



Engineering Out Arc Flash Risk Through Safety-Interlocked Design

Why This Matters

The stakes — before we get to the physics.

Every time a worker connects or disconnects power to a **reefer** or crane, they can be inches from an **arc flash** — an arc that reaches **35,000°F (19,400°C)**, **roughly three and a half times hotter than the surface of the sun.**

This webinar is about designing that hazard **out of the job** — so safety never depends on getting it right by hand, every single time.

Objectives

By the end of this session:

Everyone will leave knowing —

- What an arc flash is, and why connecting power under load is dangerous
- How the "hierarchy of controls" makes electrical work safer
- Why interlocked equipment removes the hazard instead of just managing it

Engineers will also take away —

- The physics linking inductance, back-EMF and arc initiation
- How to evaluate mechanical vs. electrical interlock strategies for safety-critical designs
- Mechanical and electrical case studies from real port deployments

Key Terms — in Plain Language

A shared vocabulary so nobody gets lost.

Reefer outlets — refrigerated shipping containers plug into these outlets that needs constant power to keep cargo cold.

eRTG — an electric rubber-tired gantry crane that stacks containers in the yard.

Interlock — a mechanism that blocks an unsafe action until conditions are safe.

NFPA 70E — the U.S. standard for safe electrical work practices.



Key Terms — Arc Terminology

From the spark to the incident.

Arc — Electrical current flowing through ionized air.

Arc Fault — An unintended electrical arc caused by a fault condition.

Arc Flash — The heat, light, molten metal, and radiant energy produced by an arc.

Arc-Flash Incident — A hazardous event where the arc flash is severe enough to create a risk of injury or significant equipment damage.

Inductive Interruption Arcing - making or breaking a live load by hand

Mechanical Flywheel vs. Inductance ("Electrical Flywheel")



MECHANICAL FLYWHEEL

STORAGE MECHANISM

Kinetic energy of a rotating mass

GOVERNING EQUATION

$$E_k = \frac{1}{2} I \omega^2$$

I = Moment of Inertia ω = Angular Velocity

KEY METRICS



Response Time

1–10+ ms — slower



Cycle Life

10^5 to 10^7 cycles, limited by wear



Dominant Losses

Aerodynamic drag (windage), bearing friction



Limiting Factors

Material tensile strength (rotor burst)



INDUCTANCE ("ELECTRICAL FLYWHEEL")

STORAGE MECHANISM

Magnetic field energy

GOVERNING EQUATION

$$E = \frac{1}{2} L I^2$$

L = Inductance I = Current

KEY METRICS



Response Time

Microseconds to 1 ms — fast



Cycle Life

Effectively infinite, non-wear



Dominant Losses

Resistive heat ($I^2 \times R$), hysteresis + eddy currents



Limiting Factors

Insulation breakdown, core saturation

In plain terms: inductance is “electrical inertia” — hard to start current flow, hard to stop current flow.

ENGINEERING COMPARISON: MECHANICAL FLYWHEEL vs. INDUCTANCE ("ELECTRICAL FLYWHEEL")

MECHANICAL FLYWHEEL

Massive rotor/flywheel

Spin massive rotor

STORAGE MECHANISM:
Kinetic Energy of a Rotating Mass



GOVERNING EQUATION:

$$E_k = \frac{1}{2} I \omega^2$$

I = Moment of Inertia
 ω = Angular Velocity

INDUCTANCE ("ELECTRICAL FLYWHEEL")

STORAGE MECHANISM:
Kinetic Energy of a Moving Charge

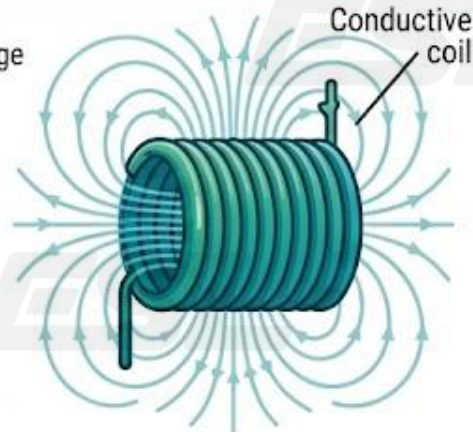


Hard to start current flowing, hard to stop

GOVERNING EQUATION:

