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BSR E1.64 – 202x

Design, Manufacturing, Inspection, Operation, and Maintenance of Stage Machinery Control Systems in the Entertainment Industry

Approved by the ANSI Board of Standards Review on _____

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Voting members:

Observer (non-voting) members:

Interest category codes:

CP = custom-market producer
DE = designer
DR = dealer rental company
G = general interest
MP = mass-market producer
U = user

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Foreword

The purpose of this standard is to consolidate into a single document the requirements for the control of stage machinery.

At the time this document was written, each individual ESTA-authored standard that related to stage machinery contained its own section on controls. The authors of this document do not intend for it to fully replace the control sections in accepted standards, as each discipline of machinery design has its own specific needs. Performer flying, for instance, has different requirements than variable speed chain hoists, stage lifts need more sensors than powered hoist systems, and acoustic curtains pose less risk of harm than turntables or wagons.

It is hoped that the consolidation of common elements into one document will harmonize the work of current and future standards and improve efficiencies as new technologies emerge.

1 Administration

1.1 Scope

This standard establishes minimum requirements for the design, manufacture, installation, commissioning, inspection, operation, and maintenance of machinery control equipment in the Entertainment Industry including equipment that is used in production, touring, and temporary or permanent installation.

It focuses on control equipment, user devices, enclosure assemblies, and directly with the action/reaction of signals sent to or from the control equipment and not the specific mechanical actuators and machinery that send and receive those signals. It should therefore be used in conjunction with an associated ESTA published stage machinery standard.

This standard offers guidance in the selection of sensors used to provide feedback of information gathered from the machinery and sent to the control system.

The assemblies covered by this standard are limited to voltages of not greater than 600V RMS.

For information regarding stage machinery the reader is directed to the ESTA Technical Standards Documents web page at https://tsp.esta.org/tsp/documents/published_docs.php to locate the appropriate documents.

Machinery standards may have additional requirements for control equipment, control system safety requirements, and/or user interface(s) that are directly related to the application, use or mechanical systems covered by those standards.

1.2 Purpose

To harmonize and become the reference point for stage machinery control sections of ESTA/ANSI Standards that pertain to the design, manufacture, service, and/or maintenance of stage machinery.

1.3 Alternative designs

The provisions of this standard are not intended to prohibit any design, materials, or methods of fabrication, provided that any such alternative is at least the equivalent of that described in this standard in quality, reliability, and effectiveness.

2 References

All equipment shall be manufactured to comply with this standard and any applicable codes or jurisdictional regulations where the requirements of such codes or regulations are more stringent.

The following documents are referenced. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document, including any amendments, shall apply.

2.1 References – ESTA standards*

The ESTA Technical Standards Program develops standards that cover the design, inspection, maintenance, and use of various stage machinery.

The reader is guided to refer to the following specifications and to review the stage machinery control system sections for additional information that may be important to the reader's application.

- ANSI E1.6-1 Entertainment Technology -- Powered Hoist Systems
- ANSI E1.6-3 Entertainment Technology -- Selection and Use of Chain Hoists in the Entertainment Industry
- ANSI E1.22 Entertainment Technology -- Fire Safety Curtain Systems
- ANSI E1.42 Entertainment Technology -- Design, Installation, and Use of Orchestra Pit Lifts
- ANSI E1.43 Entertainment Technology -- Performer Flying Systems

(see annex note)

2.2 References – other publications

The following list of documents as produced by parties other than ESTA Technical Standards Program are recommended references.

- ANSI B11.TR3, Risk Assessment and Risk Reduction

- ANSI Z535, Product Safety Signs And Labels
- CSA SPE-1000, Model Code For The Field Evaluation Of Electrical Equipment
- EN 17206 Entertainment Technology. Machinery For Stages And Other Production Areas. Safety Requirements And Inspections
- ISO 12100 - Safety of machinery — General principles for design — Risk assessment and risk reduction
- ISO 13849, Safety Of Machinery - Safety-Related Parts Of Control Systems - Part 1: General Principles For Design
- ISO 13850 - Safety Of Machinery – Emergency Stop Function – Principles For Design
- NFPA 79, Electrical Standard for Industrial Machinery
- UL 508A, Standard For Industrial Control Panels

3 Definitions

3.1 actuator. A mechanism or device that provides the primary force to move and position an object or person, either singularly or in coordination with other devices.

3.2 authorized person. A person approved or assigned by the employer to perform specific type of duties and who is qualified to perform the assigned duties.

3.3 authority having jurisdiction (AHJ). The organization, office or individual responsible for enforcement of this standard. Where compliance with this standard has been mandated by legislation or regulation, the “authority having jurisdiction” is the regulatory authority.

3.4 axis (pl. axes). A common term used to describe the combined elements that create motion in a single geometric plane. Motion can be linear or rotational and the actuator can consist of electric, hydraulic, pneumatic, or other motive power sources including human power in a manual system. Multiple axes can be combined to create motion of an object in more than one plane.

3.5 brake. A device that can stop and/or secure a load

3.6 category 0 stop. Stopping by immediate removal of motive power to the machine actuators (i.e. an uncontrolled stop – stopping of machine motion by removing electrical power to the machine actuators)

3.7 category 1 stop. A controlled stop with power to the machine actuators available to achieve the stop, then when the stop is achieved, or after a timeout occurs, power is removed from the machine actuators.

3.8 category 2 stop. A controlled stop with power left available to the machine actuators.

3.9 CCW. Counter-clockwise

3.10 CW. Clockwise

3.11 channel. A dedicated line of communication or control from one device to another.

3.12 class 2 circuit*. A control circuit supplied from a source having limited voltage (30 Vrms or less) and current capacity, such as from the secondary of a Class 2 transformer and rated for use with Class 2 remote-control or signaling circuits. (see annex note)

3.13 competent person. A person who has received training on the operation of specific equipment and hazards involved, is capable of identifying existing and predictable hazards in the workplace, and who is authorized to take prompt corrective measures to eliminate them.

3.14 contactor. An electro-mechanical or solid-state device, used to make or break the flow of current to one or more devices.

3.15 control station. A device for operating stage machinery and displaying information to the user.

3.16 drive*. An electronic/electrical device that varies the speed of the motor(s) attached to the device by changing the frequency, value of the voltage, or values of current and voltage delivered to the motor(s). (see annex note)

3.17 encoder. A sensor which provides position information to the control equipment derived from linear or rotation motion of the mechanical drive train or actuators.

3.18 E-Stop (Emergency stop). A function of the control system wherein the stage machinery is brought to a complete stop in as rapid a manner as possible leaving it in an inherently safe state at the conclusion of the stop with all sources of power or energy removed and isolated from the actuators.

3.19 enabling device. Manually operated device used in conjunction with a start control and which, when continuously activated, allows a machine to function

3.20 fault. A state or condition characterized by inability to perform a required function.

3.21 fail-safe. A design feature, operational or engineering practice that in the event of a specific failure, inherently responds in a predetermined manner to minimize or prevent harm to equipment, the environment, or people.

3.22 failure. Termination of the ability of an item to perform a required function. After a failure, the item has a "fault". A "failure" is an event, as distinguished from "fault," which is a state.

3.23 FWD. Forward

3.24 Hold-to-Run device (HTR). Control device which enables and maintains machine operation only as long as the user held operator is activated.

3.25 initial limit (Sensor). That sensor whose function is to trigger a stop command in the event of travel beyond the FWD/CW/Extended or REV/CCW/Retracted target. In the event of a contactor-based control system, this may be the same sensor as the FWD/CW/Extended and REV/CCW/Retracted sensor.

3.26 Internet of Things (IoT). A selection of physical objects (or groups of such objects) with sensors, processing ability, software and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks. IoT technologies are usually associated with consumer items and systems.

3.27 Industrial Internet of Things (IIoT). An industrial version of IoT technologies and objects that have been subjected to extended testing and quality controls that meet with industrial applications and demands.

3.28 jogging (bumping, inching). The quickly repeated opening and closing of the motive power circuit to initiate small movements of the machine.

3.29 labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an NRTL that is concerned with product evaluation, safety, requirements of periodic inspection of design, production, materials, and compliance with appropriate standards or performance.

3.30 listed. The pronouncement of compliance of a stand-alone product to meet the safety standard tests for a specific category of equipment as published by an NRTL.

3.31 Load path. The physical space used by an element of stage equipment as it is moved from one place to another.

3.32* Low Voltage Low Energy (LVLE) Circuit. A control circuit involving an open-circuit potential of not more than 42.4 V peak / 60VDC supplied by a primary battery or an isolated secondary circuit with a limited current capacity of not more than 100VA. (see annex note)

3.33 machine stop. A device that initiates an E-Stop Function to a specific machine or group of machines identified within a larger installation.

3.34 motive power. Source voltage or other energy source applied to the actuator.

3.35 normal operation. The operation of equipment, program, or activity without significant changes that would impair its ability to meet operational objectives, to wit excluding testing, maintenance, or service operation and without the presence of a failure or fault condition.

3.36 NRTL. Nationally Recognized Testing Laboratory.

3.37 override. A momentary means of temporarily bypassing a safety function, such as a key operated switch contact.

3.38 owner. Any person, agent, firm, or corporation having a legal or equitable interest in the property.

3.39 pin-out. The assignment of a function to a particular pin of a connector.

3.40 Programmable Electronic System (PES). A system for control, protection, or monitoring based on one or more programmable electronic devices, including all elements such as power supplies, sensors and other input devices, data highways, other communication paths, operators, and other output devices.

3.41 qualified person. One who, by possession of a recognized degree, certificate, or professional standing, or who by extensive knowledge, training and experience has successfully demonstrated the ability to solve or resolve problems relating to the subject matter and the work.

3.42 ready. A state of operation, often annunciated by an indicator, that shows the equipment is prepared to respond to further commands from the user.

3.43 reset. A control function that restores normal operation of the system after all fault conditions have been corrected.

3.44 REV. Reverse.

3.45 risk. Combination of the probability of occurrence of harm and the severity of that harm.

3.46 risk assessment (RA). The process of identifying, evaluating, and quantifying the potentially hazardous conditions, severity, and probability of occurrence of harm.

3.47 risk reduction (RR). Mitigation of risk created by hazardous conditions.

3.48 risk management. The process of forecasting, identifying, and limiting potential damages caused by the failure of a system, in whole or in part, to reduce the physical and economic impact on the people and property involved in the potential failure of that system or its components.

3.49 safety device. A component of the control system involved in the management or initiation of safety actions or reactions.

3.50 shall. Indicates a mandatory requirement.

3.51 should. Indicates a recommendation or non-mandatory requirement.

3.52 stage machinery. Any mechanical system that is used in the presentation of a performance or special event.

3.53 switch. The assembly that includes the switch operator and contact(s) that make or break the electrical circuit

3.54 system designer. The person or persons who specify the limits of use of the system and may also select and integrate the components of the system.

3.55 ultimate limit (sensor). That sensor whose function is to initiate a stop command to prevent damaging the machine or structure.

3.56 unattended. The state of a control station left unsupervised

3.57 user. Any person or group of persons that use the control system for the intended purpose.

4 Risk management

In stage machinery applications, risk can be reduced to acceptable levels by developing mitigation strategies and implementing procedures related to the movement of the load.

However, risk management cannot be placed solely on the stage machinery control system. It must involve a review of all components involved and it must include the affected parties (stage employees, performers, management, users) that partake, observe, and participate in/with the movement of the load.

An appropriate risk assessment, risk reduction, risk management form shall be used to identify the hazard type, origin, and potential consequence that may occur in the event of an incident involving the machinery, controls, or load in motion.

