Machine safeguarding refers to the requirements, equipment and methods used to protect people who operate or come in contact with dangerous machines.

Machine safeguarding is a critical part of any safety program and benefits workers, manufacturers and employers at several levels:

- It reduces lost work days due to injury (resulting in higher productivity),
- It minimizes liability for the employer, and
- It can demonstrate an employer’s compliance with safety standards to the appropriate regulatory agencies.
- OEMs who incorporate safeguarding into their machines enjoy a ready market for their easy-to-use, pre-integrated machines, coupled with reduced liability, because they can control safety system integration.

While the benefits of safeguarding are obvious, developing a machine safeguarding strategy can be daunting. Given the variety of machine designs, coupled with varying levels of operator and maintenance personnel interaction and compounded by the many standards and regulations to reference, machine safety implementation can easily overwhelm those involved in the process.

A Practical Guide to Machine Safeguarding

Introduction
National, Regional and International Standards Systems

Safety standards come under the heading of international, regional and national standards systems. The combination of standards and regulations that apply in each case will depend on the goals of those responsible for machine safeguarding. For instance, an OEM shipping machinery to several countries may need to consider international, national and regional requirements, while an employer safeguarding the machinery in a single plant may be more concerned with corporate specifications and local requirements.

There are two main types of standards that deal with machine safeguarding:

- Application standards, which deal with applying safety devices to machinery, and
- Product-specific standards, which define how safety devices themselves must perform.

While the basic structure and principles of the standards systems may be similar, they will usually have some important differences. Many standards agencies are working toward uniformity, and some standards systems already have been harmonized with one another.

Harmonization of Standards

In all areas of standardization – including machine safety – standards systems continue to move toward harmonization. Emerging nations embrace existing international standards rather than developing their own. Industrialized nations continue to align with or adopt standards from the international system. In the United States, ANSI encourages its members to evaluate equivalent international standards prior to drafting new ANSI standards, and significant adoption and harmonization has taken place between organizations such as UL, IEC and NFPA. Additionally, nationally recognized testing laboratories (such as UL) have established reciprocal arrangements with other labs and standards bodies throughout the world in order to simplify the process of product certification for international markets. The result has been that EN standards are accepted (often with little change) and republished as IEC standards. (One example is the progression of EN50100 into IEC 1496 and finally into IEC61496-1, Safety of Machinery – Electro-Sensitive Protective Equipment.)

A major key to understanding the world of international standards is to first understand the players.

The countries in the European Union (EU) have been developing standards for a number of years; the process was already in high gear well before the EU was a reality. As a result of their early and thorough coverage of the subject, European standards have had significant influence on international machine safety standards. In effect, when national systems and certification organizations harmonize with international safety standards, they also are harmonizing with Europe.

The advantage is that users may now obtain safety equipment from a variety of international sources that are designed and certified to strict standards. But while much harmonization has already taken place around the globe, it is important to remember that the “law of the land” in any nation may well be different than the EN or IEC standards. Individual government requirements may cause confusion for those who install safety products designed for an international market.
Machine Safeguarding Standards and Regulations

United States Standards System Structure

Formal relationships between OSHA and ANSI (via a Memorandum of Understanding) and UL (through accreditation) create the primary machine safety structure for the US.

In the US, standards regarding the use and design of personnel safety devices are regulated by the Occupational Safety and Health Administration (OSHA). Founded in 1970, this governmental body defines and enforces requirements for maintaining a safe workplace environment. Prior to the existence of OSHA, industry relied upon voluntary industry consensus standards developed by organizations such as the American National Standards Institute (ANSI) and Underwriters Laboratories (UL). OSHA recognizes the voluntary consensus standards developed by US industry through coordination with ANSI, and grants accreditation to test laboratories, including UL. OSHA also encourages the use of certain standards developed by consensus standards bodies and recognized test labs. For instance, OSHA requires “appropriate” guards to be installed on a machine, but it does not develop guard design or machine design standards. OSHA does not certify equipment, devices or installations for compliance.

