and hanger installation system (see Figure 1). The use of anchor channels has enabled faster installation of pipes, conduits, and other suspended MEP system components, and is expected facilitate the modification of these systems for the life of the building. The success of the anchoring channel system at Building 40A will serve as the model for future projects utilizing anchor channel systems at NIH.

Figure 1: Anchor channels in Building 40A

Key Benefits

Anchor channels are cost effective if they are planned into the design early. Anchor channel and hanger installation systems provide improved function and added features compared to traditional anchoring systems, simplifying workflow and reducing installation time. Anchor channels benefits include but are not limited to the following:

- Faster hanger installations
- Immediate load-carrying capability
- Easy positional adjustment
- Adjustability without drilling or welding
- Ease of maintenance
- Adaptability for future attached components

Design Considerations

The engineer of record (EOR) must account for embedded anchor channels, along with the weight of suspended systems, in the design of slabs, including slab thickness and reinforcing. Design criteria include the American Concrete Institute (ACI) Code 318, *Building Code Requirements for Structural Concrete and Commentary,* and AC232, *Acceptance Criteria for Anchor Channels in Concrete Elements*, published by the International Code Council Evaluation Service (ICC-ES).[1]

The EOR must specify and detail the anchor channel system, in conjunction with the slab, to accommodate the hangers and loads of the initial design, with capacities for anticipated future loading. Installation details, including stud/anchor embedment depth, shall comply with ACI criteria and product manufacture regarding design, specifications, and installation to ensure warranty compliance.

When specifying anchor channel systems, the EOR must consider the following factors: minimum substrate requirements, appropriate channel size for the application, T-bolt selection (standard, heavy duty, stainless steel, slotted, etc.), and strength of the T-bolt for the applied load, geometrical properties, and lead time.

NIH *Design Requirements Manual* (*DRM*) Requirements

The next *DRM* update will include requirements for the incorporation of anchor channels in new NIH buildings and building additions where the following conditions are met:

- Tensioned slab construction
- Containing utility-intensive functions (e.g., data centers, research, procedure, imaging, fabrication, testing)
- Containing facilities subject to renovation or upgrade due to technological advancement or program evolution (e.g., laboratory, vivarium, clinical)

Where the above conditions are not met, the use of anchor channels will not be required but recommended for all other new buildings and building additions. The A/E and NIH stakeholders shall assess the building's structure, density of suspended utilities, likelihood of future renovations, and other relevant factors to determine whether anchor channels are of long-term value for the building. A summary of the assessment shall be included in the BOD.

Installation shall be determined by the BIM model based on the anchors needed to support suspended utilities. 2'-0" OC channel anchor spacing is recommended in areas with primary utility distribution and highest density (mechanical rooms, interstitial spaces, utility corridors, other high-utility areas) and 4'-0" OC for lower-density, terminal use areas.

Conclusion

Anchor channels provide an efficient cast-in anchoring system that facilitates hanger installation during initial construction and for the life of the building. Their use helps avoid post-occupancy renovations that would ordinarily involve installing new embeds, generating significant levels of vibrations, noise, and cost as well as challenges in the vicinity of previously hung utilities. Future *DRM* updates will enforce and provide additional guidance relating to applicability, use, and design of anchor channels and hanger installation systems at NIH labs and clinical facilities. Given the dynamic nature of biomedical research and the need to co-evolve science and buildings, this life cycle flexibility is indispensable.

References

1. Christopher Mahrenholtz, "Robust Anchorages to Concrete Structures," Structure Magazine, September 9, 2022, https://www.structuremag.org/article/robust-anchorages-to-concrete-structures/#:~:text=Anchor%20channels%20with%20channel%20bolts,fatigue%20loads%20in%20any%20direction.

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Corrosion in Closed-Loop Water Systems Part 1 - Understanding Corrosion

Introduction

Corrosion in closed-loop heating hot water (HHW) and chilled water (CHW) systems negatively impacts efficiency, reliability, and longevity, drives up maintenance costs, and risks equipment failure. It can cause significant damage in these systems, ranging from visible leaks due to pipe perforation to unseen internal corrosion producing iron oxide/hydroxide/oxyhydroxide sludge. Key contributing corrosion factors include water chemistry, mechanical wear, and microbial activity, with parameters such as pH, conductivity, and metal/anion concentrations offering valuable insights into corrosion progression. Part 1 of this article series focuses on fundamental concepts of corrosion in closed-loop water systems (CLWSs), including types of corrosion, mechanisms, and contributing factors. Part 2 will explore key criteria for evaluating corrosion in a CLWS and outline best practices for prevention and control.

