Machine Safeguarding

A process for determining tolerable risk

By Clair Roudebush

INADEQUATE MACHINE SAFEGUARDING can often lead to traumatic injuries and death. Injury statistics from National Safety Council (NSC) indicate that approximately eight percent of all on-the-job deaths during the past decade were caused by traumatic accidents involving caught in, crushed by or other hazardous contact with industrial machinery (NSC). Such traumatic injuries could be eliminated by properly evaluating the risk potential, determining the level of tolerable risk and applying suitable safeguarding when needed.

Providing suitable safeguarding to protect workers is not as easy as it used to be. A quarter of a century ago, when an end user (manufacturing company) ordered a new machine tool (e.g., drill press, lathe, milling machine) from a machine tool builder, it came with all necessary safeguarding because the intended application of the machine tool was self-evident. A machine operator (employee) would be assigned the task of loading, operating and unloading the machine tool.

Over the past several decades, however, this situation has changed drastically because of the increased use of automation and robotics. The amount and configuration of machine safeguarding varies greatly depending on the level of human interaction. Machine tools that require limited human interaction require less point-of-operation machine safeguarding and have an increased reliance on parameter safeguarding.

As a result, machine safeguarding standards have shifted much of the responsibility for determining risk and applying risk reduction safeguarding from the machine tool builder to the end user. Consequently, when an end user orders a new machine tool without reviewing specification options, it will often arrive totally unguarded. It is, therefore, the responsibility of the user to evaluate risk potential, determine needed safeguarding and install such equipment. Machine guarding standards often only require that machine tool builders have safeguarding options available for purchase [ANSI (c)]. This shift in responsibility is an often-misunderstood concept in the field of industrial manufacturing.

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Increased integration of electronic sensing technology (e.g., light curtains, proximity sensors) into the field of machine safeguarding technology has improved tool efficiency and ease of use. The increased adoption of this technology has concurrently increased the complexity and expense of integrating machine safeguarding technology. No longer is hazard control achieved simply by "bolting on a guard." Topics such as control system reliability, tolerable risk and effects of component failure become important risk assessment considerations. Such considerations ultimately result in the decision to integrate redundant control system circuitry in situations of high-potential risk.

Risk Assessment Guidelines

Risk assessment guidelines and standards exist in both Europe and the U.S. European countries require a CE (Certified Equipment) mark (label) on all machine tools imported, sold or used within the European Community (EC). This mark can only be achieved by complying with EC machine safeguarding directives and regulations that require a documented formal risk assessment. The EC risk assessment standard is outlined in European Norm (EN) 1050, Safety of Machinery: Risk Assessment.

Guidance for conducting machine tool risk assessment in the U.S. is detailed in ANSI B11.TR3, Risk Assessment and Risk Reduction: A Guide to Estimate, Evaluate and Reduce Risks Associated with Machine Tools. This technical report (TR) is part of the B11 series which contains 21 standards (B11.1 through B11.21) that provide guidance for the design, construction, care and use of specific types of machine tools in the U.S. B11.TR3 is tailored to coincide with the conceptual aspects of International Organization for Standardization (ISO) 14121, Safety for Machinery: Principles for Risk Assessment.

Risk Assessment Is a Design Tool

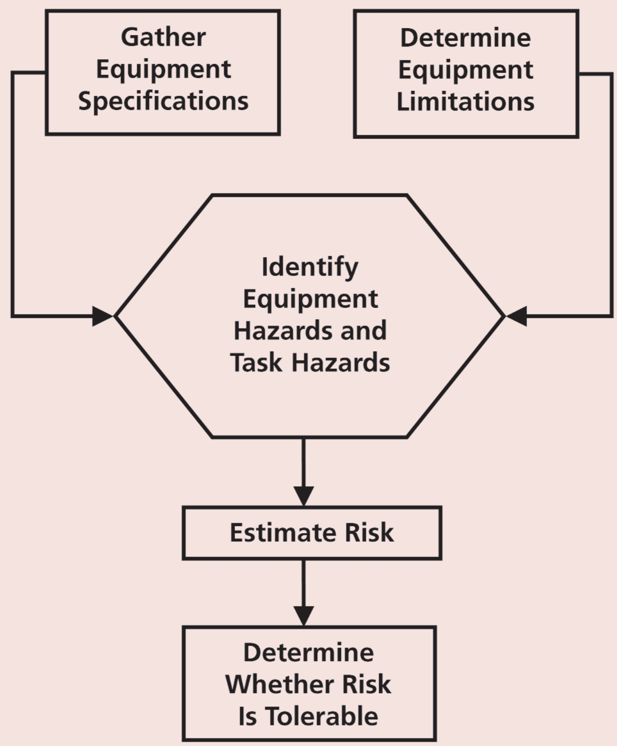
From a historical perspective, safety design principles have traditionally advocated a simplistic three-step risk assessment procedure that includes hazard 1) identification, 2) evaluation and 3) control. Development of B11.TR3, however, created a more-specialized in-depth design tool methodology for identifying and evaluating hazards and tasks such as unplanned maintenance, jam clearing and minor tool changes.