The risk assessment shall:

- prioritize which risks are most in need of mitigation or elimination
- be performed for all possible stage conditions, including the unoccupied facility, load-in, load-out, and performance
- identify and determine the severity and likelihood of harm caused by the hazard or risk

A systemic assessment shall include, but not be limited to:

- mass of the load
- load path and trajectory
- the hazard zone
- speed of the load when in motion
- machinery involved in moving the load
- medium used to move the load
- personnel involved in moving the load
- skills, experience and training of personnel under all operating conditions
- signals returned to the stage machinery control system
- the evaluation and reaction of the stage machinery control system to incoming data
- emergency stopping of the load when in motion
- severity of an accident
- operating conditions – normal/performance mode
- operating conditions – automatic without user intervention
- operating conditions – maintenance/service mode
- operating conditions – installing or dismantling (load-in / load-out)
- operating conditions – risk of unintended loss of phase (such as after an electrical storm)
- operating conditions – risk of unintended reversal of phase (such as touring applications or service panel maintenance
- environmental conditions – risk to power infrastructure during a weather event

The result of the assessment shall provide the basis to abate the hazard(s) and mitigate the risk(s). It is preferable that the risk assessment be performed by a group of two or more competent persons. When the risk assessment is completed by a single individual, that individual shall be a qualified person.

4.1 Risk management – standards compliance

The risk assessment shall be performed in compliance with a nationally or internationally recognized standard detailing the methodology of risk assessment such as ISO 12100:2010 - Safety of machinery – General principles for design – Risk assessment and risk reduction, or other accepted and recognized standard.

4.2 Risk management – stage machinery

Refer to the appropriate ANSI standards for stage machinery as produced under the efforts of ESTA for more information on risk management of stage machinery and applications.

4.3 Risk management – stage machinery control system

When evaluating the stage machinery control system for risk management the evaluator shall consider and review effects of:

- loss of primary power
- loss of control power
- loss of feedback signals
- loss of output signals
- false activation
- self-evaluation and error checking
- environmental considerations
- communications and reliability
- other systems and how they impact the stage machinery control system
- redundancy and reliability
- testing of safety devices and circuits
- visibility of load operation
- component failure
- logic failure
- access and lockout

4.4 Risk management – personnel

No risk evaluation can be complete if it does not include the function of human interaction with the described equipment. To properly ensure risk management the risk reduction shall include and identify:

- affected parties
- the normal operation roles and responsibilities of affected parties
- the actions and reactions of affected parties in the mitigation of risk
- training in the risk mitigation tasks and processes
- an evaluation of complacency to identify the need, if required, for ongoing training or retraining of the risk management program
- reporting steps in the event of an incident, close call incident, or accident

4.5 Risk management – rescue & recovery

A risk assessment and evaluation for rescue and recovery shall be created for stage machinery control system applications that involve the suspension or physical confinement of performers or other stage personnel. (Note: confinement in this context shall be considered the prevention of safe egress in the event of a system failure.)

Where the need for a rescue and recovery plan has been identified, the risk assessment shall, at minimum, additionally include:

- risks of injury during suspension/confinement
- the role of the control user in a suspended/confinement rescue
- the use of the stage machinery control system in a suspended/confinement rescue

Refer to the appropriate ANSI standard as published by ESTA for more detailed information regarding rescue & recovery when stage machinery applications involve suspension or confinement of performers or other stage personnel.

4.6 Risk Mitigation

Measures shall be taken to reduce unacceptable risk(s). The procedure shall be repeated, after the introduction of mitigation and remediation, until an acceptable level of residual risk is achieved.

4.7 Record of the risk assessment & mitigation

The risk assessment shall be recorded in a format that is convenient and durable and that can be shared with the affected parties and those needing to carry out the risk mitigation and remediation.

The report shall contain, at minimum, details describing:

- definitions of the limits of use
- identification of the hazards associated with use
- identification of hazards associated with reasonably foreseeable misuse
- classification of the risks in terms of severity and probability of harm
- methods used to mitigate the risks
- classification of residual risks after mitigation
- date of completion
- identification of document author(s)
- identification of third-party evaluators (if any)
- stamps/seals of review authority (if any)

4.8 Risk management – changes

A material change in plans, equipment, operations, or other circumstances (for example, changes in the performance itself, show order, personnel, or environmental conditions) could lead to the creation of new hazards or new levels of risk or severity of harm. Such changes shall create cause for a review of the implemented risk mitigation practices and may require an amendment to risk assessment.

Additional reviews may also be required after dismantling the equipment, in whole or in part, and reinstalling it.

5 Listings, inspections, and certifications*

Electrical Equipment Manufacturers shall ensure assemblies are designed and constructed to an appropriate standard of a Nationally Recognized Testing Laboratory (NRTL).

Pending the requirements of the NRTL, Low-Voltage Limited Energy (LVLE) circuits may be subject to exemptions.

Marks denoting approvals or conformity to specific standards by NRTLs shall be clearly affixed to equipment and machines as required by those standards and/or NRTLs. These may be on the nameplate label or internal to the electrical equipment. (see annex note)

For more information on the NRTL program and to find a list of approved testing laboratories, please refer to the OSHA website.

6 Functional safety

The requirement to apply functional safety to the use of a stage machinery control system shall be determined by hazard analysis, risk assessment, and the evaluation of the level of harm that may be caused.

Where safety functions are executed by the control system, verification that the required level of performance has been met shall be demonstrated by calculations done in accordance with section **4 Risk Management**.

7 Electrical equipment*

Electrical equipment shall be manufactured to UL508A or similar electrical safety standard.

Alternate standards shall be selected to match the type of equipment being controlled, its operation, location, and if the equipment is portable, temporary, or permanently installed. (see annex note)

Completed assemblies are exempt from any restrictions on dimensions, shapes, textures or finishes with respect to components. Vendors shall be allowed to select finishes that both suit the architectural requirements of the installation provided they meet with environmental requirements and respect the protection of the equipment from the surrounding elements.

Listing and labeling shall comply with the requirements of section **5 Listings, inspections, and certifications**. (see annex note)

7.1 Electrical safety compliance testing

It is the responsibility of the control equipment manufacturer or installer of the electrical equipment to ensure that the correct testing body is selected to meet with the requirements of the local AHJ.

Where certification to the local requirements has not been completed prior to the installation or where the AHJ requires additional testing or certification, it shall be permissible to provide the AHJ, at their discretion, with a local field inspection report executed by the recognized testing authority.

7.2 Surrounding environment and operating conditions

Manufacturers of electrical control equipment shall clearly identify the types of environmental conditions that their equipment is able to withstand. These may include, but not be limited to:

- exposure to rain, water spray, etc.
- exposure to salt spray or other corrosive elements
- exposure to sunlight
- exposure to condensing humidity
- maximum and minimum operating temperatures during operation
- maximum and minimum operating temperatures during storage and shipping

Electrical equipment shall be designed to meet the ingress protection rating (IP) required to protect the equipment from the environment it will be exposed to during operation as defined by IEC60529.

7.3 Labeling

It is the duty of the equipment manufacturer to warn and inform the user or service personnel of any hazard associated with the stage machinery control equipment.

All control equipment shall be affixed with appropriate labeling outlining the inherent risks involved in installation, operation, and service. Special attention shall be taken to provide warnings regarding limitations, shock, remote start, and operation hazards.

All markings shall be located where they can be easily viewed by a competent person before use, examination, adjustment, servicing, or maintenance of the equipment. Markings shall be clear, legible, and adhered or created in such a manner as to withstand exposure to the physical environment during intended use and storage of the equipment.

Labeling and signage shall comply with the requirements of the following standards when required, and as space on components or assemblies allows:

- ANSI Z535.1, Safety Color Code
- ANSI Z535.2, Environmental and Facility Safety Sign
- ANSI Z535.3, Criteria for Safety Symbols
- ANSI Z535.4, Product Safety Signs and Labels

7.3.1 Nameplate labeling

Equipment shall have a legible, durably marked, and permanently affixed name plate label. Information on the label shall comply with the NRTL listing and labeling requirements.

7.3.2 Safety instruction labeling

Where the size of the enclosure precludes placement of safety instruction labels, the control equipment manufacturer shall apply an information label instructing the user to refer to the user manual or other documentation source before performing any work on or with the equipment.

7.4 Indicators

Indicators should be installed so that they are visible from the user's normal working position.

Selection of indicators shall be based on the function that the indicator is intended to identify and/or display.

The following is a list of general industrial norms.

Color	Meaning according to norms	Explanation	Description
Red	Fault/Failure/Error	Signals the status of an error or fault	User attention required to correct the error or fault before normal operation resumes

Yellow/ Amber	Abnormal/Warning	Signals the status of danger, alarm, or failure.	User attention required to monitor error or prepare to act
Blue	Obligatory	Indicates a condition that requiring user's action	Obligatory activities
	Power Present	Indicates the presence of low voltage control power	Caution should be used as motive power is present
Green	Normal	Indicates normal or fault-free status	User should be aware that all functions are ready for operation
	Power Present	Indicates the presence of medium voltage power	Caution should be used as motive power is present
White	Neutral	Can be used if there is any doubt as to the use of above colors in a particular scenario/application	User shall monitor the status of the associated function.
	Power Present	Indicates the presence of source power	Caution should be used as motive power is present

The following is a list of norms specific to stage machinery control systems.

Color	Meaning according to norms	Explanation	Description
Red	Fault/Failure/Error	Signals the status of an error or fault	User attention required to correct the error or fault before normal operation resumes
Yellow/ Amber	Abnormal/Warning	Signals the status of danger, alarm, or failure.	User attention required to monitor error or prepare to act
Blue	Obligatory	Indicates a condition that requiring user's action	Obligatory activities
	Power Present	Indicates the presence of low voltage control power	Caution should be used as motive power is present
	Direction	Signals a direction of travel	User attention required to observe that the operating direction is intended
Green	Normal	Indicates normal or fault-free status	User should be aware that all functions are ready for operation
	Power Present	Indicates the presence of source power	Caution should be used as motive power is present
	Direction	Signals a direction of travel	User attention required to observe that the operating direction is intended
	GO/RUN	Indicates the GO or RUN switch operator	User is guided to press this switch operator to initiate motion
White	Neutral	Can be used if there is any doubt as to the use of above colors in a particular scenario/application	User shall monitor the status of the associated function.
	Power Present	Indicates the presence of source power	Caution should be used as motive power is present

It is considered good practice to provide a means to allow the user to test all indicator lamps.

7.5 Electrical enclosures

Entertainment applications create challenges with the design of electrical enclosures. Despite these challenges all electrical enclosures shall comply with enclosure type for which the product is labeled.

Where compliance is not possible the assembly shall be labeled as an "Open Industrial Control Panel".

7.5.1 Environmental ratings

Electrical enclosures shall be constructed and labeled to withstand the environmental conditions to which they will be exposed.

7.5.2 Connector mountings
Connector mountings shall be reinforced and secured to meet with the demand of frequent coupling and decoupling of connectors during normal operation and use. Consideration shall also be given to a reduction of strain or pulling force applied to cables connected to an electrical enclosure.

7.5.3 Cooling and venting
Electrical equipment that produces heat as a by-product of normal operation shall be cooled in accordance with the component manufacturer's recommendations. To calculate cooling requirements the system designer shall consider:

- the use and duty cycle of the equipment when in normal operation of the specific application
- the use and duty cycle during abnormal operations, such as rehearsal or during commissioning/testing procedures

Based on this calculation, steps shall be taken to ensure that the equipment is properly cooled or that the user is expressly warned of a pending overheat event.

Cooling and ventilation openings shall be covered or sized to prevent access to any hazardous situation including, but not limited to, electric shock, pinch, shearing, or other physical hazard that may be presented to an installer, user, inspector, or service person.

7.6 Disconnect switches
Disconnect Switches shall be sized in consideration of the load types that are switched by the disconnect and have an ampere rating of at least 115% of the rated service demand of the control panel.

7.6.1 Local motor disconnect
All motorized stage machinery shall employ an appropriate means of local disconnect to isolate the machinery from motive power.

Local Motor Disconnect Switches shall have an ampere rating at least 115% of the rated service demand and a horsepower rating the same or greater as the rated motor horsepower (at applied voltage).

7.6.2 Local disconnect of hydraulically powered machinery
Hydraulically powered machinery shall be appropriately labeled to direct service and maintenance personnel to the location of the power disconnect of the hydraulic power unit.

7.7 Overcurrent protection
Overcurrent Protection devices shall be selected based on the requirements for which the control equipment is labeled.

Overcurrent Protection of control circuits shall be selected based on the requirements for which the control equipment is labeled.