ANSI (a private, non-profit organization founded in 1918) gave the US its first standard relating specifically to machine safety in the workplace. ANSI B11.1-1926, Mechanical Power presses – Safety Requirements for Construction Care and Use, is the US precursor to all machine safety standards developed since. ANSI does not develop standards; it oversees standards development by voluntary consensus bodies, such as the Association for Manufacturing Technology (AMT), the Robotic Industries Association (RIA) and the National Fire Protection Association (NFPA). When a standard meets ANSI requirements for industry consensus and content, ANSI adopts and publishes it. Designing to comply with ANSI is a common method of demonstrating product conformity, but is not mandatory. As is the case with OSHA, third-party certification to ANSI machine tool standards is, for all practical purposes, non-existent.

While most United States machine safety and related standards are associated with OSHA and ANSI, independently operated Nationally Recognized Test Laboratories (NRTL) also develop support standards. NRTLs are recognized and accredited by OSHA for their ability to adequately test and certify products. Underwriters Laboratories (UL) has been most active in the development and adoption of pertinent standards for safety device certification.

UL is a private, not-for-profit organization founded in 1894 to test devices, systems and materials for hazards to life and property. UL develops standards specific to types of devices. Thus, where ANSI is concerned with applications at the machine level, UL usually takes a narrower view, toward issues related to the manufacturer of a specific item or device.

Each organization plays a specific role in supporting machine safety, and formally recognizes standards from the others. State and local codes in effect for the machine’s installation location must also be considered.

Unlike other national and regional standards systems, the United States does not have an approved entity that can certify fully integrated and installed systems for safety compliance. The responsibility of ensuring compliance falls to the employer, installer and/or OEM.

The lines can appear to blur between OSHA (a government agency) and ANSI or UL (industry consensus organizations). To simplify the role each organization plays today:
• OSHA is the enforcement agency that requires employers to provide a safe work environment. OSHA regulations direct employers to use machine-level and device-level standards from appropriate standards bodies.

• ANSI facilitates the development of standards that give guidance for applying safety at the machine level. The ANSI B11 series standards cover a variety of machine tools types, including its first machine safety standard, B11.1 *Mechanical Power Presses*, originally drafted in 1922.

• UL develops and adopts standards relating to performance and testing requirements of safeguarding devices.

Performance requirements for safeguarding devices are distinctly different from those for other industrial electrical apparatus. Specifically, OSHA and ANSI historically have required safety systems and devices to arrest hazardous motion even in the event of a failure within the safety system or device. The most common method used to achieve this high level of performance is to design redundancy and self-checking functions into the safety system or device.

**United States Standards**

The concept of control reliability is the very essence of personnel safeguarding in the United States. OSHA 1910, section 212 requires machine operators and other employees in the area to be guarded from the hazardous action of machinery; further discussion in section 217 clarifies that this is the employers’ responsibility. ANSI B11 standards also highlight the responsibility of the employer to provide redundant, self-checking protection for those who work around hazardous machinery.

Currently, the US has only a few specific design standards in place for safety systems. UL is the only agency currently publishing safety product design standards, most of which were developed in the past few years. Most useful to manufacturers are UL 991 *Tests for Safety-Related Controls Employing Solid-State Devices*, UL 61496-1 *Standard for Electro-Sensitive Protective Equipment, Part 1: General Requirements*, UL 61496-2 *Standard for Electro-Sensitive Protective Equipment, Part 2: Particular Requirements for Equipment Using Active Opto-Electronic Protective Devices (AOPDs)*, and UL 1998 *Standard for Safety-Related Software*. In addition, basic standard UL 508 *Industrial Control Equipment* ensures that the device is electrically safe from shock or fire hazard.

**State and Federal Regulation – OSHA**

Nationally, two OSHA regulations for machine safeguarding (Title 29, Part 1910, sections 212 and 217) recently appeared in a top-ten list of most-frequently-cited violations. Section 212 addresses the general requirements for all machines, while section 217 focuses on the mechanical power press. Beyond this “law of the land,” a number of standards cover the application of safety equipment on specific types of machines.