Closed-Loop Heating and Cooling Systems in Buildings

Closed-loop heating and cooling systems are designed to circulate water through various building components for heating and cooling purposes, using energy from external sources such as steam or chilled water. HHW typically serves preheat coils, reheat coils, and chilled beams and utilizes closed-loop hot water generated at the heat exchanger using utility-supplied steam. Cooling for magnetic resonance imaging (MRI) machines and chilled beams normally utilizes closed-loop chilled water created at the heat exchanger using utility-supplied chilled water. Preheat hot water generally contains anti-freeze with corrosion inhibitors (e.g., phosphate-based glycol), and reheat hot water generally contains either nitrite or molybdate as corrosion inhibitors. The chilled water may contain corrosion inhibitors such as triazoles with a borate buffer.

Corrosion Mechanisms

Corrosion occurs when four essential elements are present: an anode (where oxidation occurs), a cathode (where reduction occurs), an electrolyte (a conductive fluid), and an electrical connection (allowing electron flow). Once all these elements exist, corrosion progresses through four stages: initiation (surface damage begins), propagation (corrosion spreads), acceleration (increased degradation due to stress or temperature changes), and failure (loss of structural integrity). Removing any one of the four essential factors can prevent rusting, and protection measures like coatings and cathodic protection can also disrupt the process.

Corrosion Contributors

- Water chemistry imbalance:
  - Low or high pH: Low pH accelerates general corrosion, promotes metal dissolution, and increases the solubility of protective oxide films. High pH can cause localized corrosion, precipitation of scale-forming minerals, and alkaline embrittlement.
  - Mechanical cross-connect: Issues include steam lines cross-connected at heat exchangers or improper water source makeup, like chilled water. This can contaminate the CLWS and create a corrosive environment.
  - Dissolved oxygen: Excess oxygen accelerates oxidation.
  - Chlorides, nitrates, and sulfates: Elevated levels contribute to pitting (localized corrosion) and crevice corrosion.
- Microbial activity:
  - Microbes, such as bacteria, fungi, and algae, can adhere to pipe surfaces and form slimy biofilms. Areas under the biofilm become oxygen-starved (anodic), while surrounding areas remain oxygen-rich (cathodic), leading to pitting. Acid-producing bacteria can generate acidic byproducts like organic or inorganic acids, which directly attack metal surfaces. Sulfate-reducing bacteria (SRB) can produce hydrogen sulfide (H_2S), a highly corrosive gas that can lead to sulfide stress cracking or deep pitting in metals like carbon steel. Iron-related bacteria (IRB) can accelerate the formation of tuberculation, which blocks water flow and shelters further microbial growth underneath. Microbial colonies under sludge, rust, or scale deposits create stagnant zones that worsen under-deposit corrosion.
- Mechanical factors:
  - Flow-induced erosion or abrasion.
  - Dead legs or stagnant zones.
  - Poor system flushing.
- Material issues:
  - Use of dissimilar metals causing galvanic corrosion.
  - Low-quality or improperly coated piping materials.
- Temperature effects:
  - Elevated temperature accelerates chemical reactions. A rule of thumb: a ten-degree Celsius temperature increase doubles the reaction rate.
  - Temperature fluctuations cause thermal stress and expansion.
- Lack of routine maintenance and preventative measures:
  - Failure to perform standard chemical treatments or replenish corrosion inhibitors.
  - Infrequent or inconsistent monitoring of water chemistry.
  - Overlooking early warning signs of corrosion, such as discoloration, unusual odors, or pressure drops.

Corrosion Types

Understanding the types of corrosion that occur in HHW and CHW systems is essential for accurate evaluation. Common corrosion types include:

- Uniform corrosion – Even surface degradation, predictable and manageable. A uniform loss of metal due to oxidation, often influenced by pH and oxygen levels.
- Galvanic corrosion – Occurs between dissimilar metals in a corrosive environment.

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- Crevice and pitting corrosion – Localized attack in confined spaces or deep pits. These occur in stagnant water zones and are exacerbated by chloride presence.
- Intergranular corrosion – Affects grain boundaries, often due to heat treatment.
- Stress corrosion cracking (SCC) – Caused by tensile stress and a corrosive environment.
- Corrosion under insulation (CUI) – Hidden corrosion, occurs when moisture is trapped from the environment or condensation beneath insulation.
- Under-deposit corrosion – Results from the accumulation of scale, sediment, or biofilms, leading to localized attack.
- Erosion – Accelerated by fluid movement.
- Microbiologically-influenced corrosion (MIC) – Occurs when bacteria thrive in low-flow or stagnant areas of the system, exacerbating corrosion. Low pH sometimes indicates possible microbial corrosion.
- Dealloying – Selective removal of an alloy element, such as dezincification in brass.