When application engineers and SH&E professionals initially become involved with machine tools and automation, they quickly realize that such a systematic approach to risk assessment is an integral part of their job. It is quickly perceived that risk assessment, if properly applied, is not a burden but rather a supportive safety design tool which provides vital in-depth information for making logical decisions regarding how tolerable risk can be achieved.

A team approach is necessary when conducting risk assessment. The SH&E professional often plays a leadership role during the risk assessment process, but inevitably cannot analyze all potential hazards without technical assistance. Using specialized technicians from fields such as electronics, control sensors, electrical controls, pneumatics, hydraulics, mechanics and maintenance procedures provides a more global and comprehensive approach to the risk assessment process. By effectively conducting a risk assessment, one can determine where best to focus efforts to reduce risks to a tolerable level. An important point to consider is that there is an end point to the risk assessment process—it occurs when tolerable risk is achieved.

Figure 1

Risk Assessment Process



Abstract: *Identifying potential risks in industrial and manufacturing environments and determining whether they are tolerable is a complex process. This complexity is intensified by the range of national guidelines and international standards regarding how tolerable risk decisions should be derived. This article condenses the process into five procedural steps and summarizes supplementary considerations such as machine/task history and reliability of machine tool safety functions. The article also discusses how to identify and apply risk reduction measures to obtain tolerable risk. A four-step hierarchy of risk reduction measures and a four-step hierarchy for incorporating safeguarding technologies are provided as well.*

Tolerable Risk

Tolerable risk is defined in ANSI B11.TR3 as "risk that is accepted for a given task and hazard combination" [ANSI(c)]. The fundamental goal of tolerable risk assessment involves analyzing equipment tasks and incorporating safety-related designs and modifications that provide both improved productivity and maintainability. Most practitioners of risk assessment theory recognize that zero risk cannot be achieved. However, following an organized and logical approach, risk assessment and risk reduction can achieve a tolerable risk level.

The Risk Assessment Process

The risk assessment process can best be understood when divided into five procedural steps. These steps, illustrated in Figure 1, are:

1) Gather equipment specifications/information.
2) Determine equipment (machine tool) limitations.
3) Identify equipment and task hazards.
4) Estimate risk.
5) Determine whether risk is tolerable.

Gather Equipment Specifications/Information

Equipment specification and historical data must be gathered at the beginning of the risk assessment process. Typical equipment specification data needed for conducting a risk assessment include: a) system descriptions, b) technical drawings, c) system layout diagrams, d) energy source(s) information, e) accident/incident history and f) future expansion integration. The initial step in this process is to compile a list of all machine tools. Wherever individual machines are linked together, either mechanically or by common machine control systems, they should be considered a single unit.