**Voluntary Consensus Standards – ANSI, NFPA**

ANSI B11 standards provide the greatest depth of information on the widest variety of machinery, with machine-specific safety standards (such as ANSI B11.1, *Mechanical Power Presses*) to guide the machine designer in establishing a safety strategy. They are the best first source of information about a point-of-operation application for an employer.

One key standard for the application of safeguarding devices is ANSI B11.19 *Safeguarding when Referenced by the Other Machine Tool Standards*. ANSI B11.19 is a general guide to safeguarding and should be considered a supplement to the specific machine tool standards described above.

The Robotic Industries Association (RIA), together with ANSI, developed ANSI/RIA R15.06, which outlines safety requirements for industrial robots and robot systems. The standard is invaluable in providing information in robotics applications.

The National Fire Protection Association (NFPA) has issued a general Electrical Standard for Industrial Machinery (NFPA79), which also
Machine Safeguarding Standards and Regulations

Introduction provides application information. NFPA79 has historically been used as the basis for many other standards worldwide, and is often used as a normative reference.

The European Union

The European community has created a useful harmonized regional standards system in support of its unification efforts. In the 1980s, key nations in Europe recognized their eroding position in the global economy. Among the contributing factors, goods could not move freely across borders within Europe and trade was shifting to the United States and the Pacific Rim. The creation of the European Union (EU) addressed those concerns by implementing steps to reduce European trade barriers and by creating a harmonized standards system among member nations. This harmonized standards system required foreign manufacturers to adapt product designs to comply with EU standards and directives (in effect, protecting the European economy). Because the EU requires adherence to their standards for machines imported into EU member nations, a US firm building a piece of packaging equipment for European export must satisfy not only US requirements, but also the applicable EN or IEC requirements.

Today, it is difficult to find products that are not labeled with the CE mark, indicating compliance to European requirements.

Machine Directive

No standard or piece of European legislation has had more impact on machine safeguarding than the Machine Directive (98/37/EEC). In effect, the Machine Directive (MD) requires machines and safeguarding devices shipped to EU countries to meet essential health and safety requirements. In many cases, the machine or safeguarding device must be third-party tested for compliance by an EU-approved entity (a “Notified Body”). European Directives are laws that establish general requirements; they are not specific standards that support designers in their effort to comply. A product is proved to be in compliance with the appropriate directives after it has been tested to specific standards.

European Standards

For machine safety, the EU has developed a comprehensive system of standards that specify safety principles and requirements. Under contract by the EU, two organizations, the Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC), have been chiefly responsible for coordinating the development of machine safety standards. Four basic types of standards are used to implement machine safety:

- Type A - Basic principles for all machines
- Type B1 - Specific procedural or safety aspect
- Type B2 - Specific safety device design
- Type C - Specific machine requirements

A machine manufacturer may need all four types of standards to implement safety into its design. For instance, a press manufacturer may use:

- EN 693 Hydraulic Presses as a machine (C) standard,
- EN 1050 Risk Assessment as a basic (A) standard,
- EN 954-1 Safety Related Parts of the Control System as a safety aspect (B1) standard, and
- EN 574 Two-Hand Control as a safety device (B2) standard.

Because the European machine safety standards are so thorough, they have been routinely adopted at international, national and corporate levels. Both industrialized and emerging nations have embraced
Machine Safeguarding Standards and Regulations

harmonization with European standards to promote world trade and reduce duplication of effort.

(The prefix “pr” designates that a European Norm is in its preliminary form.)

European Certification and Documentation

Product manufacturers shipping to the EU must undergo a prescribed conformity assessment process before affixing the CE mark. This conformity assessment may entail:

- Designing to satisfy a particular Directive and a specific set of EU standards,
- Self-testing the product to ensure compliance, and
- Assembling a Technical File with documentation that proves compliance.

The Technical File typically includes instructions, drawings, test data, certifications and procedures; the manufacturer or its authorized representative must maintain it for review, should authorities ever question product conformity. A nonconforming product can result in fines and/or forced withdrawal from the market.