Understanding corrosion types and symptoms allows for early detection and monitoring, which are crucial for both preventive strategy selection and the extension of equipment life. For example, dissolved oxygen (DO) drives corrosion in closed loop systems, entering through aerated water, pressurization imbalances, or non-barrier pipes as shown in *Figure 1A*. Tuberculation, as shown in *Figure 1B*, is a form of corrosion where rust-colored mounds, called tubercles, form inside iron pipes, often due to bacteria and certain water conditions. These buildups can restrict water flow, discolor water, and lead to pipe damage over time. Signs include reddish stains, reduced water pressure, and pipe pitting, which can be confirmed through pipe camera inspections. *Figure 1C* shows an example of MIC pit caused by bacteria and other microorganisms. These organisms can form biofilms and produce corrosive substances such as acids or sulfides that accelerate pitting, especially in moist environments.

Figure 1: Steel pipe corrosion due to DO levels (1A), tuberculation (1B), and MIC (1C). [cibsejournal.com, NIH DTR, and ecscorrosion.com]

Conclusion

Understanding the fundamental concepts of corrosion in CLWSs is essential for maintaining their efficiency and longevity. Uniform, pitting, and microbiologically influenced corrosion as well as the underlying mechanisms are driven by chemical, microbial, and mechanical factors. Recognizing these contributors provides a basis for identifying early warning signs and making informed decisions to maintain system integrity and control of biofilm formation.

Additional Reading

1. Jones, D. A. (1996). *Principles and Prevention of Corrosion* (2nd ed.). Prentice Hall.
2. Schito, E. (2018). Dynamic Simulation of an air handling unit and validation through monitoring data. *Energy Procedia, 148,* 1206-1213. https://doi.org/10.1016/j.egypro.2018.08.010
3. Kreider, J. F. (2000). *Handbook of Heating, Ventilation, and Air Conditioning*. CRC Press.
4. Veolia. (2025). *Handbook of industrial water treatment.* https://www.watertechnologies.com/handbook/handbook-industrial-water-treatment
5. Prasetia, Y. (January 10, 2025). *Corrosion mechanisms understanding causes and effects*. Petrosync. https://www.petrosync.com/blog/corrosion-mechanisms/

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Corrosion in Closed Loop Water Systems Part 2 – Evaluation and Prevention

Introduction

Practical strategies for evaluating, preventing, and controlling corrosion in closed-loop water systems (CLWSs) are vital for ensuring consistent system performance, minimizing unplanned downtime, and extending the life of critical infrastructure. Key evaluation criteria such as corrosion rates, metal ion concentrations, and water chemistry parameters are essential for assessing system health. Part 2 of this article series explores proven monitoring techniques and industry best practices in chemical treatment and maintenance to support long-term reliability, protect equipment, and sustain efficient operation.

Evaluation Criteria

Evaluating corrosion in CLWSs requires focusing on corrosion monitoring methods, water chemistry parameters, corrosion inhibitor concentrations, microbial growth assessment, and system design and maintenance. Key performance indicators (KPIs) include: corrosion rate, which measures metal loss over time, typically via corrosion coupons or other electrochemical methods; water chemistry parameters, including pH, temperature, conductivity, dissolved oxygen (DO), metal ions, chloride/nitrate/sulfate ions, turbidity, and inhibitors (e.g., nitrites, molybdates, inhibited glycol or triazoles); and microbial assessment of various bacteria such as heterotrophic bacteria, sulfate-reducing bacteria, iron-related bacteria, and nitrifying and denitrifying bacteria.

Corrosion Rate:

Quantitative analysis of corrosion rates provides insight into system health. Methods of monitoring corrosion rates in a CLWS include:

- Corrosion coupons: Exposed to system water for a set period, then cleaned and weighed to determine metal loss.
- Linear polarization resistance: Measures real-time corrosion rates electrochemically.
- Electrochemical impedance spectroscopy: Assesses detailed corrosion behavior and inhibitor effectiveness.

Water Chemistry Parameters:

Regular water analysis is essential for identifying corrosion risks.

- pH levels: Depending on metallurgy, pH should be maintained within a thermodynamically and empirically established range. For carbon steel, the pH should be within 9.0–10.5 to minimize metal attack.
- Mechanical cross-connect: Intrusion of untreated makeup water or steam/chilled water leaks can introduce external contaminants, oxygen, and particulates that can potentially increase corrosion. These can be identified by comparing related water chemistry parameters with those of potential intrusion sources.
- Dissolved oxygen: Implement de-aeration and scavengers to reduce DO.
- Chlorides, nitrates, and sulfates: Elevated levels of chlorides and sulfates contribute to pitting and crevice corrosion. Nitrates can act as a dangerous inhibitor because a very localized corrosion attack can be initiated when the environment allows a passivation-activation transition.
- Conductivity: High conductivity without inhibitors increases the risk of localized corrosion.
- Iron and copper concentrations: A higher concentration of iron and copper than is present in makeup water indicates active corrosion of system components.
- High turbidity or cloudiness: Can be an indicator of a high-corrosion situation, as makeup water has minimum dirt or silt.
- Nitrite concentration: Indicates the presence of corrosion inhibitors for a CLWS with iron piping.
- Orthophosphate/molybdate concentration: Low levels or absence of orthophosphate or molybdate in glycol-added preheat hot water suggest dormancy, stagnation, leaks, or microbial issues requiring repair, cleaning, or chemical replenishment.
- Triazoles: The presence of triazoles, commonly used in closed-loop chilled water systems, in the heating hot water (HHW) system indicates potential unintended intrusion of chilled water into the HHW system.