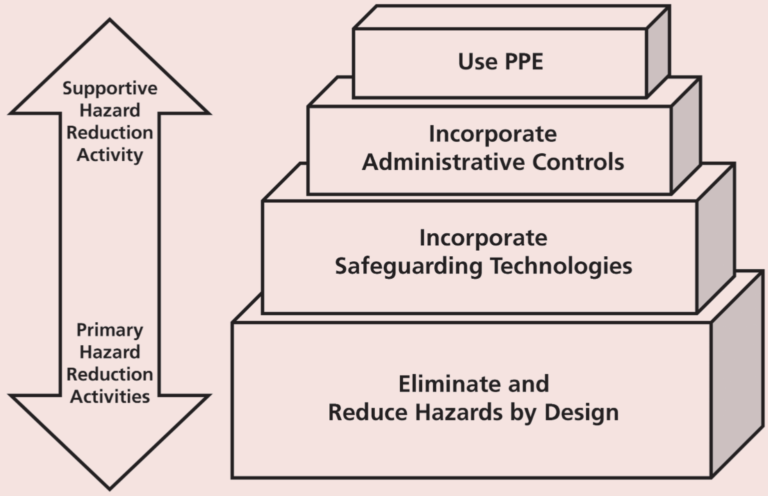
For quantitative analysis, correlating historical data regarding hazards with similar families of machine tools can provide parameters for determining risk levels. Such information can often be obtained through state workers' compensation database summaries. To obtain this information, one should visit a state's website [www.(postal abbreviation of state).gov; for example, Ohio's state website is www.oh.gov] and search for the information. If the information is not available online, paper copies can be obtained by contacting a state's workers' compensation bureau directly. Using historical data from an individual company's loss experience should not be taken as a presumption of low risk unless the operation has remained unchanged and in effect for several years.

Determine Equipment Limitations

Five equipment limitation areas must be evaluated before proceeding with the risk assessment process.

Figure 2

Hierarchical Order of Risk Reduction Measures



1) **Use limitations** are determined by evaluating the intended use of each machine including production rates, cycle times, operating speed(s), forces, materials used and number of persons involved.

2) **Space limitations** are determined by analyzing the machine's range of movement, installation space requirements, needed space for routine maintenance and space requirements for operator/machine interaction.

3) **Time limitations** are determined by analyzing maintenance intervals for mechanical, electrical and pneumatic components, tool life expectancy, lubrication intervals, and fluid replenishment and life expectancy.

4) **Environmental limitations** are determined by analyzing temperature and humidity ranges, and noise level generation.

5) **Interface limitations** are determined by analyzing the machine tool's interface with other machine tools, auxiliary equipment and energy sources.

Identify Equipment & Task Hazards

All machine tools should be examined to determine whether they present hazardous situations or hazardous task consequences. During this evaluation process, one must consider all stages in the life cycle of a machine tool—installation, commissioning, correct operation and malfunction, maintenance and decommissioning.

Typical equipment hazard categories to consider include shearing, crushing, part ejection, entanglement, noise, heat generation, ionizing and nonionizing radiation, release of toxic fumes and mist. Whenever a machine tool's safeguarding relies on anything other than its own intrinsic nature, the hazard source should be identified in the risk assessment process. For example, a machine tool with an exposed belt drive is an obvious inherent hazard. However, if the belt drive hazard is protected by an electrically interlocked barrier guard, a potential hazard could exist if the interlocking system fails.

Typical task hazard categories include setup, troubleshooting/trial-run, loading and unloading, tool changing, recovery from crashes, routine maintenance and unscheduled maintenance, major system overhaul and product packaging. Both intended use and reasonably foreseeable misuse of the machine tool should be considered as well.

Gathering information regarding how people interact with machine tools during all phases of operation is critical to the development of an effective risk assessment. Direct observation is one way to achieve this. If direct observation is not possible, a simulated human/machine tool interaction can also be conducted. This information can be used to determine human exposure to machine interaction hazards and identify training/experience requirements.

Individuals who could be included in human interaction task analysis include machine operators and assistants, maintenance personnel, engineers, technicians, equipment installation and removal millwrights, trainees, supervisory personnel and safety personnel. Administrative personnel are often also included because they are involved in procurement of safety-related equipment, raw materials used in the process and maintenance contracts with outside vendors. In some situations, people who routinely "pass by" the process (such as forklift drivers) may also be included in the risk assessment process due to inherent hazards such as noise and visual obstructions that may be created by the process being analyzed.

Estimate Risk

This step involves the development of a risk assessment matrix. Many variations exist and specialized matrixes are often developed for specific situations. Typically, the matrix incorporates only two categories because of the complexity of developing and using 3-D matrixes.

The two primary categories of a risk assessment matrix include severity of harm and probability of occurrence. The first category, severity of harm, considers both the degree of potential injury/illness as well as the extent of mediation treatment involved. Common examples of severity levels and their associated definitions include:

a) catastrophic: permanent disabling injury/illness or death;

b) serious: severe disabling injury/illness and able to return to work;

c) moderate: significant injury/illness requiring treatment beyond first aid;

d) minor: slight injury requiring only first aid.