$$E_k = \frac{1}{2} L i^2$$

L = Inductance
 i = Current

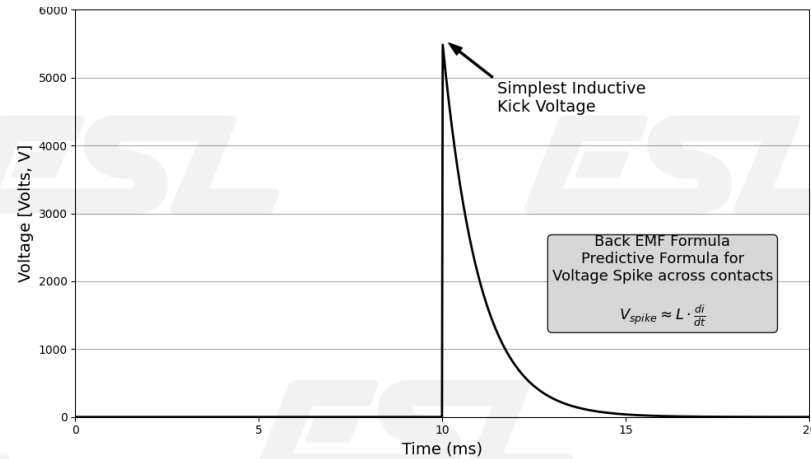


Stored Energy, Back-EMF, and the Electrical Flywheel Effect

- Stored energy in cable (E_{cable}) = $\frac{1}{2} \times L \times I^2$
- Stored energy in 10 hp motor (E_{motor}) = $\frac{1}{2} \times L \times I^2$
- **Total stored energy = 8.821 J**
- When the contacts open:
 - **Ignites** — stored magnetic energy ($\frac{1}{2} L I^2$) strikes an arc as contacts separate
 - **Sustains** — motor back-EMF from residual rotor flux holds voltage across the gap
 - **Feeds** — the source drives current into the plasma channel until a breaker trips

8.821 J $\approx$ a brick falling on your foot from coffee-table height — concentrated into a space smaller than a pinhead

The trigger, not the injury — the transformer supplies what burns you.



WORKED EXAMPLE — ASSUMPTIONS

10 hp, 480 V, 3 ϕ $\rightarrow I \approx 14$ A FLA

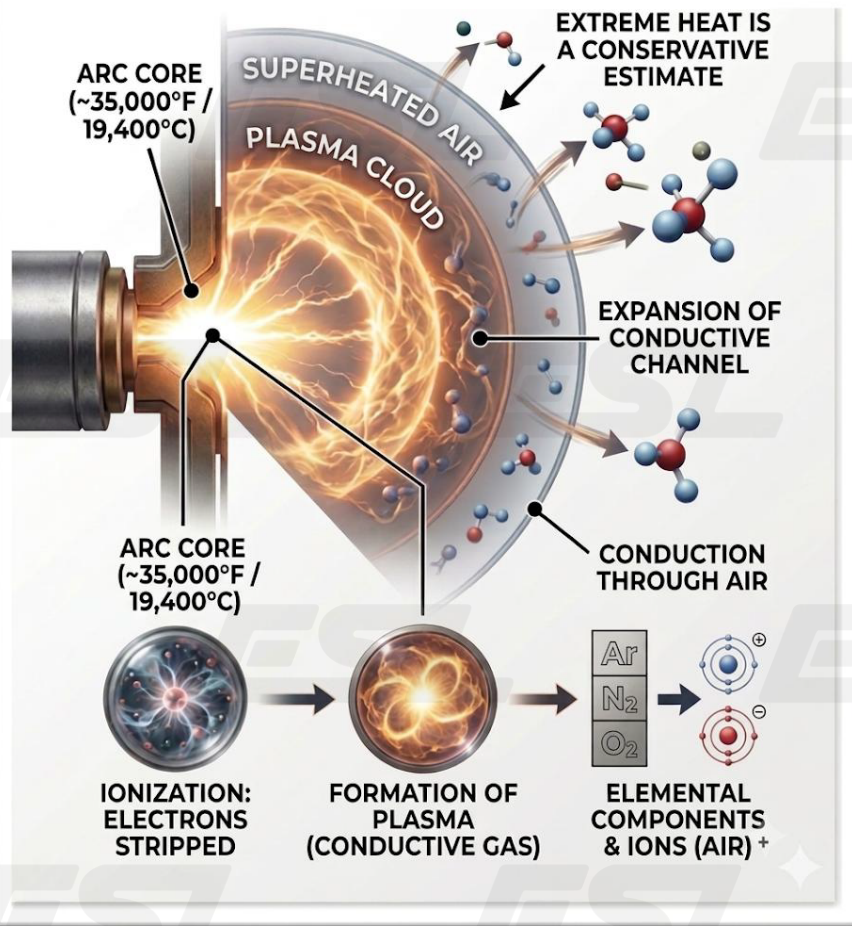
Cable 100 ft ≈ 10 μ H $\rightarrow < 0.01$ J