Microbial Assessment:

Microbial-induced corrosion (MIC) is a major concern in preheat hot water and chilled water systems. A corroded surface site provides an ideal environment for MIC to initiate or accelerate.

- Bacterial culture tests: Identify specific types of bacteria. Dip slides or Petrifilm can detect heterotrophic bacteria, while biological activity reaction tests detect sulfate-reducing and iron-oxidizing bacteria, among others.
- ATP-based methods measure microbial activity. Microscopy techniques, staining assays, and biochemical assays can visualize and quantify biofilm.
- MIC indicators: The presence of iron sulfide deposits and acidic byproducts suggest microbial activity.

Corrosion Inhibitors

The most effective corrosion inhibitors for a CLWS are molybdate and nitrite, either separately or in combination. These inhibitors protect metal surfaces by forming an oxide layer (preventing the corrosive agent from reaching the metal) or by reacting with corrosive elements in the system. Molybdate provides excellent protection in various water conditions but requires DO, while nitrite promotes oxide formation on steel but can oxidize to nitrate if air ingress occurs and feeds certain microbes. A molybdate-nitrite combination offers synergistic protection, with nitrite aiding oxide film formation. Maintaining alkaline pH is essential for this combination, though excessive pH (>12) can cause caustic embrittlement. Nitrite-molybdate-azole blends inhibit corrosion in steel, copper, aluminum, and mixed-metallurgy systems.

While inhibitors can help control corrosion, effective oxygen control remains essential for comprehensive corrosion prevention, as DO in makeup water can cause flash rusting on carbon steel. Oxygen control can be achieved by using oxygen scavengers. System materials are also a consideration; although stainless steel can tolerate a high concentration of DO, smaller components like brass valves may experience accelerated corrosion. Finally, proper pressurization and limited flushing are key to preventing air ingress. Effective corrosion control requires a combination of oxygen exclusion, controlled flushing, and microbial management.

Piping Visual Inspection and Monitoring

Routine inspections help detect early corrosion indicators.

- Internal pipe and heat exchanger inspections help detect scale, deposits, and rust.
- Corrosion coupon, instantaneous corrater, and electrical resistance probe monitoring assess metal loss.
- Ultrasonic thickness testing measures pipe wall degradation over time.

A comprehensive monitoring approach ensures early detection of corrosion risks, optimizes water treatment strategies, and enhances the longevity of closed-loop systems.

Evaluation with City Water Markers

Comparing water quality parameters between a closed-loop system and city water may indicate intrusion of unwanted sources of makeup water, inadequate treatment, or depletion of corrosion inhibitors over time, any of which may then require repair, corrective chemical dosing, and ongoing monitoring. Routine analysis of pH, conductivity, alkalinity, hardness, DO, and inhibitor levels helps assess water stability and treatment effectiveness. Steam leaks into hot water systems can be identified by comparing their pH values with that of city or makeup water. Neutralizing amine-treated steam will have a higher pH than city water. Untreated steam will have a lower pH than city water. Comparing metal ion concentrations (e.g., iron, copper, zinc) between closed-loop and city water can identify contamination sources or treatment deficiencies. Monitoring chloride, sulfate, and total dissolved solids helps detect corrosive elements introduced from city water or progressive corrosion activities. Additionally, testing for biofilm formation and MIC is crucial to prevent microbiological fouling and under-deposit corrosion.