The second category, probability of occurrence, considers topics such as exposure to a hazard, machine/task history, workplace environment, human factors, reliability of safety functions, levels of awareness/training and the possibility of circumventing protective measures. Examples of probability levels include:

a) very likely: high certainty of occurrence;

b) likely: may occur;

c) unlikely: not likely to occur;

d) remote: very unlikely.

A third category to consider is length of exposure to hazard, which includes such topics as frequency and duration of hazardous exposure, extent of exposure and number of persons exposed. Often, this category is factored into the second categorical area (probability of occurrence) due to the complexity of developing a 3-D matrix without the assistance of computer-aided mathematical modeling.

The level of risk can be derived with either numerical values or verbal descriptors. Typically, teams use verbal descriptors such as high, medium, low and negligible are used. The risk assessment team should determine which numerical values or verbal descriptors will be considered tolerable and which will be considered intolerable before the level of risk is actually determined through the risk assessment process.

Considerations During Risk Estimation

The risk estimation process should take into account all of the work methodologies and modes of operation where protective measures must be suspended or modified. Risk estimation should rely on expertise and reasoned judgment of individuals from varied disciplines familiar with machine tool tasks and hazards.

However, individuals from specialized disciplines may bias risk estimation due to their specialization focus. To minimize this factor, the person chosen to coordinate the risk assessment project should possess both the team leadership skills and human relationship skills needed to achieve group consensus.

When assessing machine/task history, consideration should be given to the reliability of statistical data in combination with the history of harm and near-hits. Whenever a tool's long-term history is not available, a low level of accident frequency or severity should not be correlated to a low risk level.

Human factors should also be assessed during the risk estimation process. Examples of such considerations include errors resulting from sequential changes to procedural steps, human interaction with machines, human-to-human interaction, human motivation to deviate from established procedures, cumulative-effects exposure and human characteristics (skill level, experience and training).

Reliability of machine tool safety functions should also be considered during risk assessment. Potential failure of safety-related control circuits, mechanical component, electrical component, hydraulic and pneumatic systems must be considered. The potential opportunity and/or incentive to circumvent protective measures that may slow production, interfere with task activities and expose support personnel to hazards should also be considered. In addition, the ability to reprogram machine tool control systems introduces the added possibility of circumventing protective measures where provisional access to operational software is not properly supervised.

Determining Risk Reduction Measures

Through the risk estimation process, a level of risk will be derived. Typically, the risk assessment team will establish parameters for when risk reduction measures are required based on the risk estimation matrix. If the risk level is determined to be intolerable, risk reduction measures must be implemented.

The level of risk reduction afforded by any risk reduction measure depends on the type of measure selected and its functional probability. Protective measure performance and utility should correlate to the desired degree of risk reduction. When evaluating the application of protective measures, the following items should be considered: risk-reduction benefits, economic impact, technological feasibility, ergonomic impact, productivity, durability, maintainability and usability.

Risk reduction measures should be applied in a hierarchical order (Figure 2). The first step should be to eliminate or reduce all hazards by design. This step should be the primary foundation of risk reduction. The next risk reduction measure should involve the incorporation of safeguarding technologies to control risk. Supportive hazard reduction activities such as administrative controls and use of PPE should be used to augment the lower level primary activities in the hierarchical order.

Eliminate/Reduce Hazards by Design

Hazard elimination through design and safeguarding technologies have the greatest impact on severity of harm and little if any impact on exposure. Examples of eliminating or reducing hazards by design include a) substitution of less-toxic/less-hazardous materials; b) modifying physical features of the machine tool; c) reducing energy sources; and d) reducing task/hazard occurrences.