7.8 Phase loss protection
Touring and semi-permanent applications shall require a device that monitors for phase loss.

The use of phase loss devices in permanent installations or applications shall be determined by risk assessment with a focus on the opportunity to cause harm in the event of a phase loss. (see annex note)

Upon activation of the phase loss device the machinery shall be placed and/or held in a safe state (stopped) and the user shall be made aware of the fault condition.

7.9 Phase rotation protection
Touring and semi-permanent applications shall require a device that monitors for phase rotation errors.

The use of phase rotation monitoring in permanent installations or applications shall be determined by risk assessment with a focus on the opportunity to cause harm in the event of a phase rotation error. (see annex note)

Upon activation of the phase rotation monitoring device the machinery shall be placed and/or held in a safe state (stopped) and the user shall be made aware of the fault condition.

7.10 Control power*

As a matter of good practice, power supplies used to provide control power shall be oversized by at least 25% of the calculated demand. (see annex note)

Branch circuits shall be appropriately protected and current limited. (see annex note)

7.11 Connectors

Connectors shall be carefully selected, fit for purpose, and appropriately sized for current demands and applied voltages.

All connectors used on portable stage machinery control equipment shall be recognized under the requirements for which the product is labeled.

The practice of using connectors that are rated at voltages higher than those applied is acceptable if:

- the rated current capacity of the connector is not exceeded
- the connector or connection point is appropriately labeled to inform and warn the installer or user of the operating voltage of the controller
- the control equipment manufacturer has received appropriate allowances and approvals from their chosen testing body

All line voltage connectors used shall contain a protective earth / ground pin that is firmly bonded to the chassis of the connected device when it is metallic. Grounding terminals shall not be used to carry operational current.

If the connector is to be used as a means to disconnect the machinery from the source power, consideration shall be given to select connectors that meet with the requirements for which the product is labeled.

7.11.1 Source power connectors (line voltage mains)

Source connectors shall be chosen to, at minimum, meet the labeled demands of the device.

7.11.1.1 Mating or rupture under load

Connectors shall be rated for interconnection and disconnection while energized.

When the connector is not rated for interrupting the load, it shall be labeled “Do Not Rupture under Load”.

When the connector is not suitable for hot connection, the supply receptacle shall be equipped with an appropriately rated disconnect or circuit breaker.

7.11.2 Output connectors

Selection of the style, size, and shape of the output connector is at the discretion of the control equipment manufacturer.

Output connectors carrying machine power shall be rated to accept motor loads (in-rush inductive loads).

All output connectors shall be chosen to match or exceed the supplied voltage and rated output current of the control channel.

7.11.3 Connector pin-outs

Pin-outs as defined in this standard are the assignment of a function, circuit, or signal to a particular connector pin. The control equipment manufacturer shall not use pin assignments that are in violation of electrical codes to which the device is listed or governed.

Pin assignments shall be the same on both ends of all line voltage cables employing mating connectors.

Where a selected connector does not employ a clearly identified ground terminal the control equipment manufacturer shall bond the grounding point to the largest pin or the pin that is the first and last connecting point when coupling / decoupling mated connectors (first make/last break).

7.11.4 Mating cycles

Connectors shall be selected based on the frequency of interconnection anticipated by the application. Stage machinery control system designers shall select connectors with a mating cycle rating that is at minimum 30% greater than the anticipated number of mating cycles over the routine component replacement schedule or the life expectancy of the product.

7.12 Cables

Cables should be selected based on the application with consideration given to:

- durability
- bend radius and flexibility
- voltage carried by the conductors
- rating of the source supply overcurrent protector
- environmental conditions and exposure
- quantity of conductors required in a single jacket
- voltage drops over the length of the cable run

Connectors shall be securely fastened to Cable jackets using an appropriately sized strain relief designed for use with the jacket material.

The practice of splitting the cable jacket to break conductors of multi-core cable out to multiple connectors is prohibited.

Cables shall be selected to meet with the demands of the application using, at minimum, the following criteria:

- dielectric strength of the insulation and sheathing
- environmental conditions
  - indoor or outdoor use
  - wet/damp/dry
  - temperature
- exposure to sunlight or other factors that may affect or degrade the sheathing
- requirements for fire/flame retardance
- flexibility
- mitigation of signal interference and/or shielding
- portability
  - ability to coil and uncoil without kinking or damage
  - weight of the cable if it is to be frequently handled
- number of conductors

7.12.1 Power cables

Power supply cable should be listed as portable cable for extra hard usage and shall be rated for the labeled voltage and current draw of the connected device.

7.12.2 Control cables

Where control cables are to be bundled with other cables, attention shall be paid to the needs for shielding to ensure that transient electrical noise from one cable is not transmitted to others that may be carrying noise sensitive signals.

7.12.3 Motor cables

Motor cables shall be selected to meet with the demands of the specific type of motor and drive. When terminating motor cables to connectors the connector shall include enough pins to carry the brake signals for all holding brakes so that if the motor conductors are disconnected so are the brake conductors.

7.13 Motor starters

Motor starters shall be selected to match or exceed the motor nameplate voltage and current demand.

When the application includes the ability to reverse the rotation direction of the electric motor, a method of electrical and mechanical interlocks shall be provided to prevent accidental simultaneous activation of both direction contactors.

7.14 Motor overloads

Each motor shall be independently protected by a thermal overload device or drive function that interrupts the motive power circuit and alerts the user to the fault condition.

Overload devices and/or functions shall be sized, configured, or adjusted to match the full load amperage (FLA) value posted on the motor nameplate.

7.15 Motor drives

Motor drives shall be sized based on the electronic drive manufacturer's recommendations.

Consideration shall be given to the service factor of the stage machinery and duty cycle of the application to ensure the drive has time to cool between use cycles. Calculated duty cycles shall be based on the following considerations:

- the worst-case scenario for repeated use
    - if worst-case is a short-term experience, such as rehearsal periods, then other over-use mitigation practices may be applied
- normal operating conditions
- adding a buffer to allow for unknown, extended, or unanticipated usage

It is common in Entertainment Applications to set the switching frequency above the common base value of 4kHz. When this is required, most electronic drive manufacturers recommend selecting a drive with a greater motor kW/HP value than the motor FLA. Should this practice be applied, the control equipment Manufacturer shall ensure that conductors are appropriately sized and protected from overload and drive settings are appropriately configured for the motor nameplate values.

When sizing servo applications the control equipment manufacturer shall consider all aspects of motion (acceleration, maximum velocity, duty cycle, loading, and torque) to correctly size the motor drive.

7.16 Valves and controllers

When selecting a valve and controller for fluid power the control designer shall, at minimum, consider:

- type of pressurized material, liquid or air (others may be considered but in most entertainment applications pressurized fluids are either hydraulic oil or air)
- pressure rating of the actuator devices
- operating temperature of the components and need for cooling systems
- flow rate required
- flow coefficient (Cv) – the flow rate (GPM) for a pressure drop of 1 PSI across the flow passage
- installation requirements
    - configuration of the hardware
    - piping type and size
    - valve mounting requirements and restrictions
- service type and duty cycle
- industry/country standards, key standards may include American Petroleum Institute (API), American Society of Mechanical Engineers (ASME), Canadian Registration Number (CRN), and Pressure Equipment Directive (PED).

7.17 Encoding & position sensing*

Encoding and position sensing hardware shall be selected based on the following criteria:

- the type of signal required by the receiving device
- the mechanical attachment to the equipment being measured
- the resolution required for measurement accuracy
- the minimum and maximum data management capabilities of the receiving device

There shall be a method to restore lost position information caused by power down or power loss to the position sensing equipment. (see annex note)

Where machinery may be operated while encoder receiving equipment is powered off, the use of absolute encoders is recommended.

7.18 Load sensing

When designing a load sensing system, the following shall be considered:

- the output signal of the load sensor
- the distance of signal transmission between the load sensor and the signal amplifier
- opportunity for thermal shift of the load sensor
- maximum and minimum operating capacities of the load sensor

The software controlling or reading the data from the signal amplifier shall have a means of calibration. Calibration routines and/or methods shall be detailed in user guides or service manuals.

7.19 PLCs and motion controllers

PLCs and Motion Controllers shall be selected at the discretion of the stage machinery control equipment manufacturer. It is recommended that the manufacturer utilize devices that operate on compatible communications platforms.

Where the stage machinery control equipment manufacturer is employing the use of custom or proprietary printed circuit boards, these boards shall be tested for dielectric strength and proven to withstand the voltages to be applied to all components to standards as set out by a recognized testing authority.

Sensitive data such as but not limited to position data, safety configurations, calibration data, or machine parameters, shall be stored in a fashion so that the data is retained through a power cycle of the device.

7.20 Circuit design and wiring practices

7.20.1 Standards, practices, and training

Control equipment manufacturers shall provide employees with appropriate training in the application of the intended product/assembly listings.

7.20.2 Touch safe

Limit switches, sensors, or other circuits that require removal of covers for adjustments shall be touch safe or a Low Voltage, Limited Energy (LVLE) or class 2 circuit.

Testing points or other regularly accessed components that are used by service personnel should be separated or protected to prevent service personnel from coming into contact with voltages and currents above those of an LVLE or Class 2 circuit. Where this is impractical or impossible, exposure to voltage and currents higher than LVLE / Class 2 shall be done while wearing appropriate PPE as determined by an electrical safety program.

7.20.3 Circuit routing

Circuits shall be routed through components or devices in a logical manner using the component manufacturer's recommended terminal assignments.

As an example, motor leads shall be terminated to the T terminals on motor control devices and line, or supply voltages terminated to L terminals.

7.20.4 Mounting position

The mounting position of components in an assembly shall be in accordance with the component manufacturer's recommendations.

Exception: Where the component manufacturer's recommended mounting position is impractical for the required application the System Designer shall mitigate the risks associated with the demand through the application of additional efforts.

Under no circumstance shall a component be placed in such a position during active operation that will risk or cause an unintended or uninitiated activation of the device or cause the required operation not to occur.

7.20.5 Wire terminations

Wire terminations shall be made in accordance with the recommended practices of the wire termination product manufacturer. Personnel shall be properly trained in the use of required tools used to the execute the termination.

Assemblers shall pay strict attention to the wire termination product manufacturer's instructions on:

- the use of ferrules
- the use of tinned copper wire
- the use of solid or stranded copper wire
- torque specifications for screw terminals
- minimum and maximum wire gauges
- maximum quantity of wires allowed per terminal

7.20.6 Bend radius

Control equipment manufacturers shall ensure that assembly designs adhere to the limitations of minimum bend radii for which the product/assembly is labeled or the wire/cable manufacturer.

7.20.7 Clamping and routing

System Designers shall specify applicable methods of clamping, support, and routing to facilitate installation, repair, and maintenance of wires, wire bundles, and cabling.

7.20.8 Separation and barriers

System Designers and Assemblers shall ensure that separation practices and the use of barriers within assemblies meet with the requirements for which the product/assembly is labeled.

7.20.9 Grounding and bonding

The control equipment manufacturer shall ensure that circuits are appropriately grounded or bonded.

7.20.10 Shielding

Special attention may need to be given to ensure the quality of LVLE signals and data transmission including but not limited to shielding practices and materials.

7.20.11 Repair and maintenance

System Designers and Assemblers shall:

- consider and develop procedures for repair and maintenance of assemblies
- ensure that fasteners used to secure serviceable parts and components are easily accessible, removable, and replaceable
- position component, device, and wire labels so that they are easily read by service personnel where practical

7.20.12 Inspection methods

System Designers shall document general visual inspection (GVI) and detailed inspection (DET) methods to be included in use, service and/or maintenance manuals/guides for use by authorized service and maintenance personnel.

Methods shall include but not be limited to inspection for:

- heat damage
- chafing, cracked or delaminated insulation
- arcing
- corrosion
- broken wires or terminals
- contamination
- loose terminals

8 Communications

Network communication, or inter-networking, for stage machinery controls employing a PES architecture shall meet with the required standards of the selected communications protocols employed by the manufacturer or the PES.

The selection of protocols and hardware shall minimize the time it takes to transfer data from one device to another and shall update the user on status of the machinery and safety devices under their observation.

8.1 Communication protocols

Communications between devices within a programmable electronic control system for stage motion control shall conform to the requirements of common industrial standard.