Prevention and Mitigation Strategies

Effective strategies to prevent or mitigate corrosion in a CLWS include:

- Chemical treatment: Use oxygen scavengers (e.g., sodium sulfite, erythorbate, and diethylhydroxylamine) and corrosion inhibitors (e.g., nitrite, molybdate, phosphate, and triazoles). For new piping or equipment tie-ins, regular flushing and passivation are recommended.
- Electropolishing and passivation: Stainless steel is widely used in cleanroom applications for its durability and corrosion resistance. However, to prevent and mitigate corrosion—especially in welded systems and piping—surface treatments such as electropolishing and passivation are essential. These processes, as specified in the *Design Requirements Manual* Section 13.8.21 and Exhibit 6.3, Sections A–C (see also ASTM A967 and ASTM A380), enhance the protective oxide layer and improve surface finishes, reducing the risk of contamination and corrosion. Electropolishing can also be applied to other compatible pipe materials to further enhance corrosion resistance.
- System design optimization: Minimize dead legs, maintain proper flow rates, and avoid dissimilar metal contact by using dielectric unions or insulating fittings at joints to prevent galvanic corrosion.
- Filtration and backwash practices: Remove particulates to reduce the risk of under-deposit corrosion.
- Cathodic protection: Apply sacrificial anodes or impressed current systems where appropriate.
- Regular monitoring and maintenance: Conduct periodic water testing, system flushing, and condition assessments to detect and address early signs of corrosion. Regular monitoring for specific bacteria, like sulfate-reducing bacteria and iron-related bacteria, is essential to detect and prevent MIC.

Conclusion

Regular corrosion evaluation in closed loop heating and cooling systems is essential for maintaining efficiency and extending system lifespans. Routine monitoring and preventive strategies help protect system components and ensure long-term performance. Monitoring water chemistry, physical inspections, and corrosion rate assessments offer vital information on system conditions. By adopting proactive mitigation measures, it is possible to reduce the risk of early failure and expensive repairs.

Additional Reading

Jones, D. A. (1996). *Principles and Prevention of Corrosion*. Prentice Hall.

Bastidas, D. M., Martin, U., Bastidas, J. M., & Ress, J. (2021). Corrosion inhibition mechanism of steel reinforcements in mortar using soluble phosphates: A critical review. *Materials*, *14*(20), Article 6168. https://doi.org/10.3390/ma14206168

Felipe, M. J., Ponnapati, R., Pifer, M., Murugesan, S., & Kristen, C. (2020, March 15-19). *Closed loop systems: Electrochemical studies on nitrite/molybdate corrosion inhibitors*. CORROSION 2020, Houston, TX, United States. https://doi.org/10.5006/C2020-15204

Xu, W., Zhang, B., Deng, Y., Yang, L., & Zhang, J. (2021). Nitrate on localized corrosion of carbon steel and stainless steel in aqueous solutions. *Electrochimica Acta*, *369*, Article 137660. https://doi.org/10.1016/j.electacta.2020.137660

Veolia. (n.d.). *Handbook of industrial water treatment*. Veolia Water Technologies and Solutions. https://www.watertechnologies.com/handbook/handbook-industrial-water-treatment

Petrosync. (2025, January 10). *Corrosion mechanisms understanding causes and effects*. https://www.petrosync.com/blog/corrosion-mechanisms/#:~:text=Electrochemical%20processes%20are%20the%20primary,causing%20the%20material%20to%20deteriorate.

Division of Technical Resources. (2024). *Design Requirements Manual* (digital ed. 2.1). National Institutes of Health. https://orf.od.nih.gov/TechnicalResources/Documents/DRM/DRM2.108022024.pdf

ASTM International. (2025). *Standard specification for chemical passivation treatments for stainless steel parts*. (ASTM Standard No. A967). https://store.astm.org/a0967-01.html.

ASTM International. (2025). *Standard specification for plates, carbon steel, structural quality, furnished to chemical composition requirements.* (ASTM Standard No. A380). https://store.astm.org/a0830_a0830m-18.html

ABLE Electropolishing. (n.d.) *How electropolishing improves corrosion resistance*. https://www.ableelectropolishing.com/benefits-of-electropolishing/corrosion-resistance/

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Advanced Arc Flash Risk Reduction in Medium Voltage Systems

Introduction

An arc flash event in a medium voltage (MV) switchgear is a high-energy transient that can release extreme thermal radiation, molten metal, and pressure waves within milliseconds. These events pose a serious risk to personnel and equipment, especially in environments requiring high reliability and rapid recovery. Regulatory mandates such as OSHA 1910.269 and NFPA 70E require formal hazard assessments and effective strategies to limit incident energy exposure through protective system design.

Reducing arc flash incident energy is critical not only for regulatory compliance but also for safeguarding human life, preserving infrastructure, and ensuring uninterrupted operations in mission-critical systems. Traditional overcurrent protection methods—characterized by fixed time-current coordination and broad margin allowances—are frequently inadequate at clearing faults swiftly enough to limit arc energy. In contrast, modern mitigation strategies combine high-speed detection technologies, coordinated protective relaying, and embedded system analytics to significantly reduce both the incident energy level and the arc flash boundary.

Modern Arc Flash Mitigation Techniques

The technologies below are grouped by their principal function: (A) high-speed detection and clearing, (B) system integration and maintenance, and (C) passive/structural solutions to allow engineers to quickly identify which approaches best suit their risk-reduction goals and logistical constraints.