Some products may require third-party certification. Third-party certification requires, at minimum, an EU-approved Notified Body to validate the manufacturer’s Technical File. In some cases, the Notified Body will perform specific testing before providing an EC-type examination certificate or certificate of adequacy. The Machine Directive requires many types of machinery and complex safety devices to be Notified Body-approved, and also requires a document (a “Declaration of Conformity”) to accompany all CE-marked products. (In the case of personnel safety devices, such as safety light screens and safety modules, mandatory certification is required.) The Declaration of Conformity lists the product’s make, type, standards applied and the manufacturer’s name and address.

The CE mark is a mandatory administrative mark that assures free movement of products within member nations of the EU. Basically a “ticket of admission,” this mark is a sign from the manufacturer that the requirements of relevant directives have been met, and that the required conformity assessment procedures have been carried out.

International Standards

The topic of international safety standards is confusing, because each country has its own safety guidelines.

Harmonized international standards benefit manufacturers by allowing access to many markets with one design, while users enjoy competitive products that meet uniform quality and functional requirements – regardless of where they are made. Two international entities, the International Electrotechnical Committee (IEC) and the International Standardization Organization (ISO), play a significant role in machine safety. Regional and national systems in each participating market can influence international standards development through formal relationships. In the United States, this involvement is coordinated by ANSI through its Technical Advisory Group (TAG), supervised by the United States National Committee (USNC) and International Advisory Committee (IAC). Similarly, CEN and CENELEC coordinate European Union participation at the international level.
Introduction

Machine Safeguarding Standards and Regulations

Safety System Performance

The performance integrity requirements for safety system controls are different from those used in production and quality system controls. In many cases, the safety control system (including components such as safety devices, relays, actuators and the wiring between them) must default to a safe state in the event of failure(s) within the safety control system.

To accomplish the high integrity requirements of safety system design, redundancy and self-checking functions are incorporated for back-up and to detect component failures that may occur. Failures may include shorted or open wiring circuits, welded or shorted circuit components, power failures, electrical or magnetic disturbances, or stuck valves. Depending on the level of risk associated with the machine or operation, an appropriate level of safety control circuit performance must be incorporated into the design. Standards that detail safety system performance levels include ANSI/RIA R15.06 - 1999, Safety Requirements for Industrial Robots and Robot Systems and EN 954-1 Safety Related Parts of Control Systems.

Safety Circuit Integrity Levels

Safety control circuits have been segmented into categories, depending on their ability to maintain their integrity in the event of failure(s). The most recognized standard detailing machine safety system design integrity levels is ISO 13849-1 (EN 954-1) Safety Related Parts of Control Systems, which establishes five levels: the lowest, Safety Category B to the highest, Safety Category 4.

In the United States, only one well-defined level of safety system integrity has been defined: control reliability. Typically, both ANSI and OSHA have associated control reliability requirements with the point of operation of machines, where operators feed and remove parts. Control reliability typically incorporates redundant control and self-checking circuitry to maintain a safe working environment. Redundancy ensures that a single failure cannot prevent the safe stopping of the machine, and self-checking ensures that a safety critical fault that does occur is detected so the safety system can react properly.

Because a Safety Category 4 application typically requires the use of both redundancy and self-checking, it is often equated to the US standard of control reliability. One major difference must be noted, however: in a Safety Category 4 application, the requirement is to detect a fault at – or before – the next demand on the system. Control reliability allows the fault detection during the next demand on the system, as long as the system can still safely stop the hazardous motion. Thus, a Safety Category 4 application will always meet the requirements of control reliability, but the reverse is not necessarily true.

If an application meets the guidelines for a lower level of safety by EN definitions, those devices may not meet legal requirements in the United States. Recently, however, ANSI/RIA R15.06 - 1999, Safety Requirements for Industrial Robots and Robot Systems has detailed both risk assessment and multiple levels of safety system integrity, the lowest referred to as a Simple system and the highest a control reliable system.
Introduction

Machine Safeguarding Standards and Regulations

The following general descriptions of safety circuit integrity levels are not specific to any standard. The general rule: with increased risk of injury comes a higher demand on safety system integrity.

**Basic:** May use non-safety-rated components designed to withstand the environment in which they will be placed and integrated in accordance with relevant standards. Provision for redundancy is not required; the system may fail to danger in the event of a single fault within the system.