Motor L ≈ 90 mH $\rightarrow \approx 8.8$ J



ESL

The Physics of an Arc Flash



Why Arcs Escalate

- Copper vaporizes and expands **~67,000X**, driving a pressure blast and acoustic shock
- Arc core **~35,000°F (19,400°C)** — roughly 3.5X hotter than the sun's surface
- Ionized air becomes a conductive plasma channel — the transformer now sees a low-resistance fault
- Positive feedback: more heat → more current → more heat, all within milliseconds

Design takeaway

If a connector can be operated while energized, the conditions for arc initiation already exist.



THE HUMAN VARIABLE: WHY ADMINISTRATIVE CONTROLS FAIL



COMMON FAILURE FACTORS

-  High-Stress Environments
-  Production Pressure
-  Fatigue & Complacency
-  Complexity of Systems

TRAINING HELPS, BUT..



STRESS + DISTRACTIONS

→ LEAD TO MISTAKES

Human Factors & the Limits of Administrative Controls

- Stress & time pressure drive errors even in well-trained teams.
- Live connection points create single-point failures at the operator interface.
- Administrative controls (LOTO, PPE, training) reduce—not eliminate—exposure.
- Engineering controls must remove the opportunity for an unsafe action.

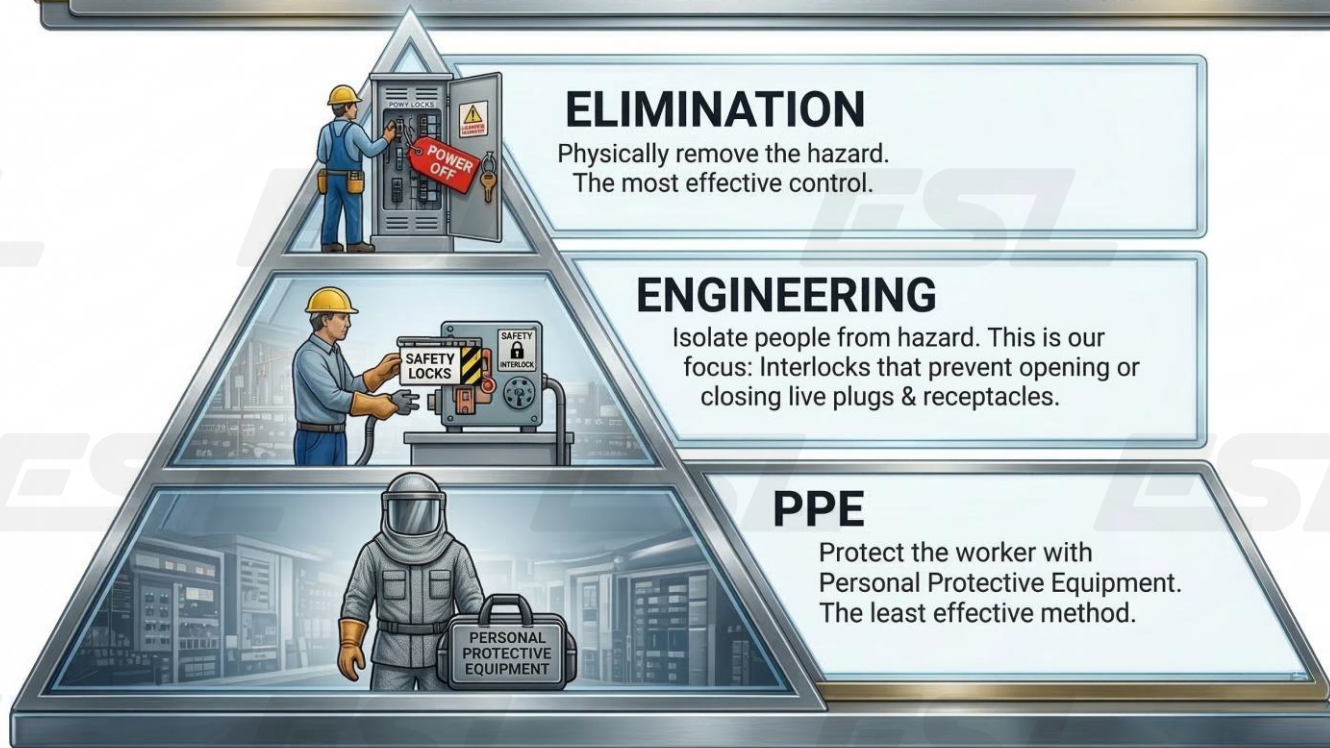
NFPA 70E Electrical Safety Training Requirements