A. High-speed detection and clearing
   1) Arc flash detection relays (AFRs)[1] – Offer millisecond-level response via optical and current sensors, directly truncating arc duration and minimizing incident energy; ideal when fault currents exceed ~20 kA and reducing PPE categories (e.g., from Category 4 to 2) is paramount, though fiber-optic routing and higher capital cost must be weighed.
   2) Active arc quenching systems[1] – Divert fault current into a low-impedance path within 4–6 ms, collapsing the arc plasma and greatly reducing thermal and pressure damage; best suited for full retrofits in mission-critical or confined switchgear rooms, but introduce mechanical complexity and require regular maintenance.
   3) Current-limiting fuses[2] – Offer extremely low let-through energy (I^2t) and a simple, sacrificial design that requires no electronics, making them budget-friendly; however, coordination with downstream breakers can be challenging, and replacement after operation must be anticipated.

B. System integration and maintenance
   1) Zone-selective interlocking (ZSI)[2] – Enhances selectivity by allowing downstream breakers to trip first, blocking upstream devices unless needed; provides marginal delay (<5 ms) but requires a pilot wire or communication wiring and does not reduce incident energy as dramatically as AFRs.
   2) Differential protection schemes[2] – Enable sub-cycle detection (<8 ms) with precise zone isolation, especially effective for bus or transformer zones; however, high-impedance variants demand stabilizing resistors and complex settings, and low-impedance schemes necessitate high-accuracy current transformers.
   3) Maintenance mode/alternate relay settings[2] – Reduce relay pickup times for live-work scenarios (per NFPA 70E), cutting arc duration when personnel perform in-cubicle tasks; these “work-mode” settings carry higher nuisance-trip risk if not rigorously managed.
   4) Energy-reducing line-side isolation (ERLSI)[3] – Inserts a small fuse or isolating device upstream of the main breaker to suppress arc initiation, achieving 80-90% incident energy reduction; extra cubicle space and careful coordination (ensuring the isolator trips first) are prerequisites.

C. Passive/structural solutions
   1) Isolation barriers[3] – Mechanical dividers that prevent arc propagation between compartments, offering low-cost, low-maintenance containment; while they do not reduce energy at its origin, they effectively limit

multi-cubicle escalation and require only periodic inspection.

2) Vertical bus with barriers (VCBB)[4] – A vertical conducting bus (VCB) with internal barriers yields 20-40% lower incident energy than a horizontal conducting bus (HCB), per IEEE 1584-2018; optimal for new switchgear designs where achieving incident energy targets (e.g., < 1.2 cal/cm^2) is essential, though retrofit into existing HCB layouts is often impractical.

Implementation Considerations

Each mitigation technique is most effective when integrated into a comprehensive protection strategy, ensuring that one method's limitations are compensated for by another's strengths. Combining ERLSI, AFRs, and ZSI, for instance, provides both passive containment and active mitigation. Practical implementation must account for system constraints such as available fault current, spatial limitations, retrofit viability, and coordination of protective devices.

Conclusion

Effective arc flash risk reduction requires a holistic strategy that melds robust structural containment, high-speed sensing, and adaptive relay protection to ensure incident energy remains below PPE thresholds. To implement this, begin with a comprehensive arc flash study per IEEE 1584 to identify high-risk locations and establish PPE requirements; then optimize relay settings (using zone-selective interlocking or differential schemes) and install high-speed interruption devices such as AFRs and ERLSI switches; retrofit existing switchgear with arc-quenching modules or mechanical barriers—or select arc-resistant designs for new installations—and reconfigure busbar layouts toward vertical orientation with barriers; finally, validate and maintain all systems through periodic testing and updated coordination studies, train maintenance personnel on NFPA 70E live-work procedures, document every setting, and revisit risk assessments whenever system changes occur to drive continuous improvement.

References

1. Kay, J. A., Arvola, J., & Manninen, M. (2024, September 16-19). *Do ARC mitigating systems really work?* [Conference paper]. 2024 IEEE IAS Petroleum and Chemical Industry Technical Conference (PCIC), Orland, FL, United States. https://doi.org/10.1109/PCIC47799.2024.10832356
2. Wester, C., Hartmann, W., Elliott, D., & Virost, D. (2024, September 16-19). *A comparison of protection-based arc flash mitigation techniques* [Conference paper.] 2024 IEEE IAS Petroleum and Chemical Industry Technical Conference (PCIC), Orland, FL, United States. https://doi.org/10.1109/PCIC47799.2024.10832256
3. Carne, C., Brown, W. A., Clark, H. H., & McConnell, M. (2024). Comparison of low-voltage arc-resistant equipment, equipment with isolation barriers, and equipment with energy-reducing line-side isolation for reduction of arc-flash hazards. *IEEE Transactions on Industry Applications*, *60*(5), 7930-7939. https://doi.org/10.1109/TIA.2024.3409522
4. Pillay, U., Khan, M. F., & Behari, S. (2025, January 29-30). *Proactive arc flash mitigation in MV and LV electrical systems: Evaluating protection coordination, modern detection systems, and busbar configuration on arc flash incident energy levels* [Conference paper]. 2025 33rd Southern African Universities Power Engineering Conference (SAUPEC), Pretoria, South Africa. https://doi.org/10.1109/SAUPEC65723.2025.10944337