PES manufacturers shall ensure that their selected industrial communication standard provides bidirectional communications, self-diagnostics, and error checking.

PES manufacturers are responsible for complying with the standard selected and shall be prepared to respond to evaluations as required by an AHJ when requested. Evaluations may include, but not be limited to, quantification of error processing and checking, qualification of packet delivery, communications speed, and other qualifiers.

8.2 Networking hardware

Networking hardware shall be selected in accordance with the standard(s) applied.

8.3 Wireless systems

Wireless connection of PES equipment shall be permitted so long as the same design and safety requirements of wired systems are applied.

8.4 Loss of communications

If any component of the PES loses communications with another related component of the PES, a failure shall result. The affected machinery shall come to a safe stop.

8.5 Remote monitoring

Remote connection devices, when installed, shall not delay, affect, or cause unexpected operation of the PES.

It shall not be possible for an unauthorized user to access the PES from outside the local network. It is recommended that the PES manufacturer provide a secure password protected appliance that allows the user to disconnect or “turn-off” the remote connection device without it affecting the operation of the PES.

PES manufacturers shall provide users with a written code of ethics and responsibilities defining usage of the remote connection appliance on the part of the PES manufacturer, Authorized service bodies and personnel, and the user themselves.

8.6 Internet of Things (IoT) and Industrial Internet of Things (IIoT)

The use of IoT and IIoT is expanding. PES Manufacturers that utilize this technology shall ensure that connections are secure and limited to authorized devices.

9 E-Stop (Emergency Stop)

An E-Stop system shall be included in the design of installations using a PES for the purpose of controlling stage machinery. The E-Stop system shall provide the user with the ability to safely bring to a full stop all machinery in motion by activating an E-Stop operator.

The E-Stop shall be so designed that a decision to use it during an emergency event does not require the user to hesitate engaging it due to consideration of the possible resultant effects.

Operation of the E-Stop system shall not be hampered or made inactive by any other component of the stage machinery PES. The E-Stop system shall operate, as per the design intent of the system at all times. Should a component of the E-Stop system fail the system shall register and report the fault and fail in an open state to prevent motion until the failure can be rectified.

The design application of the E-Stop system shall first begin with an assessment of the risks involved with the operation of the stage machinery.

The risk assessment shall determine:

- the quantity and location of E-Stop operators
- the required category of E-Stop function

- the required functional safety standard
- the location and quantity of users
- the required skill level and training of users

In addition to the risk assessment the system designer shall determine:

- the specific control needs of the stage machinery application
- the impact of the required E-Stop category on the machinery and loads in motion and how they may impact associated structure(s) and/or building(s)
- if additional risk is created in the execution of an E-Stop and if control solutions may be able to minimize it

Equipment employed in the design of an E-Stop System shall comply with the following:

- All systems – ISO 13850
- Electrical Equipment – IEC 60204-1
- Hydraulic Equipment – ISO 4413
- Pneumatic Equipment – ISO 4414

9.1 E-Stop function

The E-Stop Function is a complementary protective measure applied to the overall PES design that shall not be applied as a substitute or impair the effectiveness of other safeguarding measures or procedures.

The E-Stop function shall be always available and operational and shall override all other control functions and operations regardless of the operation mode of the machinery.

The E-Stop function shall be designed so that after activation of the E-Stop operator(s), motion and operation of the machinery under the management of the E-Stop System are brought to a safe stop. All machinery shall remain in a safe state, without creating additional hazards or requiring additional intervention by the user.

9.2 E-Stop architecture

E-Stop control circuitry shall employ fail-safe design of, at minimum, a single control loop that maintains power to relays that open when a break in the control loop removes the E-Stop control signal.

Where the control loop requires the use of relays the control equipment manufacturer shall, at minimum, select relays that are mechanically force guided.

Where practicable the use of the following materials and practices shall be employed:

- safety rated relays
- safety rated inputs
- multi-channel circuitry
- feedback and status circuits

9.3 E-Stop categories

The required E-Stop Category shall be determined by risk assessment.

The basis of determining the required Category for the risk assessment shall be drawn from one of the following standards:

- IEC 60204-1, Safety of machinery — Electrical equipment of machines — Part 1: General requirements
- NFPA 79, Electrical Standard for Industrial Machinery
- ISO 13850, Safety of machinery — Emergency stop function — Principles for design

(Note: CSA C22.2, which draws heavily on IEC 60204-1, or NFPA 79, Electrical Standard for Industrial Machinery may also be referenced but are not normative requirements of this standard.)

IEC 60204-1, NFPA79, and CSA C22.2 No.301 all describe the different types of emergency stopping – commonly referred to as Category 0, Category 1, and Category 2, not to be confused with Control Categories of ISO13849.

(Note: The chart below is provided as a reference of the descriptive actions required by the standards named above. It has been included in the normative language of this standard to provide details of E-Stop categories.)

Category	IEC 60204-1	NFPA79	CSA C22.2 No. 301
0	stopping by immediate removal of power to the machine actuators.	an uncontrolled stop by immediately removing power to the machine actuators.	stopping by immediate removal of power to the machine actuators (i.e., an uncontrolled stop.)
1	a controlled stop with power available to the machine actuators to achieve the stop and then removal of power when the stop is achieved.	a controlled stop with power to the machine actuators available to achieve the stop then remove power when the stop is achieved.	a controlled stop with power available to the machine, actuators to achieve the stop and then removal of power when the stop is achieved;
2	a controlled stop with power left available to the machine actuators.	a controlled stop with power left available to the machine actuators.	a controlled stop with power left available to the machine actuators.

At minimum the control of all stage machinery shall employ a means to be bring all machinery in motion to a Category 0 stop.

While it is acceptable to achieve this by switching off power by using the disconnecting means or by physically “pulling the plug” from the power supply socket, it is not recommended to apply this technique in the entertainment industry.

The nature of Entertainment applications normally requires users to be situated in an operating position that is remote from the control panels, therefore, a control relay circuit shall be employed to remove power via a safety rated function on an electronic power source (drive or otherwise) or by releasing a power safety contactor that in turn cuts power to the operating machinery.

9.4 E-Stop operators

E-Stop systems shall include at least one E-Stop operator and contact block, selected to comply with ISO13850.

Contacts must be self-monitored to ensure that the contact block is securely connected to the switch operator. If the operator and the contact block become disconnected the contacts must open leaving the system in a safe state.

9.4.1 E-Stop operator types

Operators may include:

- push-buttons easily activated by the palm of a hand
- wires, ropes, bars
- handles

9.4.2 E-Stop operator color

The operator of the E-Stop device shall be RED and, where it is practicable, the background shall be YELLOW.

Refer to ISO13850 – section 4.3.7 for details and additional information on symbols and labeling.

9.4.3 Locating E-Stop operators

E-Stop operators shall be mounted in such a manner and location that the activation cannot be easily blocked by simple means.

E-Stop operators shall be located:

- in such a place that the user of the device is not exposed to additional hazard
- at each user control station
- at locations where intervention to monitor for hazardous situations is needed
- at places where it is expected that personnel will encounter machinery in operation

9.4.4 Detachable E-Stop operators

Where E-Stop operators are detachable from the Controller or E-Stop system (e.g., plugable user control stations) the control equipment manufacturer shall perform a risk assessment to determine if there is need for at least one E-Stop operator to be permanently available.

In addition, at least one of the following measures shall be taken to identify operational state of the detachable E-Stop:

- change of operator color or visibility using illumination
- automatic or manual covering of inactive E-Stop operators
- procedures for proper storage, application of signage, or removal

Instructions and training shall be provided to authorized personnel who remove, install, or store inactive E-Stop operators to prevent confusion or operational error.

*(Note: for additional information refer to section **9.9 Bypassing**)*

9.4.5 Guarding E-Stop operators

Guards and shrouds shall be permissible providing the operator is readily available to all potential users and a risk assessment has determined the need and reliability for the guard or shroud.

9.5 E-Stop labeling

Where it is practicable, the background surface of an E-Stop device shall be YELLOW. Labeling may be applied to the yellow background where additional clarity is required but shall not exceed greater than 30% coverage of the yellow surface.

Refer to ISO13850 – section 4.3.7 for details and additional information on symbols and labeling.

9.6 E-Stop Activation*

Upon activation of an E-Stop device the E-Stop Function shall be executed as per the prescribed intent of the E-Stop system design. The E-Stop system shall be placed in a safe state (idle) and ready for user intervention to reset as described in section **9.7 E-Stop Reset**.

All machinery in motion shall come to a safe and complete stop.

All machinery under control of the E-Stop Function shall be left in a disabled state until the system is reset.

Activation of an E-Stop event shall not create an additional hazard. (see annex note)

9.6.1 E-Stop reaction – variable speed axes

Upon activation variable speed axes shall come to a complete and safe stop using a Category 0 or Category 1 stop as described in section **9.3 E-Stop categories**.

9.6.2 E-Stop reaction – fixed speed axes

Upon activation fixed speed axes shall come to a complete and safe stop using a Category 0 stop as described in section **9.3 E-Stop Categories**.

9.6.3 E-Stop reaction – hydraulic axes

Upon activation hydraulic axes shall come to a complete and safe stop using a Category 0 or Category 1 stop as described in section **9.3 E-Stop categories**. Risk reduction may require that reserved pressure be released or held to secure the load.

9.7 E-Stop reset

Resetting of an activated E-Stop:

- shall only be possible by an intentional action of the user.
- shall not restart the machinery but only permit restarting upon the execution of control commands by the user.

The system shall inform the user of the status of error checks and processes being performed once the reset action has been committed and alert the user when the system has been returned to a ready state.

9.8 E-Stop lockout*

If intended by the system design, the E-Stop control circuit may be permitted to restrict use of the stage machinery control system using an access limiting device such as a key-operated switch.

The use of a locking emergency stop device shall not be permitted as a method to de-energize or render equipment safe for servicing. (see annex note)

9.9 Bypassing

The E-Stop system design shall incorporate, when necessary, the ability to bypass selected devices or functions under special circumstances.

Where bypassing of an E-Stop component is required, the system shall:

- leave the component in a safe state
- provide indication, at the component, that it is not actively connected to the E-Stop system
- provide indication, at the user controls, that the specific component is not actively connected to the E-Stop system

Bypassing shall not be performed on any active device.

9.10 E-Stop linking to other systems*

Entertainment applications that employ more than one stage machinery control systems for performance-based stage machinery shall have the capability of linking E-Stop systems together so that when the E-Stop operator of one system is activated both systems enter an E-Stop state.

Systems shall require independent reset that does not cause a reset on the other systems.

The systems shall also employ a means to be isolated from one another for the purpose of testing and notice should be given to the users of both systems that each are in an isolated state.

Dedicated control systems employed to operate an orchestra lift, acoustic curtain system, fire safety curtain, or other non-performance-based stage machinery equipment are exempt from this requirement. (see annex note)

9.11 E-Stop, wireless systems

Wireless E-Stop applications shall be as reliable and function in the same manner as wired systems.

A risk assessment shall be performed to determine the architecture of the wireless system.

The risk assessment shall specifically consider the appropriate response to a loss of communications of the wireless devices. Possible responses may include a) a system-wide E-Stop, b) a sub-system E-Stop, c) an alarm, d) a call for user action.

9.12 Machine stop

A machine stop shall remove motive power from the machinery to which the machine stop operator is associated.

9.12.1 Machine stop operators*

Machine stop operators may be colored yellow, grey, or white. The button or the adjacent background must be labeled Machine Stop. (see annex note)

Machine stop operators shall latch in the depressed position and require direct action by the user to release.

Contacts must be self-monitored to ensure that the contact block is securely connected to the switch operator. If the operator and the contact block become disconnected the contacts must open leaving the system in a safe state.

10 Hold-To-Run (HTR)*

An HTR provides a method of enabling the operation of stage machinery and triggers a controlled stop of the machinery in motion if the user holding the device identifies a hazardous condition and releases the HTR or becomes incapacitated during the operation.

HTR Controls shall only be used by competent persons authorized to operate the HTR operator and trained in the safe monitoring of the activity being observed. (see annex note)

10.1 HTR function

The HTR Function is a complementary protective measure applied to the overall stage machinery control system design that shall not be applied as a substitute, or impair the effectiveness, of other safeguarding measures or procedures.