**Single Channel:** Safety-rated components are used in conjunction with proven safety principles and designs. Provision for redundancy is not required; the system may fail to danger in the event of a single fault within the system.

**Single Channel with Monitoring:** Safety-rated components are used in conjunction with a periodic check of the system at suitable intervals. The periodic check may be automatically or manually performed during normal operation and at start-up. Normal operation is allowed if faults remain undetected. If a single unsafe fault is detected, the system will either default to a safe state or indicate that an unsafe condition exists.

**Dual Channel:** This redundant system does not fail to danger if a single fault occurs, because the second independent channel maintains the ability to arrest dangerous motion. While it is always good for a system to detect failures immediately, this may not be practical, due to limitations in the technology or components. If a critical fault goes undetected, a second unrelated fault and its resultant loss of safety function could still occur.

To further increase the safety of a dual-channel safety system, diverse redundancy is employed. In a diverse-redundant system, the second independent channel is different from the first (for example, normally open switches in the first channel, normally closed in the second).

**Dual Channel with Monitoring:** Redundancy and fully integrated checking functions, used together, provide this high level of safety system design integrity. No single failure can cause the loss of the safety function and any fault is detected immediately or at the next demand on the system. Once a safety-critical fault is detected within the system, a safe state is maintained until the failure is corrected. Because the single fault is detected and a safe state is achieved quickly, the likelihood of multiple unrelated faults in both channels causing a failure to danger is statistically remote.

The method for monitoring safety systems often depends on the components used within the system. For example, because some mechanical devices, such as relays or safety interlock switches, can not be actively monitored for unsafe faults during machine operation, a deliberate testing or checking procedure must be executed to verify appropriate response.
Risk Assessment

The rule of thumb in the U.S. for determining the required level of safeguarding has historically been to provide the highest possible level, wherever an identified hazard exists. In Europe and other markets, a risk assessment process is used to determine the level of safety protection needed for a given application.

Risk assessment is an established process with many uses, including the evaluation of machinery hazards. Specific procedures include Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA). For machine safety, risk assessment is used to identify, document and eliminate or reduce hazards in a particular machine or process. Standards that detail risk assessment include ANSI/RIA R15.06 - 1999, Safety Requirements for Industrial Robots and Robot Systems, ANSI B11: TR3 Risk Assessment and Risk Reduction, and ISO 14121 (EN 1050), Principles of Risk Assessment. EN 1050 and EN 954-1 standards outline the process of risk assessment and specify categories of safety equipment.

To decide the required level of safety, a risk assessment considers such factors as the severity of possible injury, the frequency with which exposure to that injury can take place, and the possibility of the worker avoiding the injury.

Risk estimation weighs such factors as the anticipated tasks performed by all personnel; their knowledge, training and experience; and the possibility that they can defeat safety measures or ignore safety procedures. Once problem areas are identified and safety measures (procedures, safeguards, training and warnings) are proposed, the solution must be evaluated to determine if the risk has been eliminated or reduced to an acceptable level. Depending on the hazard’s risk level, the reliability and performance integrity of the safety system and all its components (devices, wiring and actuators) may be evaluated.

Conclusion

Determining how to address the safeguarding requirements for any particular machine design will depend on several factors. These factors may include:

- What modes of operation the machine will be used in,
- How operators and other personnel will interact with the machine,
- How the machine controls function, and
- The level of severity a particular hazard represents.

Once problem areas and machine limitations are identified, the selection of appropriate guarding techniques can be contemplated. Because of increased uniformity among systems of safety standards around the globe, the decision-making process continues to become easier to understand. And because of increased understanding of safety principles and requirements, the world may become a safer place in which to work.