How to Achieve OSHA Compliance & Practical Methods



The Hierarchy of Risk Control

ARC FLASH HAZARD MITIGATION HIERARCHY



What Safety Interlocks Do

Regardless of the technology — *mechanical, electrical, or software-based* — every safety interlock performs the same three core functions to keep personnel out of harm's way.

1



Prevent Hazardous Access

- Blocks contact with energized or moving parts until proven safe
- No live circuit or motion is accessible while the hazard exists

2



Enforce Correct Sequence

- Permits only one valid order of operations across devices
- Out-of-sequence actions are physically or logically blocked

3



Guarantee De-Energization

- Cuts power or motion automatically when the interlock breaks
- Equipment stays off until the safe state is confirmed

**ANY INTERLOCK
TECHNOLOGY**

**REMOVES OPERATOR
RELIANCE**

**A CORE ENGINEERING
CONTROL**

Engineering the Solution

Mechanical Interlocks



Traditional "physical-first" design

Trapped keys, levers, sliding steel bars

Classic example: lock & key

Complexity: Low

Fewer moving parts, fully passive

No programming or electronics required

Reliability: Very High

Immune to power loss (works in blackout) and EMI/RFI interference

Limits set by physics & material strength — not software

Engineering the Solution

Electrical Interlocks

Modern design

Uses circuit loops, switches & complex logic

Examples: light curtains, proximity sensors, safety relays, PLC systems

Complexity: High

Multiple active sub-components

Requires constant power, wiring, programmed logic, sensors & actuators

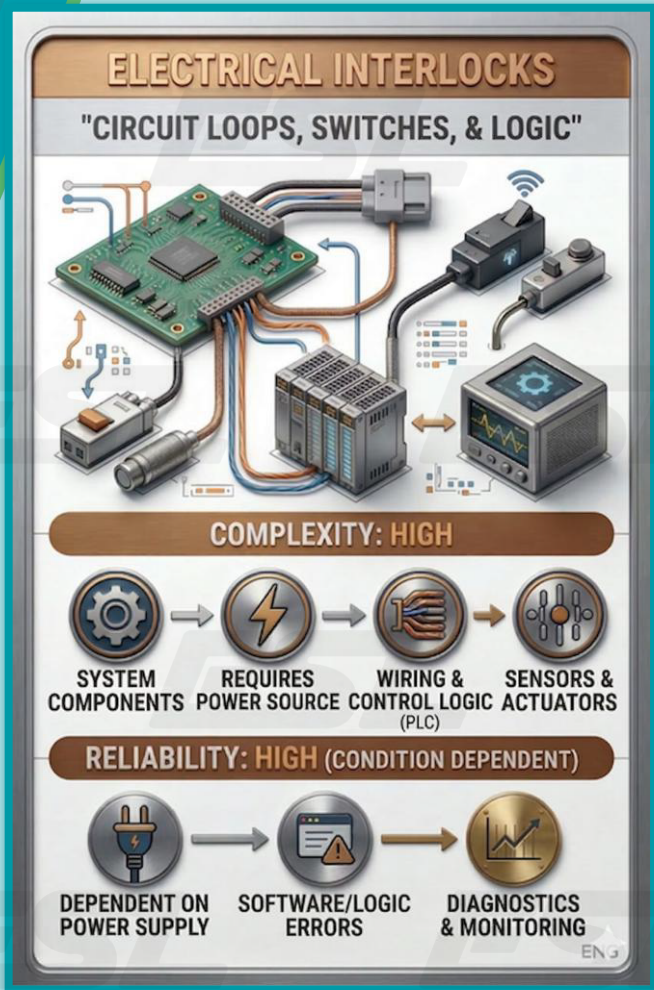
Every element = potential single point of failure