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Effect of Electrical Disturbances on LED Drivers

Introduction

Electrical disturbances such as voltage variations can significantly impact light-emitting diode (LED) drivers and lighting systems, leading to issues like flickering, premature failure, and reduced lifespan, the effects of which range from minor annoyance to costly operational disruption. One of the most noticeable issues with the existing LED lighting in Building 10 on the NIH campus is caused by power surges affecting LED lighting drivers, resulting in inconsistent lighting performance. Unlike traditional bulbs that respond to any small change in the quality of voltage, LED brightness is primarily determined by the current flowing through the LED driver. A slight variation in voltage can cause a larger change in the current, leading to a noticeable difference in brightness. A thorough evaluation of the electronic driver is critical to understand and address the effects of disturbances and ensure optimal performance and longevity.

LED Driver Stages

A programmable LED driver has multiple components. The first component is a driver input circuit. Alternating current (AC) input voltage is applied to the driver input circuit. The second component is a typical bridge rectifier which converts AC to direct current (DC). The third component uses capacitors to smooth the ripples from the second stage, while the fourth utilizes a power factor correction (PFC) technique. PFC detects the amount of phase shift between the AC input voltage and current and corrects the power factor on the AC input. The PFC circuit shifts the AC input current to match the AC input voltage as closely as possible, which corrects the harmonic distortion of the current. The fifth component is the programmable DC-to-DC converter, which provides voltage and current regulation necessary to operate the LED light array. Feedback from the light array is provided back to the converter. User controls, such as dimming and LED tuning, can be transmitted to the programmable converter.

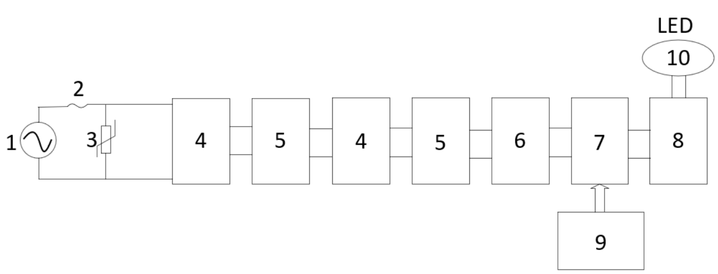

Fig 1: Stages of an LED Driver

1. AC Input
2. AC Line Fuse
3. Metal Oxide Varistor
4. Electromagnetic Interference Filter
5. Rectifier
6. DC Current Filter
7. Power Factor Correction Unit
8. Programmable DC to DC Converter
9. Lighting Control Apparatus
10. Light Array

Causes and Effects of Voltage Variations

Voltage variations are caused by a combination of factors, including changes in electrical load, faulty wiring, disturbances in the power grid, electrical load variations in the system, or switching operations. Poor power quality or other voltage variations lead to voltage swells or sags, harmonic distortion, transient line surge, voltage drop, flickering of LED lights, etc. Long periods of voltage variation can negatively affect the functionality and reliability of the LED drivers and as a result reduce LED lighting performance.

Mitigation Techniques

Voltage variation can be mitigated by installing surge protectors, voltage regulators, a dynamic voltage restorer (DVR), and power conditioning equipment; optimizing driver placement; using appropriate wire sizes; adjusting driver output; and choosing high-quality LED drivers with built-in protection against fluctuations. The best practice to manage voltage variations effectively involves selecting the correct LED driver for the voltage and wattage requirements and keeping a short distance between the driver and the lighting fixture.

Conclusion

Poor power quality can lead to costly equipment damage such as LED driver malfunctions and failures while increasing energy consumption and utility bills. Excessive voltage fluctuations can generate heat and potentially damage a component's insulation or even lead to electrical fires. Frequent also voltage issues accelerate wear and tear on equipment, leading to more frequent repairs and replacements, increasing maintenance costs. Proper mitigation of electrical disturbances like voltage variations is a key aspect of facility management and will save money while extending the lifespan and reliability of LED fixtures.