The HTR function shall be designed so that it does not impair other protective safety functions, such as egress of persons from confined spaces.

Unlike the E-Stop Function, the HTR function shall be designed so that after activation of an HTR event the machinery shall be left in a safe state that does not require additional action by the user for reset.

Upon release of an HTR device, all machinery in motion shall come to a safe and complete stop with all braking and holding brake systems engaged and remain in a safe state, without creating additional hazards or requiring additional intervention by the user.

10.2 HTR architecture

The HTR is the ideal solution to ensure the safe operation of stage machinery during unpredictable situations, or in situations where the control equipment user cannot make visual contact with the activity on stage or where the situation calls for focused attention.

When practicable, the HTR system shall provide the ability to program Category 0, 1, or 2 Stop functions as described in section **9.3 E-Stop categories** as required by specific machinery or applications under review of risk assessment and risk reduction strategies.

10.3 HTR operators

Selection of the HTR operator shall be determined through the application of a risk assessment focused on determining the risks and consequences involved in deliberate activation or nuisance/erroneous activation of the HTR operator to the OFF position.

HTR operators that employ more than one set of switch contacts shall be connected to a disparity detection circuit that ensures that both circuits are operational.

- Both switch contacts closed – machine(s) can operate
- Both switch contacts open – machine(s) is(are) disabled
- One switch contact open + one switch contact closed - machine(s) is(are) disabled

The operating force required to activate the switch contacts of the HTR operator shall be:

- between 2N and 16N from position 1 to 2
- between 14N and 56N from position 2 to 3

10.4 User startle reaction

A person's startle reaction can vary; one person may tighten and squeeze the hand switch; another may let it go. Where practical and as determined by risk assessment, the use of a 3 position OFF-ON-OFF enable switch in the HTR operator is recommended.

10.5 HTR release

Upon release of an HTR operator the HTR stop function shall be executed as per the prescribed intent of the operating environment to cause:

- all machinery in motion to come to a safe and complete stop
- all machinery under control of the HTR function to be left at rest until the system is reset

Activation of an HTR event shall not create an additional hazard.

10.6 HTR reset

Resetting the HTR circuit shall not require any additional action by the user.

10.7 HTR linking to other systems

Where multiple stage machinery control systems are operating within the same performance space, linking of the HTR systems is not recommended or required.

10.8 HTR compliance testing

HTR Compliance Testing shall involve:

- a functional check of the HTR operator to ensure that the STOP function is triggered in all open circuit positions
- a visual inspection that all known and anticipated risks are visible from the operating position
- confirmation that the user of the HTR controls is not at risk of being exposed to a hazard
- confirmation that the HTR controls can only be held in place when the user is in the immediate vicinity of the HTR operator
- confirmation that the stopping distance initiated when releasing the HTR operator does not expose the machinery or load in motion to an additional hazard

11 Signal termination*

The termination of signals deriving from or received at the stage machinery control system shall be performed by a Competent Person.

The use of sinking signals is not recommended. Where devices are supplied from the component manufacturer with sinking signals an additional device shall be employed, within the control enclosure, to switch the action of the field wiring from sinking to sourcing. For clarity, the sinking signal shall remain inside the control enclosure to protect it from hazards due to exposure to physical damage that may present the opportunity for a false signal (see annex note).

Signals affecting safety shall be configured to be fail-safe. All other functions shall be configured according to the applicable function.

The use of double throw switches to verify and validate the position of the switch wiper is highly recommended. (see annex note)

11.1 Digital input signal, normal high signal received

For the context of this standard normal high signal received shall be any signal received by the signal processing device that is of an expected positive voltage value greater than 0V when referenced to the supply return.

Normal high signals may be used for:

- confirmation signals of non-critical safety functions
- confirmation signals of switch contact in safety functions controlled by Normal Low Signals

Normal high signals shall not be used solely to activate critical safety functions.

11.2 Digital input signal, normal low signal received

For the context of this standard normal low signal received shall be the removal of any signal received by the signal processing device that is of an expected positive voltage value greater than 0V when referenced to the supply return.

Normal low signals shall be the preferred method of receiving all signals regardless of safety level as they are fail-safe by nature.

11.3 Digital output signal, normal high signal sent

For the context of this standard normal high signal sent shall be any signal sent by the signal processing device that is of an expected positive voltage value greater than 0V when referenced to the supply return.

Normal high outputs shall be the preferred method of sending signals to operation functions that require functional processing such as brake release.

11.4 Digital output signal, normal low signal sent

For the context of this standard normal low signal sent shall be any signal removed by the signal processing device resulting in a neutral or 0V value at the receiving device when reference to the supply return.

Normal low outputs shall be the preferred method of sending all signals to receiving devices that require fail-safe operation.

11.5 Analog signal

Attention shall be given to ensure that analog signals are of an amplitude and strength to be transmitted over the distances as required by the application.

Attention shall be given to signal quality and to maintain a minimal signal to noise ration at the receiver.

11.6 Loss of signal

Loss of signal from any sensor used to protect the machinery or load path shall be observed as a failure to cause a fault and bring all affected machinery to a safe stop.

12 Constraining travel*

The action of protecting machinery, connected elements, and structural limitations is performed using position sensors.

When applicable, sensors shall be installed and connected to the stage machinery control system to prevent over-run travel and/or restrict travel.

The hazard analysis and risk assessment shall define the requirements of the position sensors and the system reactions when position-constraining sensors are activated or sensing positions are reached.

See annex note for a list of machinery that may not require the use of limits or sensors to limit travel.

12.1 Position constraint terminologies

Due to the variations in travel directions and types of basic mechanical applications of entertainment machinery the following terminologies should be considered.

Positive direction should align with moving the load to increase the distance value from the orientation reference point.

Negative direction should align with moving the load to decrease the distance value from the orientation reference point.

12.1.1 Constraining sensor terminologies

Constraining sensors should be named as follows:

TERM	ABBREVIATION
Ultimate Plus	U+
Initial Plus	I+
Soft Plus	S+
Soft Minus	S-
Initial Minus	I-
Ultimate Minus	U-

12.1.2 Applying direction terminologies to stage directions

Constraining sensors should relate to the following actuator direction and stage positions/directions:

TERM	Actuator Direction	Vertical Motion	Horizontal Motion	Rotational Motion
Ultimate Plus	FWD/CW/Extend	Out/Above Stage	Off SR/Onstage	Clockwise

Initial Plus	FWD/CW/Extend	Out/At Stage	Off SR/Onstage	Clockwise
Soft Plus	FWD/CW/Extend	Out/At Stage	Off SR/Onstage	Clockwise
Soft Minus	REV/CCW/Retract	In/Below Stage	Off SL/Offstage	Counterclockwise
Initial Minus	REV/CCW/Retract	In/Below Stage	Off SL/Offstage	Counterclockwise
Ultimate Minus	REV/CCW/Retract	In/Below Stage	Off SL/Offstage	Counterclockwise

12.2 Sensors
For the purpose of this section, sensors shall refer to switch contacts that are mechanically closed or opened by a physical switch operator, electronic sensors, proximity sensors, or optical sensors employed for the purpose of identifying or confirming the location of the load or machine component in motion.

12.2.1 Sensor selection
The selection of the sensor type shall be based on the requirements and environmental conditions of the application. (see annex note)

12.2.2 Use of hard struck sensors
When used, these sensors shall be related to the travel of the load or machinery and activated by physically contacting a mechanism that moves with the load. A risk assessment shall be used to determine which element of the load requires constraint of travel and determine if hard struck sensors are appropriate.

12.2.3 Use of rotary struck sensors
When used, these sensors shall be related to the rotation of a mechanical element of the machinery. A risk assessment shall be used to determine which element of the machinery requires constraint of travel, if the rotation can be appropriately linked to the movement of the load, and if rotary struck sensors are appropriate.

12.2.4 Use of proximity sensors
When used, these sensors shall be related to the travel of the load or machinery and activated without physical contact with the load. A risk assessment shall be used to determine which element of the load requires constraint of travel and determine if proximity struck sensors are appropriate.

12.2.5 Use of soft limits
Soft limits may only be employed as convenience limits and shall not be used to replace hard limits or safety encoders as described in section **12.2.6 Use of safety encoders without limit sensors**.

12.2.6 Use of safety encoders without limit sensor
Applications should only use encoders without hard struck limit sensors when the hazard analysis and risk assessment determines that it is acceptable to do so.

12.2.7 Initial constraining sensor
The initial sensor shall be triggered before the travel of the load reaches the ultimate limit sensor.

The initial sensor shall present the stage machinery control system with a fault that prevents the user from continuing travel in the same direction. (see annex note)

12.2.8 Ultimate constraining sensor
The Ultimate Sensor shall protect the travel of the load before it reaches any physical object and causes damage to the machinery, load, or any fixed or temporary obstruction.

The Ultimate Sensor shall present the stage machinery control system with a fault that requires the control equipment user to perform a reset and bypass action. The bypass action shall prevent the control equipment user from continuing to travel in the same direction.

12.3 Machine constraints and protection*
In some cases, a machine may require additional sensors to prevent damage to the machine during normal operation. When these sensors are not the Initial or ultimate sensors these should be referred to as machine limits. (see annex note)

When required to protect the machinery from damage these sensors shall operate in the same manner as described in section **12.2.8 Ultimate constraining sensor**.

12.4 Speed constraints
Speed of the load in motion may be constrained by position sensors where required. When position constraining devices trigger changes in speed the stage machinery control system shall warn and inform the user of the speed change.

13 Protection of load path
The load path is any path that is traveled by the load attached to the stage machinery. Paths may be unrestricted space within the playing or backstage areas of the performance venue, or they may be restricted vertical or horizontal shafts, chambers, closets, coves, alcoves, interstitial spaces, storage rooms, or other space within the architecture of the performance setting, building, or temporary structure.

Load paths will be routinely protected by the attention of the stage machinery control system user and may also require safety devices to prevent the creation of hazards by restricting operation of the machinery under certain circumstances.

13.1 Access doors & hatches
Load paths that operate in or create confined spaces, or prevent personnel or public from avoiding the load in motion, shall be protected by electronic locks and/or signal processes that stop all motion to prevent harm.

13.2 Crossing load paths
Load paths that cross with others shall employ signal processing that ensures that the load paths are adequately aligned to allow the safe passage of cross-traffic.

13.3 Fall hazards
The creation of fall hazards is common in stage machinery operation. Lifts, trap doors, and other operational or scenic elements must be moved throughout performances.

The stage machinery control system shall provide adequate warning to users and personnel when fall hazards are present. The degree of warning required may differ during setup, maintenance, and dismantle from that of a performance. Regardless, it is imperative that warnings are included in any stage machinery control system that is employed with such features or equipment.

Additional administrative and engineering controls shall also be employed as covered or described in other standards.

13.4 Pinch or crush hazards
Pinch or crush hazards that cannot be mitigated by guarding shall be protected using machine control processes and signaling devices, such as an astragal on a stage lift edge.

13.5 Emergency egress hazards
Due to the nature of functional safety requirements that bring machinery to a safe and complete stop to remove all potential hazards caused by motion, there exists an opportunity to create a scenario where emergency egress may need to be considered.

In such cases other administrative or engineering controls may be required. Monitoring of such by the stage machinery control system may be essential to harm reduction.

13.6 Protection of artists and stage employees
Protection of artists and stage employees who perform their duties within the load path during normal operation of the stage machinery control system may require additional engineering or administrative controls that are not within the scope of this standard.

14 Local operation
Operation from a remote-control station shall not be possible when a user activates local operation.

14.1 Local machine disconnect

A means shall be provided to disconnect the machinery from the power source. Operation of the disconnecting means shall not expose the user to a hazard or create a hazard by changing the state of the disconnect.

The disconnecting means must be lockable in the off position.

The disconnecting means may be a multi-pole switch device or a multi-pole cord and plug. The selected disconnect means must be rated for switching the applied currents and voltages under load.

The disconnecting means shall remove motive power to the actuator and shall also prevent the release (opening) of the brake. The disconnecting means may include additional power poles for the brake coil or signal the stage machinery control system to prevent unintended release of the brakes.

14.2 Protection during service and maintenance

Remote operation of machinery shall be prevented during maintenance procedures.