Reliability: High (Condition Dependent)

Extremely robust when perfectly designed

Fails on power dips/loss → defaults to “safe” state (stops process)

Risk of invisible software/logic errors



Engineering the Solution: Interlock Decision Matrix

Criteria	Mechanical Interlock	Electrical Interlock
Design Philosophy	Physical-first, passive safety Trapped keys, levers, sliding steel bars	Logic-driven, active monitoring Sensors, relays, PLC systems, light curtains
Complexity	Low Fewer moving parts, fully passive No programming or electronics required	High Multiple active sub-components Requires power, wiring, programmed logic
Reliability	Very High Immune to power loss and EMI/RFI Limits set by physics, not software	High (Condition Dependent) Robust when perfectly designed Risk of invisible software/logic errors
Power Loss Behavior	Fully operational during blackout No power source needed	Defaults to safe state (stops process) Requires constant power supply
Failure Mode	Limited by physics and material strength Fewer failure modes, highly predictable	Each sensor is a potential single point of failure Software/wiring faults may be invisible
Diagnostics	Visual/physical inspection only No remote status feedback	Real-time feedback and status monitoring Integration with SCADA/control systems
Best Fit	High-consequence safety interfaces Corrosive/salt-air environments, blackout-prone sites, operator connection points	Operational diagnostics and monitoring Controlled environments, systems requiring remote feedback, fleet management

The right interlock is not about which is better — it's about which failure mode is right for the job



From Principles to Hardware

How ESL builds interlocks into real port equipment

Safe Connections By Design

Mechanical Interlocks

- Rely on physical mechanisms like trapped keys or cam-style linkages. They physically force a safe sequence of operations.
 - Extremely robust and reliable
 - Does not depend on control power
 - Visual indications of status

ESL Examples:

- Safety-interlock reefer power module
- eRTG fused disconnects

Electrical Interlocks

- Use solenoids, limit switches, and/or control logic (PLC/Relay) to prevent unsafe operations.
 - Flexible for complex logic
 - Requires control power to function
 - Susceptible to wiring faults or software bugs

ESL Examples:

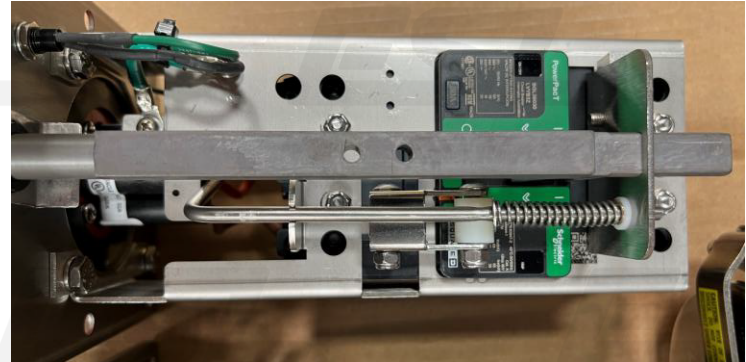
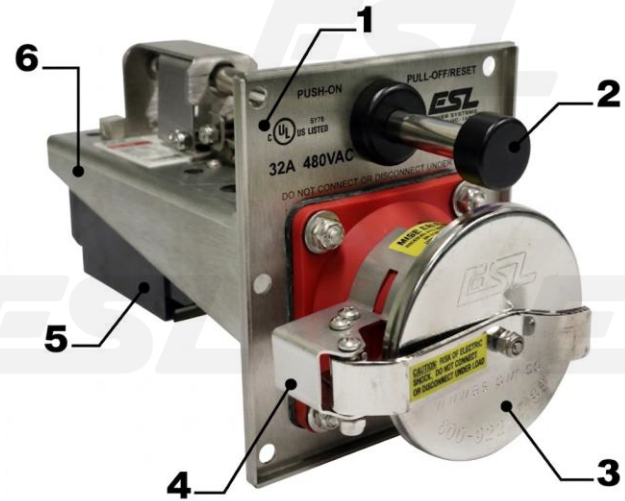
- MIL-C-24368 Receptacle micro-switch
- Numerous safety-interlock power modules