<table>
<thead>
<tr>
<th>SEVERITY</th>
<th>Degree of possible harm</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROBABILITY</td>
<td>Probability that a hazardous event will occur</td>
</tr>
<tr>
<td></td>
<td>Possibility of avoiding or minimizing harm</td>
</tr>
</tbody>
</table>

Frequency and duration of exposure
Machine Safeguarding Standards and Regulations

Introduction

U.S. Application Standards

ANSI B11.1 Mechanical Power Presses
ANSI B11.2 Hydraulic Power Presses
ANSI B11.3 Power Press Brakes
ANSI B11.4 Shears
ANSI B11.5 Iron Workers
ANSI B11.6 Lathes
ANSI B11.7 Cold Headers and Cold Formers
ANSI B11.8 Drilling, Milling, and Boring Machines
ANSI B11.9 Grinding Machines
ANSI B11.10 Metal Sawing Machines
ANSI B11.11 Gear Cutting Machines
ANSI B11.12 Roll Forming and Roll Bending Machines
ANSI B11.13 Single- and Multiple-Spindle Automatic Bar and Chucking Machines
ANSI B11.14 Coil Slitting Machines/Systems

ANSI B11.15 Pipe, Tube, and Shape Bending Machines
ANSI B11.16 Metal Powder Compacting Presses
ANSI B11.17 Horizontal Extrusion Presses
ANSI B11.18 Machinery and Machine Systems for the Processing of Coiled Strip, Sheet, and Plate
ANSI B11.19 Performance Criteria for Safeguarding
ANSI B11.20 Manufacturing Systems/Cells
ANSI B11.21 Machine Tools Using Lasers
ANSI B11.22 Numerically Controlled Turning Machines
ANSI B11.23 Machining Centers
ANSI B11.24 Transfer Machines
ANSI/RIA R15.06 Safety Requirements for Industrial Robots and Robot Systems
NFPA 79 Electrical Standard for Industrial Machinery

OSHA Regulations

OSHA Documents listed are part of:
Code of Federal Regulations Title 29, Parts 1900 to 1910
OSHA 29 CFR 1910.147 The Control of Hazardous Energy (lockout/tagout)
OSHA 29 CFR 1910.212 General Requirements for (Guarding of) All Machines
OSHA 29 CFR 1910.217 (Guarding of) Mechanical Power Presses

European Standards

ISO/TR 12100-1 & -2 (EN 292-1 & -2) Safety of Machinery – Basic Concepts, General Principles for Design
ISO 13852 (EN 294) Safety Distances
ISO 13850 (EN 418) Emergency Stop Devices, Functional Aspects – Principles for Design
ISO 13853 (prEN 811) Safety Distances
ISO 13849 (EN 954-1) Safety-Related Parts of Control Systems
ISO/DIS 13855 (EN 999) The Positioning of Protective Equipment in Respect to Approach Speeds of Parts of the Human Body

ISO 14121 (EN 1050) Principles of Risk Assessment
ISO 14119 (EN 1088) Interlocking Devices Associated with Guards – Principles for Design and Selection
IEC/EN 60204-1 Electrical Equipment of Machines Part 1: General Requirements
IEC/EN 61496 Electro-sensitive Protection Equipment
IEC 60529 Degrees of Protection Provided by Enclosures
IEC/EN 60947-5-1 Low Voltage Switchgear – Electromechanical Control Circuit Devices
IEC/EN 60947-1 Low Voltage Switchgear – General Rules

Sources

ANSI B11 Documents
American National Standards Institute
11 West 42nd Street
New York, NY 10036
Telephone: (212) 642-4900

ANSI/RIA Documents
Obtain from ANSI (above) or:
Robotics Industries Association
900 Victors Way, P.O. Box 3724
Ann Arbor, MI 48106
Telephone: (734) 994-6088

NFPA Documents
National Fire Protection Association
1 Batterymarch Park
P.O. Box 9101
Quincy, MA 02269-9101
Telephone: (800) 344-3555

OSHA Documents
Superintendent of Documents
Government Printing Office
P.O. Box 371954
Pittsburgh, PA 15250-7954
Telephone: (202) 512-1800

EN and IEC Standards
Global Engineering Documents
15 Inverness Way East
Englewood, CO 80112-5704
Phone: (800) 854-7179
Fax: (303) 397-2740

BS Documents
British Standards Association
2 Park Street
London W1A 2BS
England
Telephone: 011-44-908-1166