A signaling or disabling device shall be placed at each machine to prevent remote control and signal the stage machinery control system that the machine is in maintenance mode.

Normal remote operations shall only be restored once the remote signaling device is returned to the normal operating position and faults created by the switching of operations cleared by the user.

14.3 Signal override (muting)

Local operation stations may include devices that enable the user to override machine constraining signals that force the machine into a fault or prevent a machine from operating. The stage machinery control system shall display warnings when signal override devices are in use.

It is recommended that the stage machinery control system prevent the return to normal operation until all signal override devices are removed or returned to an at rest condition.

14.4 Mechanical guards

The removal of machine guards shall be enunciated and, if necessary, prevent operation of the machine to which they are attached when deemed appropriate by risk assessment.

15 Stage machinery control system operation

15.1 Stage machinery control system commissioning

The stage machinery control system shall provide a competent person with functions to allow them to commission the machinery to meet with the needs of the application.

Commissioning steps should include but not be limited to the following:

- maximum and minimum operating speeds, loads, temperatures, accelerations, decelerations, current demands, etc.
- calibration of positioning sensors, load cells, speed sensors, thermal protection, etc.
- function mapping of position sensors

Machinery shall only be commissioned within the engineering restrictions and capabilities of the machinery and load being moved. The stage machinery control system shall not be configured to exceed the design intention of the machinery.

15.2 Operating modes

Operating modes may differ in the method of handling limits, special signals, speed, load restrictions, or load capacities.

15.2.1 Normal operating mode

Normal operating mode is that mode in which the machinery is ready to function as intended by the equipment design without the presence of fault.

When normal operating mode is selected, the user shall be able to operate the stage machinery control system within the designed limitations of the machinery and with all the protections in place to prevent harm to personnel, or damage to machinery, load, other equipment, and property.

15.2.2 Local operating mode
Refer to section **14 Local operation**.

15.2.3 Service/Maintenance mode
Refer to section **14.2 Protection during service and maintenance**.

15.2.4 Commissioning/Testing mode
Operation of the stage machinery control system during commissioning and testing shall be defined by the system manufacturer. Users shall recognize the risk(s) involved and take additional precautions when employing this mode of operation to prevent damage to property and harm to personnel.

15.2.5 Emergency operating mode
The need for and the methodology of Emergency operating mode shall be determined by risk assessment.

15.3 Machine start
Prior to starting any machine, advanced stage machinery control systems employing a PES shall perform a series of checks to ensure that the machine is ready for operation as intended by the application and design of the machine. These checks may be performed at any time prior to commencement of motion and may include but not be limited to:

- fault and error checks
- brake status
- status of available motive and brake power
- speed controller status
- encoder status
- state of the E-Stop System
- operating mode
- status of other devices or machinery

Should the status of any of the checkpoints not meet the criteria for a safe machine start, the start procedure shall be aborted, and the user informed of the failure to start.

15.4 Machine brake release (opening)
Fixed speed and variable speed machinery will have different stopping and braking characteristics. In both cases the machine must produce holding torque before the brake(s) is(are) released.

When controlling variable speed machinery, the stage machinery control system must ensure that the torque being produced by the speed controller is sufficient to hold the load in place with minimal motion. Motion caused by opening the brake in zero speed holding shall not exceed what is determined by risk assessment as allowable or within design tolerance.

15.5 Machine stopping and braking (applying)
Fixed speed and variable speed machinery will have different stopping and braking characteristics.

Upon removal of motive power supplied to fixed speed machinery:

- power to the brake or brake rectifier shall be removed simultaneously or within a defined set time as per the machinery designer/engineer’s requirements
- the machine shall coast until the mechanical brake is applied

Upon initiation of STOP on a machine controlled with a variable speed controller:

- the machine shall decelerate at a predetermined or programmable rate
- where the speed controller is capable of zero speed holding the load shall be stopped and held in place within the torque production limits of the speed controller
- where the speed controller is not capable of zero speed holding the speed controller shall continue to produce torque and minimal speed without dropping the load within the limitations of the speed controller

- upon reaching zero speed hold or minimum speed brake(s) shall be applied
- after a predetermined delay the speed controller shall be set to rest and power removed from the machinery actuator

During an E-Stop event the brakes shall be applied by a safety rated function of the stage machinery control system or a function independent of the, starter, electronic drive, PLC, or motion controller.

15.6 Machine reversing
When reversing the operating direction of a machine the stage machinery control equipment shall be designed to sequentially perform the action to prevent damage to the machine or the load in motion. Users and/or System Designers shall consult the machinery specifications or consult with the machinery designer, engineer, user, or other competent person with knowledge of the machinery capabilities and limitations.

15.7 Machine jogging (bumping or inching)
Stage machinery control system components shall be selected and, if required, programmed to allow bumping, or inching of the machinery. Where bumping or inching is not possible, the user guide shall provide instruction on how to apply engineering or administrative controls to achieve small movements of the load.

15.8 Holding position at zero-speed
When applying zero speed holding of a position the stage machinery control system shall:

- prevent position oscillations from exceeding 15% of the processed position encoder values required to travel one inch
- prevent the motor from thermally overloading
- warn the user when 20% of the duty cycle time has expired without normal motion occurring
- stop the zero holding function, return the speed controller to a resting state, and inform the user of the action when 50% of the duty cycle time has expired without normal motion occurring
- respond to a fault of the function in compliance with risk assessment
- report to the user the holding status of any affected machinery in the stage machinery control system

15.9 Load monitoring
The accuracy of the load monitoring feature shall not be required to be greater than the accuracy ratings of the load cell device provided by the machinery manufacturer or supplier.

Where thermal shift of load monitoring equipment has an opportunity to create a hazard due to erroneous load readings, steps shall be taken in accordance with risk assessment to mitigate the hazard.

15.10 Machine and control faults
Faults shall not lead to a hazardous operating condition(s).

15.10.1 Fault response
Fault response shall be suited to mitigate risk associated with the application and fault type, as determined by risk assessment.

In all cases of a fault the user shall be informed of the fault type, details, and be directed to available documentation or help features to aide the user in removing the fault and resetting for normal operation to resume.

15.10.2 Fault reset
The action of resetting a fault shall require direct input from the user.

15.10.3 Fault logs
Faults should be logged with a timestamp for recall by the user for troubleshooting.

15.11 Limits
See section **12 Constraining travel.**

15.12 Multi-motor applications

Multi-motor applications require additional consideration to protect the individual motor from causing harm during normal operation and under fault conditions.

15.12.1 Fault interlocks

The faulting of one motor, for whatever reason, in a multi-motor application shall prevent the operation of all other motors in the group unless the stage machinery control system and mechanical systems are designed to compensate for a motor failure.

15.12.2 Shared loading

Where the load must be shared, in any percentage relationship, between multiple motors a mismatched load shall cause a fault of the operation and bring all motors to a safe stop.

15.12.3 Individual overload protection

Each motor in a multi-motor application shall be protected as described in section **7.15 Motor overloads**.

15.13 User location

The architecture of the installation of a stage machinery control system shall allow for the user to have first-person visual contact with all loads in motion.

Manufacturers of stage machinery control equipment shall inform their users of the importance of first-person visual contact in their user guides and manuals.

Where the user is unable to gain first-person visual contact with the loads in motion due to constraints of the installation, a risk assessment shall be performed to determine the specifics of a secondary system for visual contact.

Acceptable means that may be used are:

- the use of a second user operating an enabling device connected to the HTR system
- cameras, lights, signals, or other visual means to ensure load paths are clear
- radio communications with an authorized person

No matter the means employed when first person visual contact is not possible, there shall be a procedural document detailing the safe movement of the load(s) in question.

16 PES user interface

In the context of this standard the a PES shall employ a control processor (computer, PLC, embedded computer, or other processing device), and software for communication with other devices to control the machinery, monitor inputs, monitor safety, and trigger outputs.

Interfaces may contain input devices that are physically manipulated by the control equipment user to provide instructions to execute the user's needs and intents of operation.

Interfaces shall include feedback devices that provide the control equipment user with information to make decisions on the safe operation of the PES, stage machinery, and loads in motion.

16.1 User windows and instructions

16.1.1 Alphanumeric displays

Alphanumeric displays have limitations in function. Details in section **16.1.2 On screen indicators** to **16.1.5 Pop-up windows** may not apply.

16.1.2 On screen indicators

On screen indicators shall provide users with up-to-date status of devices connected to the PES. The use of colors shall correspond with other uses of color in the PES.

16.1.3 On screen warnings and alarms

On screen warnings and alarms may be presented to the user using on screen indicators, pop-up windows, or other attention drawing techniques.

Indicators shall include an easily legible label using recognizable pictograms or in a language that is understandable to the user. Where short forms or special pictograms are employed the PES manufacturer shall clarify the details in the user guide or user manual.

Indicators may flash pending the requirements of the application or status of the device being monitored by the indicator.

16.1.4 On screen operators (buttons, sliders, dials, etc.)

On screen operators shall be sized large enough to prevent erroneous execution or mistaken press.

On screen operators shall not be used for safety critical operations without a risk assessment to determine the mitigating requirements to minimize the opportunity to create a hazard.

16.1.5 Pop-up windows

Where pop-up windows are employed, they shall not impede the function of the primary active window.

16.2 User input devices

User input devices shall include any device that is activated by the user to send an electronic signal to the PES.

16.2.1 Switch contacts

Switch contacts shall employ debounce techniques or circuitry to prevent erroneous recognition of multiple presses of the switch operator.

16.2.2 Switch operators

Switch operators shall be selected for reliability with a minimum active use rating of 250,000 operations.

16.2.3 Joysticks

Joysticks shall be selected for reliability with a minimum active use rating of 150,000 operations. Joysticks shall not be used for critical operations without a risk assessment to determine the mitigating requirements to minimize the opportunity to create a hazard.

16.2.4 Sliders

Sliders shall be selected for reliability with a minimum active use rating of 150,000 operations.

16.2.5 Indicator lamps

Indicator lamps shall be illuminated by low consumption LED. Where LED illumination is not possible dual lamp systems may be required in compliance with a risk assessment review of any hazards that may be presented due to a lamp failure.

16.3 Use of color for indicators and operators

PES design shall employ common practices in the selection of colors used for switch operators (mechanical or on screen) and indicators (mechanical or on screen).

PES manufacturers shall ensure consistent use of color throughout the system ensuring that both physical and electronically displayed functions utilize the same color.

It is permissible to vary shading so long as the shade does not create an opportunity for confusion by altering the intent of the response or action to a secondary color group (example – red shifts to pink).

The table below outlines the recommended use of color according to general industry norms.

Color	Meaning according to norms	Explanation	Description
Red	Fault/Failure/Error		
Yellow/ Amber	Abnormal/Warning	Signals the status of danger, alarm, or failure.	User attention required to monitor error or prepare to act
Blue	Obligatory	Indicates a condition that requiring User’s action	Obligatory activities

Green	Normal	Indicates normal or fault-free status	User should be aware that all functions are ready for operation
White	Neutral	Can be used if there is any doubt as to the use of above colors in a particular scenario/application	User shall monitor the status of the associated function.

The table below outlines the recommended use of color, specific to stage machinery control systems norms.

Color	Meaning according to norms	Explanation	Description
Red	STOP	Stops motion	Identifies operator from others that may be presented to the user
Yellow/ Amber	Abnormal/Warning	Signals the status of danger, alarm, or failure.	User attention required to monitor error or prepare to act
	Reset	Indicates and identifies reset operator	Reset required or identifies operator from others that may be presented to the user
Blue	Direction	Signals a direction of travel	User attention required to observe that the operating direction is intended
	Obligatory	Indicates a condition that requiring User's action	Obligatory activities
	Reset	Indicates and identifies reset operator	Reset required or identifies operator from others that may be presented to the user
Green	Direction	Signals a direction of travel	User attention required to observe that the operating direction is intended
	GO/RUN	Indicates the GO or RUN switch operator	User is guided to press this switch operator to initiate motion
	Normal	Indicates normal or fault-free status	User should be aware that all functions are ready for operation
White	Neutral	Can be used if there is any doubt as to the use of above colors in a particular scenario/application	User shall monitor the status of the associated function.