Further Reading

1. Switching Power Supplies by Sanjaya Maniktala https://www.google.com/books/edition/Switching_Power_Supplies_A_Z/cuyyQ3N_8hIC?hl=en&gbpv=1&pg=PR3&printsec=frontcover
2. Power Supplies for LED Driver by Steve Winder https://www.google.com/books/edition/Power_Supplies_for_LED_Driving/lQPeDAAAQBAJ?hl=en&gbpv=1&printsec=frontcover
3. The Basics of LED by Eric Strandberg, LC & Jeff R. https://www.lightingdesignlab.com/sites/default/files/pdf/Basics%20of%20LEDs.%20pdf

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Concrete Slab Penetration Infill

Introduction

Concrete slab penetration infill is the process of restoring and repairing penetrations in concrete slabs that were initially made to accommodate mechanical, electrical, plumbing (MEP), or structural systems. These penetrations may be left unused after layout changes, system removal, or design revisions. Once they are no longer needed, it is essential to properly infill these penetrations to restore structural integrity, ensure safety, and maintain the appearance and functionality of the floor. Poorly executed or neglected infills can result in uneven surfaces, shrinkage zones, or depressions that create tripping hazards. A professional, code-compliant infill ensures a flush, durable surface that meets design standards and building code requirements.

Benefits of Proper Infill

Proper infill offers several key advantages. Structurally, it restores the slab's original load-bearing capacity. Open or poorly filled penetrations can become points of stress concentration, leading to cracking, deflection, or long-term degradation. For this reason, ACI 318 Section 7.2.1 requires designers to evaluate the effect of slab penetrations on flexural and shear strength. When penetrations are present, they create potential new critical sections. The presence of concentrated loads near penetrations can also cause a one-way slab to behave like a two-way slab. A well-executed infill prevents these issues and ensures floor durability.

Fire safety is another critical consideration. In many buildings, concrete slabs serve as fire-rated horizontal assemblies. Unsealed or improperly filled penetrations compromise this fire separation, allowing smoke and flames to spread between floors during a fire event. For this reason, NFPA 101 Section 8.3.5.1 mandates that penetrations through fire-rated barriers be properly protected by tested firestop systems. ASTM E814 provides a standardized test method to evaluate such firestop systems.

Adequate infill improves thermal and acoustic performance. In multi-story or mixed-use buildings, unsealed penetrations can become pathways for heat transfer and noise transmission. Using appropriate infill materials enhances energy efficiency and occupant comfort.

Adequate infill also prevents water infiltration through the slab, which can otherwise lead to corrosion of embedded reinforcement and mold formation. Both conditions accelerate structural deterioration and pose potential health risks.

Infill Strategies

One common effective method for infill involves chipping the concrete around the penetration to form a reverse cone shape, where the top diameter is greater than the bottom. This geometry prevents the hardened infill from being pushed out under load. Additionally, installing at least four concrete screws with 1-1/4" embedment into the existing slab and a 1/2" projection into the infill area improves mechanical bonding. Screws shall be placed opposite each other along two perpendicular directions for optimal anchoring. The infill material shall consist of a non-shrink grout with a minimum compressive strength at least 1.5 times greater than that of the surrounding concrete to be repaired (see Figure A for reference).

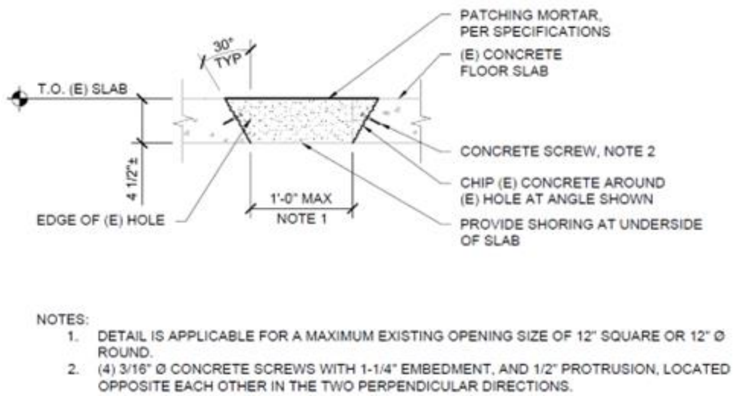

Figure A: Common infill construction detail

Conclusion

Concrete slab penetration infill is a critical process for maintaining structural strength, life safety, and the functional quality of building floors. Selecting the right materials and methods based on slab type, penetration size, load requirements, and fire-rating ensures long-term success. The Division of Technical Resources at NIH has developed several reliable infill details that can be referenced by design professionals at their discretion. Early coordination with design professionals helps ensure penetrations are properly restored, reducing future risks and ensuring a safe, code-compliant, and durable building environment.

Additional Reading

1. ACI 318 Section 7.2.1- Building Code Requirements for Structural Concrete
2. NFPA 101 Section 8.3.5.1 - Life Safety Code (for firestop requirements)
3. ASTM E814 - Standard for Firestopping