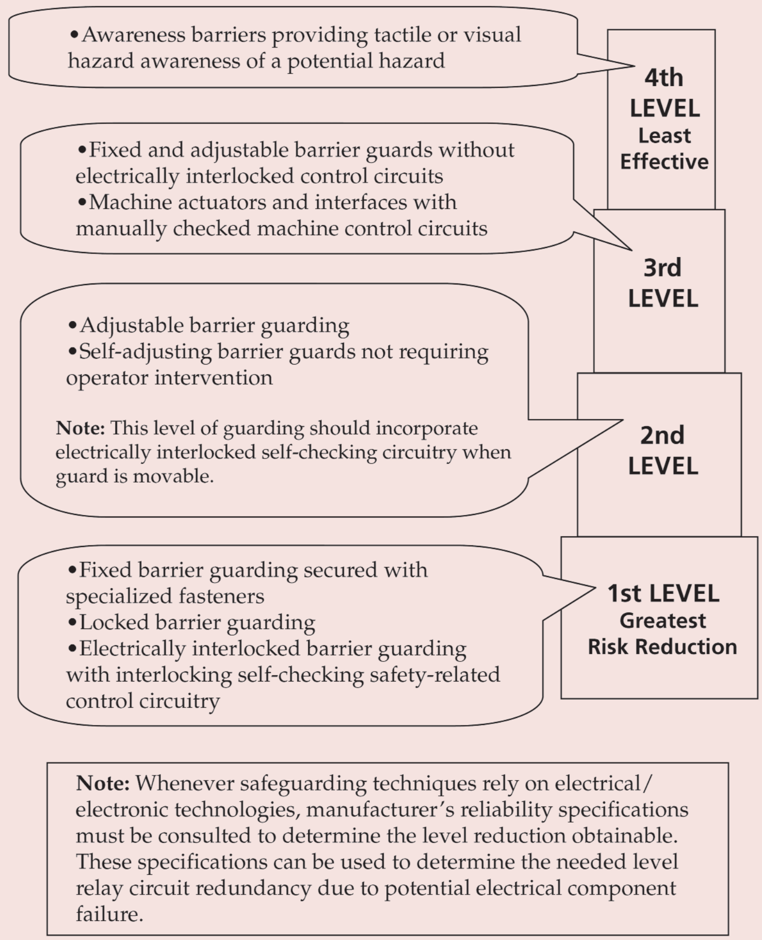
Incorporate Safeguarding Technologies

The hierarchical order of hazard reduction safeguarding techniques are presented as four levels of risk reduction (Figure 3). Hazard reduction safeguarding should be applied in accordance with applicable standards, which should be considered a minimum requirement.

Machine tool suppliers and users must have cooperative risk assessment and risk reduction responsibilities. Suppliers should reduce risks

Figure 3

Hierarchical Order of Safeguarding



through engineering design techniques. Additionally, suppliers need to provide safeguarding alternatives and information for users to employ during the risk assessment process.

Implement Administrative Measures

These measures should only be taken after hazard reduction by design or implementing safeguarding technologies has been pursued to the fullest extent practicable. Tasks requiring safeguards to be removed or disabled should incorporate administrative controls which ensure that the safeguards are restored before the equipment is returned to full operational status.

Administrative measures that rely on human response include:

1) hazard warning signage;
2) safe working procedures;
3) employee training.

Hazard warning signage includes signs, signal lights, alarms and awareness barriers. Typically, safety hues of red, orange and yellow are used to indicate the relative danger of a specific hazard. Universal symbols and multiple languages should be used where applicable. Hazard warning signage has no impact on severity of harm. The relative effectiveness of hazard warning signage for controlling hazard probability depends on how it is integrated and supported by other administrative measures.

Safe working procedures are often developed based on direct observation of individuals performing hazardous tasks. Based on these direct observations, procedures, instruction manuals and work permit systems evolve. The relative effectiveness of these procedures for controlling hazard exposure depends on training effectiveness, positive safe behavior reinforcement and supervision techniques. Safe working procedures have no impact on the potential severity of harm.

Employee training should be incorporated to properly implement safe working procedures. Training methods include formal classroom instruction, computerized instruction, and on-the-job training and certification programs. Employee training has no impact on the potential severity of harm and its relative impact on hazard exposure depends on training effectiveness and reinforcement.

Use of PPE should be implemented only after all other hazard reduction measures have been pursued. Typically, PPE is used to augment other hazard reduction measures. For example, if engineering controls can only reduce the noise level of a machine tool by 80 percent, hearing protection could be used to reduce the noise intensity to a tolerable level. The relative effectiveness of PPE to reduce both probability and severity of harm depends on the effectiveness of other associated administrative measures, including training, safe behavior reinforcement and supervision.

Conclusion

Determining tolerable risk in industrial and manufacturing environments is a complex process that involves a multitude of potentially hazardous interacting factors. With guidance in the U.S. from ANSI B11.TR3 and in Europe with EN 1050, a logical risk assessment process can be implemented to identify hazards, estimate the level of risk and implement risk reduction measures where needed. ■

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