16.4 Use of flashing for user attention

PES designers and manufacturers should employ the use of flashing indicators (mechanical or on screen) or illuminated switch operators to draw the attention of the user and indicate the level of urgency for corrective action.

When employed, this practice shall be consistent throughout the PES and documented in user manuals and guides.

The table below outlines the recommended use of flash rates.

Rate of flash	Level of urgency	Explanation	User reaction
None	Low, normal	No alarm, user shall observe and take note	User shall monitor the source of the fault (if one is present) and take corrective action when safe to do so (*Note: applies to indicators when they are on or off)*
Slow	Low to medium	Level 1 alarm, user shall be on alert to take corrective action	User shall determine the source of the alarm, alert other stage personnel, and prepare to execute corrective action when safe to do so

(0.5Hz)			
Medium (1.0Hz)	Medium to high	Level 2 alarm, user shall take corrective action	User shall determine the source of the alarm, alert other stage personnel, and execute corrective action following safety protocols for such action
Fast (2.0Hz)	Very high	Level 3 alarm, user must take immediate corrective action	User must determine the source of the alarm and alert other stage personnel while immediately executing corrective action following safety protocols for such action

(Note: The intended level of urgency may be additionally punctuated by the selection of indicator color.)

16.5 User settings
The user Interface shall provide for multiple users to have access to the device with access limiting protections. The number of potential users is at the discretion of the PES Manufacturer.

16.5.1 Limiting access
User interface equipment shall be protected against unauthorized access and operation using key operated switch contacts, passwords, key cards, or another securing device.

Passwords, secure access devices or methods shall be associated with restrictions that prevent unauthorized users from accessing sensitive or safety related settings, specific machinery or functions, and any other data that requires specific training or demonstration of competency.

16.6 User preferences
The user settings function should record the preferences of specific users. Preferences should include but not be limited to:

- screen layouts and views, if adjustable
- colors of unrestricted view details, if adjustable
- user defined indicators or on-screen buttons, if adjustable
- username and password changes

16.7 Multiple User control interfaces
Where an installation is provided with multiple user control interfaces, there shall be interlocking hardware and/or software to prevent the simultaneous control of a hoist or group of hoists by more than one control station.

16.8 Groups
PES user interface software should provide for the creation of groups.

16.8.1 Synchronous groups
Synchronous groups electronically connect the position encoding equipment of two or more machines to match the positioning of the machinery within the group. Positions shall be maintained at a constant ratio throughout all parts of the movement.

Position ratios shall have a tolerance limit that monitors the position data to ensure alignment. Should the alignment reach values outside the tolerance the PES shall create a fault and respond accordingly. Tolerance limits shall be determined by risk assessment.

The triggering of any safety input or constraining sensor on one machine shall fault the other machines in the group.

All fault responses by the PES with respects to a synchronous group shall be determined by risk assessment and shall meet with the appropriate safety requirements of the selected safety standard for the application.

16.8.2 Fault groups

Fault groups electronically connect two or more machines within the PES for the purpose of cross referencing and triggering faults on the machinery within the group.

All fault responses by the PES with respect to a fault group shall be determined by risk assessment and shall meet with the appropriate safety requirements of the selected safety standard for the application.

16.8.3 Asynchronous groups

Asynchronous groups electronically connect two or more machines within the PES for user convenience. These groups may be used to create user views, set position targets, provide ease of monitoring, or any other function that does not include synchronizing position or creating faults.

16.9 Maintenance warnings and indicators

The PES may include a feature to track the use of machinery based on time or another quantifiable factor. Systems that employ this feature shall also present the user with warnings regarding the requirement for maintenance.

Warnings and indications of pending or overdue maintenance shall not affect the normal operation of the PES nor cause to draw the user's attention and create a hazard during normal operation. Rather, indicators shall direct the user to take additional steps at an appropriate time to view the maintenance notification.

16.10 Logging

The PES should have the capability of logging and storing operation data, with date and time stamps, for review by the user or service agent.

Logged data shall include but not be limited to:

- user information
- faults and fault sources
- execution of motion
- stopping of motion
- status and status changes of machinery controlled by PES
- errors
- user notes and troubleshooting instructions

16.11 Displays

Displays may be alpha-numeric or graphic pending the intent of the design by the PES manufacturer.

Sizing shall be selected based on the application and at the discretion of the PES manufacturer.

16.11.1 Touch screens

Touch screens may be selected pending the intent of the design by the PES manufacturer. They shall meet with the electrical and emissions standards and requirements of an NRTL as outlined in section **5 Listings, inspections, and certifications**.

16.12 Local and push button operation

Local user control stations may be temporarily affixed to a surface, mounted in a protective case, or held by the user.

Voltages used to power either the user control station, or the control signal, shall not exceed 120 volts for alternating current and 50 volts for direct current. User devices and chassis shall be isolated from errant voltages, and properly bonded to ground where required.

Direction selectors must be maintained or latching for at least the duration the GO/RUN or DIRECTION switch operator is being pressed.

Selection switch operators, regardless of function, shall be clearly marked so that the function of the selected position is obvious to the control equipment user.

All switch operators used in the execution of motion shall be protected from accidental activation or damage when the user control station is left unattended or is dropped for any reason.

GO/RUN or DIRECTION switch operators shall be actively held in the engaged position for motion to occur and shall be mounted in a comfortable and ergonomic operating position to ensure control equipment user comfort while reducing strain on the user's hands, arms, and joints.

GO/RUN or DIRECTION signal buttons and switches shall be able to withstand the physical and electrical effects applied to them by the practice of bumping/inching.

17 Interactions with other systems

Stage machinery PES should be capable of communicating and interacting with other systems within the performance venue environment.

This connection may be done via input/output controllers, digital communications, or other third-party control or communications platforms.

17.1 Multiple user stations – common platform

Where multiple user stations of the same PES manufacturer are employed as part of a stage machinery control installation, the PES shall prevent the simultaneous operation of any control device from more than one user station.

User stations shall share input data, positioning, status conditions and any other data collected by the PES on the machinery control devices based on the results of the risk assessment. The risk assessment in this case shall determine the data that is required to be shared and any response, if required, by the PES or the individual user stations in accordance with the selected safety standard for the application.

17.2 Multiple user stations – uncommon platform

Where multiple user stations of more than one PES manufacturer are employed as part of a stage machinery control installation, the systems may be required to share data in accordance with the risk assessment.

The details of what data should be shared and what the response to the data shared, sent, and received between the user stations shall be in accordance with the selected safety standard for the application.

Data may be shared via analog format using digital inputs and outputs or via a common communication protocol. Where communications protocols are used the parties involved shall agree upon the communication standard.

17.3 Other disciplines

There are many disciplines within entertainment applications. When required to do so the PES manufacturer shall connect to these other disciplines using acceptable industry standards.

Applicable communication standards may include those published by ESTA, IEEE, or other standards organizations.

PES manufacturers shall follow the standards to provide the connection between the PES and other disciplines and shall also apply a risk assessment to determine best practice for handling, responding, and checking the data sent and received.

Additional engineering and/or administrative controls may be required to ensure the safety of users and personnel working within, around, or as part of the application.

18 Touring or temporary applications

The act of moving equipment for the purpose of touring or temporary applications imposes physical strains on equipment that are not seen in permanent installations. These forces shall be accounted for in the design and steps taken to minimize the effect they impose on terminations, mounting, and reliability.

Equipment shall be designed to provide opportunity for a factory trained service person to access field serviceable parts without exposing the service person to additional hazards.

18.1 Electrical enclosures

Electrical enclosures for touring applications require design considerations that differ from permanent installations.

Enclosures shall employ input power connectors that qualify as suitable for disconnect under load. Panels that are painted and mechanically fastened together shall be individually bonded to protective earth.

Panels to which connectors are attached shall be of a thickness and structure to prevent connector fasteners from loosening or the panel being bent or damaged during normal use and life expectancy.

Vents shall be designed, positioned and sized to prevent opportunity for external objects from coming in contact with exposed electrical contacts.

Stage machinery control system manufacturers shall consider dust and dirt controls to prevent components from exposure to same.

Stage machinery control system manufacturers shall assemble and test the completed components to applicable standards as defined by an NRTL as outlined in section **7 Electrical Equipment**.

When used in outdoor applications or where touring electrical enclosures are exposed to external naturally occurring or manmade elements, additional controls shall be applied to reduce or limit hazards.

Enclosures should require tools to access components that expose the user or service personnel to shock hazards.

Additional labels may be required to identify risks that the user or service personal may be exposed during use or service.

18.2 Roadworthiness

Stage machinery control equipment for use in portable applications, such as tours or temporary installations, shall be designed and manufactured to be “road worthy”. This requires the manufacturer to consider, but not be limited to, the following:

- aggressive use
- impact and drop resistant
- frequent plugging and unplugging of connectors
- higher than anticipated operations of switch operators
- protection of switch operators from inadvertent physical strikes or erroneous operations
- labels that are resistant to peeling, fading, or being rubbed off

18.2.1 Shock mounting

Components of the stage machinery control system should be mounted in shock absorbing cases, racks, or frames to prevent damage while in transit.

18.2.2 Protection against loose connections

Stage machinery control equipment and PES manufacturers shall select connection devices and termination procedures to ensure that connections do not become loosened during transit periods. These controls may include, but not be limited to, selection of cage clamp style terminals, soldering, or confirming appropriate torque is applied to screw terminations.

Control equipment and manufacturers shall create testing procedures and apply them to test the robustness of terminations. These tests may include applying stress to the completed device, or an identified sample of the device, through vibration or dropping.

18.2.3 Service and inspections

Service and inspection of stage machinery control systems shall only be performed by authorized competent persons.

Devices shall be inspected prior to reconnection after being moved from one location to another even if that location is within the same venue.

18.2.3.1 Cable service and inspections
Cables should be inspected before use for signs of wear, insecure cable clamps or other damage. Damaged cables shall be removed from service until they are inspected and/or repaired by a qualified service technician.

18.2.3.2 Control devices service and inspections
Control devices shall be inspected for signs of wear, damaged connectors, arching, burns, loose hardware, damaged switch operators, damaged indicators, unusual odors, and any other inspection point as recommended by the stage machinery control system manufacturer.

18.2.3.3 User interface devices service and inspections
User interface devices shall be inspected for signs of wear, damaged connectors, arching, burns, loose hardware, damaged switch operators, damaged indicators, unusual odors, and any other inspection point as recommended by the stage machinery control system manufacturer.

19 Manuals, guides, & documentation
The stage machinery control equipment and PES manufacturer shall provide documentation to aid in the operation, maintenance, troubleshooting, inspection, and repair of the equipment.

Documents shall include but not be limited to:
- operation overview
- installation and use overview
- circuit diagrams (except for those that may expose the manufacturer's intellectual property)
- pin assignments and part numbers of all connectors
- recommended cable types for attaching external remote-control components
- service, maintenance and troubleshooting information
- inspection methods
- detailed list of user serviceable parts
- warnings and safety instructions
- listing or inspection certificates from a testing body

In the best interest of environmental policy, the recommended format is digital, but print format may be preferred.

20 Inspection and maintenance
Stage machinery control equipment and PES manufacturers shall provide users with instructions on inspection and maintenance, so that they may be included in the user or equipment owner's inspection and maintenance routine. Instructions shall include recommended procedures, frequency, tool requirements, and mitigation steps to prevent damage to the equipment.

20.1 Authorized repair process
Stage machinery control equipment and PES manufacturers shall identify user serviceable parts and provide detailed instructions on the process to repair or replace those parts.

Stage machinery control equipment and PES manufacturers may provide additional instructions at their discretion.

20.2 Voiding of warranty*
Stage machinery control equipment and PES manufacturers shall provide explicit detail on any inspection or maintenance activity that may void the user's warranty. (see annex note)

20.3 Inspection requirements
The requirements set forth below establish the minimum criteria for inspection that are to be included in the stage machinery control equipment and PES manufacturer's documentation for inspection.

20.3.1 Performance of inspections
Stage machinery control equipment and PES manufacturers shall provide detail on the training required to allow the person performing the inspection to be competent at the task.