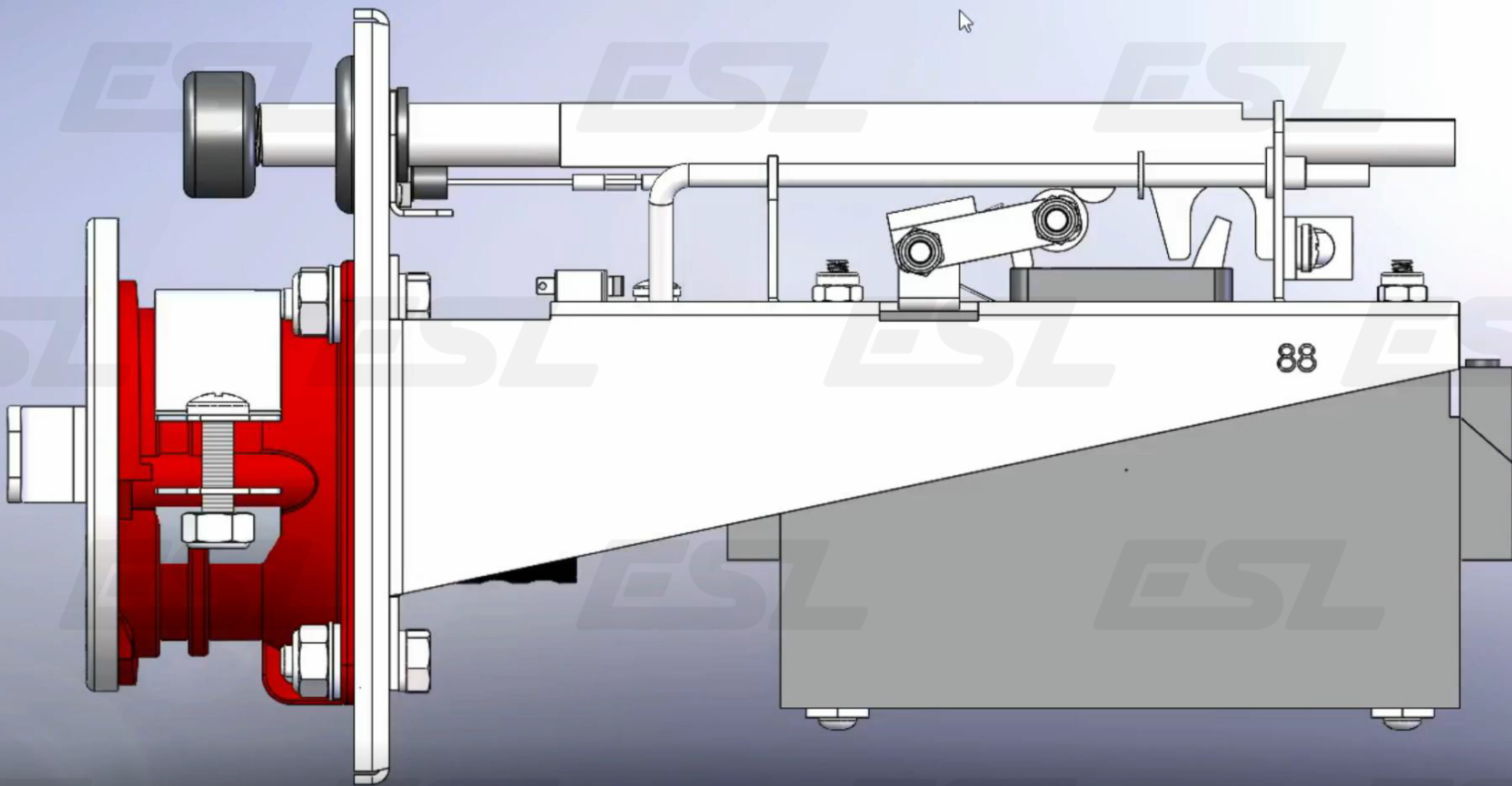
Anatomy of ESL's Reefer Outlet Safety-Interlock Power Module

- 1 Interlock Mechanism
- 2 Actuator Rod
- 3 Stainless Steel Snap Cover
- 4 Receptacle
- 5 UL 489 Listed Molded Case Circuit Breaker
- 6 Stainless Steel Frame

Options:

- Pilot Lights
- Power "ON" Light
- Power "Available" Light
- Shunt Trip
- Auxiliary Contact
- Electrically Interlocked
- Nylon Screw Cover
- Trip Alarm Contact
- Plug Sensing Contact





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Variety of Outlet Assemblies