Where tools are required to perform the recommended inspection task, the PES manufacturer shall identify the tool by the function or common tool name. (As an example – multimeter, #3 Phillips tip screwdriver.)

20.3.2 Inspection frequency

At minimum, stage machinery control equipment and PES manufacturers shall recommend users or equipment owners to inspect equipment before and after each period of use and when returning it to storage, in whole or in part.

Additional inspection frequencies may be recommended at the control equipment and PES manufacturer's discretion.

20.3.3 Corrective actions

Control equipment and PES manufacturers shall provide users or equipment owners with recommended steps to take to correct problems discovered during an inspection.

Details shall include, but not be limited to:

- determination of severity of the problem
- removal from service, if required
- steps involved with servicing or repairing the problem
- the skill level required to service or repair the problem
- steps to determine if the problem can be user serviced or if it requires manufacturer's service

All corrective actions shall be performed by competent persons who have been thoroughly trained in the skills required to perform such corrective actions.

20.4 Preventative maintenance

Users shall be instructed on preventative maintenance procedures such as but not limited to:

- tightening of fasteners
- cleaning of contacts, parts, fans, dust grills, etc.
- removal of corrosion when present
- paint touch ups
- label replacement
- environmental restrictions

Annex A – explanatory information

A2.1 References – ESTA Standards. At the time of writing additional ESTA standards related to stage machinery were in progress but not yet accepted by the committees or ANSI.

A3.12 class 2 circuit. Class 2 Circuits supplied by listed Class 2 power supplies are accepted as safe from electric shock and risk of fire by the NEC and UL508A. They present an easy way to provide "safe" control circuits where the device is simple or LVLE does not apply. Users should be aware and ensure that they are not misusing a Class 2 power supply by placing it into an application that requires a greater level of protection from environmental conditions or hazards.

A3.17 drive. VFDs alter the speed of an AC motor by varying the frequency to the motor.

VSDs alter the speed DC motors by varying the voltage to the motor.

Servo systems vary the current and voltage supplied to the motor.

A3.32 Low Voltage Low Energy (LVLE) Circuit. For more information on the requirements for the design and application of LVLE circuits refer to UL508A Section 43.

A4.1 Risk management – basic steps of risk assessment. The risk assessment may be one large document or multiple documents covering the different uses or operating modes of the machine.

Risk assessment and hazard determination are ongoing activities as conditions change. Hazards that were once unlikely may become probable as equipment ages, stage employees and artists become complacent, or the equipment or scenery changes. Risk reduction solutions that were initially addressed may become inadequate or outdated.

In its simplest form, a risk assessment answers the question “What if...?”

The foundation of risk management is the establishment of process for risk assessment. That process should include, but not be limited to, the following six steps.

- Establish a Risk Management Framework
  - Timeframe and frequency of assessment
  - Acceptable levels of risk
  - Methodology: scenario or asset-based risk assessment
- Identify the affected parties
  - Those identified as users of the stage machinery and/or control equipment
  - Those working with or attached to the stage machinery during normal operation
  - Those working with or attached to the stage machinery during unusual operation (testing, service, maintenance)
  - Those who are bystanders to the stage machinery during normal operation
  - Those who are bystanders to the stage machinery during unusual operation (testing, service, maintenance)
  - Those who are bystanders to the load carried by stage machinery during normal operation
  - Those who are bystanders to the load carried by stage machinery during unusual operation (testing, service, maintenance)
- Identify the risks
  - Involved in the operation of the stage machinery in performance
  - Involved in the operation of the stage machinery during setup/dismantle/service
- Analyze all identified risks
  - Risk to property
  - Risk to personnel
    - Minor injury
    - Recoverable injury
    - Permanent injury
    - Death

- Evaluate the risks and assign a score
  - Most risk assessment matrices look like this. One axis representing the probability of a risk scenario occurring and the other representing the damage it will cause.

		Severity				
Probability		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Extreme (5)
	Very Unlikely (1)	1	2	3	4	5
	Unlikely (2)	2	4	6	8	10
	Possible (3)	3	6	9	12	15
	Probable (4)	4	8	12	16	20
	Very Likely (5)	5	10	15	20	25

Sample risk assessment Table

Low risk 1 – 3
Moderate risk 4 – 8
High risk 9 – 14
Extreme risk 15 – 25

- Select risk treatment options.
  - Avoid the risk by eliminating it entirely
  - Modify the risk by applying security controls
  - Mitigate the risk by applying process or management
  - Retain the risk (if the risk falls within established risk acceptance criteria)

The above "Sample risk assessment Table" is one of many possible risk assessment tables. Different tables will have different number ranges and different criteria for separating different risk levels, but all serve the function of helping with a risk assessment by ranking the risk levels of various hazards. By ranking the risks in an organized manner, the user may develop an agenda for mitigation.

As can often be the case at the inception of an application of stage machinery, there is little reliable accident data available. However, it is important to put forth a concerted effort to conduct risk assessments where needed. Leveraging experience or simply approaching the process on an intuitive basis will often allow an understanding of the task.

Additional sources of information can assist in identifying where a risk assessment is most needed or needs to be repeated. Sources such as internal incident and accident reports, OSHA 300 log data, and insurance claim/loss information can all be sources that can be used to identify injury trends and may also identify trends from both a frequency and severity of injury perspective.

A5 Listings, inspections, and certifications. Below are some of the labs that are Nationally Recognized Testing Laboratories for electrical components. Their common “also known as” names are listed for clarity in support of this standard.

- Underwriters Laboratory (also known as UL)
- Canadian Standards Association (also known as CSA)
- QPS Evaluations Services Inc.
- Electrical Safety Authority (also known as ESA)
- Intertek Testing Services NA, Inc. (ITSNA)
- Technischer Überwachungsverein, (English translation: Technical Inspection Association, also known as TÜV Rheinland, or TÜV)

Type ratings for enclosures specifically refers to the environmental rating as determined by UL50E and is the only acceptable rating for UL508A panels; NEMA ratings are not acceptable. UL does not permit the listed mark for enclosure to appear on any nameplate or label except the listing sticker. This is typically applied inside the enclosure.

A7 Electrical equipment. It is important to note that under UL508A it is possible to list a panel as either "Industrial Control Panel" or "Industrial Control Panel for Industrial Machinery". The former requires adherence to Sections 1-61 of UL508A. Should the control equipment manufacturer determine that their assembly is an ICP for Industrial Machinery they must also adhere to sections 65-67 of UL508A, which has been derived from NFPA79.

Control equipment manufacturers may voluntarily choose to follow NFPA79 and/or sections 65-67 of UL508A for two reasons: 1) to align their design, construction practices, listing, and labeling with IEC60204-1 and 60204-32 that are commonly used in the UK/EU follow for their control panels, and 2) to apply best practice for panel construction when it comes to door interlocking and wire coloring.

A7.3.1 Nameplate labeling. This format follows the nameplate requirements prescribed by UL508A and provides the information a qualified person needs to correctly connect a piece of equipment to the power distribution system.

The SCCR rating is required by:

- NFPA 70 Article 110.10 (Circuit Impedance, Short-Circuit Current Ratings, and Other Characteristics)
- NFPA 70 Article 409.22 (Industrial Control Panels) and in turn UL508A
- UL508 (Motor Controllers)

More importantly, identification of SSCR ratings on the nameplate label is required as part of electrical safety programs under NFPA70E and OSHA 29CFR1910.303(b)(4).

Matching the SCCR of a piece of equipment to the available fault current is of the utmost importance. If a motor controller is only rated for 10kA and it is attached to a large distribution system with an available fault current of 25kA, an electrical fault could create a hazard capable of causing serious harm. The presentation of this information provides a qualified person with the information to determine if it is electrically safe to utilize the equipment.

SCCR Ratings for Industrial Control Panels and packaged motor controllers that are used to operate stage machinery can be calculated based on the ratings of components contained within by using UL508A Supplement SB.

A7.8 Phase loss protection. A phase may be lost during a weather event or through aging or faulty wiring in the building that houses the stage machinery control system

A7.9 Phase rotation protection. A phase rotation error may occur during maintenance of the electrical infrastructure of the building that houses the stage machinery control system

A7.10 Control power. UL508A allows for a power supply to be used at 100% ampere rating as long as the supply has been Temperature Tested in accordance with the UL508 Standard for Industrial Control Equipment.

A7.17 Encoding & position sensing. Restoration of lost positioning requires a procedure that ensures the user is able to confirm the restored position is accurate. Restoration of lost position data may be performed via homing sequence or by reloading position data stored or backed up to a secondary device or in non-volatile storage.

The use of analog encoding systems on stage machinery is not recommended.

A7.20.4 Mounting position. Of particular concern is the mounting position of spring actuated devices such as contactors that are only approved for mounting in specific orientations.

The mounting position of heat generating components and the cooling airflow required shall also be observed.

A9.6 E-Stop activation. It is important that the activation of an E-Stop event does not create an additional hazard. Users are required to evaluate the use of E-Stop categories to ensure that:

- the load will not become detached from the media being used to suspend, pull, push, lift, manage, or rotate the load
- the load will not be uncontrollable and encounter other immobile objects or surfaces
- the load in motion will not launch or otherwise project objects that are part of or loosely attached to the load

A9.8 E-Stop lockout. Locking Emergency Stop devices are not an allowable substitute for Lock-Out / Tag-Out (LOTO) procedures as directly clarified by OSHA. Users should consult OSHA requirements when planning, documenting, and performing training of a LOTO program.

A9.10 E-Stop categories – selecting a stop function. Once the risk assessment is complete, consider these points:

- If the machinery does not have a significant amount of inertia, meaning it won't coast more than a very short time, then a Category 0 stop may be all that is required.
- If the machinery can coast when power is removed, or if the machinery can be stopped more quickly under control than when power is simply removed, then a Category 1 stop is likely the best choice, even if the power-off coasting time is short.
- If the machinery includes devices that require power to keep them in a safe state, then a Category 2 stop is likely the best choice.
- If you choose to use a Category 2 stop, be aware that leaving power on the machinery leaves the user open to hazards related to having power on the machinery. Careful risk assessment is required in these cases especially.
- Category 2 stops may not be permitted for E-Stop functions pending review by the local AHJ. There is an option to use a Category 2 stop if it can be justified by the risk assessment.

A9.12.1 Machine stop operators. Alternatively, the operator may be red with "EMO" (Emergency Machine OFF) across its face.

A10 Hold-To-Run (HTR). Hold-To-Run devices are commonly referred to as "deadman devices" or simply "a deadman". The term, deadman, was used in the past to identify a device that would automatically release the operating mode of a machine if the user became incapacitated.

In the context of this standard the correct term is Hold-To-Run wherein the user holds the HTR device to allow the operation of the machine and is therefore entrusted with the task of ensuring the operation remains safe. Should an unsafe operating scenario occur the user has the resources to stop operation by releasing the HTR.

"Deadman" was also identified as outdated and archived to respect social norms and political correctness as of the writing of this document.

A11 Signal termination. A damaged wire on a sinking signal that shorts to ground may create a false trigger of that signal.

A12 Limiting Travel. Some stage machinery may not require travel limiting switches or sensors. These may include, but not be limited to:

- Certain types of curtain machines
- Continuous rotation machines
- Certain types of stage effect machines

Machinery that utilizes a drive system that relies on friction may need a switch or sensor that causes the control system to execute a routine to reset the "start" position to a known value.

A12.2.1 Sensor selection. Sensors may be selected based on the following criteria:

- media being identified
- restrictions of contact
- exposure to environmental conditions
- exposure to accidental activation or damage

A12.2.7 Initial constraining sensor. It is allowable for the fault that stops the machinery upon the striking of an initial constraining sensor to auto reset.

A12.3 Machine constraints and protection. An example of this would be a performer winch that is configured for a range of travel between stage floor and grid, yet still has capacity on the drum to travel further. In this instance, the regular set of sensors are configured to limit the piece/performer being hoisted to within the normal range of motion, and a second mechanical sensors is used to protect the machine from damage if it were to overtravel beyond the mechanical limitations.

A20.2 Voiding of warranty. An example of an activity that may void a warranty is a situation where a user detects a loose component inside a controller or decides on their own accord to test the torque on terminal screws thus requiring them to open the controller and potentially voiding their warranty.