Pedestal / Pad Mount Assemblies

Bunker Mount Assemblies

Rack / Wall-Mount Assemblies

Single-Gang Modules

Rear Actuated Assemblies

Inserts for Power Pack Assemblies

Portable Distribution Trees

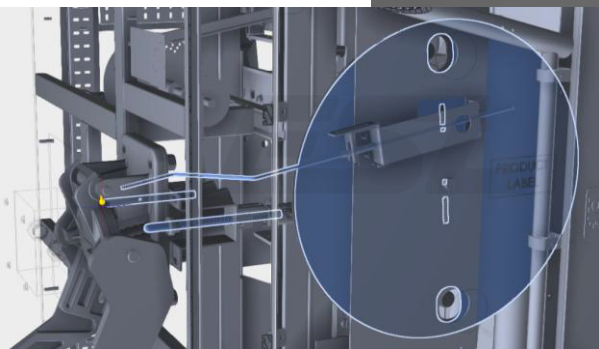
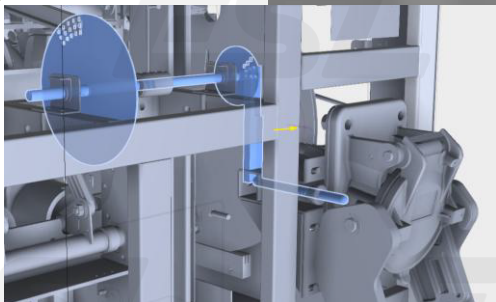
Reefer Sharing Units RSU's



Mechanical & Electrical Safety-Interlocked Power Outlets

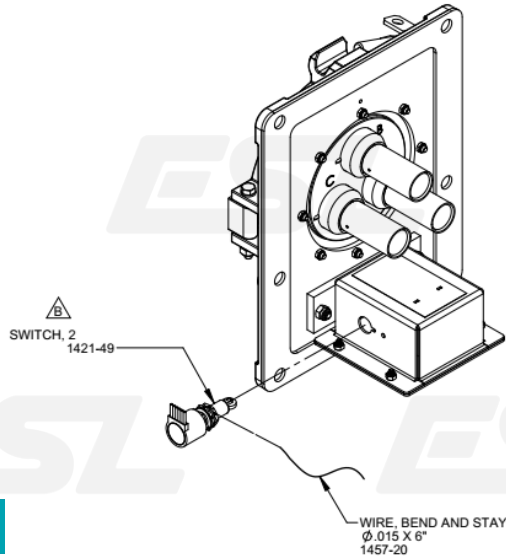
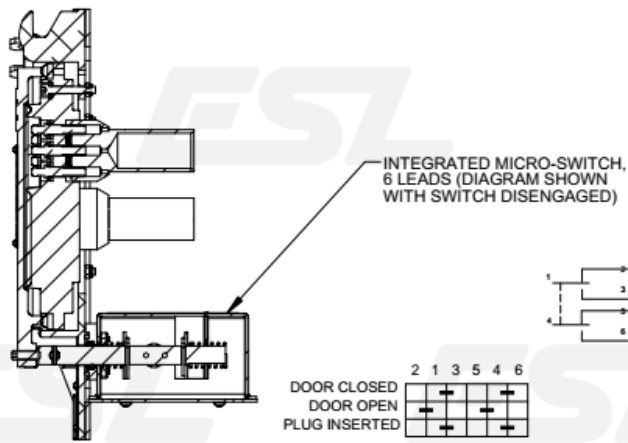


- Prevents “Making or Breaking” Under Load (Safety-interlocked)
- Functions as a Manual Disconnect
- Provides Branch Circuit Protection
- Modular Design - Easy to Install and to Maintain
- Fabricated with Stainless Steel Components
- Optional Pilot Light, Auxiliary Contact and Shunt Trip
- Factory Rebuild Program Available

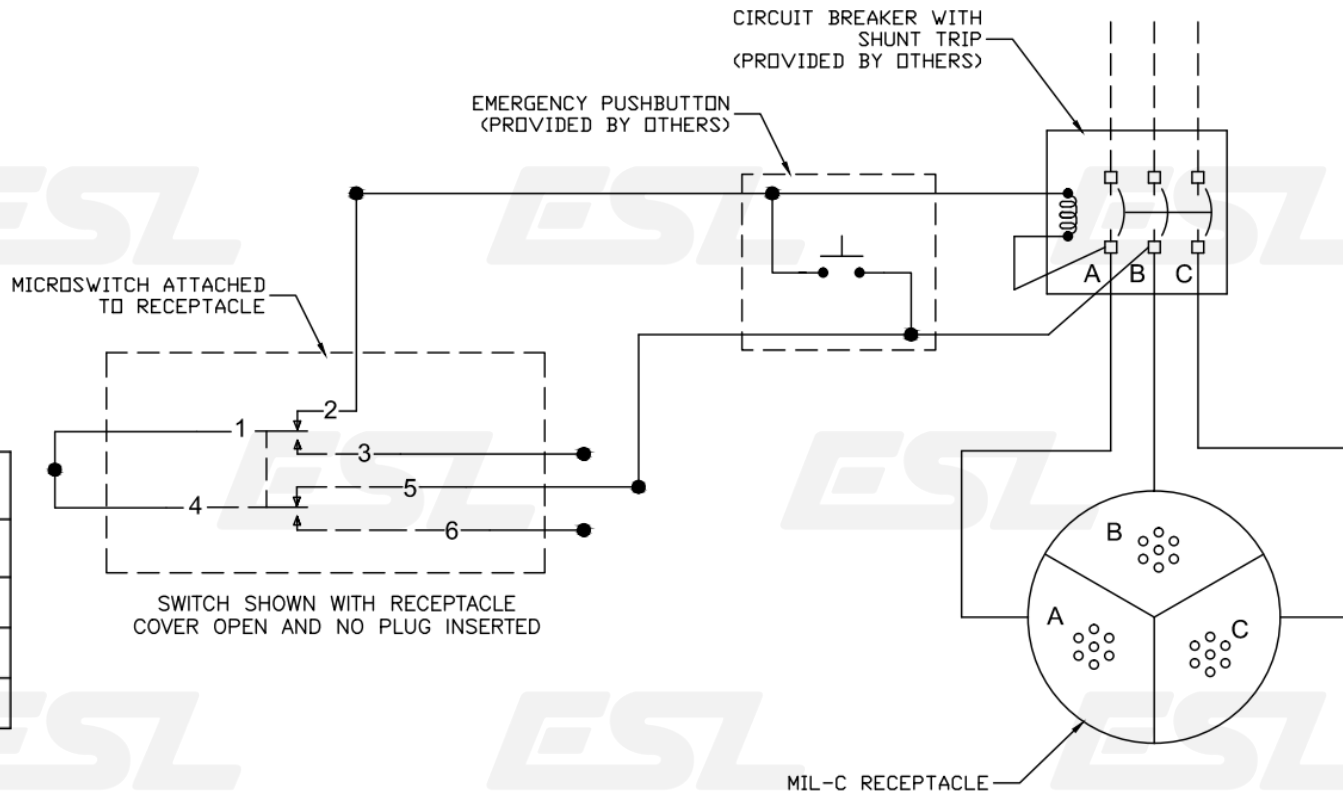




Electrical Safety-interlock MIL-C-24368/2



MIL-C-24368/2 Electrical Safety-interlock



OPERATIONS - RECEPTACLE
MICROSWITCH

MICROSWITCH WIRES	2	1	3	5	4	6
DOOR CLOSED			—			—
DOOR OPEN		—			—	
PLUG INSERTED			—			—

" — " INDICATES CONNECTION

TYPICAL APPLICATION

Dockside Power Connection Station

10-Gang Dockside Power Connection Station



- (10) MIL-C-24368/2 safety-interlocked receptacles, 500 A / 500 VAC
- 10 ga. Type 304 or 316 stainless steel enclosure — Type 3RX (vented) or Type 4X (sealed)
- Powder-coated exterior finish to meet IEEE C57.12.28/.29
- Integrated fiber optic, cable TV, and telephone connections
- 3-phase 200 A / 480 VAC safety-interlocked auxiliary power port

Summary

Design the hazard out of the job, so safety is not a function of human performance

The hazard is physical — so design it out

- Connecting or disconnecting under load can ignite an arc flash — a ~35,000°F blast driven by stored cable and motor energy (back-EMF)
- LOTO, PPE and training reduce exposure, but only engineering controls remove the chance of an unsafe action

Interlocks are the engineering solution

- Mechanical — passive, blackout-immune, very high reliability
- Electrical — flexible logic, condition-dependent; match the failure mode to the job

Proven in port products

- Reefer power modules, MV fused disconnect cabinets, MIL-C-24368/2 receptacles, and dockside power connection stations

Thank You!

Questions?

